Investigating the Climatological Impact of Atmospheric Rivers on the Sierra Nevada (USA) Seasonal Snowpack

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August 10, 2016

Background/Motivation

Sierra Nevada snowfall and atmospheric rivers (ARs)

- California heavily relies on the seasonal snowpack
- Accumulation season is dominated by a few large snowstorms
- ARs typically contribute ~30-40% of the total snowfall (*Guan et al., 2010*)

Previous work

- Limited observations inhibit full spatiotemporal characterizations of precipitation/snowfall distributions
  - In situ point-scale measurements
    e.g. Snow sensors (*Guan et al., 2012; Rutz et al., 2014*)
  - Coarser resolution distributed datasets
    e.g. Precipitation: 0.25° CPC precipitation (*Kim et al., 2013*)
    Snow: 1-km SNODAS, 500-m blended SWE product (*Guan et al., 2010, 2013*)
- **Snow distributions tend to be well resolved at ~100 m** (*Clark et al., 2011*)

To overcome these limitations…

- We use a <u>*higher*</u> resolution (90-m, daily) gridded snow water equivalent (SWE) dataset over the <u>*entire*</u> range

Science Questions

1. How does the distribution of AR-derived snowfall vary spatially and temporally in the Sierra Nevada? *Are there differences in orographic enhancement between AR and non-AR elevational snowfall distributions?*

2. How much snowfall is delivered to the Sierra Nevada during AR events?

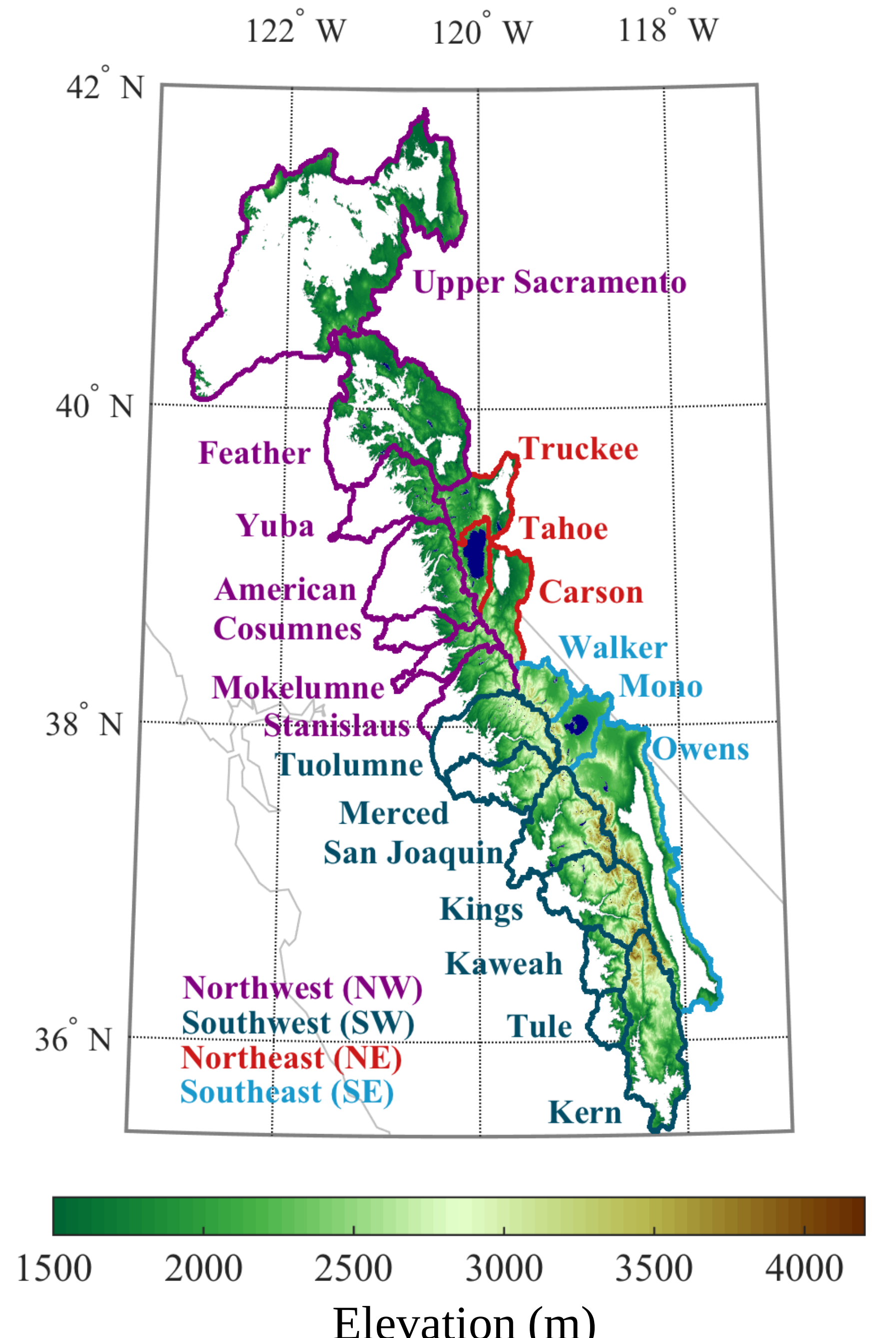
3. What fraction of the seasonal snowfall is derived from ARs from the local to range-scale? *How does it vary between extreme wet and dry years?*

Sierra Nevada Domain

Western Sierra Nevada
- 7 basins in the NW
- 7 basins in the SW

Eastern Sierra Nevada
- 3 basins in the NE
- 3 basins in the SE

Total: 20 basins
(Area ~49,000 km^2)



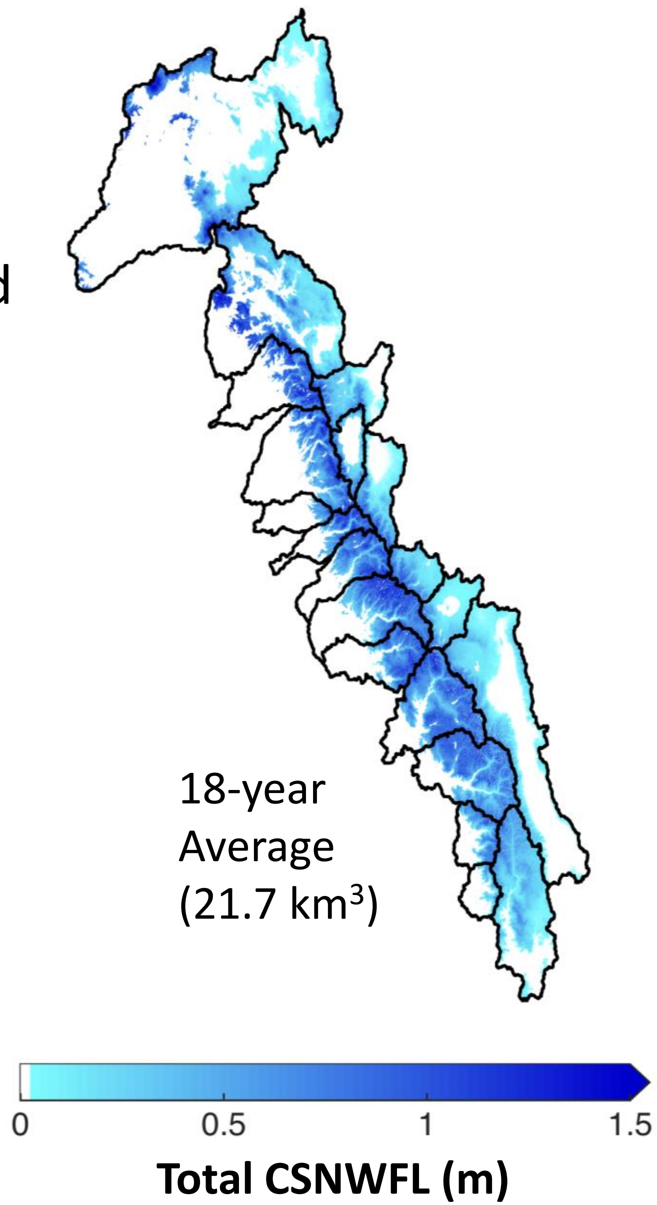
Cumulative Snowfall Dataset: WY 1998-2015

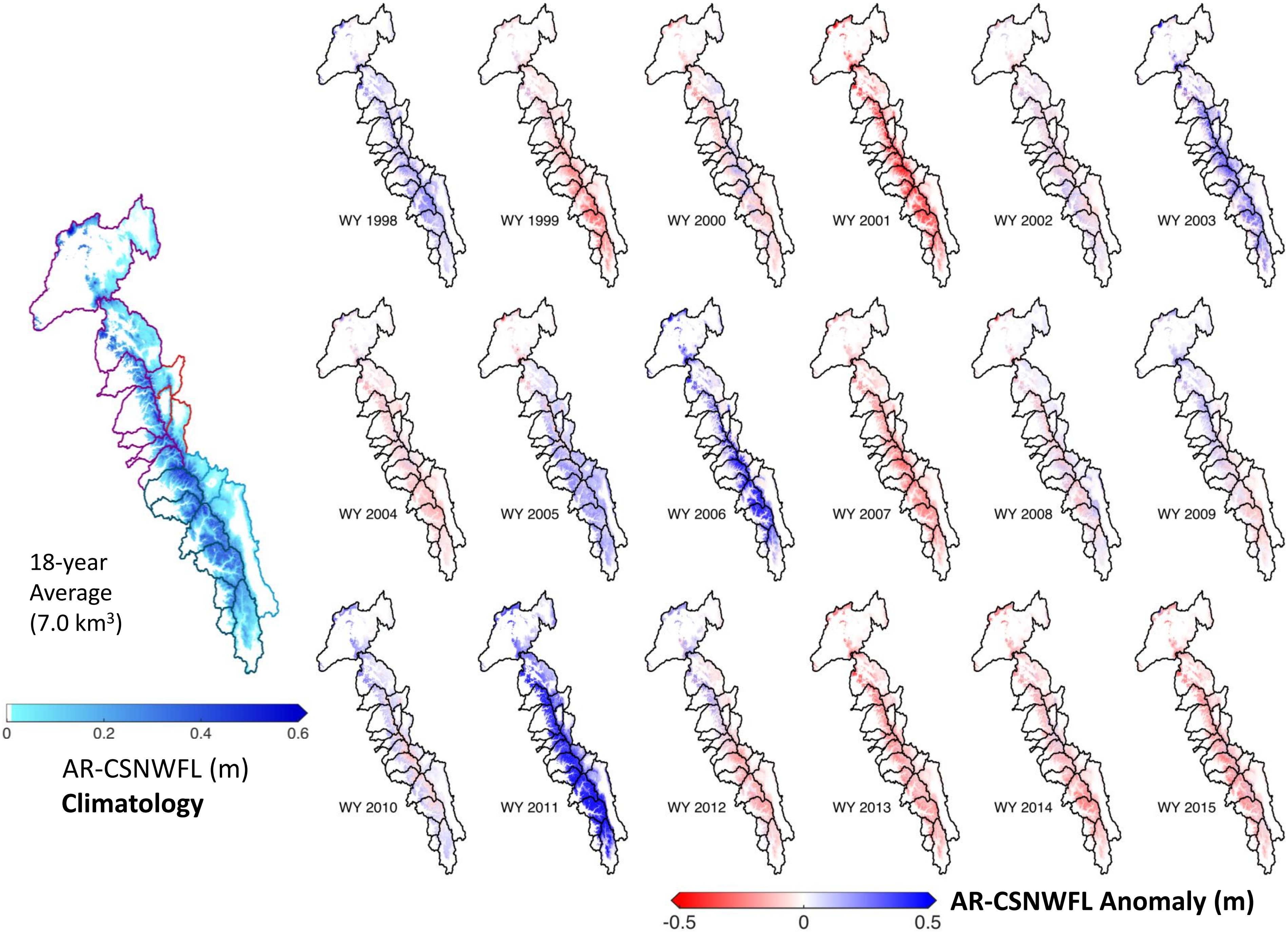
Sierra Nevada snow water equivalent (SWE) reanalysis (*Margulis et al., 2016*)

- **Resolution:** Daily, 90-m
- **Elevations:** >1500 m
- Assimilated Landsat fractional snow-covered area (fSCA) images (*Margulis et al., 2015*)
- Spatially *and* temporally continuous *maps*

- **Cumulative snowfall (CSNWFL):** Daily increases in SWE
- **Accumulation season:** November to the *range-wide* day-of-peak SWE (*Variable* season length)

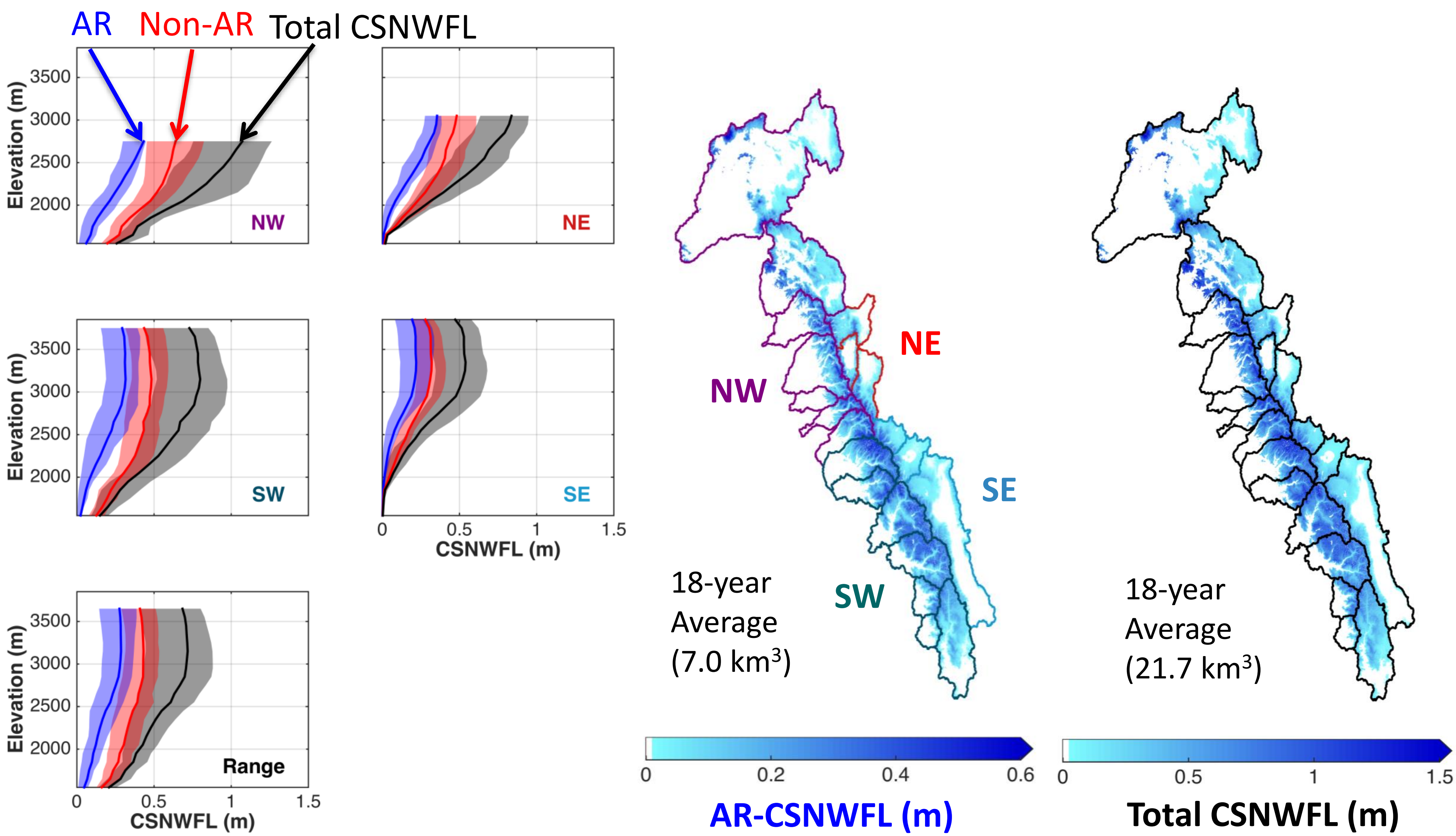
- **AR-CSNWFL** is diagnosed with California AR landfall dates from SSM/I and SSMIS (*Neiman et al., 2008*)



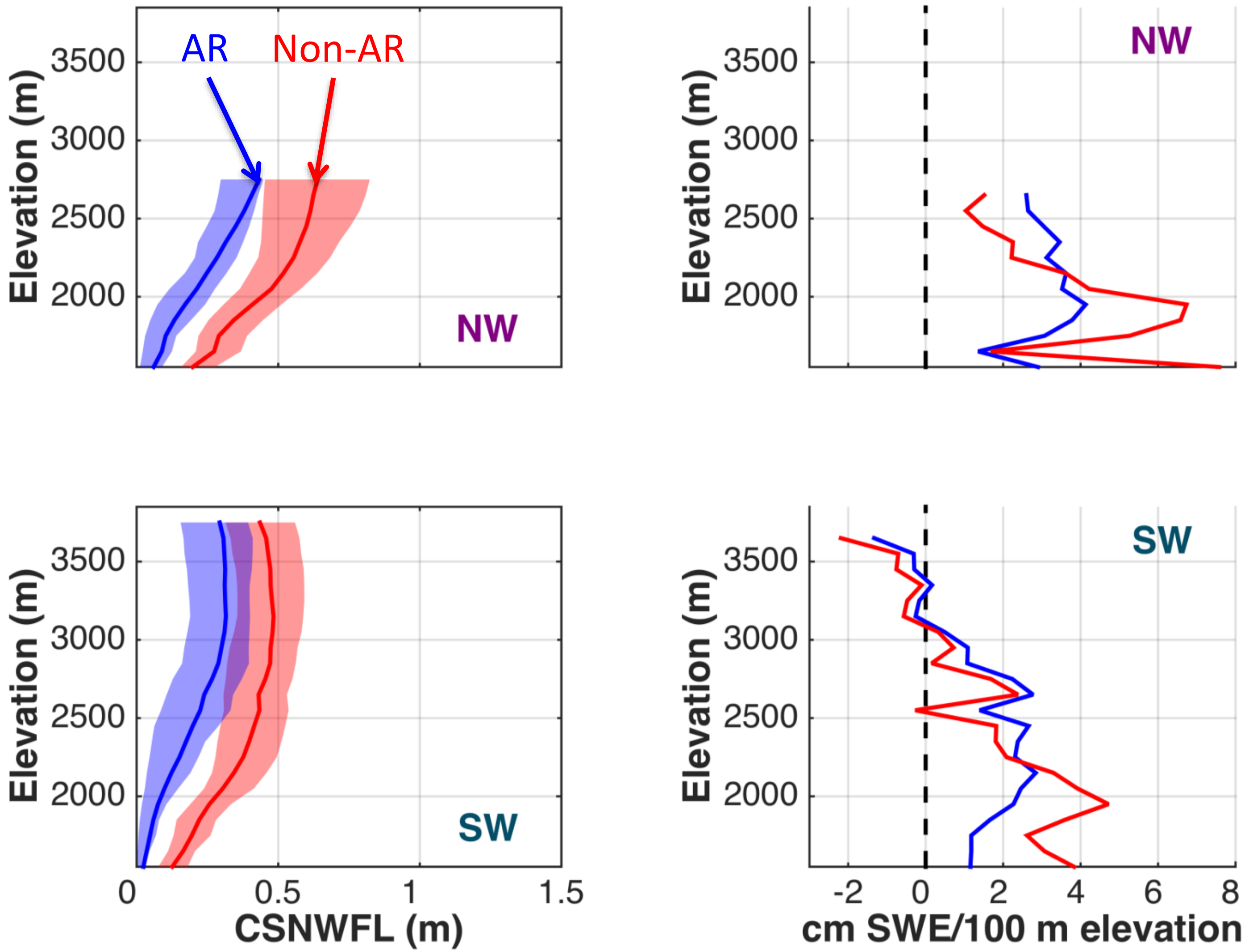


18-year Average (7.0 km³)
0
0.2
0.4
0.6
AR-CSNWFL (m)
Climatology
WY 1998
WY 1999
WY 2000
WY 2001
WY 2002
WY 2003
WY 2004
WY 2005
WY 2006
WY 2007
WY 2008
WY 2009
WY 2010
WY 2011
WY 2012
WY 2013
WY 2014
WY 2015
-0.5
0
0.5
AR-CSNWFL Anomaly (m)

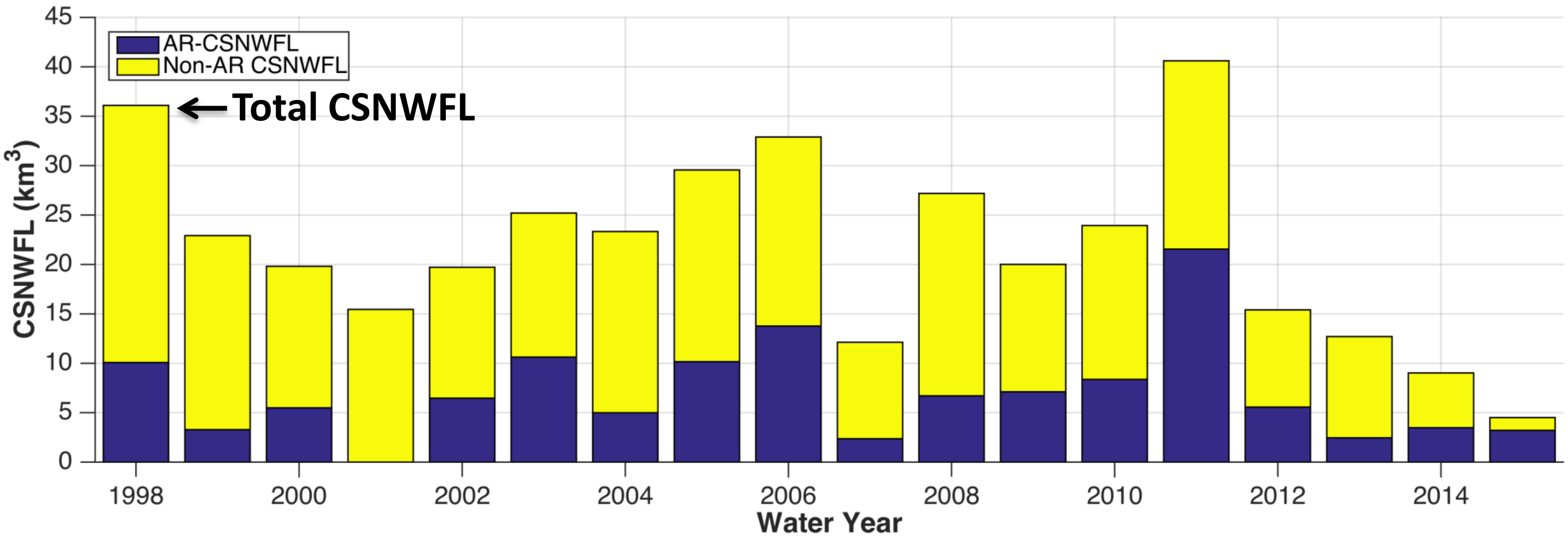
Elevational Distributions



Orographic Enhancement in the Western Sierra Nevada

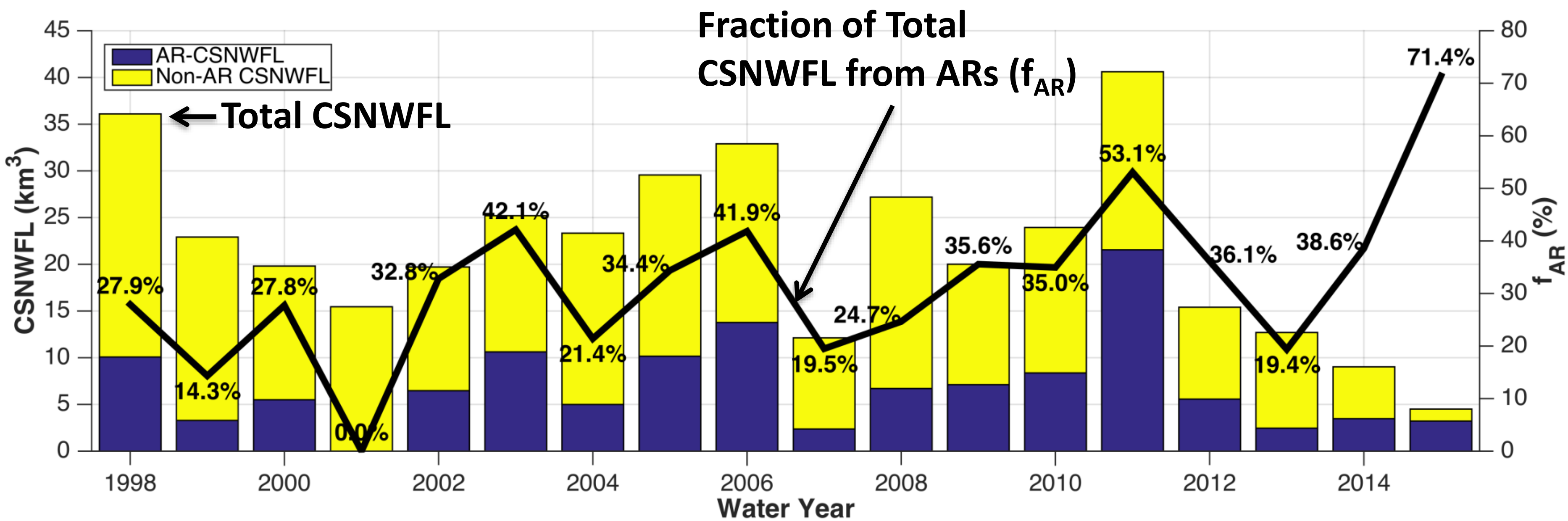


Integrated CSNWFL for WY 1998-2015



	AR-CSNWFL (km^3)	Total CSNWFL (km^3)
Minimum	0.0 (in WY 2001)	4.5 (in WY 2015)
Maximum	21.6 (in WY 2011)	40.6 (in WY 2011)
Mean	7.0	21.7

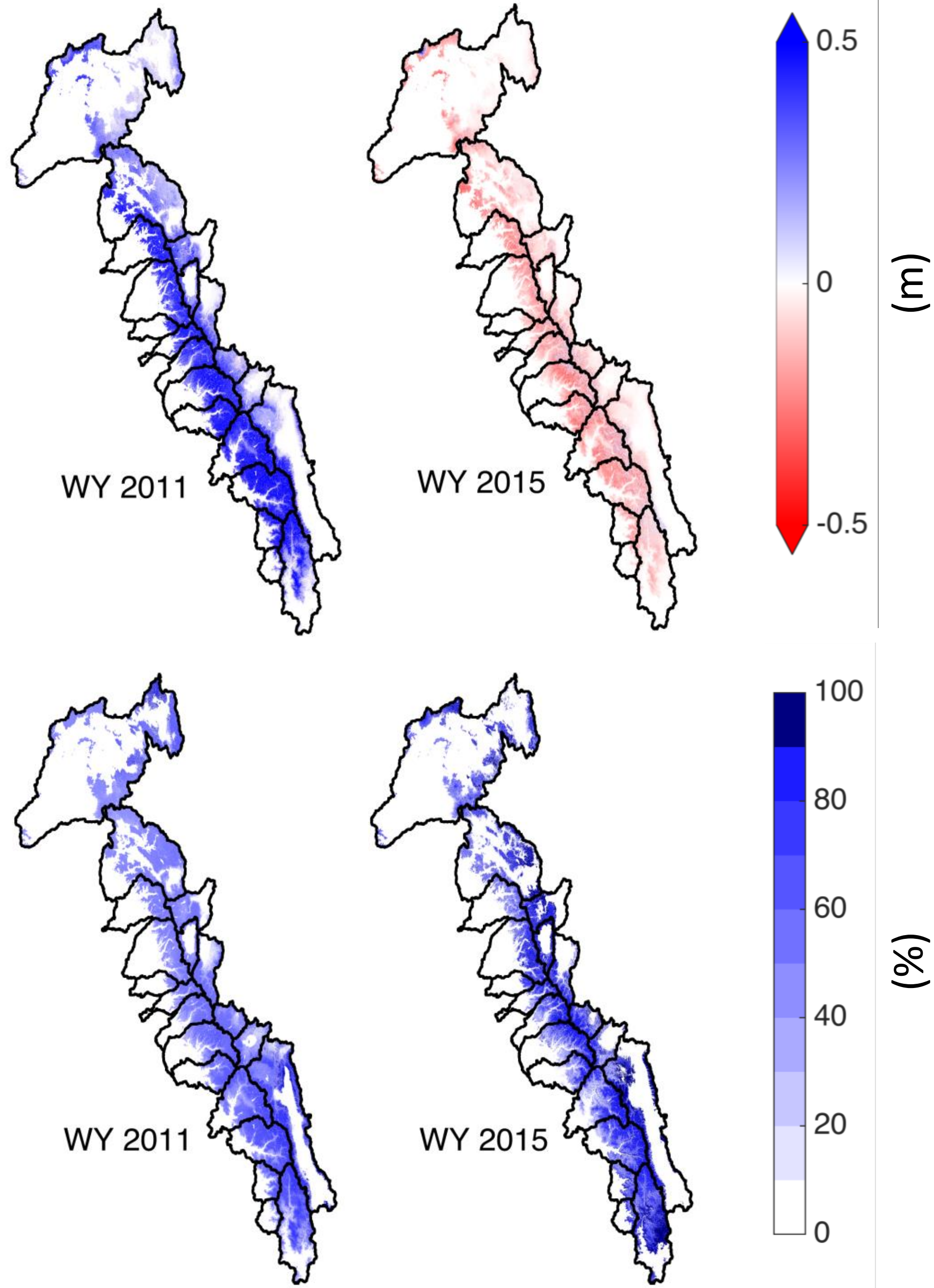
Integrated CSNWFL for WY 1998-2015



	AR-CSNWFL (km^3)	Total CSNWFL (km^3)	f_{AR} (%)
Minimum	0.0 (in WY 2001)	4.5 (in WY 2015)	0.0 (in WY 2001)
Maximum	21.6 (in WY 2011)	40.6 (in WY 2011)	71.4 (in WY 2015)
Mean	7.0	21.7	32.0

AR-CSNWFL Anomaly

Fraction of Total CSNWFL from ARs (f_{AR})

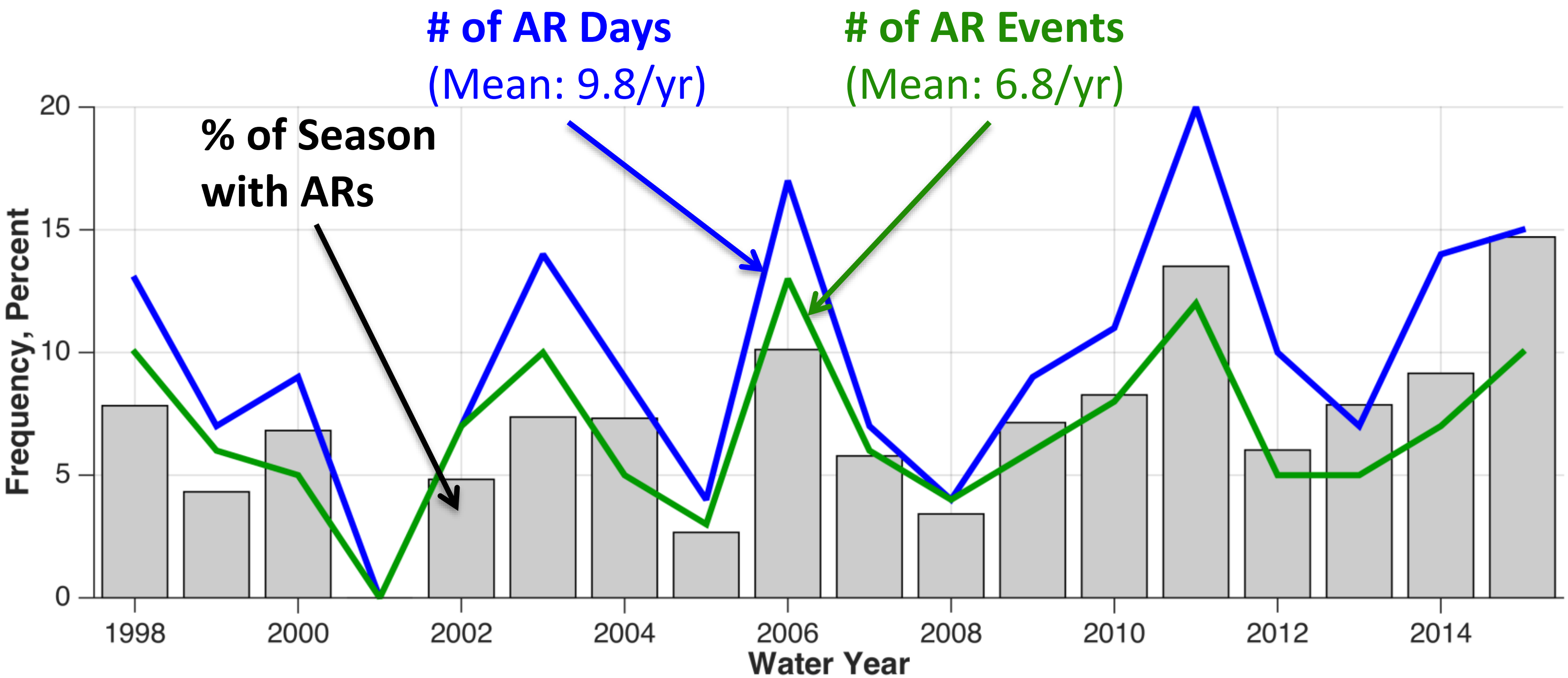


Conclusions

- Application of novel CSNWFL dataset highlights local to range-scale spatial/temporal differences in AR-CSNWFL distributions
- AR-CSNWFL exhibits greater orographic enhancement than non-AR CSNWFL at high elevations in western basins

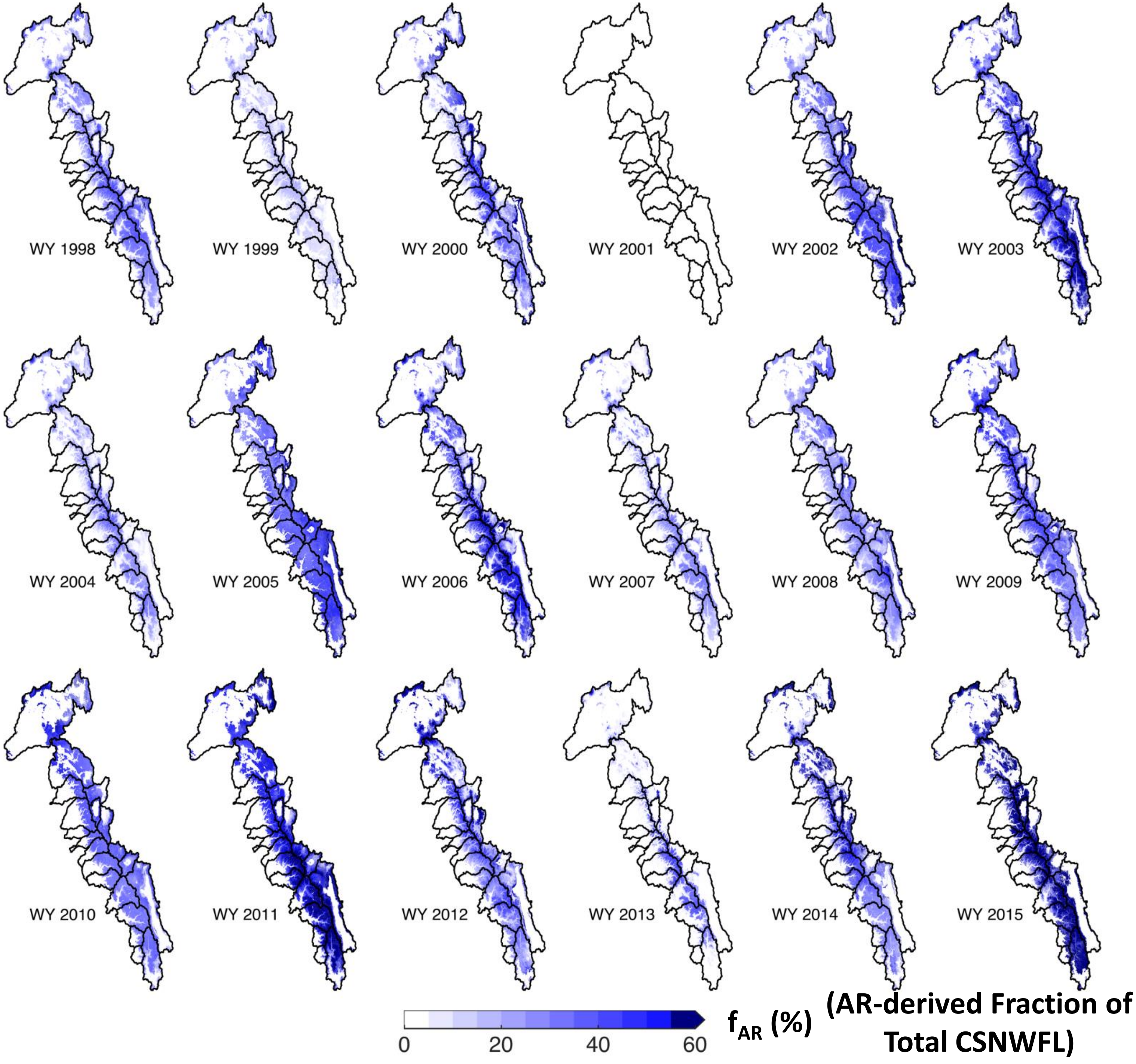
- Significant inter-annual variability in AR-CSNWFL (0-21.6 km^3)
- 32% of the total CSNWFL volume is derived from ARs (7.0 km^3) on average (Range: 0-71%)

- Simply knowing f_{AR} may not be a good predictor of the "wetness" of a year
- ARs play important roles during both wet years and dry years



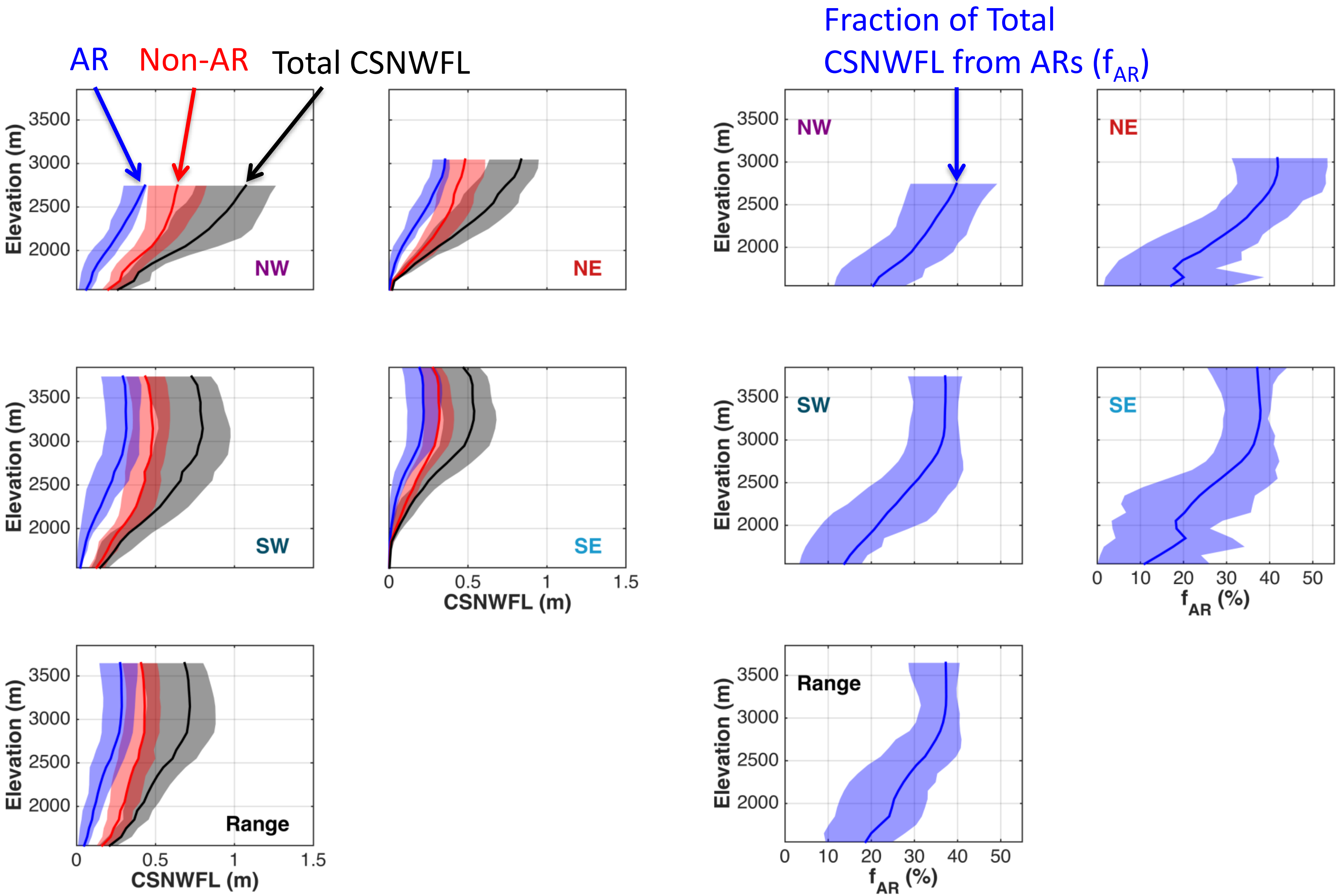
Correlation Coefficients

	Total Integrated CSNWFL	AR Integrated CSNWFL
# of AR days	0.289 (p=0.245)	0.655 (p=0.003)
# of AR events	0.387 (p=0.113)	0.671 (p=0.002)



WY 1998
WY 1999
WY 2000
WY 2001
WY 2002
WY 2003
WY 2004
WY 2005
WY 2006
WY 2007
WY 2008
WY 2009
WY 2010
WY 2011
WY 2012
WY 2013
WY 2014
WY 2015
0
20
40
60
f_{AR} (%)
(AR-derived Fraction of Total CSNWFL)

Elevational Distributions



Integrated CSNWFL Anomalies