The Limitations of the Winkler Index

By Patrick L. Shabram

The Winkler Index or Winkler Scale is a standard for describing regional climates for viticulture in the United States. Developed by A.J. Winkler and M.A. Amerine at the University of California, Davis in the first half of the 20th century, the index was constructed to correlate wine quality with climate, focusing on California viticulture. Wine-producing regions of California were broken into five climatic regions using heat summations above 50° F, or growing degree days (GDD). Heat summations are a way of looking at accumulated temperatures over a given time period. Despite the common usage of the Winkler Index, the classifications offer greater uncertainty than the system suggests.

An obvious drawback to the Winkler Index is the focus on temperature alone. Winkler's groundbreaking resource "General Viticulture" notes the influence of "rainfall, fog, humidity and duration of sunshine," but Amerine and Winkler's work and subsequent research found that temperature plays the greatest role in the development of wine grapes. As the focus of Winkler and Amerine's wine-grape research was on California viticulture, their climatic regions had the luxury of ignoring precipitation, as little rain falls during the growing season. Indeed, Winkler et al. in "General Viticulture" suggest that the *vinifera* grape "is not suited to humid summers, owing to its susceptibility to certain fungus diseases and insect pests that flourish under humid conditions."[9]

Advances in viticulture have expanded the range of successful commercial *vinifera* production, while more recent research notes the importance of wind on photosynthesis rates.[2] Winkler et. al. also point out the importance of ongoing refinement of local variations, stating, "It is hoped that refinements will be developed so as to delimit subregions within the present regions, thereby ensuring the greatest potential for quality when the most favorable climatic subregion for a given variety is planted to that variety."

Therefore, the Winkler Index was designed at a state scale, and not necessarily intended for smaller viticultural subregions or single vineyards.

Methodology of the index

Modern-day calculations of GDD most often utilize daily accumulations of degree days. That is to say that they sum the total degrees of average daily temperatures above 50° F (10° C) for every day from April 1 to Oct. 31 [$\sum_{Apr\ 1}^{Oct\ 31}$ *daily* (T_mean-50,0)]. If the average temperature for a given day is 75° F, then the total degree days added to the total sum for that specific date would be 25° F. Any average below 50° F constitutes zero GDD for the given day.

An initial problem with some calculations is how "average" is determined. In most cases, average is calculated as the mean of the lowest recorded temperature and the highest recorded temperature, so a high temperature of 85° F and a low temperature of 65° F would produce 75° F [$(T_{max}-T_{min})/2$]. Another method to calculate average temperatures is to take the mean of all temperature readings for a given day. If a weather station reports hourly temperature readings, the mean of those temperature readings would constitute the average of the 24 daily temperature readings, while if a station reports in 15-minute intervals, the average temperature would be the mean of the 96 daily temperature readings. The simple difference in methodology for calculating average temperatures can have an impact on GDD readings. A recent study of five weather stations in the Livermore Valley AVA, for example, found variations in 10-year average GDD as high as 206 based on the methodology utilized.[6] As many weather stations have software generating GDD figures for the user, the methodology deployed is not always obvious. Further, many software programs will vary on GDD calculations, including but not limited to growing season, threshold (e.g., 50° F or some other number), and how temperatures below that threshold are handled. Some weather station software programs, for example, will not include temperatures below 50° F in the average temperature calculation.

Daily accumulation methodologies, however, are not consistent with the methodology deployed by Winkler and Amerine. Rather, Winkler and Amerine used monthly means. Specifically, the mean monthly temperature above 50° F was multiplied by the number of days in the month for each month from April to October, then summed for the entire growing season [$\sum_{Apr}^{Oct} monthly((T\_mean\text{-}50)\bullet 30)$].

Further, a 1998 assessment of temperatures in the city of Sonoma, Calif., determined that Amerine and Winkler's original calculations may have been simplified to account for only 30 days in each month.[7] Hence, GDD originally calculated in 1944 may have had four fewer days figured into the equation than what modern assessments typically apply.

The discrepancy between daily accumulation of degree days and monthly accumulation of degree days is most pronounced in early-season and late-season numbers, when mean daily temperatures may be below 50° F. As a simple example, assume that the average temperature for each day from April 1 to April 15 is 48° F and mean temperature for each day April 16 through April 30 is 54° F. Using the daily accumulation method, each day from April 1 to April 15 would have a degree-day total of 0, while each day from April 16 to April 30 would have a degree-day total of 4, for an April total of 60 degree days. With an average monthly temperature of 51° F, using the monthly average would yield a GDD total of 30 degree days for the month.

Even with consistency in methodology, other factors impact the overall GDD total, and hence the climatic region assigned to that total. Equipment and placement of weather stations are considered, although most government and research weather stations, and even most

FIGURE 1: GDD (°F) AT CAMINO, CALIF. USING TWO METHODOLOGIES

	Daily Accumulation	Monthly Accumulation
Lowest (1998)	2889	2752
Highest (2017)	4034	3932
30-Year Average	3439	3300
10-Year Average	3583	3465
5-Year Average	3821	3639

30-year average GDD based on 2017-1987 excluding 1988 because of incomplete data in 1988.

10-year average GDD based on 2017-2008. 5-year average based on 2017-2013.

commercial weather stations installed in vineyards, are assumed to be placed to limit variables that may impact climatic data. The duration of the data (i.e., number of years of data), however, can have a significant impact on numbers. Typically, meteorological normals (i.e., what is considered to be the average weather for a particular location) are based on 30-year averages, updated every new decade (e.g., 2010-1981, 2000-1971, etc.). Finding complete data sets covering 30 years in a given area can be difficult, so GDD averages used in viticulture are most commonly given in some significantly shorter duration.

Further complicating data sets is what happens around a given weather station during that 30-year period. Urban development can create warmer conditions that, combined with a changing climate, lead to migration from one climatic classification to another over the course of historical data sets. Further, academic studies are often done in Celsius, with the Winkler climatic regions converted to Celsius equivalents. For example, Region II is converted to 1,389-1,667° C (from 2,501-3,000° F), giving the impression that the climate-region breakdowns are based on something more accurate than the convenience of even 500 degree day intervals. (Since the original region breakdown is in Fahrenheit, and this article is a discussion of those regions, Fahrenheit is used throughout this article unless otherwise noted.)

To demonstrate how varied GDD numbers can be for a given location, data were assessed from a California Irrigation Management Information System (CIMIS) station at Camino in El Dorado County, Calif. This station was chosen because it is one of the longest continuously operating CIMIS stations, having been installed Oct. 19, 1982. Data from this station are also nearly complete, especially after 1989. The station is not near a growing urban center. Camino is listed in "General Viticulture" (Region III with 3,400 GDD). This station is not the same weather station used in the Winkler calculations but offers some historical context for the Camino area in general. Thirty total years of data were assessed from 2017 to 1987, with 1988 removed from the analysis, as data were incomplete. The results in Figure 1 show that daily accumulations led to higher GDD totals than using monthly means.

Variations in averages

Both the daily accumulations and monthly accumulations totals at the Camino station are relatively consistent with the total found in Winkler et al., although the numbers are 139 degree days different, based on methodology. If a grower had been given a single year's data, however, and that year happened to be either the year with the lowest GDD (1998), or the year with the highest GDD (2017), very different conclusions could have been reached about the climate of Camino.

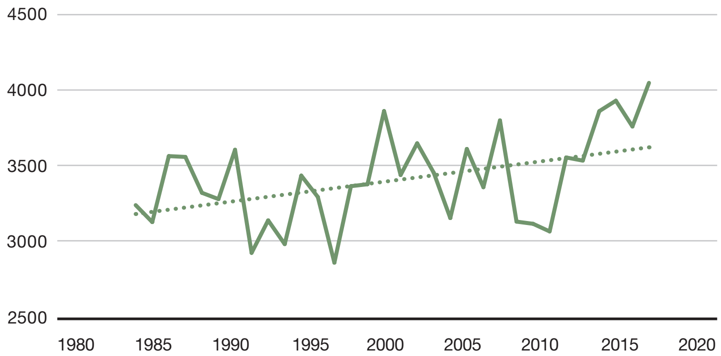
The averages for the five most recent years show both a warmer climate than the 30-year average would suggest and greater variance between methodologies. Keeping with standards of climatology and meteorology would discredit the five-year average as insufficient, as weather varies season to season, and climate is a long-term averaging of weather. Yet getting five years of data is often much more achievable than obtaining 30 years of data. The climate is also warming. Figure 1 demonstrates the long-term temperature trend in GDD for Camino, with every academic indication that this trend will continue. The prospects are very likely that ongoing climatic conditions at Camino will more likely reflect GDD above the 30-year average. Which Winkler Index climate region is most appropriately applied to Camino? Any interested party could have a choice between Region III or Region IV, or if they were really looking to cherry-pick, Region II or Region V.

Comparative analysis is where a more appropriate usage of GDD may come into play. How does Camino compare to other nearby areas? A CIMIS station is also located at Diamond Springs, approximately nine miles southwest of Camino. Diamond Springs is a much newer station, installed Sept. 20, 2010, so a 30-year average is not possible. The five-year average at Diamond Springs based on daily accumulations is 3,997 degree days compared to 3,821 at Camino. The seven-year daily accumulation average (2011-2017) at Diamond Springs is 3,913 compared to 3,679 at Camino. Every year with the exception of 2017 shows higher GDD at Diamond Springs than at the Camino weather station (2017 shows Camino 30 degree days higher than Diamond Springs). Even if you could not give a good long-term average GDD for Diamond Springs, it would be safe to say that the climate at the Diamond Springs station is warmer than at the Camino station. As viticultural growing districts become more defined at subregional levels and as we test new environs for commercial viticulture, local comparisons are valuable.

Duration of high temperatures

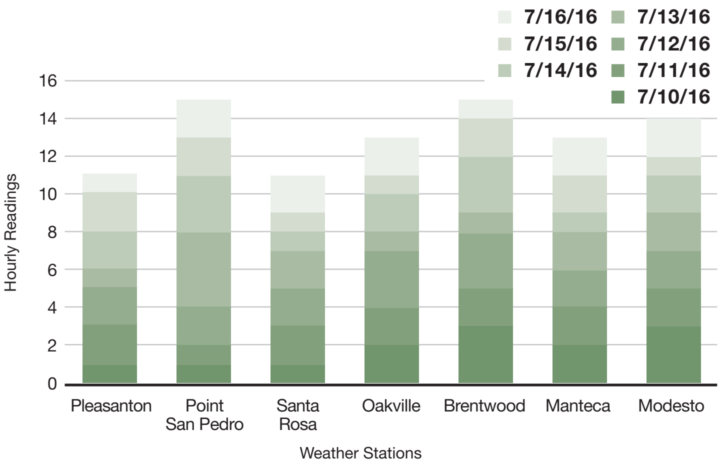
Another consideration with Winkler climatic regions is the duration of high and low temperatures. GDD calculations based on mean daily temperatures treat high and low temperatures equally, even if the high temperature is reached for only for a few minutes, but the low temperature persists for several hours. Areas impacted by afternoon marine inversions may be especially susceptible to briefly maintained high temperatures. Figure 3, created for a study done in the Livermore Valley AVA, shows the cumulative number of

FIGURE 2: GDD TREND APRIL 1-OCT. 31 AT CIMIS 13 CAMINO 1984-2017



Using daily accumulation method based on daily mean temperature. Data for 1986 and 1988 are incomplete and are not included in the graph.

FIGURE 3: HOURLY READINGS AT HIGH TEMPERATURE



Adopted from Shabram, 2017. All data collected from California Irrigation Management Information System. Temperature reading within 0.3°C or 0.5°F of the daily maximum temperature were counted from July 10-16, 2016.

hourly readings at or near the daily high temperatures for several CIMIS weather stations in Northern California over a one-week period in July 2016. Cumulative high temperatures were maintained for a shorter period at Santa Rosa and Pleasanton, two areas known for variable summer marine intrusions, than at Point San Pedro, Brentwood and Modesto. Point San Pedro, at the immediate coast, has greater consistency in marine stratus layers than Santa Rosa and Pleasanton, which experience fluctuations in coastal fog. Brentwood and Modesto, both inland from the coast, are known to be relatively free of coastal fog. Many areas transitioning from coastal to inland may show GDD numbers similarly influenced by brief durations of high temperatures. Comparatively, similar GDD summations for areas at higher latitudes or greater elevations may show greater total hours near high temperatures or longer periods of solar radiation. Using average air temperature rather than daily mean temperature may create more accurate comparative numbers, assuming that the methodology is consistent across the areas being assessed.

Variations in growing season

A final consideration is the April 1 to Oct. 31 growing season used in GDD calculations. In areas of the West Coast, bud break typically occurs in March, sometimes as early as February, while harvest dates in August and September are more common than in October. Grape variety and microclimatic conditions in individual vineyards also play a role.

A review of 50% bud break from 2013 to 2018 and harvest dates from 2013 to 2017 was conducted in seven vineyards in the Livermore Valley AVA, three planted to Chardonnay, three planted to Cabernet Sauvignon and one planted to Sauvignon Blanc. The average 50% bud break ranged from March 28 to April 5, depending on vineyard, for the three Cabernet Sauvignon vineyards, but the Chardonnay vineyards had average dates of March 14 to March 15. The Sauvignon Blanc vineyard experienced 50% bud break around March 26. Harvests for Cabernet Sauvignon approximated Oct. 8 to Oct. 21, depending on the vineyard. Chardonnay saw average harvest dates of Sept. 20 to Oct. 7. The vineyard with Sauvignon Blanc saw average harvest dates around Aug. 28. In many cases, bud break began prior to the April 1 growing season start, while harvest was most often completed prior to the Oct. 31 growing season end.

The rationale for calculating heat summations from April 1 through Oct. 31 are not clear, at least not in Amerine and Winkler's best-known works on the subject. The 50° F threshold is based on shoot growth, so April 1 may represent an approximate estimation of bud break, but harvest for many varieties occurred, even in the first half of the 20th century, prior to Oct. 31. Amerine and Winkler also calculated heat summations from bloom to harvest and noted the role of heat summations in the 30 days preceding harvest, therefore not limiting their assessment to just April through October. Heat summations based on bloom and harvest are only possible when grape production already exists within an area and would be difficult to use as a tool to match varieties to an area yet to see vines. Differential timing and lengths of growing seasons across North America further complicate the equation.

Is there a better index?

Other indexes also exist for assessing temperature. The Heliothermal Index, also known as the Huglin Index (HI), was introduced by Pierre Huglin in 1978. HI is the April 1 to Sept. 30 sum of the mean of the daily mean temperate above 10° C and the high temperature above 10° C, multiplied by a coefficient indicative of the latitude. Other indices include Average Growing Season Temperatures (GST) and Biologically Effective Degree Days (BEDD), along with several other formulas for calculating heat summations.

A 1999 study by Jorge Tonietto and Alain Carbonneau suggests that a multicriteria system of calculating HI, a dryness index (DI), and a cool night index (CI) are needed to account for potential water balance in soil and nocturnal temperatures in grape development.[8] Gregory Jones and others used PRISM climate models to assess spatial climatic distribution across California, Idaho, Oregon and Washington based on the four most commonly used indices in viticulture.[3,4] The results suggested that GST and GDD had the greatest correlations, but HI and BEDD demonstrated better differentiation of climate types. A similar study by Rosalyn Francine MacCracken and Paul R. Houser used the PRISM model to predict how well these four indices, along with a modified version of the GST accounting for the common length of a growing season (Modified-GSTavg or Mod-GSTavg), performed in U.S. states east of California, Oregon and Idaho.[5] The MacCracken and Houser study found all common indices to be less than perfect at predicting the viability of successful viticulture when comparing the indices' results with existing viticulture. Mod-GSTavg showed more promise as a predictor of successful viticulture by taking into account the length of the growing season.

The Jones et al. study and the MacCracken and Houser study looked at viticulture on a super-regional scale, albeit using climatic models with 400m to 400m resolution. One could argue that the Winkler Index was never meant to be utilized on a super-regional scale, but rather as a statewide guide specific to California. The original 1944 paper looked only at California locations, with Winkler later introducing other U.S. and international locations into the scale for comparison. Winker et al. are clear that the regional scale was not meant to be definitive at a subregional scale: "These divisions into climatic regions should be considered as general demarcations."[9]

Winkler et. al. suggest more extensive work be conducted on more local areas and specifically note the work of Robert Sisson, who, during his 35-year career as viticulture farm advisor to Sonoma County from the 1950s to the 1980s, created a climate classification system unique to Sonoma County. Sisson's model broke the county into Marine, Coastal Cool and Coastal Warm climate types, based loosely on heat summations of hours spent between 70° F and 90° F. While much work has been done to delineate subregions of viticultural areas, both formally through the creation of new, smaller AVAs and informally through the identification of subregional districts by winegrowing associations, work to create climatic classification systems at more local levels unfortunately is scarce.

Use of the Regions I-V designations of the Winkler Index presents several limitations and errors. GDD calculations, on which the Winkler Index is based, can be a valuable tool for comparing growing areas, but GDD is just one aspect of climatic analysis that alone gives an incomplete picture (as are other indices designed to summarize heat summation). The methodology, daily climatic patterns, period assessed and length of growing season can all tell a different picture of mesoclimates that might otherwise appear to be similar by Winkler designation. Ideally, each viticultural region would find a climatic classification system that best suits the unique characteristics that define it, while reserving simpler indices like the Winkler Index for broader generalizations. Alternatively, GDD makes a good comparative tool when consistency in methodology and comparison are made within regional locations.

Patrick Shabram is a geography professor at Front Range Community College in Colorado and an expert on American Viticultural Areas (AVAs). He conducts geographic research on wine-grape growing regions and is a consultant for growers interested in establishing new AVAs or modifying boundaries to existing AVAs.

The references for this article are available online at winesandvines.com