4-2000

Predicting Vintage Quantity and Quality in Coastal California Using Pacific Sea Surface Temperatures

Ramakrishna R. Nemani

Michael A. White

Daniel R. Cayan

Gregory V. Jones

Steven W. Running
University of Montana - Missoula

Recommended Citation

Nemani, R. R., White M. A., Cayan D. R., Jones G. V., and Running S. W., Predicting Vintage Quantity and Quality in Coastal California Using Pacific Sea Surface Temperatures. Proceedings of International Forum on Climate Prediction, Agriculture and Development, April 26-28, 2000 in Palisades, NY.

SESSION III. IMPACTS OF CLIMATE VARIABILITY ON CROP AND LIVESTOCK SYSTEMS

Predicting Vintage Quantity and Quality in Coastal California Using Pacific sea surface temperatures

Ramakrishna R. Nemani[1], Michael A. White[1], Daniel R. Cayan[2], Gregory V. Jones[3], Steven W. Running[1]
[1]University of Montana, USA
[2]United States Geological Survey, USA
[3]Southern Oregon University, USA

INTRODUCTION

California produces 90% of all wine within the U.S. and dominates the $33 billion/year domestic retail wine industry. Since the 1950s, wine grape growers in California have seen dramatic increases in premium wine quality, grape yield, and crop value. Advances in viticultural practices (irrigation, nutrition, pest/disease control, trellising etc.) and experience in wine making have certainly contributed to the success (Jackson and Lombard 1993). In spite of such advances, wine growers generally believe climate plays a significant role in determining the quantity and quality of a given vintage.

Widespread changes in climate have been reported globally during the last few decades, attributed mainly to the greenhouse effect of rising atmospheric CO_2 levels (Houghton et al. 1995). Depending on the magnitude and seasonality of climatic changes, their impacts on agriculture can be either positive or negative (Watson et al. 1998). For example, warmer winter/spring temperatures reduce frost damage and increase growing season length in northern latitudes. Given that high quality wines are generally associated with (Gladstones 1992), 1) low frost damage during mild winters (January, February, March), 2) early and even budburst, flowering and development during warm springs (April, May, June), and 3) low summer (July, August, September) temperature variability during maturation, the question arises: have regional climatic changes helped the California wine industry?

To answer this question, we analyzed daily climatic data (1951-1997, 47 years) from four places (Napa State Hospital, St. Helen, Healdsburg, Santa Rosa) in the premium California wine producing areas of Napa and Sonoma valleys. Here we report results of our analysis as: 1) observed changes in climate, 2) potential causes for the changes, 3) how observed climatic changes impact viticulture in coastal California, 4) predictability of quantity and quality of California vintages.

OBSERVED CHANGES IN NAPA/SONOMA CLIMATE

Consistent with reported global trends, annual average air temperature (Tave) over Napa/Sonoma valleys increased 1.13°C between 1951 and 1997. Nearly all the warming was caused by increases in night minimum temperature (Tmin, 2.06°C/47 yr), with very little change in daytime maximum temperatures (Tmax). As a consequence of the asymmetric warming, the diurnal temperature range (DTR, difference between daily maximum and minimum temperatures) declined by 1.87°C/47 years. Such asymmetric changes in temperature have been widely reported for various regions of the globe, and are presumed to be signatures of global warming. It is the asymmetric nature of climate warming, as will be discussed later, that has significant implications for agriculture in coastal California. Monthly analysis showed the warming trends to be highly seasonal (Figure 1). For example, average spring warming was nearly double that of rest of the year. Similarly, summer DTR showed the largest decline. Trends for Tave are significant at the 5% level for all months except December, while DTR trends are significant in March, May, July, August, September and October. Tmax increased during spring months and declined during summer, but changes are not significant in any month. There were no significant changes in monthly or annual precipitation.

PACIFIC OCEAN AND CLIMATE WARMING

While increased atmospheric CO_2 is considered to be the main reason for recent global warming, on a regional scale changes in atmospheric water vapor (another important greenhouse gas) also play a crucial role. Premium wine producing areas of California are strongly influenced by the maritime weather of the Pacific Ocean. Figure 2 shows the linkage between Pacific Ocean and coastal California climate, with the primary mechanism for the co-variation between ocean and land temperatures being the horizontal transport of water vapor. A strong relation was observed (Figure 3) between Pacific sea surface temperatures along coastal California and coastal dewpoint tempera-

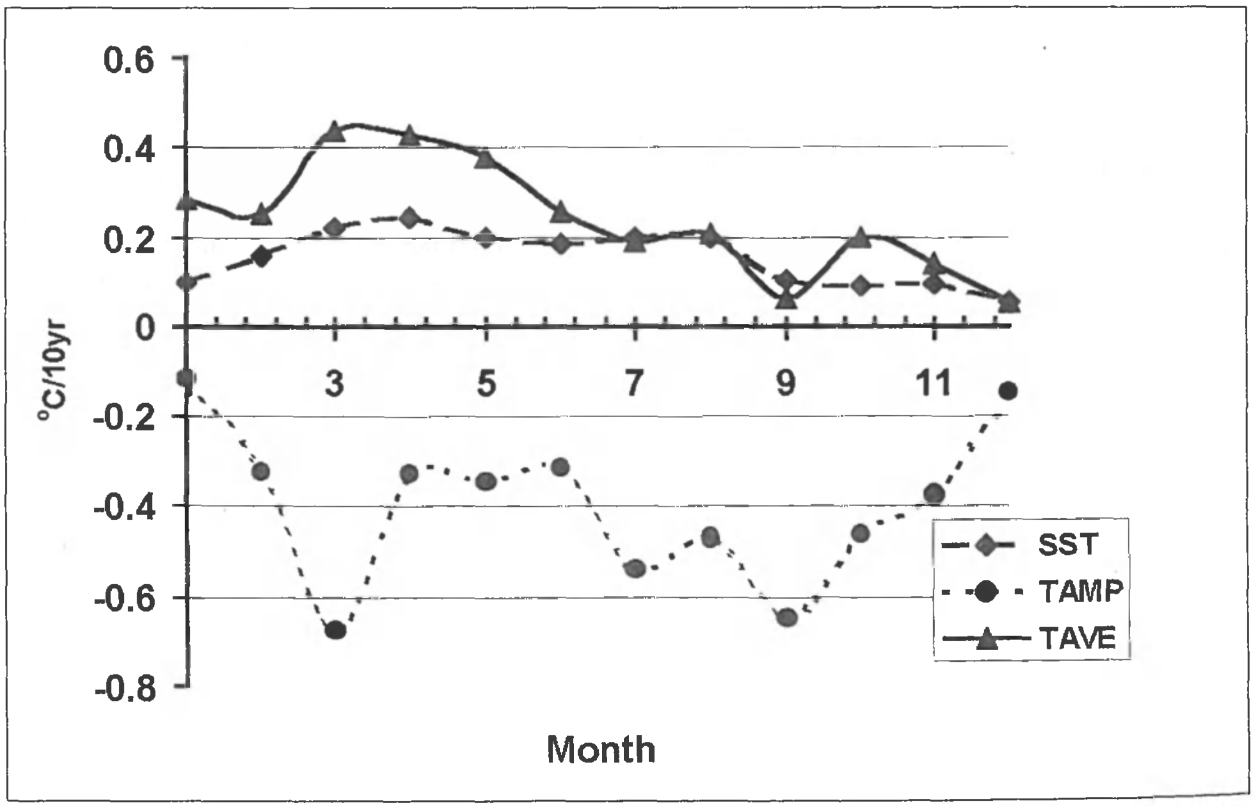

Figure 1. Monthly average temperature (TAVE) ,SST and temperature amplitude (TAMP) trends in Napa/Sonoma valleys, observed between 1950-1997. Higher spring temperatures and reduced DTR have been found to help improve the quality and quantity of vintages.

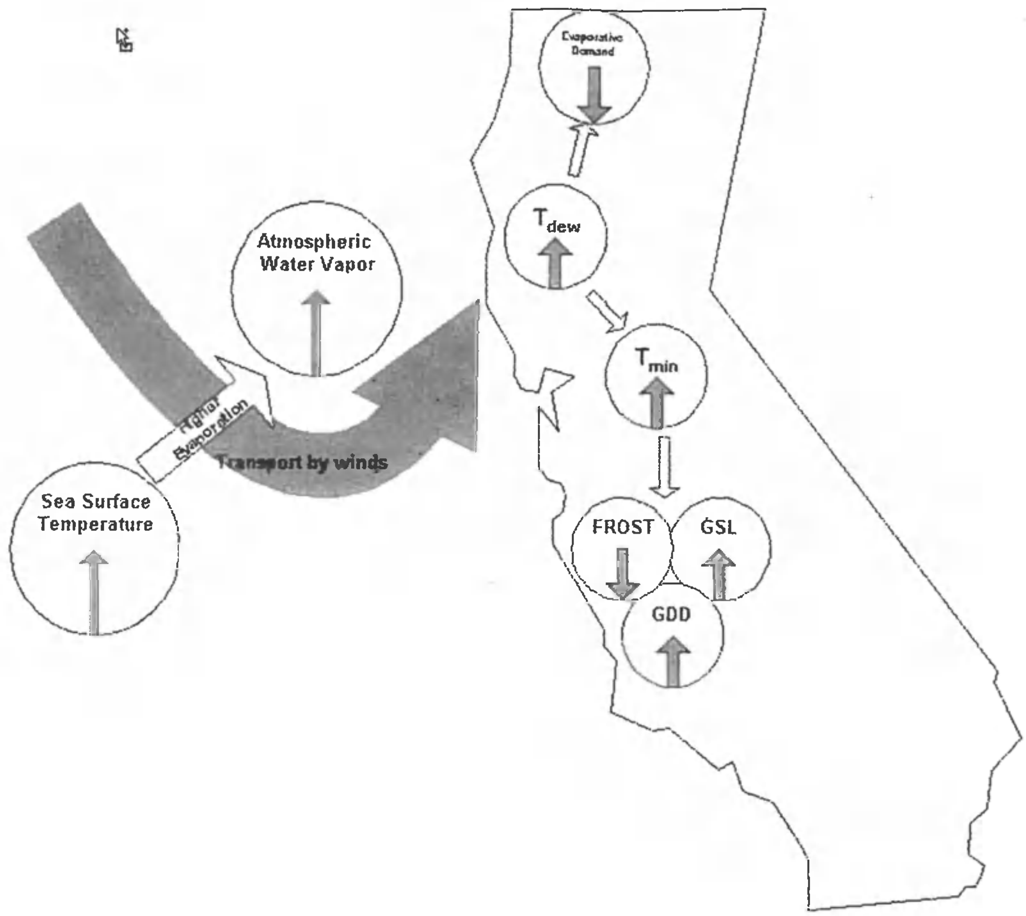

Figure 2. *Pacific climate influences coastal temperatures mainly through transport of water vapor. Changes in atmospheric water vapor, in turn, modify a number of biophysically important variables (frost frequency, evaporative demand, growing season length, GSL and growing degree days, GDD) for viticulture through changes in Tdew and Tmin*

ture (a measure of atmospheric water vapor, observed at San Diego and San Francisco), confirming the mechanisms shown in Figure 2. Pacific sea surface temperatures along the California coast increased by 0.7°C ($p = 0.0030$) between 1951 and 1997, with much of the warming occurring after the well documented shift in pacific climate during 1976-77 (Ebbesmeyer et al. 1990). Similarly, coastal dewpoint temperatures have also increased by 0.9°C/47 yr ($p < 0.001$). As a result of the proposed mechanism (Figure 2), there is a strong relation between SSTs and frost occurrence (Figure 4).

CLIMATIC CHANGES AND VITICULTURE

Reported as annual averages, the observed climatic changes in Napa/Sonoma are modest (1.13°C/47 yr for Tave), but biological consequences can be extensive. For example, the 2.06°C/47 yr increase in Tmin translated to a 71% decline in frost frequency (28 days/yr to 8 days/yr,) and a 25% increase in frost-free growing season length (GSL, 254 days/yr to 320 days/yr, $p < 0.001$). Longer growing seasons allow vineyard managers greater flexibility in scheduling various viticultural operations (pruning, harvest, etc.). If the current trends in frost frequency continue, Napa/Sonoma will become a frost-free climate.

Enhanced water vapor shown by increases in Tdew, along with small changes in Tmax, resulted in an estimated 7%/47 yr reduction in growing season (March—October) vapor pressure deficit (VPD, $p = 0.042$). We calculated VPD as the difference in vapor pressures at Tdew and Tmax. Based on a high correlation ($r^2 = 0.92$, $Tdew = -0.35 + 0.98Tmin$) between observed Tdew and Tmin

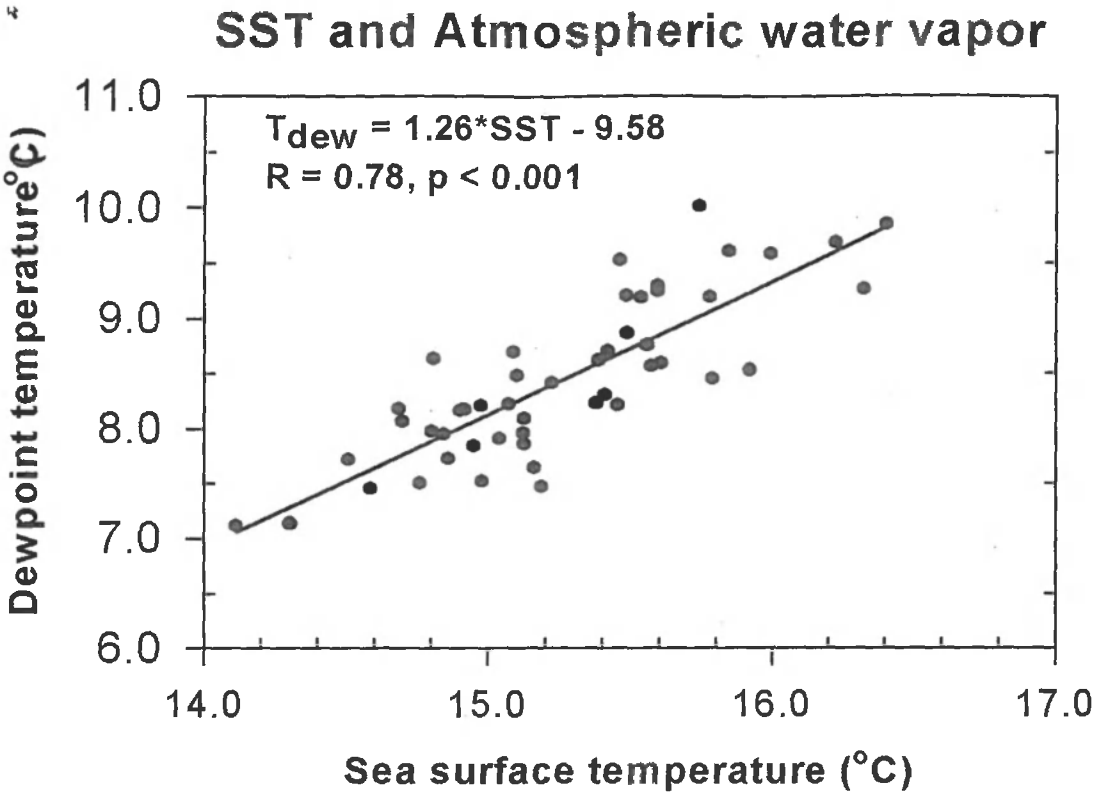

Figure 3. *Observed relation between Pacific sea surface temperatures and coastal dewpoint temperatures from 1951-1997. Eastern Pacific sea surface temperatures increased by 2.0oC following the 1976-77 shift in Pacific climate*

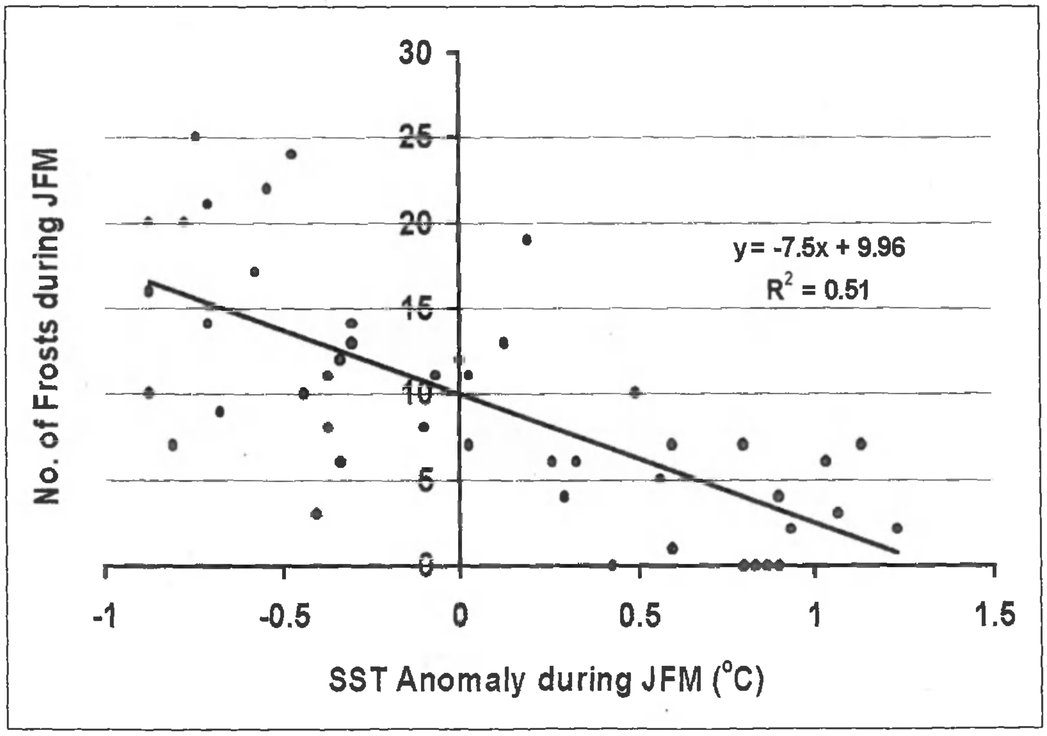

Figure 4. *Observed relation between JFM Sea surface temperature anomaly and the number of frosts*

along the west coast of U.S, we assumed that Tmin = Tdew at Napa/Sonoma (Gaffen and Ross 1999). Lower VPDs reduce evaporative demand and water stress and increase plant growth.

Use of growing degree days (GDD) is quite common in agriculture for predicting various phenological stages (budburst, flowering, crop maturity) and pest/disease outbreaks. Degree days are calculated as accumulated heat units above a base temperature generally taken to be 10°C for grapes. Observed warming trends increased GDD totals and accumulation rates. Between 1951 and 1997, GDD increased 14%, indicating higher sugar accumulation and improved quality (Gladstones 1992). GDD summations also showed that 1600 GDD, the amount required for harvesting grapes for wine making in Napa/Sonoma, were accumulated 20-25 days earlier in 1997 than in 1951. Faster accumulation allows vineyard managers to leave the grapes on the vines until the optimal balance of sugars and acids is achieved.

Temperature variability and temperature extremes, as measured by temperature variability index (TVI, Gladstones 1992), are related to wine quality. TVI = sum ((TDmax – TDmin) + (TMmax – TMmin)), where TD and TM represent daily and monthly values between March and October. Low TVIs favor high-quality wines. In Napa/Sonoma, the TVI declined from 36.1 in 1951 to 31.4 in 1997. TVI values under 30 indicate that any variety of table wine may be produced. Locations within a vineyard that maintain higher Tmin and low DTR as a result of soils or topography are regularly associated with high quality wines. Observed climatic changes (Figure 1) are likely to have similar positive influence on wine quality for entire vineyards.

CLIMATE CHANGE AND CALIFORNIA VINTAGES

Wine quality ratings by Sotheby (Stevenson 1997), available for California wines from 1963-1996 and dominated by north coast wines, increased by 0.22 points/yr (Figure 5, p=0.022). Wine ratings produced immediately after production, such as the Sotheby (Stevenson 1997) and Wine Spectator ratings (Laube 1996) are more indicative of climatic influences than are ratings updated on a yearly basis. However, annually updated ratings, such as the Wine Advocate vintage

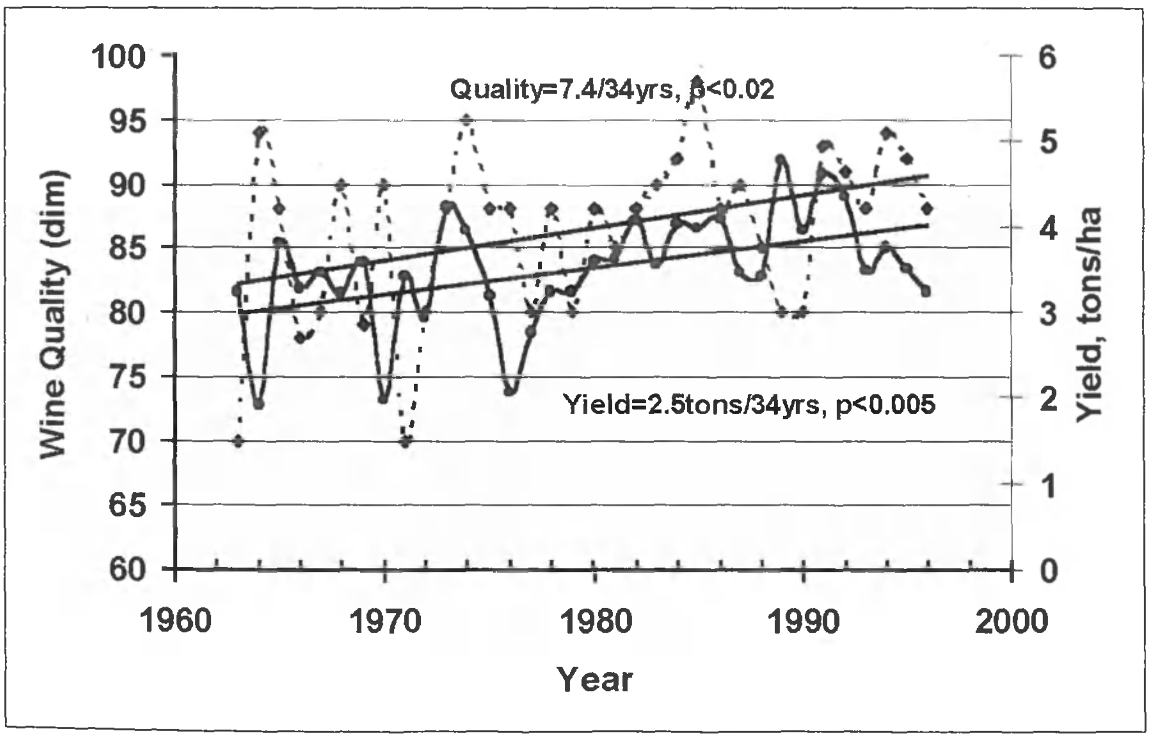

Figure 5. *Trends in Napa valley wine quality and yields. After the 1976-77 shift, consistently better vintages followed warmer temperatures during winter and spring month*

Table 1. Climatic variables important for vintage quantity and quality (Gladstones 1992): 1951-1997 increases and mean (standard deviation, SD) before and after the 1976-1977 regional Pacific climate shift . All differences between periods were significant at the 1% level (t-test).

Parameter	1951-1997	1951-1976	1977-1997
changes	mean (SD)	mean (SD)	
Winter Tmin (°C)	2.39	3.74 (0.88)	5.06 (1.16)
Spring Tmin (°C)	2.44	8.04 (0.63)	9.42 (0.77)
Summer DTR (°C)	–3.14	19.0 (0.85)	17.5 (0.98)
Number of Frosts/year	–20	22 (9)	10 (9)
Frost-free GSL (days)	65	272 (18)	311 (29)
Growing Degree Days	240	1714(102)	1830(112)
VPD (kPa)	–0.159	2.41 (0.12)	2.29 (0.15)

charts for north coast California wines (R. Parker, "The Wine Advocate's vintage guide, 1970-1997" (http://www.winetech.com/html/vintchrt.html, 1997)) show similar trends, as do all long-term datasets of California wine quality. Since long-term current year ratings were not available specifically for north coast wines and because the Laube ratings are on a limited 1-5 scale, we used the Sotheby system (1-100 scale) in this study. Among the variables listed in Table 1, the decline in frosts was significantly correlated with the increase in wine ratings (r^2=0.41, Figure 6). A possible explanation for such a relation could be that frosts damage buds on the vine, delaying subsequent phenological events lead-

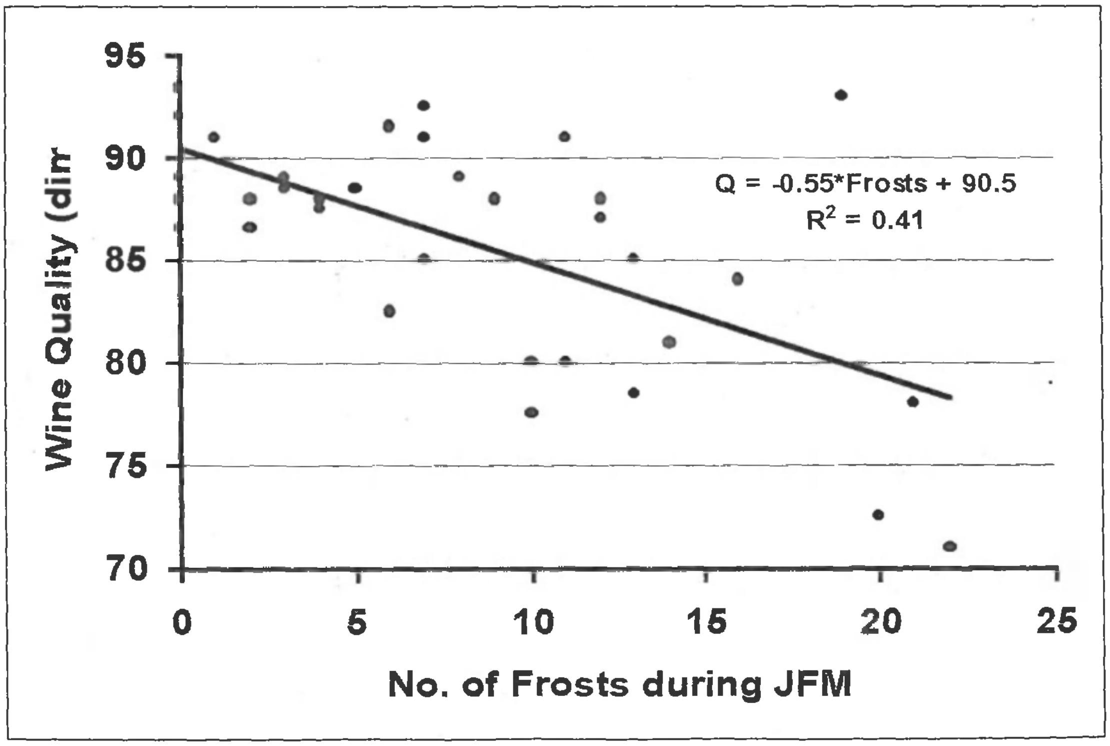

Figure 6. Observed relation between wine quality (100 point scale) and the number of frosts during January, February and March. Since SSTs are persistent for 6-12 months, such a relation is useful for predicting vintage quality months in advance

ing to uneven maturity and poor wine quality. Years with low frost also showed warm springs and low summer DTR, both of which promote wine quality (Coombe 1987). Wine ratings have a major impact on wine value. For example, analysis of Wine Spectator data showed that for 1995 Napa wines, a rating increase of 10 points translated to a 220% per bottle price increase. Grape yield grew (34%, Figure 5) from 7.3 ton/ha to 9.8 ton/ha from 1963-1996 (NAPA County crop reports), suggesting that high yield and high quality are not mutually exclusive. Increases in spring Tmin and decreases in summer VPD are able to explain more than 56% ($r2=0.56$, $p<0.001$) of the upward trend in Napa yields. In Napa valley, consequent with increasing quality and quantity, the value of the grape crop increased from $640/ha in 1963 to $19,600/ha in 1996 (NAPA County crop reports).

All parameters shown in Table 1 exhibit a pronounced increase over the 1951-1997 record, especially since the 1976-1977 shift in Pacific climate (Ebbesmeyer et al. 1990). Before 1976, a number of vintages had poor ratings associated with frequent winter frosts. However, after 1976, ratings as well as yields steadily improved with the near disappearance of frosts. Warmer SSTs after 1976, coupled with low sea level pressures enhancing the horizontal transport of water vapor (Figure 2) during 1977-1988 (Trenberth and Hurrell 1994), resulted in an unprecedented string of years with high quantity and quality. Similar warming trends accompanied advancement in phenological events and better sugar to acid ratios in Bordeaux, leading to higher wine quality over the last two decades (Jones 1999).

IMPLICATIONS FOR THE FUTURE

Unfortunately, along with the positive effects from recent climatic changes, there could be future negative impacts for the wine industry. Although Napa/Sonoma humidity levels are currently optimal (Gladstones 1992), trends toward increasing humidity and air temperature suggest that in the future, the risk of fungal and vector borne disease outbreaks may increase. Pierce's disease, a fatal bacterial (*Xylella fastidiosa*) disease transmitted by sharpshooter beetles (Cicadellidae family) and apparently limited by frost occurrence, is increasing in Napa/Sonoma. Climatic change may therefore require increased investment in pesticide application and disease-resistant rootstock.

Finally, the strong coupling between Pacific SSTs and coastal land temperatures suggests a possibility for predicting future vintages. For example, warmer winter SSTs, because of their persistence, also lead to warmer spring temperatures. This suggests that given winter SSTs, reasonable prediction of next-year wine quality may be possible. Warmer winter SSTs, on average, lead to higher quality wines from coastal California.

REFERENCES

Coombe BJ. 1987. Influence of temperature on composition and quality of grapes. Acta Hort., 206: 23-35.

Ebbesmeyer CC, Cayan DR, McLain DR, Nichols FH, Peterson DH, Redmond. KT.1976. Step in the Pacific Climate: Forty environmental changes between 1968-1975 and 1977-1984. Proc. Seventh Annual Pacific Climate (PACLIM) Workshop. Eds. JL Betancourt, Tharp VL, Interagency ecological studies program technical report, Dept. of Water Resources, Sacramento, CA, pp.115-126.

Gaffen DJ, Ross RJ. 1999. Climatology and trends of U.S. surface humidity and temperature. J. Climate, 12: 811-828.

Gladstones, J. 1992. Viticulture and Environment. Winetitles, Adelaide, Australia.

Houghton JT, Filho LGM, Callander BA, Harris N, Kattenberg A, Maskell K. 1995. Climate change 1995: The science of climate change. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K.

Jackson DI, Lombard PB. 1993. Environmental and management practices affecting grape composition and wine quality: A review. Am. J. Enol. Vitic., 44: 409-430.

Jones, GV. 1999. Relationships between grapevine phenology, composition and quality for Bordeaux, France. Arboreta Pheanologica, 42: 3-7.

Laube, J. 1996. Wine Spectator's California wine. Wine spectator press, New York, NY.

Stevenson, T. 1997. The new Sotheby's wine encyclopedia. DK Publishing Inc., New York, NY.

Trenberth KE, Hurrell JW. 1994. Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics, 9: 303-319.

Watson RJ, Zinyowera MC, Moss RH. 1998. The regional impacts of climate change: An assessment of vulnerability. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K.