What can we learn from time-varying sensitivity analysis?

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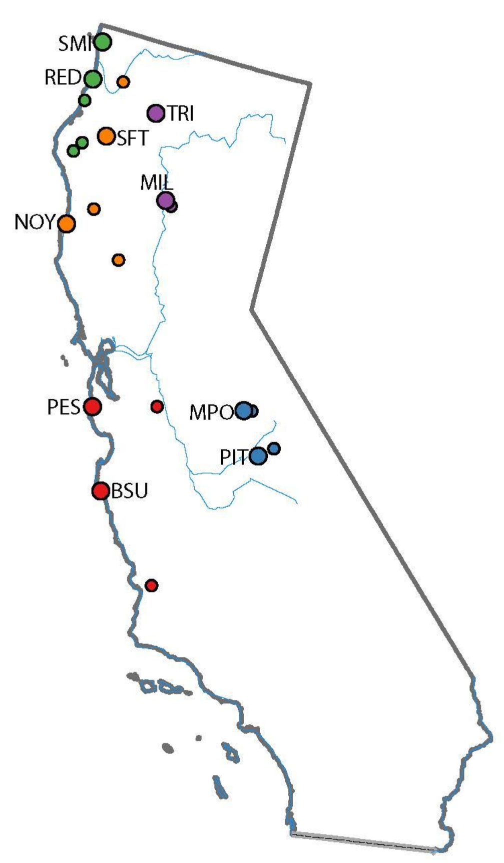
Research Objectives

Changing climate affects watershed hydrologic cycles, therefore it is becoming increasingly important to analyze outcomes of this variability on long-term watershed behavior. In particular, we aim to analyze how strong seasonal and annual shifts from wet to dry may be attributed to shifting importance of different model parameters and therefore key watershed processes.

Our objectives were to:

- Determine if parameter sensitivities across regionally distributed watersheds varies spatially and temporally
- Analyze if sensitivity analysis results from annual and sub-annual scales vary

Study Area - California

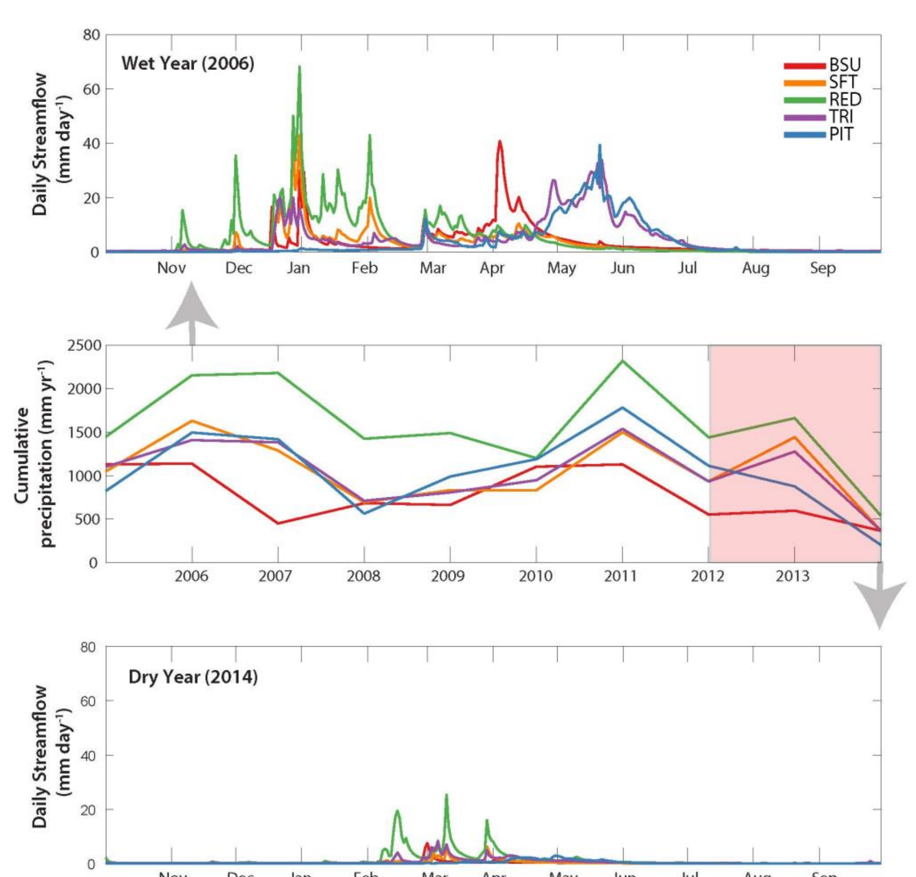


We focused on California in particular because of its climate and tendency for extreme weather events, which allows us to better analyze the effects of changing climate on shifts in watershed controls. Time-varying sensitivity analysis can assist in identifying dominant processes in a system and can provide important insight on system responses when observing concurrent changes in parameter sensitivities alongside real-world dominant process variations (Wagener et al., 2001, 2003; Herman et al., 2013).

Our analysis includes sites in three different regions across the state: watersheds located in the Sierra Nevada Mountains (snowmelt driven), watersheds located in northern California (high rainfall), and watersheds located in the Central Valley (low rainfall).

We included watersheds spanning an elevation and hydroclimatologic gradient to explore how model-derived controls may vary with elevation as well as climate variables like temperature and precipitation.

We simulated streamflow spanning extreme annual variations in precipitation, from 200 to almost 3000 mm per year.

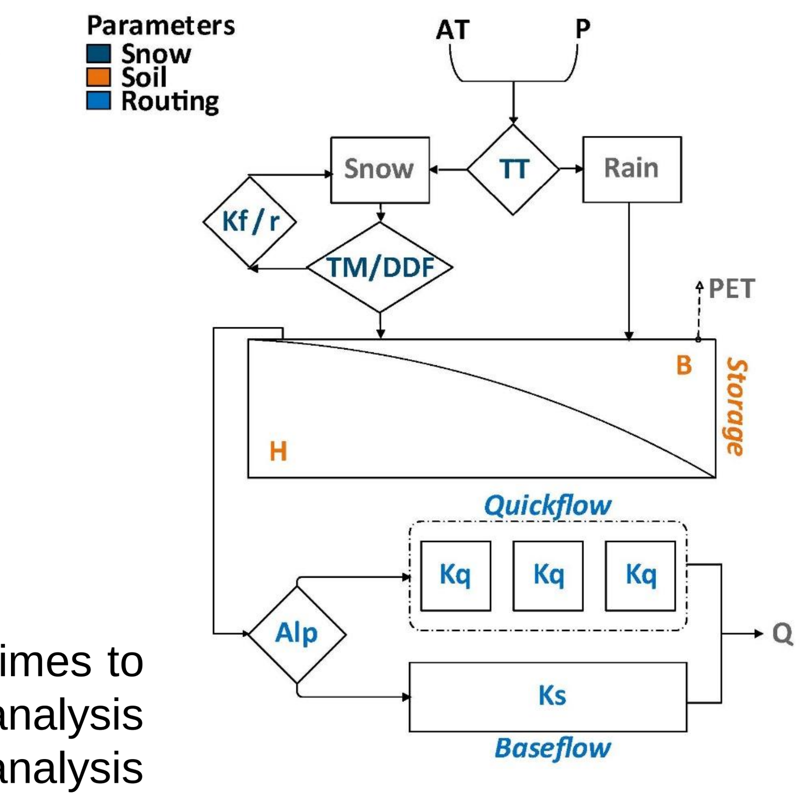


References: [1] Herman, J. D., Reed, P. M., Wagener, T. (2013). Time-varying sensitivity analysis clarifies the effects of watershed model formulation on model behavior. Water Resources Research, 49: 1400-1414; [2] Wagener, T., Boyle, D. P., Lees, M. J. (2001). A framework for development and application of hydrological models. Hydrology and Earth System Sciences, 5(1): 13-26; [3] Wagener, T., McIntyre, N., Lees, M. J. (2003). Towards reduced uncertainty in conceptual rainfall-runoff modelling: Dynamic identifiability analysis. Hydrological Processes, 17

Simulating hydrology

We used a simple version of Hymod, a conceptual rainfall runoff model, to simulate streamflow and perform sensitivity analysis across our sites.

Parameter	Function	
Kq	Quick flow reservoir rate constant	Routing
Ks	Slow flow reservoir rate constant	Routing
Alp	Division between quick/slow routing	Routing
H	Maximum soil moisture storage	Soil
B	Distribution of soil storage function shape	Soil
DDF	Degree day factor (snow melt rate)	Snow
TT	Base temperature below which snow forms	Snow
Kf	Degree day factor (refreezing)	Snow
TM	Base temperature above which melt forms	Snow
r	Retention coefficient	Snow

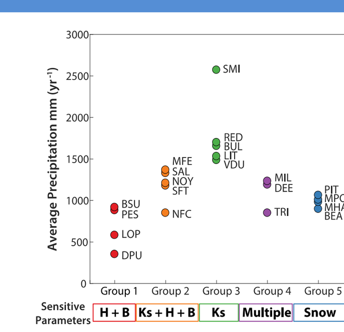


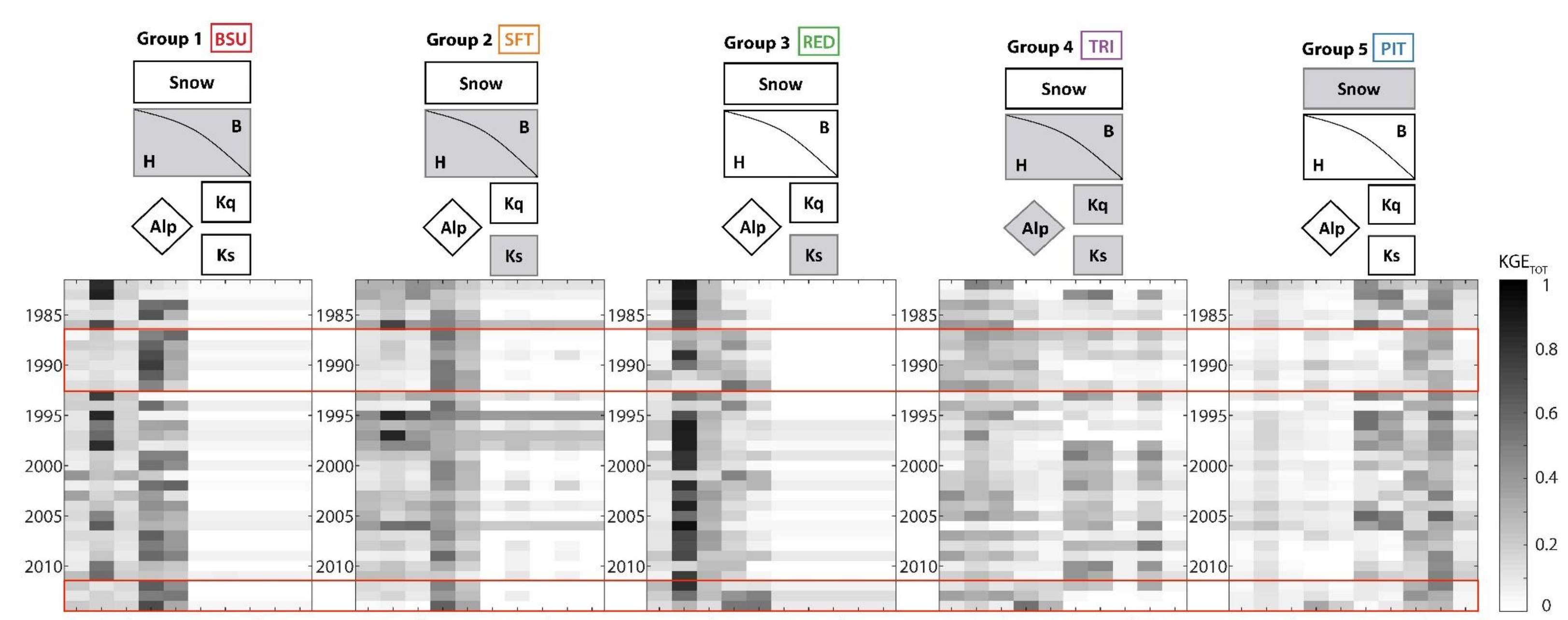
Model parameters were sampled 60,000 times to execute variance-based sensitivity analysis (global Sobol' method). Our sensitivity analysis used three different time periods for aggregation: annual, monthly, and weekly. Annual values were assessed for each water year using Kling-Gupta Efficiency (KGE). Monthly and weekly values were assessed using the root mean squared error (RMSE) implemented in a moving window.

Time Scale	Error Metric
Annual	KGE
Monthly	RMSE
Weekly	RMSE

30+ year annual results reveal …

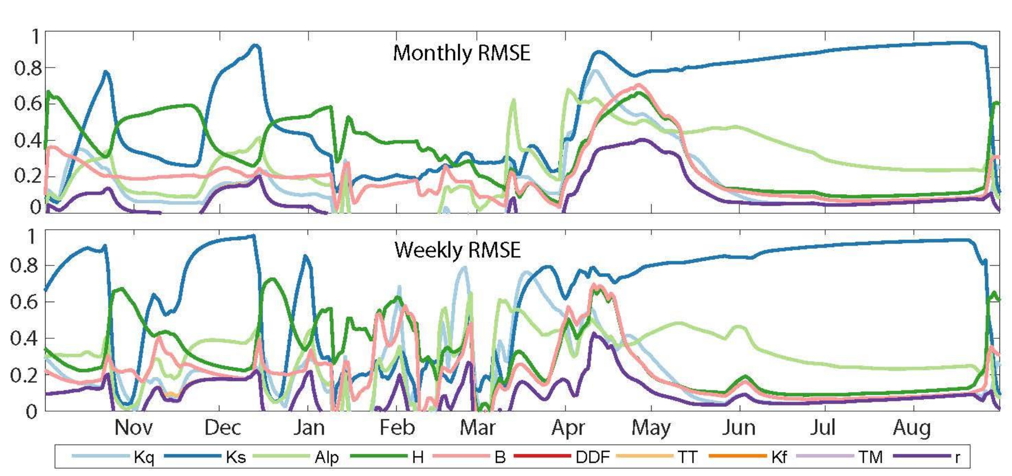
Total order sensitivity indices indicated that dominant watershed controls changed noticeably across much smaller spatial scales than previously thought. Watersheds located within a few 100 km are characterized by five unique patterns of parameter sensitivity (KGE metric).



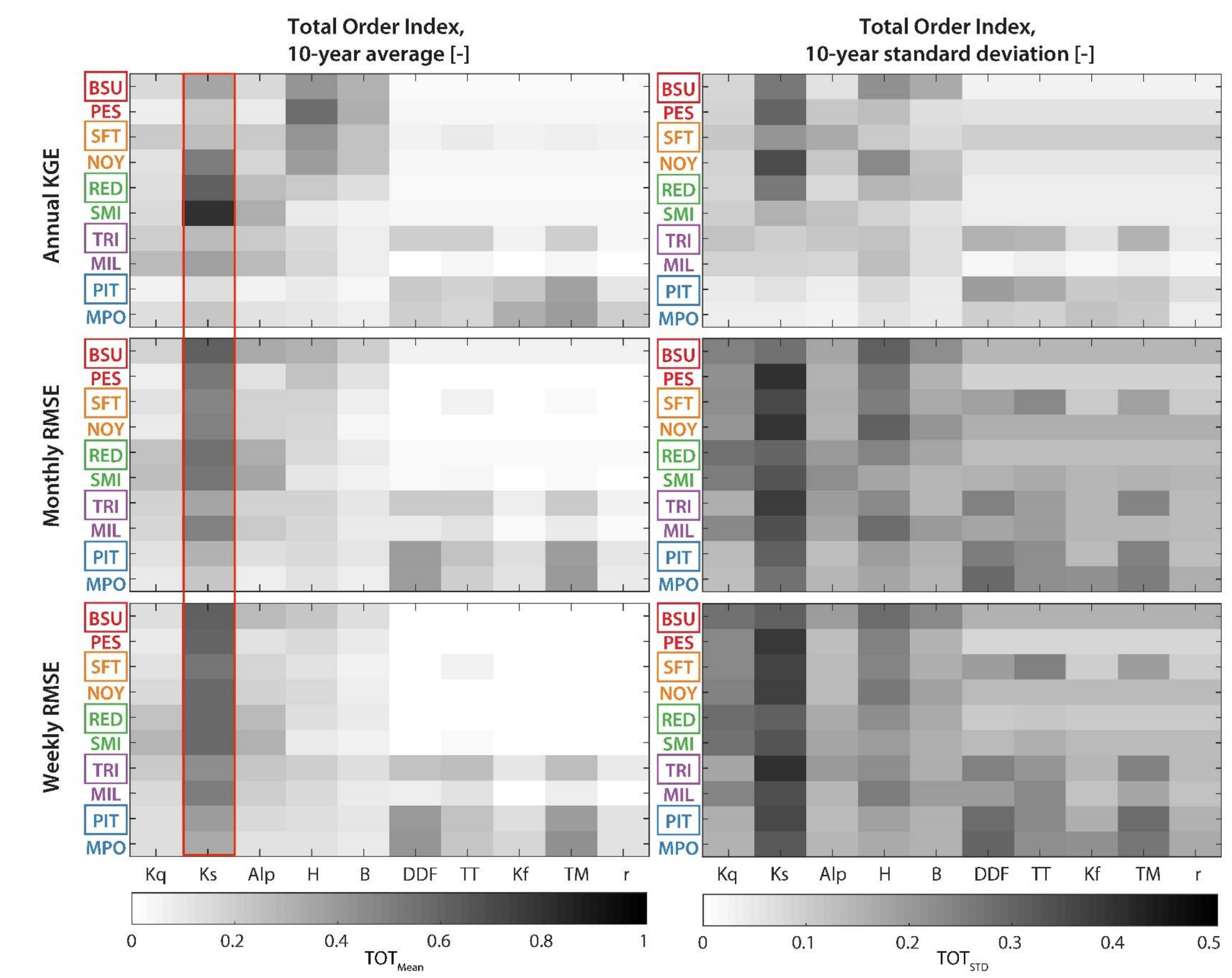


Monthly and weekly indices capture greater variability in dominant parameters

Unsurprisingly, monthly and weekly total index values were more variable in time as compared to annual metrics. Although the timing and magnitude of sensitivity indices differed across sites, many parameters were time-varying despite not being non-dominant (soil and snow parameters). Monthly and weekly time-scales conveyed a similar story.

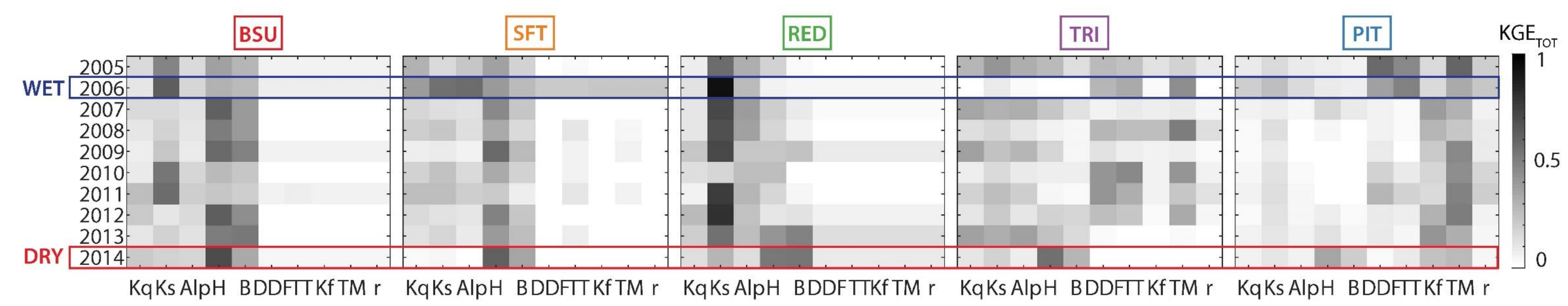


What is missed at annual time scales?

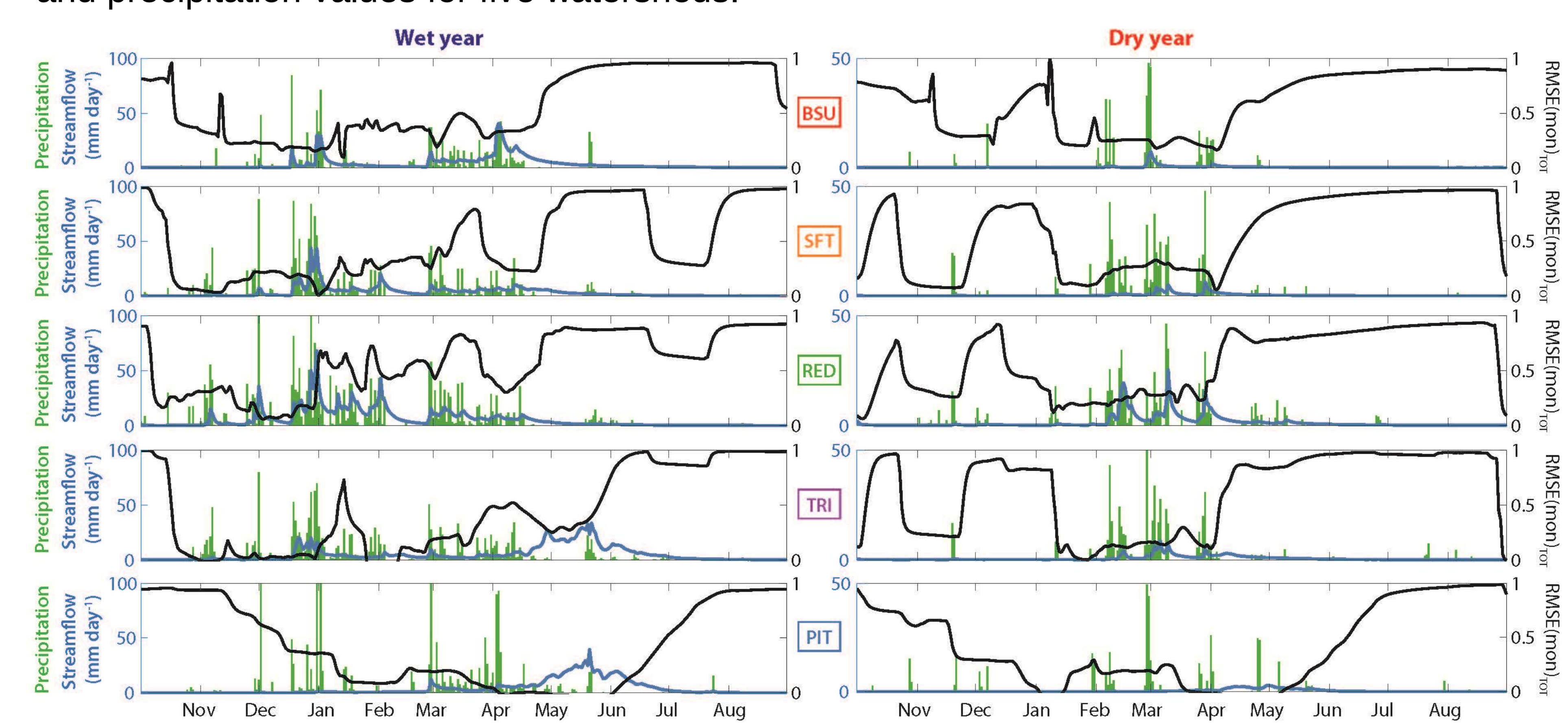


Average total order sensitivity indices indicate that the annual time scale conveys a different story about which parameters are sensitive across watersheds as compared to monthly and weekly sensitivity results. This shows that annual indices might not capture important hydrologic processes that occur at sub-annual scale.

To demonstrate what information can be missed by annualized sensitivity indices, we selected a wet and dry year in order to compare monthly sensitivity results for five watersheds as a way to analyze how parameter dominance changes under different weather conditions.



Sensitivity indices at sub-annual scales allow us to analyze seasonal changes in hydrologic processes, which are more informative in a highly seasonal system like California. As average total order sensitivities were most sensitive for one parameter (Ks), we analyzed monthly (moving window) RMSE sensitivity indices for Ks (below), contextualized by daily streamflow and precipitation values for five watersheds.



Our results show that parameter dominance for Ks is highly variable through time. In addition, total order sensitivity indices show that parameter sensitivity differs greatly between a dry and wet year, with exceeding dominance during extended dry periods which likely results in high parameter sensitivity values at an annual time-scale.