Advancing the Amerine-Winkler Index and Adaptive Capacity of California's Wine Industry

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Introduction

Over roughly two decades, from 1935 to the mid-1950s, Maynard Amerine and Albert Winkler (1944, 1963) characterized the grape and wine chemistry and quality for more than 100 grape cultivars and thousands of wine vintages to develop the temperature-based Winkler Index and classify California's burgeoning wine growing regions. Over the years, this seminal work drove varietal choice, proved critical to the development of California's fine wine industry, and established the UC Davis Department of Viticulture and Enology as a global leader in practical, industry-driven research. While impressive in scale and scope for its time, Amerine and Winkler acknowledged the limitations of their index, noting that their focus on mean temperature ignores the multiple environmental factors beyond ambient air temperature that drive the capacity for fine wine production. Over the intervening decades, the considerable developments in the fields of plant sciences, climate and physical modeling, and proximate and remote sensing can now be directly applied to filling the gaps that Amerine and Winkler lacked the data to address. The resulting updated index will include environmental parameters that most significantly affect plant health, berry chemistry, and ultimately wine quality. With renewed interest by industry and stakeholders to understand how to best mitigate climate change effects on existing vineyards and choose appropriate cultivars for the future, it is timely to use updated methods and data sources to generate a new metric of cultivar suitability that integrates all relevant climatic and environmental parameters. As one of the most important historical figures in bringing both California and Napa wine into the international spotlight, it seems only fitting that the above stated efforts should be supported by Warren Winiarski to facilitate both the development of an updated Winkler Index and efforts to maintain the U.C. Davis Viticulture & Enology Dep't as a global leader in viticulture, enology and climate change.

The Winkler Index is based on a heat summation approach, but since the time of its publication, researchers have recognized several limitations to this approach for wine grapes. For example, Wang (1960) noted the importance of several factors not addressed in such indices, including variation in temperature response across phenological or developmental phases (e.g, budburst to flowering, flowering to veraison, etc.), the non-linearity of temperature responses, and the failure to include other parameters such as water availability (i.e., soil moisture) and atmospheric demand or vapor pressure deficit, which increase vine water use and influence developmental rates as well as whole plant physiology and berry chemistry. In addition, factors such as the amount and intensity of light or radiation, day length, and within-canopy light environment are critical factors not considered in the current index. Hourly climate data in the form of growing degree hours and diurnal temperature fluctuations have proved to be more accurate in predicting time to maturity and other critical phenological periods (Gu 2016). Further, improved physiological understanding of grape vine response to temperature suggests it is inappropriate to assume the base temperature of 10 °C (50 °F) is accurate for all cultivars, or that there is a linear accumulation of degree hours or degree days above that base temperature. The linear increase approach to modeling developmental rates or berry chemical traits is especially problematic under extreme climate conditions, such as heat waves and drought, which have and will continue to increase in intensity, duration and frequency (Figure 1). Additionally, we now have the data and methods to base the initiation of growth not on calendar days, but a model of chilling accumulation and subsequent warming to achieve budbreak and shoot growth. While there are other indices that have incorporated some of these additional factors such as day length, temperature extremes and/or diurnal temperature ranges (Jones et al. 2010), none have gained significant traction. In fact, they are only slight modifications of the Winkler growing degree day index, and none have included VPD, vine water use, variation across developmental stages, or cultivar-specific parameterizations of responses to water availability and heat.

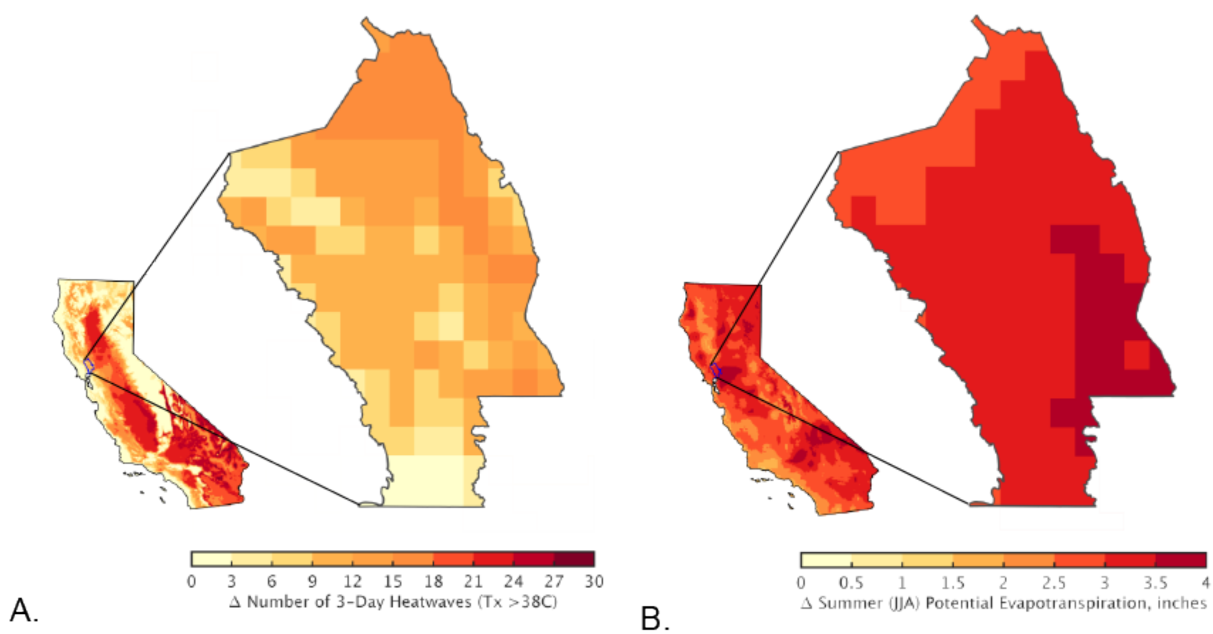

Figure 1. Napa Vally observed climate means (1981-2100) minus end of century (2071-2100) projections for: (A) Change in number of heatwaves where maximum temperatures exceed 38° C (100° F) for three consecutive days, and (B) Change in potential evapotranspiration in units of inches. Climate data are from CMIP5 RCP 8.5 20 model-means at 4 km grid cell resolution.

We propose the development of an improved Amerine-Winkler Index that incorporates data on: 1) cultivar-specific growth parameters and models (i.e., a non-linear model of growth and development, initially for Cabernet Sauvignon, eventually extended to other varieties and regions), 2) accurate data on light intensity and radiation at small spatial scales (400 m2), 3) clone and rootstock identity, 3) soil characteristics (Toby O'Geen, UC Davis SoilWeb), 4) field-specific irrigation practices and estimates of vine water use (ETo, VPD), 5) downscaled remotely sensed hourly temperature data and daily ET, and, 6) berry temperature and physiology data. These data will first be collected across diverse vineyard sites in the Napa Valley AVA, which will enable the establishment of parameters for a new index that will be more site and cultivar specific. This approach will subsequently be extended to and tested in other regions, and to downscaled future climate projections (Flint & Flint 2012, 2014). The establishment of a new index and the development of new models of grapevine and berry development will provide guidance for the viticulture and wine industry to cope with current and future climate, manage existing vineyards, and make decisions on future plantings and wine making choices.

Phase 1: Updating the Winkler Index for Cabernet Sauvignon in Napa

For the initial work to advance the index, we propose to focus on the Napa Valley and its constituent AVAs, and on Cabernet Sauvignon as the initial research cultivar. This is for both historical and practical reasons: Napa is a prominent and widely recognized high-quality wine region, and Cabernet Sauvignon is the most widely planted and profitable grape cultivar, both as fruit and in the bottle, for California and globally. It is critical to address how this renowned California wine region and preeminent grape variety will fare under current and future climate scenarios. The Winkler regions within the Napa Valley AVA spanned Regions I-III in the original classification, but based on an analysis of current and updated climate data, has moved out of Region I into Regions II-V, thus spanning a warmer but wider range of climatic diversity today (Figure 2). We propose to collect data across the range of conditions and climates that Cabernet is grown in Napa by working directly with industry contacts. In the first two years (2020 & 2021), site visits will be made to wineries and vineyards to collect data on rootstock, clone, vineyard age, slope, aspect, trellis, canopy architecture, historical phenological data, berry chemistry, and any other relevant historical data. In conjunction with these data, we will integrate new soil maps (California Soils Resource Labs), remotely sensed potential and actual evapotranspiration, thermal imagery, high-resolution microclimatic data from existing weather stations, and ET stations (CIMIS and grower installed systems such as Tule). As many growers across Napa utilize the Tule system, and Co-PI McElrone guided the original development of the surface renewal system, we are confident that we will be able to work at multiple vineyards with the system in place. This will also enable validation of new remote sensing methods to measure ET being developed by the McElrone Lab. Additionally, at a subset of sites we will supplement these remotely sensed data and field records with collections of berry chemistry and vine physiology during berry maturation. These data would enable us to model and test what the most relevant environmental factors and agronomic practices are driving grapevine maturity, berry chemistry, and potential wine quality. Ultimately these methods and models can be expanded across California and to wine regions around the world.

Collaboration with Special Collections and the UC Davis Library: As part of the effort to update the Winkler regions, we are also recording the original cards from the study, and information on varieties to generate a visual tool that illustrates the Winkler Regions and their movement through time. Additional context and data will be incorporated from findings in the papers of Maynard Amerine and Harold Olmo. Supporting research on the cultural and historical importance of the Winkler Index would provide context for the proposed work and provide bridges between the department and the world's most comprehensive wine and viticulture library and species collections, as well as support the basis for further research on these historical documents, and foster collaboration across the sciences and humanities.

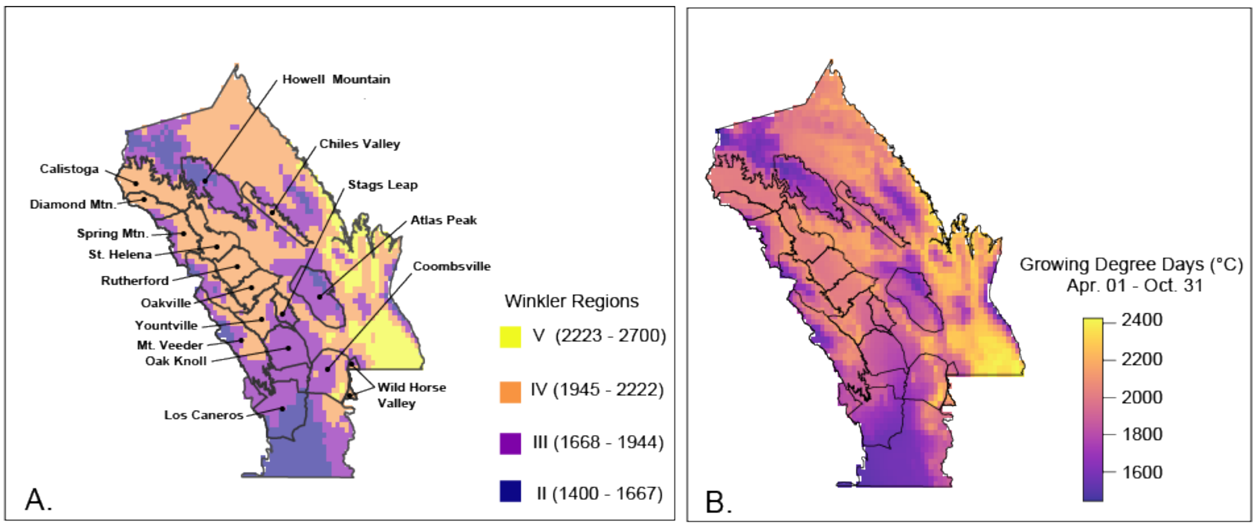

Figure 2. (A) Winkler Regions for American Viticultural Areas (AVA) within the Napa Valley and associated range of growing degree days, (B) and growing degree days above a base temperature of 10 degrees Celsius between April 1 and October 31st calculated according to Winkler & Amerine 1944. Degree days were calculated from the 1980-2010 climate normals at 800 meter grid cell resolution from the PRISM downscaled climate dataset (Daly et al. 2015).

Phase 2: Expanding cultivar diversity and geographic extent

In the second phase of the project, we will characterize the physiological and chemical properties of other grapevine cultivars widely planted in California, as well as others that may be potential cultivars for the future of California such as those adapted to higher heat and greater atmospheric water demand. This will entail taking detailed physiological measurements and monitoring of these additional cultivars across the growing season, which will be used in to build phenological models to predict berry maturation and associated chemical properties, as well as parameterize models estimating whole plant water use and energy balance. These empirical data will be integrated into new computational and model building tools developed by co-PI Brian Bailey, who had begun building physical models of water use and berry temperature under variable canopy architectures or trellis designs, topography, row orientations, climatic parameters, light interception, and soil depths. Prof Bailey has laid the groundwork to generate practical and increasingly accurate 3D models of vine and whole vineyard growth and production, which will be critical for predicting the appropriate vineyard establishment and cultural practices, cultivars and irrigation regimes for a given site. We will be able to use our empirical data in combination with these new modeling approaches to test and extend the new index to other regions.

While relevant ongoing research and experimental vineyard establishment of Future Variety Blocks for California are underway both in Oakville and Davis, there is no long term funding secured to support these and related efforts associated with the adaptive capacity of viticulture in the face of climate change. PI Forrestel has been provided seed funding to establish an International Initiative for Viticulture Adaptation which initially includes Adelaide and Bordeaux as partners for collaboration and data sharing, and we foresee potential future funds supporting efforts to maintain UC Davis as a global leader in viticulture and climate change.

Timeline

Year 1: Phase 1, Site identification and data collection in Napa Valley for Cabernet Sauvignon, and model/index development, with outputs produced specific to the development of a new index.
Phase 2: Measurement and parameterization of additional cultivars
Year 2: Phase 1. Data collection in Napa Valley, focus on berry chemistry and sensory study.
Phase 2: Measurement and parameterization of additional cultivars
Year 3+: Phase 2. Continue developing/testing models for a broader set of grapevine cultivars, potential refinement of index broader geographic extent and climatic/environmental range.

Executive Summary (Projected Project Outcomes):

- Update seminal heat summation index of Amerine & Winkler
- Bring their historical work into the 21st century
- Utilizing new data, technology & methods, model environmental drivers of vine and berry chemical properties for Cabernet Sauvignon in the Napa Valley
- Parameterization and model development for characterizing other wine grape cultivars
- Provide groundwork for extension of methods and index to other regions and cultivars

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