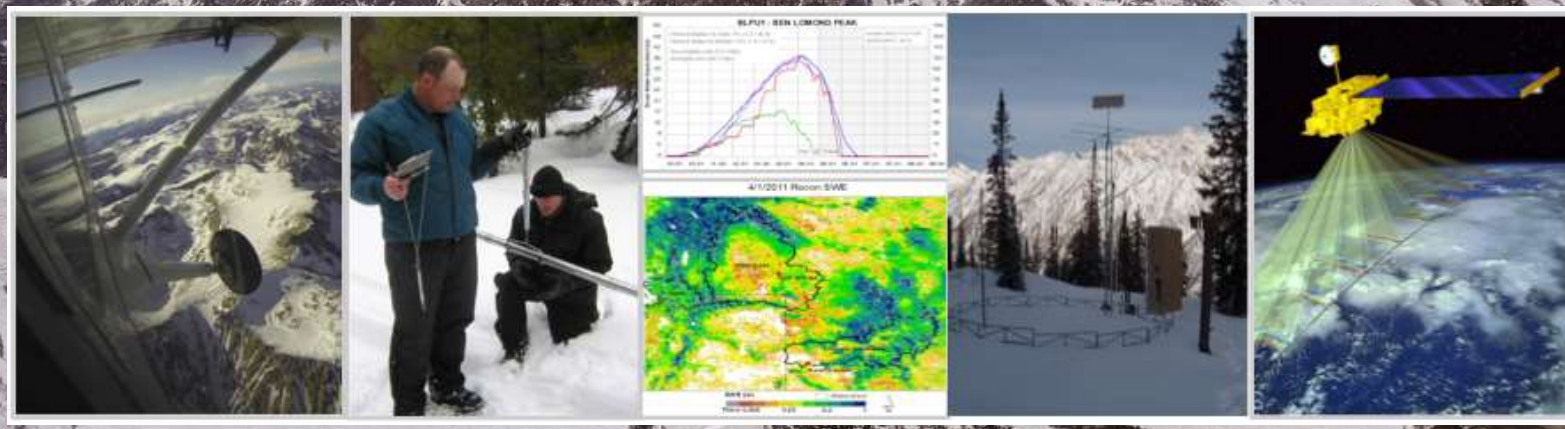
MODIS-Based, Real-time SWE Data Product

Noah Molotch, Dominik Schneider, Leanne Lestak, Jeff Dozier, Jeff Lukas & Tom Painter



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West Jordan, Utah – August 11, 2015

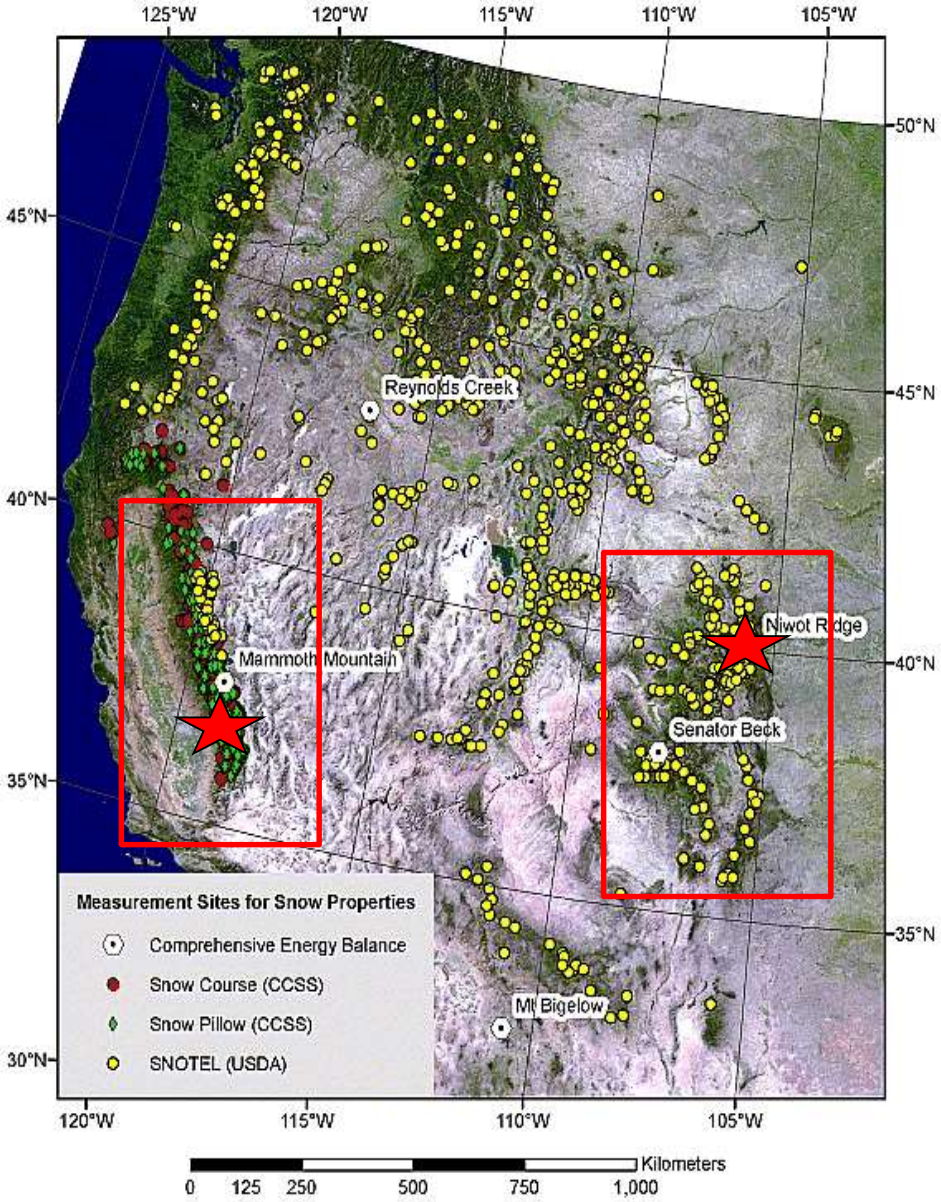
Background Photo: Jim Steenburgh, Wasatch Weather Weenies

NIDIS NRCS Natural Resources Conservation Service Snow Survey CBRFC Colorado Basin River Forecast Center Jordan Valley Water Conservancy District

Objective

- Develop near real-time SWE estimates using SNOTEL and MODIS-based SWE Reconstructions.
  - Reconstruct SWE distribution using MODIS snow cover data and an energy balance model.
  - Use multi-variate regression to interpolate SNOTEL SWE based on topography.
  - Add historical SWE reconstructions as independent variable in multi-variate regressions.
  - Reanalysis and real time daily SWE products at 500-m resolution from 2000 – 2015.

Study Areas & Data



Snowpack Metrics

- 350+ SNOTEL SWE sites
- MODIS-based SWE Reconstruction (*Guan et al., 2013; Molotch et al., 2009*)

Independent Variables

- Elevation, slope, aspect, distance to ocean, barrier height, others.
- MODIS-based SWE Reconstruction

SWE Reconstruction model

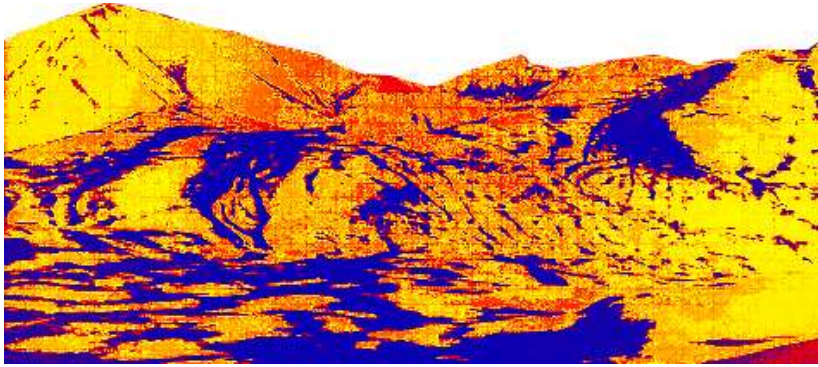
$$SWE_n = SWE_0 - \sum_{j=1}^{n} M_j$$

when $SWE_n = 0$,

$$SWE_0 = \sum_{j=1}^{n} M_j$$

snow covered area

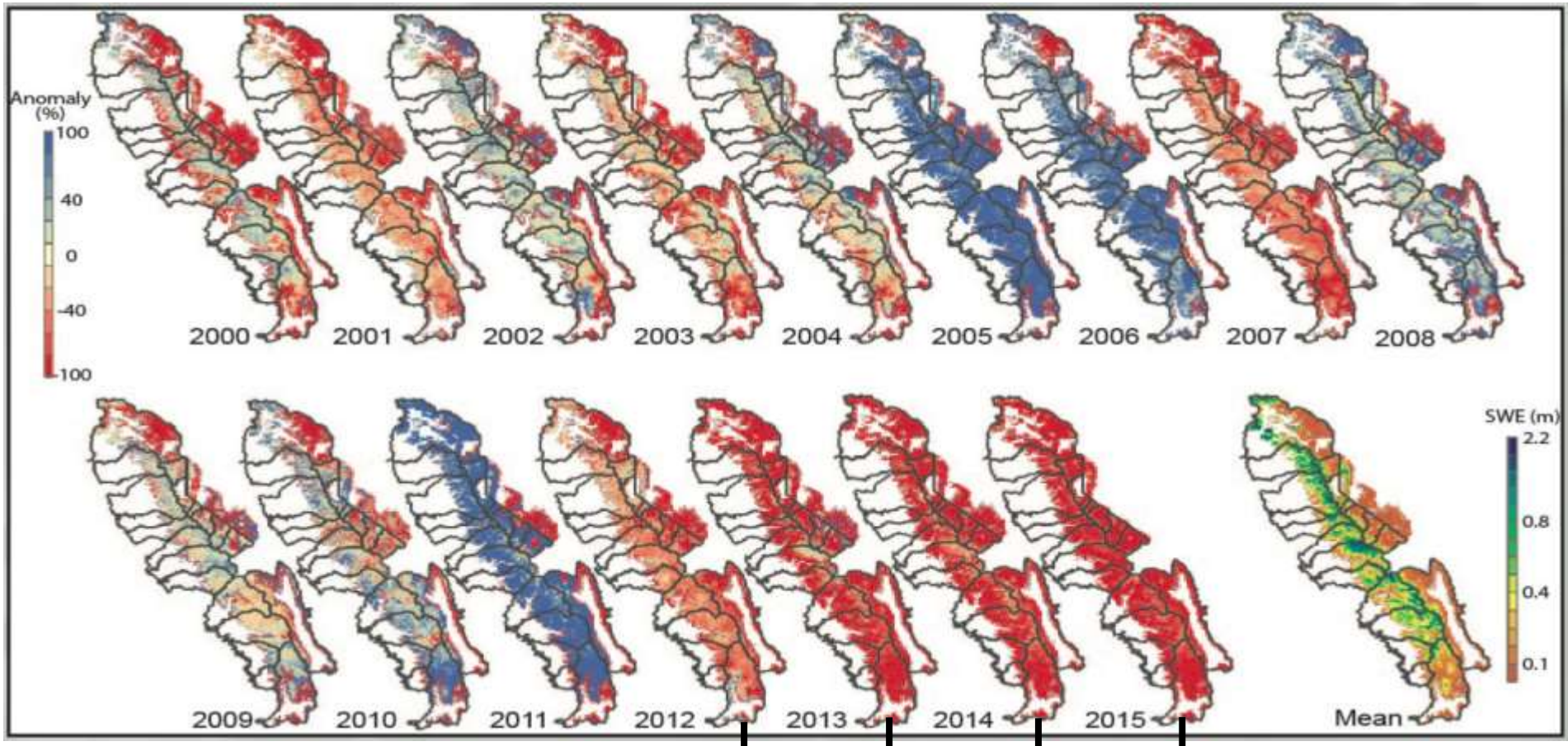
daily snowmelt, cm



0 1.6 3.2

Cline et al., 1998a,b; Liston, 1999; Molotch et al., 2004b; Molotch & Bales, 2005;2006; Durand et al., 2007; Molotch, 2008.

Snow Water Equivalent Anomalies



Guan et al., 2013 - WRR

Model Validation

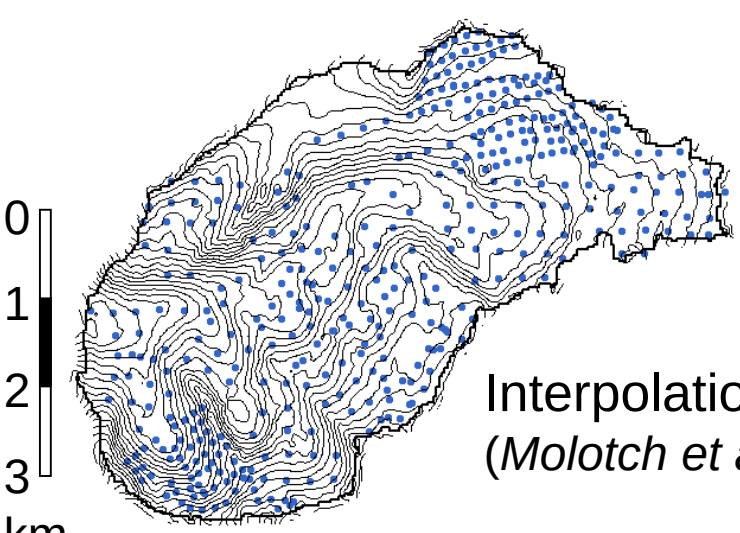
snow depth

6 people

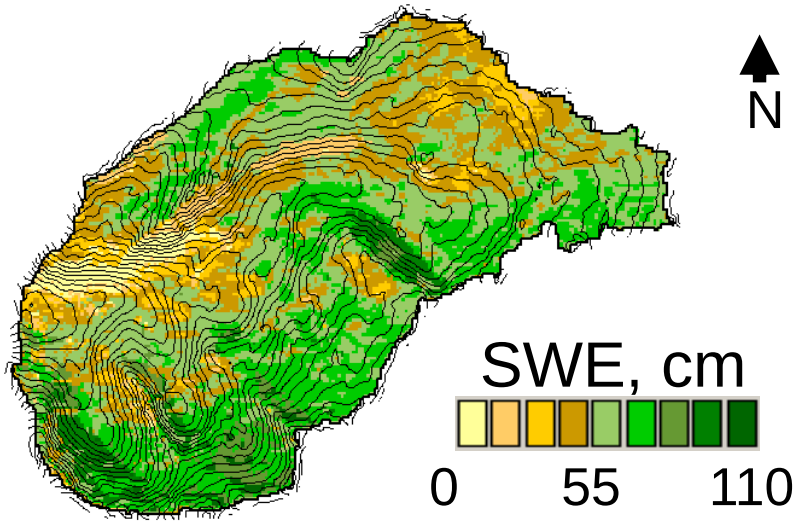
8 days

snow density

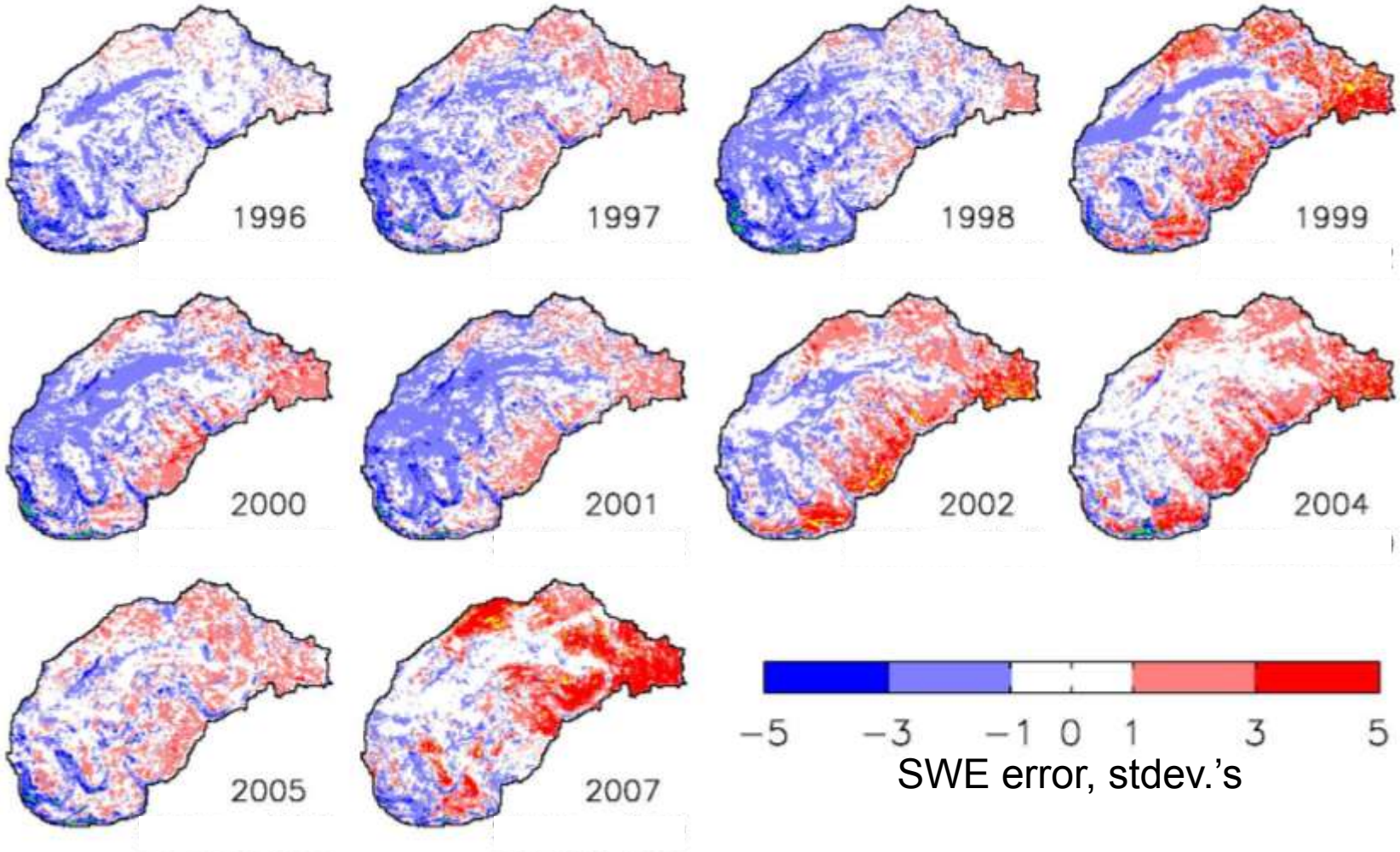
- 400+ measurements



Interpolation model
(*Molotch et al., 2004a*)



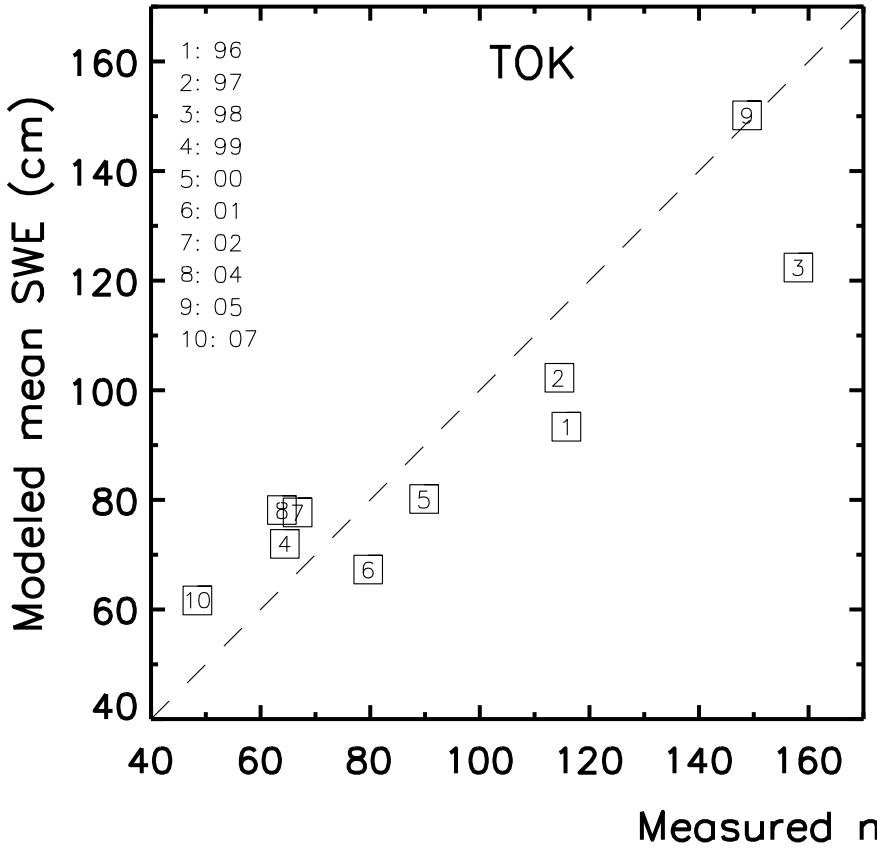
Model Validation



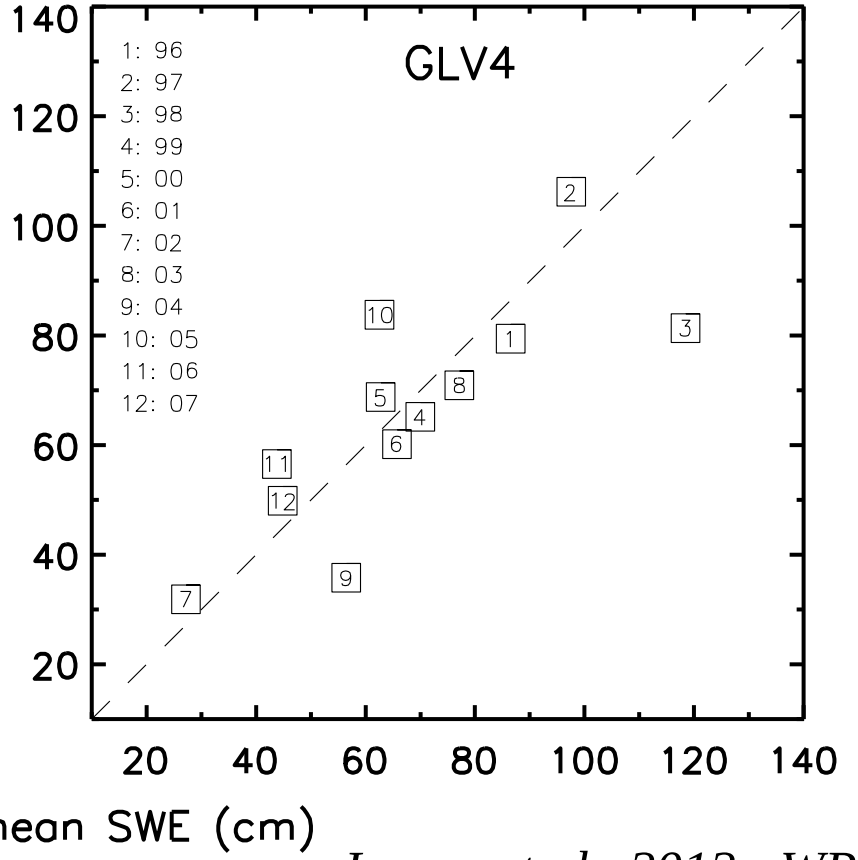
Jepsen et al., 2012 - WRR

Model Evaluation: Sierra and Rockies

Tokopah, Sierra Nevada, CA



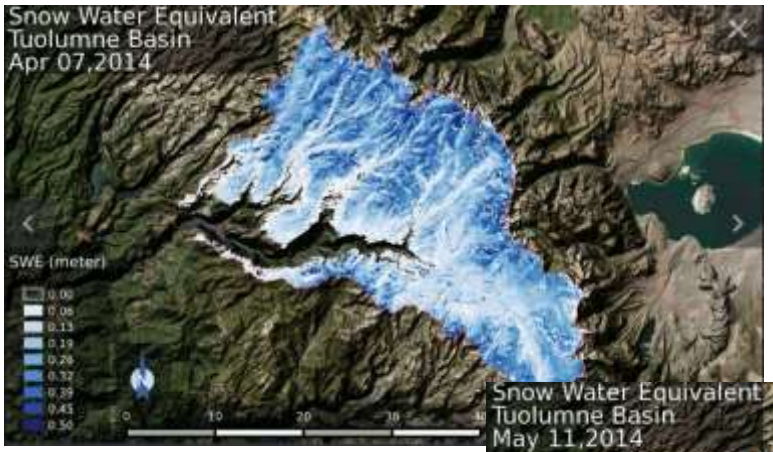
Green Lakes Valley, CO Rockies

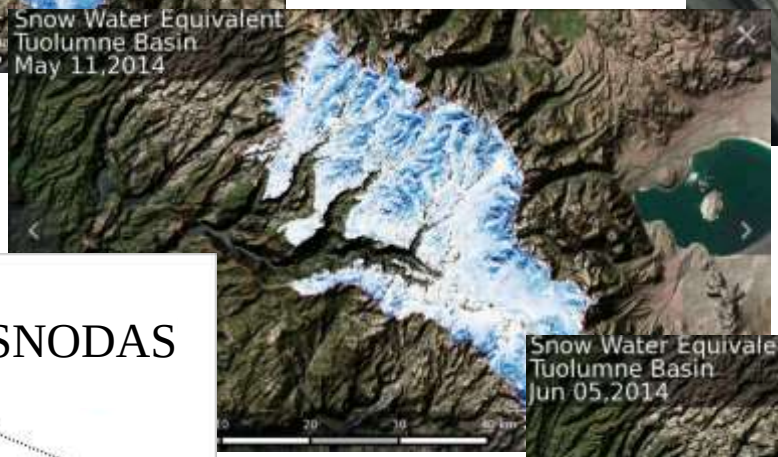


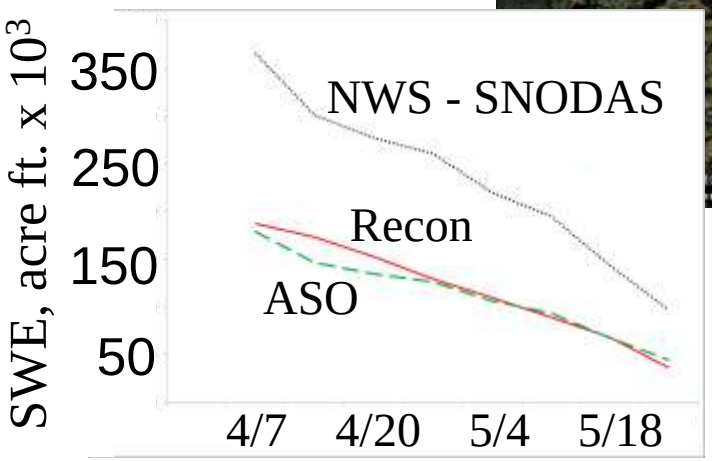
Measured mean SWE (cm)

Jepsen et al., 2012 - WRR

Model Validation: Airborne Snow Observatory (ASO)

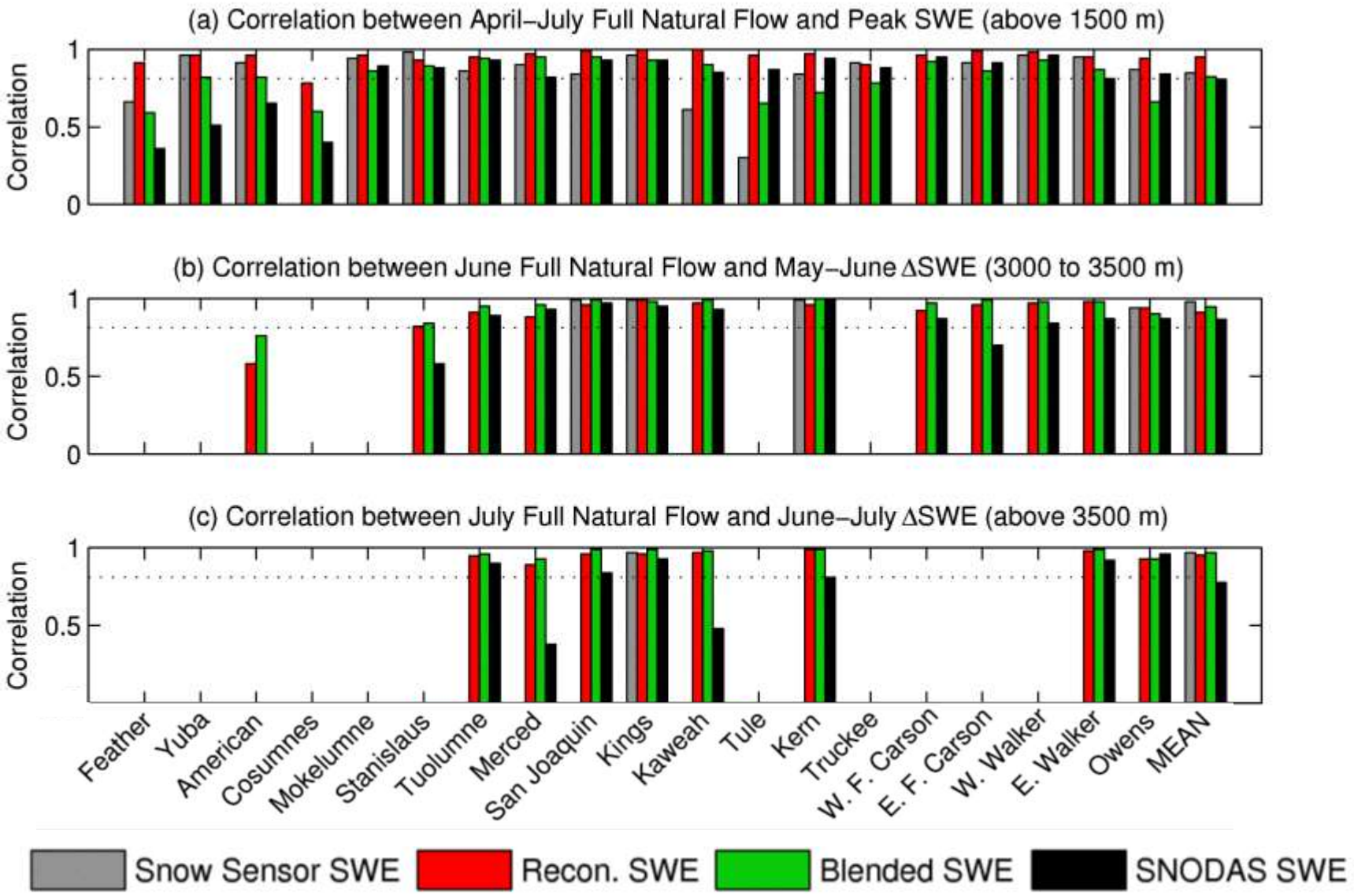






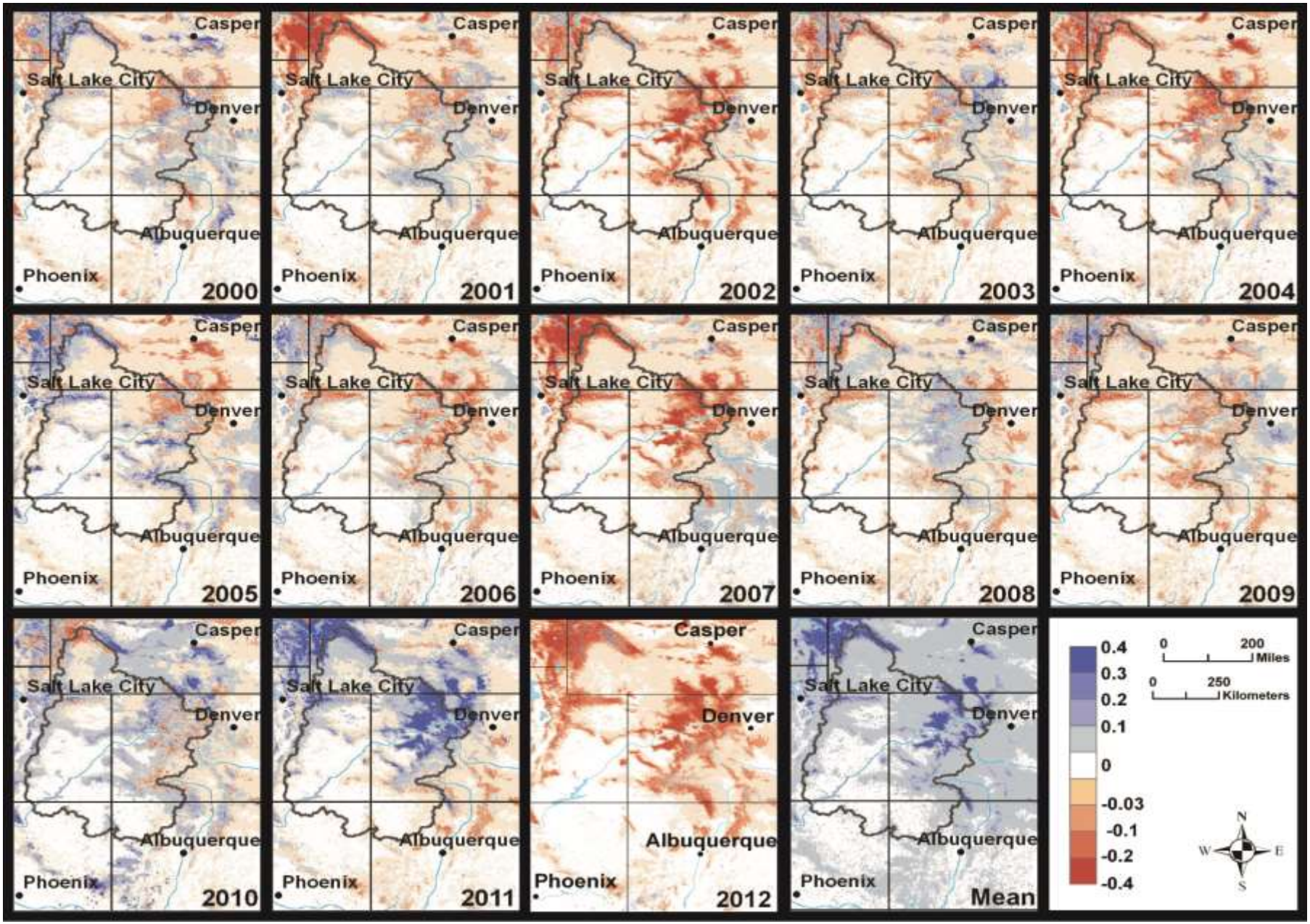
ASO data courtesy of T. Painter

Correlation of SWE with Streamflow



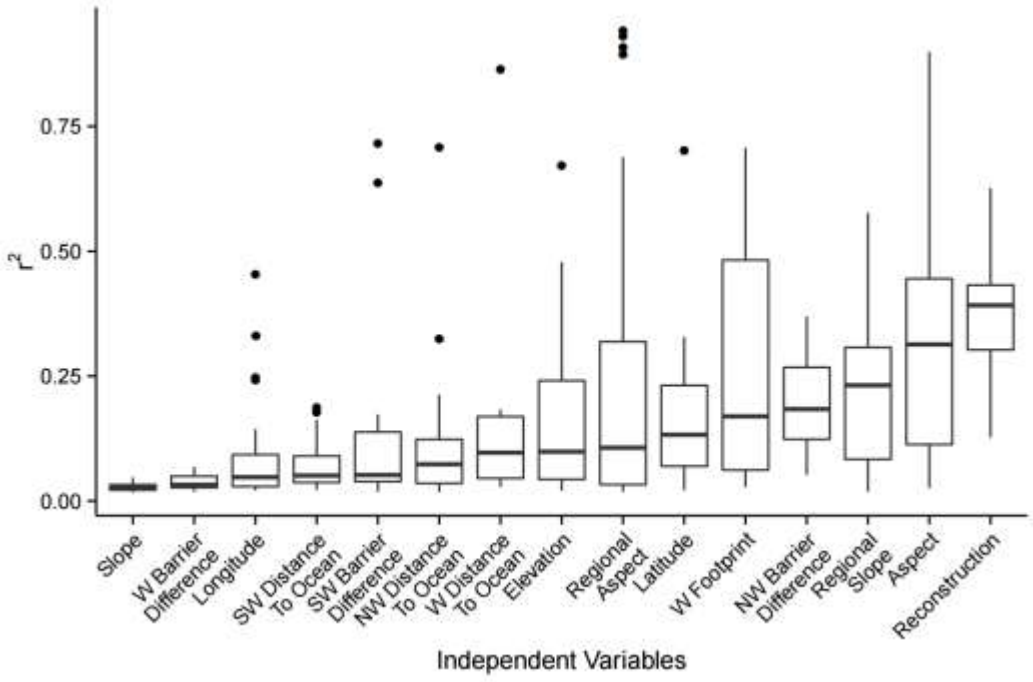
Guan et al., 2013 - WRR

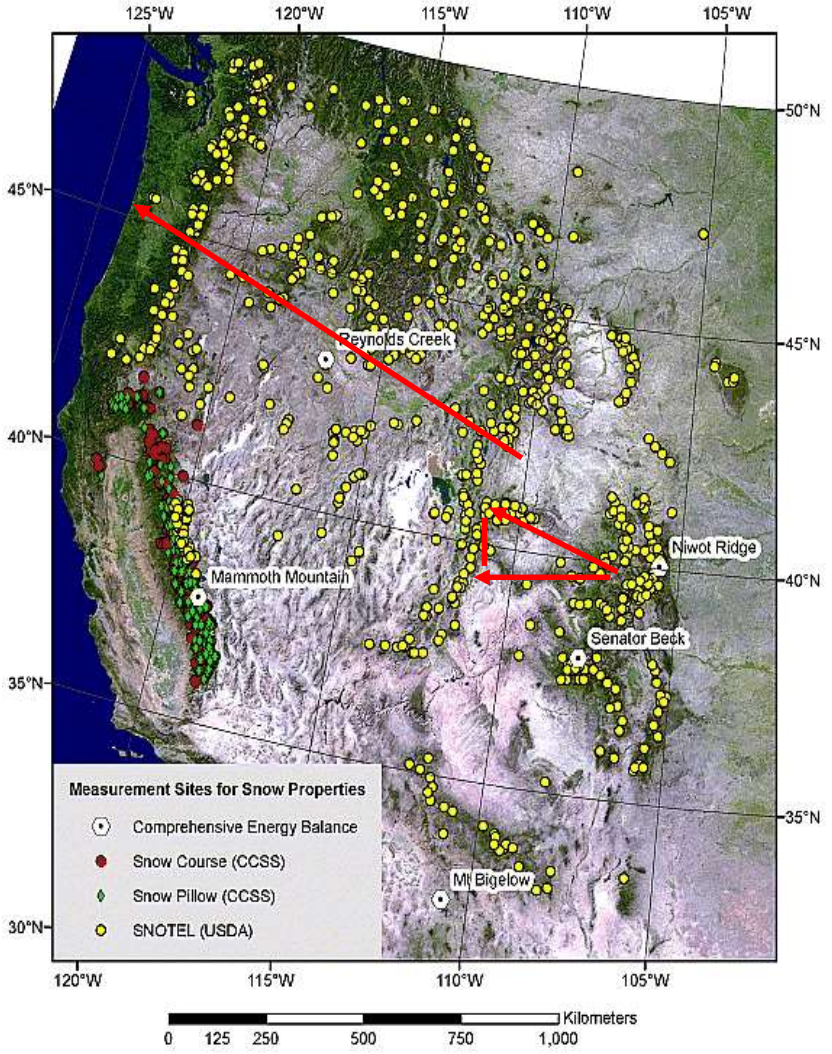
Colorado River Basin Snowpack



Correlation between SNOTEL SWE & Single Variables

April 1, 2010 - 2015

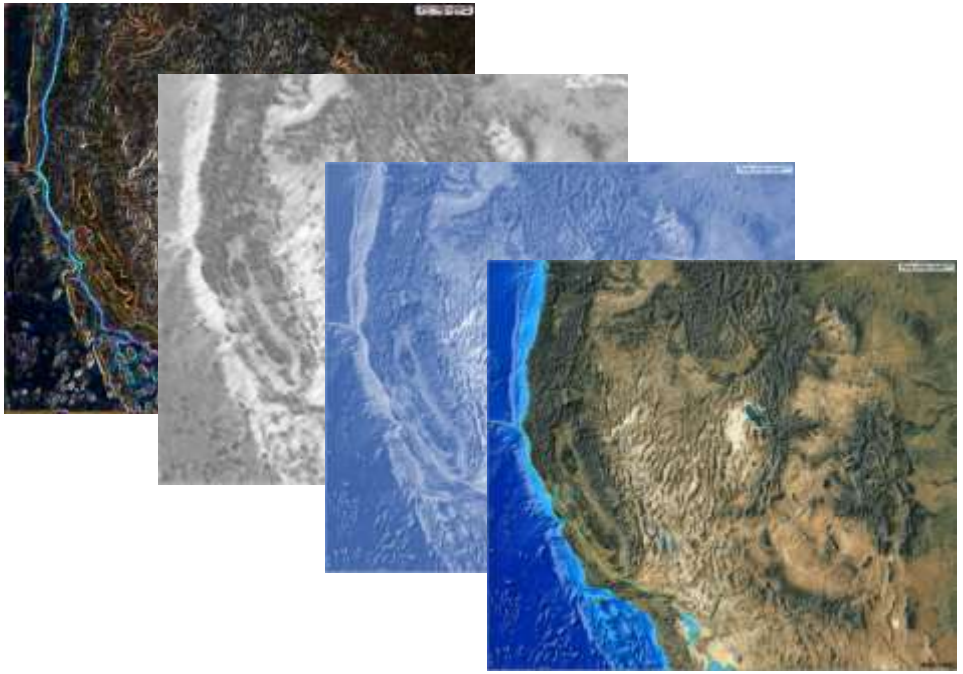




SNOTEL SWE Interpolation

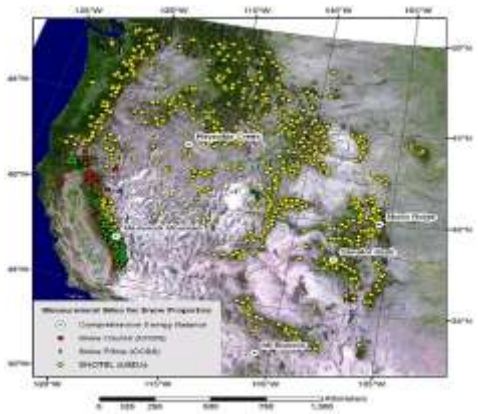
Independent Variables

DEM: slope, aspect, elevation, NW barrier difference, distance to ocean, others.

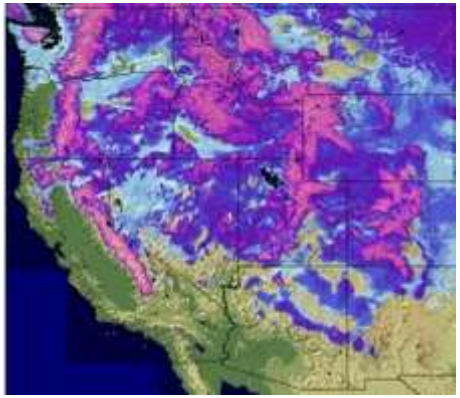


Dependent Variable

SNOTEL SWE Measurements

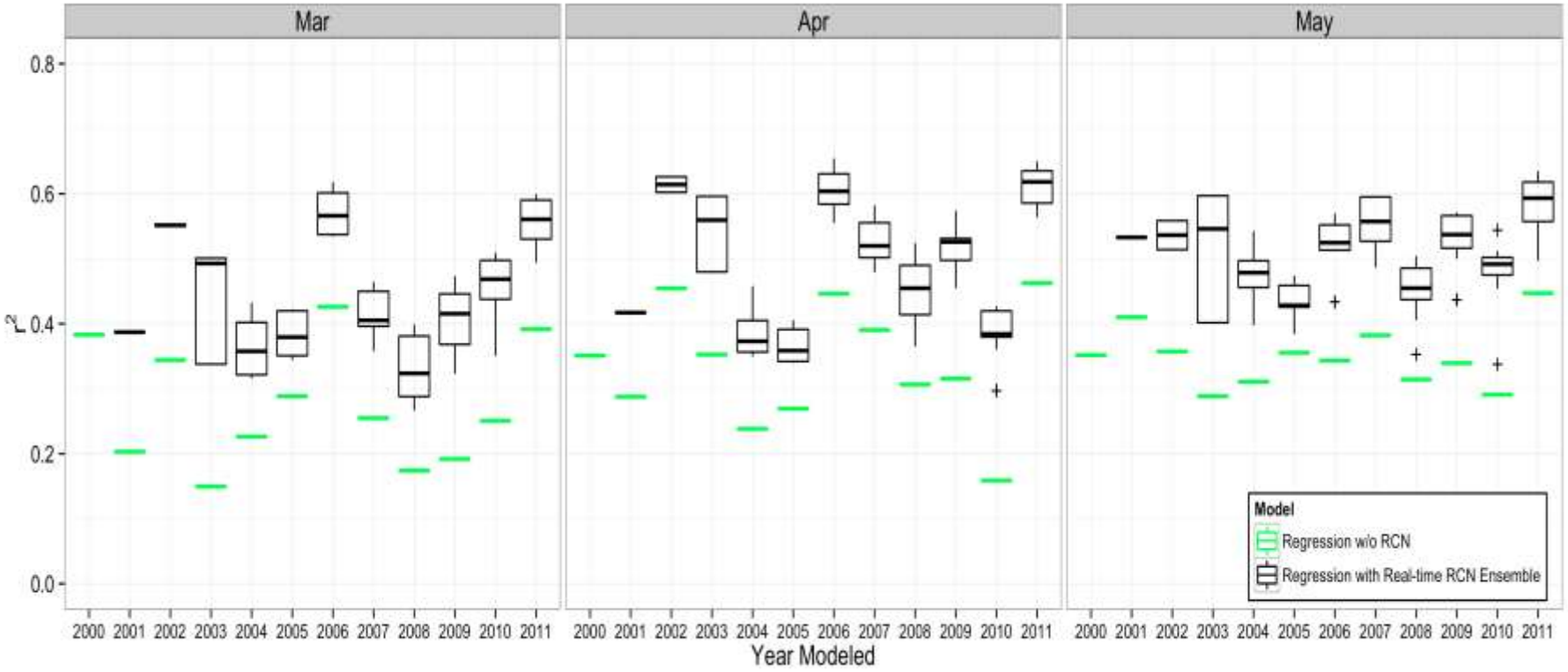


Gridded SWE Prediction

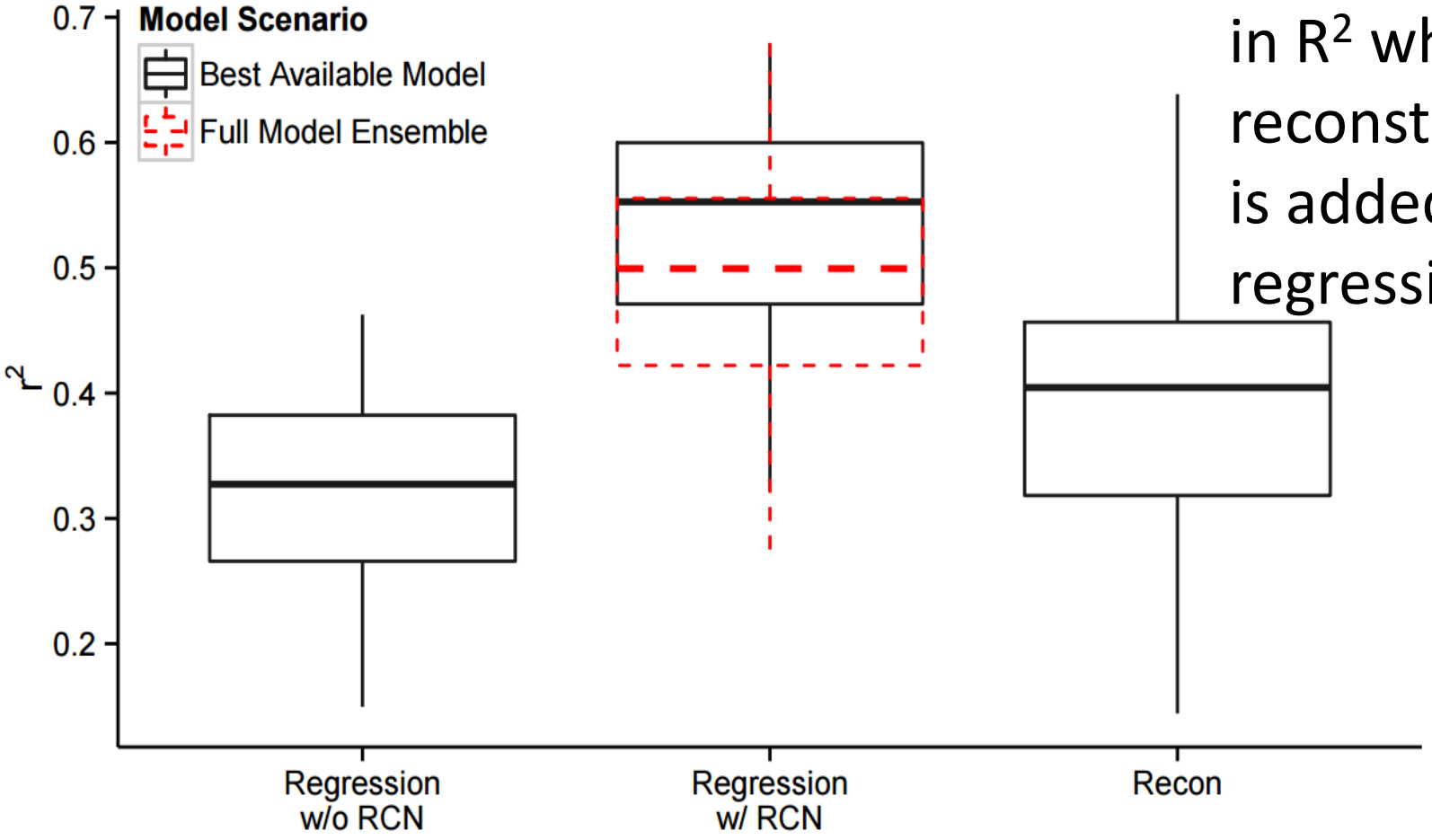


Correlation of SWE & Independent Variables: With and Without Reconstruction

Upper Colorado River Basin Domain, 2000 – 2011.



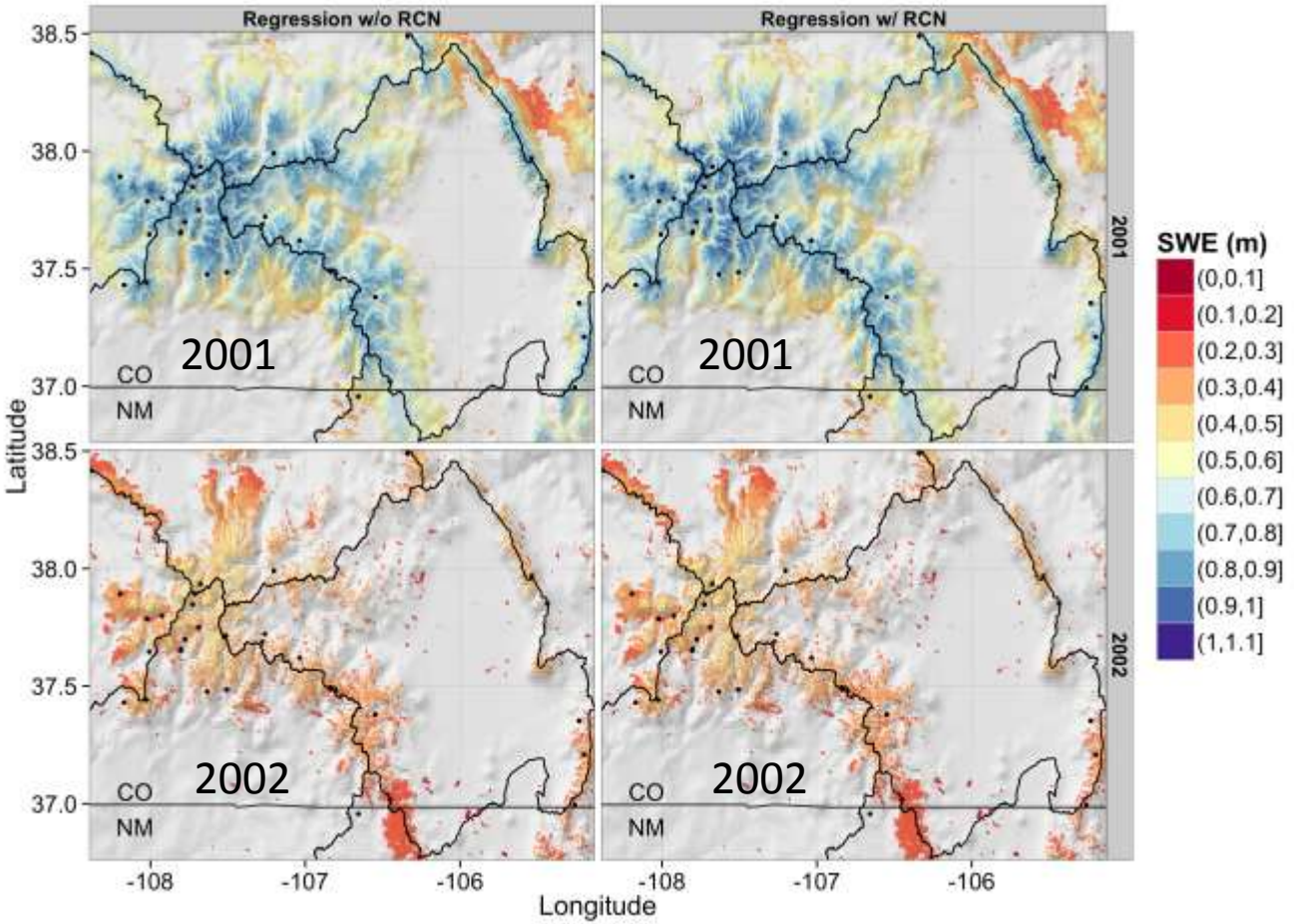
Correlation of SWE & Independent Variables: With and Without Reconstruction



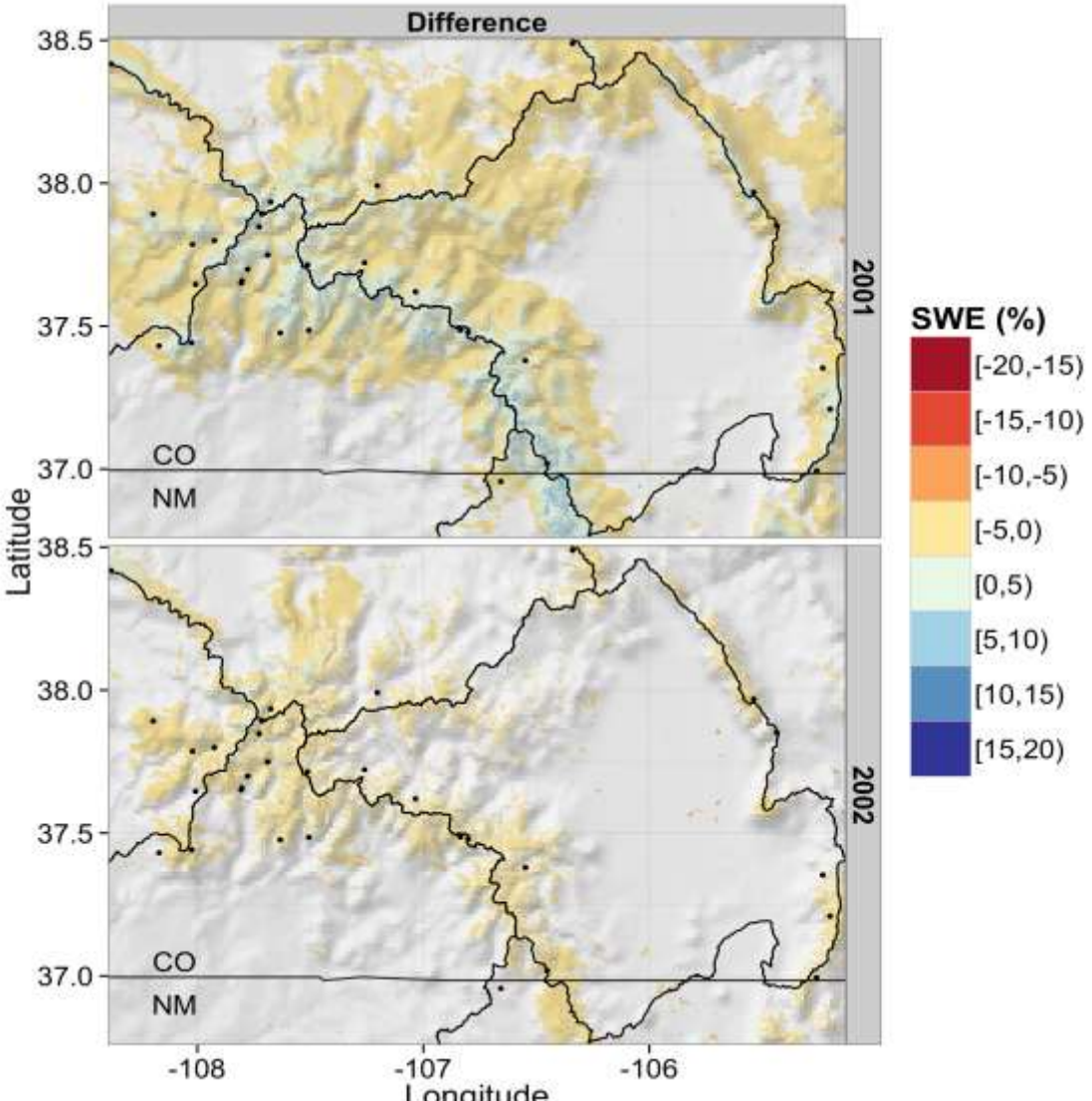
- 67% increase in R^2 when reconstruction is added to regression.

SWE for the Rio Grande Headwaters, Early April 2001 & 2002

- Range of SWE estimates increases with reconstruction.
- Higher elevation SWE increases with reconstruction.
- Lower elevations decrease SWE.



SWE Differences: With and Without Reconstruction

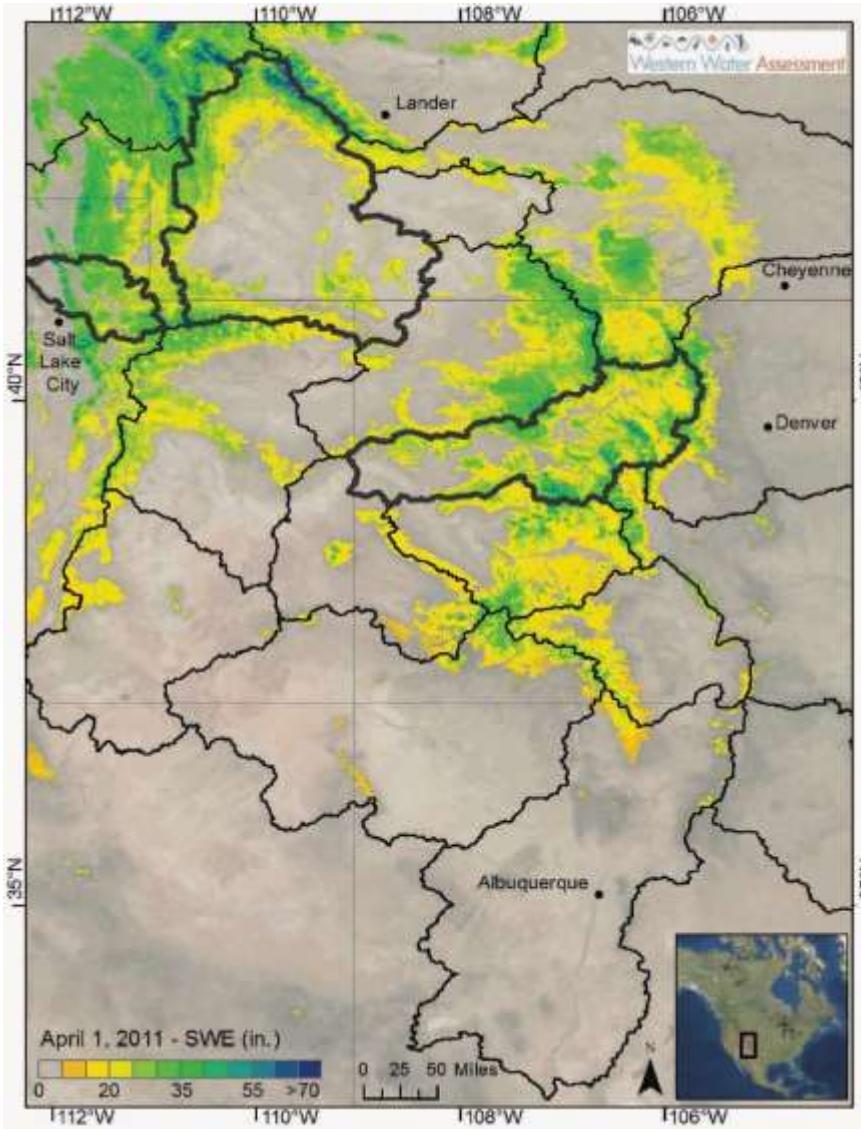


When adding reconstruction as an independent variable:

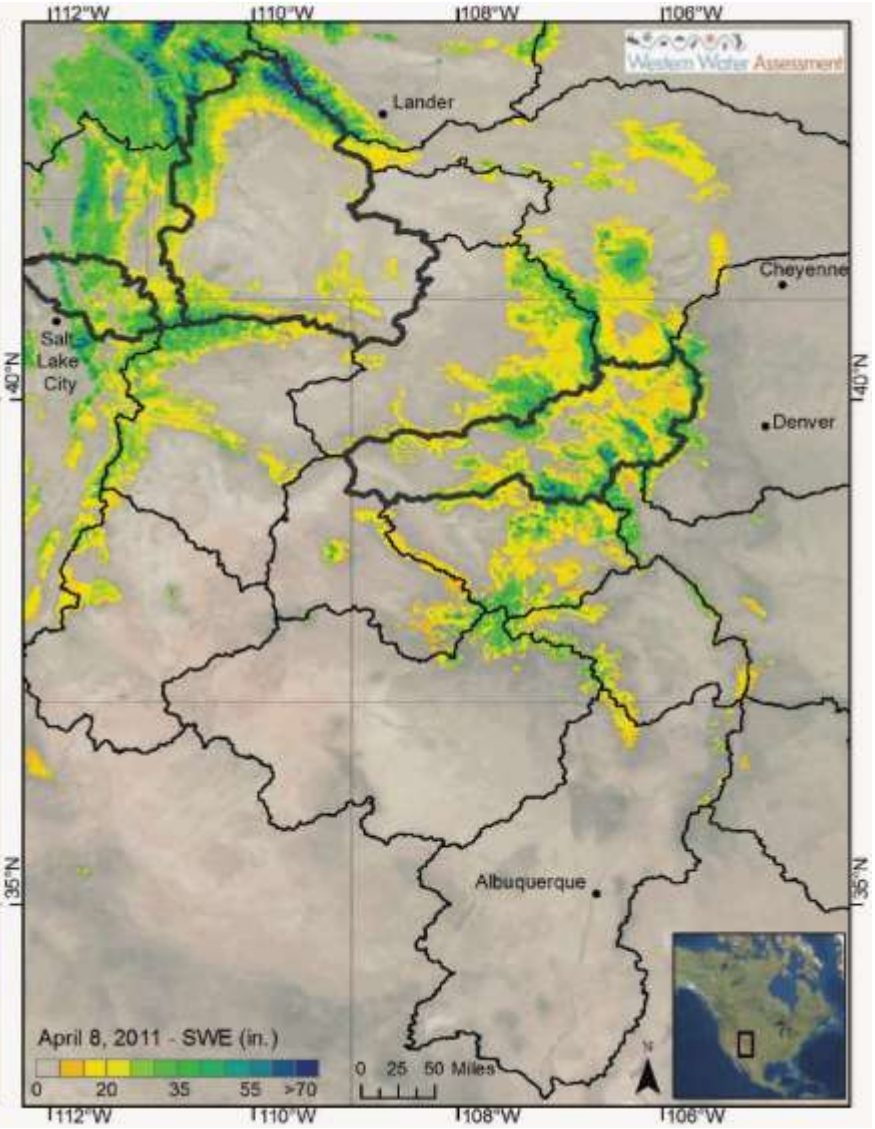
- SWE increases in highest elevations
- SWE decreases in lowest elevations
- RMSE decreases (for a large majority of stations)
- R^2 Increases

Real-time SWE for Upper Colorado River

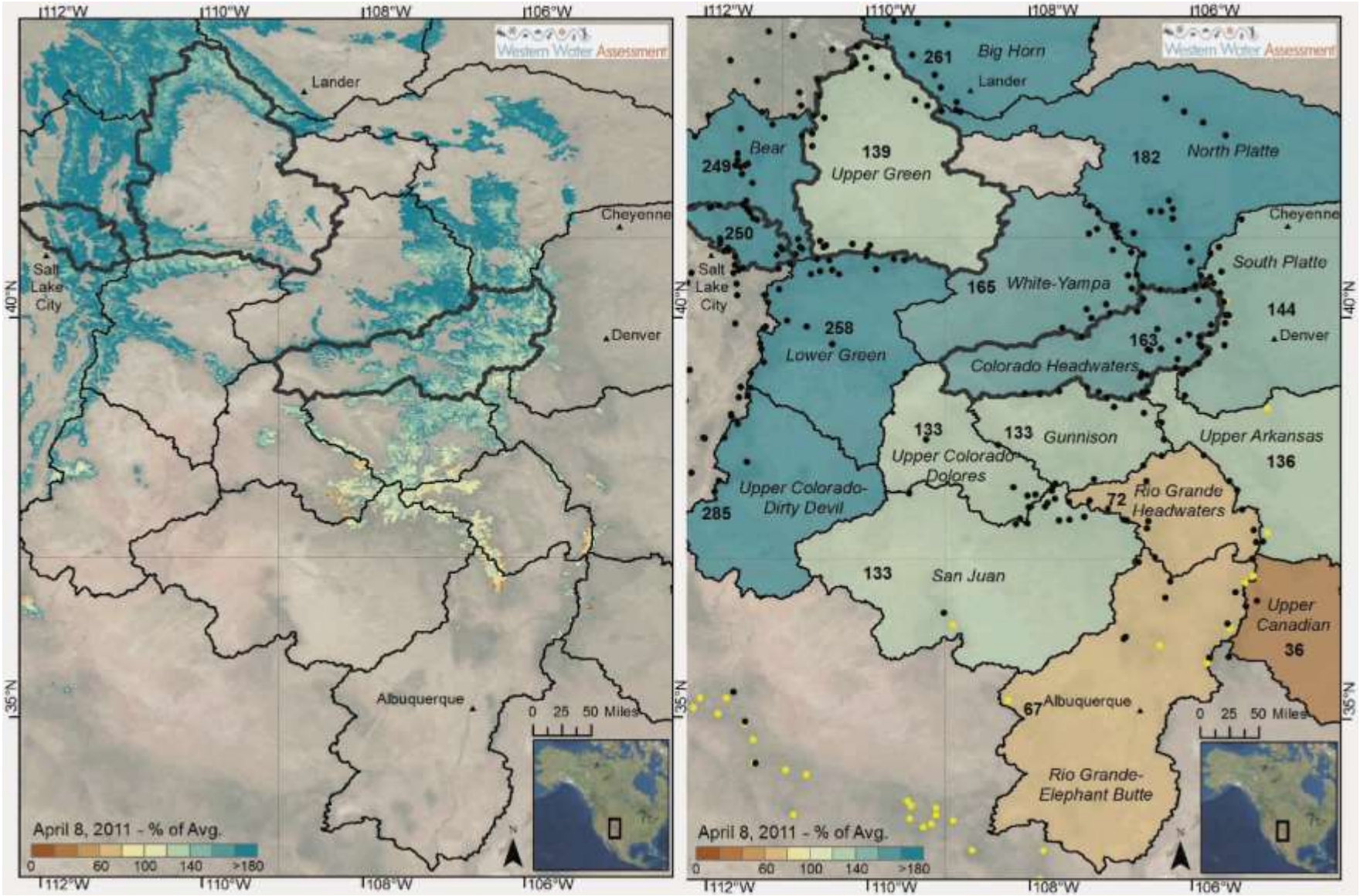
April 1, 2011



April 8, 2011



Real-time SWE Anomalies: Upper Colorado River, April 8, 2011



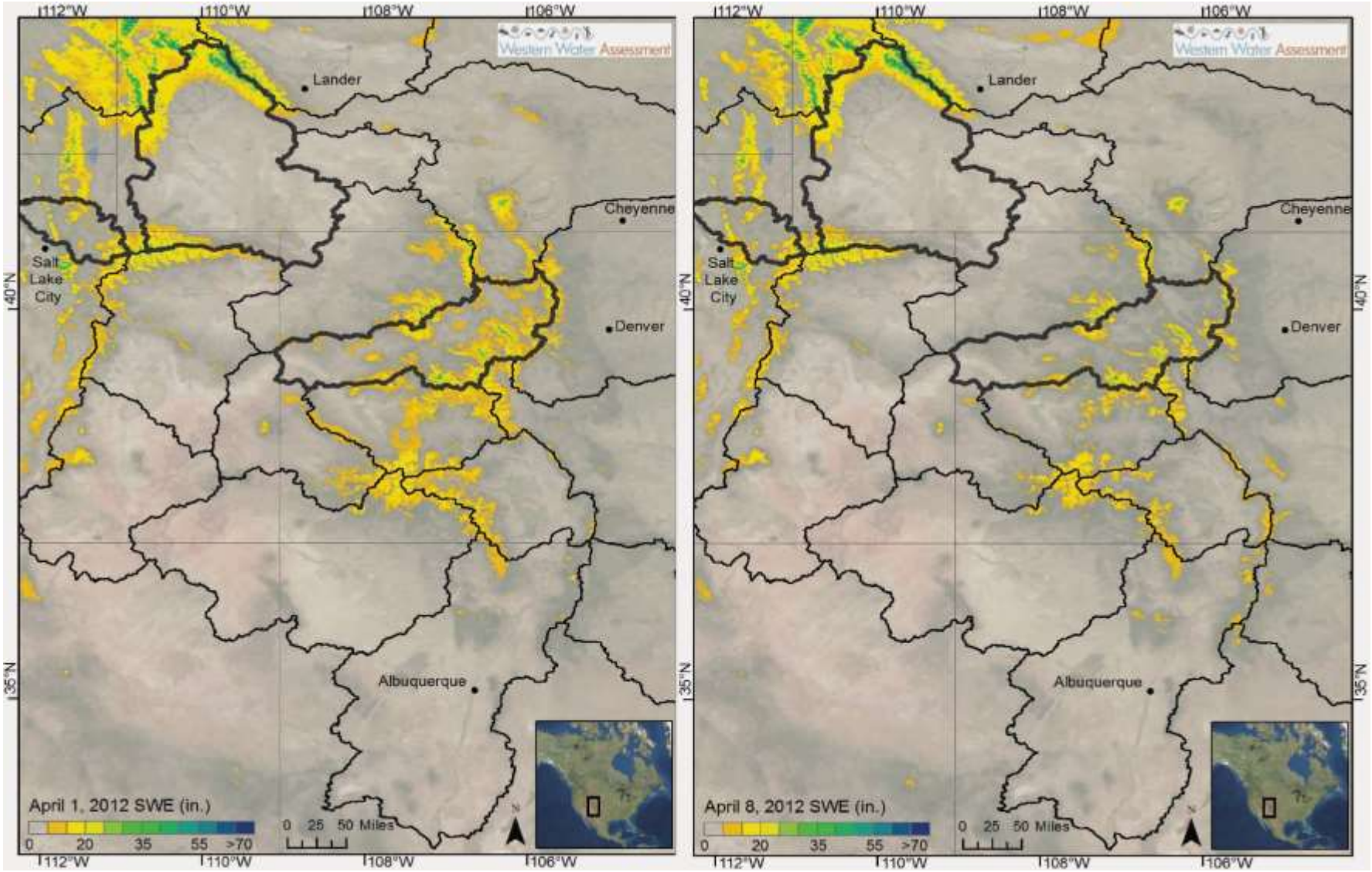
Real-time SWE Anomalies by watershed:
Upper Colorado River, April 8, 2011

	4/8/11 % of Avg to Date		4/8/11 SWE (in)		4/1/11 SWE (in)		4/1-4/8 Change SWE (in)	
Watershed	Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL
Bear	248.75	174.78	20.06	28.47	22.42	27.24	-2.36	1.23
Big Horn	260.92	127.52	12.27	13.74	12.16	12.89	0.11	0.85
Colorado Headwaters	163.46	140.55	14.45	21.03	17.03	20.86	-2.58	0.17
Gunnison	133.43	130.75	9.66	19.26	12.28	19.51	-2.62	-0.25
Lower Green	258.39	156.44	8.82	18.83	9.84	19.63	-1.03	-0.80
North Platte	182.34	148.91	6.49	27.67	11.02	26.84	-4.53	0.84
Rio Grande Headwaters	71.98	88.38	3.17	8.72	4.34	9.12	-1.17	-0.39
Rio Grande-Elephant Butte	67.31	60.77	0.27	4.23	0.39	4.40	-0.11	-0.17
San Juan	133.38	97.28	1.37	15.05	1.89	16.19	-0.52	-1.14
South Platte	143.74	136.84	2.91	16.43	4.24	16.35	-1.33	0.08
Upper Arkansas	135.81	82.00	2.70	7.87	2.81	7.97	-0.11	-0.10
Upper Canadian	36.39	12.86	0.10	0.60	0.05	2.90	0.05	-2.30
Upper Colorado-Dirty Devil	285.32	146.57	2.30	12.03	2.35	12.75	-0.05	-0.72
Upper Colorado-Dolores	133.02	98.25	2.86	12.55	3.88	13.72	-1.02	-1.17
Upper Green	139.21	146.82	7.77	20.77	9.09	20.05	-1.33	0.73
Weber	250.32	158.24	21.54	29.24	22.36	28.31	-0.82	0.93
White-Yampa	165.10	147.62	7.64	29.39	10.60	28.77	-2.96	0.62

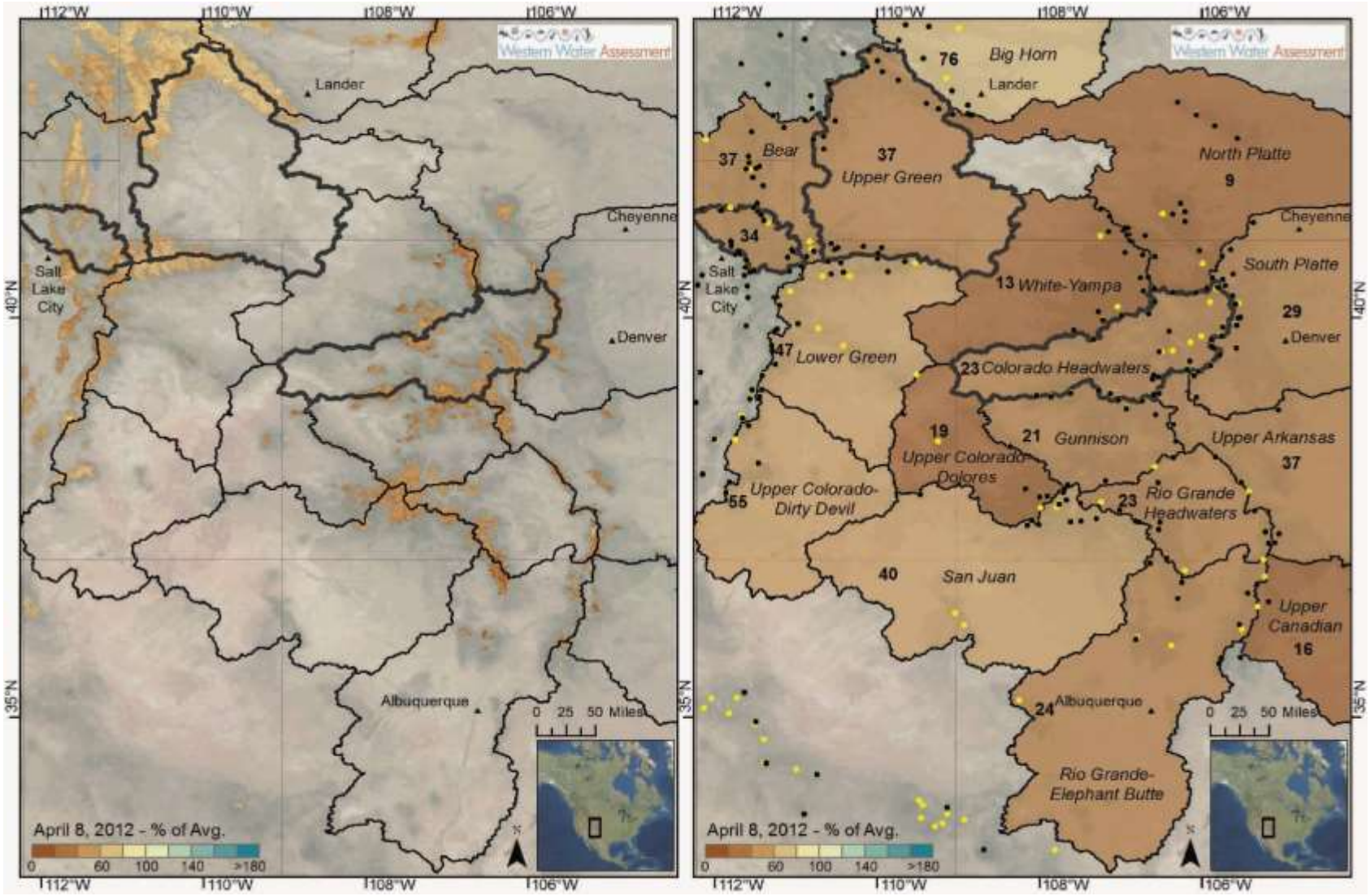
Real-time SWE for Upper Colorado River

April 1, 2012

April 8, 2012



Real-time SWE Anomalies
Upper Colorado River, April 8, 2012



Real-time SWE Anomalies by watershed: Upper Colorado River, April 8, 2012

	4/8/12 % of Avg to Date		4/8/12 SWE (in)		4/1/12 SWE (in)		4/1-4/8 Change SWE (in)	
Watershed	Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL
Bear	37.44	56.64	3.02	9.23	3.97	10.28	-0.95	-1.06
Big Horn	75.93	82.59	3.57	8.90	3.44	9.04	0.13	-0.14
Colorado Headwaters	22.94	43.14	2.03	6.46	3.28	7.89	-1.25	-1.44
Gunnison	20.98	51.32	1.52	7.56	2.60	9.33	-1.08	-1.77
Lower Green	46.63	39.21	1.59	4.72	1.88	5.89	-0.29	-1.17
North Platte	9.26	59.33	0.33	11.03	0.73	12.47	-0.40	-1.45
Rio Grande Headwaters	23.07	53.41	1.01	5.27	1.34	5.61	-0.32	-0.34
Rio Grande-Elephant Butte	23.68	53.25	0.10	3.71	0.07	4.03	0.03	-0.32
San Juan	40.40	53.12	0.41	8.22	0.56	9.75	-0.15	-1.53
South Platte	29.35	67.63	0.60	8.12	0.88	8.36	-0.29	-0.24
Upper Arkansas	37.32	57.16	0.74	5.48	0.80	5.68	-0.06	-0.20
Upper Canadian	16.19	70.71	0.04	3.30	0.00	1.90	0.04	1.40
Upper Colorado-Dirty Devil	54.68	42.97	0.44	3.53	0.52	4.83	-0.08	-1.30
Upper Colorado-Dolores	18.82	33.14	0.41	4.23	0.75	6.68	-0.35	-2.45
Upper Green	37.18	79.83	2.07	11.29	2.44	12.01	-0.36	-0.72
Weber	34.26	50.83	2.95	9.39	3.37	10.23	-0.42	-0.83
White-Yampa	12.51	41.69	0.58	8.30	1.03	10.40	-0.45	-2.10

Real-time SWE Anomalies by watershed: Upper Colorado River, April 8, 2012

Watershed	Elevation	4/8/12 % Avg to Date		4/8/12 SWE (in)		4/1/12 SWE (in)		4/1-4/8 Change SWE (in)		Area
		Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL	Sq Mi
CO Headwtrs	6000-7000'	0.00	**N/A**	0.00	**N/A**	0.01	**N/A**	-0.01	**N/A**	1,732.4
	7000-8000'	0.01	**N/A**	0.00	**N/A**	0.06	**N/A**	-0.06	**N/A**	2,293.2
	8000-9000'	0.55	1.76	0.04	0.14	0.70	2.08	-0.66	-1.94	3,108.4
	9000-10,000'	6.67	29.31	0.69	3.55	2.85	5.28	-2.16	-1.73	2,237.1
	10,000-11,000'	20.94	50.41	3.17	9.94	6.10	11.36	-2.93	-1.43	2,300.9
	11,000-12,000'	39.81	60.13	10.09	9.90	12.08	10.35	-1.99	-0.45	1,150.5
	12,000-13,000'	48.34	**N/A**	16.53	**N/A**	17.79	**N/A**	-1.26	**N/A**	346.3
	13,000+	51.88	**N/A**	18.55	**N/A**	19.51	**N/A**	-0.96	**N/A**	25.1
Upper Green	6000-7000'	0.02	**N/A**	0.00	**N/A**	0.00	**N/A**	0.00	**N/A**	11,164.6
	7000-8000'	9.71	104.51	0.44	11.00	0.84	12.50	-0.41	-1.50	10,008.7
	8000-9000'	40.53	81.87	4.84	12.38	5.96	13.27	-1.12	-0.89	2,482.9
	9000-10,000'	61.44	74.18	10.51	9.87	11.81	10.32	-1.31	-0.45	1,230.6
	10,000-11,000'	66.18	75.48	17.61	10.30	18.56	10.55	-0.95	-0.25	926.1
	11,000-12,000'	67.43	**N/A**	27.57	**N/A**	27.98	**N/A**	-0.41	**N/A**	300.6
	12,000-13,000'	66.93	**N/A**	31.36	**N/A**	31.64	**N/A**	-0.28	**N/A**	50.9
	13,000+	68.57	**N/A**	41.76	**N/A**	41.82	**N/A**	-0.06	**N/A**	1.7
Weber	6000-7000'	6.64	22.01	0.43	1.90	0.30	3.80	0.13	-1.90	1,155.3
	7000-8000'	19.46	48.36	2.19	10.90	2.94	11.94	-0.75	-1.04	1,039.4
	8000-9000'	46.67	65.24	8.01	8.97	9.06	9.27	-1.06	-0.30	363.5
	9000-10,000'	53.72	61.62	10.77	14.80	11.55	14.65	-0.78	0.15	124.6
	10,000-11,000'	61.21	**N/A**	15.80	**N/A**	16.42	**N/A**	-0.62	**N/A**	70.1
	11,000+	60.99	**N/A**	20.87	**N/A**	21.35	**N/A**	-0.48	**N/A**	0.9

Conclusions & Future Work

- Spatial SWE estimates provide valuable information for augmenting SNOTEL data.
- Products are used by CA Department of Water Resources to adjust statistical forecasts.
- Approach can be applied in conjunction with airborne snow measurements in context of validation and / or temporal change analysis.
- We are looking for new partners to tailor SWE reports for local needs.

Contact Us

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University of Colorado at Boulder

WWA & Center for Water, Earth Science and Technology

Acknowledgements

- USDA/NSF Water Sustainability and Climate
- NSF: Hydrologic Sciences
- NSF: CZO
- NASA: Terrestrial Hydrology & Applied Sciences
- NOAA-CIRES: Western Water Assessment