Comparison of Modeled Snow Water Equivalents

Angelique M. Fabbiani Leon
California Department of Water Resources
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Introduction

California Department of Water Resources (DWR), Snow Survey Section has been looking into improving and including additional resources to their forecasting procedure. Forecasting April-July full natural flow (A-J FNF) includes the use of statistical regression equations as a basis, but also additional resources and intuition.

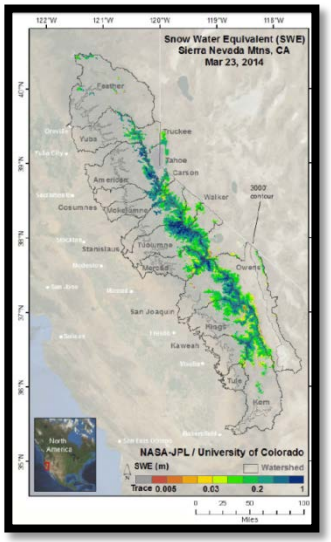
DWR has invested into using USGS Precipitation-Runoff Modeling System (PRMS), which calculates snow water equivalent (SWE) as a parameter for runoff.

DWR would like to make use of newer tools in estimating SWE, but need a way to include it into current practices or determine its accuracy.

Few Issues Discussed

- SWE in higher elevations → snow sensors are only within certain elevation band
- SWE estimated products (gridded source, PRMS, etc.) are comparable to DWR regression equations
- If SWE estimated products are comparable to DWR regression equations, how to make use of it into current practices

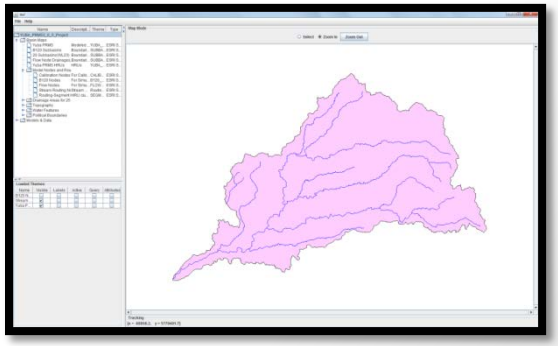
JPL SWE Blended Product



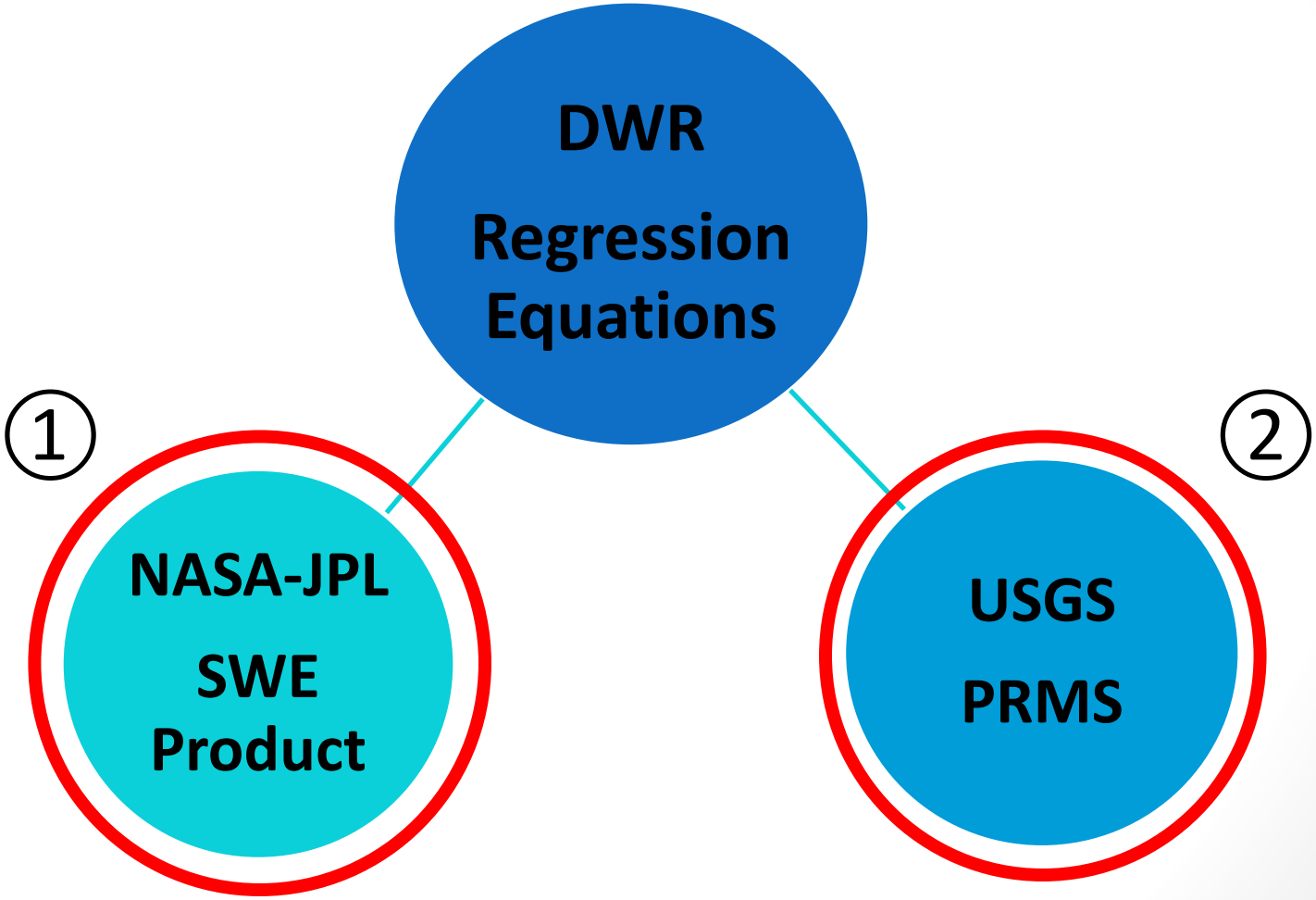
Incorporating Gridded SWE Images into PRMS?

?

USGS PRMS



Purpose of Research: Comparison to DWR Regression Equations



Overview of:

1. DWR Regression Equations
2. JPL SWE Blended Product
3. PRMS Feather Model

DWR Regression Equations

Statistical Method Using Multiple Linear Regression

Primary Forecasting Tool → Multiple Linear Regression Analysis

- Specific for each watershed

Dependent Variable → April-July Cumulative Unimpaired Runoff

Independent Variables → Prior Year April-July Cumulative Unimpaired Runoff

→ October-March Cumulative Unimpaired Runoff

→ Snow Index (High Elevation)

→ Snow Index (Low Elevation)

→ October-March Precipitation Index

→ April-June Precipitation Index

Sample Snow Index Calculation for Feather River High Snowpack

Feather River inflow to Lake Oroville — **High Snowpack**

#	ID	Name	Basin	Dir	Elev	4/1avg	Pr.st	Ratio	Sched	Date	raw WC	int Pcp	adj WC	% avg	est %
361	KTL	Kettle Rock	Feath	⌖	7300'	23.0	7	.7	_2345	03/25/14	0	+3.1	3.1	13.3	
48	MDY	Mount Dyer	Feath	↑	7100'	25.5	6	1.0	_234_	04/02/14	11.0	-.1	10.9	42.9	
359	GRZ	Grizzly	Feath	⌖	6900'	30.3	7	1.1	_2345	03/24/14	1.0	+5.1	6.1	20.1	
279	ERB	Eureka Bowl	Feath	↓	6800'	44.3	8	2.6	_2345						
280	RWL	Rowland Creek	Feath	→	6700'	17.8	7	.7	12345	03/26/14	1.0	+2.9	3.9	21.9	
360	MHG	Mount Hough	Feath	⌖	6700'	29.5	7	1.1	12345	03/28/14	2.5	+4.3	6.8	23.1	
75	CHU	Church Meadows	Feath	↓	6700'	32.1	8	1.9	12345	03/27/14	1.5	+2.4	3.9	12.2	
74	YBP	Yuba Pass	Yuba	↘	6700'	30.9	8	.9	_2345	04/02/14	6.5	0	6.5	21.0	
45	SVR	Silver Lake Meado	Susan	↖	6450'	29.6	5	.9	45	04/01/14	5.5	0	5.5	18.6	
53	3LK	Three Lakes	Feath	←	6250'	39.9	7	1.5	_234_	03/25/14	2.0	+6.7	8.7	21.8	
54	MLF	Mill Creek Flat	Feath	←	5900'	39.2	7	1.5	_234_	03/25/14	4.0	+6.6	10.6	27.1	
49	LTT	Letterbox	Feath	←	5600'	49.9	7	1.9	_234_	03/25/14	3.0	+8.4	11.4	22.9	
	Basin average:				6590'	32.7				03/27/14	3.5	+3.6	7.0	22.3	22.3
	Average of reporting courses:				6500'	32.5			Feb 1	Mar 1	Apr 1		Future Increment:		0.0
12	courses					Hist Median Increm:			30	8	0		Apr 1 Index:		22.3

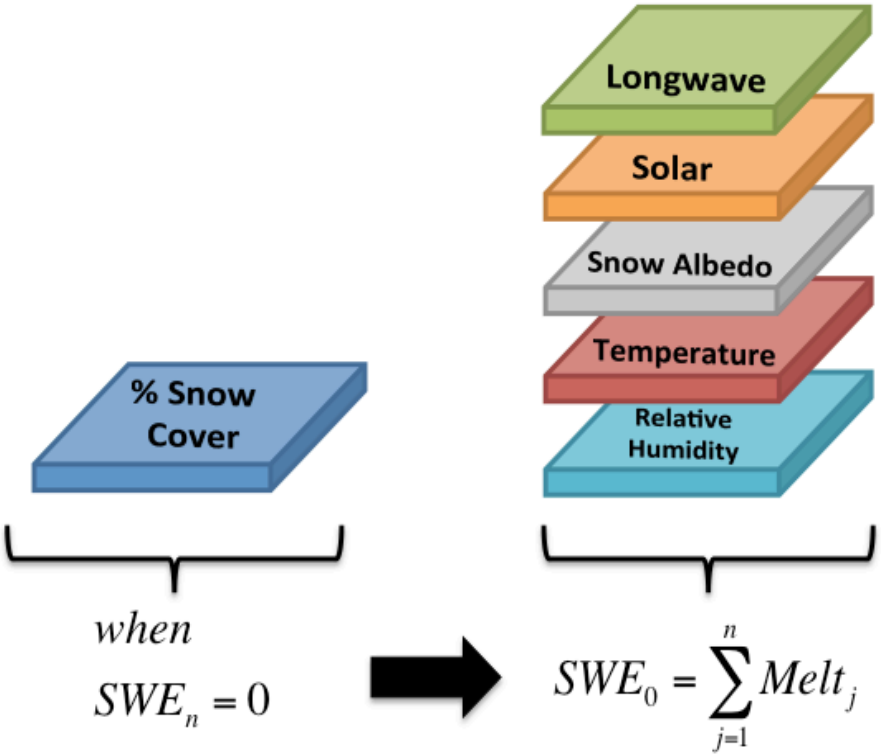
JPL Reconstructed SWE Product

Reconstructs daily gridded estimates of SWE by the following:

$$M = M_p \times f_{SCA}$$

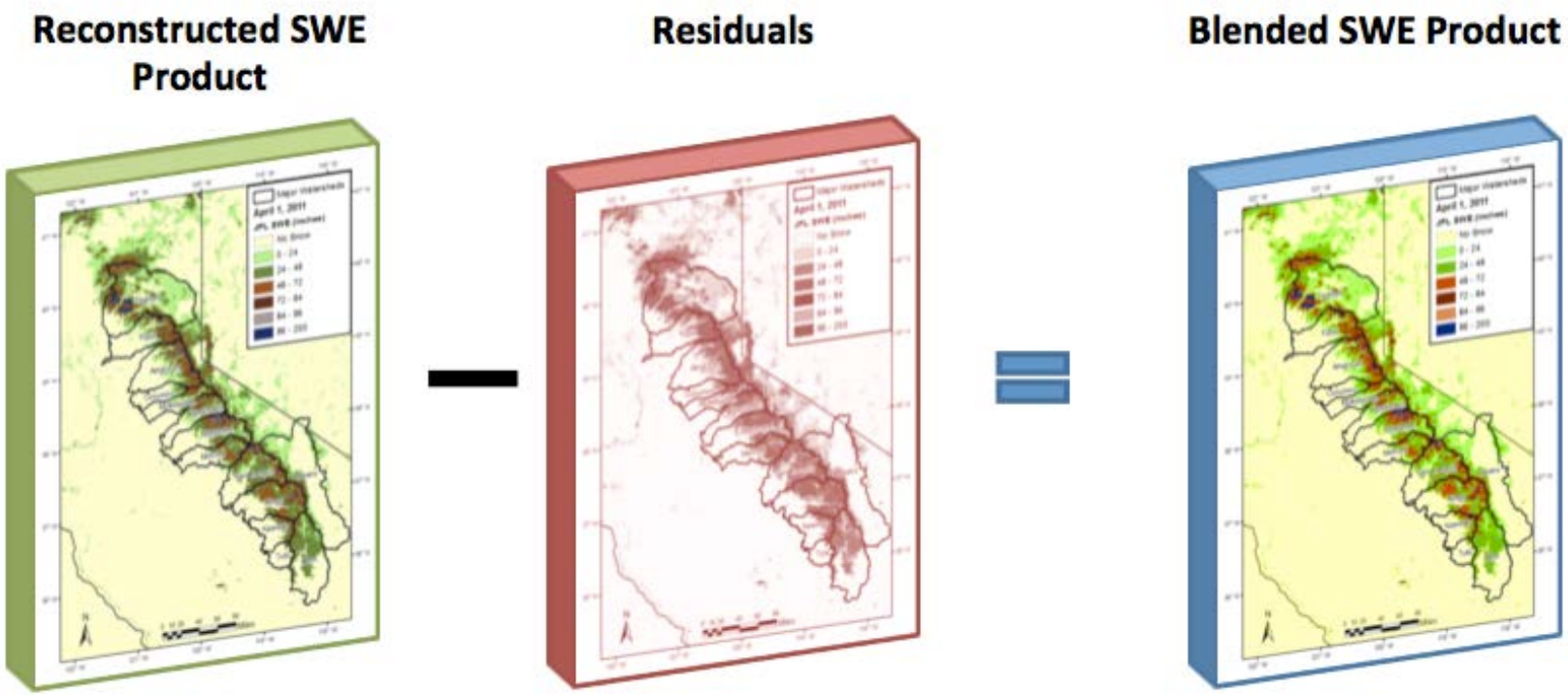
$$SWE_n = SWE_0 - \sum_{j=1}^{n} M_j$$

SWE_0 (i.e. peak SWE), can be determined by the cumulative melt flux when there is no more snow in a pixel (i.e. $SWE_n = 0$):



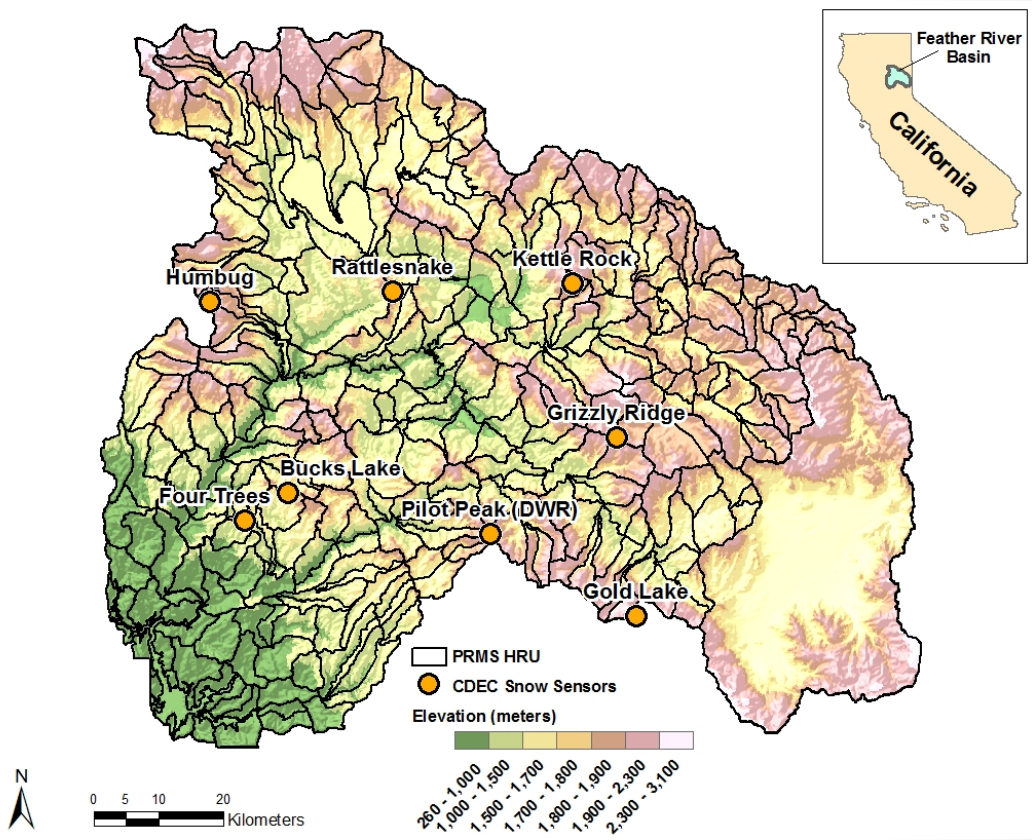
JPL Blended SWE Product

1. Difference between Reconstructed SWE and snow sensor SWE readings (at each snow sensor location) determined
2. Difference distributed to all pixels → using inverse of squared distance as distribution weights → **Distributed Residuals**
3. For each pixel: Reconstructed SWE – Distributed Residual = **Blended SWE**

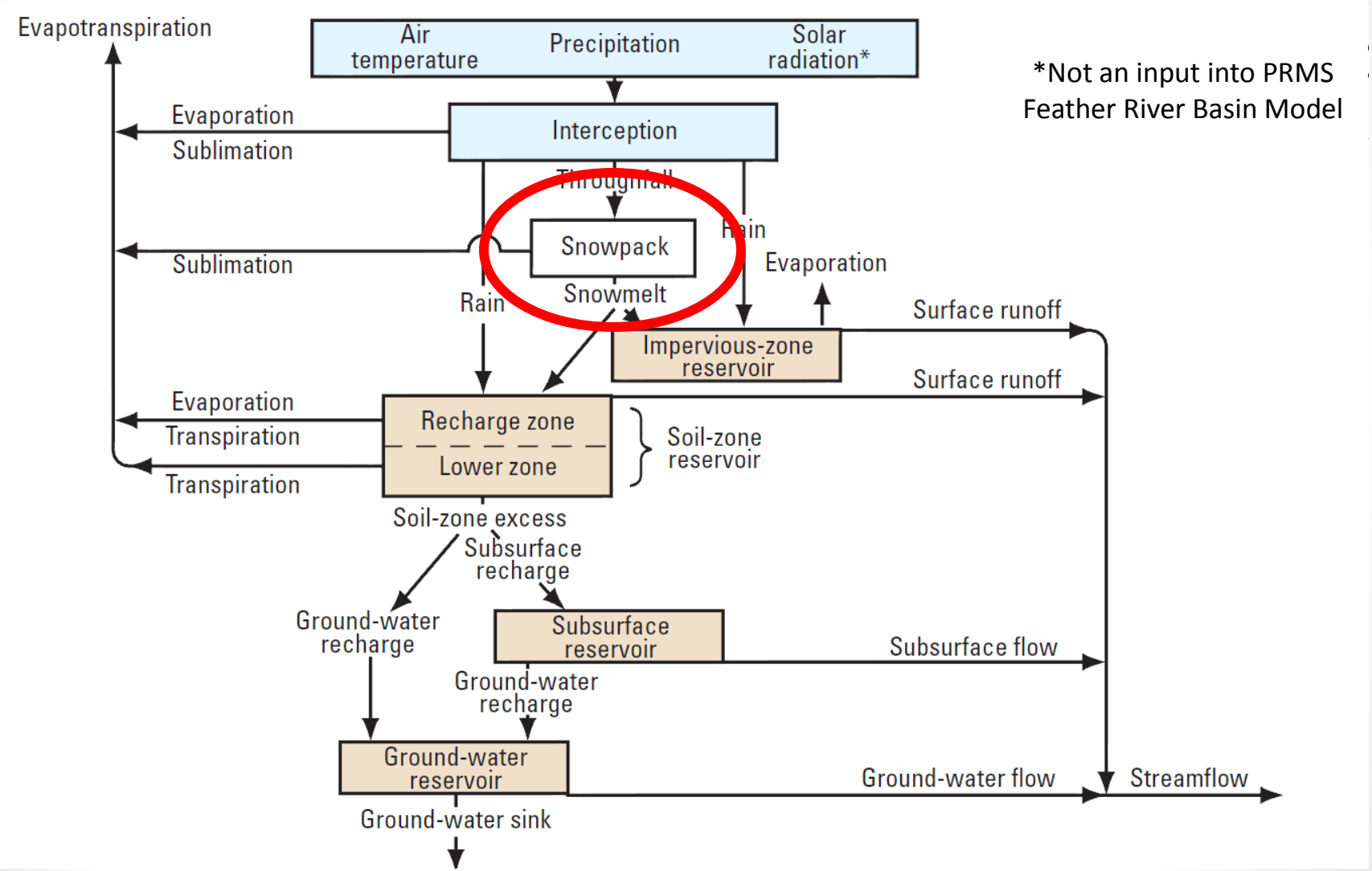


Overview PRMS Feather Model

- **Conceptual, spatially-distributed model**
- **Hydrologic Response Units:** homogeneous with water/energy balance for each time step at each HRU
- **Total HRUs:** 324



PRMS Modules



*Not an input into PRMS
Feather River Basin Model

Overview of Comparison: JPL Blended Product and DWR Regression Equations

Comparison on Elevation Band Average SWE

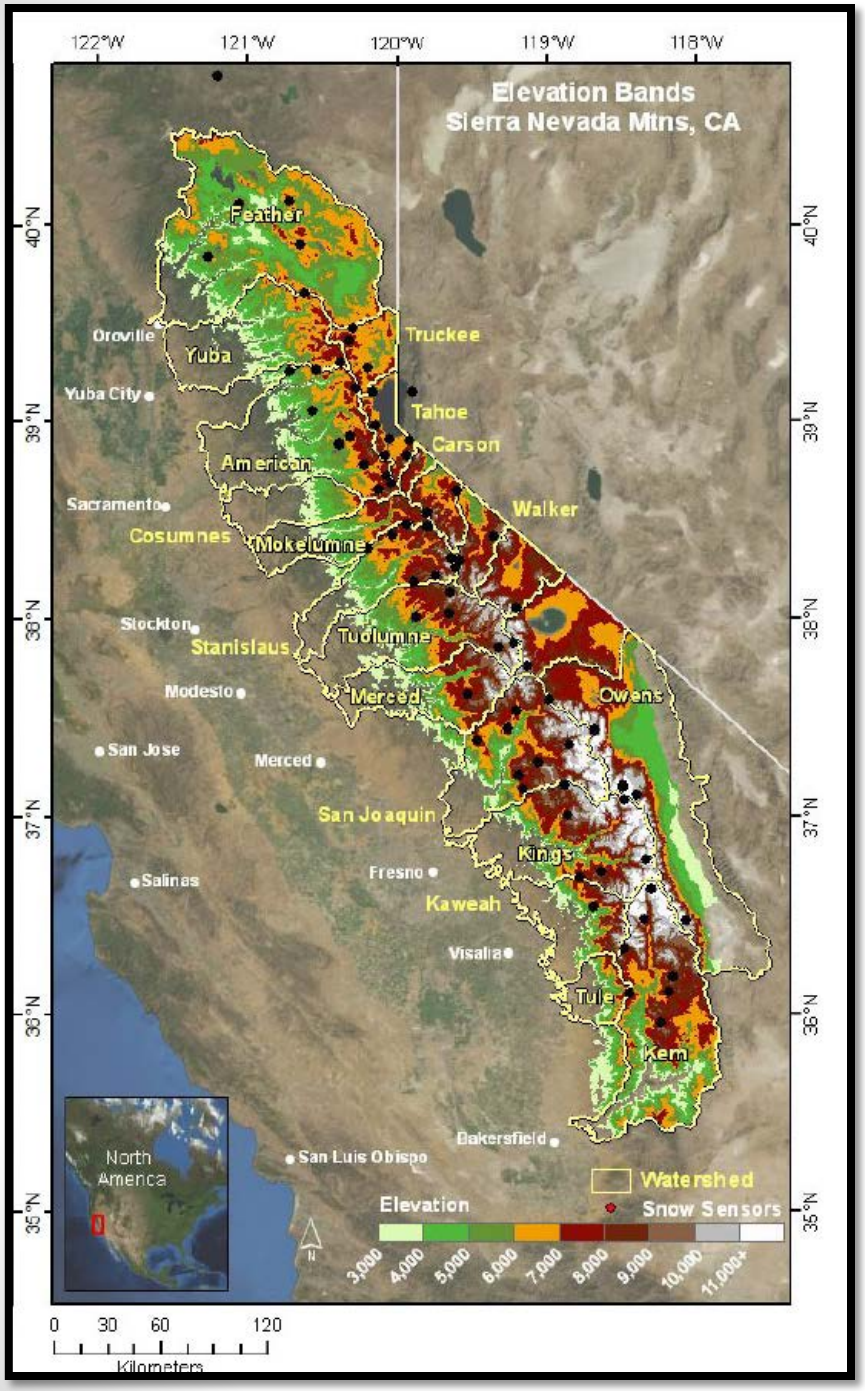
① Determine Average SWE Based on Elevation Bands

Watershed	Elevation	3/16/14 % Avg to Date	3/23/14 SWE (in)	3/16/14 SWE (in)	3/16 thru 3/23 Change SWE (in)	Area Sq Mi
FEATHER	3000-4000'	0.00	0.00	0.00	0.00	286.2
	4000-5000'	0.00	0.00	0.00	0.00	735.8
	5000-6000'	0.35	0.05	0.11	-0.07	1305.1
	6000-7000'	5.16	0.91	1.47	-0.57	871.3
	7000-8000'	12.15	3.07	3.99	-0.92	124.6
	8000-9000'	17.98	5.43	6.14	-0.71	5.2

② Interpolate Average SWE In-between Elevation Bands

- In order to compare with sensor station readings used to develop DWR snow index value

③ Select Elevation Snow Sensor is Located for Analysis



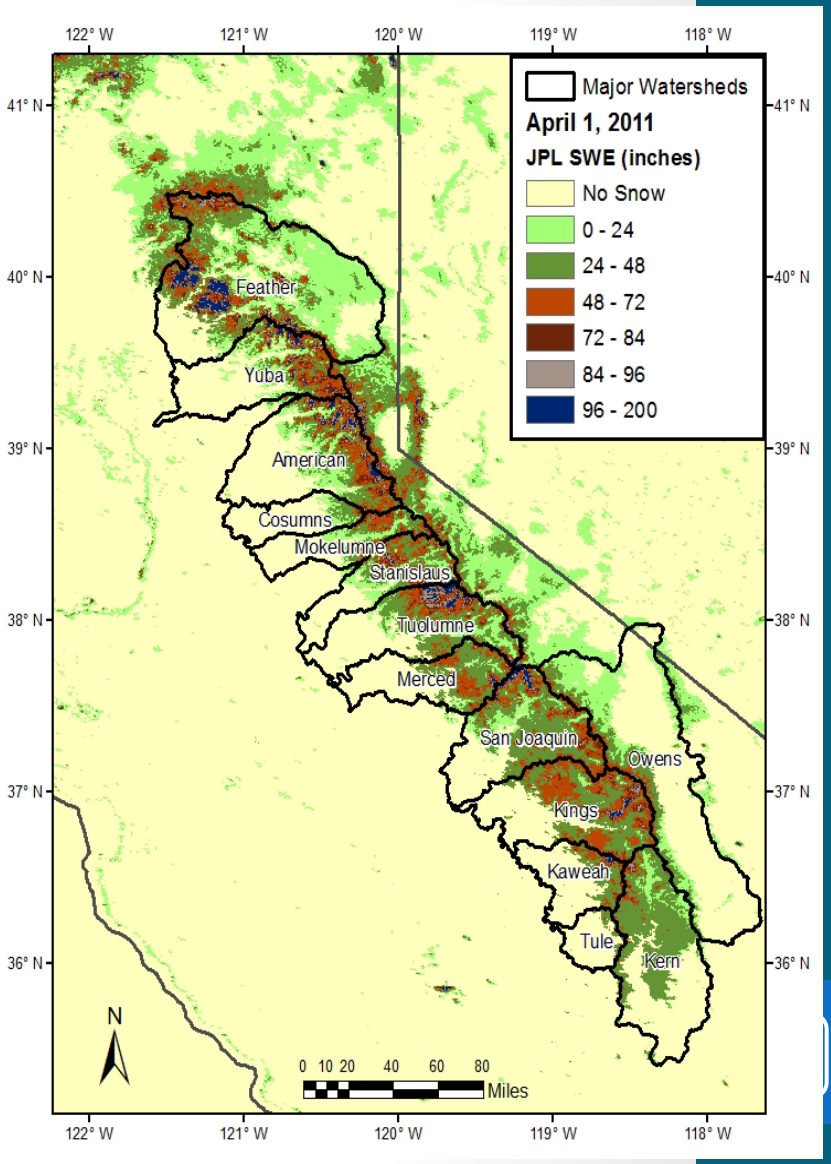
Elevation Bands

Average SWE determined with the following elevation bands:

3,000 – 4,000 feet
4,000 – 5,000 feet
5,000 – 6,000 feet
6,000 – 7,000 feet
7,000 – 8,000 feet
8,000 – 9,000 feet

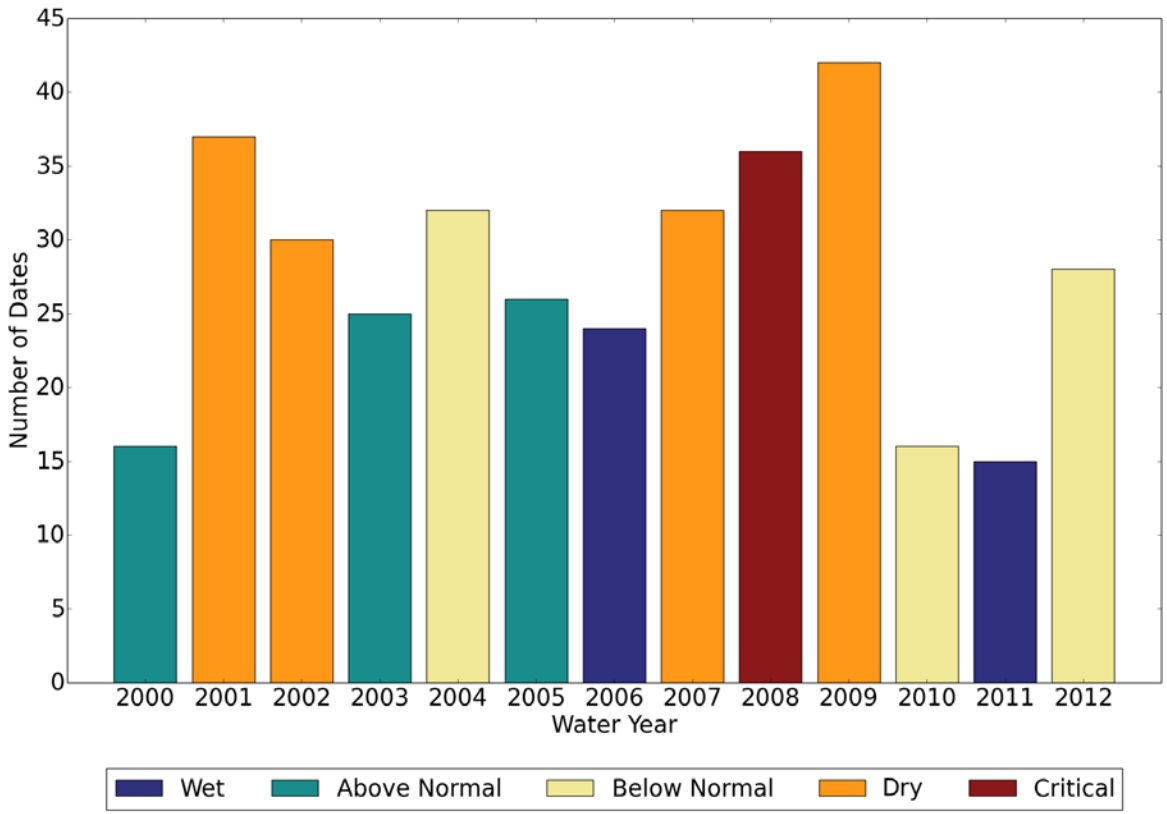
Simulation Work

- Processed through roughly 840 JPL Blended SWE images for Feather:
  - Cloud-free satellite image dates
  - March-August for years 2000-2012
  - To obtain tables for elevation banded average SWE



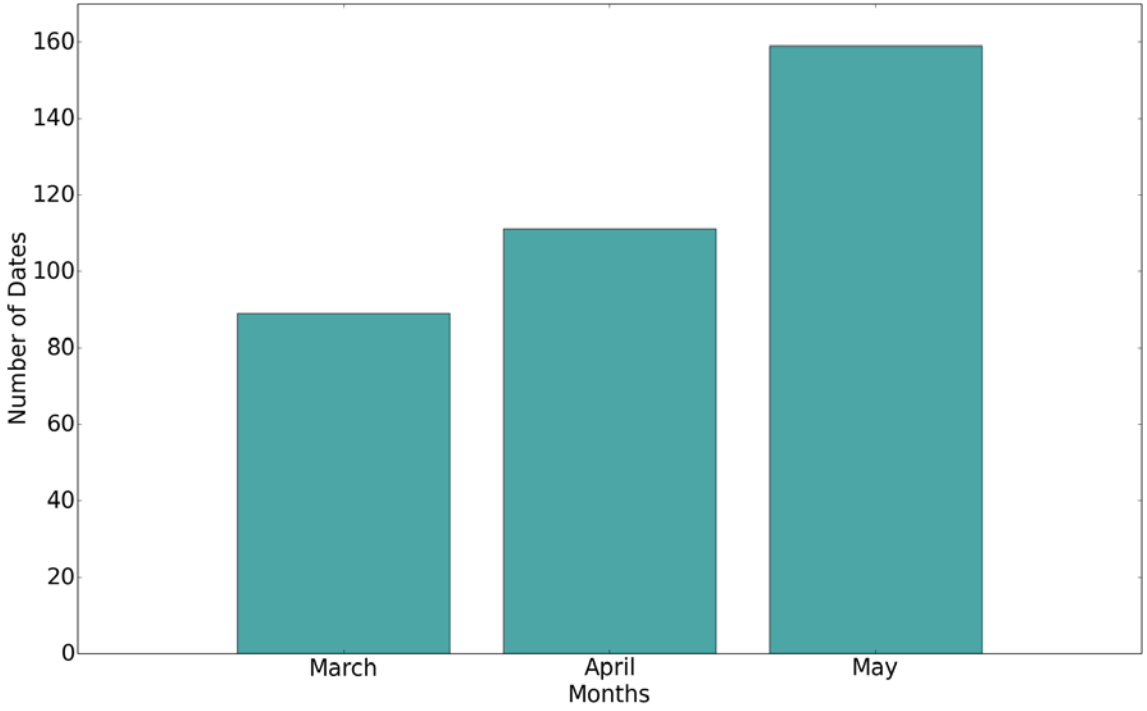
Satellite Image Dates: Water Years 2000-2012

- The number of dates: 15 (in 2011) to 42 (in 2009)
- Above average/wet water years: less satellite images → impact of more cloud coverage.
- During dry/below normal water years: more satellite images → increase in cloud-free days.
- This is important to note when comparing results for data intensive water years to those with less data.



Satellite Image Dates: Months March-May

- March: less satellite images → impact of more cloud coverage.
- May: more satellite images → increase in cloud-free days.
- This is important to note when comparing results for data intensive water years to those with less data.

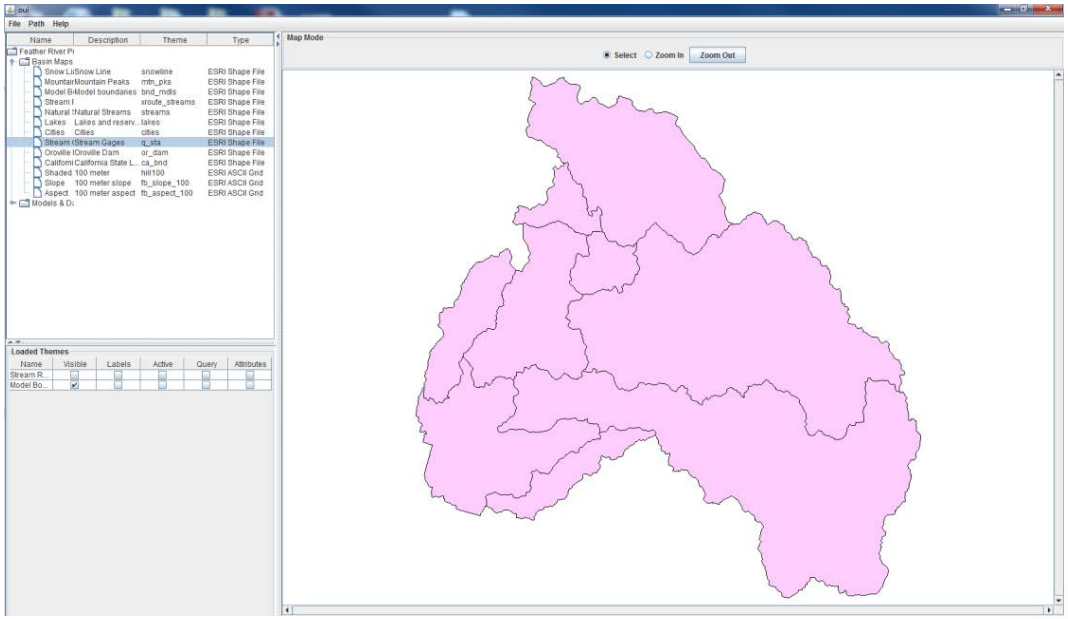


Overview of Comparison: PRMS and DWR Regression Equations

Simulation Work

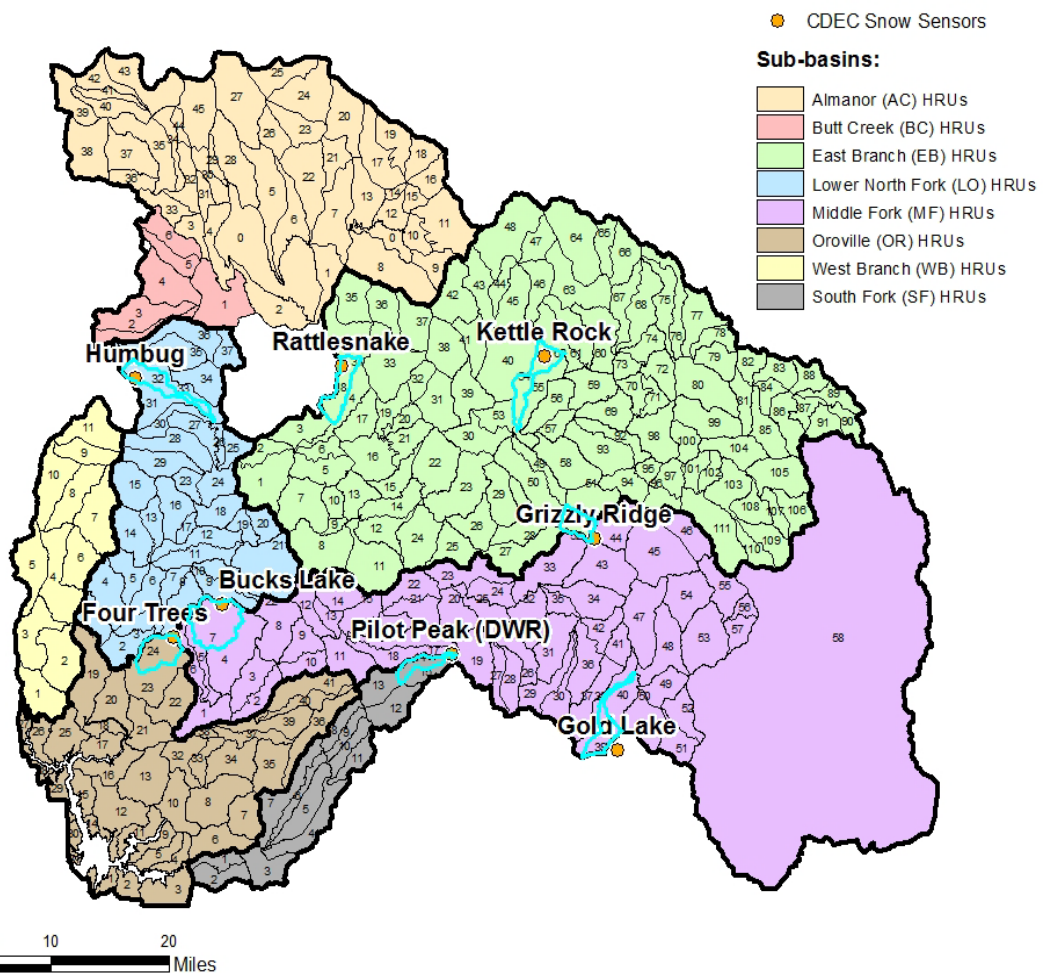
- Simulations for HRUs with snow sensors were located:
  - Used simulated SWE from “pkwater_equiv” parameter in PRMS
  - Same JPL cloud-free satellite image dates
  - March-August for years 2000-2012

- HRUs are the smallest unit involved in PRMS
  - Hydrologic processes for each HRU is assumed uniformed with homogeneous physical characteristics for HRU polygon.



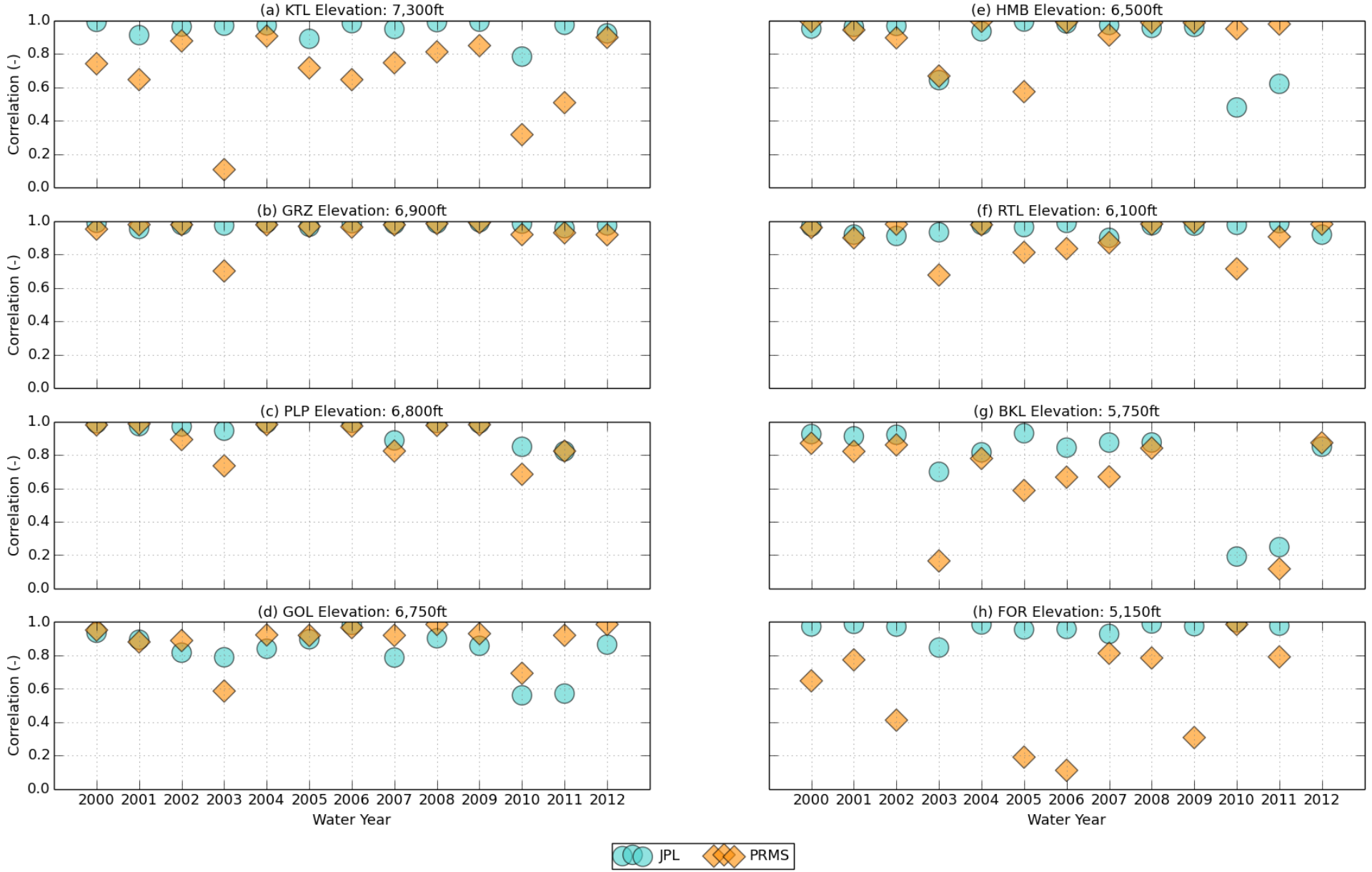
Selected HRUs

PRMS HRUs	Elevation Ranges (ft)	Area (acres)
EB 54	3,600–7,800	5,536
EB 52	5,800–7,100	3,251
SF 14	5,100–7,000	2,524
MF 39	4,300–7,400	4,090
LO 32	3,800–7,100	4,924
EB 18	4,100–6,200	4,761
MF 7	4,000–6,200	9,066
OR 24	2,500–5,100	5,152



Results:
1. Correlation
(Water Years 2000-2012 and Months March-May)

Correlation: Water Years 2000-2012

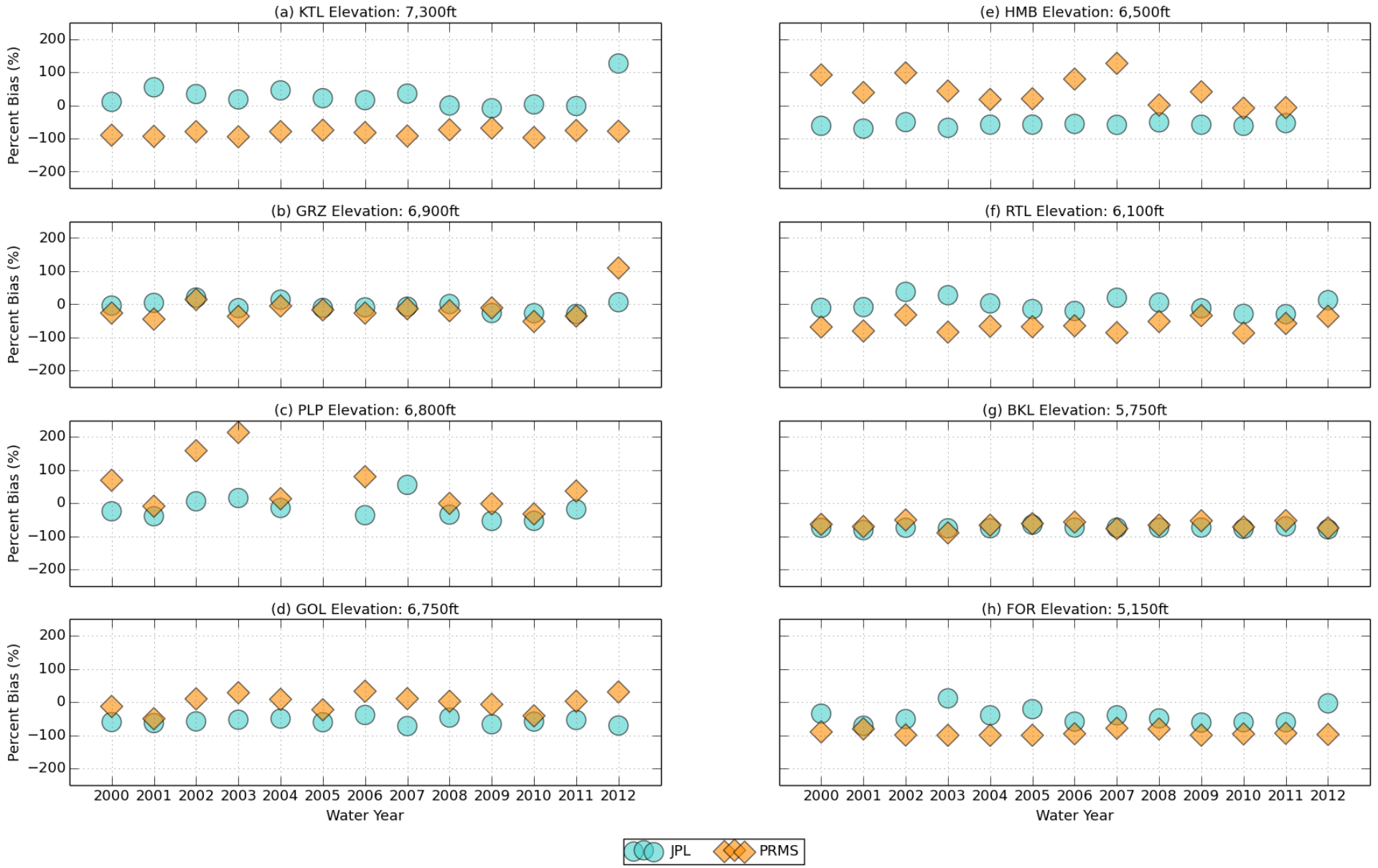


Correlation: Months March-May Summary Table

Month (For years: 2000 – 2012)	JPL Correlation Ranges	PRMS Correlation Ranges
March	0.64 – 0.91	0.06 – 0.86
April	0.84 – 0.96	0.52 – 0.88
May	0.87 – 0.96	0.73 – 0.87

Results:
2. Percent Bias
(Water Years 2000-2012 and Months March-May)

Percent Bias: Water Years 2000-2012

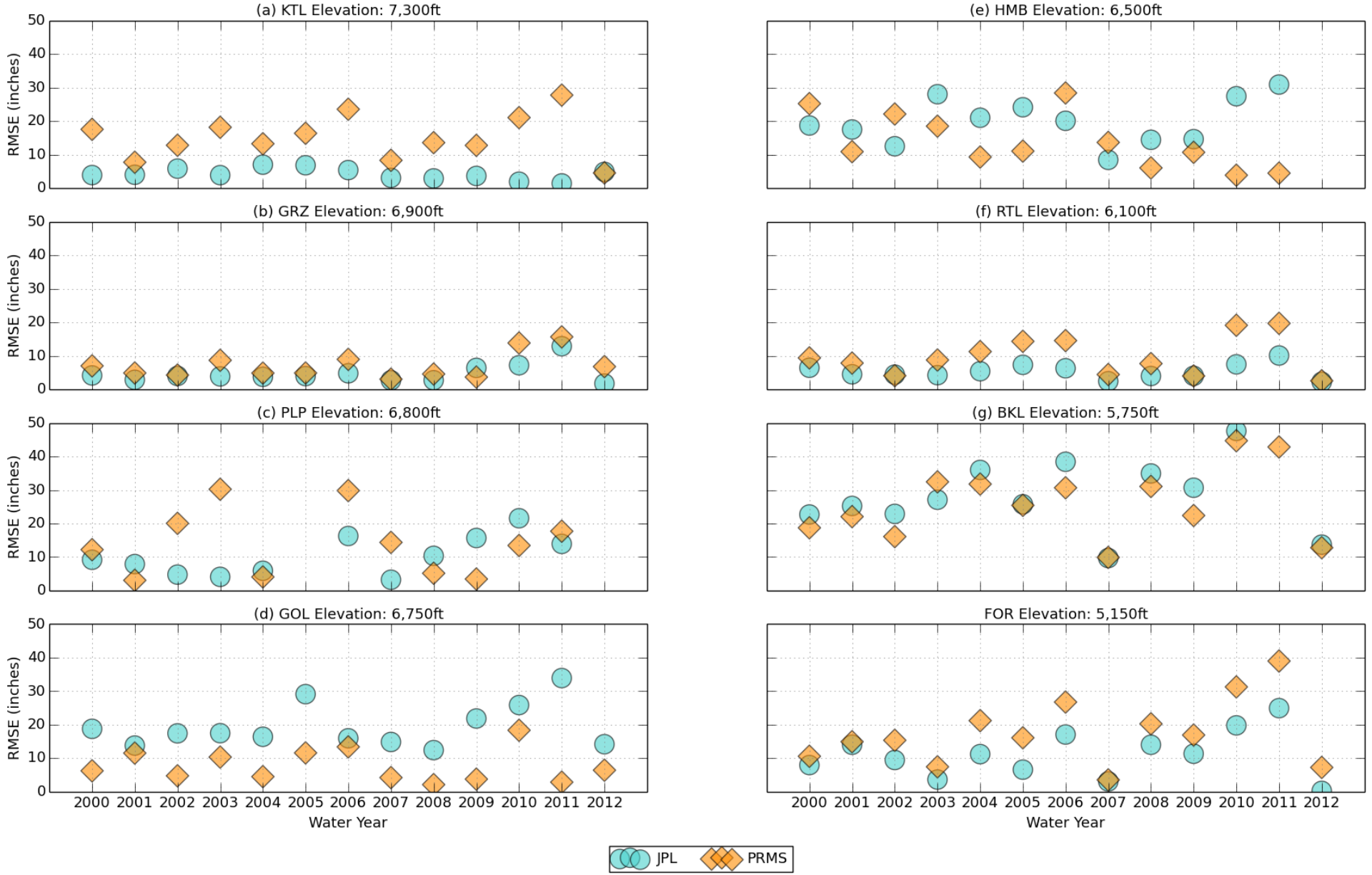


Percent Bias: Months March-May Summary Table

Month (For years: 2000–2012)	JPL Percent Bias Ranges	PRMS Percent Bias Ranges
March	-67.43 – -3.06	-68.63 – 9.38
April	-75.24 – 10.97	-84.43 – 29.41
May	-80.70 – 62.33	-100.00 – 121.70

Results:
3. Root Mean Squared Error, RMSE (WY and Mar-May)

RMSE: Water Year 2000-2012

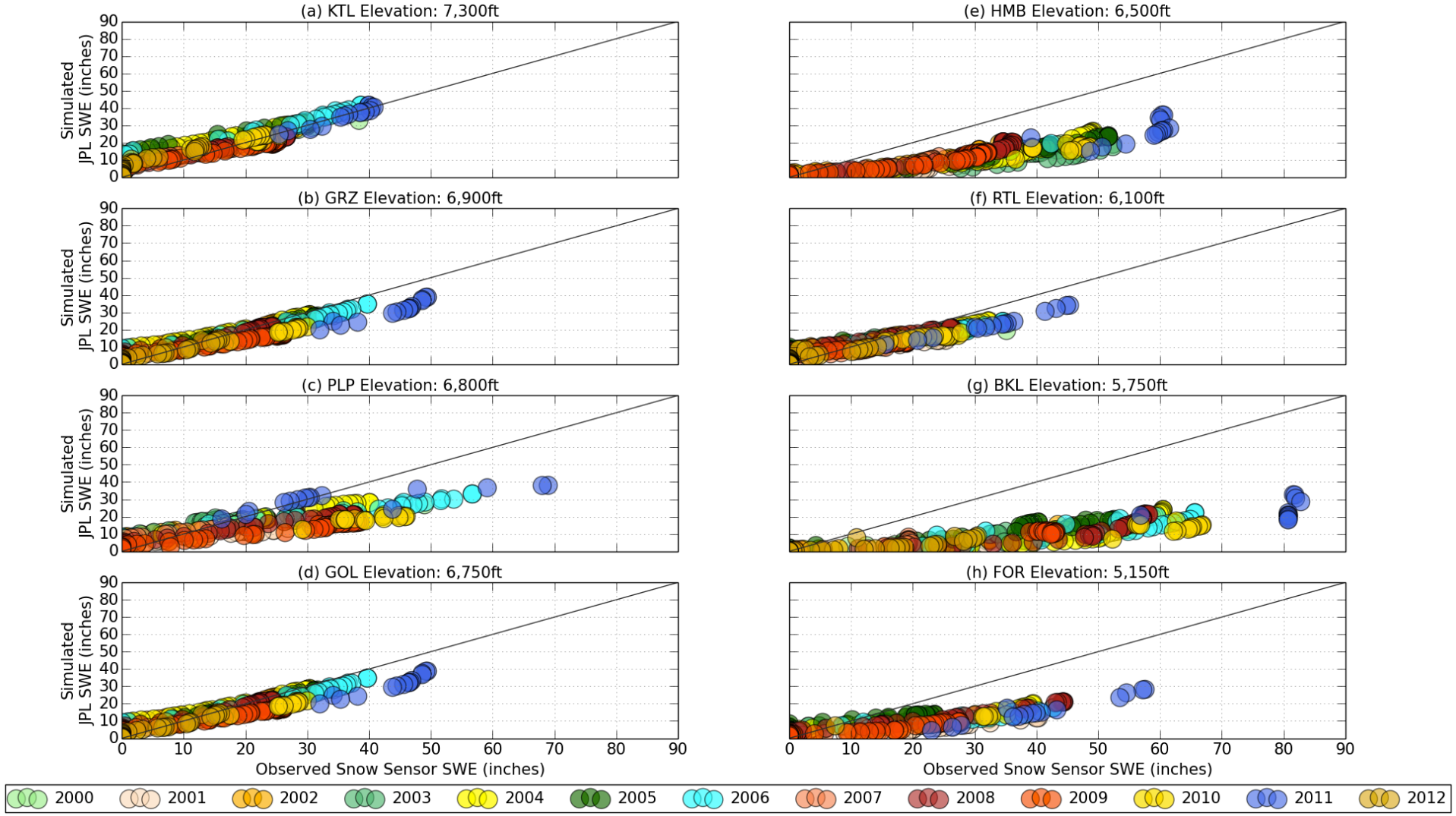


RMSE: Months March-May Summary Table

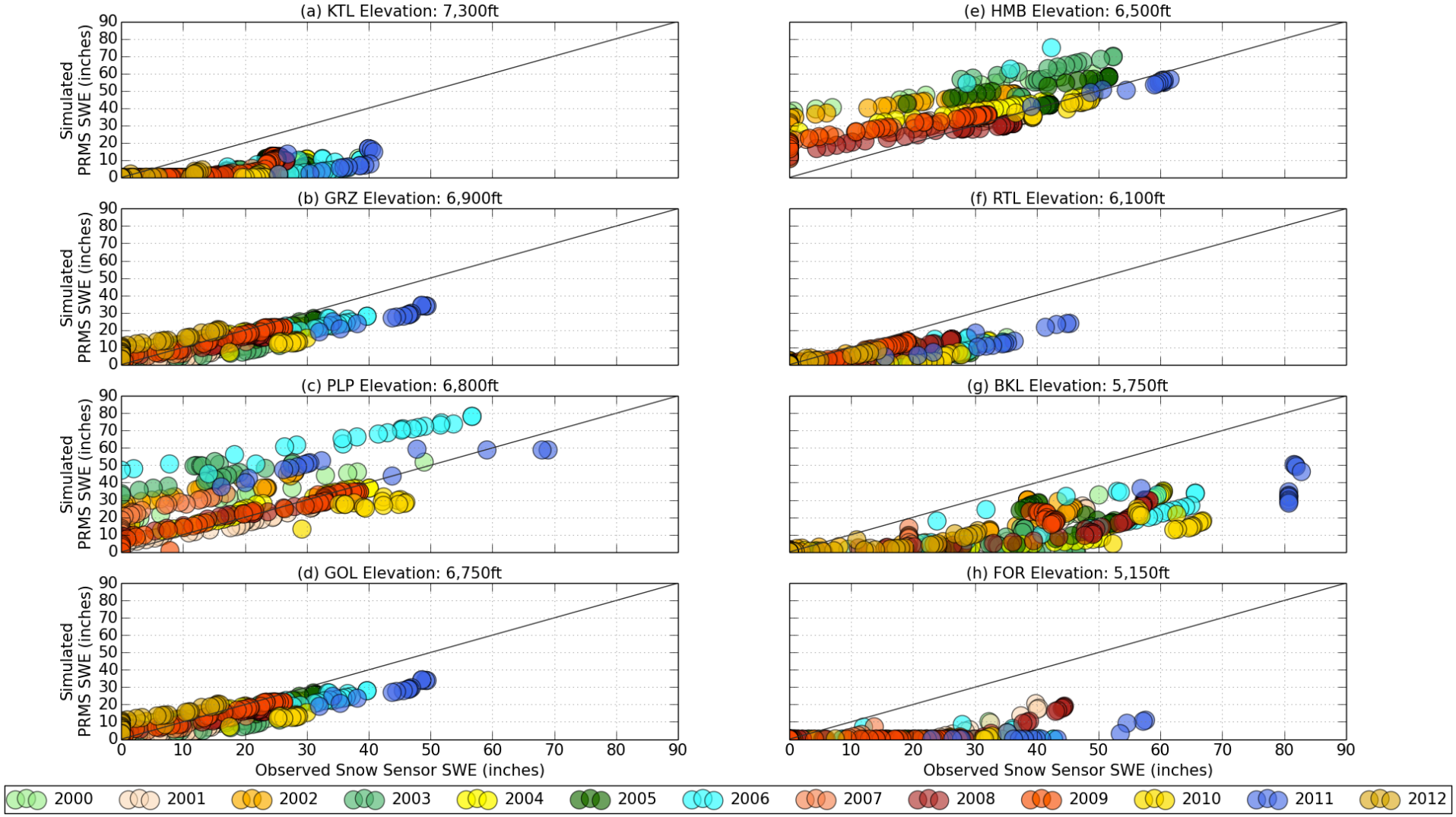
Month (For years: 2000–2012)	JPL RMSE Ranges	PRMS RMSE Ranges
March	2.85 – 30.92	6.51 – 25.02
April	4.05 – 35.88	6.74 – 32.08
May	4.22 – 25.05	6.74 – 24.50

Results:
4. Simulated vs. Observed (WY)

JPL Simulated vs. CDEC Snow Sensor: March-May, 2000-2012



PRMS Simulated vs. CDEC Snow Sensor: March-May, 2000-2012



Results:
5. First of the Month SWE (WY)

April 1 Difference between Snow Sensors and Simulated SWE

	SWE Difference (inches)	Elevation (Snow Sensor ID)	Water Year
JPL Smallest April 1 Difference	0.32	7,300 ft (KTL)	2001
JPL Greatest April 1 Difference	47.41	5,800 ft (BKL)	2011
PRMS Smallest April 1 Difference	0.98	6,800 ft (PLP)	2009
PRMS Greatest April 1 Difference	46.89	5,200 ft (FOR)	2011

Summary of Results

JPL Comparison to Snow Sensor

Com

Less

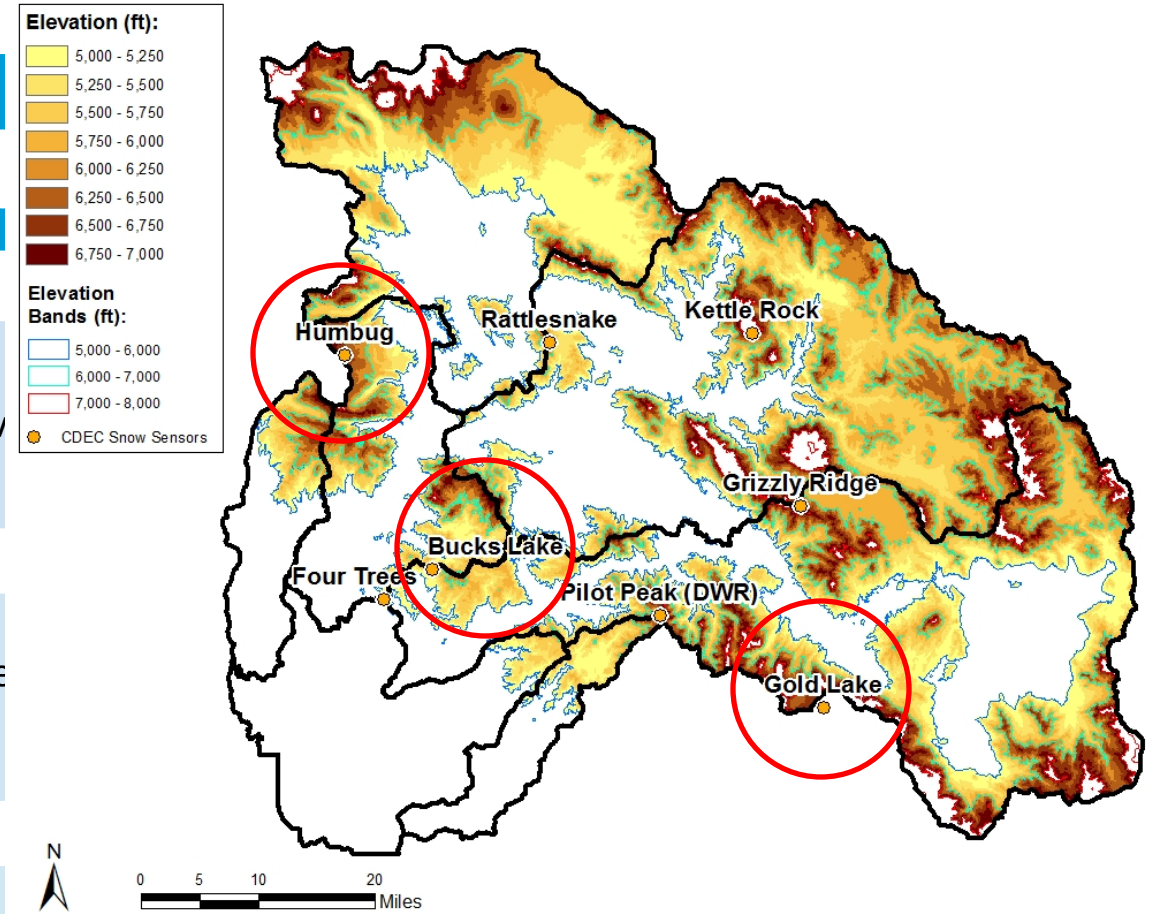
Higher Elev

and HMB

: BKL

Possible Re
capture snow

eather River
hese sensors



Range:

SNOTEL stations are implemented to produce JPL Blended SWE Product

60% Feather River Basin

Majority of landscape covered in trees

PRMS Comparison to Snow Sensor

Compare

npared Less

PRMS HRUs	Associated CDEC Snow Sensor	Associated CDEC Snow Sensor Elevation	Elevation Ranges (ft)	Area (acres)
East Branch 54	KTL	7,300	3,600 - 7,800	5,536
East Branch 52	GRZ	6,100	5,800 - 7,100	3,251
South Fork 14	PLP	6,800	5,100 - 7,000	2,524
Middle Fork 39	GOL	6,700	4,300 - 7,400	4,090
Lower North Fork 32	HMB	6,500	3,800 - 7,100	4,924
East Branch 18	RTL	6,100	4,100 - 6,200	4,761
Middle Fork 7	BKL	5,700	4,000 - 6,200	9,066
Oroville 24	FOR	5,200	2,500 - 5,100	5,152

Mid-Elevation Sensor: GOL

Possible Reason: HRU's area or elevation range

Possible Reason: HRU's area or elevation range

HRU Area → lower area range (GRZ: 3,251 acres and GOL: 4,090 acres)

HRU Elevation Range → varying elevation differences (GRZ: 1,300 ft and GOL: 3,100 ft)

HRU Area → higher area ranges (BLK: 9,066 acres and FOR: 5,152 acres)

HRU Elevation Range → lower elevation differences (BLK: 2,200 ft and FOR: 2,600 ft)

Concluding Remarks: JPL SWE Estimates

Research Goals/Questions

1. Can we effectively use JPL SWE products into PRMS models?
2. How well does JPL SWE products compare to currently used SWE estimation measures used in forecasting FNF?
3. Develop comparison method between JPL/PRMS SWE estimates to DWR regression equation

Research Conclusions

~ JPL SWE est. did well

→ higher elevations

~ JPL SWE est. less comparable

→ mid/lower elevations

~ Potential for JPL to be included into PRMS for higher elevation→ JPL gridded, PRMS distributed model

Possible Future Directions

→ Make product more operational (wasn't able to test operational set)

→ Historical images could potentially be used for a resource in calibration of snow module

→ Determine if elevation band estimates would be beneficial in entering in place of snow sensor readings for snow index in DWR Snow Surveys regression equations

Concluding Remarks: PRMS SWE Estimates

Research Goals/Questions

1. Can we effectively use JPL SWE products into PRMS models?
2. How well does JPL SWE products compare to currently used SWE estimation measures used in forecasting FNF?
3. Develop comparison method between JPL/PRMS SWE estimates to DWR regression equation

Research Conclusions

~ PRMS SWE compare well:

→ mid-elevations

~ More comparable → HRUs with smaller areas (elevation range varied)

~PRMS SWE compare less well:

→lower-elevations

~ Less comparable → HRUs with larger areas (elevation range smaller)

~ PRMS peak SWE date typically earlier (if wasn't the same as snow sensors)

Future Directions

~HRU area could have more effect on computation of SWE; therefore making significantly large HRUs smaller could help

~ Earlier peak SWE date may be due to depletion curve, improving this curve for the basin/subbasin could improve the peak SWE amount/timing.

~ Possible application for JPL SWE Product into PRMS for higher elevations to help improve results, but what about the lower elevations?

Questions ?

Angelique M. Fabbiani Leon
California Department of Water Resources

Office: (916) 574-2369
Angelique.Fabbiani-Leon@water.ca.gov

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JPL SWE Products

What is the JPL SWE product?

Spatial distributed estimates of daily melt-season SWE over Sierra Nevada for March to August from 2000-2012 by the following methods:

① **Reconstructed**

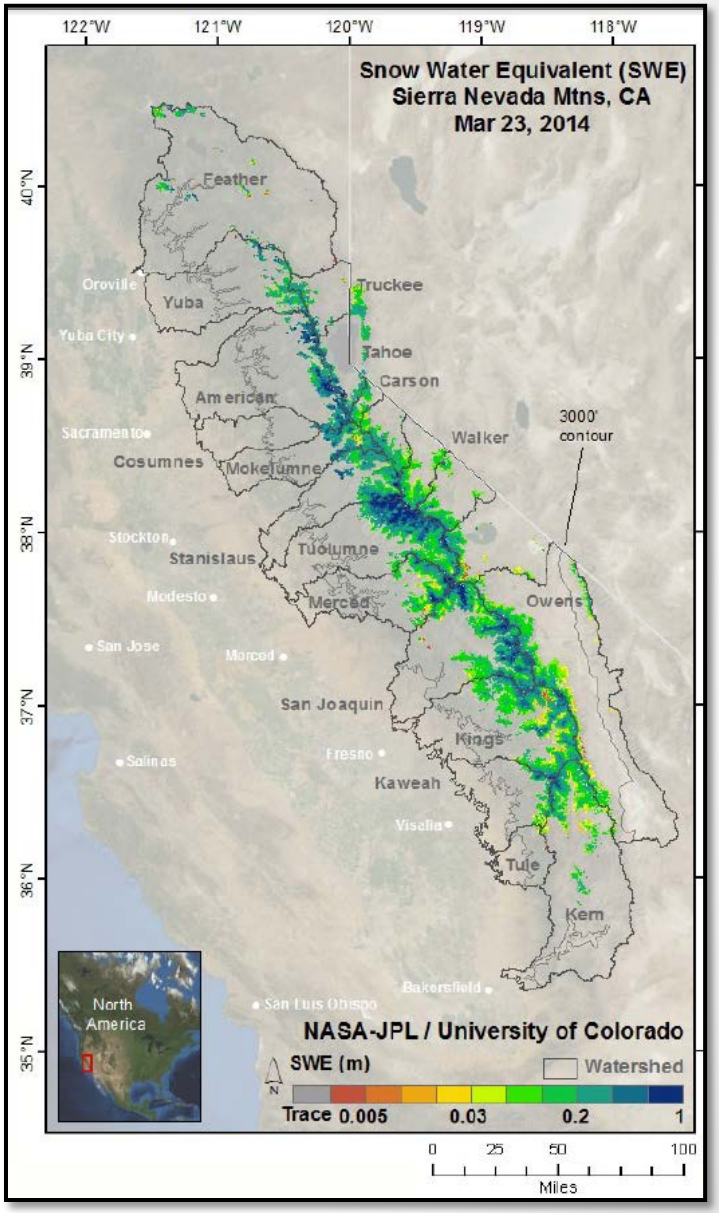
② **Blended**

Reconstructed Method:

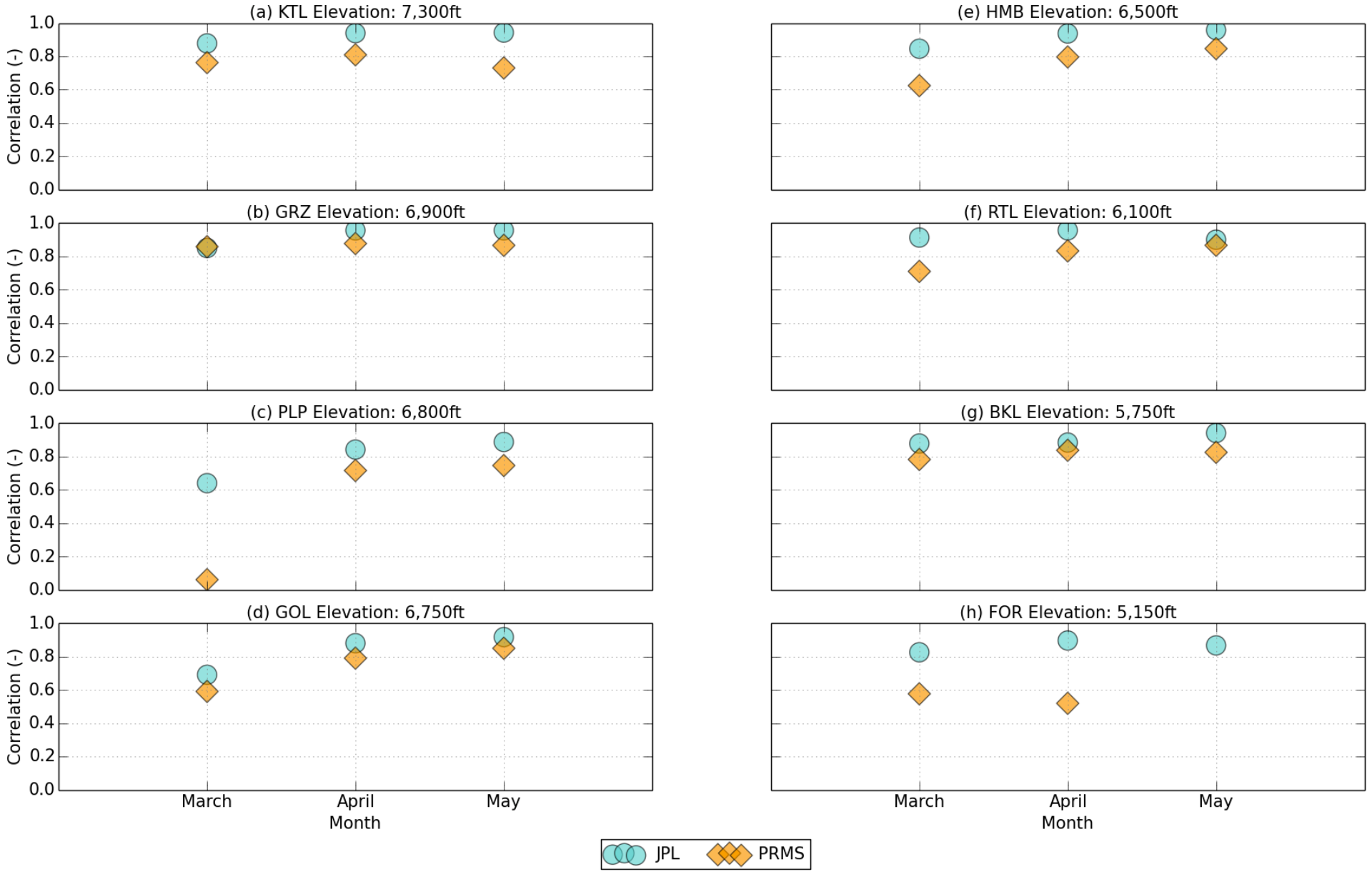
- Combines snow cover area images from satellite images (i.e. MODSCAG) with a spatially distributed snowmelt model

Blended Method:

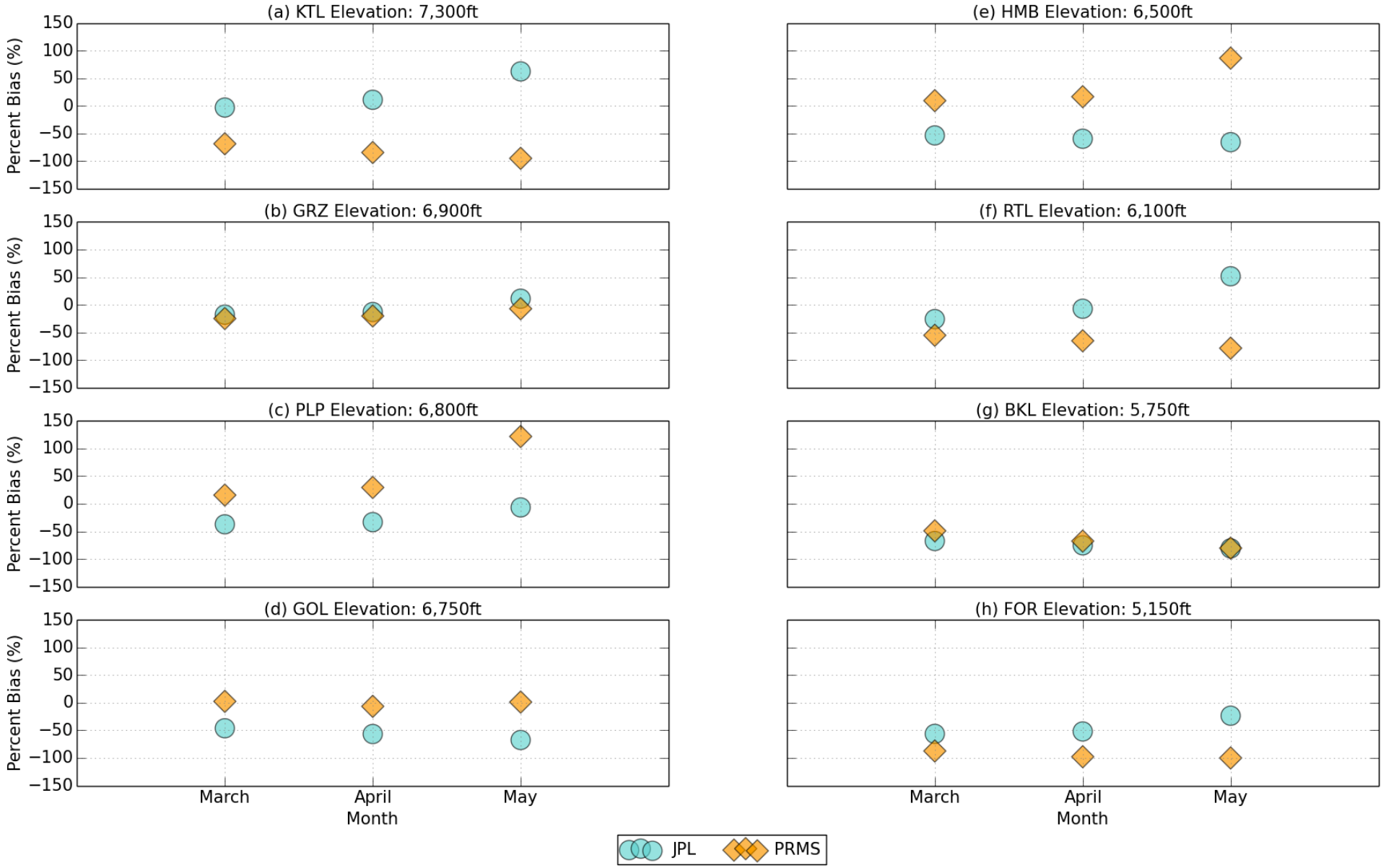
- Reconstructed product combined with snow sensor readings



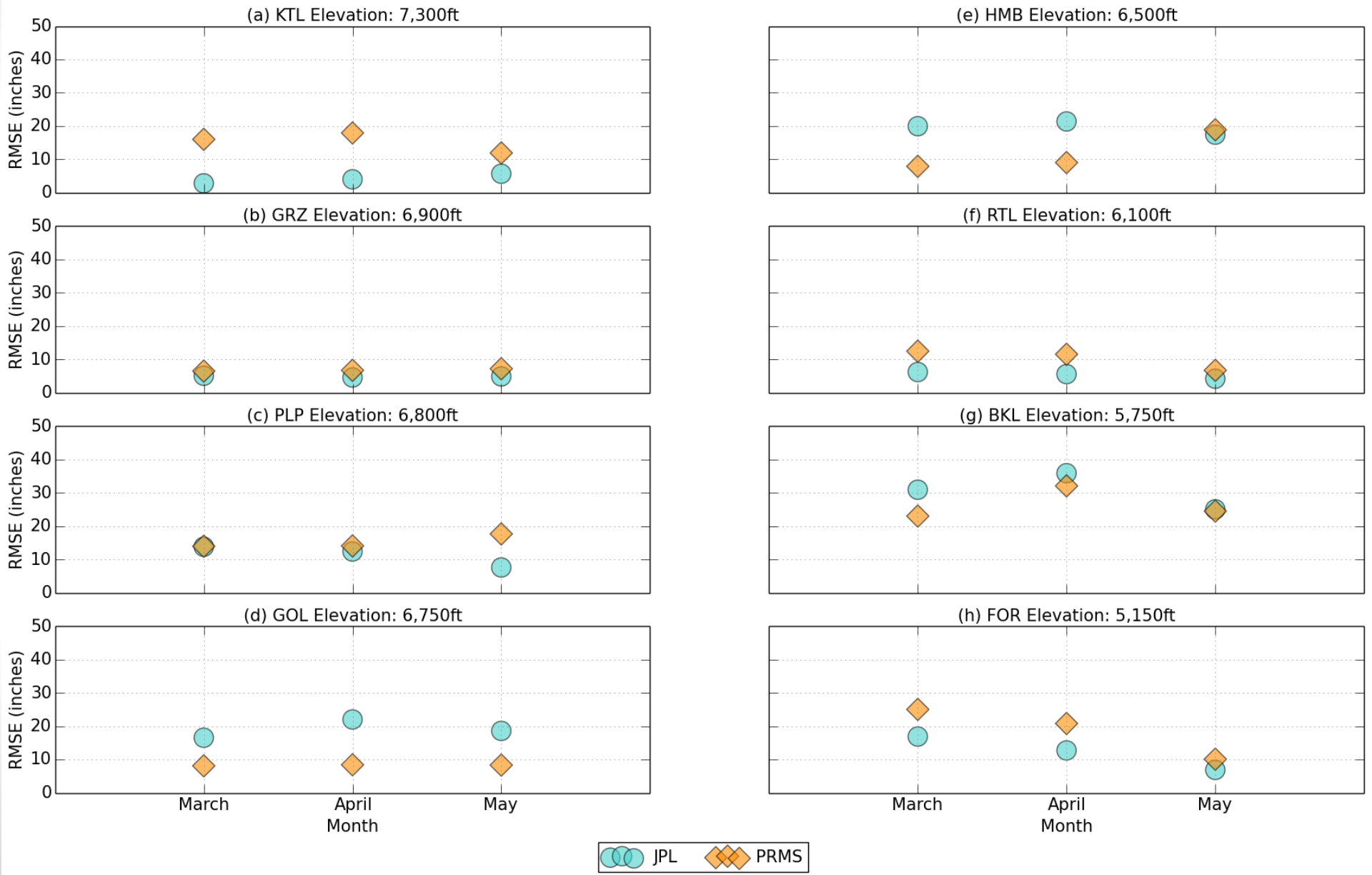
Correlation: Months March-May



Percent Bias: Months March-May



RMSE: Months March-May

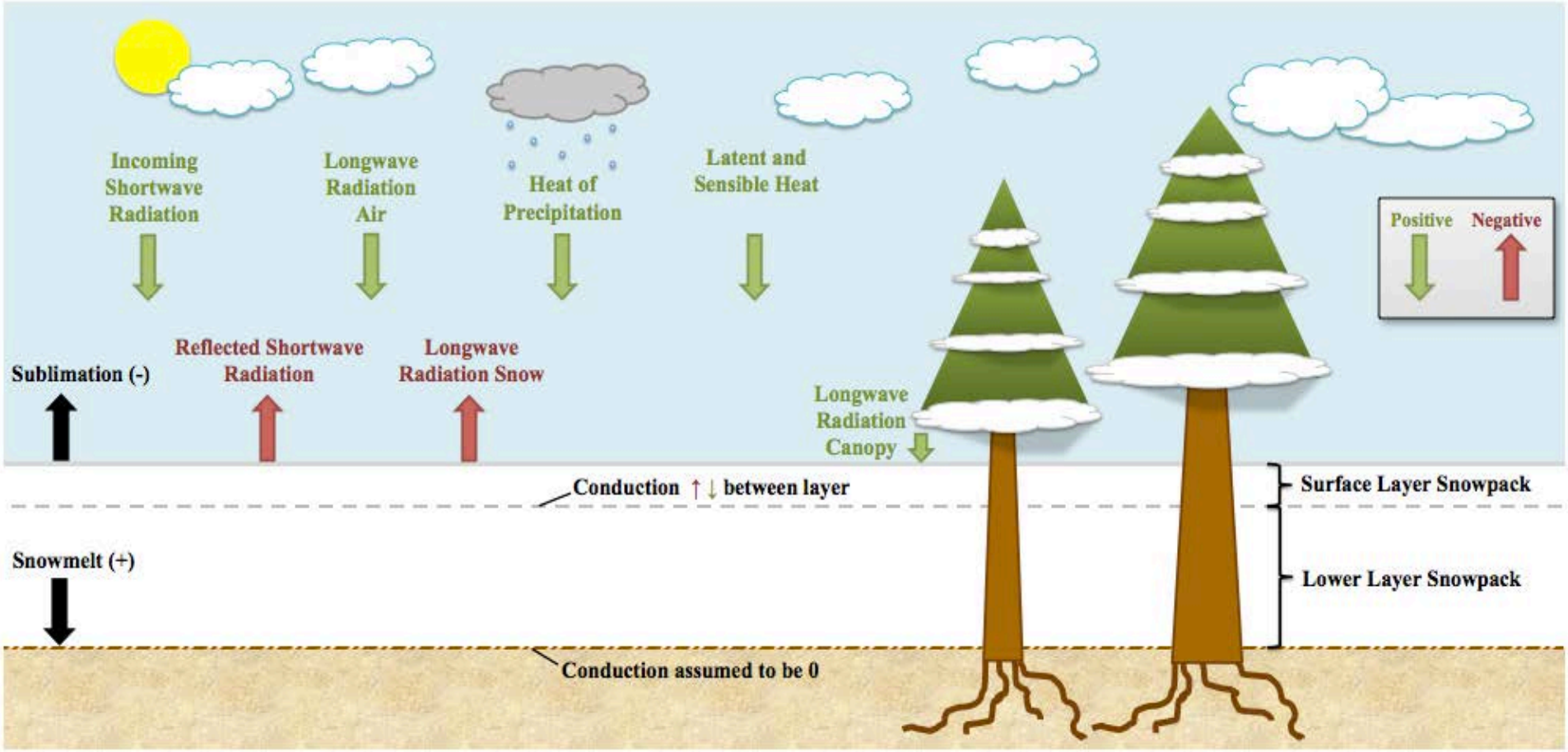


PRMS Snow Module

- Snow module of PRMS simulates on each HRU:
  - Initiation
  - Accumulation
  - Depletion

- The snow module computes mass and energy balances by estimating:
  1. **Mass/energy change** from precipitation (with also calculating the melt potential)
  2. **Change** in SCA and albedo
  3. **Potential** for other snowmelt based on additional energy balance terms (convective, radiant, and conductive fluxes)
  4. **Evaporative** result

PRMS Snowpack Module



Correlation

- Measurement of the relationship between two variables.
- Ideally → 1

$$Correlation = \frac{\sum_{i=1}^{T}(Sim_i - SimAve_i)(Obs_i - ObsAve_i)}{\sqrt{\sum_{i=1}^{T}(Sim_i - SimAve_i)^2 \sum_{i=1}^{T}(Obs_i - ObsAve_i)^2}}$$

T=Total entries

Percent Bias

- Measures the average tendency of the simulated values to be larger or smaller than observed values.

- Ideally→ 0, with low-magnitude values indicating accurate simulations.
  - Positive values → simulated overestimate bias
  - Negative values → simulated underestimate bias

$$Percent\ Bias\ (\%) = \left[\frac{\sum_{i=1}^{T}(Sim_i - Obs_i)}{\sum_{i=1}^{T} Obs_i}\right] * 100\%$$

T=Total entries

RMSE

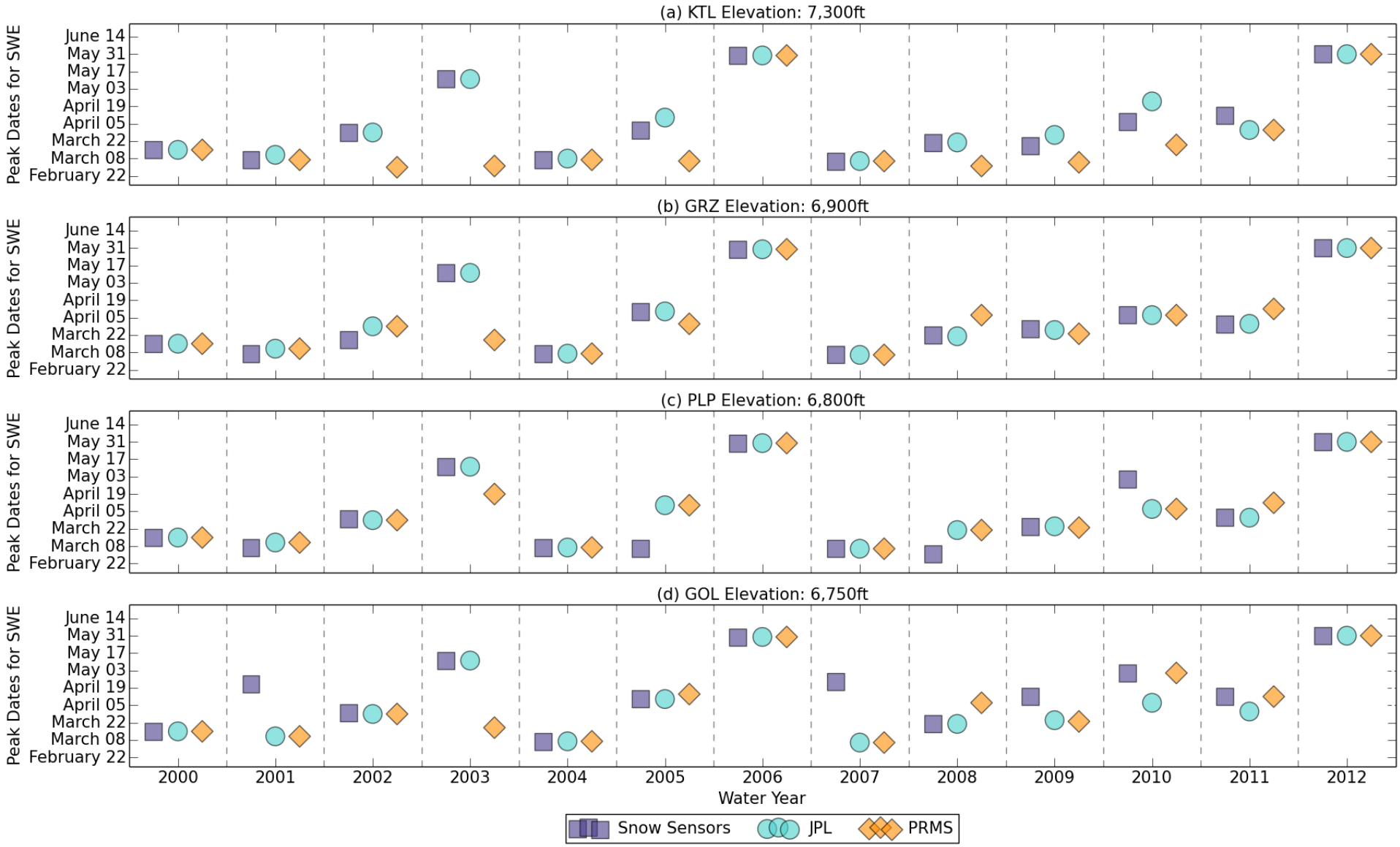
- Measures the differences between simulated values and the observed
- Ideally → 0

$$\mathrm{RMSE} = \sqrt{\frac{1}{T}\sum_{i=1}^{T}(Sim_i - Obs_i)^2}$$

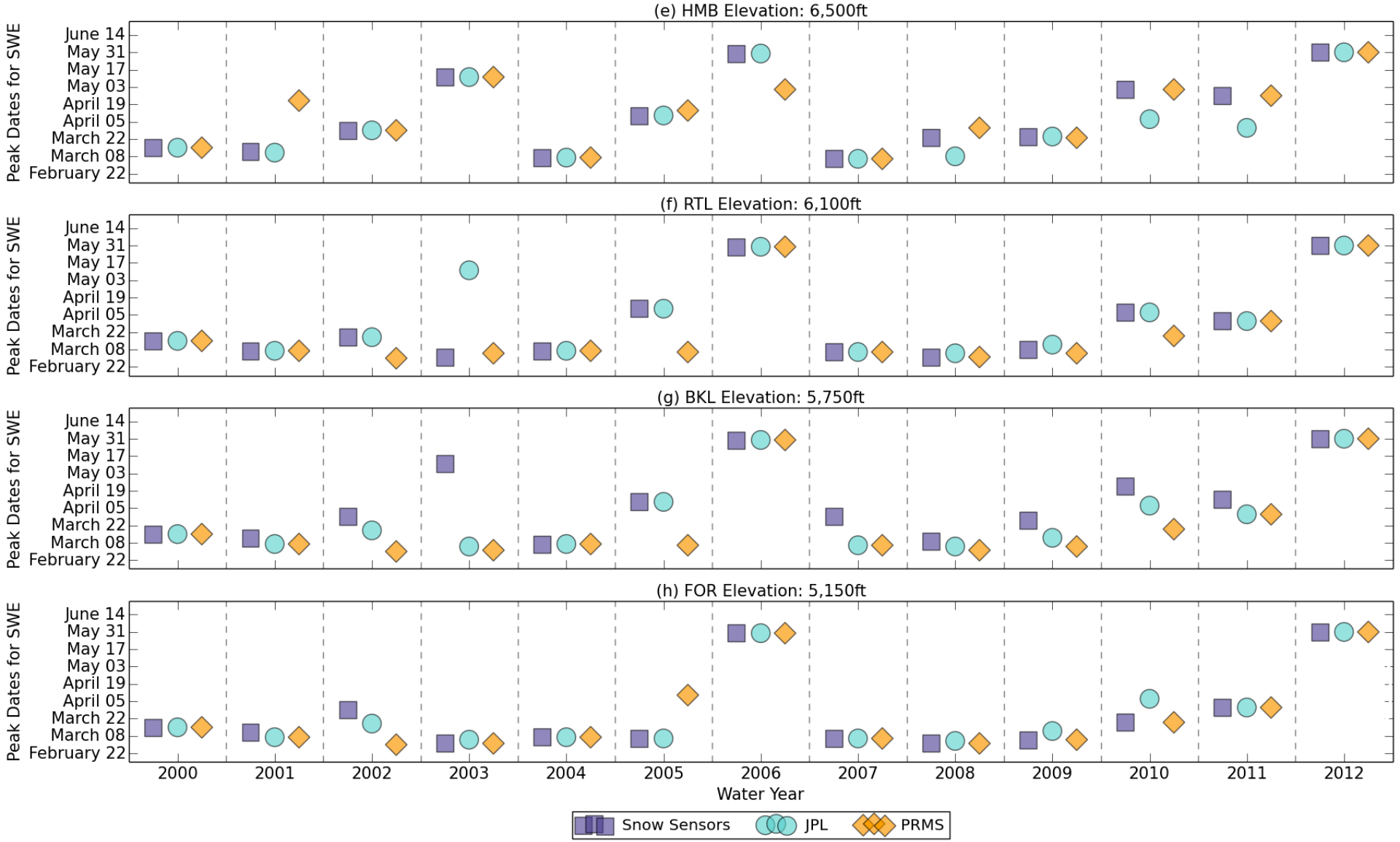
T=Total entries

Results:
7. Peak SWE Date (WY)

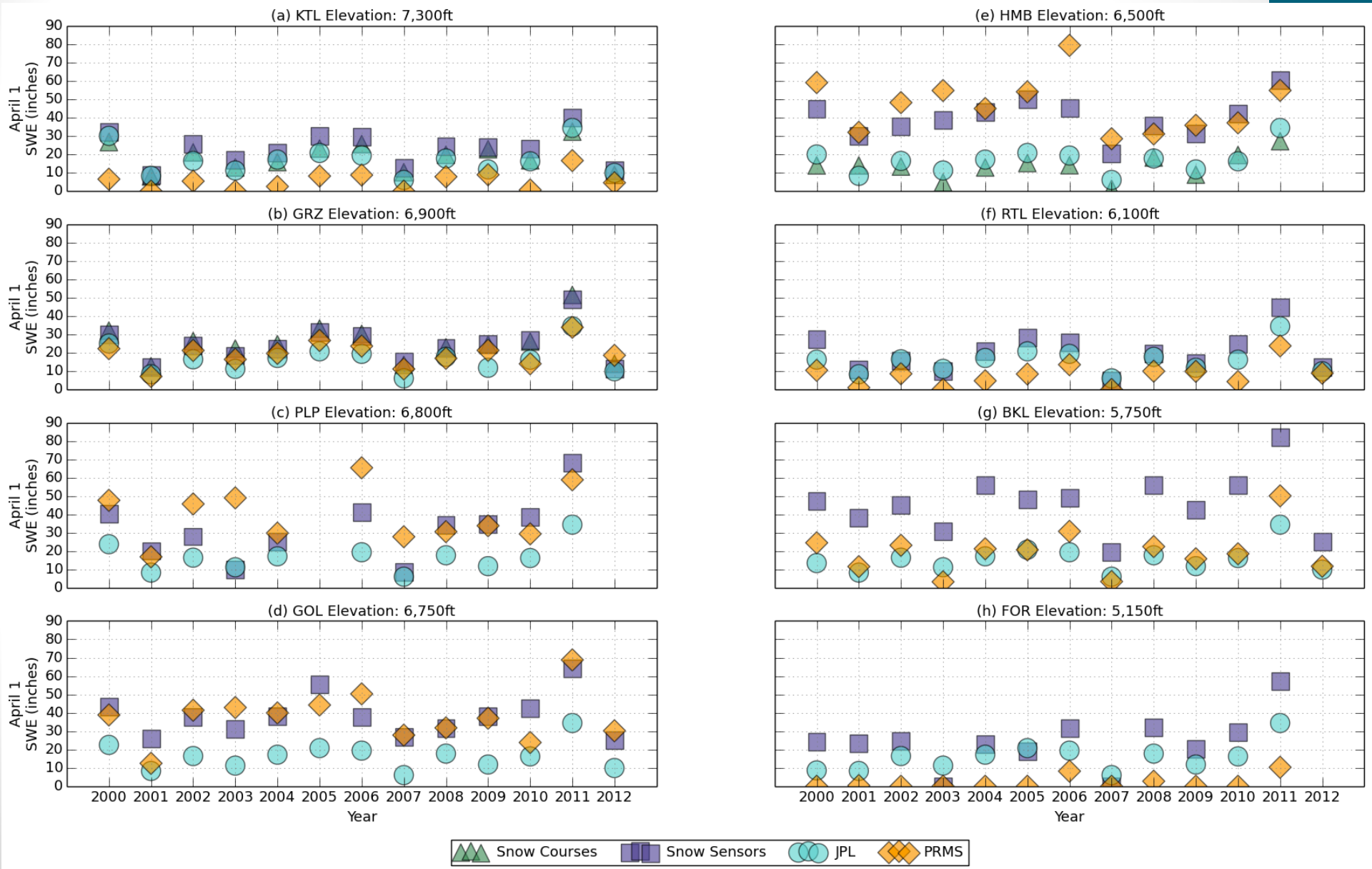
Peak SWE Date: Higher Elevations



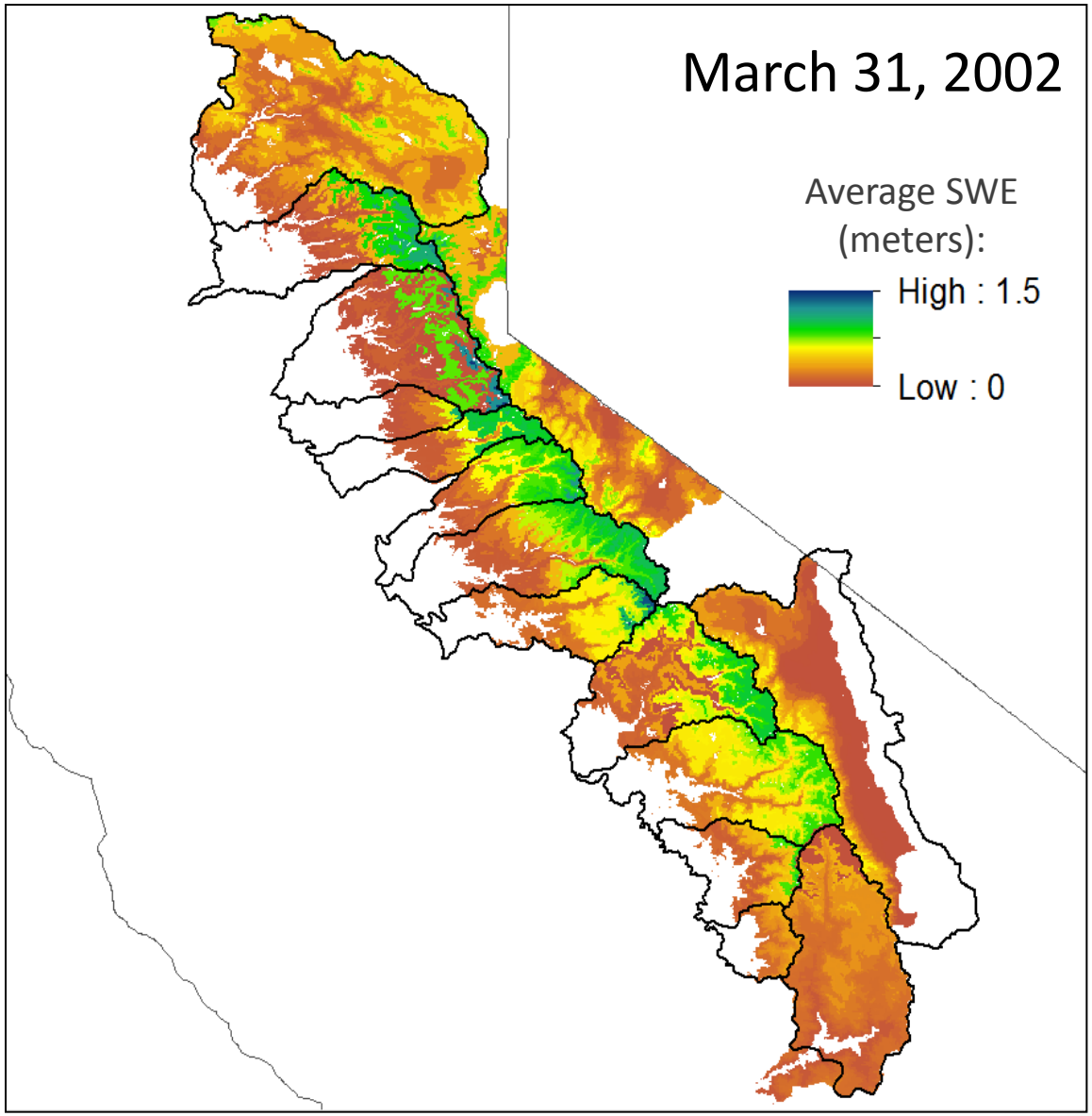
Peak SWE Date: Lower Elevations



Basin Average SWE: April 1

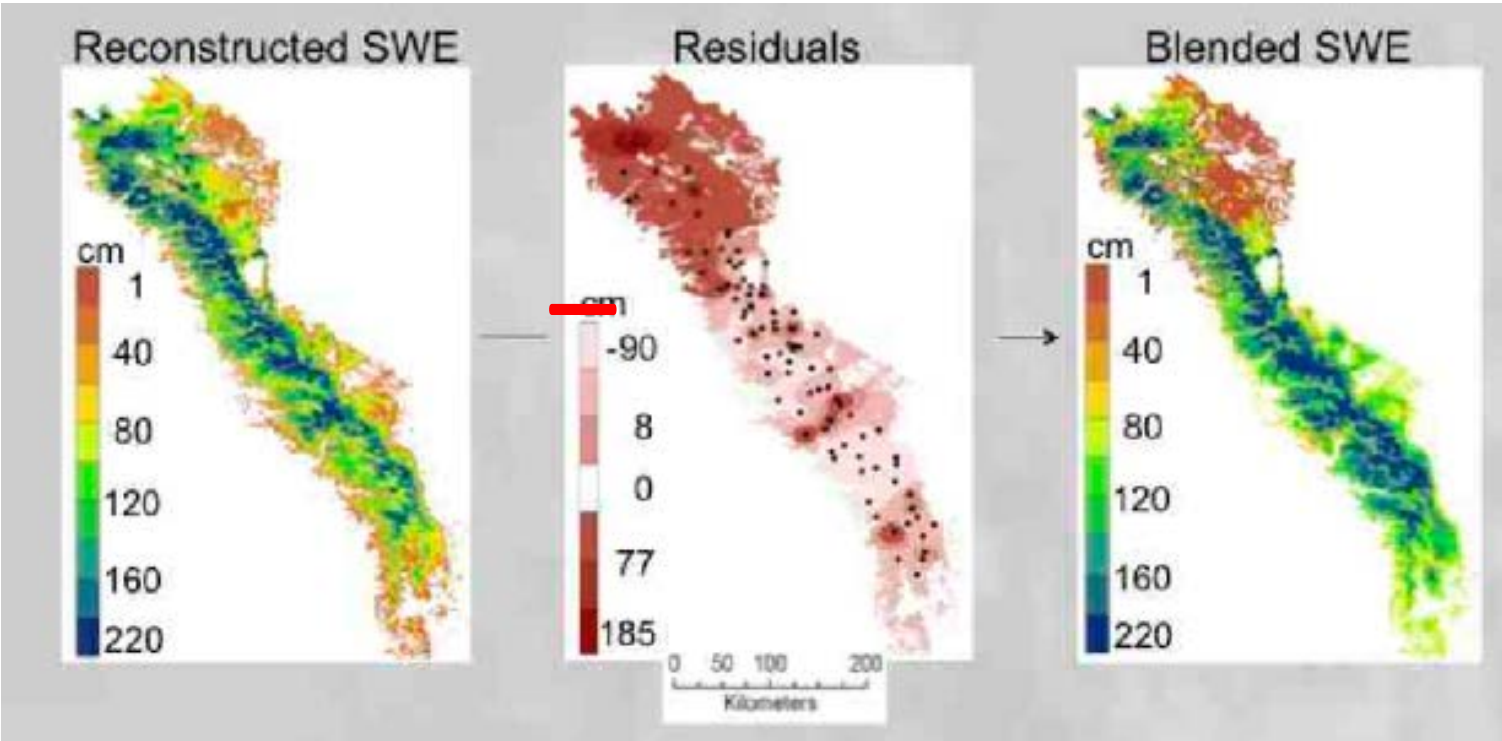
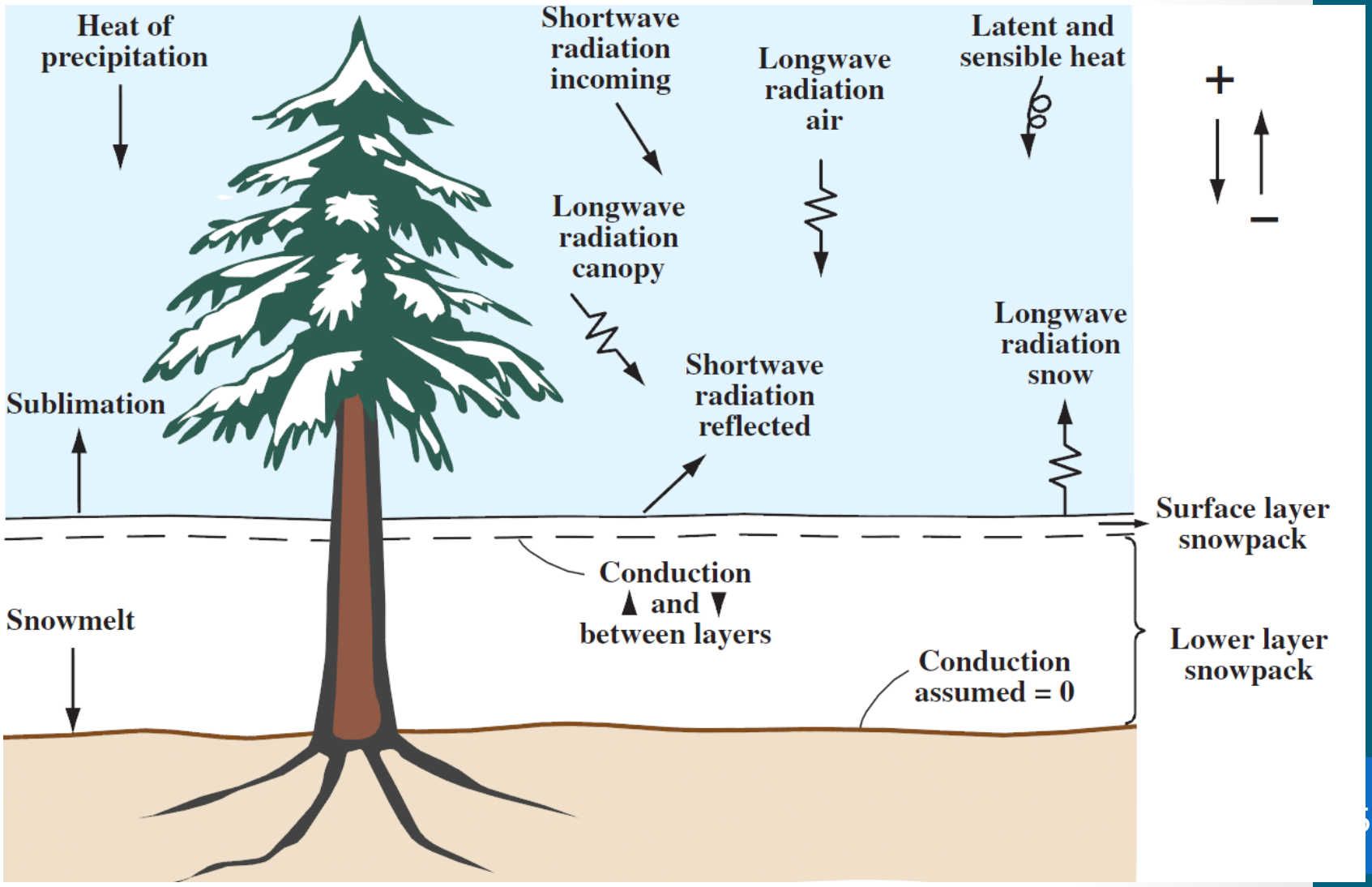


Elevation Band Average SWE



JPL Blended SWE Product

1. Difference between Reconstructed SWE and snow sensor SWE readings (at each snow sensor location) determined
2. Difference distributed to all pixels → using inverse of squared distance as distribution weights → **Distributed Residuals**
3. For each pixel: Reconstructed SWE – Distributed Residual = **Blended SWE**



PRMS Snowpack Module