California Energy Security Project
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The University of Washington contribution to this project is the development and application of models that simulate both the hydrology and operations of the Columbia River hydropower system, and the Sacramento-San Joaquin (combined State Water Project and federal Central Valley Project). These models are driven by gridded daily historical climate data, now complete from 1916 to 2002. We intend to use these sequences of historical climate data to drive the hydrology and operations models, which will allow us to answer the following question: *If the current system of hydropower reservoirs, and thermal energy plants in both the Pacific Northwest and California had existed throughout the period 1916 to 2002, how frequently would winter and summer power production and demand have been out of phase?, and how predictable would those episodes have been, given current climate prediction methods?*

In previous progress reports we describe the creation of climatological driving data bases from for the period 1916-2002 for the Pacific Northwest (PNW) and California (CA), and the use of the Variable Infiltration Capacity (VIC) hydrologic model to produce hydrologic simulations over the PNW and CA. The streamflow simulations from the hydrologic model were then bias corrected and used as input to water management models simulating monthly hydropower production from the Columbia River basin and Sacramento San Joaquin basins.

During the most recent reporting period, a data base of hourly energy use was obtained by SIO form the California Energy Commission and was provided to us. This data set was constructed from the FERC 714 archives for the period 1993-2000, and covers both the PNW and CA. We used this data set to construct aggregate demand models for the two regions at both monthly and daily timescales based on linear relationships between monthly heating and cooling degree days (monthly model) and daily maximum temperature and day of week (daily peak model) and energy load as reported in the CEC data set. These demand models were then used to produce a long time series from 1915-2002 of energy demand in the two regions. Each of these time series was analyzed in terms of the covariation with the other time series, and in terms of predictability using PDO and ENSO indices. The sections below describe the results of the covariability analysis.

1) Covariability of regulated streamflow with climate signals and temperature degree days

We define warming degree days as the daily accumulation of degrees below 18.3^{o}C and conversely for cooling degree days. Temperature degree days and climate oscillations such as El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) are significantly correlated. During a warm ENSO and/or PDO event, the Pacific Northwest (PNW) tends to be warmer (less warming degree days) and drier and conversely during the cold event (Hamlet and Lettenmaier 1999). Northern California climate tends to be somewhat similar to the PNW while Southern California (south of the Delta), climate tends to be opposite. Overall, California tends to have a cooler summer (less cooling degree days) during a warm ENSO and/or PDO event and conversely for a cold event. Naturalized streamflow shows good correlation with climate oscillation in the PNW (Hamlet and Lettenmaier 1999). The streamflow response in California is less responsive on average because northern and southern California tend to be out of phase. The shift in sign tends to occur around the Sacramento – San Joaquin Delta and therefore California has a lower correlation with ENSO than the PNW as the transition zone can shift from one event to the other. During a warm ENSO, Southern California tends to have higher flow while North California tends to have lower flow and vice versa during cold ENSO.

Regulated streamflow (as produced by our reservoir simulation models) shows a significant negative correlation between January-April monthly discharge and monthly warming degree days (R^2 = 56%) at the Dalles, OR. There is a positive correlation for May through July, although it is not as strong as the winter signal. Sacramento-San Joaquin River discharge at the San Francisco Bay delta is significantly (R^2 = 25%) correlated to August and September cooling degree days, which is mostly due, we think, to irrigation water demand. Streamflow in the early spring tends to be held back for later irrigation.

2) Hydropower generation as simulated by reservoir models.

Hydropower generation as simulated by reservoir models is not clearly related to temperature degree days. Indeed, the reservoir models have no information about temperature degree days and operations simulations try to follow targets which are mostly independent of temperature degree days.

Alternatively, hydropower generation depends partly on the total discharge (if not the timing). The hydropower generation in the PNW in June and July is correlated to climate signals from the previous winter – especially precipitation. The hydropower generation is on average correlated to climate signals, especially positively correlated during winter of a cold PDO or cold ENSO/PDO year. The climate signals responses in California are not clear as South and North California are negatively correlated for similar climate signals (reference).

Therefore, with no change in current operations there is an opportunity to predict potential additional energy transfers from the PNW based on information about the following winter's PNW climate that becomes available (e.g., due to the ENSO signature) in the preceding summer and fall. The predictability of California hydropower generation, which is a function of summer climate, is less clear. However hydropower accounts for about 25% of the energy production in California (energy imports included).

3) Energy demand Model

In order to assess the economic benefit of hydropower covariability, we have developed two energy demand models for California and the PNW, a daily peak hour demand model based on 1993-2000 peak hour demand time series and a monthly energy demand based on 1993-2000 monthly energy demand.

A data base of hourly energy use was constructed from the FERC 714 archives from 1993-2000 and aggregate demand models were constructed for the two regions at both monthly and daily timescales based on linear relationships between monthly heating and cooling degree days (monthly model) and daily maximum temperature and day of week (daily peak model) and energy load. These demand models were then used to produce a long time series from 1915-2002 of energy demand in the two regions.

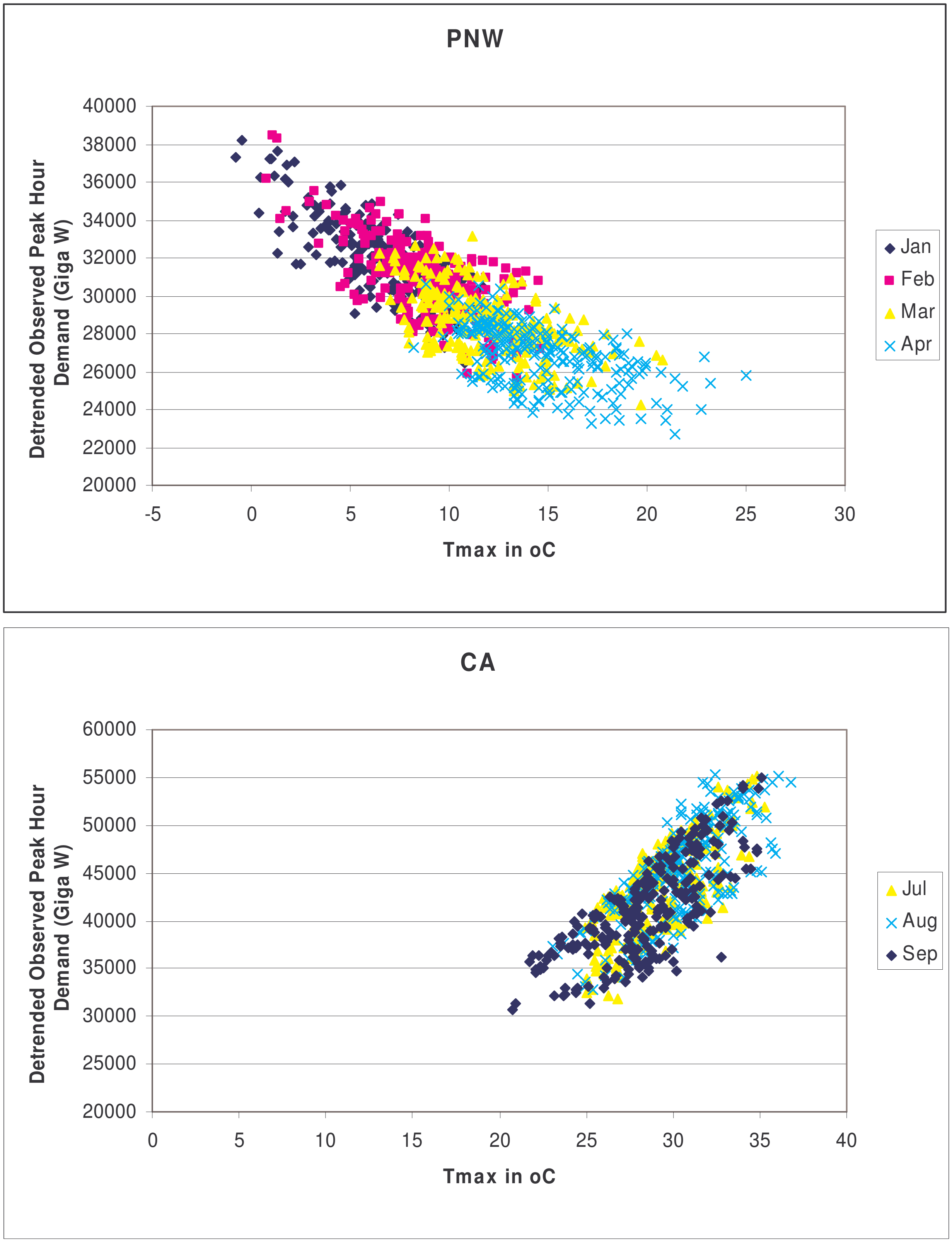
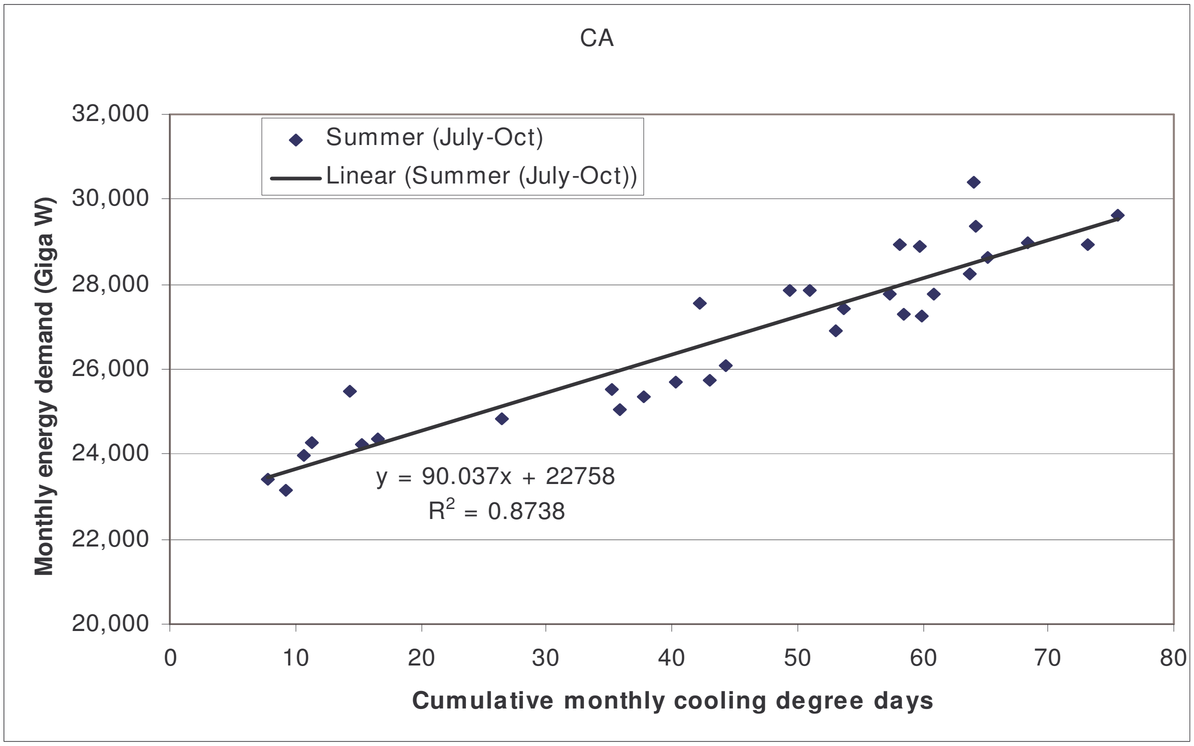


Figure 1: Daily detrended observed peak hour demand regressed with daily maximum temperature (related to warming/cooling degree days).

Similarly we have developed a monthly regression model for regional demand based on population weighted monthly heating or cooling degree days in the major urban centers. This model is only skillful in summer in CA and in winter in the PNW, but shows some interesting relationships to seasonal to interannual climate predictors like ENSO.



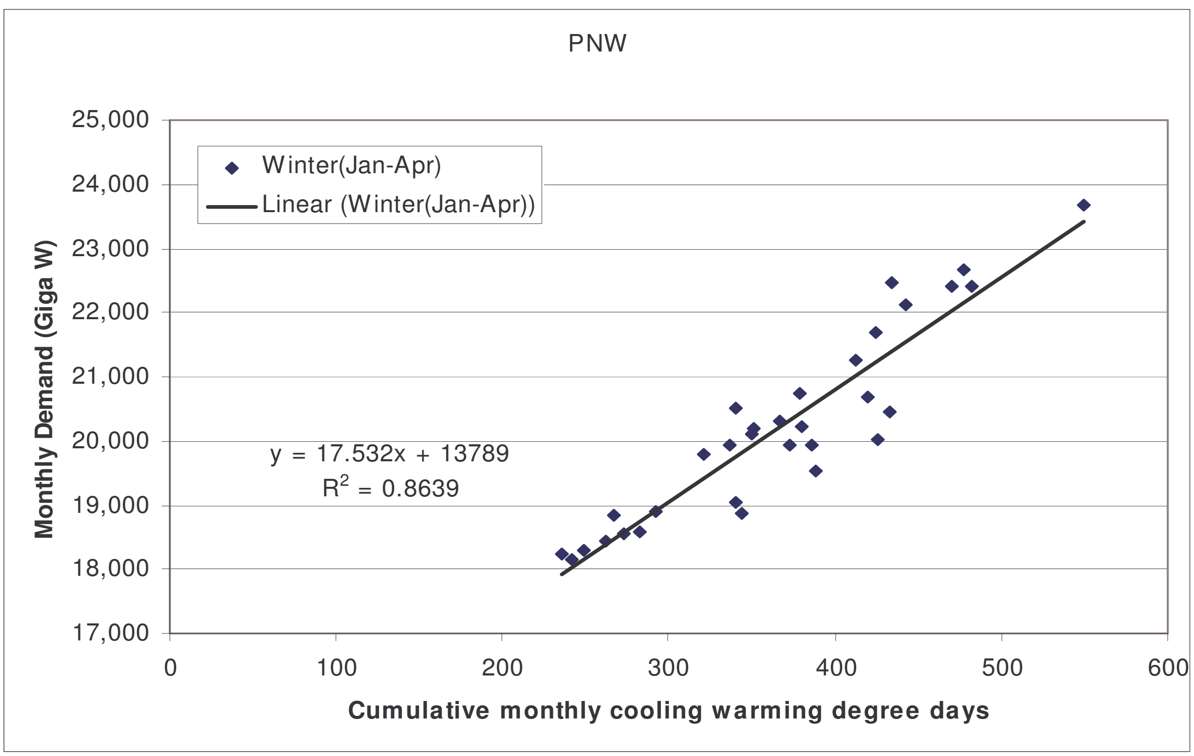


Figure 2: 1993-2000 observed monthly energy demand regressed with wintertime warming degree days in the PNW and summertime cooling degree days in California.

Using each of these models we can produce a time series of power demand from 1915-2002 based on our gridded climate data sets. During warm ENSO and ENSO/PDO events, the peak hour and monthly demand are low on average for warm PDO events and inversely for cold corresponding cold events. July and August peak hour and monthly demands in California are correlated to cooling degree day ($R^2 = 0.7$). The energy peak hour and monthly demand in the PNW is well predictable, with highly significant correlation for the months of January to April ($R^2 > 0.88$).

4) Overall Covariability

The table below shows the covariability of energy demand and hydropower production for different climate signals.

Table 1: Trends of covariability over the simulated 1917-2002 period for different climate signals. A and B mean respectively "Above" and "Below" average and X means unpredictable. Winter includes January to April and Summer includes July and August.

TRENDS		Temperature		Peak Hour Demand		Monthly Demand		Hydropower	
		CA summer	PNW winter	CA summer	PNW winter	CA summer	PNW winter	CA winter	PNW June-July
WARM	ENSO	B	A	A	B	A	B	X	B
	PDO	B	A	A	B	A	B	X	B
	ENSO/PDO	B	A	A	B	A	B	X	B
COLD	ENSO	A	B	B	A	B	A	X	A
	PDO	A	B	B	A	B	A	X	A
	ENSO/PDO	A	B	B	A	B	A	X	A

Table 2: Anomalies of energy demand and hydropower production over the simulated 1917-2002 period for different climate signals. A and B mean respectively "Above" and "Below" average and in brackets means low predictability. Winter includes January to April and Summer includes July and August.

ANOMALIES		Temperature Degree Day		Peak Hour Demand (GigaW /Mth)		Monthly Demand (GigaW /Mth)		Hydropower (Mega W-hr/Mth)	
		Cooling, CA summer	Warming, PNW winter	CA summer	PNW winter	CA summer	PNW winter	CA winter	PNW June-July
WARM	ENSO	2	-17	239	-288	209	-285	(70)	-335
	PDO	2	-12	463	-200	170	-210	(41)	-353
	ENSO/PDO	2	-31	302	-537	208	-533	(97)	-652
COLD	ENSO	-1	4	-269	82	-104	74	(26)	110
	PDO	-2	7	-191	128	-148	122	(13)	218
	ENSO/PDO	-2	15	-526	291	-188	262	(34)	152

We intend to further analyze the inertia opportunity between the Pacific Northwest and California based on the 85 year monthly time series of potential energy generation capacity as simulated by reservoir models and energy consumption as simulated by our demand models. In current operations, there is a southward transfer of energy during peak hours and a northward energy transfer during night hours (BPA 1994). The potential transfers we intend to investigate is the monthly average of the energy exceeding these (existing) daily transfers. The energy generation capacity for the Pacific Northwest is primarily hydropower. When the hydropower production exceeds the energy demand, a transfer toward California is possible. For California, the conventional resources provide enough capacity to meet the demand. However hydropower capacity allows for the use of less expensive energy. The energy demand in California is met in priority with hydropower generation from California and then from excess energy transfer from the Pacific Northwest and the Colorado Basin. Conventional resources provide the difference. Northward transfers are generally desirable when the hydropower generation in the Pacific Northwest does not meet the demand.

Instantaneous transfers are restricted by the intertie capacity, contracts and other power system requirements. In future work, we intend to examine the feasibility of these transfers based on transmission line capacity and other operations procedures like timing for example.

5) Conclusion

Hydropower generation is (primarily) a function of total monthly discharge which is climate-sensitive. On the other hand, the energy peak hour demand is highly correlated to temperature degree days, whose variability is correlated to climate oscillations. Therefore there is a predictable potential to define new transfers during the intertie. In subsequent work, we will examine the feasibility of these transfers. We will also examine the opportunity to change some operations procedures based on climate signals predictability in order to improve the transfers.