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How Hot Is Too Hot?

Climate will always play a significant role in wine production and quality, but as global climates shift, how will grape-growing and winemaking practices be affected?

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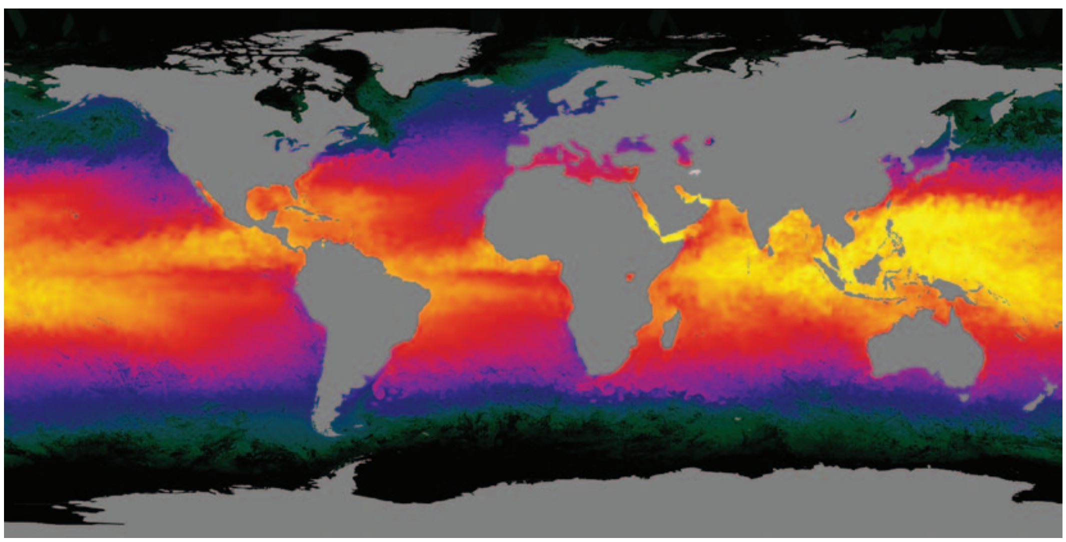

Sea surface temperatures from June 2–9, 2001, measured by the Moderate Resolution Imaging Spectroradiometer (MODIS). Cold waters are black and dark green. Blue, purple, red, yellow, and white represent progressively warmer water. MODIS is particularly helpful in forecasting events like El Niño and La Niña, as well as the Pacific Decadal Oscillation.

THE PURSUIT OF growing grapes for wine production involves a continuum of issues and processes. This starts with matching a variety to the environment (terrain, soil and climate) and continues with viticultural processes of training, pruning, vineyard care and harvest methods, then moves into the winery where style-directed methods of crushing, fermentation and aging result in a finished product. In addition, all along this continuum there are numerous cultural ties with wine production, such as regional associations with varieties, regional traditions in husbandry and wine making, and even legal constraints. This continuum is often embodied in the notion of terroir, the French concept where both physical and cultural factors interact to define the wine styles and quality that comes from any site or region.

In comparison with other broad-based agricultural crops, the growing of grapes for wine production is limited to fairly narrow geographical zones that provide the optimum environmental conditions needed for ripening quality fruit. Of all of the environmental factors, climate arguably exerts the most profound effect on the ability of a region or site to produce quality grapes and therefore wine.

In general, the average climate of a wine region determines to a large degree the grape varieties that can be grown and the style of wine made, while vintage-to-vintage wine production and quality variations are chiefly influenced by site-specific factors, husbandry decisions and short-term climate variability.

While no single study can ever capture the sum of all influences in the terroir debate, a recent study out of the University of Bordeaux may have come the closest. Studying numerous plots in the St. Émilion and Pomeral regions of Bordeaux, France, **Kees van Leeuwen** and co-authors examined the effect of vintage (climate), soil and variety (Cabernet Sauvignon, Cabernet Franc, and Merlot) on wine quality parameters (*American Journal of Enology and Viticulture*, Issue 55, No.3). The parameters included plant effects that influence quality (i.e., phenology, shoot growth cessation, vine water status, etc.) and yield components, such as fruit weight, sugar and acid levels, and phenolics (e.g., anthocyanin). The results showed that climate was the dominant factor, accounting for over 50 percent of the variation when averaged across all quality parameters, and appears to be most important in how it regulates vine water status.

Soil type and structure were the next most important factors, accounting for a quarter of the resulting wine quality. Variety differences, while not as important as climate or soil, still accounted for 10 percent of the variation in quality parameters. While the study controlled for many cultural practices (e.g., pruning type and timing, trellising and harvest timing), it would appear in this case that the cultural component of terroir roughly accounts for 15 to 20 percent of the variation in important wine quality parameters. If the results from this study are applicable elsewhere, it would appear that climate plays the most significant role in wine quality.

In the recent *Wine Business Monthly* issue "How Ripe is Too Ripe" (July 2004), the feature articles do a great job of discussing the trends in California and elsewhere toward harvesting

The spatial depiction of the Western United States American Viticultural Areas (AVAs), the general grape-growing areas studied, and the U.S. Historical Climatology Network cooperative stations used (from the 7th International Symposium on Grapevine Physiology and Biotechnology; held in Davis, CA June 2004; in press in Acta Horticulturae).

grapes at high sugar levels that produce wines with higher alcohol content. The articles go on to describe how this trend is partially a natural consequence of increasing tendencies to harvest by phenolic ripeness, not sugar ripeness, but that much of it plays to the role of being "highly rated" in large comparative tastings where concentrated, powerful wines stand out. Author **George Vierra** even calls for a new category of wine, "social wines," because they are more for show than for what wine has traditionally been associated with: food.

However, one thing lacking in the discussion was the role that climate has had in creating the conditions by which riper fruit can be achieved.

HISTORIC CLIMATE VARIATIONS

We know from history that climate has played a significant role in wine production. This was clearly evident during the Little Ice Age when viticultural viability was threatened throughout much of Europe. Records of dates of harvest and yield for European viticulture have been kept for nearly a thousand years, revealing periods with more beneficial growing season temperatures and greater productivity.

During the medieval "Little Optimum" period (roughly 900 to 1300 AD), the data indicates that temperatures were up to 2°F warmer with vineyards planted as far north as the coastal zones of the Baltic Sea and southern England. During the High Middle Ages (12th and 13th centuries), harvesting occurred in early September as compared to early- to mid-October today, and that growing season temperatures must have been 3°F warmer than today.

Conversely, temperature declines during the 14th century were dramatic, leading to the Little Ice Age (extending into the late 19th century) and resulting in northern vineyards dying out and growing seasons so short that harvesting grapes in southern Europe was difficult.

More recently, the warming of the last century or more appears to have largely benefited grape growing and wine production through the expansion of viable growing regions (England is at it again!), providing longer growing seasons, earlier phenological development, and more optimum ripening leading to better overall quality. During this time, advances in viticultural practices such as irrigation, nutrition, trellising, pest/disease control, better plant material and more experience in winemaking techniques, have certainly contributed to larger yields and better quality. In spite of such advances, grape growers and winemakers know that climate will always play a significant role in wine production and quality.

However, recent research looking at the impacts of climate change on viticulture reveals that all is not necessarily rosy. Most evident is that future impacts of climate change are not likely to be uniform across all varieties and regions, but are more likely to be related to a climatic threshold whereby any continued warming would push a region outside of its ability to ripen varieties that are already established. For some regions, the range of potential varieties that can be ripened will expand (cooler regions). However, if a region is already a warm to hot climate and warms beyond what is considered viable, then grape growing becomes challenging and maybe even impossible.

Indirect impacts show up where both new pests, and greater pest and disease pressure due to milder winters are occurring in many regions. In addition, while some studies indicate that increases in CO_2 might have a positive effect on grapevine growth and production, others suggest that concomitant environmental changes may combine with increasing atmospheric CO_2 to stunt plant growth and lower quality. Finally, as an indirect effect on wine quality, higher CO_2 concentrations have also been shown to alter the texture of oak wood used for making wine barrels.

OBSERVED CLIMATE CHANGES IN THE WESTERN US, 1948-2002

Variable	North Coast	Average Change across all regions
Growing Degree-Days (Apr-Oct, base 50°F)	295	325
Growing Season Average Temperatures	1.4°F	1.6°F
Growing Season Maximum Temperatures	+, NS	1.8°F
Growing Season Minimum Temperatures	3.4°F	2.4°F
Ripening Period Average Temperatures (8/15-10/15)	+, NS	1.8°F
Number of Days below Freezing – Annually	-25	-18 days
Number of Days below Freezing – Spring (March-May)	-5	-7 days
Number of Days below Freezing – Fall (Sept-Nov)	-3	-3 days
Date of Last Spring Frost (32°F)	52 days earlier	24 days earlier
Date of Last Fall Frost (32°F)	16 days later	10 days later
Frost-Free Period	68 days longer	34 days longer

The wine quality issues related to climate change and shifts in climate maturity potential are evidenced mostly through more rapid plant growth and out-of-balance ripening profiles. If a region currently experiences a maturation period (véraison to harvest) that allows sugars to accumulate while maintaining acid levels and producing the optimum flavor profile for that variety, then balanced wines result. In a warmer than ideal environment, the grapevine will go through its phenological events more rapidly, resulting in earlier sugar ripeness and, while the grower or winemaker is waiting for flavors to develop, the acidity is lost through respiration.

In addition, harvests that occur earlier in the summer, in a warmer part of the growing season, will result in hot and potentially desiccated fruit without greater irrigation inputs. While too high sugar or too low acid can be dealt with to varying degrees in the winery, something has to change, with flavor and/or style, most likely.

SHORT-TERM VARIABILITY

In the short-term, climate variability can play a significant role in vintage yield and quality variations. From abnormally dry seasons to prolonged drought, increased frost frequency to mild winters, cool to warm growing seasons, and dry ripening periods to untimely rains, climate variability has numerous potential impacts. While many of these climate variations are random circumstances that have little understood structure, some of the variation can be tied to large-scale geophysical mechanisms, such as sea surface temperature and atmospheric circulation changes.

Over the Pacific Ocean and North America, probably the most recognizable mechanisms—mostly due to media coverage—is El Niño. Seemingly blamed for everything from California's budget woes to 49er loses, to poor vintages, El Niño actually has a geographically mixed and minor impact on vintages originating from the western United States.

El Niño and its counterpart, La Niña, result from ocean/atmosphere interactions over the tropical Pacific, from the coast of South America to Australia/Indonesia. They typically produce wetter conditions during the winter and spring from the California/Oregon border southward, drier winters and springs in Washington, and mixed conditions in Oregon. However, both mechanisms of regional climate variability are much more influential during the winter, with little impact on the growing season climate structure in the west. Any impacts on wine production are typically indirect through water-related issues, such as heavy winter rains or inadequate seasonal rainfall that induces drought.

Arguably the more dominant mechanism for climate variability in the western United States is the Pacific Decadal Oscillation (PDO). The PDO is a measure of variation in large-scale, North Pacific sea surface temperatures and, by coupling with the atmosphere, plays a dominant role in regional circulation patterns, which in turn largely determines our weather and our climate. When the North Pacific Ocean is warmer than normal, the western United States has typically wetter and colder winters and springs, while colder than normal ocean temperatures are associated with drier and warmer winters and springs.

In terms of impacting vintage quality, the PDO has a greater impact (correlation) with vintage ratings for California Cabernet Sauvignon over the last 70 years than does El Niño/La Niña (although both are very low correlations). In addition, while the PDO and El Niño/La Niña are similar in that they are large-scale ocean-atmosphere mechanisms, their differences are quite important. Besides the geographic location that they occur, the other major difference is the time scale over which they operate: the PDO operates at something on the order of a 20- to 30-year time scale, while El Niño/La Niña events are typically on the order of six to 18 months in length. However, research has shown that the PDO and El Niño, when acting in the same phase (warm or cold event), couple to produce stronger Pacific-wide impacts than either acting alone.

WHERE WE ARE NOW

The Climate Prediction Center (*www.cpc.ncep.noaa.gov*) currently predicts neutral to weak El Niño conditions over the next 12 months, which indicates a slight tendency toward warmer and wetter than average conditions for the west coast. However, NASA's Jet Propulsion Laboratory (*www.jpl.nasa.gov*) scientists think we have transitioned to the "cool" phase of the PDO, which typically leads to wetter conditions in the U.S. Pacific Northwest, and colder and drier than normal conditions in Central and Southern California.

Because the two weather and climate features—the PDO and El Niño—are out of phase with each other (cool versus warm), the predicted impacts are not as clear. What may be most important is understanding that one represents long-term tendencies (PDO) and the other short-term impacts (El Niño).

WESTERN U.S. CLIMATE

To examine climate variability and change in the western United States, I recently completed an analysis of climate from 1948 to 2002 for 11 wine-producing regions in California, Oregon and Washington (see map).

The research examined changes in numerous temperature parameters important for grape growing and wine production, including growing season temperatures and degree-days, ripening period temperatures, and frost occurrence and timing. Over the 54-year period, the average changes in the western U.S. wine regions include: warmer growing seasons (1.6°F) with greater heat accumulation and higher ripening period temperatures; less frost on an annual and spring basis; earlier last frosts in the spring and later first frosts in the fall; and longer growing seasons (see table).

The analysis shows that the warming over the time period is largely coming from increases in minimum temperatures. Declining trends in annual (averaging 18 days over all regions) and spring (averaging seven days over all regions) frost occurrence are found in the majority of the regions. The frost-free period has increased by an average of 34 days over the time period, the last spring frost date has occurred 24 days earlier on average, and the first fall frost date is typically later (17 days on average). However, most of the change in frost occurrence and timing has come in the spring.

Focusing on the North Coast wine producing region (see map), climate changes from the middle of last century have clearly been seen where growing season degree-days have risen by nearly 300 units, with the warming largely coming from a 3.4°F increase in the average growing season minimum temperature (see table). As a result of this warming, the number of days below freezing has declined on an annual spring and fall basis, and there has been a dramatic increase of 68 days in the frost-free season length.

From this discussion and the *WBM* articles in the "How Ripe is Too Ripe" issue, the question arises, "How have the observed climate changes in the western U.S. influenced sugar levels?"

To examine this issue I used the sugar level data for the Napa Valley, described by George Vierra in *WBM* ("Pretenders at the Table"), vintage ratings for Cabernet Sauvignon (largely dominated by Napa Valley) given by *Wine Spectator* (WS), *Wine Enthusiast* (WE) and **Robert Parker** (RP) and the climate data described above for the North Coast (from 1970 through 2002).

First, a comparison of the sugar levels (higher potential alcohol) with the vintage ratings of *WS*, *WE* and RP finds that relationship is stronger for the WS than for WE or RP, indicating that *Wine Spectator* is the more important rating system for Napa Valley wines. A statistical analysis of what is driving the increases in sugar levels finds that roughly 35 percent of the variation is related to the influence of trying to achieve higher *WS* ratings and 30 percent is due to climate. In other words, climate has allowed the conditions needed to produce riper fruit, but the tendency to harvest at higher sugar levels is also driven by the economics of higher ratings.

The climate influence is dominated by variations in the length of the frost-free season, which in turn is driven by increases in minimum temperatures during the spring (most dominant) and fall (less dominant). This climate effect allows for early growth and a longer period of ripening, by which growers have more freedom in deciding when to pick. This is confirmed by phenological data from a couple of large producers in the Napa Valley that show clear trends toward earlier bud break and generally later harvests over the last 20 to 25 years.

The remaining variation in sugar levels is due to several potential factors: (1) large scale replanting due to leaf-roll virus, which when present, retarded growth and made it difficult to ripen to Brix levels beyond the low 20s—the result is a significant reduction of the ripening period in Napa by 40 to 45 days, (2) changes to better canopy management practices (trellising and fruit exposure), and (3) some inherent randomness in the system.

WHERE WE ARE HEADED

None of this discussion, however, answers the question of where are wine styles headed and what affect future climates will have on the issue. **Jordan MacKay**, in a recent article in the *LA Times* (October 4, 2004), interviews numerous wine industry and research notables, and asks, "Are California's big, ripe wines climatically dictated or are they a stylistic fad?" While climate clearly has a measure of influence, the stylistic fad question is more complex and should ask, "Are today's winemakers making wine to *their* stylistic choices, or are they playing to changing consumer tastes or wine critics?"

From a viticultural and wine-style perspective, it's hard to imagine that the current trend to riper and riper fruit can continue without impacting the vines (and growers) and causing greater adjustments to be made in the winery. But at what cost to varietal character?

Growers have been clamoring for years that the trend toward later harvests at higher sugars reduces their yield and weakens the vine. While adjusting contracts to the acre instead of the ton can ameliorate the finances, somewhat, the science is still out on what long-term effect there is on vines.

What is clear is that today's higher alcohol wines will not age as well or as long as wines of the past. This plays into the hands of the "immediate consumption trend," however wine has a mystique of age that may dominant once again. It is also clear that the process of rating wines will not end as it provides a good indicator of quality for the consumer and is entrenched in the economics of the industry. But when an average rating increase of 10 points in *Wine Spectator* translates to a 200- to 300-percent price increase per bottle, who can blame winemakers for changing their wine styles.

From a climate perspective, while the magnitude of future temperature changes is still in debate, the direction of the change is clear: climates are projected to get warmer.

From a climate perspective, while the magnitude of future temperature change is still in debate (climate models are becoming better over time), the direction of the change is clear: climates are projected to get warmer. Recent analyses of climate model output by this author and others indicate that growing season climates are projected to warm by 2.0 to 3.5°F in the western U.S. grape growing regions over the next 50 years.

The ramification of this additional amount of warming (remember that these same climates have already warmed by 1.6°F in the last 50 years) has numerous potential impacts to wine production, including: additional changes in grapevine phenological timing where average ripening periods could occur roughly one to two months earlier and at higher temperatures than today; increased challenges in achieving optimum varietal ripeness and wine balance; further changes in existing varieties grown and regional wine styles; and more spatial changes in viable grape growing areas.

Can anything be done? Probably the most evident thing is to simply be aware of changing conditions and integrate planning and adaptation strategies to adjust accordingly. Most evident will be how to deal with further changes in growth and ripening that will require adjusting site-specific management strategies and varietal makeup to achieve optimum wine characteristics and production.

Wine writer and Master of Wine **Jancis Robinson** has suggested that to achieve concurrent physiological and sugar ripening, growers may need to alter the trend to reducing crop levels through thinning, which she claims may have gone too far, and may be largely responsible for ripening and wine style changes. By allowing vines to carry a larger crop load, she argues that ripening can be slowed to some degree. Robinson also mentions work by others which suggests that mild irrigation deficits and dramatically lowered fertilizer amounts early in the season can be used to "trick" the vine into building phenolics earlier in the growth cycle and producing fewer and smaller berries per cluster.

Clearly more work on these and many other potential adaptation strategies need to be done. In addition, more research into how grapevines will respond to warmer conditions, which includes better phenological observation networks and better regional climate modeling, will be needed. **wbm**

Dr. Gregory Jones is climatologist in the Geography Department at Southern Oregon University. His research interests are in spatial relationships of grapevine phenology and varietial suitability, and how climate variability and change impact agriculture.