NOTES AND CORRESPONDENCE

Relationships between the Irrigation-Pumping Electrical Loads and the Local Climate in Climate Division 9, Idaho

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ABSTRACT

The electrical load from irrigation pumps is an important part of the overall electricity demand in many agricultural areas of the U.S. west. The date the pumps turn on and the total electrical load they present over the summer varies from year to year, partly because of climate fluctuations. Predicting this variability would be useful to electricity producers that supply the region. This work presents a contingency analysis and linear regression scheme for forecasting summertime irrigation pump loads in southeastern Idaho. The basis of the predictability is the persistence of spring soil moisture conditions into summer, and the effect it has on summer temperatures. There is a strong contemporaneous relationship between soil moisture and temperature in the summer and total summer pump electrical loads so that a reasonable prediction of summer pump electrical loads based on spring soil moisture conditions can be obtained in the region. If one assumes that decision makers will take appropriate actions based on the forecast output, the net economic benefit of forecast information is approximately $2.5 million per year, making this prediction problem an important seasonal summer forecasting issue with significant economic implications.

1. Introduction and overview

The goal of the National Oceanic and Atmospheric Administration (NOAA)-funded California Energy Security Project was to produce and assess the economic value of weather and climate forecasts tailored for energy producers in the U.S. west. One of the detailed case studies we examined involved forecasting the onset and total summer electrical load of irrigation pumps in the interior Pacific Northwest. In this region, potatoes and wheat are major irrigated crops. It is found that the date on which the irrigation pumps turn on and their total load over the summer vary considerably from year to year. If electrical producers could anticipate this variability, it would allow them to optimize their operations for the expected load (e.g., by purchasing power contracts ahead of time rather than waiting

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until the electricity is needed and paying spot-market prices). Predicting the total summer electrical load of the pumps is therefore an important seasonal summer forecasting issue with important economic implications. This note discusses the construction of a simple scheme for predicting total electrical loads for the May, June, July, and August (MJJA) season and the potential economic benefits of those forecasts. Most of the concepts of a "useful forecast" as described by Stern and Easterling (1999) are applicable to this case.

The fundamental variable we use to predict summer conditions is springtime soil moisture (SM). There is good observational and modeling evidence that such soil moisture fluctuations can affect subsequent climate. For example, Namias (1991, 1989, 1978, 1960, 1952) found that soil moisture anomalies could have an impact on the seasonal cycle of some tropospheric variables, thereby explaining some of the persistence of surface air temperature from spring to summer in the interior United States. He also noted that dry springs tend to be followed by hot summers, and vice versa. Barnett and Preisendofer (1987) noted that the persistence of local conditions could give some summer temperature predictability in certain regions of the central United States. Karl (1986) found empirical relationships between soil moisture and subsequent monthly and seasonal temperature during spring and summer. All of these observational studies suggest that there are regions in which soil moisture has an important influence on local climate, not only in the sense of reflecting past conditions, but also as an indicator of future climate tendencies.

In a modeling study, Delworth and Manabe (1988, 1989) examined the seasonal to interannual variability of soil moisture in a multiple-year integration of an atmospheric general circulation model. They found that soil moisture influences the climate through perturbations to the outgoing surface heat flux's partition between sensible heat and latent heat (the ratio of which is known as the Bowen ratio). Positive soil moisture anomalies are associated with positive latent heat flux anomalies and negative sensible heat flux anomalies. This set of conditions results in cool, moist surface air anomalies.

Several authors have more recently described the relationship between surface air temperature and soil moisture and the potential use of this relationship in prediction (e.g., Huang et al. 1996; van den Dool et al. 2003). In particular, the persistence of spring soil moisture conditions has been shown to affect summer temperatures in different modeling predictive studies (e.g., Douville 2003; Mo 2003; Huang et al. 1996) over much of the continental United States.

2. Climate data and results

We obtained the irrigation-pump electrical-load data from PacifiCorp (our energy-industry stakeholder for this scenario), which services agricultural regions of Idaho, Utah, and Nevada. The period covered was 1997–2003; one of the limitations of the analysis is the short length of the pump electrical-load data. The data are from an electrical substation in Idaho Falls, Idaho; this station was used because it is dominated by irrigation-pump electrical load and thus other confounding factors are minimized. Pump electrical loads are expressed here as normalized values of the maximum pump load experienced in the record. This normalization is done because, as is common with electrical utilities, PacifiCorp is sensitive to exact load values being published. The actual magnitude of the pump electrical loads is irrelevant to the climatological issues or application of these results to other regions.

The surface air temperature data used are from Idaho's Climate Division 9, "Upper Snake River Plains" (43.83°N, 112.82°W; 1932–2003), and are representative of temperatures at the same location as that of the pump data. The location of this climate division is shown in Fig. 1. We also used observed temperature data from the Idaho Falls station (43.52°N, 112.93°W; station identifier 104460; 1954–2001), with results that were very similar to those obtained using the climate division data (not shown). Soil moisture data for the climate division were obtained from the National Centers for Environmental Prediction through the Internet (http://www.cpc.ncep.noaa.gov/soilmst/). The data were estimated by using a one-layer hydrological model [for details see Huang et al. (1996) and van den Dool et al. (2003)].

The persistence relationships between soil moisture and temperature mentioned in the introduction hold true at our locale of interest as is illustrated in Fig. 2, which shows the annual time series for standardized anomalies of soil moisture and mean temperature (Tmean) in Idaho's Climate Division 9 for different seasons. In the summer (MJJA), there is a statistically significant negative correlation ($r = -0.63$) between soil moisture and mean air temperature, as can be seen in Fig. 2a. Moreover, this relationship holds even when preceding springtime [February–March (FM)] soil moisture conditions are related to summer air temperatures (Fig. 2b; $r = -0.31$). This correlation between spring soil moisture and summer air temperature occurs because there is, in turn, a positive correlation between spring and summer soil moisture (Fig. 2c; $r = 0.70$). In other words, spring soil moisture conditions tend to persist to the summer and then affect air temperature. These linear relationships are significant at the 99% level.

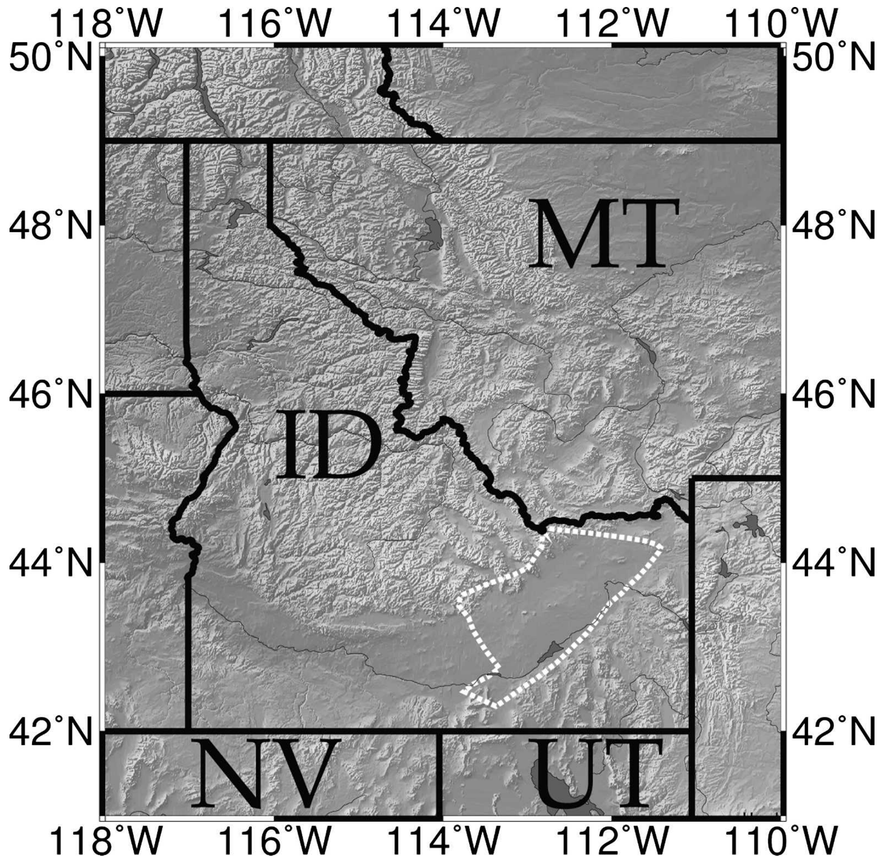

FIG. 1. Map showing Idaho Climate Division 9 (white dotted line): Upper Snake River Plains.

Table 1 shows the contingency analysis between soil moisture and Tmean in Idaho Climate Division 9. The top one-third of Table 1 shows the relationship between summer temperatures and soil moisture conditions in the preceding spring. Below-normal soil moisture conditions in February–March are associated with warmer-than-usual temperatures in MJJA, and vice versa (the upper right and lower left values). This relationship is straightforward and is the same as that inferred from the time series discussed above. The middle one-third of Table 1 shows that there is a strong simultaneous relationship between dry soil conditions and hot temperatures in summer, and the bottom one-third of Table 1 shows that dry spring conditions tend to persist through midsummer. Taken together, they support the physical interpretation that dry spring soil conditions tend to persist to midsummer, which then leads to warmer-than-usual air temperatures.

3. Relationship to irrigation-pump electrical loads

Our stakeholder partner, PacifiCorp, originally requested that we forecast the date on which the pumps first reached 20% of maximum load (i.e., their turn-on date). We used a stepwise routine to identify the most skillful linear regression model between soil moisture/temperature and pump start date. The pumps turn on in spring, and this model (not shown) requires *contemporaneous* (i.e., springtime) precipitation rather than antecedent conditions. Other predictors did no better than climatologically based predictions. As a result, this regression is useless for planning.

PacifiCorp's reaction was instructive. They indicated that they were not interested in the pump start date *in and of itself*, but rather were interested in the start date because it *predicted total summer pump electrical load*. We found repeatedly that the utilities, being unfamiliar with climate forecasts, initially asked for forecast products that were not what they ultimately wanted. Converging on the most useful forecast product often took several iterations of the process. Here it worked to our advantage, because the pump turn-on date is not predictable but the persistence of spring conditions into summer would be expected to provide a way to predict total summer load.

Not surprising is that there are statistically significant

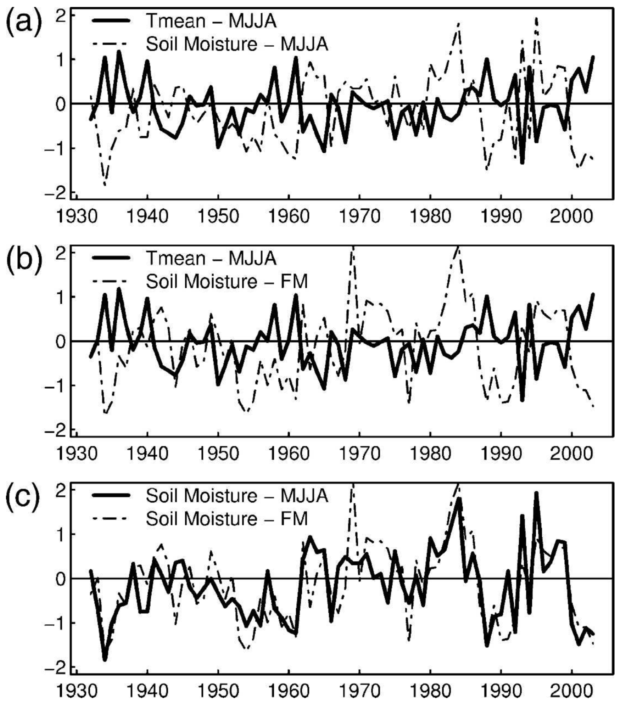

FIG. 2. Time series of soil moisture and mean temperature in Idaho Climate Division 9 for different seasons: (a) SM_{MJJA} and $Tmean_{MJJA}$, (b) SM_{FM} and $Tmean_{MJJA}$, and (c) SM_{FM} and SM_{MJJA}, for 1932–2003. All values are standardized anomalies (base period: 1974–2003).

simultaneous relationships between the total summer pump electrical load and both mean air temperature and soil moisture. Figure 3a shows that when the soil is drier than usual in summer, electrical loads tend to be higher than usual, and vice versa. In addition, when temperatures are above average, pump loads are as well (Fig. 3b).

The results shown in Figs. 2–3 and Table 1 support the idea that springtime soil moisture or air temperature could be used to predict the total summer irrigation-pump electrical load. For when the forecast should be issued, PacifiCorp indicated that, because of various business constraints, a prediction issued by the beginning of April was desirable. We again used a stepwise routine to identify the most skillful predictive linear regression models between various parameters. The cross-validated skill was used by omitting data from the predicted year in the model construction so that artificial prediction skill would be minimized. For predictors, we examined values of various hemispheric climate indices from the preceding winter (the December–February Pacific decadal oscillation and Southern Oscillation indices) in addition to the local variables already described (spring mean air temperature and soil moisture). For the predictand, we used the sum of the summer (MJJA) normalized pump electrical-load data (i.e., total pump load over the summer).

We found that only soil moisture anomalies during the previous FM and February were retained as predictors for the total summer pump electrical-load estimation. These models can be summarized in the following equations:

$$\hat{Y} = 62.863 - 0.211\mathrm{SM}_{\mathrm{FM}} \quad \text{and} \tag{1}$$

$$\hat{Y} = 63.917 - 0.202\mathrm{SM}_{\mathrm{Feb}}, \tag{2}$$

where $\hat{Y}$ is the estimated value of total MJJA loads (in arbitrary units, because the pump loads are normal-

TABLE 1. Contingency analysis between (top) SM_{FM} and $Tmean_{MJJA}$, (middle) SM_{MJJA} and $Tmean_{MJJA}$, and (bottom) SM_{FM} and SM_{MJJA}. All data are for Idaho Climate Division 9, for 1932–2003 (boldface indicates significance level $\alpha = 0.01$; italics indicate $\alpha = 0.05$). Here, BN indicates below normal, N is normal, and AN denotes above normal.

		$Tmean_{MJJA}$		
		BN (<16.3°C)	N	AN (>16.7°C)
SM_{FM}	BN (<156.0 mm)	*21*	33	*46*
	N	33	38	29
	AN (>190.8 mm)	*46*	29	25
		$Tmean_{MJJA}$		
		BN (<16.3°C)	N	AN (>16.7°C)
SM_{MJJA}	BN (<137.0 mm)	**17**	*20*	**63**
	N	*20*	*51*	29
	AN (>178.7 mm)	**63**	29	**8**
		SM_{MJJA}		
		BN (<137.0 mm)	N	AN (>178.7 mm)
SM_{FM}	BN (<156.0 mm)	**67**	25	**8**
	N	29	37	34
	AN (>190.8 mm)	**4**	38	**58**

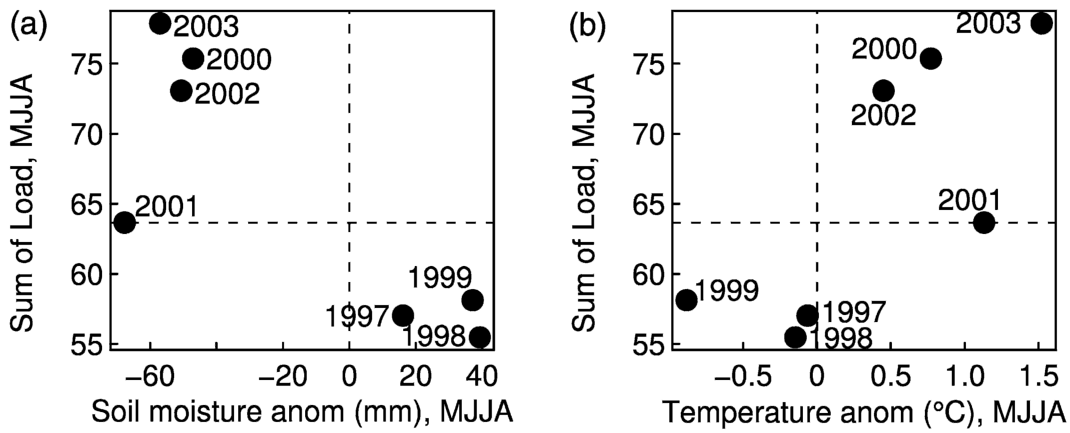

FIG. 3. Scatterplots between the sum of the MJJA normalized pump electrical-load values vs (a) SM_{MJJA} and (b) $Tmean_{MJJA}$, for 1997–2003. Vertical lines are for the zero anomaly value (base period: 1974–2003) and the horizontal ones are for the load's median value.

ized). The model statistics are summarized in Table 2. Equations (1) and (2) show models with negative correlations between soil moisture anomalies in spring and the irrigation-pump electrical load in summer, as confirmed by Fig. 4. When the soil is wet, less water is pumped because the crops do not need to be irrigated as much as when the soil is dry. Also, moist soils moderate air temperature because of modification to the Bowen ratio discussed previously. It is not surprising that a similar result is obtained for the simultaneous relationship, that is, if MJJA soil moisture anomalies are used in a regression as independent variable (see also Fig. 3a):

$$\hat{Y} = 62.757 - 0.164\mathrm{SM}_{\mathrm{MJJA}}, \tag{3}$$

where $\hat{Y}$ is the estimated value of total MJJA pump electrical loads, as before.

The total summer irrigation-pump electrical load predicted by these relationships, along with that actually observed over the period of record, is shown in Fig. 5. (Notice that the maximum absolute deviations described in Table 2 occur in 2001. The year 2001 is often found to be anomalous in energy data of the U.S. west, because it was the year that the deregulation of California's electricity market had severe impacts on electricity price and availability throughout the west.) In Figs. 5a and 5b the estimation for 2004 is also included. Both estimated values are greater than the median for the 1997–2003 period, a fact which is related to the dry conditions observed during the previous February and March, but the confidence interval for this estimation is large because of the small sample size used (7 yr).

TABLE 2. Statistics associated with the models described in Eqs. (1)–(3). The skill, mean absolute deviation (MAD), and maximum absolute deviation values were obtained by cross validation. All of the skill values have statistical significance at greater than the 95% level.

Statistics	Eq. (1)	Eq. (2)	Eq. (3)
r	0.86	0.86	0.82
r^2	0.74	0.74	0.67
Skill	0.76	0.76	0.64
MAD	4.37	4.56	5.60
Max absolute dev	11.52	11.08	15.06

4. Economic valuation

The benefits of the pump-load forecasts would accrue by being able to purchase power contracts in advance of 1 June for usage in May and June of that same year. For the purposes of this study, we evaluated the benefit of power contracts purchased 1–2 months ahead, using forecasts produced by 1 April for the ramp-up date for the following spring–summer (usually in April, May, or June). This analysis assumes that decision makers will take appropriate actions based on the forecast output.

The net economic benefit of forecast information is estimated to be approximately \$2.5 million per year, using the following assumptions. Irrigation load averages roughly 500 000 MW h yr^{-1}, with a swing of $\pm$100 000 MW h yr^{-1}. If decision makers knew by 1 April that the ramp-up date would be at the beginning of May (or earlier) rather than toward the end of May (or later), then they could purchase contracts 1 or 2 months ahead (for energy usage in May and June). The difference between the contracts and the spot-market price (i.e., if they waited to buy the power in May and

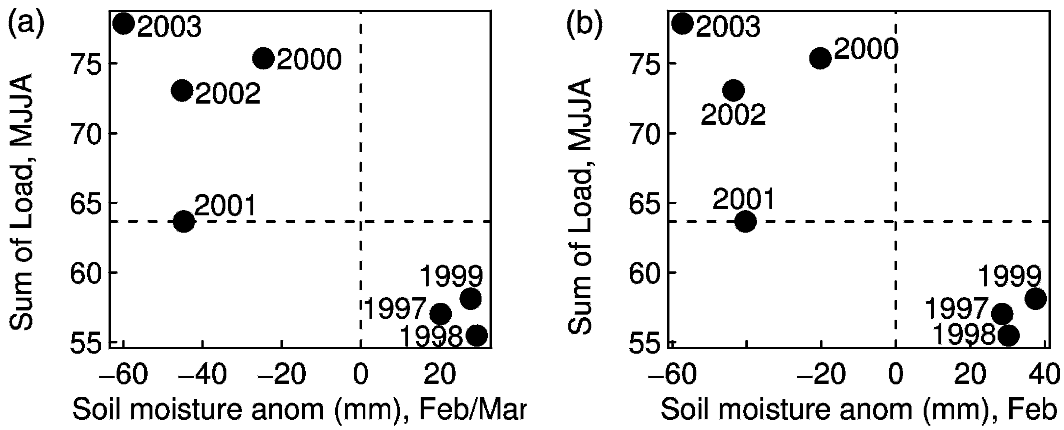

FIG. 4. Scatterplots between the sum of the MJJA normalized load values vs (a) SM_{FM} and (b) SM_{Feb}, for 1997–2003. Vertical lines are for the zero anomaly value (base period: 1974–2003), and the horizontal ones are for the load's median value.

June) is approximately \$25 (MW h)$^{-1}$. This calculation assumes that the 1-month-ahead and 2-month-ahead contracts are \$40–\$50 (MW h)$^{-1}$ and that the spot-market price ranges from \$60 (MW h)$^{-1}$ to as high as \$120 (MW h)$^{-1}$, with an average of around \$60–\$75 (MW h)$^{-1}$. The cost of a forecast of an early May ramp-up date but with actual ramp up occurring in late May is approximately \$200 000–\$300 000 per year, because the surplus power would need to be sold back to the market at a cost of approximately \$2–\$3 (MW h)$^{-1}$.

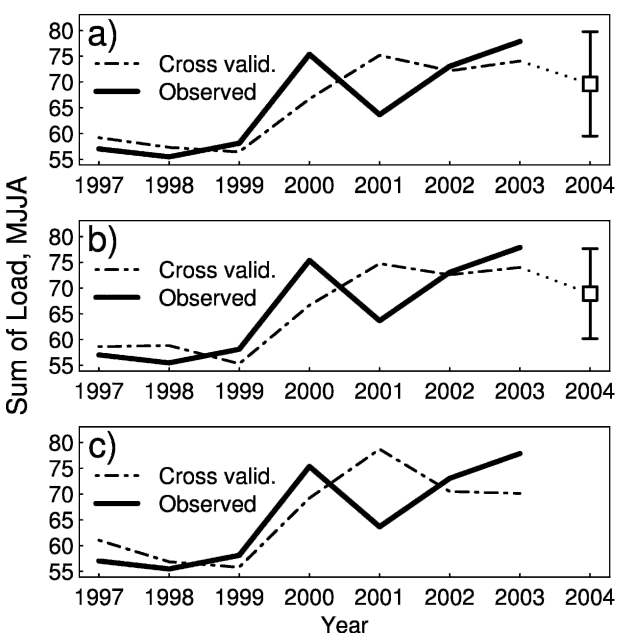

FIG. 5. Observed and estimated values for the models described in (a) Eq. (1), (b) Eq. (2), and (c) Eq. (3). The 2004 estimated values in (a) and (b) include the 95% statistical confidence levels.

5. Summary

As part of the California Energy Security Project, we worked with an energy industry partner (PacifiCorp) to evaluate the feasibility of predicting total irrigation-pump electrical load over the summer based on conditions observed up to the beginning of April. We found that such a predictive model could be constructed and that it could exhibit useful cross-validated skill. The climate factors behind the model are straightforward: spring soil moisture conditions have a strong tendency to persist through the summer. There is then a strong (negative) correlation between summer soil moisture conditions and summer temperatures; that is, wet soil tends to moderate the summer temperature extremes. Last, there is a strong simultaneous relationship between summer soil moisture/temperature conditions and total summer pump loads. As a result, there is predictive skill of summer pump loads based on spring soil moisture conditions in southeastern Idaho.

PacificCorp indicated that the economic value of such a prediction, in the limited area studied, would be approximately \$2.5 million per year. Although we lack the irrigation-pump data needed to verify this model across a broader region, our analysis of soil moisture and temperature in all climate division zones suggests that the results found here would be expected to hold across the majority of the interior western United States.

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