hydrology

MDPI

Supplementary materials

Estimation of Daily Spatial Snow Water Equivalent from Historical Snow Maps and Limited In-Situ Measurements

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1. Content

This document contains supplementary table and figures showing the simulation results of the daily mean SWE maps using menoi, menoic and menoi_ynn from 1985 to 2016 analyzed on the Feather River basin. Figure S13 shows the locations of the existing eight snow-pillows used in the Feather river basin simulation. It also contains the results of the sensor placement experiments in Figures S13 to S16.

For each year, the error metrics for the peak snow-season day for each of the 3 ensemble-selection method are reported in Table S1. The last row summarizes the findings and shows that the use of all historical SWE maps (*menoi*) exhibits the least error in terms of RMSE (median of 20%) and MAE (median 35%). The other two methods have similar performances in terms of MAE (both median of 22%) and RMSE (both median of 39%) with the nearest-neighbor maps (*menoi_ynn*) having the least bias.

However, results also show that no method is error-wise consistently better than the other for that simulation period. The highest errors are during dry water years, for example 1987 (dry), 2014 and 2015 (critically dry), where *menoi* has worst performance compared to the other two. The minimum MAE was 13%, 22% RMSE (2006-*menoic*) and 0% bias. Figure S1 visualizes the table as cumulative distributions of the three performance metrics. Figures S2 to S12 shows the time-series evolution of the RMSE as percent of daily spatial-mean SWE for each of the methods.

The scaled daily spatial-mean SWE is also shown in dotted line. The RMSE exhibits a U-shape plot, with RMSEs increasing at the edges of the snow season when the daily spatial mean SWE is low. We note the water year 1998 in Figure S6 as the wettest water year on record. Figures S2 to S12 similarly to Table S1, no method consistently outperforms the other. The *menoi* exhibits a smooth RMSE series, while *menoic* and *menoi_ynn* show a rougher pattern with occasional spikes.

Results show that the three methods do not perform as well in dry years as in wet years in terms of % RMSE.

Table S1. Peak snow-season error statistics for each ensemble-selection method for water years from 1985 to 2016.

	RMSE, %			MAE, %			Bias, %		
Water year	menoi	menoic	ynn	menoi	menoic	ynn	menoi	menoic	ynn
1985	39	44	36	23	27	21	-19	-23	-11
1986	28	33	28	16	20	15	7	14	3
1987	86	90	73	57	56	46	47	44	34
1988	32	30	30	18	17	17	1	1	-5
1989	36	35	35	21	19	21	1	-13	5
1990	34	45	34	21	28	20	-9	-18	-7
1991	42	52	57	23	29	32	-10	-22	-22
1992	32	34	32	19	20	19	9	9	6
1993	48	50	50	32	33	33	-31	-31	-30
1994	50	53	57	26	29	28	14	16	5
1995	31	30	36	17	18	23	4	8	15
1996	29	26	30	17	15	17	-9	-2	-10
1997	52	53	51	32	33	33	27	27	28
1998	38	38	41	23	22	25	-15	-16	-19
1999	40	39	45	24	21	27	19	16	23
2000	39	44	39	22	27	22	8	14	6
2001	61	57	45	33	36	26	18	24	7
2002	26	25	25	16	14	15	3	0	2
2003	34	37	32	20	22	18	5	-3	-13
2004	28	32	44	16	20	25	2	13	-7
2005	55	47	48	36	31	32	-29	-27	-27
2006	27	28	28	13	14	15	-2	0	5
2007	31	42	47	18	26	27	2	0	0
2008	35	29	40	20	18	25	-6	-8	-18
2009	24	22	33	14	13	20	-5	-2	-10
2010	32	32	30	19	19	18	0	-9	-5
2011	35	37	33	20	22	19	-13	-16	-12
2012	53	51	54	31	27	31	6	2	3
2013	35	43	39	19	23	21	-5	-9	-5
2014	152	129	137	88	50	52	56	24	32
2015	176	138	111	115	84	54	95	68	36
2016	34	44	37	17	23	18	0	8	6
Median	35	39	39	20	22	22	9	13	7[b]

[a] For each of *ynn* (*menoi_ynn*), *menoic* and *menoi* the covariance is represented by a sample of yearly nearest neighbor maps, climatologic maps and all maps respectively.
[b] The last row, last three columns represent the average of the absolute bias metrics.

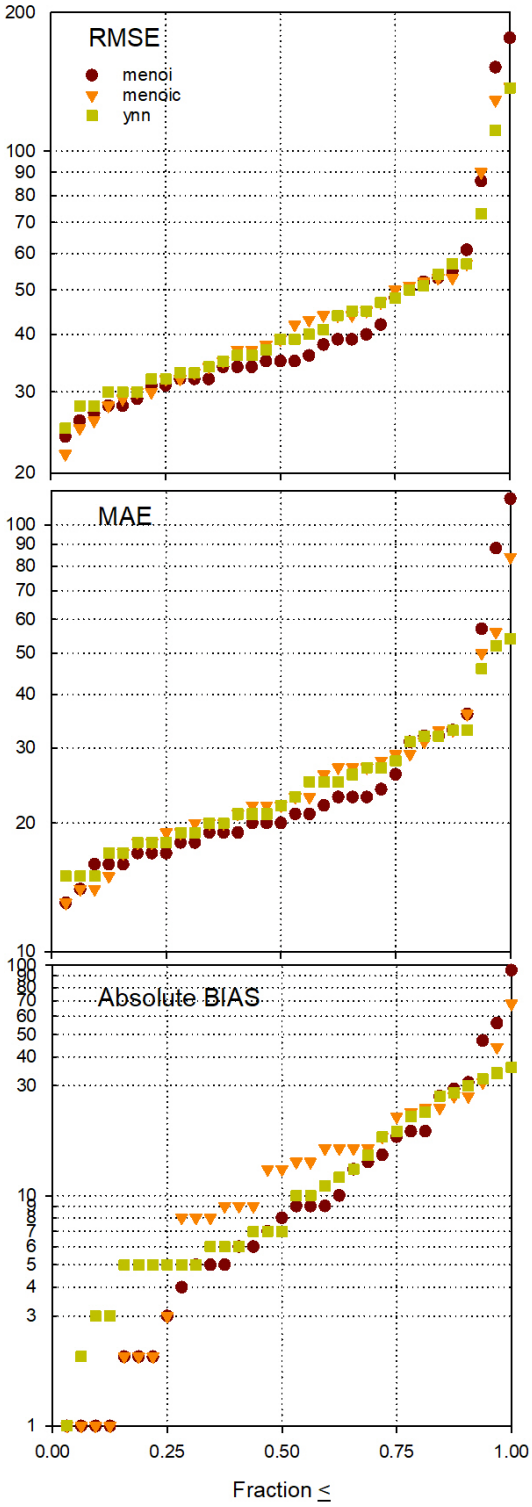

Figure S1. Peak snow-season error statistics for each ensemble-selection method for water years from 1985 to 2016 [6].

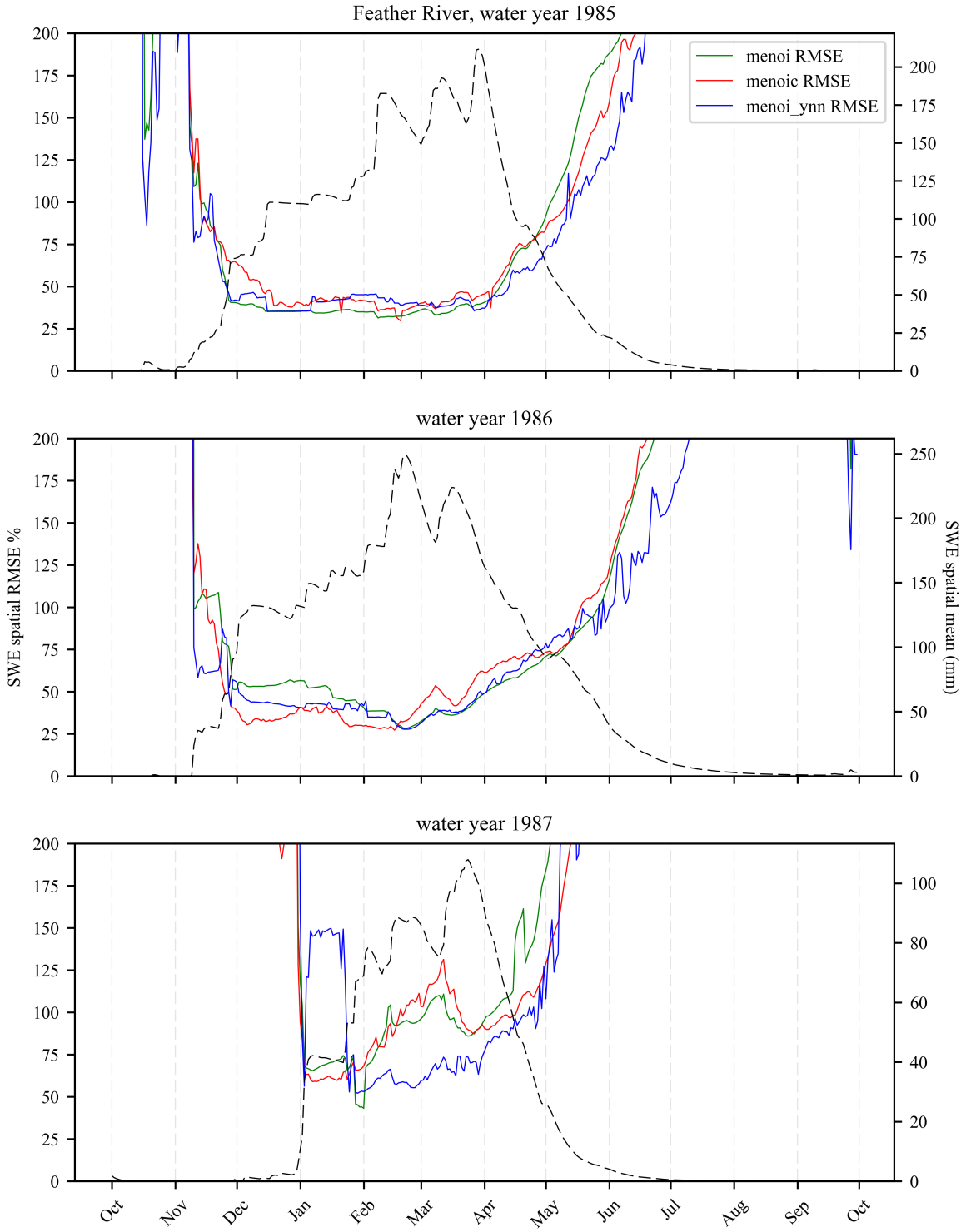

Figure S2. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 1985, 1986 and 1987.

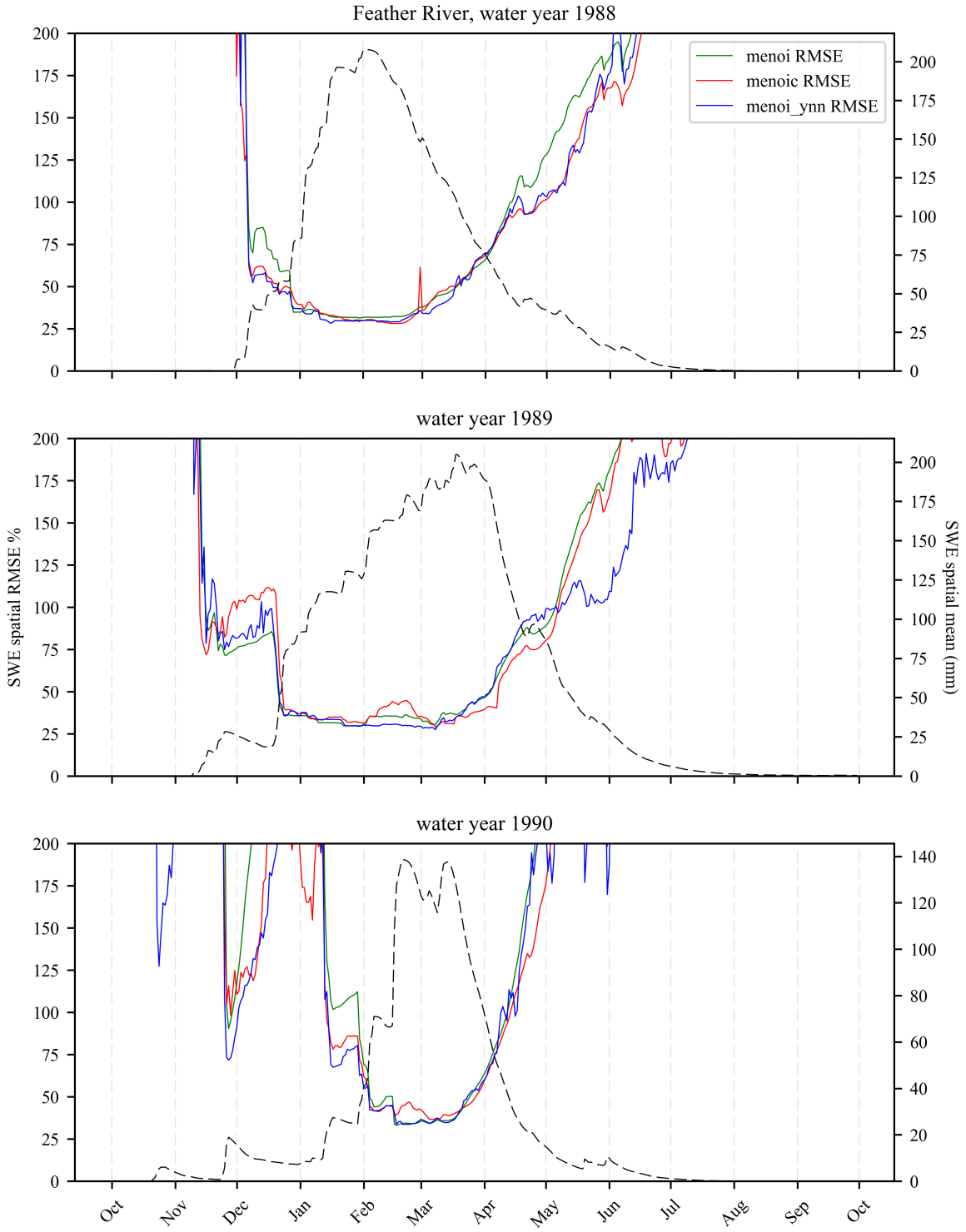

Figure S3. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 1988, 1989 and 1990.

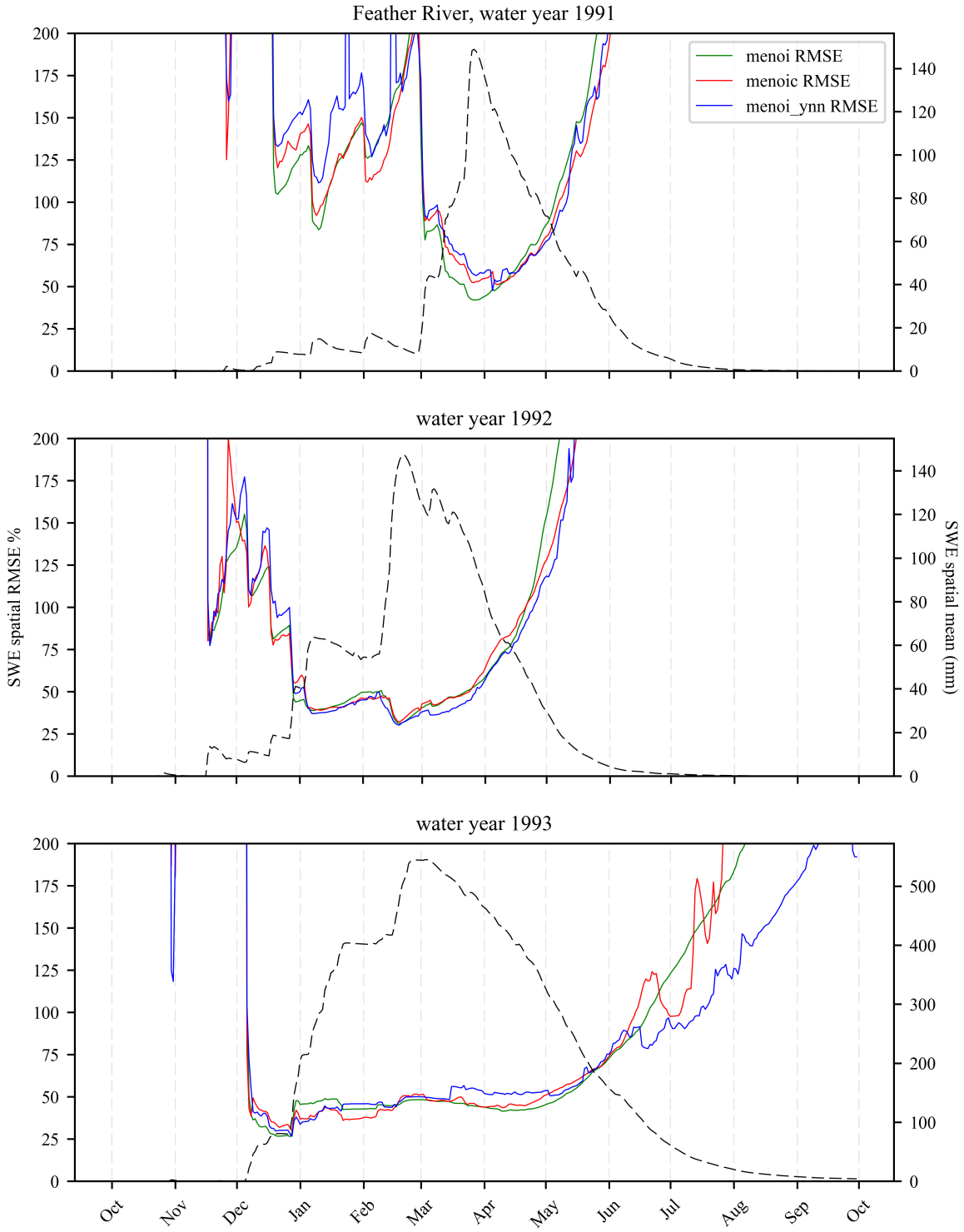

Figure S4. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 1991, 1992 and 1993.

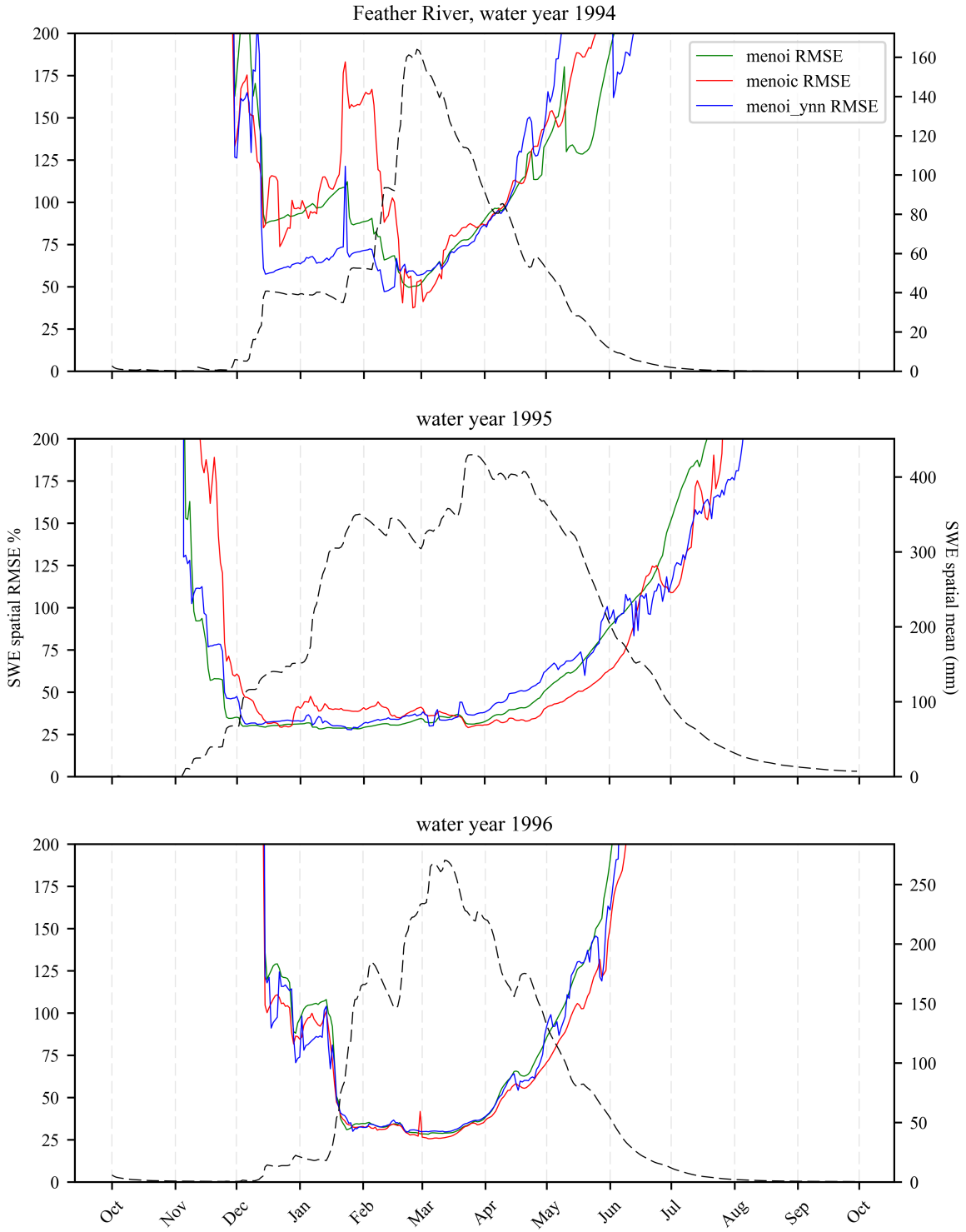

Figure S5. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 1994, 1995 and 1996.

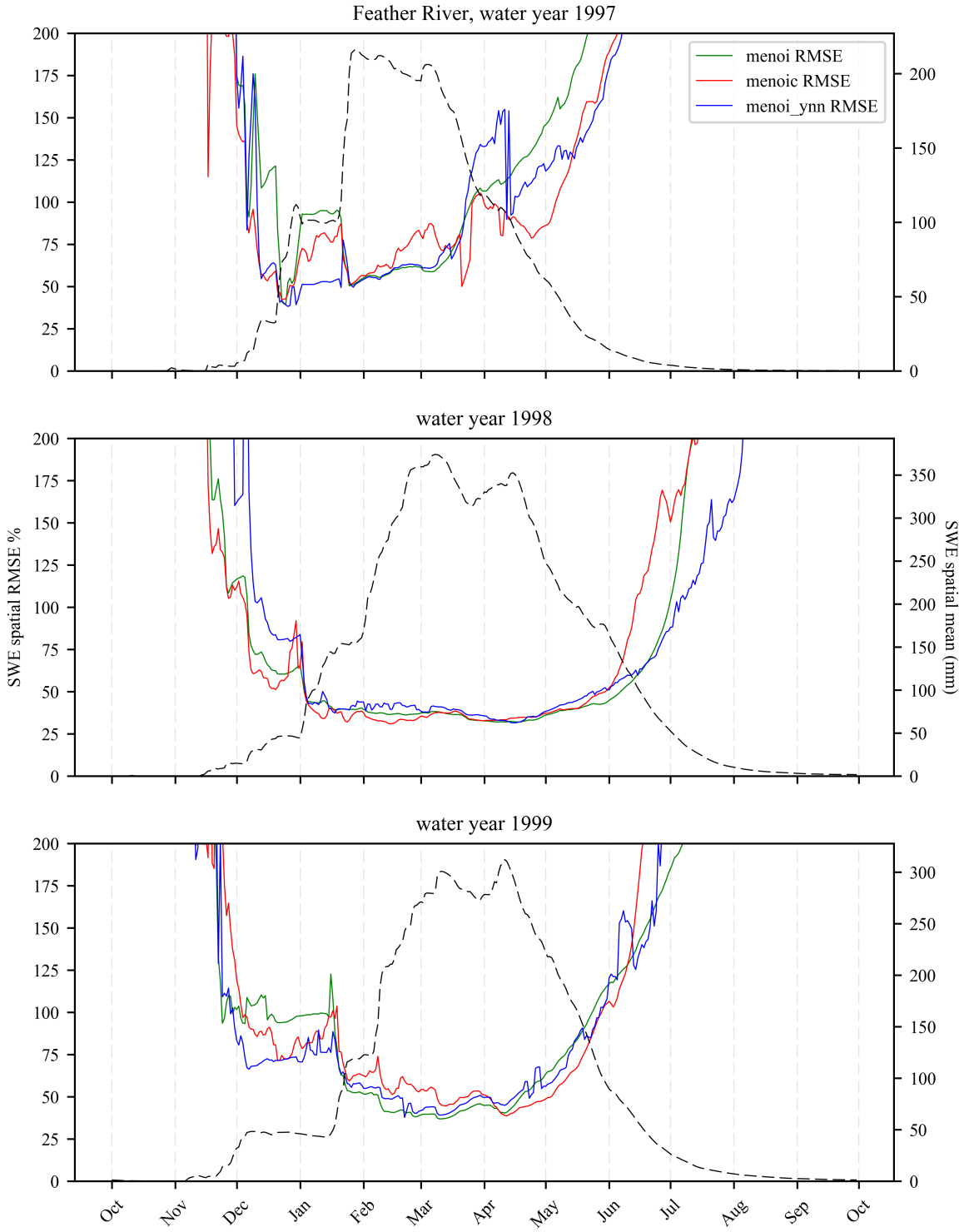

Figure S6. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 1997, 1998 and 1999.

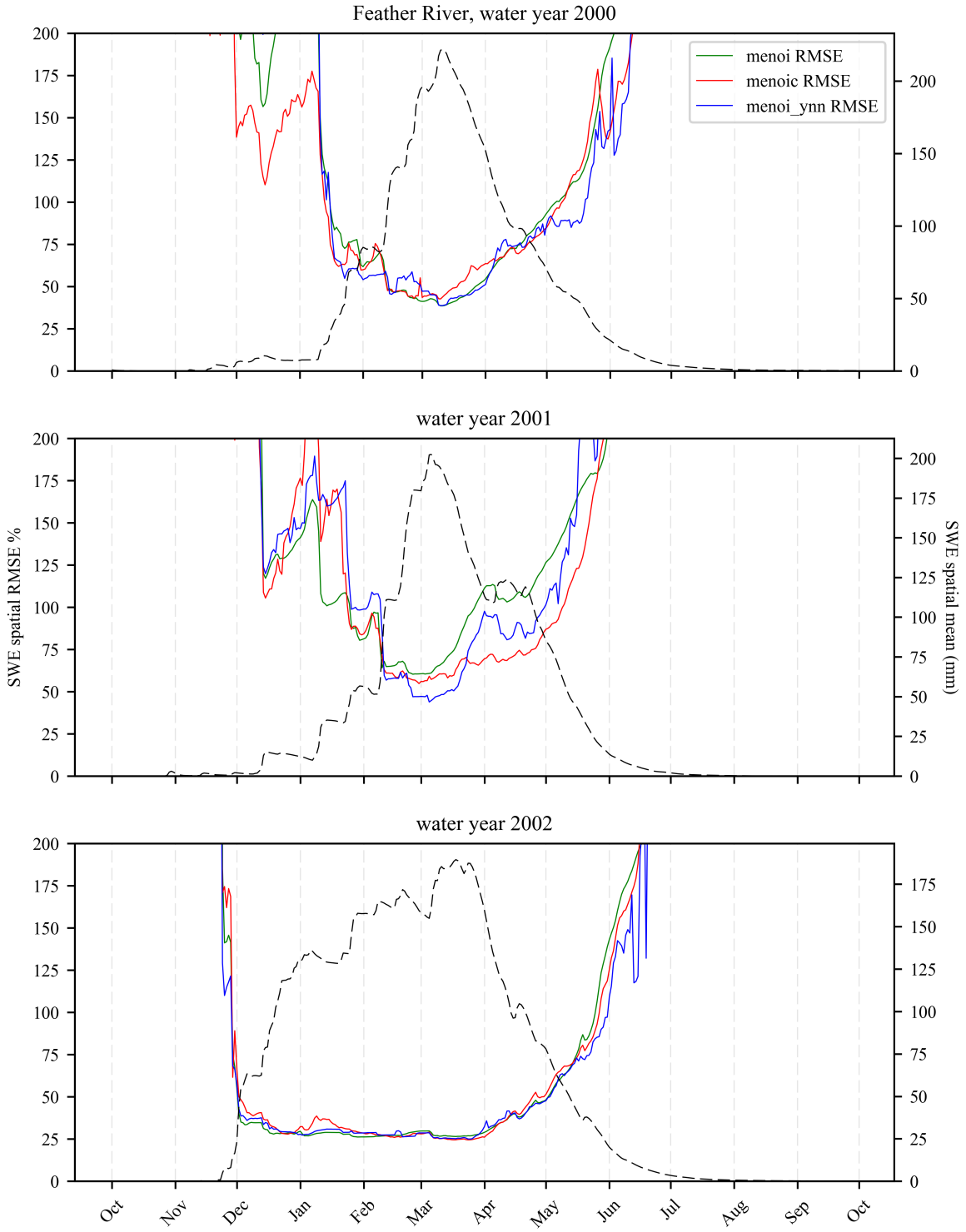

Figure S7. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 2000, 2001 and 2002.

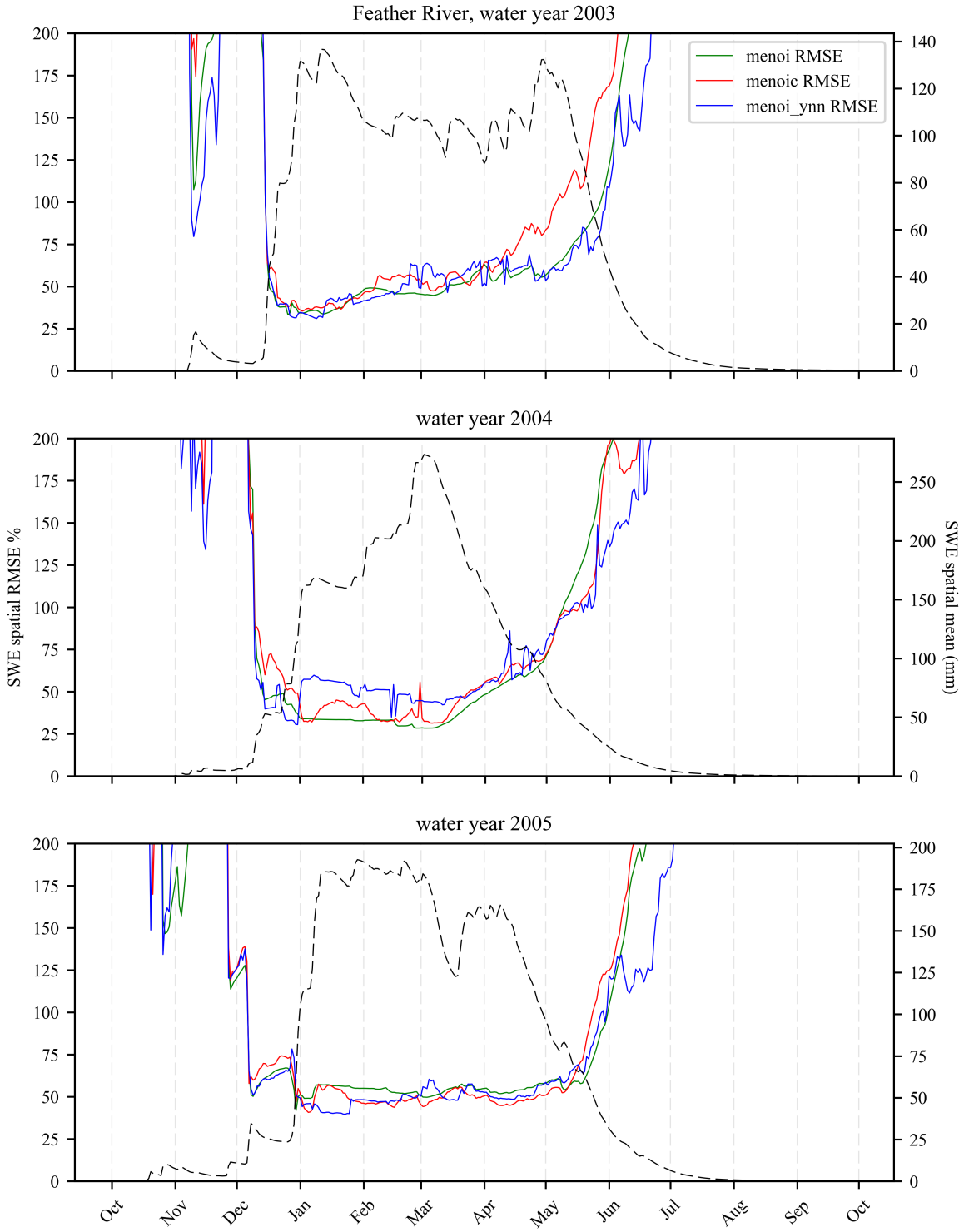

Figure S8. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 2003, 2004 and 2005.

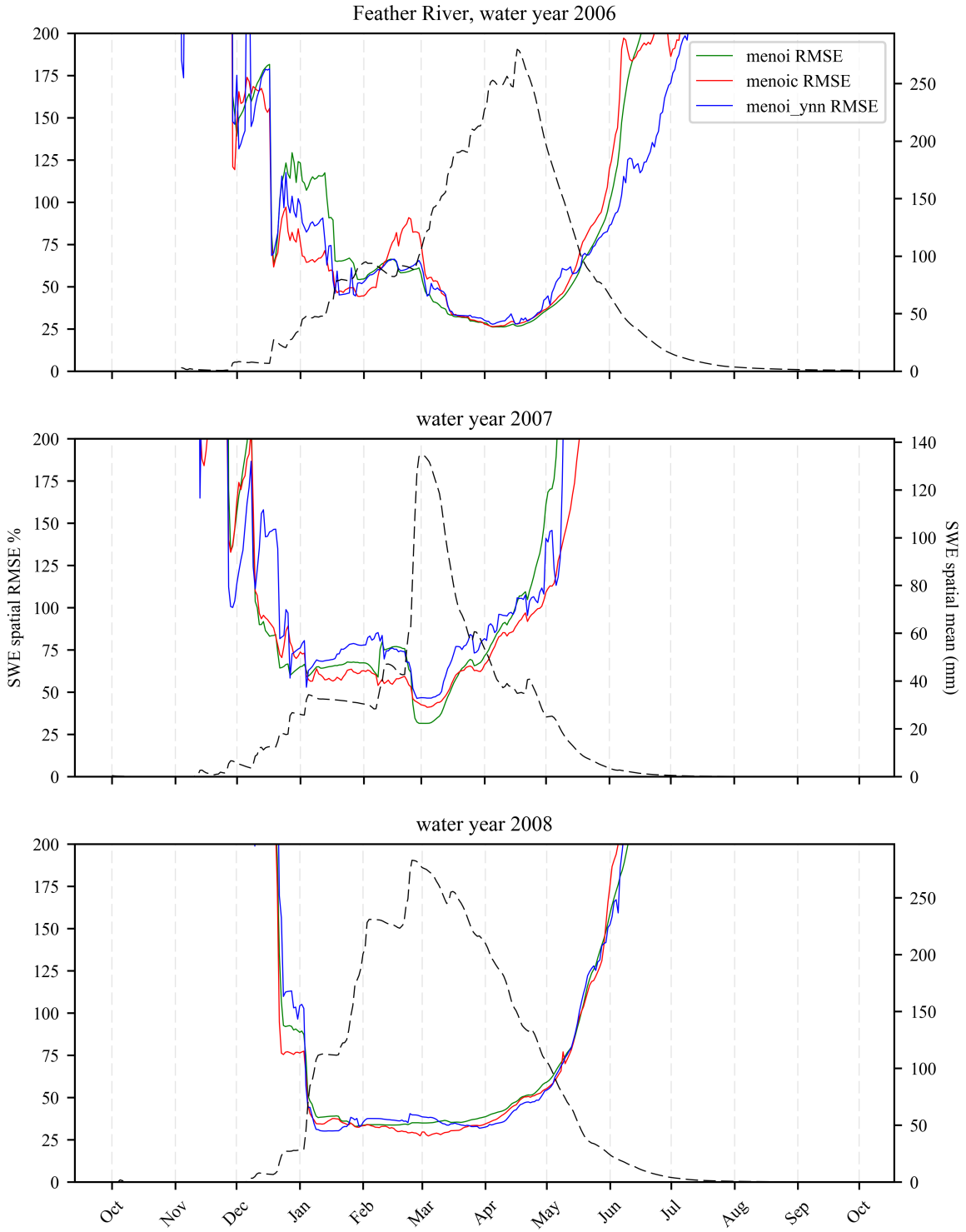

Figure S9. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 2006, 2007 and 2008.

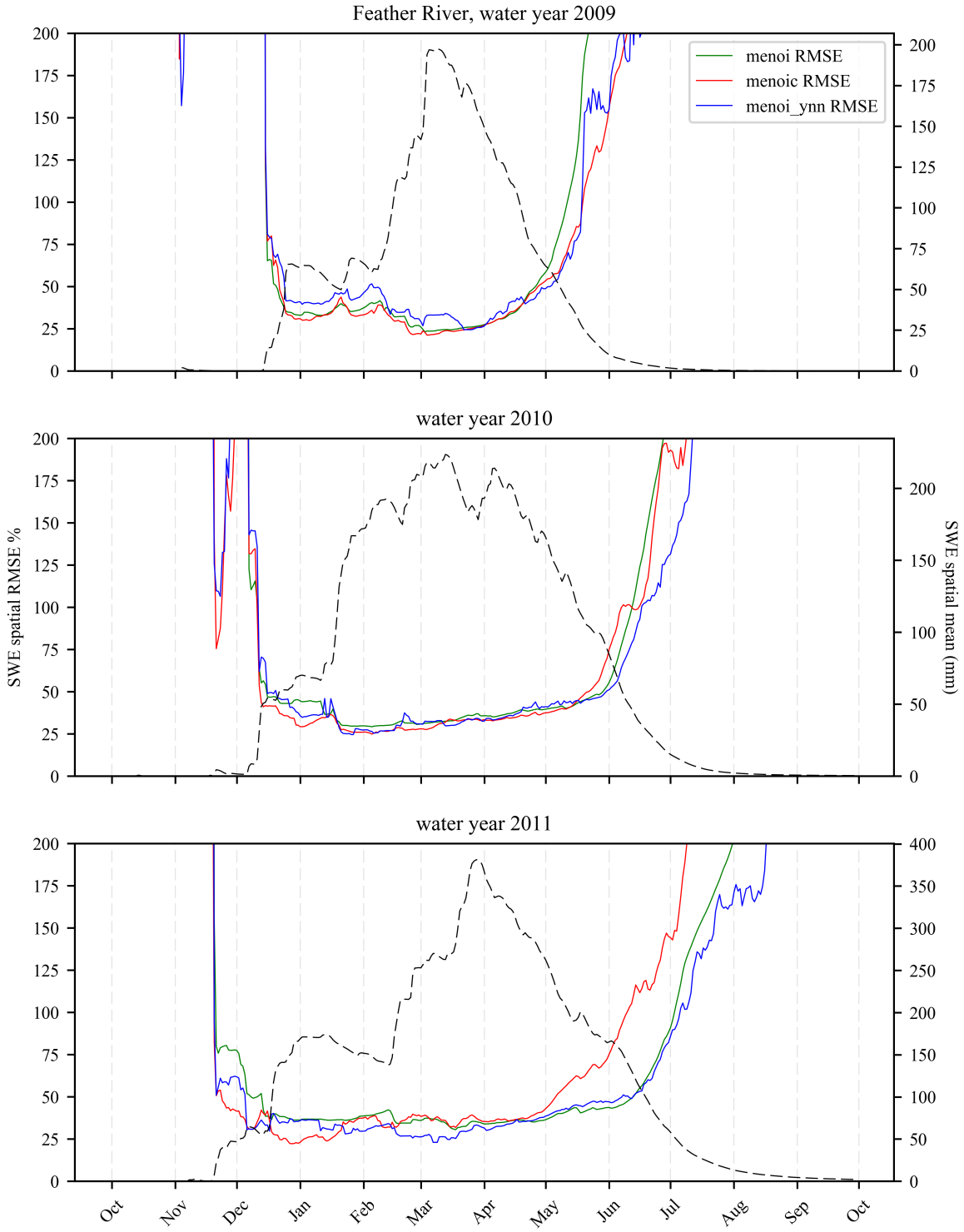

Figure S10. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 2009, 2010 and 2011.

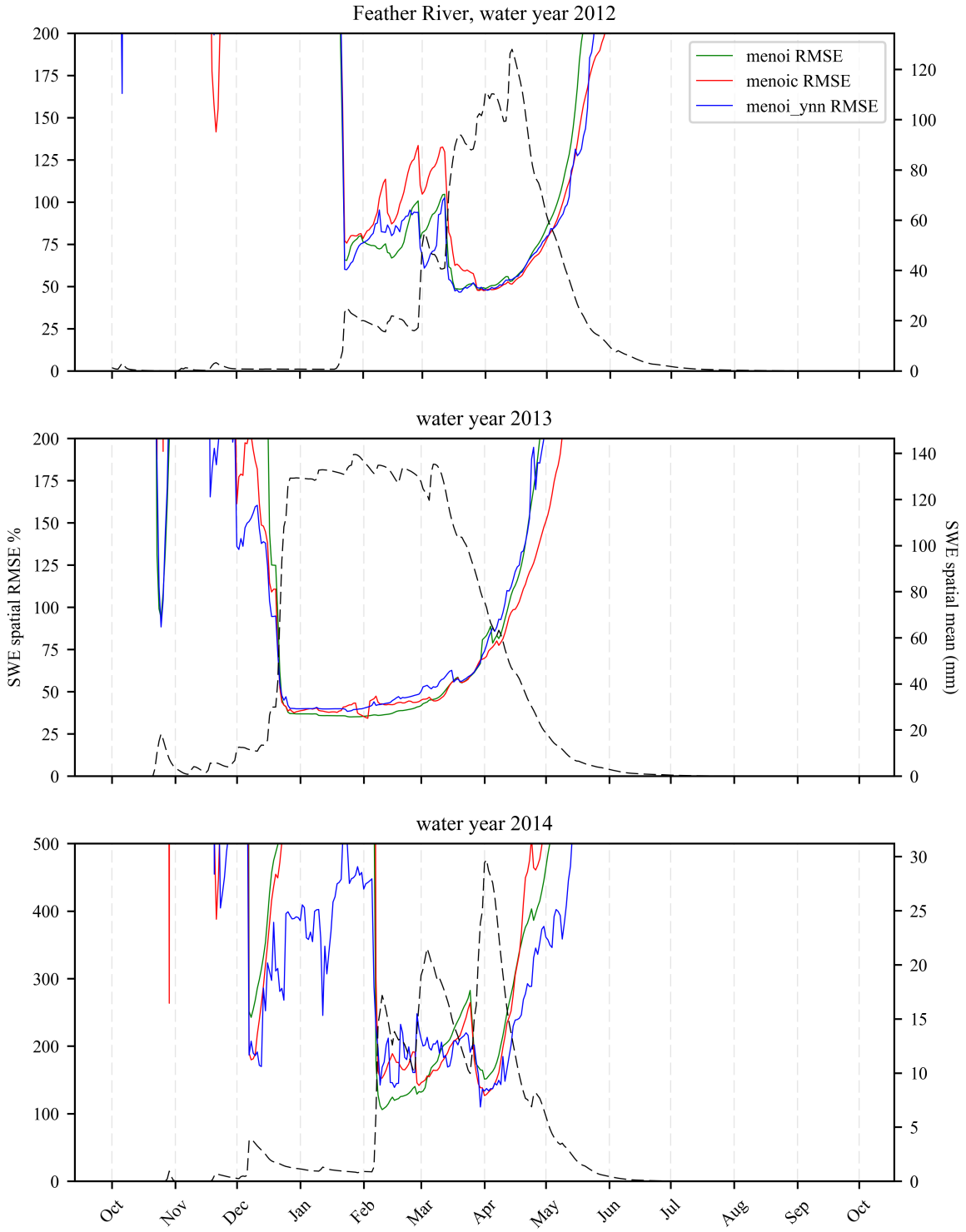

Figure S11. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 2012, 2013 and 2014.

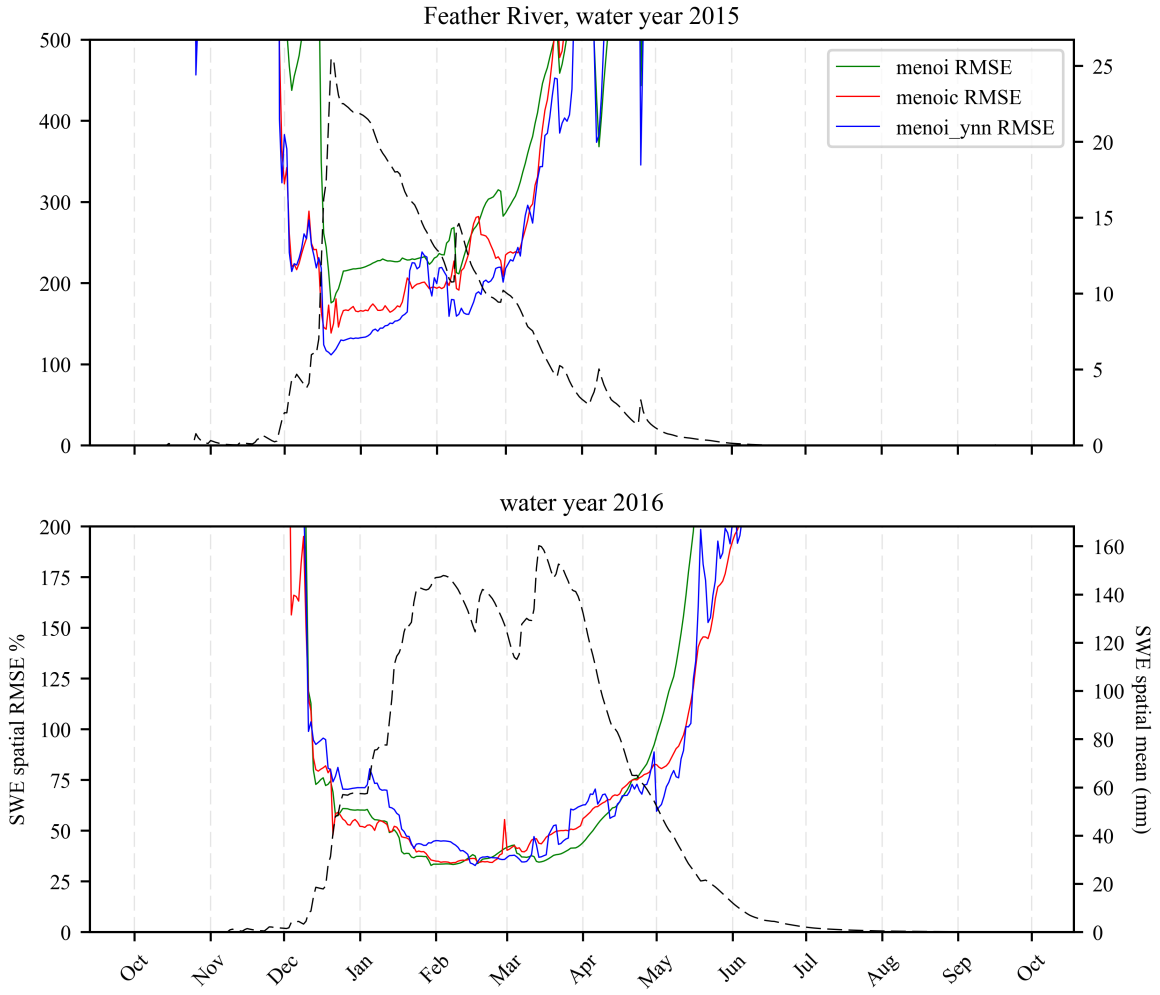

Figure S12. Feather River *menoi* RMSE as percentage of the daily spatial mean SWE with different Ensemble selection for water-years 2015 and 2016.

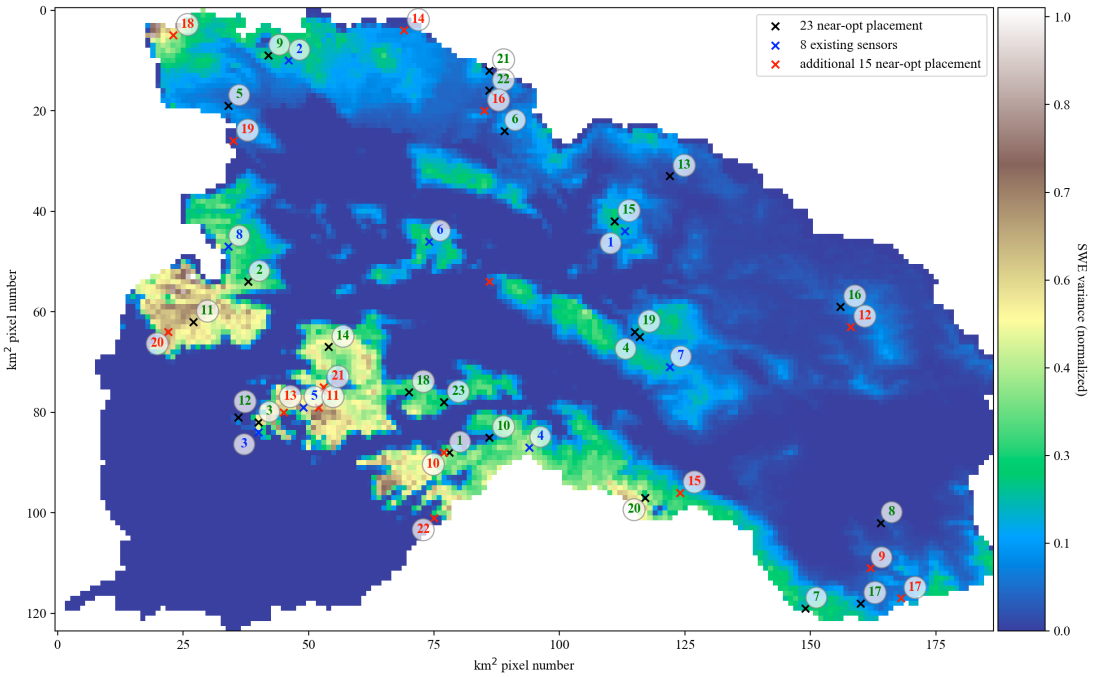

Figure S13. Near-optimal sensor placement of 23 (black and green) and additional 15 (red) complementing the existing 8 sensors at Feather basin, overlaid on the normalized ensemble variance map of the Landsat-derived product.

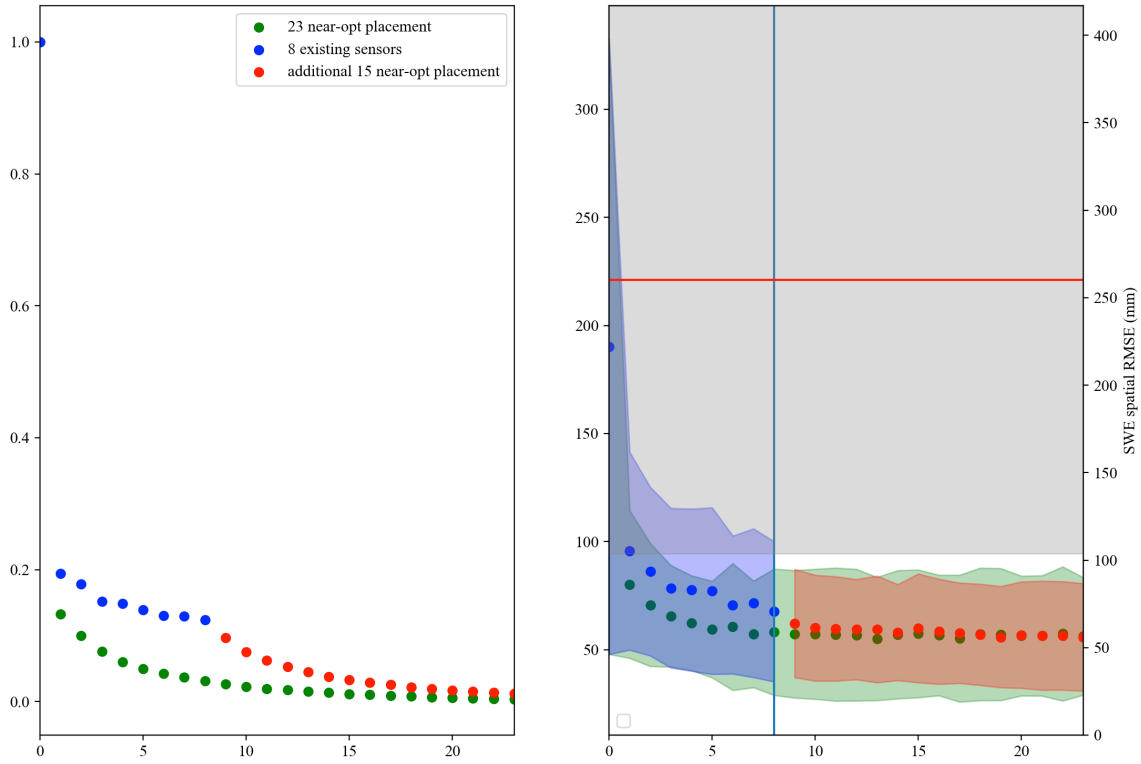

Figure S14. Reduction in normalized basin-wide ensemble variance (left) and in the 1985 to 2016 mean of April 1st SWE spatial RMSE (right) given the near optimal sensor placement of the 23 and complimentary 15 (to the existing 8) sensors at Feather basin shown in Figure S13. The red horizontal line is the 1985 to 2016 mean SWE. The envelops represent the stanrdard deviations across 1985 to 2016 of both mean and errors.

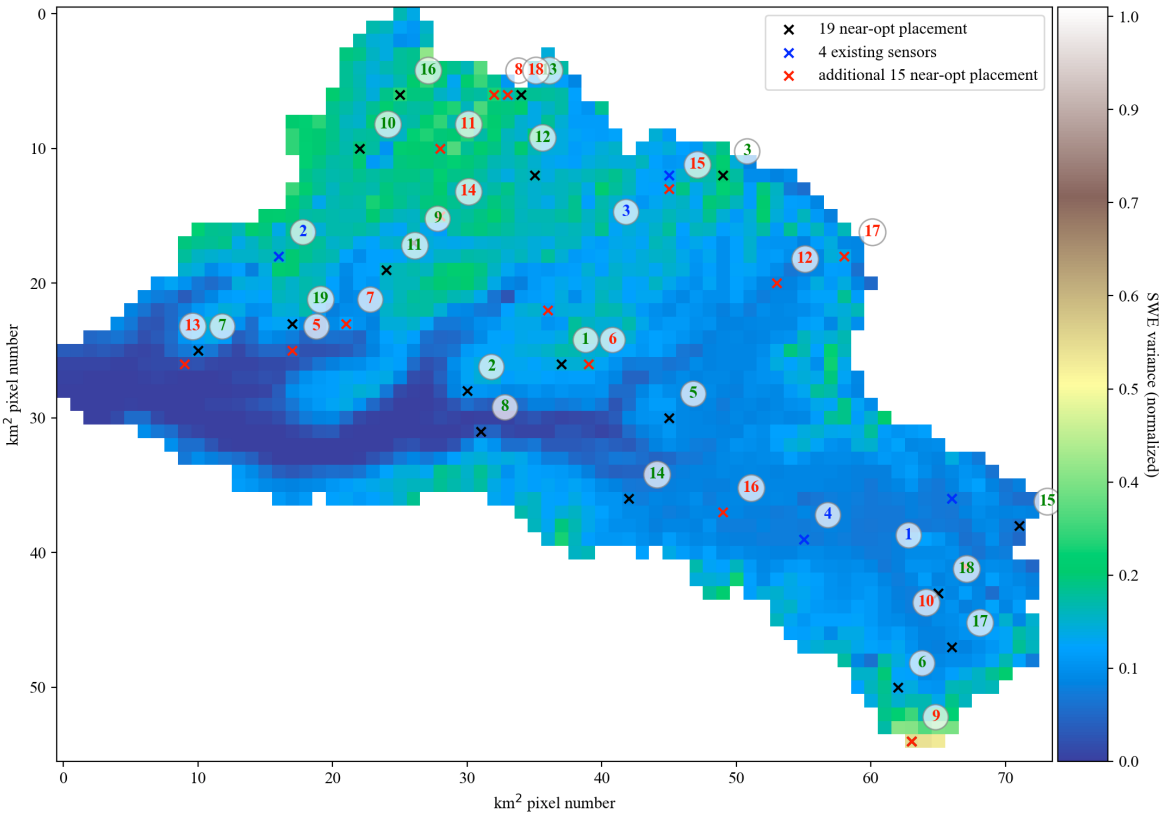

Figure S15. Near-optimal sensor placement of 19 (black and green) and additional 15 (red) complementing the existing 4 sensors at Tuolumne basin, overlaid on the normalized ensemble variance map of the Landsat-derived product.

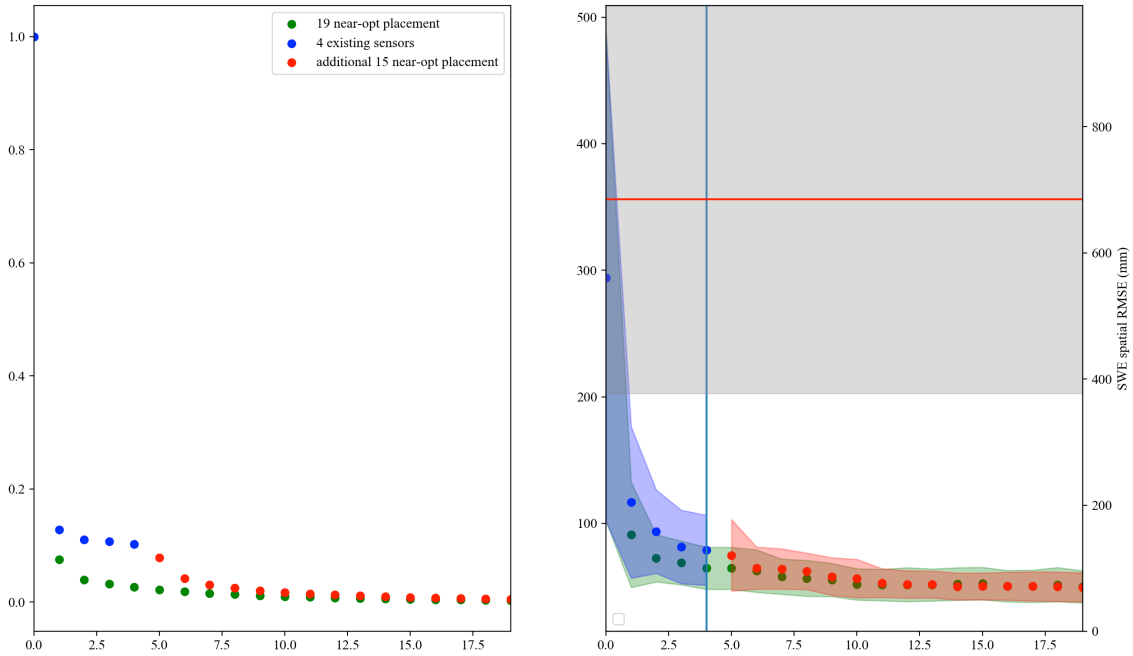

Figure S16. Reduction in normalized basin-wide ensemble variance (left) and in the 1985 to 2016 mean of April 1st SWE spatial RMSE (right) given the near optimal sensor placement of the 19 and complimentary 15 (to the 4 existing) sensors at Tuolumne basin. The red horizontal line is the 1985 to 2016 mean SWE. The envelops represent the stanrdard deviations across 1985 to 2016 of both mean and errors.