Climate and Phenology in Napa Valley:
A Compilation and Analysis of Historical Data

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Executive Summary

In response to, and sponsored by the Napa Valley Vintners (NVV), this study was designed to evaluate the climate of the Napa Valley (NV) and explore links between climate and wine grape phenology and composition. Specific objectives of this study are to a) *describe the spatial and temporal structure of climate in NV*; b) *explore linkages between climate and phenology/harvest*; and c) *evaluate historical trends in temperature*.

NV shares traits of both coastal and interior climates. The southern portion of NV is more coast-like while the central northeastern side of NV is more interior-like. Elevation also plays a strong role, e.g., heavier precipitation and lower summer daytime temperatures generally occur in higher elevations relative to the valley floor.

Approximately 30 private weather stations distributed throughout NV allow inspection of fine-scale temperature variability from north to south, and along a transect of changing elevations across the valley from east to west. These records vary in length, but mostly cover 2 to 15 years from the last two decades. Generally, all stations display similar variations (i.e., warm periods are relatively warm at all stations). There is marked variability by location (i.e., southerly and higher-elevation sites are cooler in summer months, containing lower daytime maximum temperatures and higher nighttime minimum temperatures than more inland and valley floor sites. The daily and seasonal temperature ranges and temperature extremes observed in NV are greater than cool coastal climates, but smaller than warmer inland climates. During summer, cloud cover in NV shares patterns more similar to the coast than to the interior Central Valley. Cloud cover in the southern part of the NV is greater in July and August than it is in April, May, and June. Days with higher morning cloud cover in NV generally do not attain afternoon temperatures as high as those with lower morning cloud cover, even though cloudiness may dissipate by early afternoon.

In addition to local influences, climate in NV has a very clear, significant association with large-scale variations and trends. Large-scale atmospheric circulation plays a strong role in setting up anomalously warm and anomalously cool days in NV. Anomalous Pacific Ocean temperature patterns are linked quite strongly to NV temperatures during winter and early spring months, but not so much during summer months.

Temperature records from the longer-term stations in the region indicate that the NV has experienced warming over the last several decades. At several of the stations, the warming that is detected is stronger during the nighttime than in the daytime, and it has occurred preferentially during the year--primarily during January through August. Relatively high rates of warming in NV are found in 6-9 decades of temperature records within the NV from the Napa

State Hospital and St. Helena cooperative observer (COOP) stations. Similar warming trends are found at other cooperative stations surrounding NV.

The trends of minimum and maximum temperature at the COOP (COOP) stations, which amount to a warming of mean temperature that is approximately .03 ^{o}F/yr since 1931, are essentially the same trends that have been reported in previous studies of regional temperature in the Napa region, including the study by Jones and Goodrich (2008). However, COOP stations have undergone several location changes and have had instrument changes. The present installations and locations do not give confidence for stable, un-altered temperature records. The Napa State Hospital installation is very close to a building and an air conditioner outlet. St Helena is mounted on the roof of a building. That there may be an excessively high warming in the Napa and St Helena COOP records is suggested by comparisons between the temperatures from the COOP stations with those from other stations in the region. These include the temperature recorded at and above the earth's surface by the Oakland radiosonde (upper air sounding) record. California Irrigation Management Information System (CIMIS) weather records and several sets of vineyard temperature records mimic the variability shown by the longer records.

The U.S. Historical Climate Network (HCN) cooperative station temperature record from the National Climatic Data Center provides a record that is adjusted, in attempt to eliminate spurious trends. The adjusted trends in maximum and minimum temperature are lower than the trends from the COOP data, however this change is problematic because of the lack of a long stable record in the immediate region that could be used as a reference series. Petaluma, which appears to be the record having minimal amounts of adjustment, has itself gone through moves and is in a dubious site as it is also close to a structure. Thus it is possible that even adjusted Napa State Hospital COOP trend may still be affected by some, unknown amount of artificial trend, although the amount of that error could be by way of either too little or too much warming trend.

While the records that have several decades of record are not of sufficiently high quality to precisely determine the temperature trend in the non-developed portions of NV, the evidence suggests that the warming in most non-urban parts of NV over the last 6-8 decades has been *significantly less* than the approximately +0.03^{o}F/year trend in mean temperature that is contained in the unadjusted COOP stations from Napa State Hospital and St. Helena. Comparisons between the COOP stations and other temperature records from sites that are less affected by human alterations suggests that the amount of nighttime warming has been significantly less than the .05°F/yr that is derived from the raw COOP records, and that daytime temperature warming has been close to zero. *It is important to emphasize that while the trends from the COOP stations appear to be artificially affected and too much warming, there nonetheless has been a real warming trend.* Overall, it appears the warming that has occurred in the Napa region has mostly occurred during nighttime hours, as exhibited by daily minimum temperatures. Warming of nighttime temperature exceeds that of daytime temperature, as indicated by daily maximum temperatures.

NV grape phenological stage timing and harvest characteristics are significantly influenced by antecedent weather and climate, with these antecedent influences in some cases being detected as early as early winter. A rule of thumb is that earlier phenological stages are linked to prior warm conditions. Correlations between phenological stages are relatively robust amongst three stages (bloom, véraison, and harvest), but weak for any of these stages in association with budburst. Phenological dates are not very well-correlated with total annual growing degree-days (January-December), in the sense that higher degree days associates with earlier phenological timing. However, each phenological stage is strongly correlated with the accumulation of specific thresholds of degree-days (which may vary by variety). These could be used to predict the timing of development by variety.

Analysis of comprehensive county-wide crush reports from 1990 onward demonstrated that there is a strong trend of increasing Brix at harvest over time. The most dramatic increase was for Zinfandel, from close to 20 to above 26 over the 18 year record. Sauvignon blanc has seen the least change, an increase of about 1 degree Brix. Cabernet has increased from about 23 to 26 degrees. There is also a trend across all varieties except Sauvignon blanc for decreased yields over time, most dramatically for Zinfandel (from close to 6 to about 2.5 tons/acre) and Merlot. Chardonnay yields have declined only slightly, holding steady near 4 tons/acre. Sauvignon blanc has the highest yields of all varieties studied, and has been increasing over time. There is some synchronicity in yields across varieties within a given vintage, presumably due to climatic conditions (for example, 1997 was a high yielding year for all varieties). Vineyard management practices, used to achieve desired wine styles, have changed over the last 20 years, in ways that may affect phenological dates. For example, later pruning can lead to later budburst dates. Practices such as leaf thinning and cluster thinning may act to speed up ripening, while vineyard practices such as hedging may delay ripening. However, we lack access to management records that would allow examination of the statistical importance of these practices. Nonetheless, climate plays a dominant role in setting phenological dates (for example, in initiating bud growth in the spring, and affecting fruitfulness and berry set, among other factors).

As a general pattern, Brix increases with later harvest dates. However, recent harvests (last 8 years) have been very high in Brix, and not anomalously late. Generally, the trend has been toward later harvest dates, though it varies by variety (Pinot earlier; Cab Franc, Cab Sauvignon and Merlot about 2-3 weeks later over 30+ year period). Recent Brix increase is believed to be due to stylistic and winemaking preferences, but needs further investigation.

This data collection and synthesis was a substantial effort on the part of both contributors and analysts. Now that it has been completed, there is a valuable template for moving forward. The effort highlights the need to continue to, and improve monitoring, which will provide the means for an ongoing assessment of both climate and vine development in NV.