A new climatology of North American mountain snow water storage and impacts on river basin-scale water budgets

Melissa Wrzesien[1], Michael Durand[1], Tamlin Pavelsky[2] and Sarah Kapnick[3]

[1]Ohio State University, Columbus, OH

[2]University of North Carolina, Chapel Hill, NC

[3]NOAA/GFDL, Princeton, NJ

7 May 2018

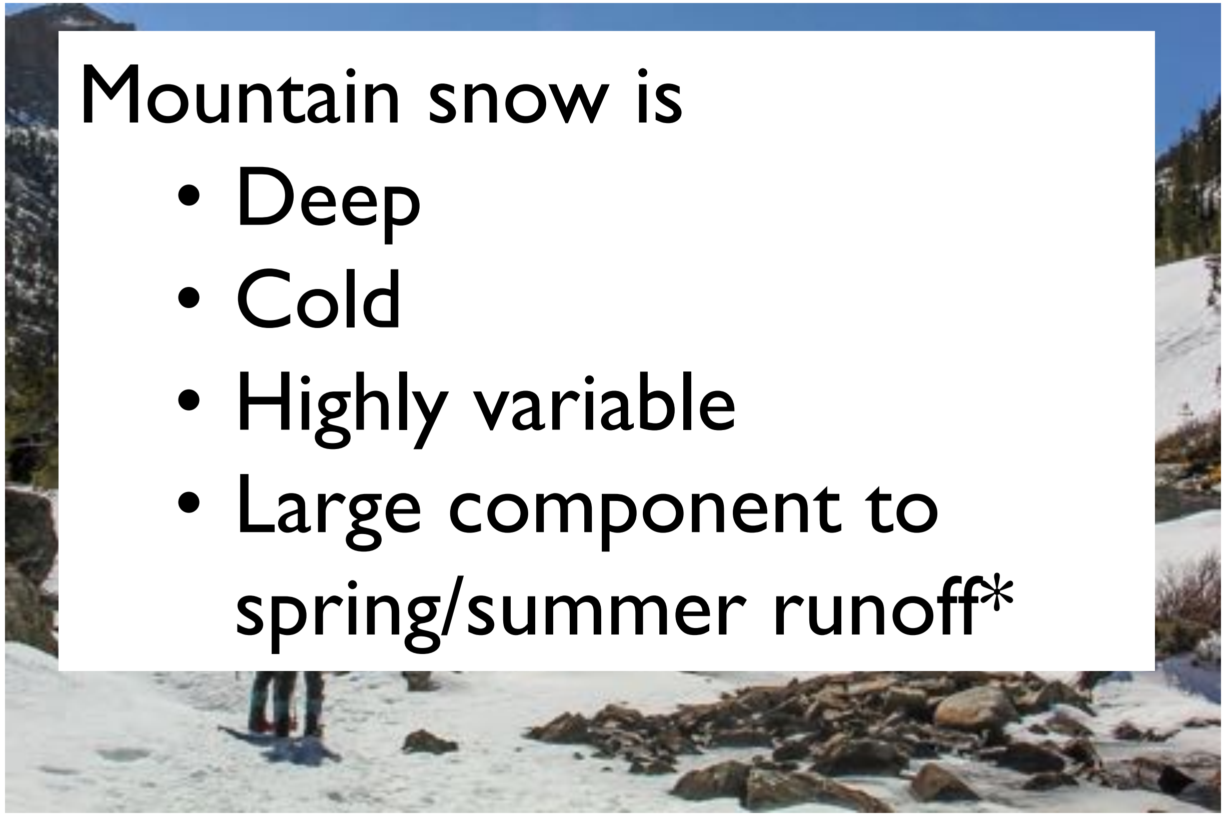
BPCRC.OSU.EDU

Snow characteristics depend on where accumulation occurs

Photo by the NPS, Rocky Mountain National Park

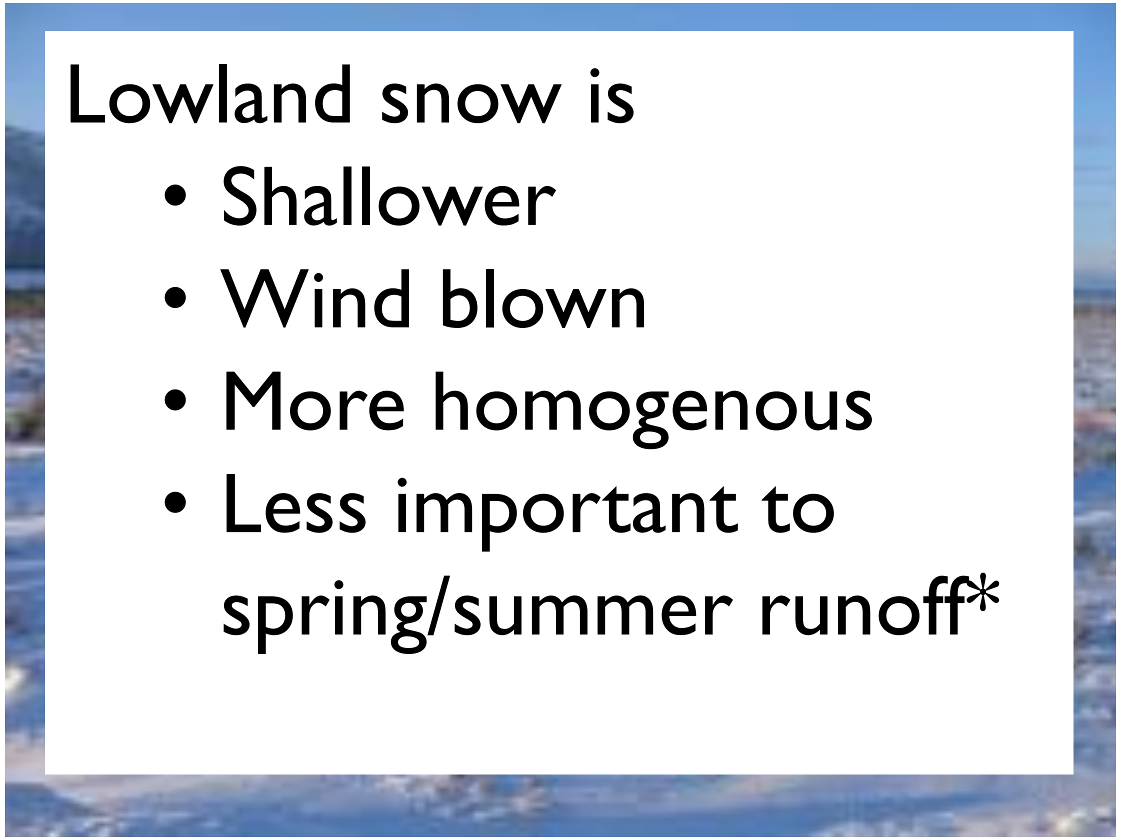
Photo by the NPS, Grand Teton National Park

Snow characteristics depend on where accumulation occurs



Mountain snow is
- Deep
- Cold
- Highly variable
- Large component to spring/summer runoff*

Photo by the NPS, Rocky Mountain National Park



Lowland snow is
- Shallower
- Wind blown
- More homogenous
- Less important to spring/summer runoff*

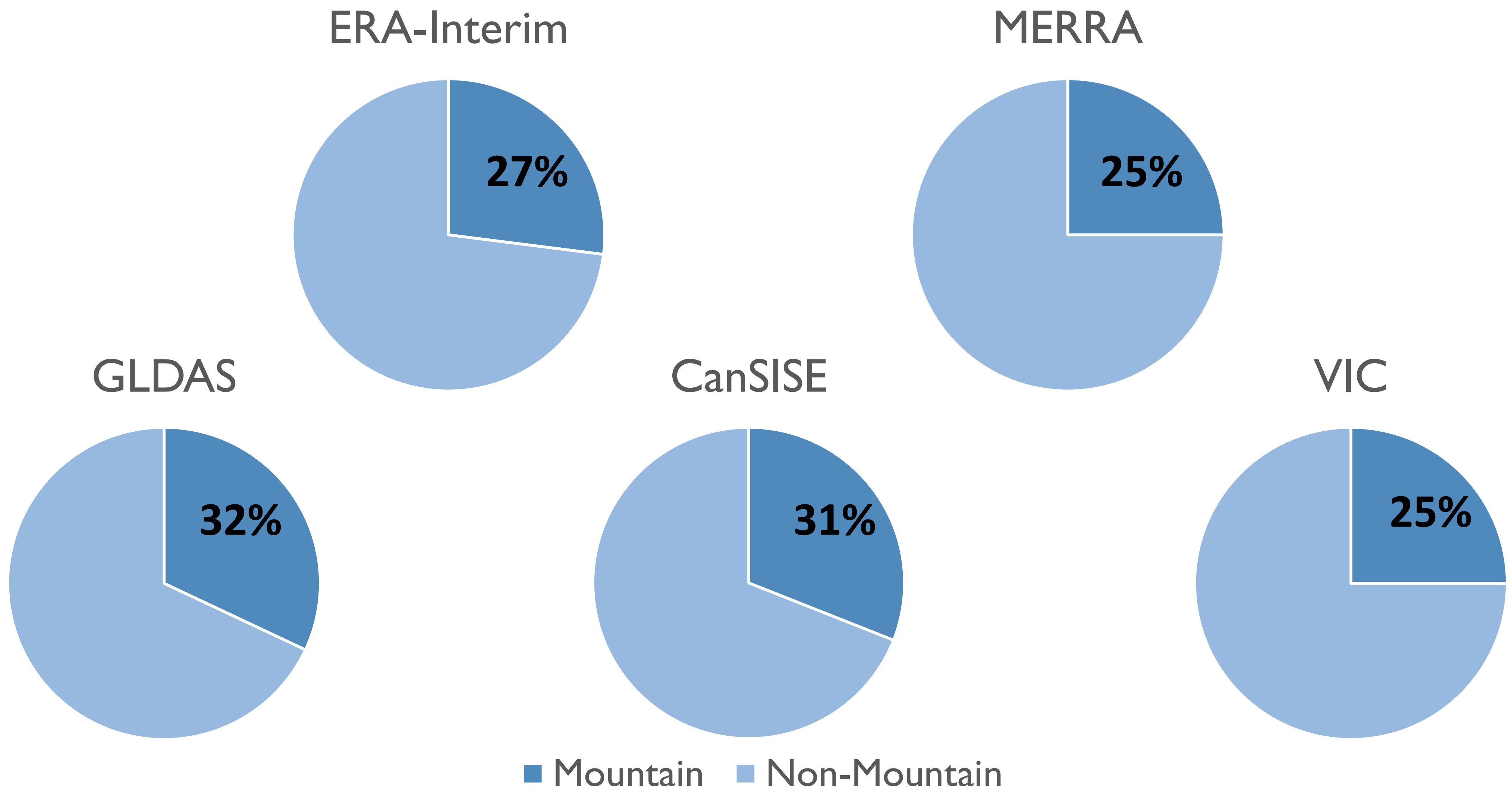
Photo by the NPS, Grand Teton National Park

* Li et al. (2017) *GRL*

North America is ~25% mountainous

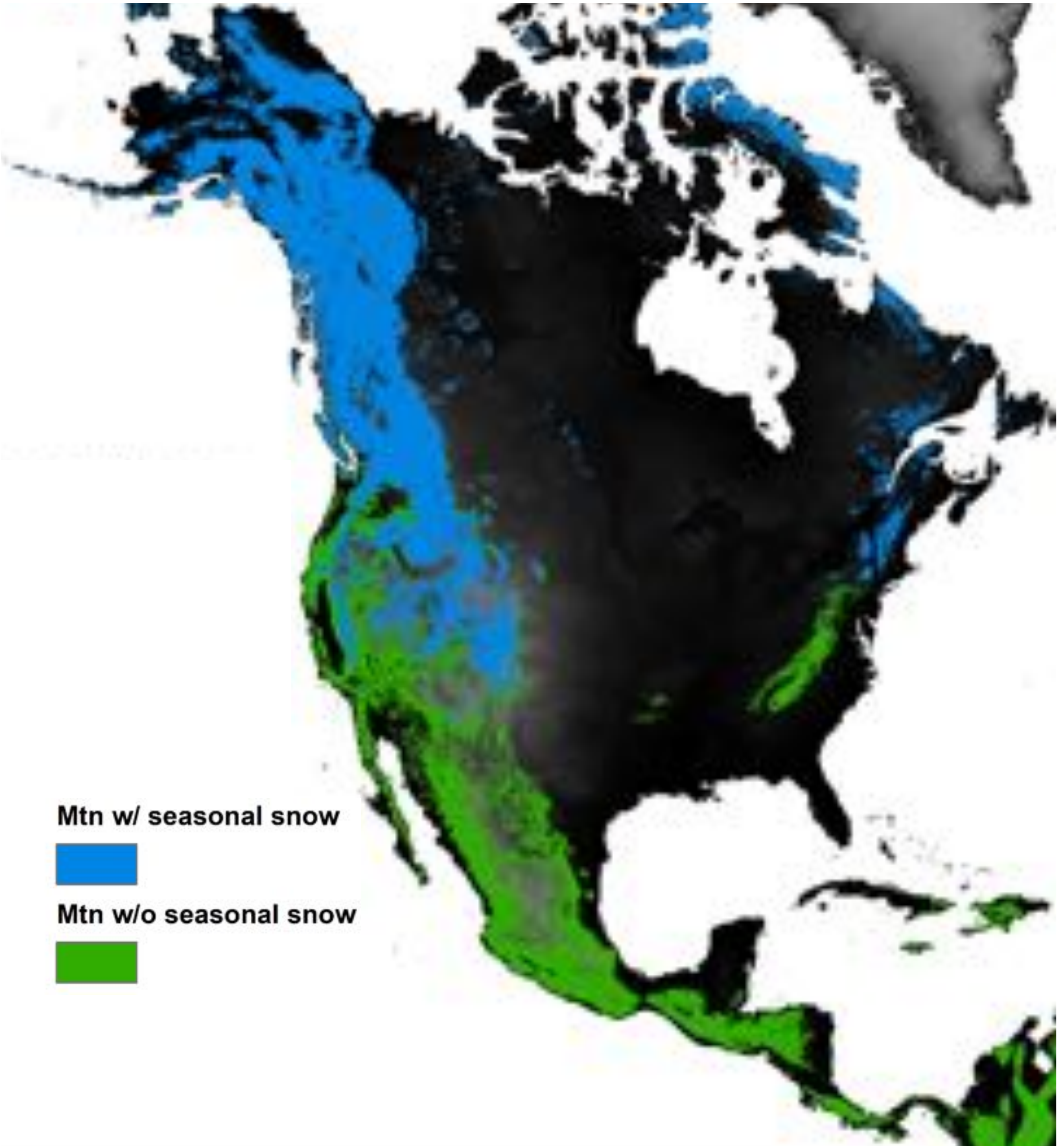
How much of the continent's snow is in the mountains?

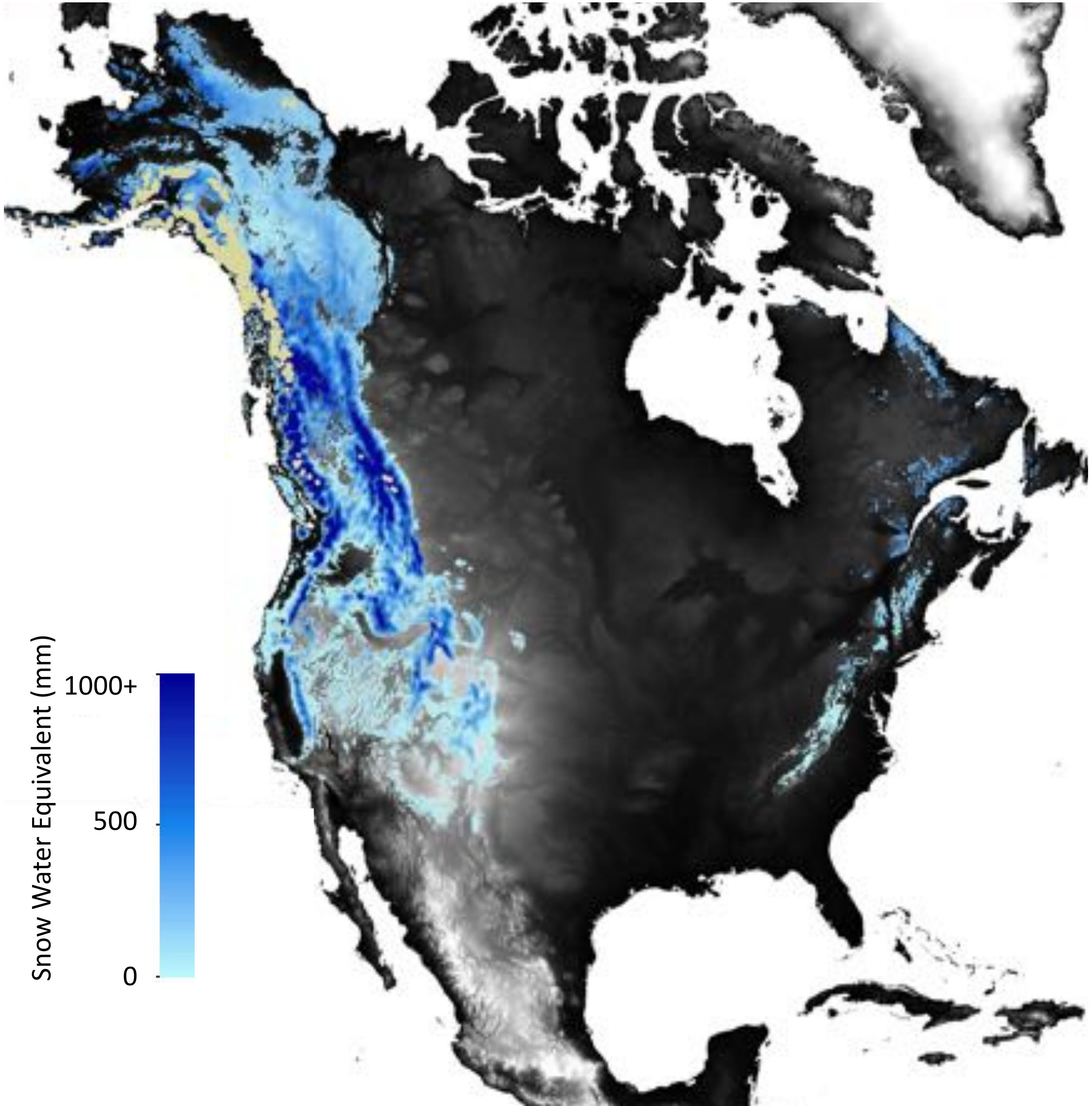
Global data products estimate ~25% of North America's snow is in the mountains.



Continental SWS Simulations

- Forcing data: ERA-Interim
- Spatial resolution: 9 km (nested down from 27 km)
  - WRF version 3.6.1
  - External forcing data: NARR
  - Land surface model: Noah-MP
  - Microphysics: Thompson
  - Spatial resolution: 9, 27 km (one way nested)
  - Time step: 3 minutes, output saved every 3 hours





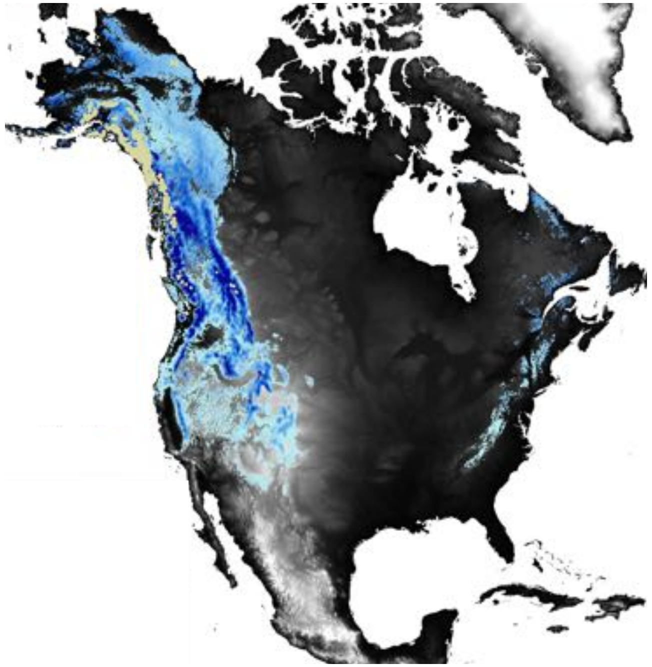
We created a new North American mountain snow climatology.

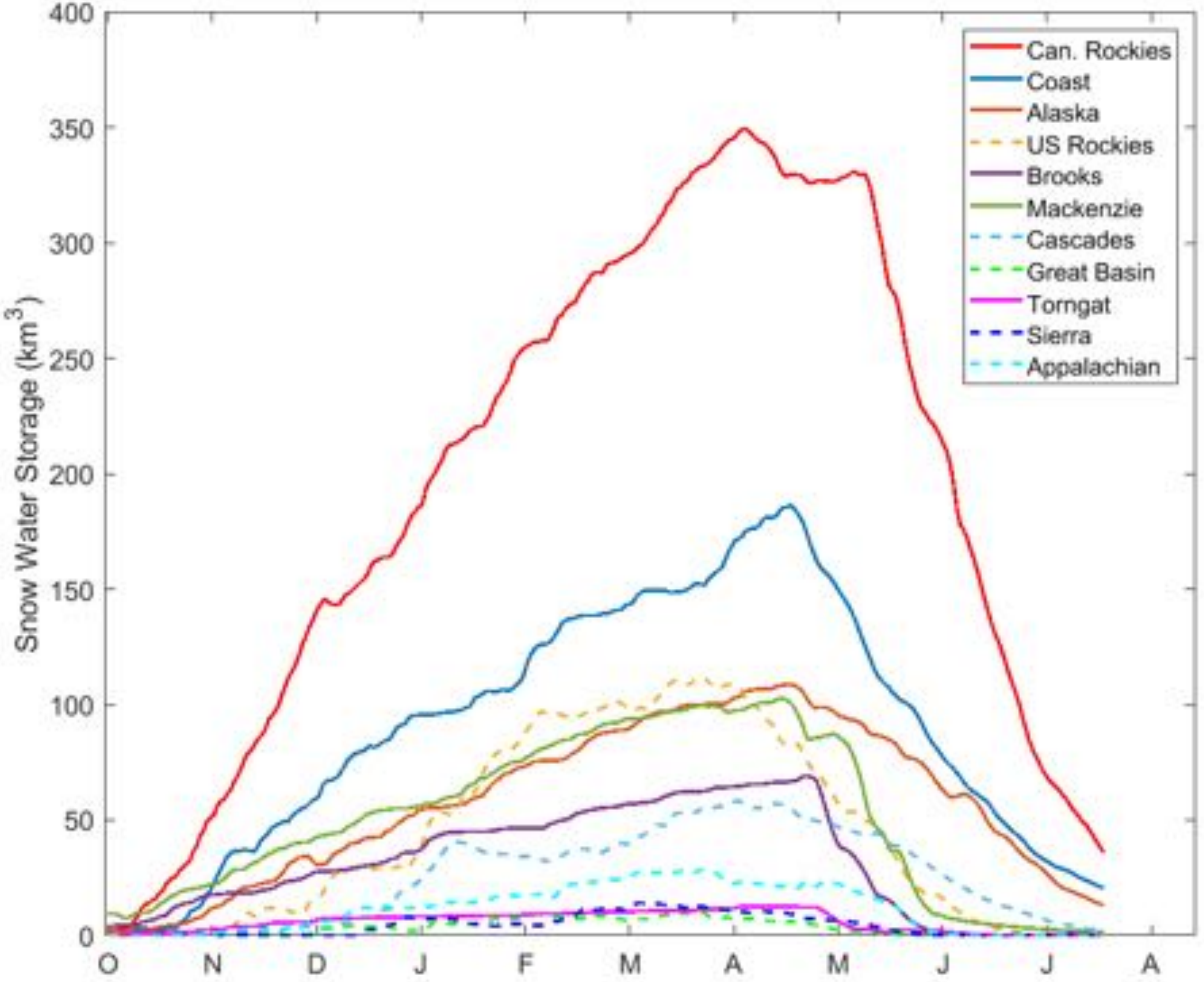
Used the WRF regional model and simulated an average water year for each mountain range to build a *representative climatology*.

Wrzesien et al. (2018) *GRL*

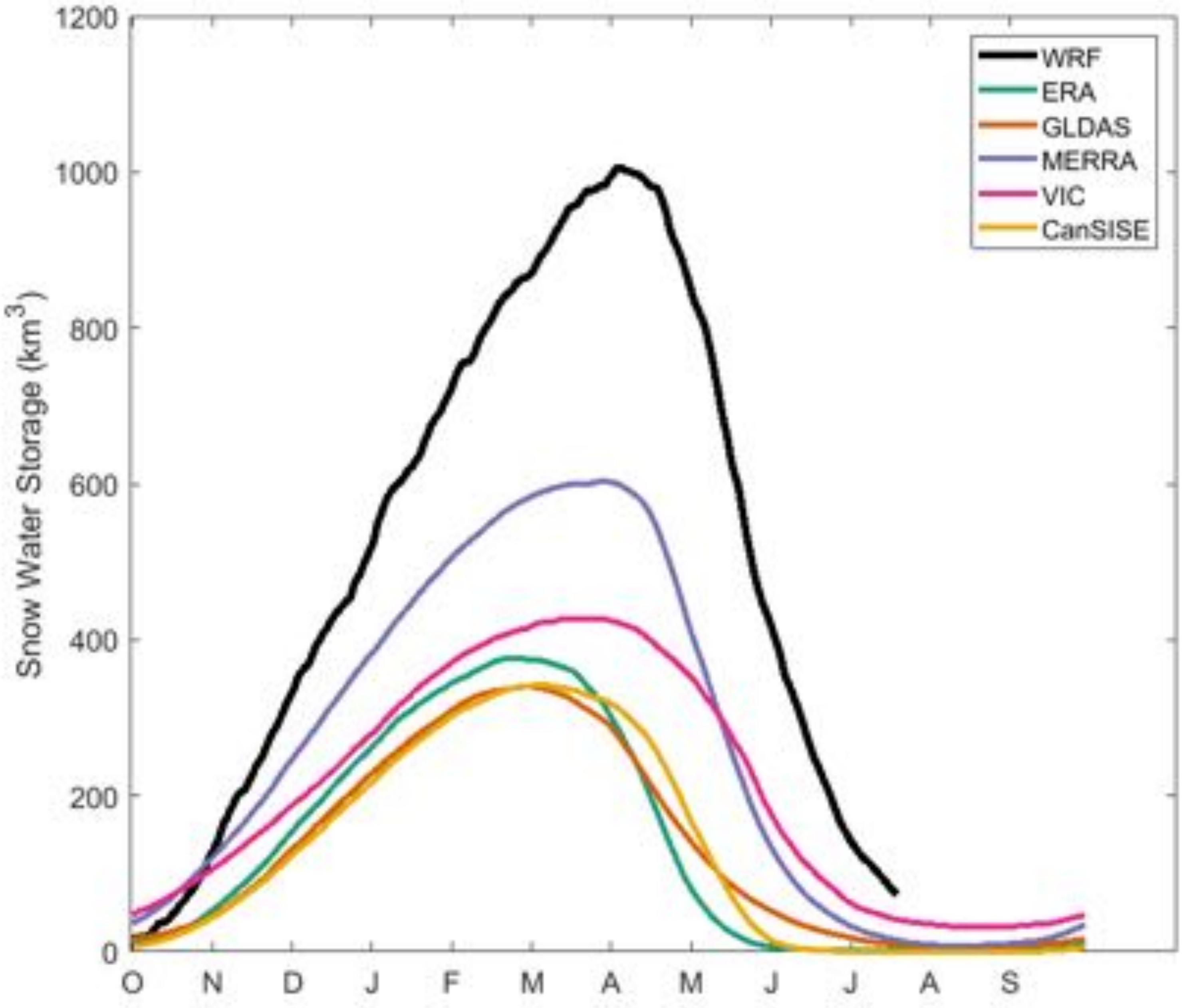
~20% of the continent's snow is in CONUS

CONUS: 224 km^3
Rest of North America: 823 km^3





Wrzesien et al. (2018) *GRL*



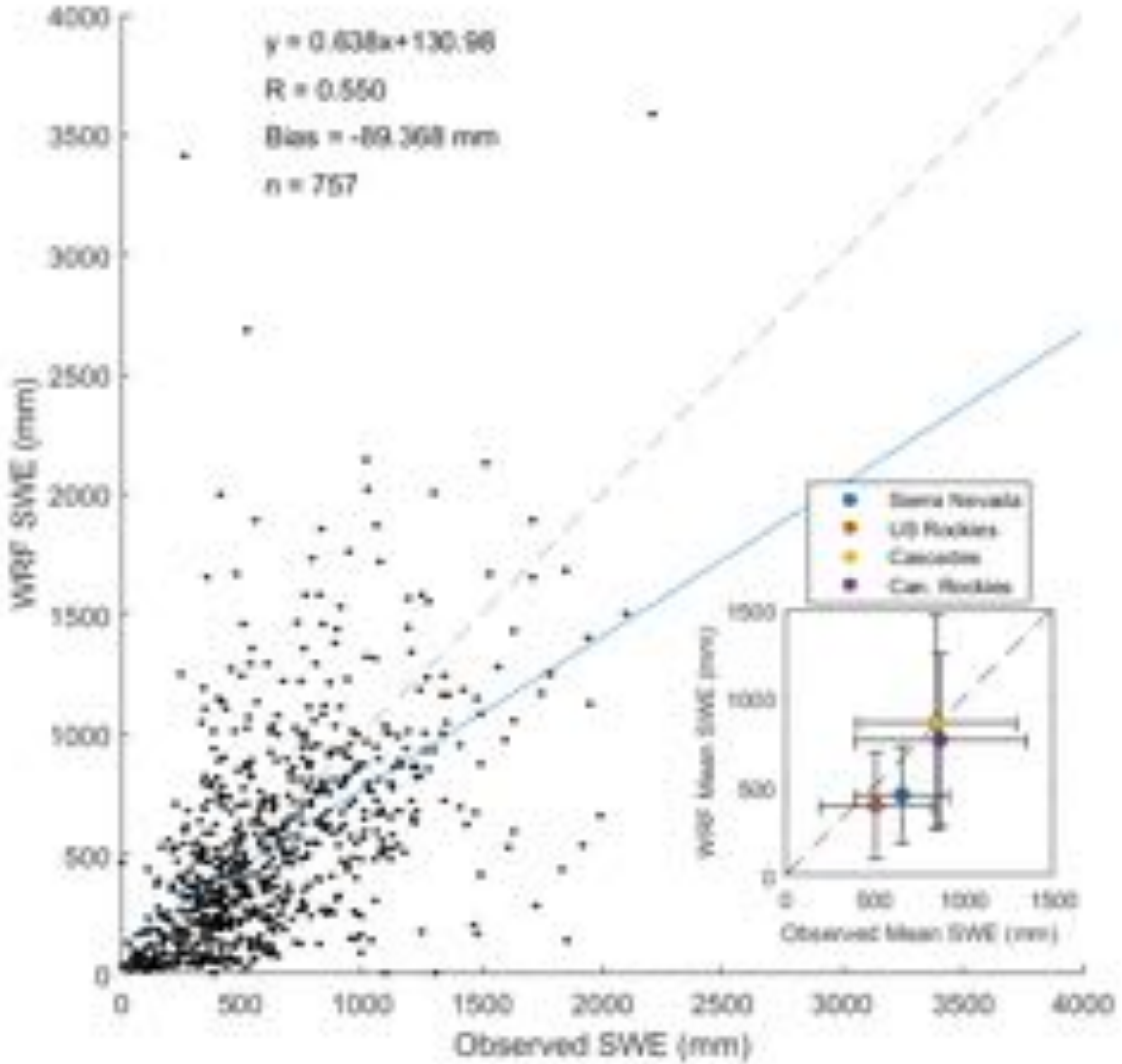
North American mountain snow water storage

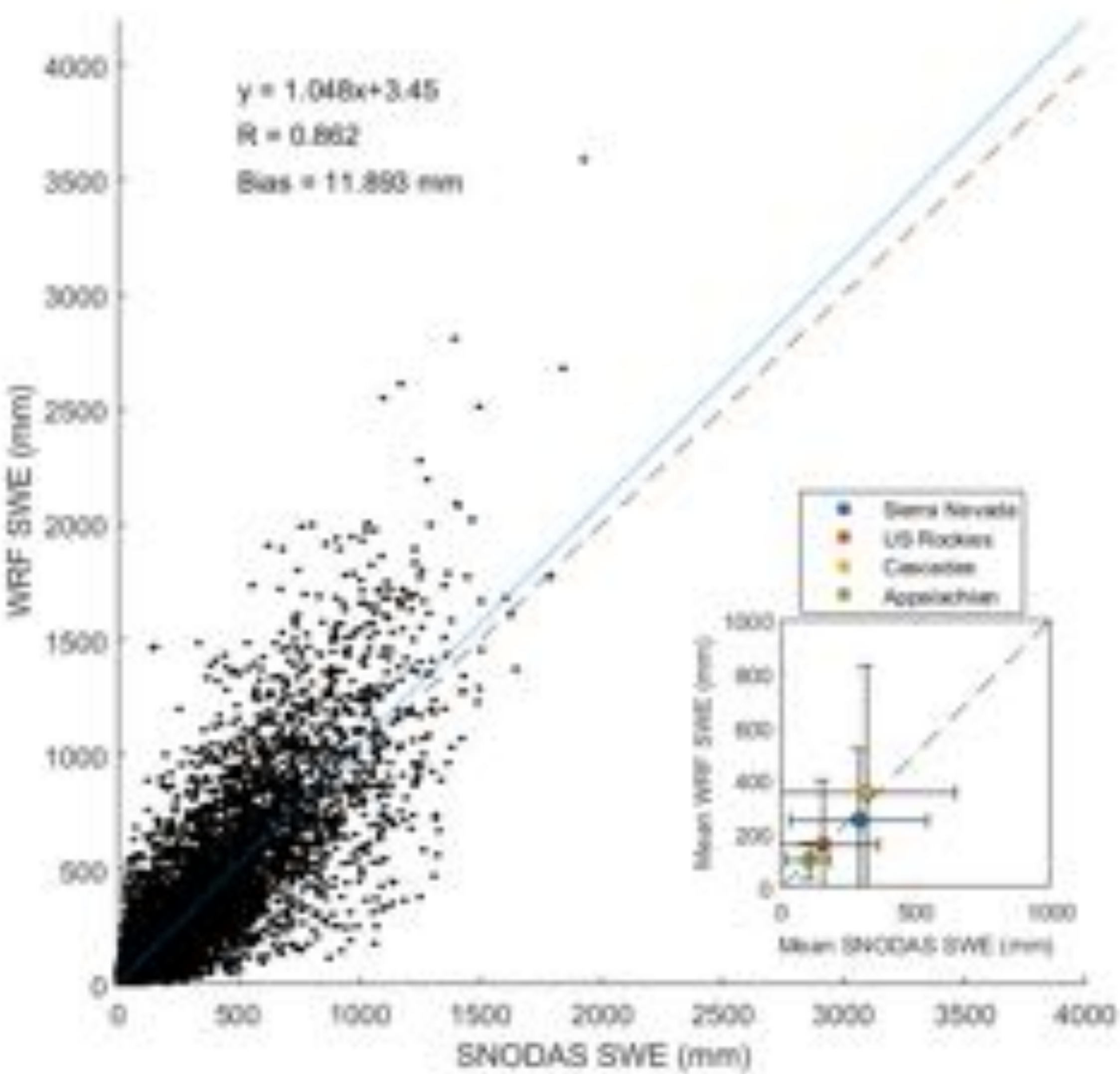
Percent difference from WRF maximum:

- ERA-Interim -63%
- GLDAS -66%
- MERRA -40%
- VIC -57%
- CanSISE -66%

Wrzesien et al. (2018) *GRL*

Evaluating WRF against snow pillows and SNODAS





Wrzesien et al. (2018) *GRL*

CanSISE global SWE product

- Canadian Sea Ice and Snow Evolution (CanSISE) network
- One degree blended SWE product
  - Includes GlobSnow, ERA-I Land, MERRA, Crocus, and GLDAS
- Produced by Mudryk and Derksen (2017) and available at NSIDC

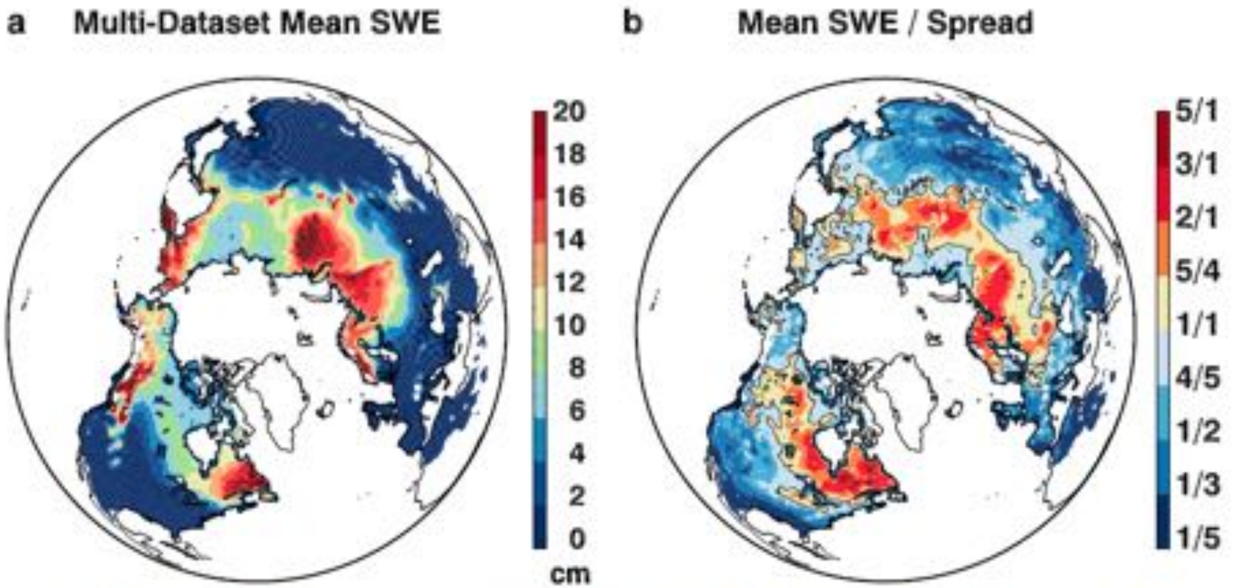
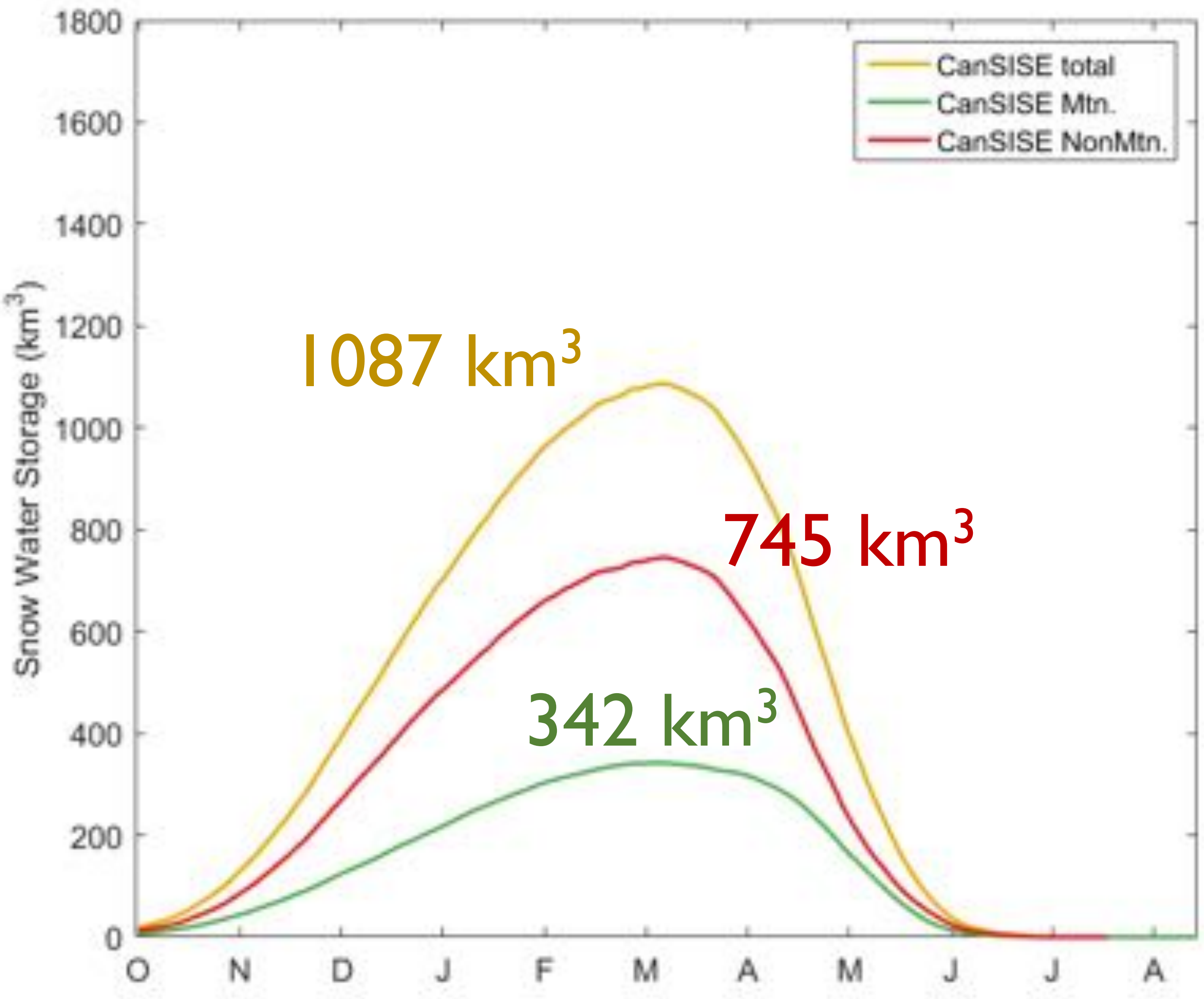


FIG. 5. (a) Climatology of multidataset mean SWE for February–March over 1981–2010 period. (b) Ratio of climatological SWE to spread among the five component datasets calculated for February–March over 1981–2010 period. The black contour delineates the 1:1 ratio.

Mudryk et al. (2015) *Journal of Climate*

CanSISE SWS Climatology

30 year average climatology for:
Entire record
Non-Mountain areas
Mountain areas



Create North America snow climatology

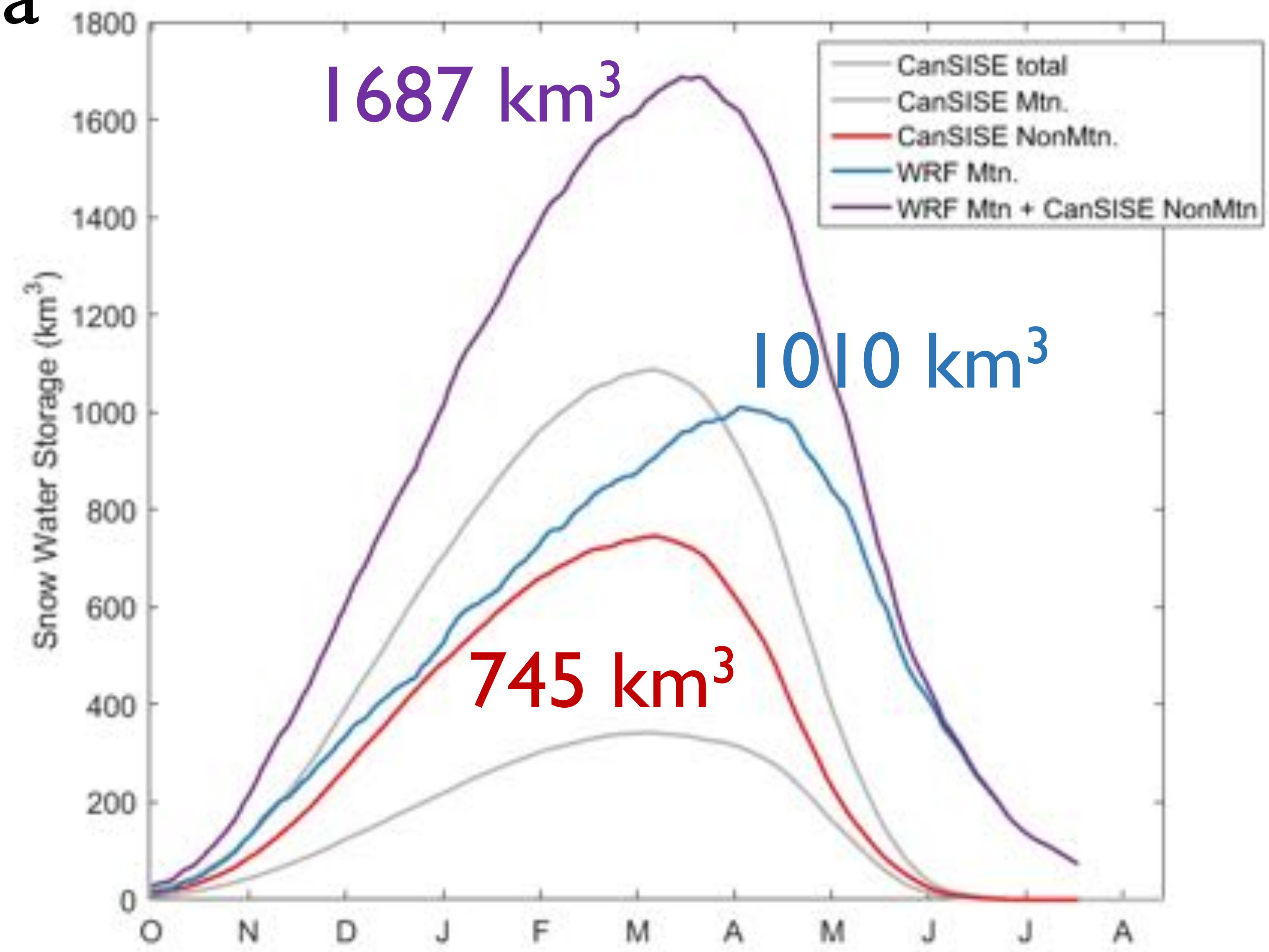
Non-Mountain areas from CanSISE

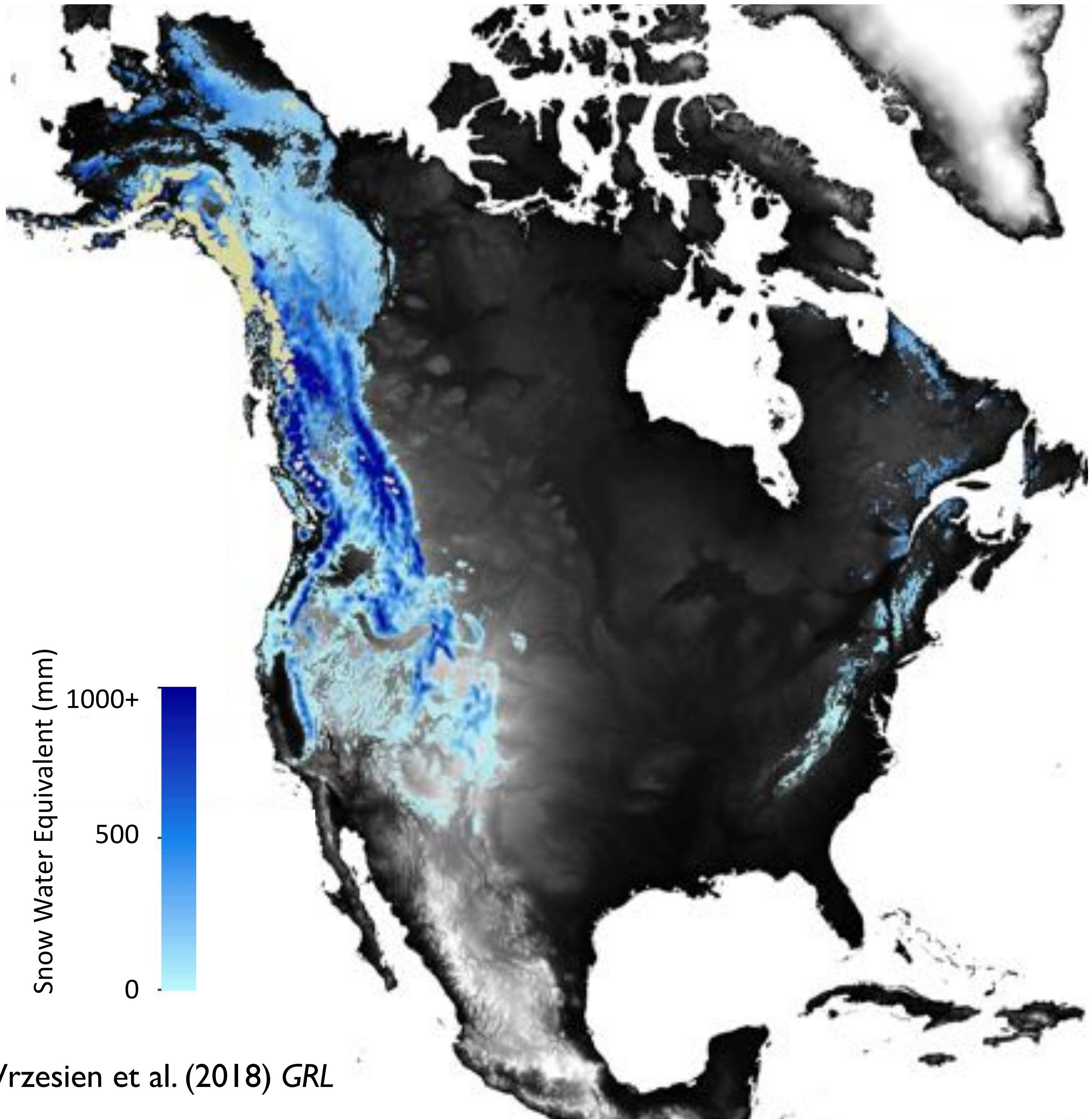
+

Mountain areas from WRF

=

Representative climatology for snow accumulation





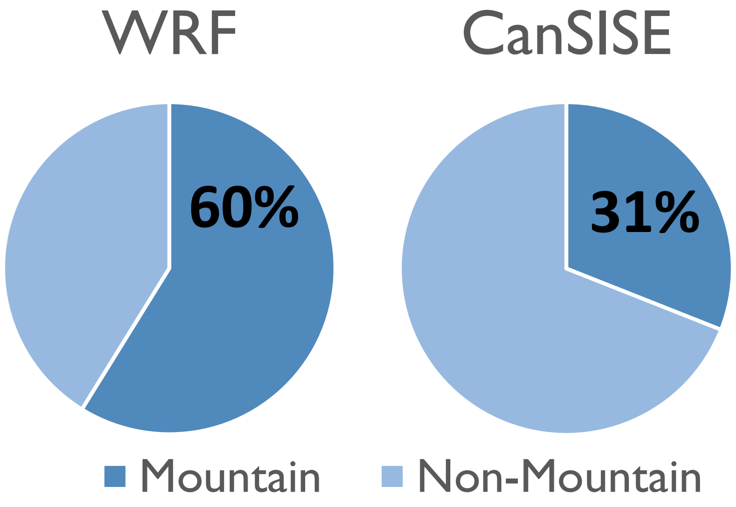
Wrzesien et al. (2018) *GRL*

A revised estimate of North American snow water storage in *mountains*

~1000 km³

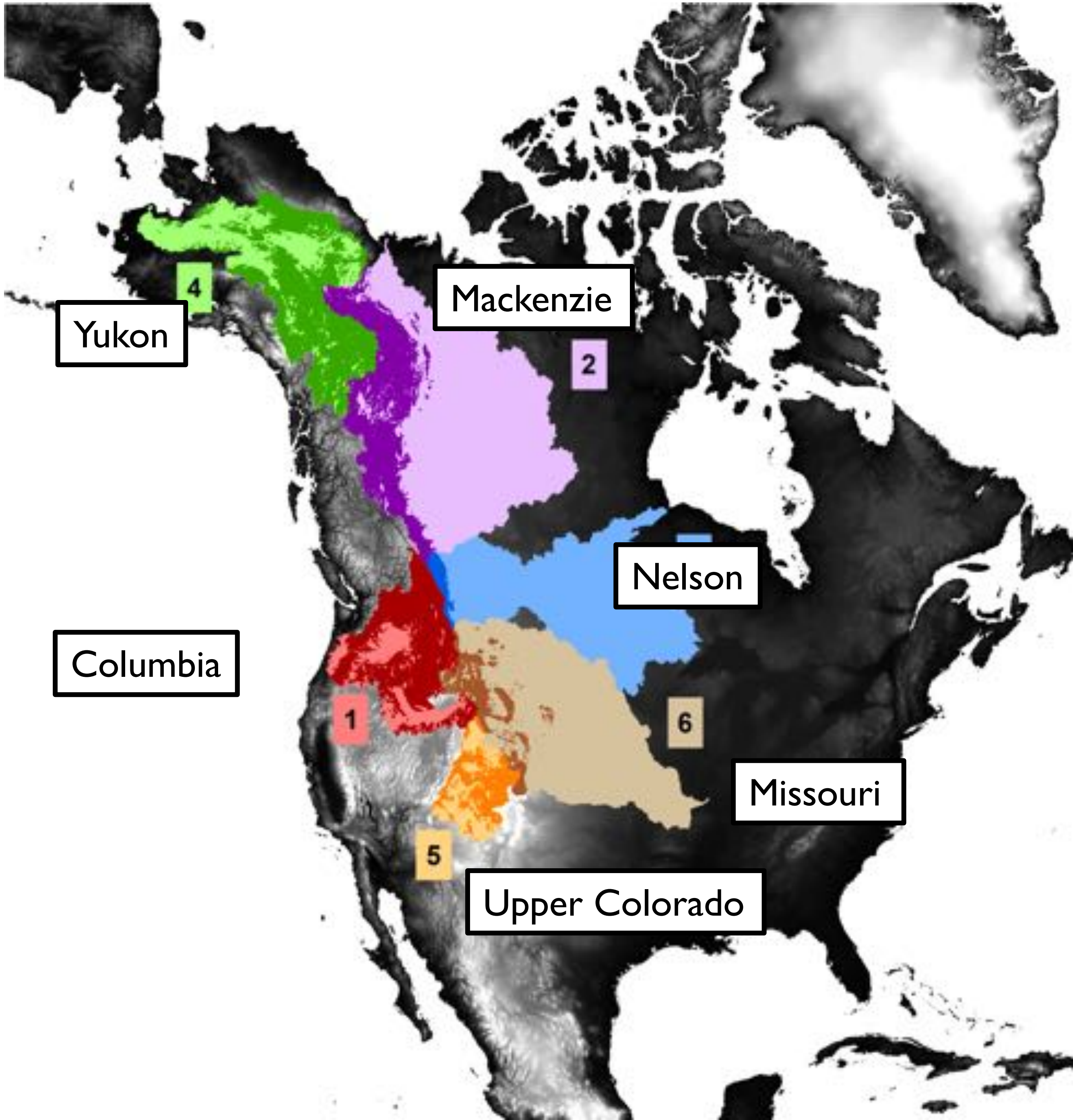
Total North American snow water storage

~1700 km³



Implications of SWE underestimation on the Water Budget

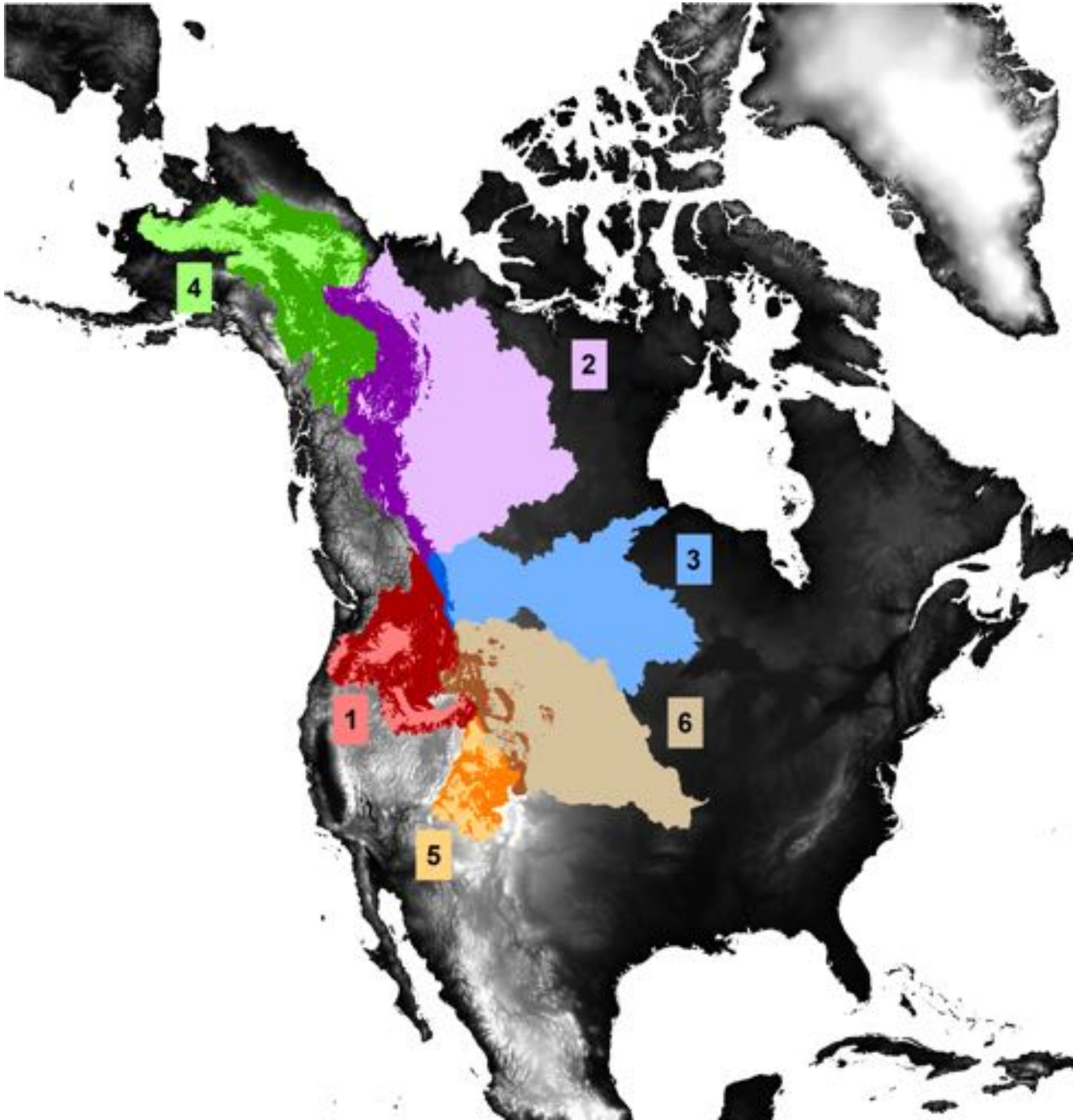
- Are SWE biases due to underestimation in precipitation?
  - Implications for continental water budget
- Do the mountain SWE biases persist across the entire watershed?
  - Implications for runoff



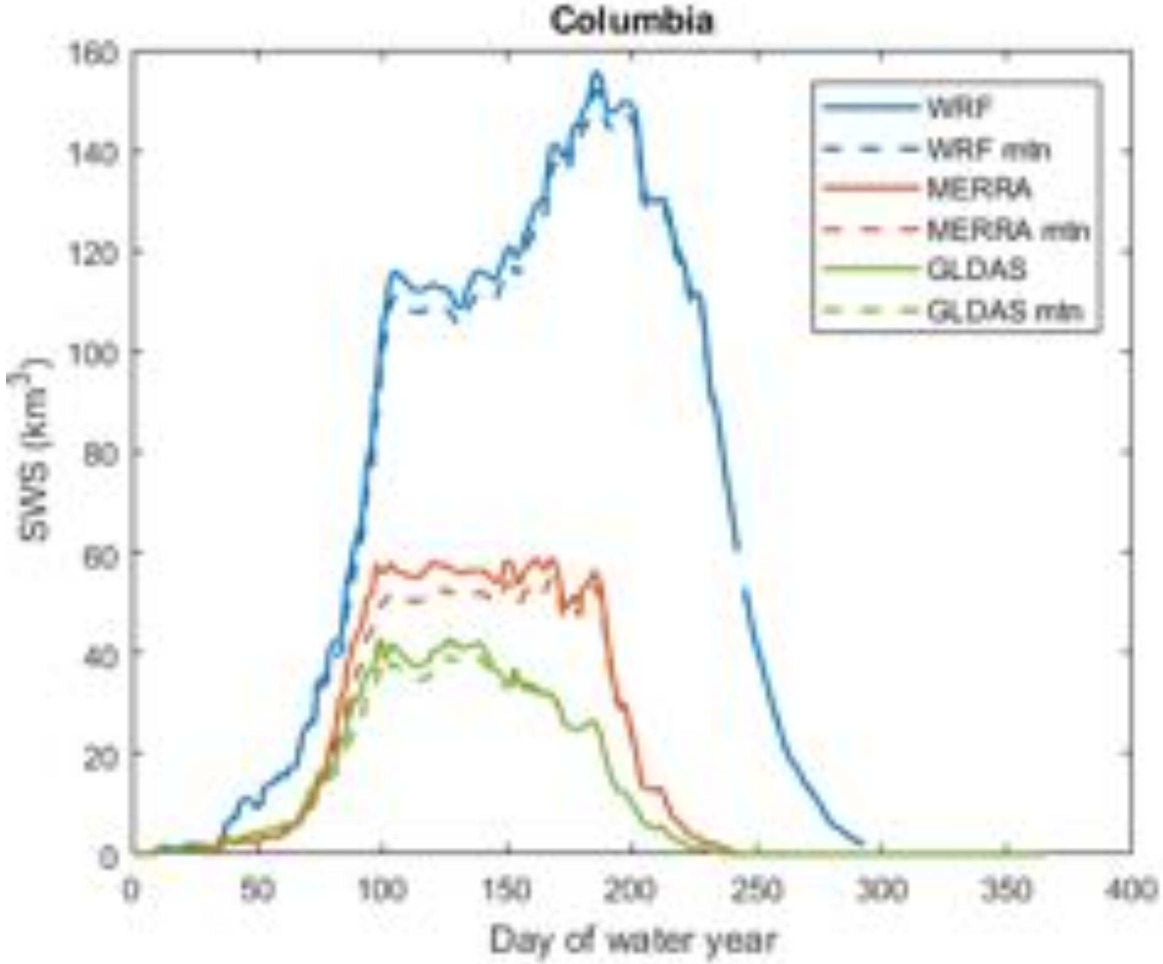
Snow Water Storage (SWS) and Precipitation Datasets

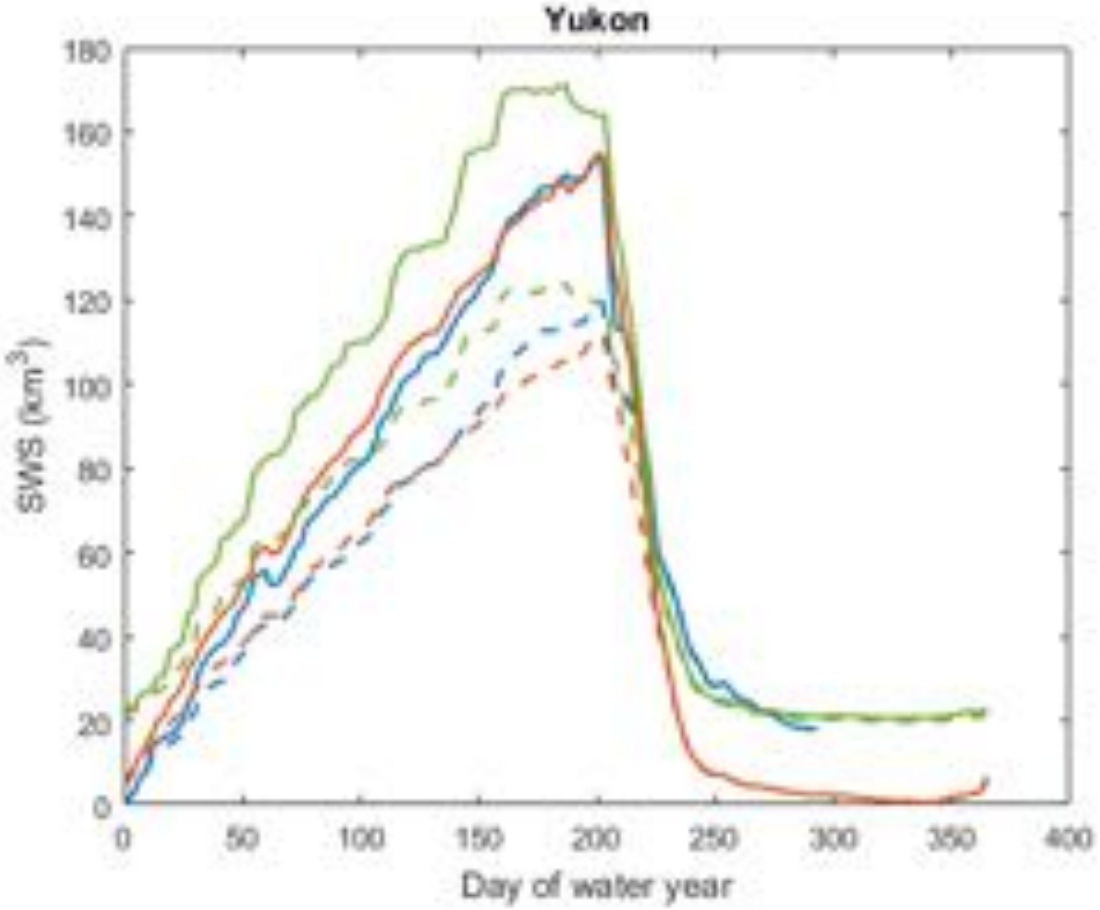
- WRF @ 9 km*
- MERRA2: 0.5°x0.67°
- GLDAS2: 0.25°

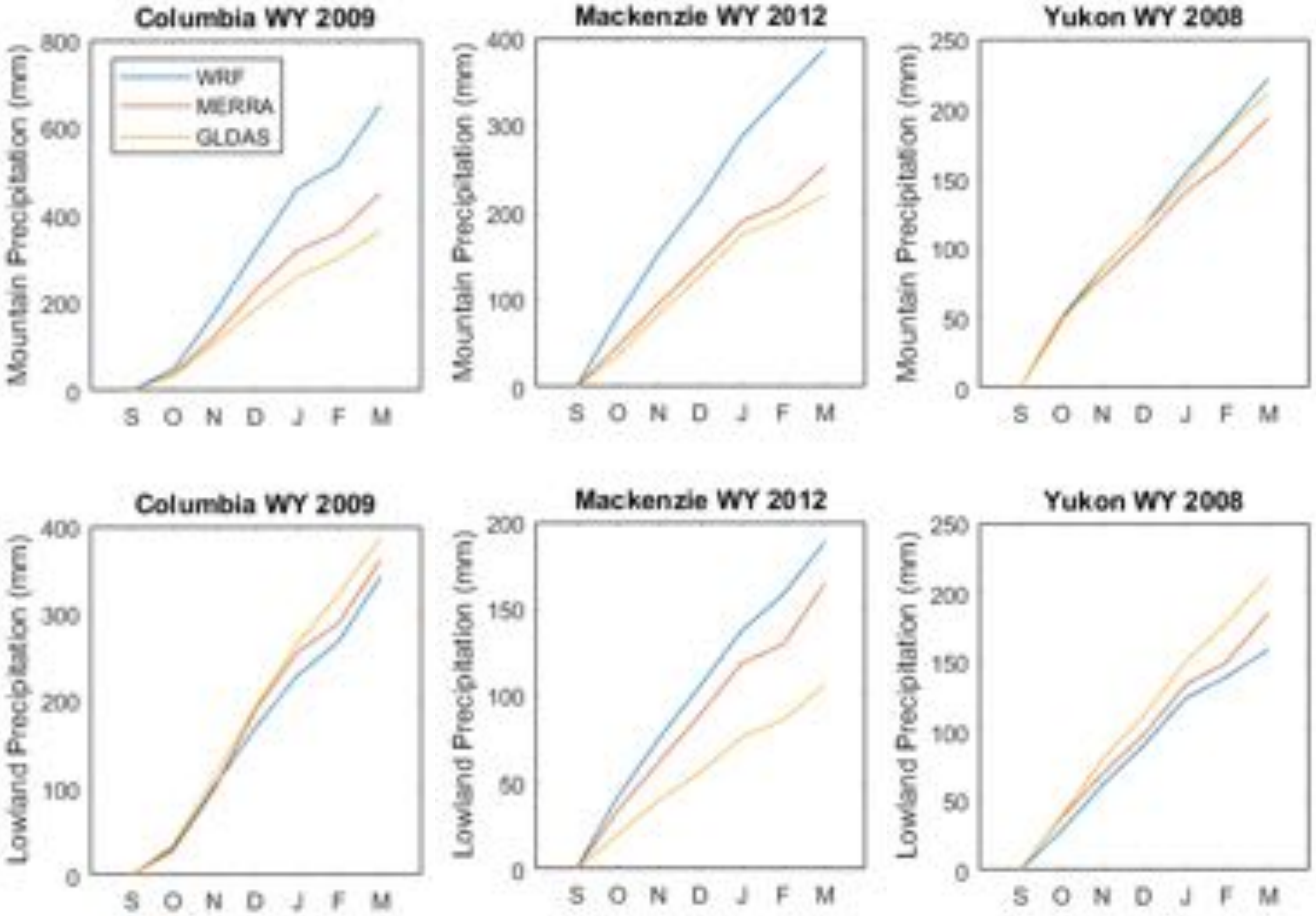
*note: WRF 9 km domains covered both mountains and lowlands of each watershed



SWS differences vary by basin; generally latitude seems more important than what fraction of basins are mountainous in determining SWS bias in MERRA and GLDAS.





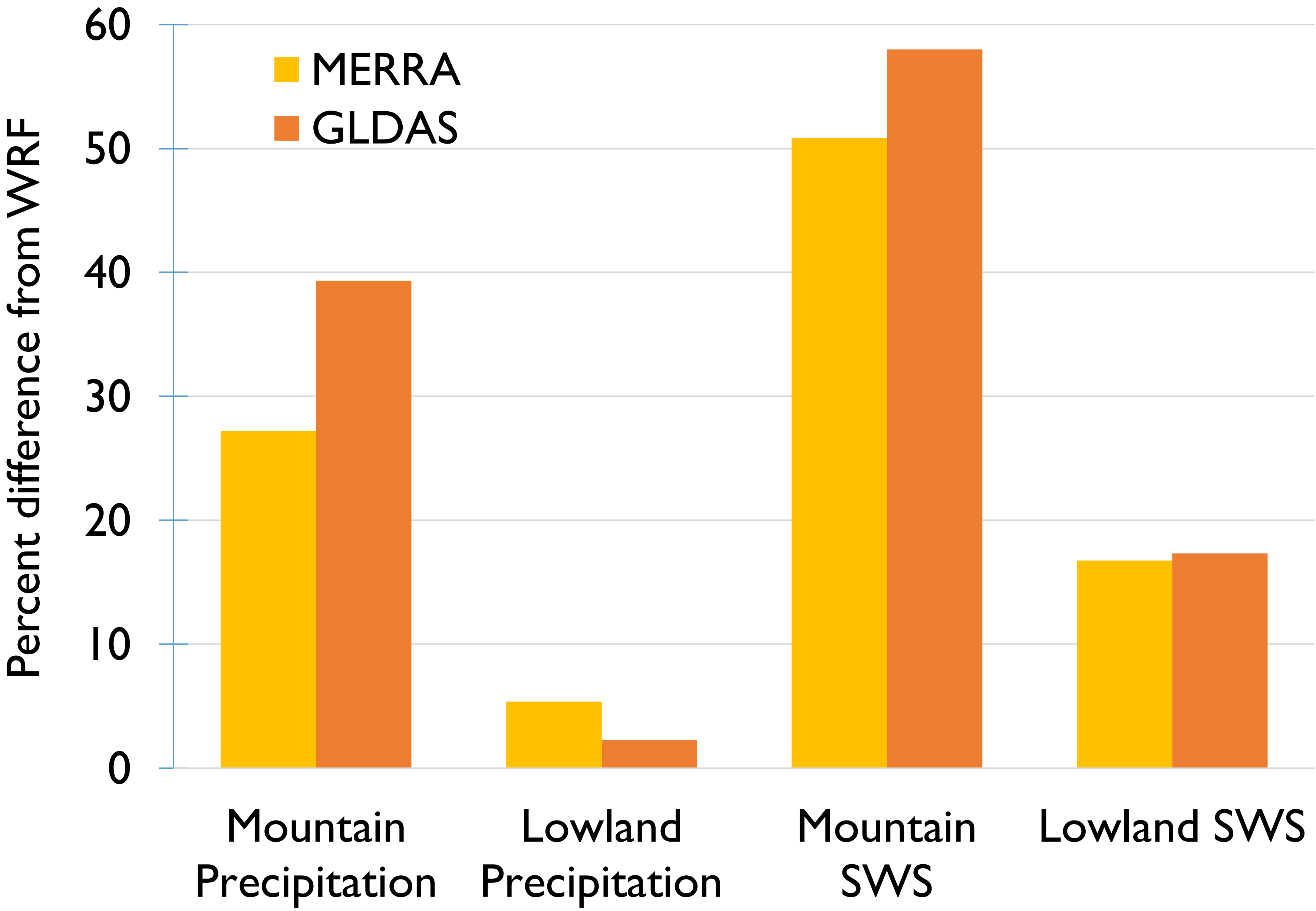


Precipitation differences vary among the basins & mountains (top) vs lowlands (bottom).

Precipitation differences less than SWS from Wrezsien et al. 2018

Averaged over all six basins

- Differences exist for precipitation & peak SWS
- Difference in peak SWS is significantly greater than precipitation, especially for MERRA



Conclusions

- How important is mountain snow for the continental water budget?
  - WRF results indicate that mountains are 25% of North America, yet hold 60% of the continent's seasonal SWS

- WRF and global models produce similar winter precipitation and SWS in lowland areas across all watersheds

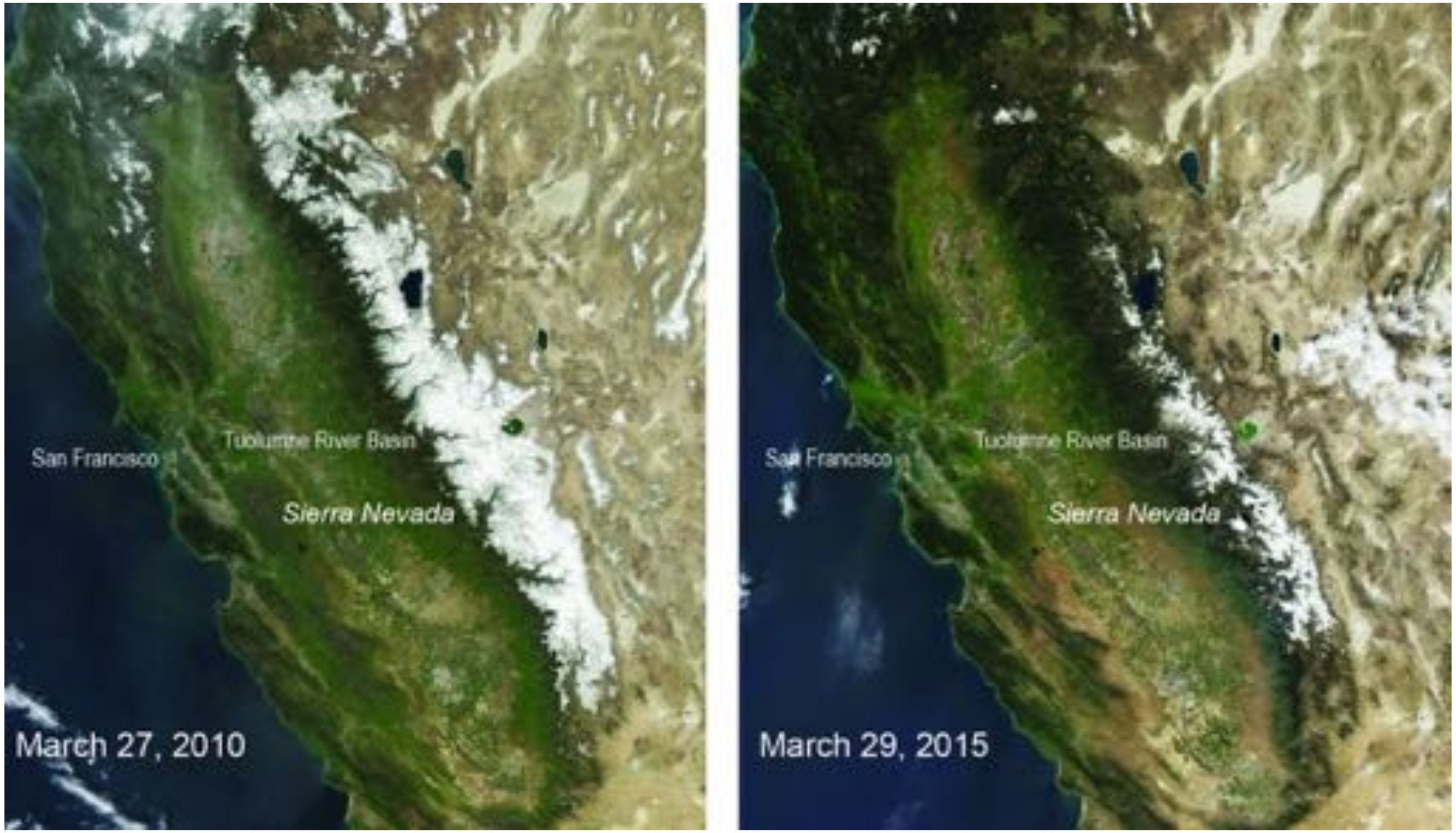
- Global models may be underestimating mountain snow by 60%

- WRF SWS is 50%-60% greater than MERRA2 and GLDAS2, with smaller differences at higher latitudes

Acknowledgements

- Supercomputer time provided by NSF (XSEDE) and NASA (Pleiades)

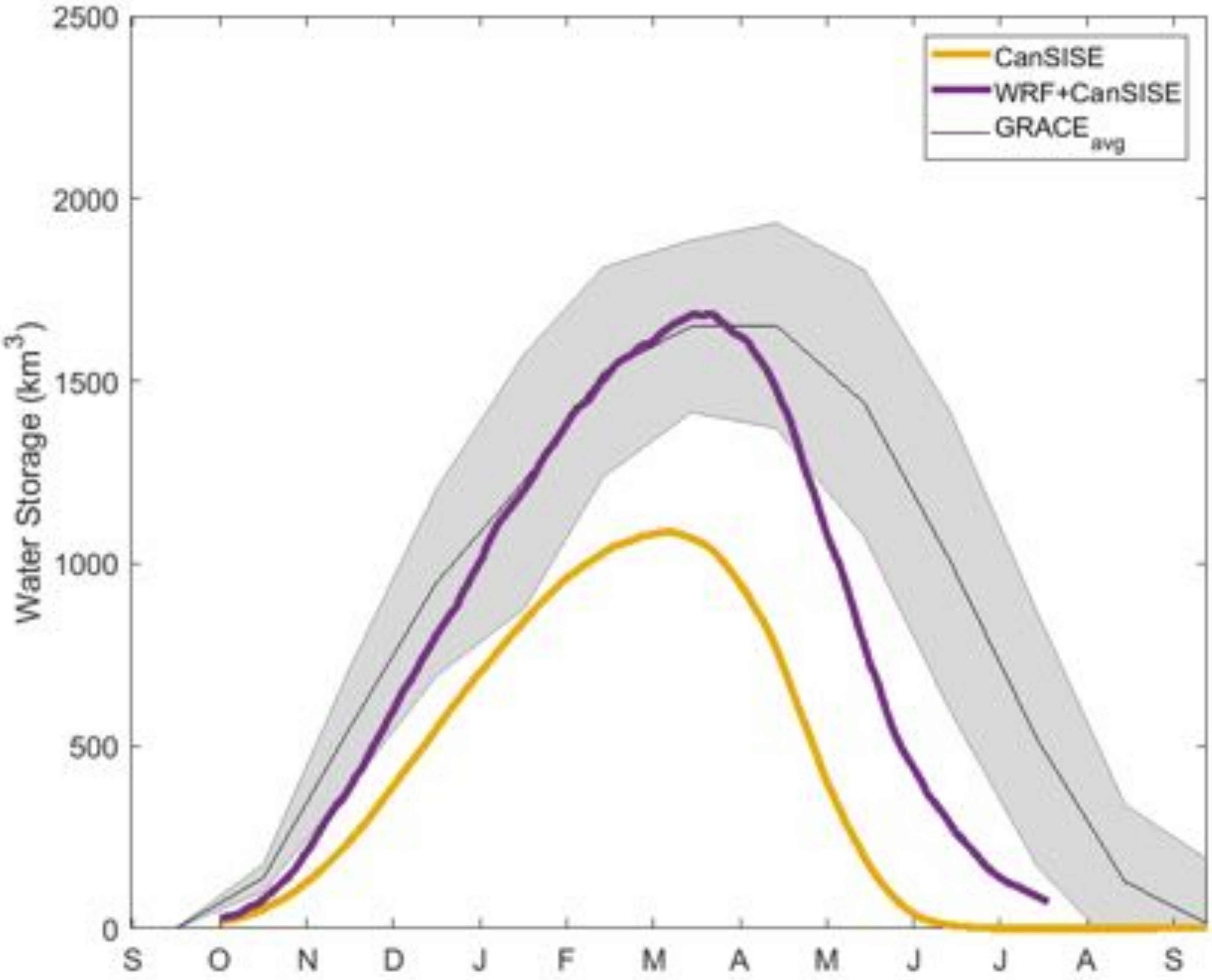
- Graduate Student support from NASA Earth & Space Science Fellowship, and the Terrestrial Hydrology Program



From NASA/MODIS


Questions?

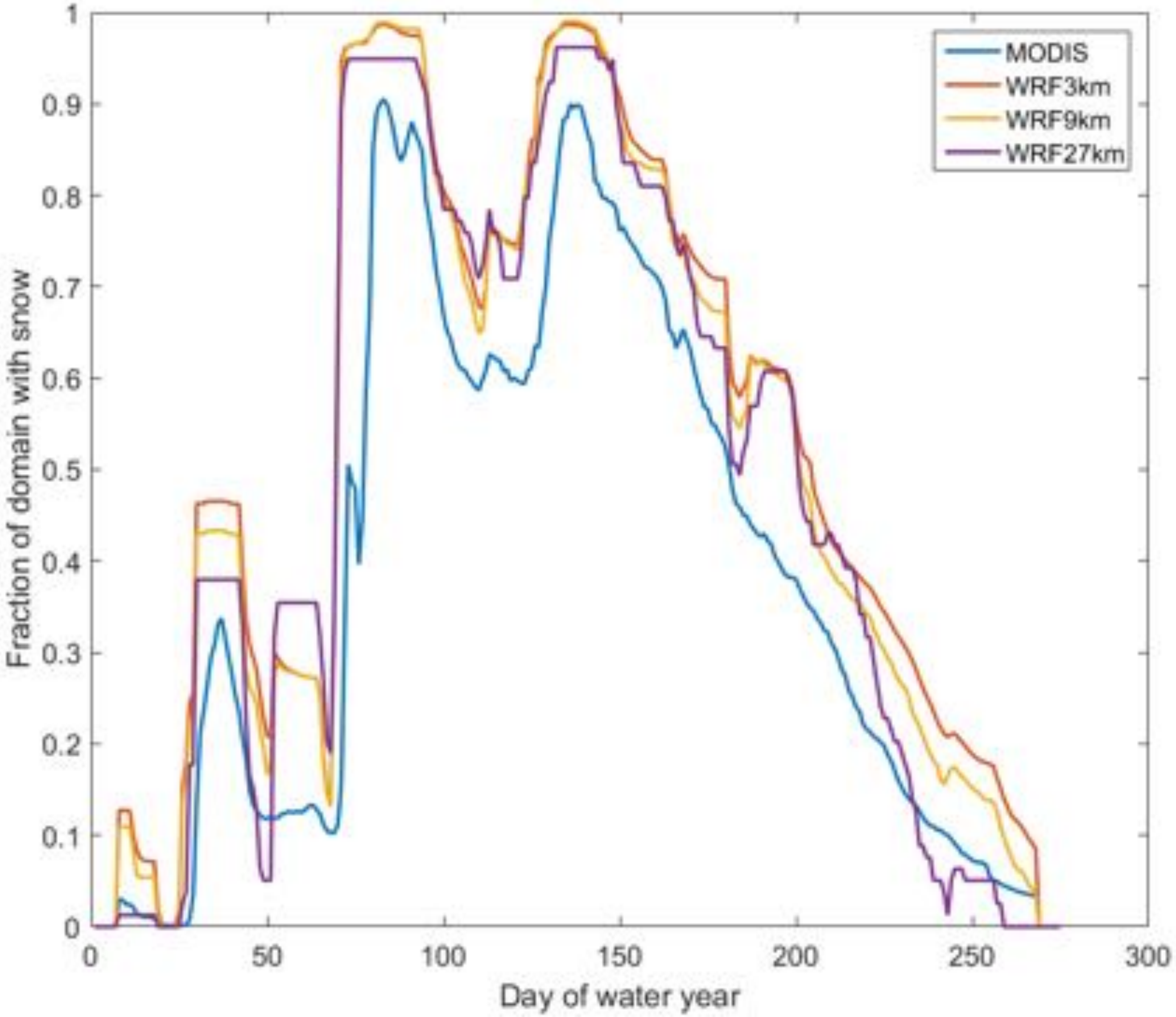
For a continental evaluation, compare WRF SWS with GRACE TWS

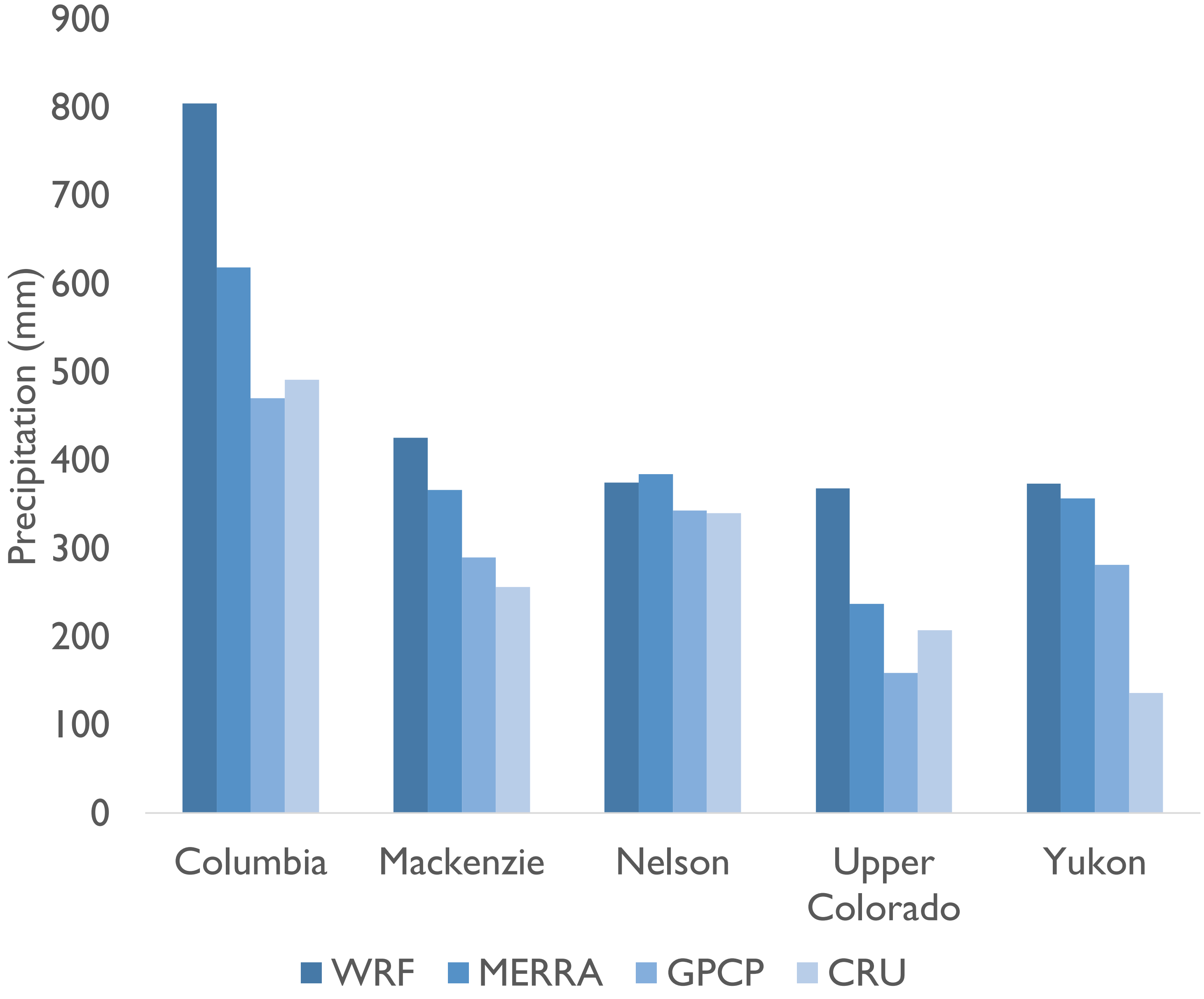


Wrzesien et al. (in review) *GRL*

Comparison to MODIS snow cover fraction

- Count “snowy pixels”
  - Does WRF correctly identify the presence/absence of snow?
- Shown here for the entire Sierra Nevada
  - 3 resolutions of WRF (3, 9, 27 km)





~Annual Watershed precipitation

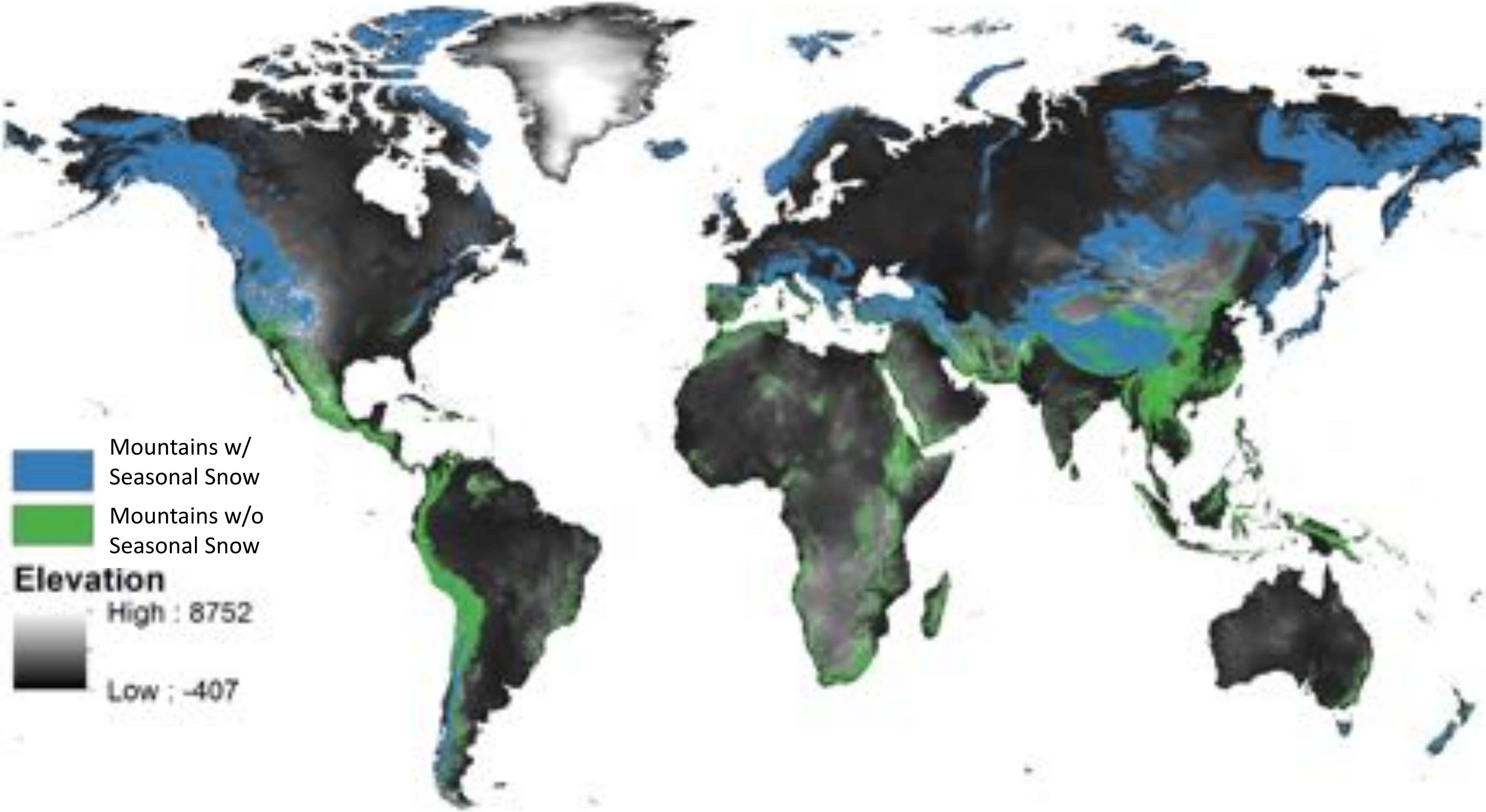
October - July

Assuming WRF is correct:

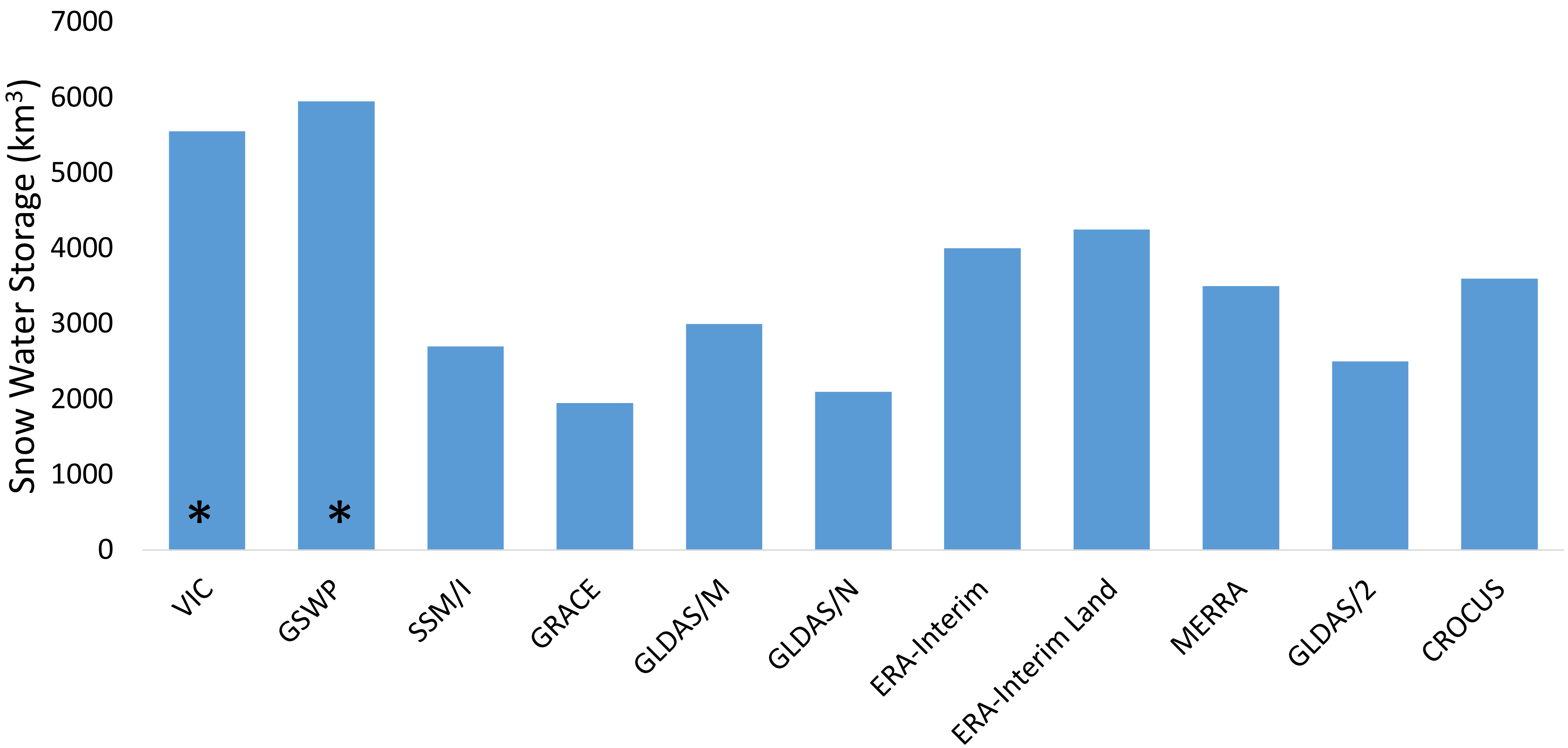
- MERRA is 15% low, on average
- GPCP is 33% low
- CRU is 40% low

Global products almost always lower than the WRF estimate

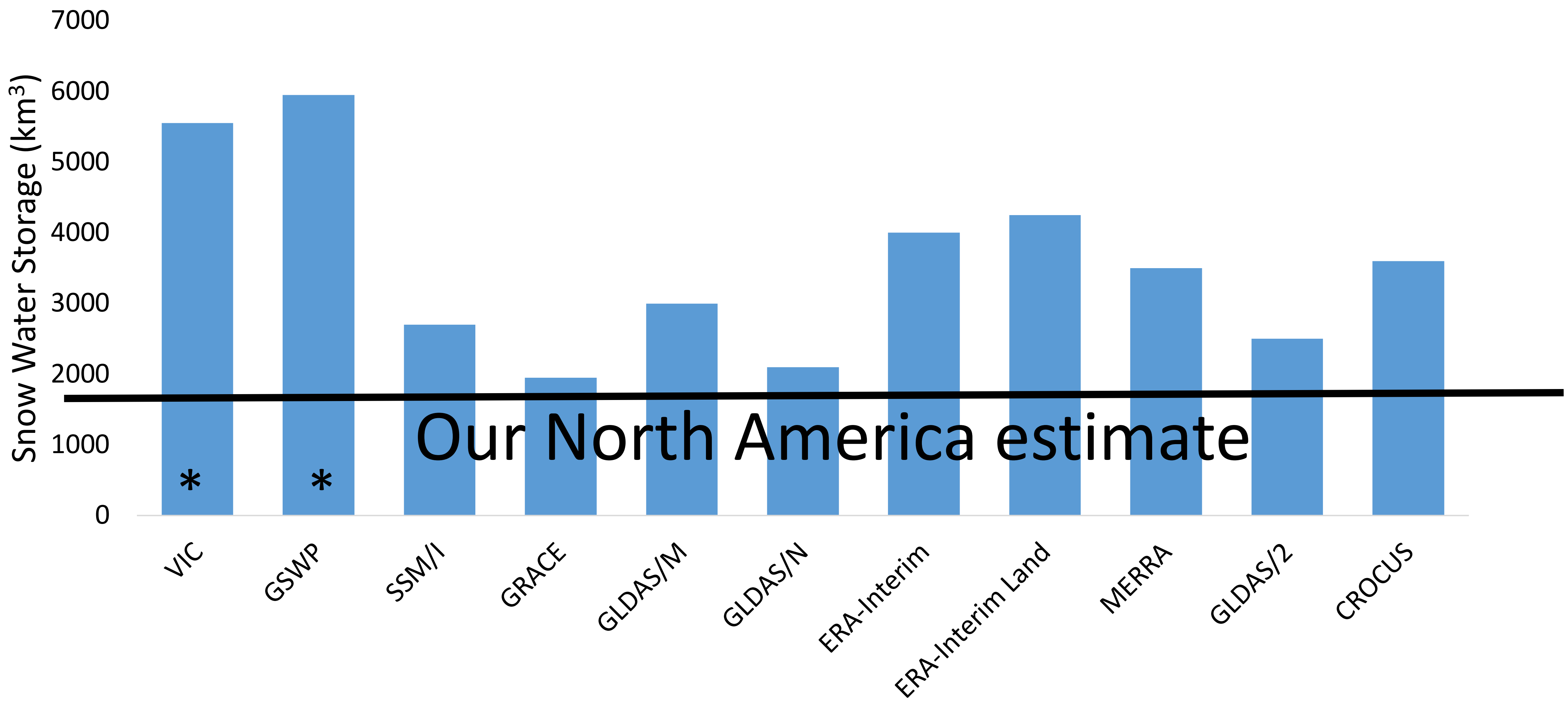
Mountain area: 28.9 million km^2 (19% total land area)
Seasonal snow: 15.2 million km^2

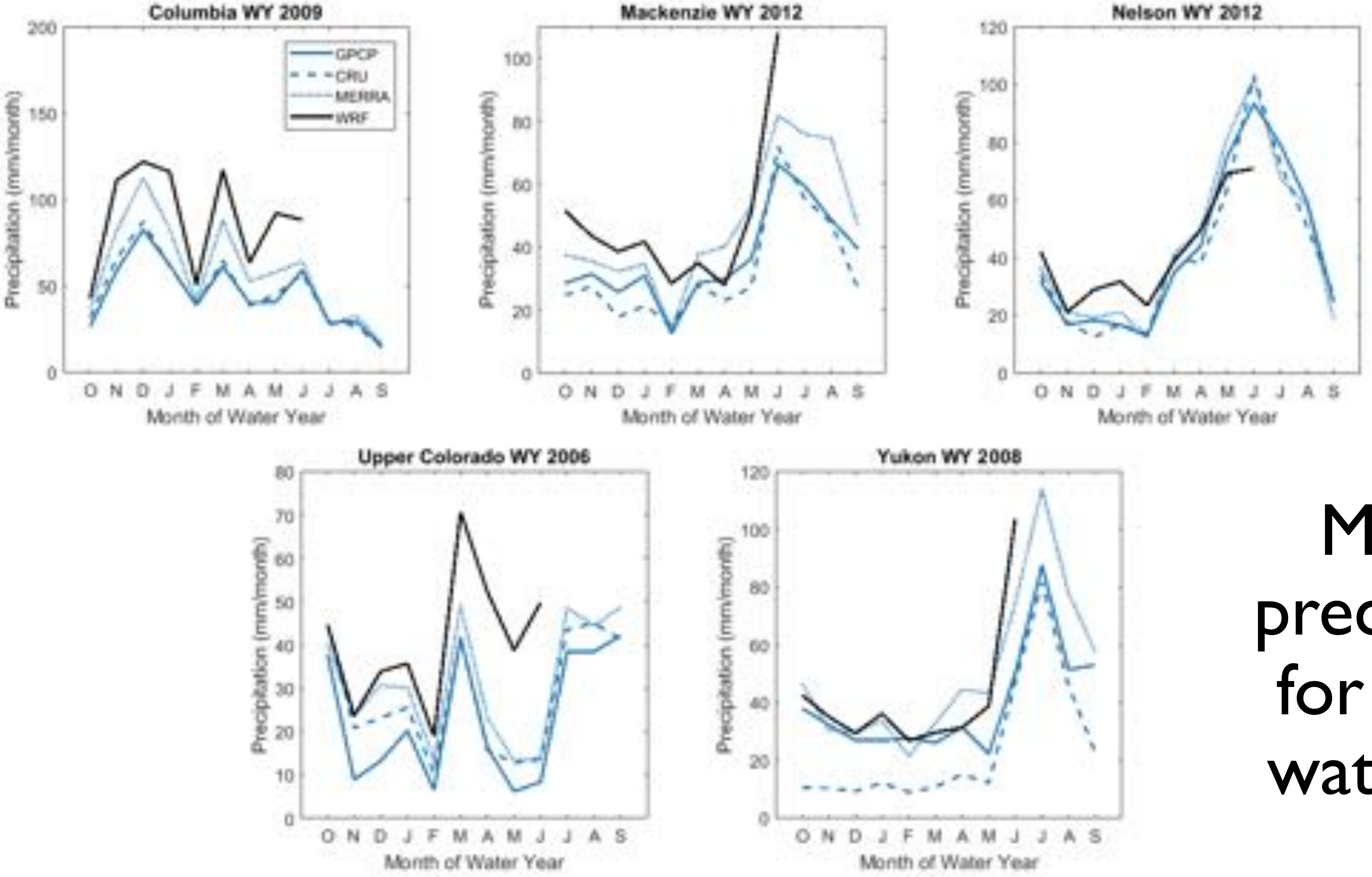


Published estimates of global*/North Hemisphere snow accumulation

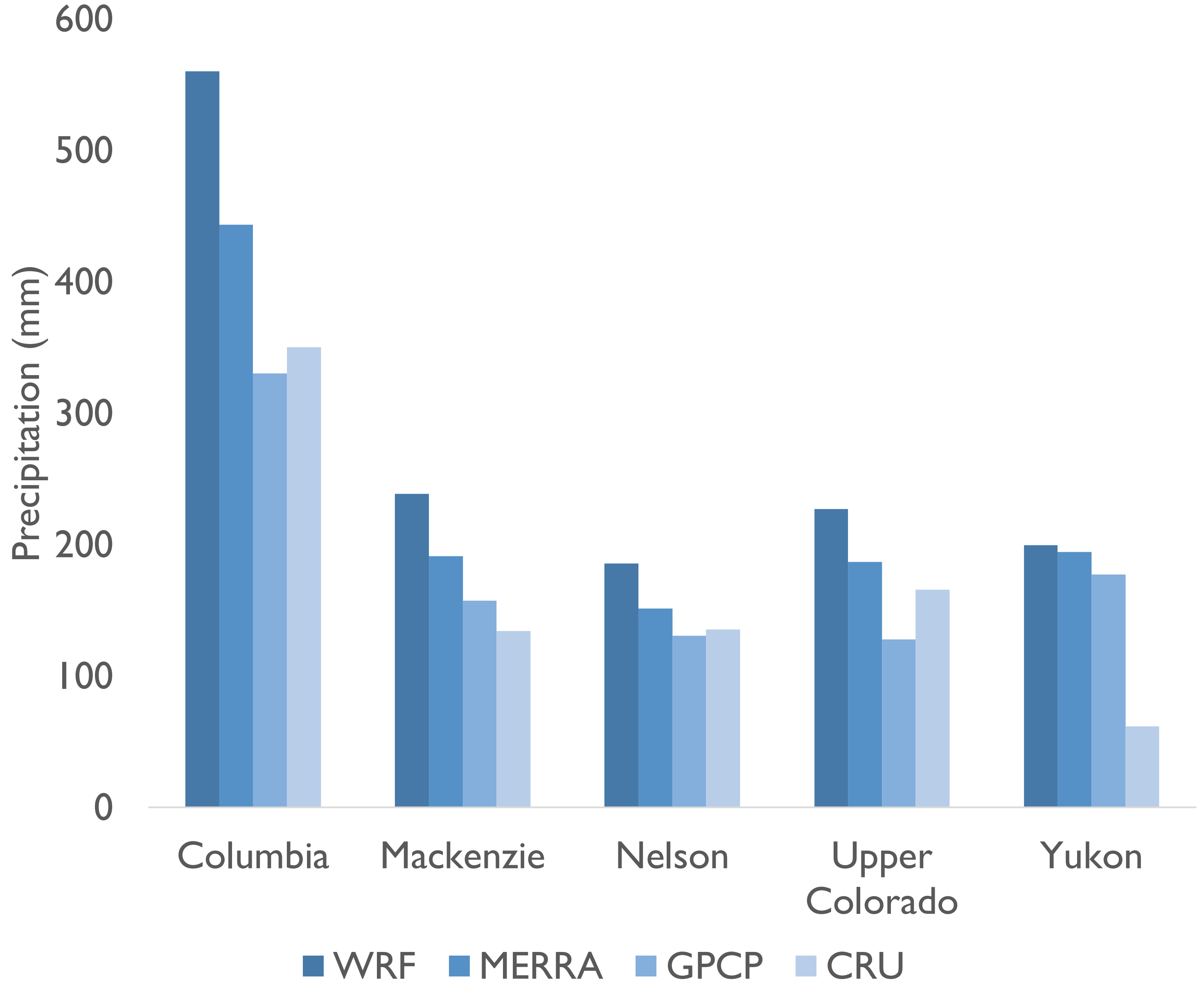


Published estimates of global*/North Hemisphere snow accumulation





Monthly precipitation for average water years



Winter watershed precipitation

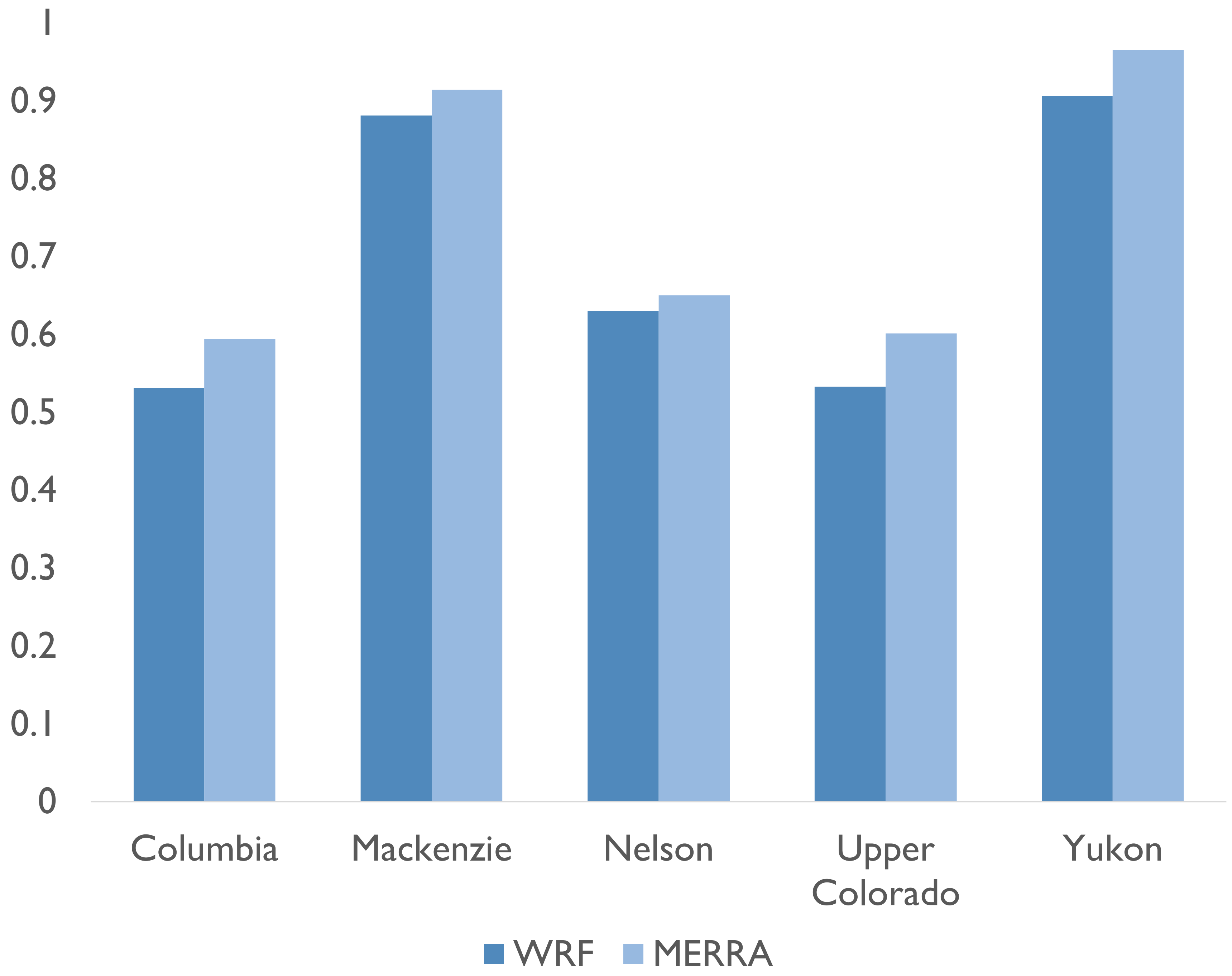
October - March

In comparison to WRF:

- MERRA is 16% lower
- GPCP is 32% lower
- CRU is 41% lower

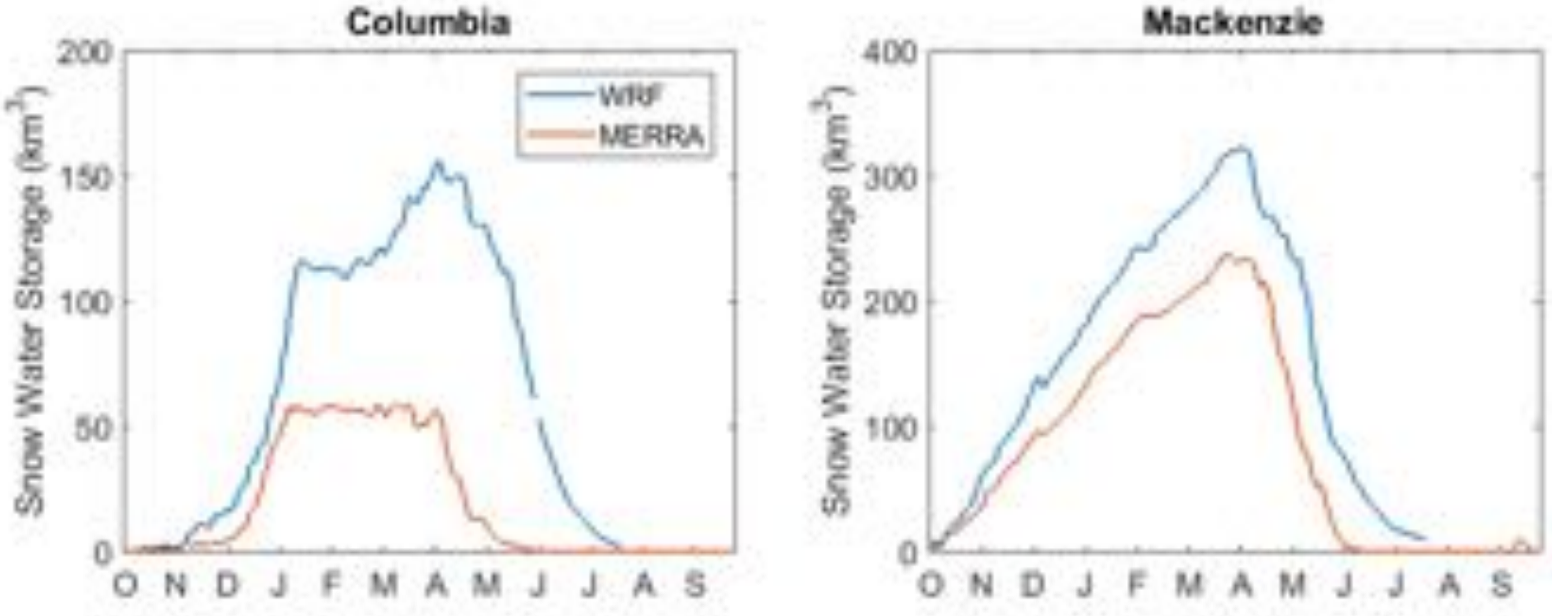
Fraction of winter precipitation that falls as snow

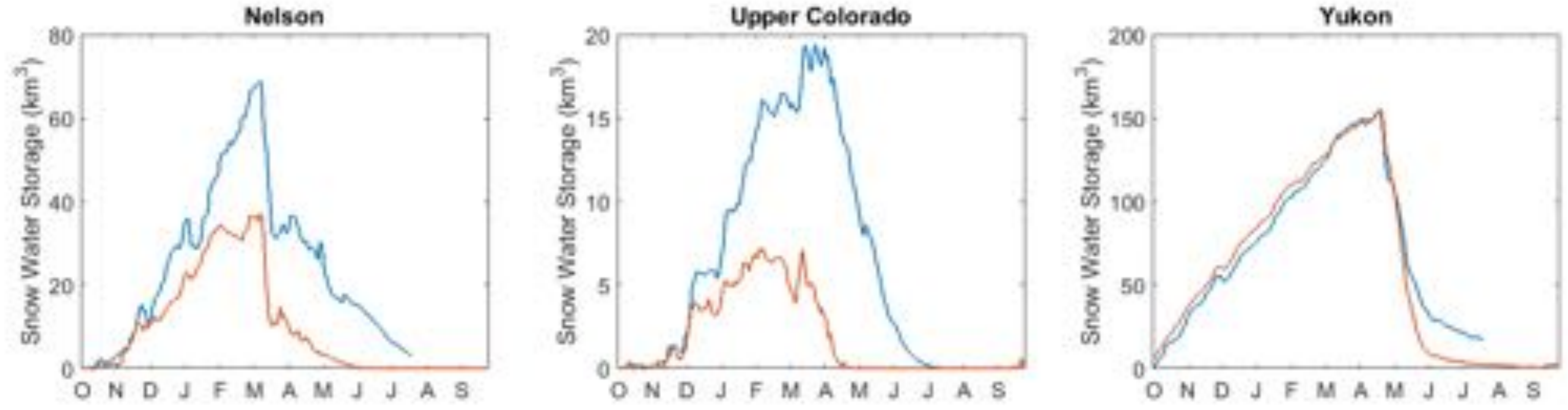
Similar snow/rain partitioning for for WRF and MERRA



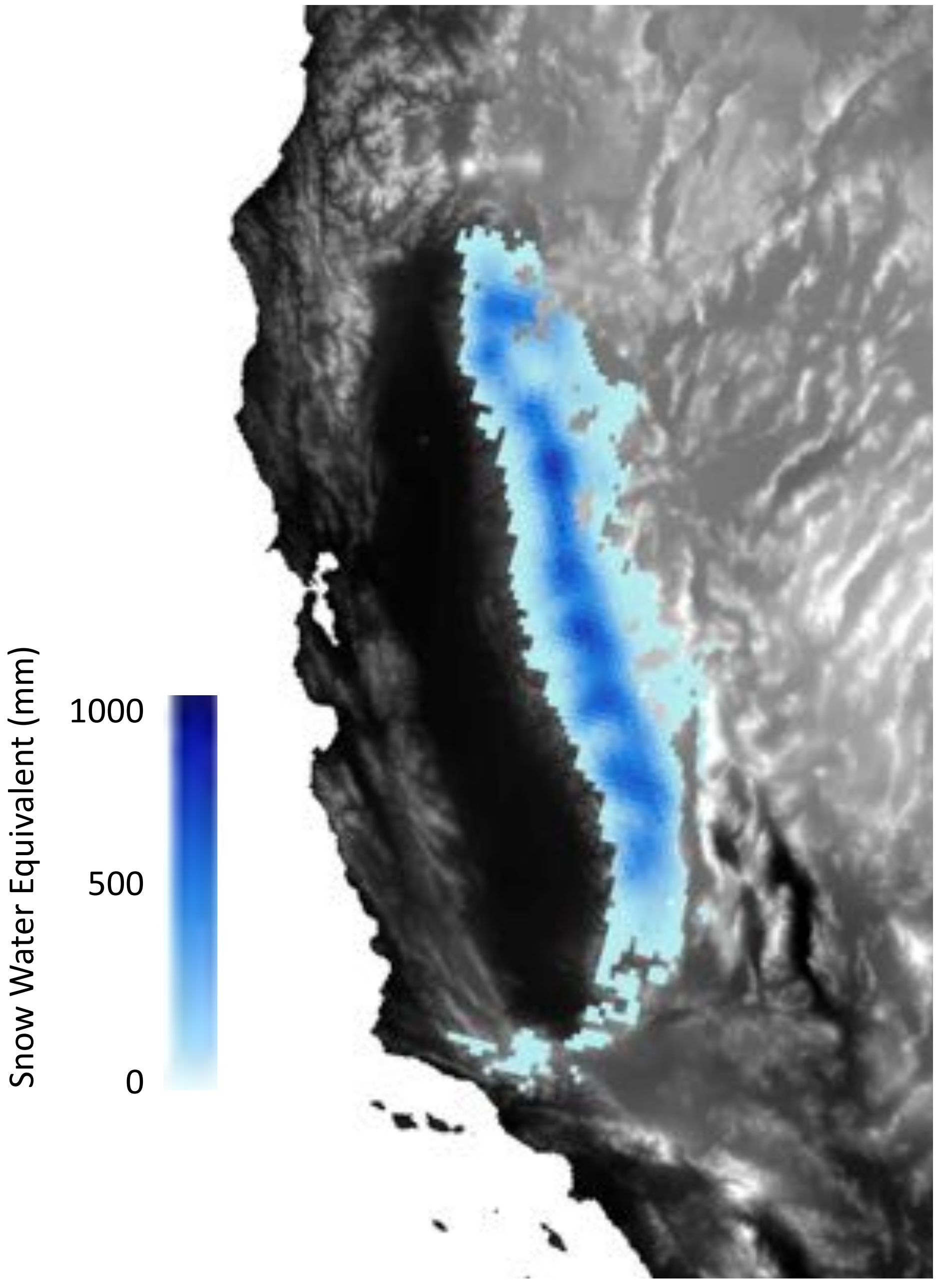
Watershed SWE

- MERRA and WRF are similar for the Yukon
- For all others, MERRA 26-63% underestimated





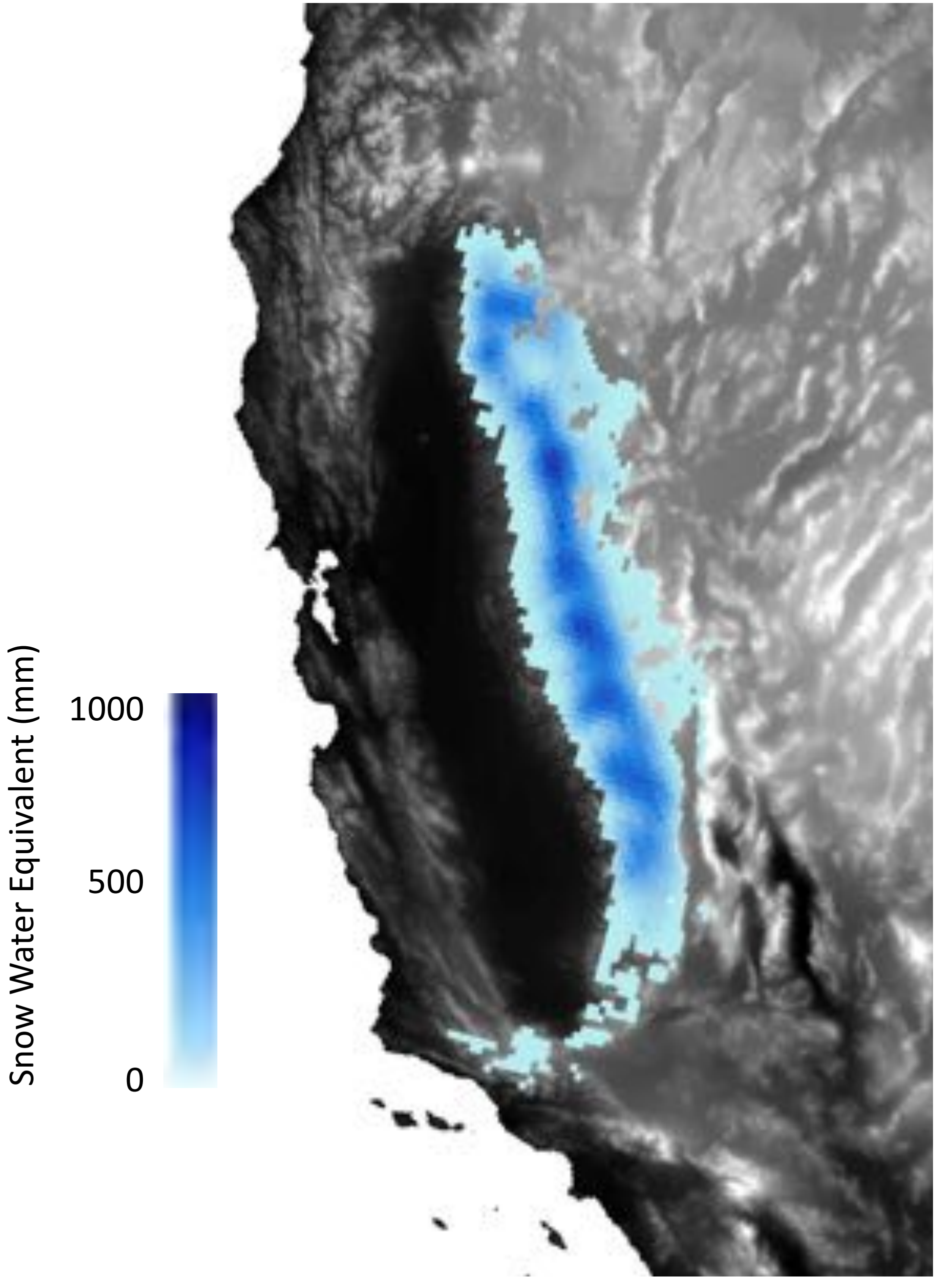
How important is mountain snow for the continental water budget?



Wrzesien et al. (2017) *JHM*

How important is mountain snow for the continental water budget?

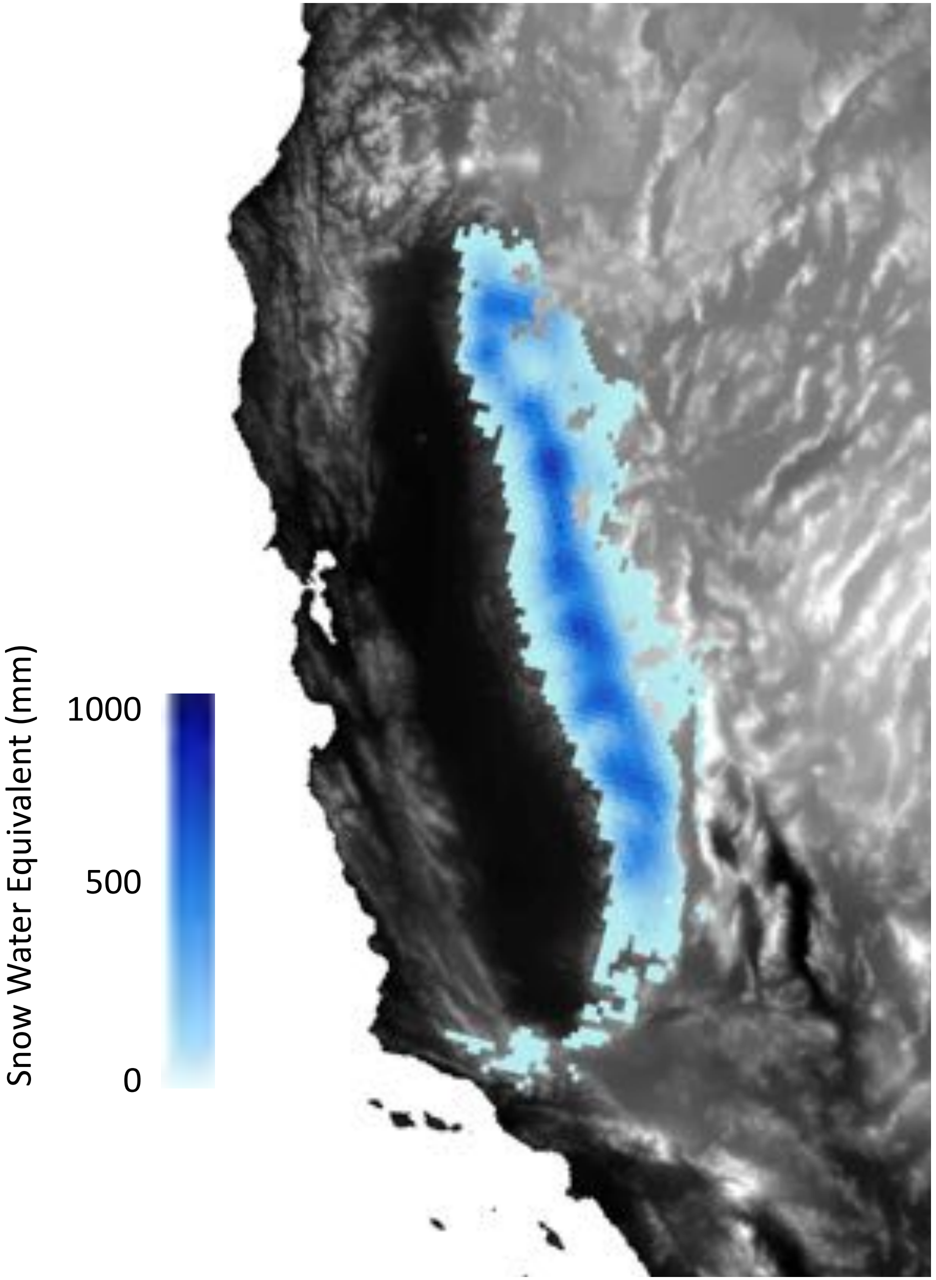
- Initial work – see how the Weather Research and Forecasting (WRF) model compares to other estimates of *snow water storage* (SWS) for the Sierra Nevada



Wrzesien et al. (2017) *JHM*

How important is mountain snow for the continental water budget?

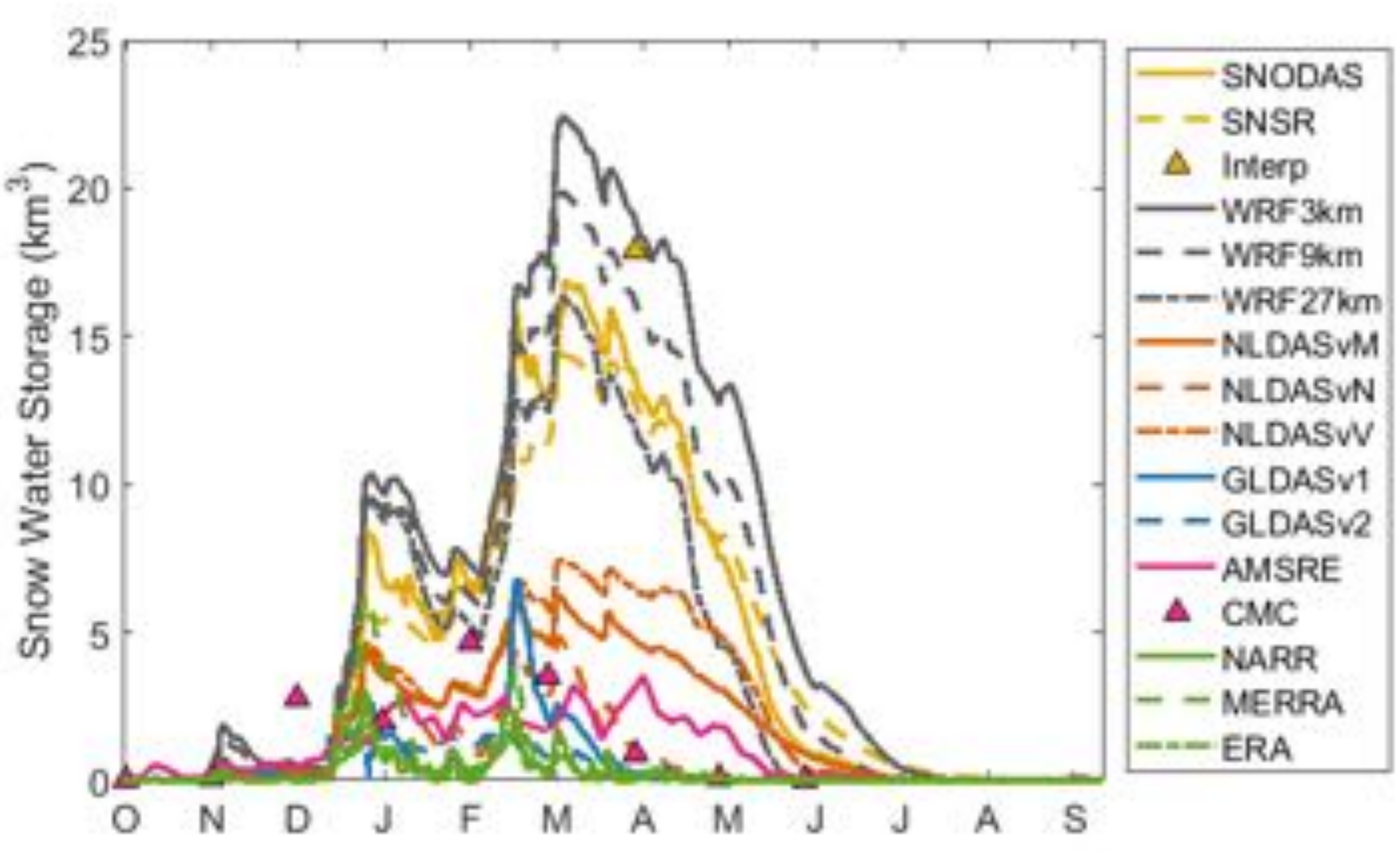
- Weather Research and Forecasting (WRF) model setup:
  - WRF version 3.6.1
  - External forcing data: NARR
  - Land surface model: Noah-MP
  - Microphysics: Thompson
  - Spatial resolution: 3, 9, 27 km (one way nested)
  - Time step: 3 minutes, output saved every 3 hours



Wrzesien et al. (2017) *JHM*

Time series of snow water storage reveals two groupings of datasets

- Comparing **reference** to **WRF**
- WRF SWS is within ±50% of the reference mean
- WRF more reasonable than global/CONUS products



Wrzesien et al. (2017) *JHM*