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RESEARCH ARTICLE

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A 4-week advance in the growing season in Napa Valley, California, USA

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Abstract

The growing season start and duration, along with other temperature-related measures of importance to premium wine grapes in Napa Valley, California have changed as climate over the western United States has warmed. The growing season start has varied from year to year with a standard deviation of about 3 weeks, but over the 1958–2016 record a linear fit to the time sequence shows it advanced by more than 4 weeks. Over the study period, advances in the growing season were strongly influenced by temperature increases beginning in the late 1960s with warm anomalies generally persisting through recent years. The date upon which the growing season accumulated 1400 growing degree-days also shifted earlier by about 4 weeks. Other measures swung to a warmer status, including the mean temperature of the last 45 days of the growing season, which warmed by over 1.5°C. Warming days and especially warming nights contributed to the growing season advance as well as trends towards warmer expressions of other viticultural measures. Years with earlier and warmer growing seasons experienced a substantial reduction in the number of daily cool extremes, and an increase in daily warm extremes, including the number of days whose temperature reaches or exceeds 35°C.

KEYWORDS

California, climate change, climate variation, growing season, Napa Valley, phenology, temperature, viticulture

JEL CLASSIFICATION

Q10

1 | INTRODUCTION

Napa Valley, located north of San Francisco Bay in the transitional climate between California's coast and Central Valley (Figure 1) is one of the premiere viticultural regions of the world. Wine grapes, reported as the world's most valuable crop (Wolkovich et al., 2018), contribute substantially to California's agricultural economy. Napa Valley's wine grapes and wines are dependent upon its Mediterranean climate with warm dry summers and cool wet winters (Skinner, 2003). Napa Valley shares characteristics of both interior and coastal climates of the central California

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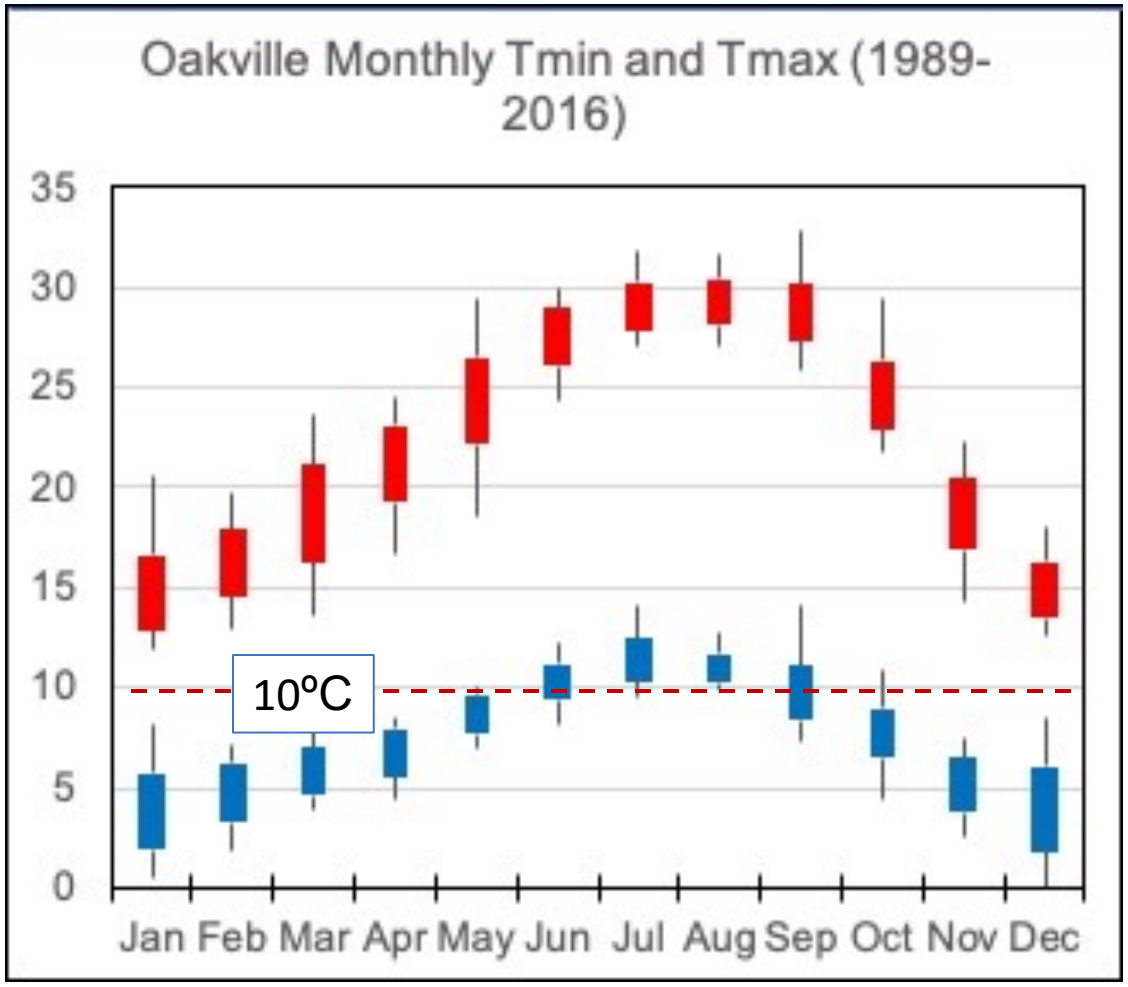
Napa State Hospital
Temperature Recorder
outside Fire Station

ºC

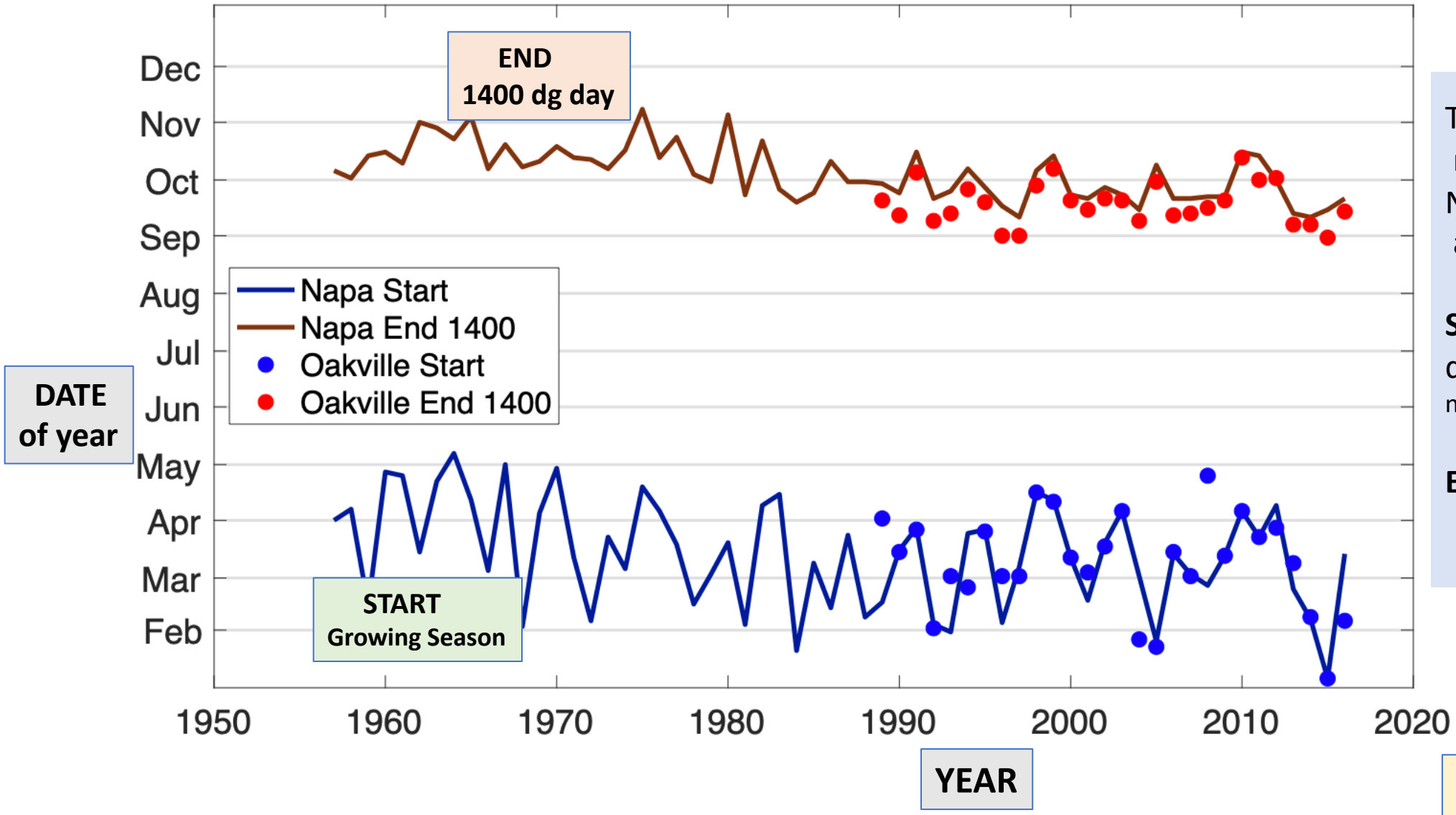


Average Daily Tmax and Tmin (ºC)
Oakville CIMIS Monthly average
1989-2016

Growing season start
when mean daily temperature
rises to 10ºC (50ºF) or above
without dipping below for
more than 3 days

Napa Growing Season shifted 4 weeks earlier

from late 1950's to mid-2010's



Temperature-based measure from Napa State Hospital and Oakville CIMIS

Start

daily T ≥10dg C (≥50dg F

no more th 3 d of interruptions

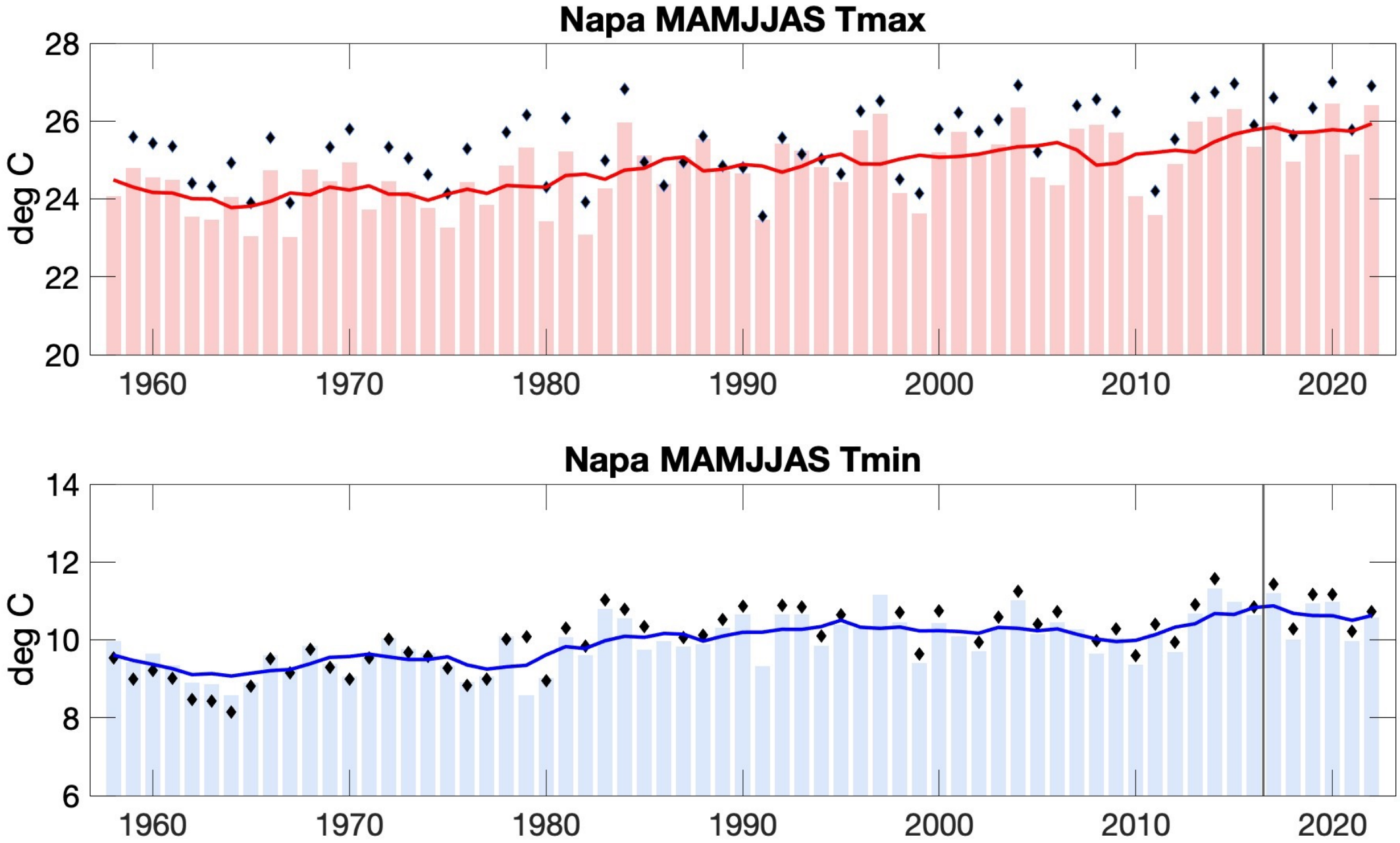
End

1400 dg day (Celcius)

2520 dg day (Fahrenheit)

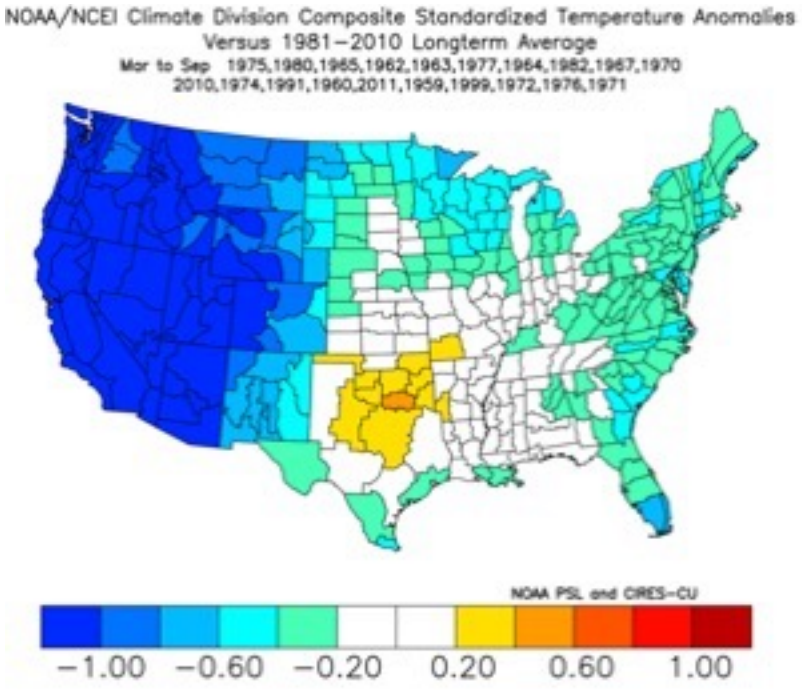
Napa v. Oakville correlations

start 0.71 end 1400 0.93

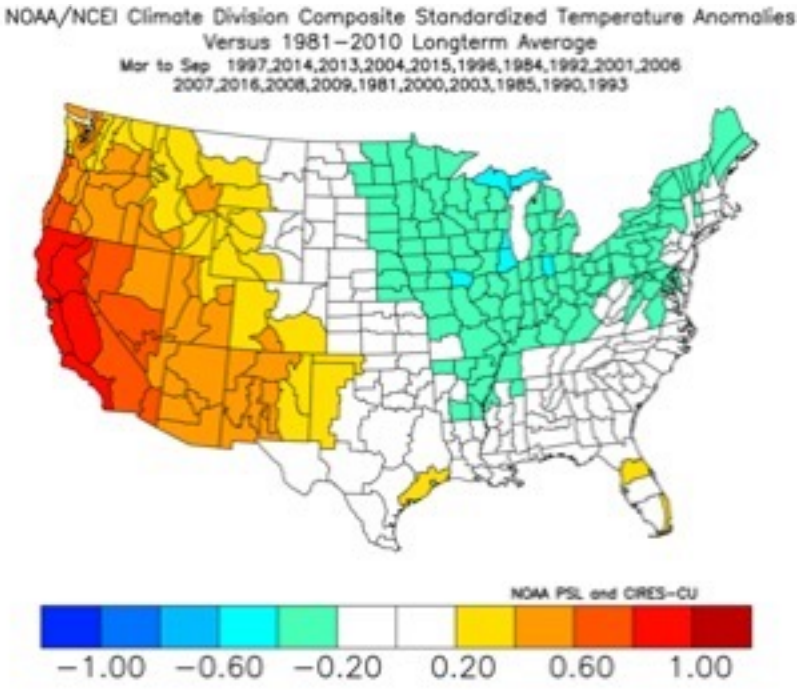

Napa MAMJJAS Tmax
deg C
28
26
24
22
20
1960
1970
1980
1990
2000
2010
2020
Napa MAMJJAS Tmin
deg C
14
12
10
8
6
1960
1970
1980
1990
2000
2010
2020

Napa Growing season fluctuation linked to regional temperature anomalies

Mar-Sept divisional temperature anomaly average (std deviations) during late and early growing season end 1400 dg days



Late End growing season

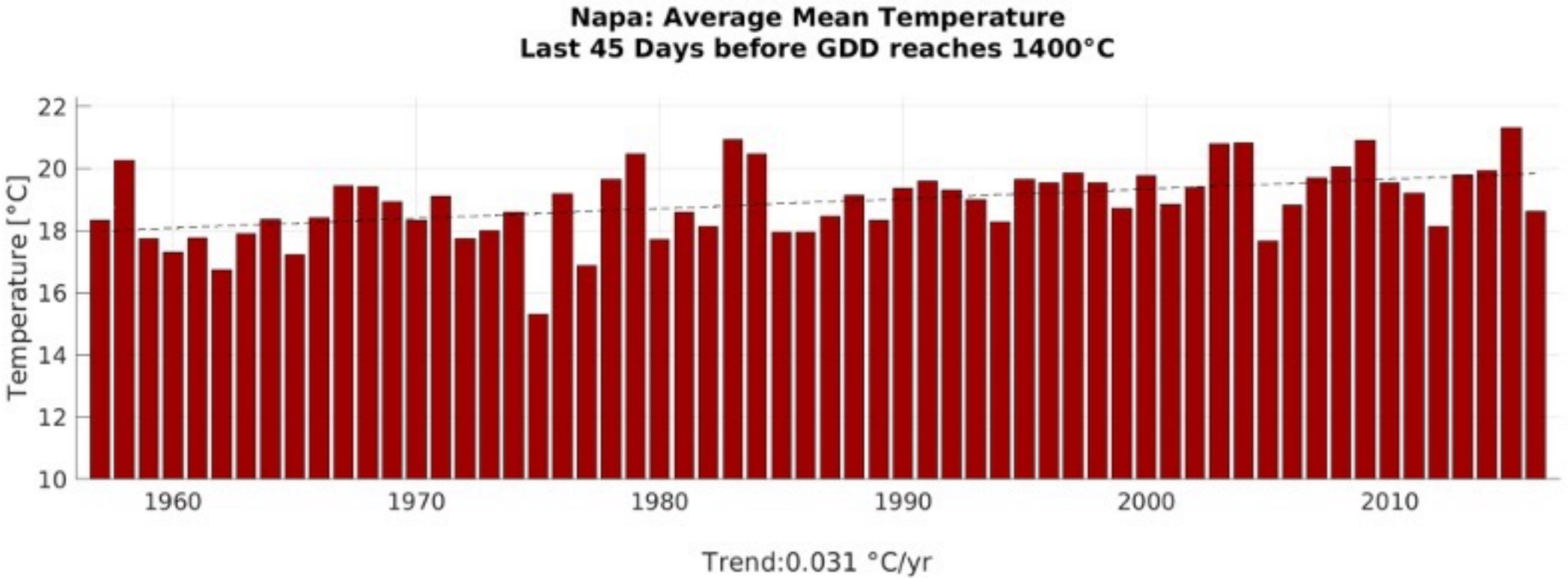


Early End growing season

Napa GHCN-adjusted 1958-2016	mean	s dev	Trend (per yr)
Start day	Mar 16	29.4 days	-0.557 days/yr
End day (1400)	Oct 5	14.5 days	-0.536 days/yr
Length (1400)	202.7	24.9 days	0.022 days/yr
T 45 (1400)	18.9 °C	1.16 °C	0.032°C/yr
End day (whole)	Dec 2	13.4	-0.060 days/yr
Length (whole)	262.1	34.0	0.499 days/yr
XT35	5.8	3.27	0.047
Sep Tmin	11.3 °C	0.91 °C	0.110°C/yr
Days w T < 0	15.8 days	9.05 days	-0.060 days
GDD (apr-oct)	1586 °C	120 °C	4.47 °C days/year

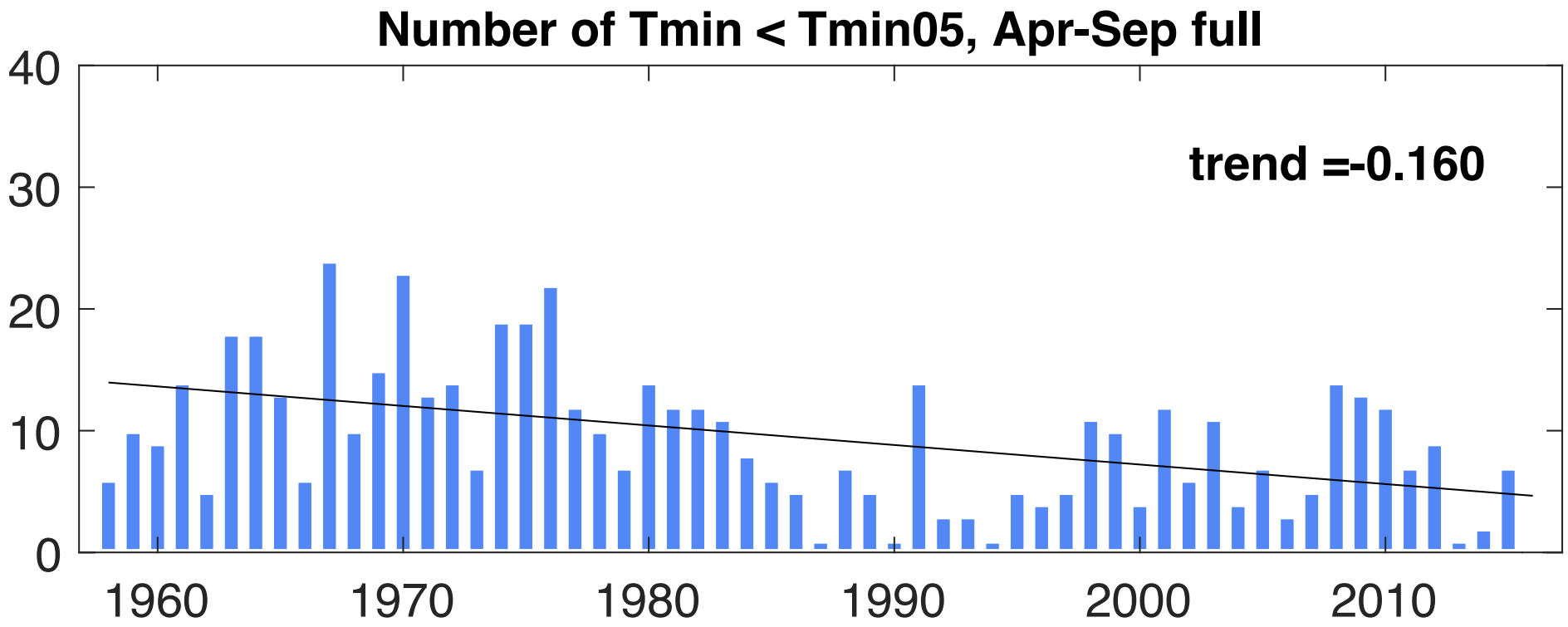
Table 1. Viticultural Statistics based on Napa adjusted GHCN 1958-2016 temperature record. Trends significant (Mann-Kendall test) at 95% confidence level shown in bold.

Mean Temperature last 45 days of Growing Season (1400dd)
1958-2016 increase 1.8 ºC (3.2 ºF)



Decreasing cool extremes

5th percentile daily Tmin half as many 2000's as in 1950's-60's



Summary

Warming has shifted Napa growing season earlier 1958-2016 ***temperature reckoned (not grapes)***

daytime and nighttime warming
hot extremes increased warm extremes declined
region-wide warming -- similar increase as global temperature
summer napa fluctuations more correlated w coastal than inland temperature
largest changes observed btw 1950's and 1960's and 1990's but warmth has persisted

Warming will quite certainly continue due to anthropogenic change--

warming during last 60 years about .3^{o}C / decade
+2^{o}C **additional warming predicted by 2050's**

Observations are vital to track and understand climate variation and changes—

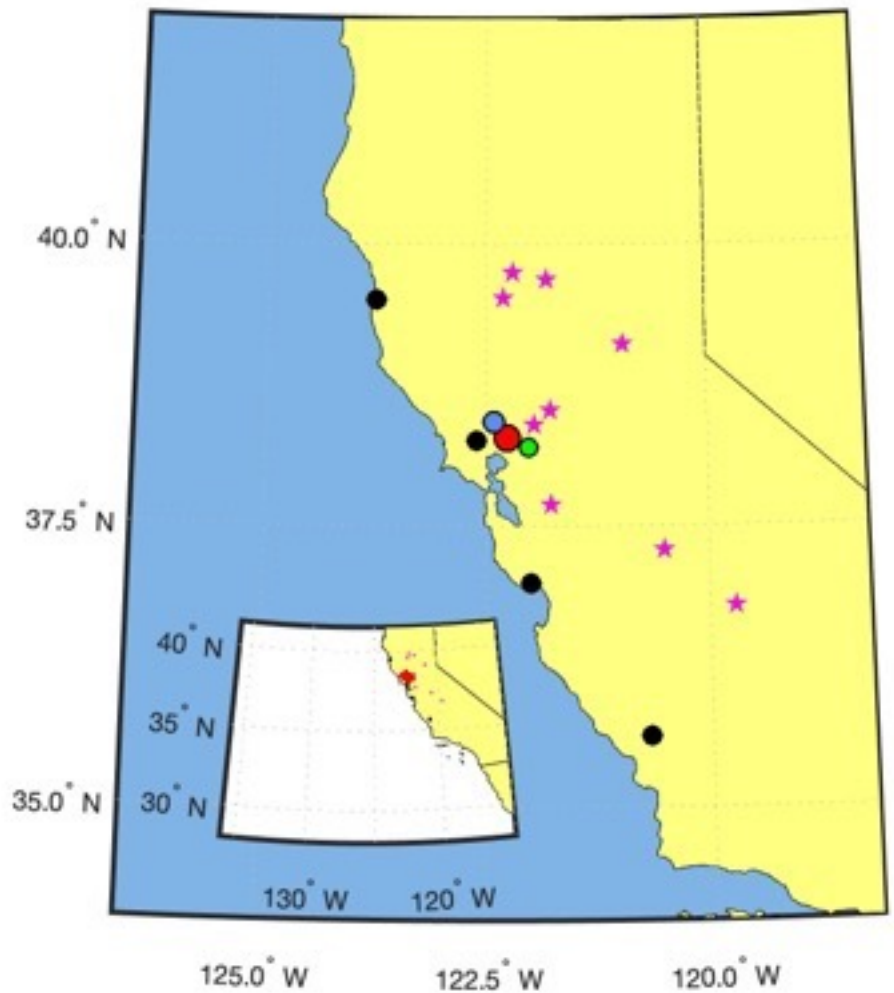
sustain Napa State Hospital and Oakville CIMIS but broader network is very useful

Lower degree of warming is predicted for coast than inland

will Napa Valley more closely track coastal temperature regime or inland? Influence of marine layer?

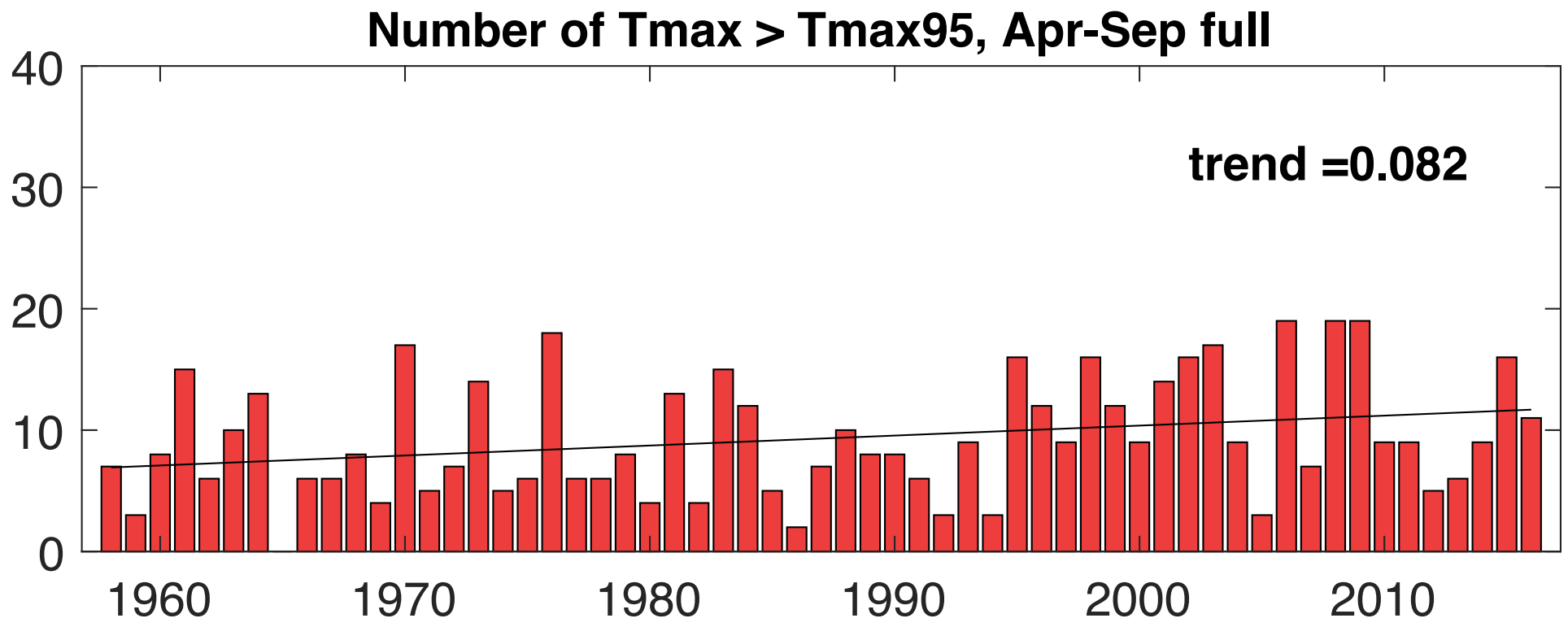
Grape phenology, wine quality records greatly important

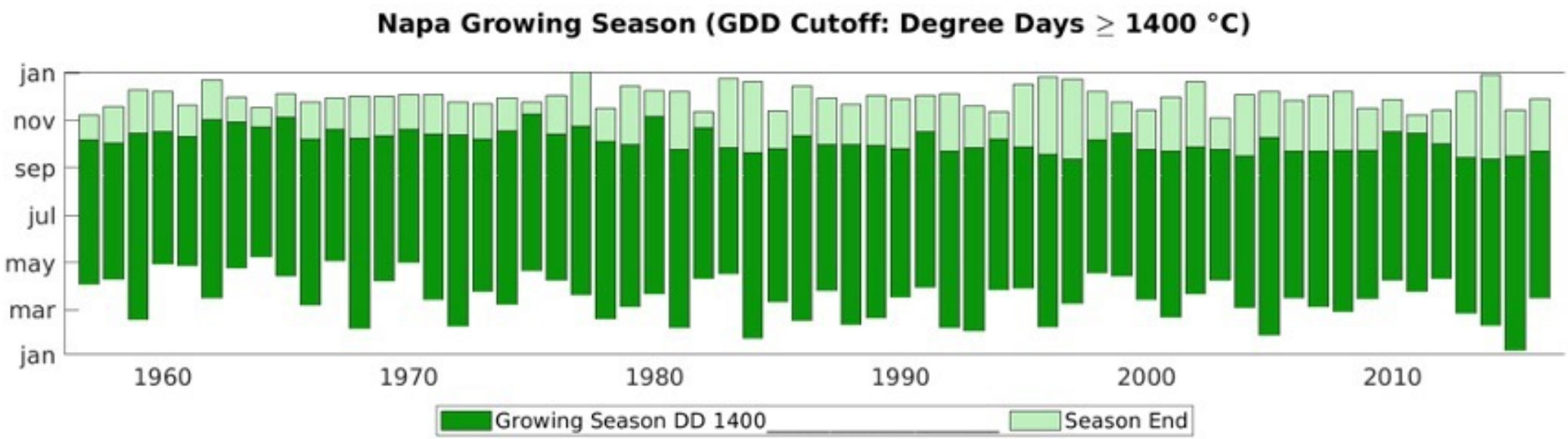
long continuous records vital

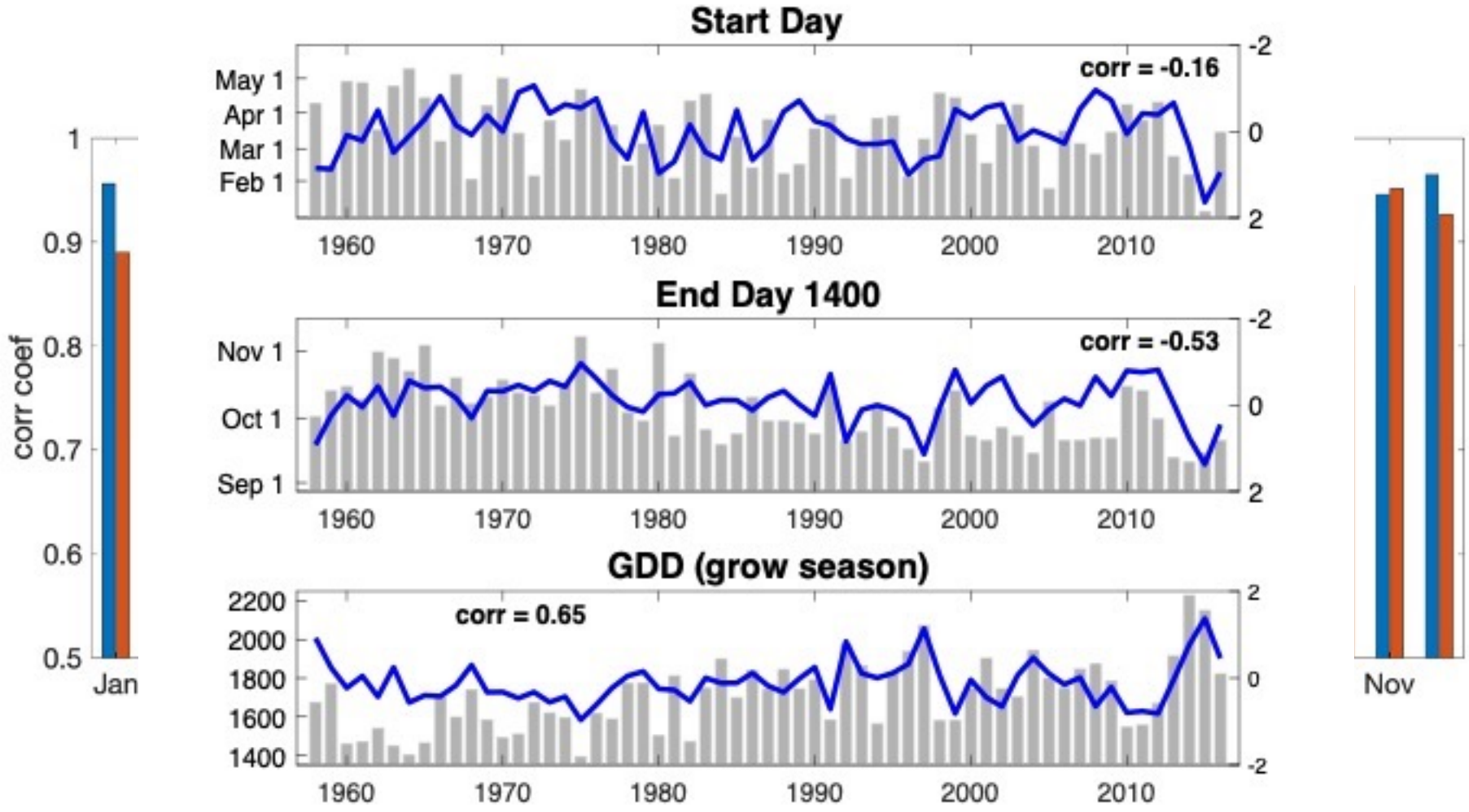

40.0° N
37.5° N
35.0° N
40° N
35° N
30° N
130° W
120° W
125.0° W
122.5° W
120.0° W

Increasing warm extremes

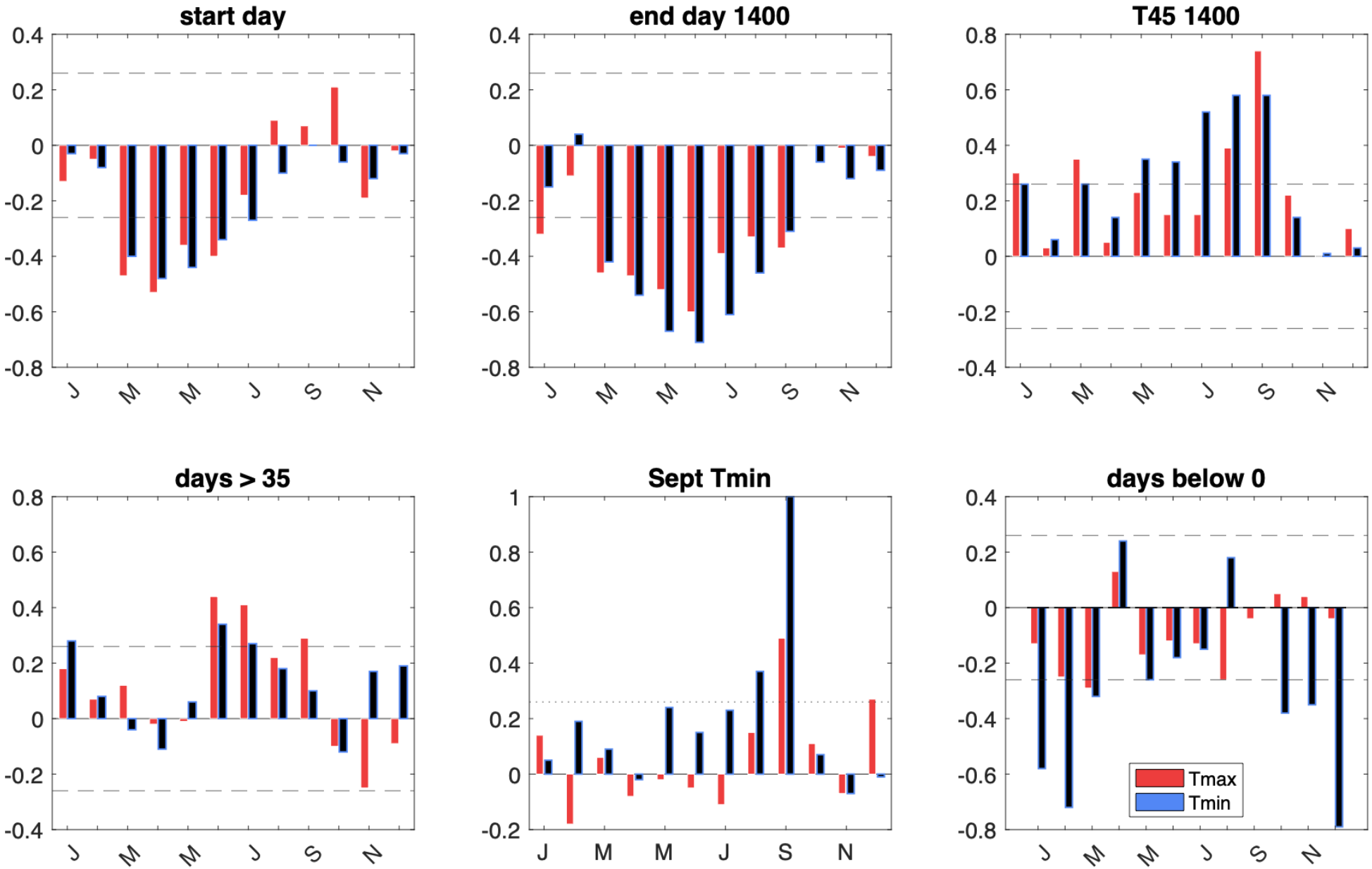
95th percentile daily Tmax 1.5 more 2000s than 1950's and 60's




Napa Growing Season (GDD Cutoff: Degree Days ≥ 1400 °C)
jan
nov
sep
jul
may
mar
jan
1960
1970
1980
1990
2000
2010
Growing Season DD 1400
Season End


Start Day
corr = -0.16
May 1
Apr 1
Mar 1
Feb 1
End Day 1400
corr = -0.53
Nov 1
Oct 1
Sep 1
GDD (grow season)
corr = 0.65
2200
2000
1800
1600
1400
1960
1970
1980
1990
2000
2010
-2
0
2
corr coef
1
0.9
0.8
0.7
0.6
0.5
Jan
Nov

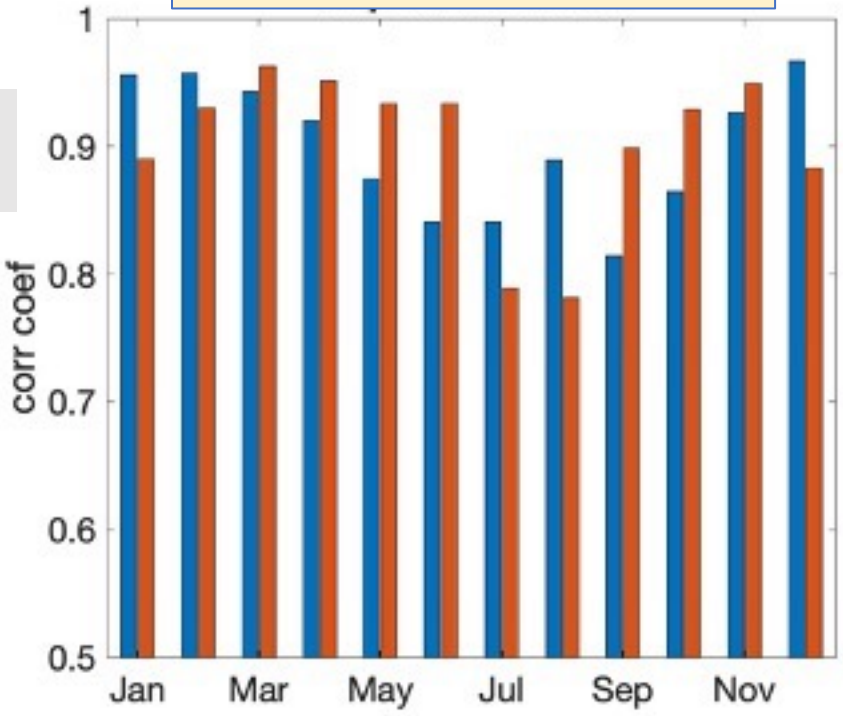
Napa 1958-2016 Viticultural measure correlations with Tmax and Tmin



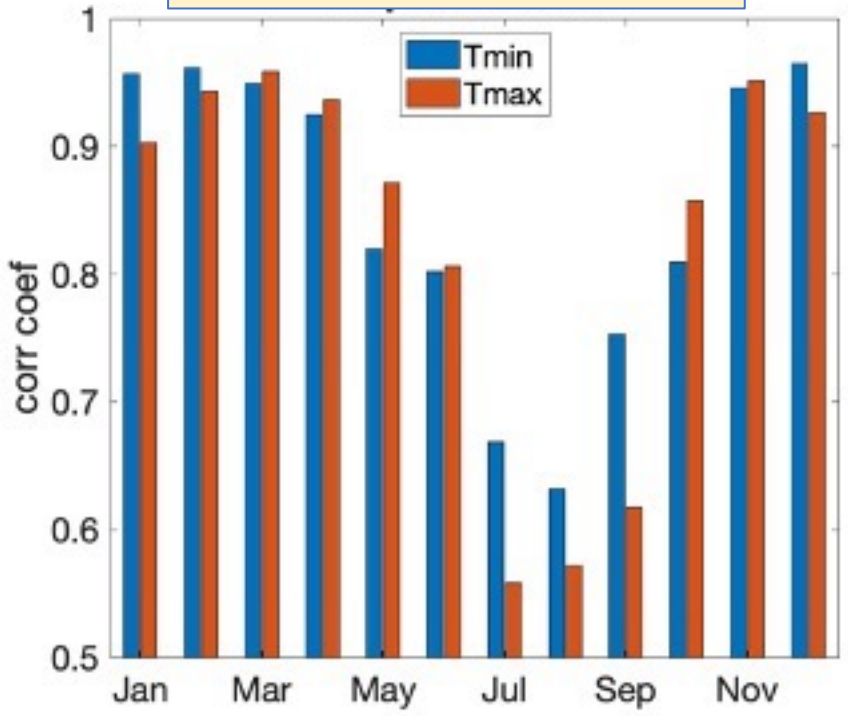
Napa day-to-day temperature fluctuations in summer more closely correlated with Coastal than Inland temperatures

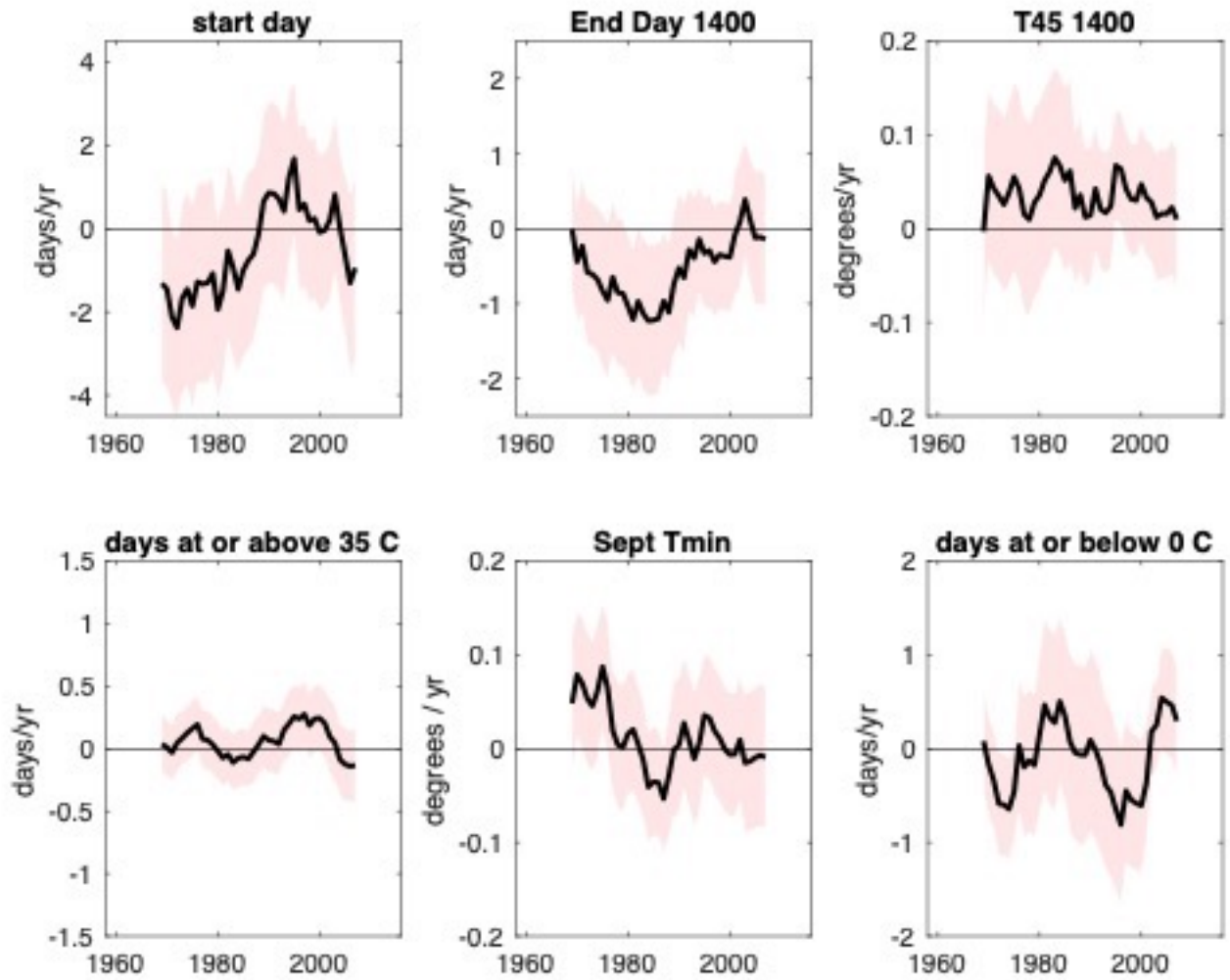
Correlation Coefficient

Napa vs Coastal temp

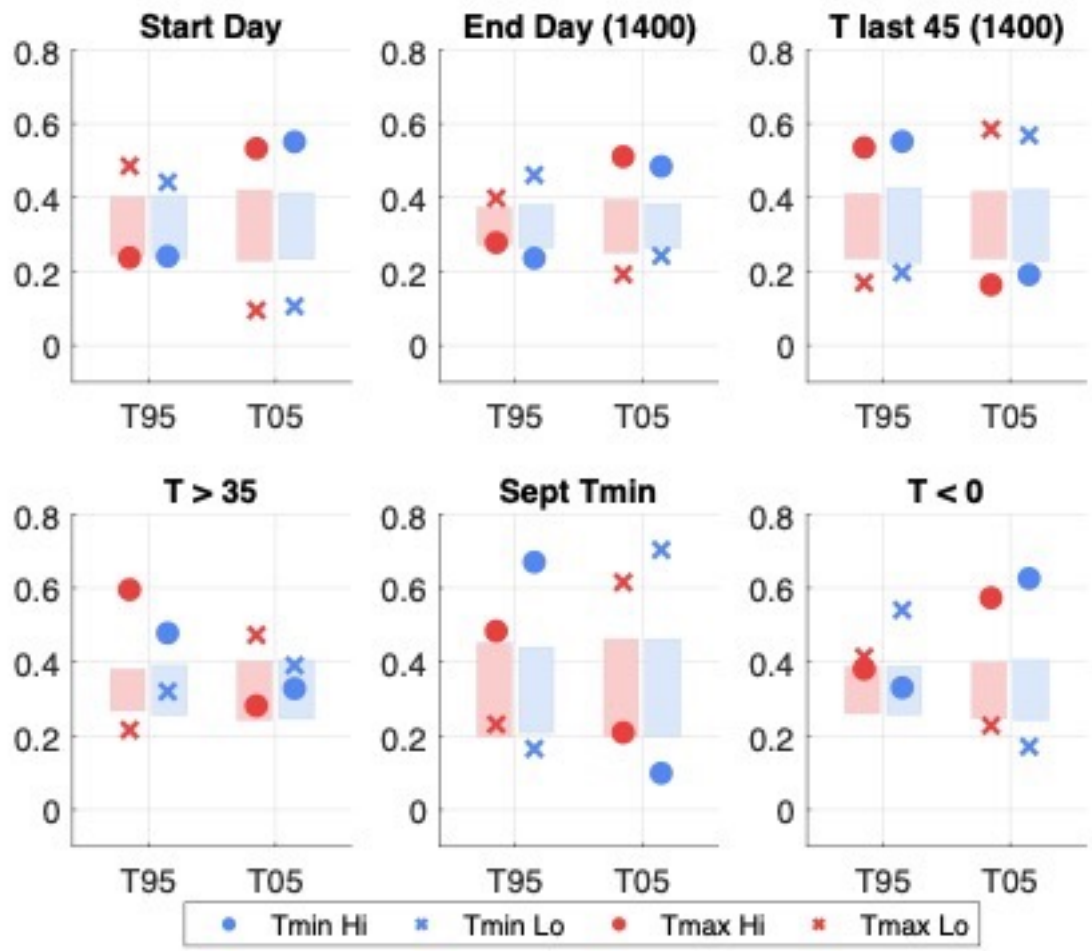


Napa vs Inland temp




start day
days/yr
4
2
0
-2
-4
1960
1980
2000
End Day 1400
days/yr
2
1
0
-1
-2
1960
1980
2000
T45 1400
degrees/yr
0.2
0.1
0
-0.1
-0.2
1960
1980
2000
days at or above 35 C
days/yr
1.5
1
0.5
0
-0.5
-1
-1.5
1960
1980
2000
Sept Tmin
degrees / yr
0.2
0.1
0
-0.1
-0.2
1960
1980
2000
days at or below 0 C
days/yr
2
1
0
-1
-2
1960
1980
2000

	SST vs Tmax & Tmin				Tdew vs Tmax & Tmin				SST vs Tdew (1958-2016)
	Napa (1958-2016)		Oakville (1989-2016)		Napa (1958-2016)		Oakville (1989-2016)		
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	
ONDJFM	0.37	0.44	0.12	0.37	0.07	0.62	0.12	0.59	0.28
AMJJAS	0.30	0.54	0.14	0.38	-0.07	0.51	-0.15	0.27	0.57
	Coast		Inland		Coast		Inland		
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	
ONDJFM	0.39	0.47	0.28	0.47	0.09	0.63	0.06	0.59	
AMJJAS	0.37	0.62	0.14	0.41	0.06	0.65	-0.06	0.27	


Start Day
End Day (1400)
T last 45 (1400)
T > 35
Sept Tmin
T < 0
0.8
0.6
0.4
0.2
0
T95
T05
Tmin Hi
Tmin Lo
Tmax Hi
Tmax Lo