ASSESSING THE IMPACTS OF CLIMATE CHANGE ON WINE PRODUCTION IN THE COLUMBIA VALLEY AMERICAN VITICULTURAL AREA, WASHINGTON

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Description of Research

- Applying GIS (Geographic Information Systems) to climate change studies and viticulture
  - Availability of climate change data for mapping and analysis
  - GIS already used as a suitability analysis tool for locating vineyard sites and for monitoring grape harvest output[1]
- Use of climate model projections to forecast impacts on viticultural activities
  - Numerous climate variables need to be accounted for in the production of grapes
  - Comparison of various models and scenarios necessary for complete picture
- Explore spatial interpolation methods to improve climate data resolution for fine-scale analyses
  - Spatial Interpolation: Estimation technique used to change the way data is represented in a GIS

1. Jones, G.V., P. Nelson, and N. Snead, 2004. "Modeling Viticultural Landscapes: A GIS Analysis of the Terroir Potential in the Umpqua Valley of Oregon." *Geoscience Canada*, 31(4): 167-178.

Basic Vine Phenology

- Growth stages for the grapevine *Vitis Vinifera*
  - Bud Break, Flowering, Fruit Set, Veraison, Harvest, Leaf Fall
- Growing Season: April to October
  - Bud Break-Flowering: April-June
  - Veraison-Harvest (aka "Ripening Period"): August 15-October 15 [2]
- Important Climatological Factors[3]
  - Temperature
  - Precipitation
  - Timing of such factors during the growing season is an important consideration
- Climate Risk Factors for Vines[4]
  - Extreme Heat/Cold
  - Frost
  - Heavy Precipitation/Hail
  - Drought

2. Jones, G.V., 2005. "Climate Change in the Western United States Grape Growing Regions." *Acta Horticulturae*, 689: 41-60.
3. Van Leeuwen, C., P. Friant, X. Choné, O. Tregoat, S. Koundouras, D. Dubourdieu, 2004. "Influence of Climate, Soil, and Cultivar on Terroir." *American Journal of Viticulture and Enology*, 55(3): 207-217.
4. White, M.A., N.S. Diffenbaugh, G.V. Jones, J.S. Paul, and F. Giorgi, 2006. "Extreme heat reduces and shifts United States premium wine production in the 21st century." *Proceedings of the National Academy of Sciences*, 103(30): 11217-11222.

Selection of Study Area

Columbia Valley American Viticultural Area (AVA)

- Location: East and Central Washington
- Climate: Continental (high annual temperature range)
  - Experiences a rain shadow from the presence of the Cascade Range
  - Unique to Pacific Coast AVAs
- Important Viticultural Risk Factors: Susceptible to frost and drought
- Contains 99% of Washington's vine acreage (30,660 acres) and total vines planted (25.6 million vines)[5]
- Wine Grape output: approx. 145,000 tons (2008)
- Economic Value: $149,350,000 in 2008 ($1,030 per ton)
  - In 2006, over 5.5 million cases of wine sold from Washington vineyards[6]

5. United States Department of Agriculture, 2007. *Washington Vineyard Acreage Report 2006*. (National Agricultural Statistics Service, Washington Field Office: Olympia, WA).
6. United States Department of Agriculture, 2009. "2008 Washington Wine Grape Production up 14 percent: Cabernet Sauvignon up 20 percent; White Riesling up 10 percent" in: *Grape Release*, (National Agricultural Statistics Service, Washington Field Office: Olympia, WA).

Data Sources and Methods

- Climate Data used in this analysis comes from the IPCC 4th Assessment Report[7]
  - Emissions Scenarios
  - Climate Model Projections
- Analysis Tools
  - ArcGIS Software
  - Map Algebra functions
  - Deterministic and Geostatistical Interpolation

7. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.), 2007. "Summary for Policymakers" in: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, (Cambridge University Press: New York, NY).

Analysis Description

- Comparison of Temperature and Precipitation projection data
  - Climate Models: MIROC3.2, CSIRO-Mk3.0, UKMO-HadCM3
  - Projection Years: 2050 & 2100
  - Time Scales: Annual and Growing Season
  - Emissions Levels: High-A2, Medium-A1B, Low-B1

- Comparison of Different Interpolation Methods
  - Inverse Distance Weighted (IDW)
  - Spline (Radial Basis Function)
  - Kriging

Low Emissions Scenario

	Low Emissions Scenario			
	2050		2100	
	Annual	Gr. Season	Annual	Gr. Season
Mean Temperature				
CSIRO-Mk 3.0	+1.7743°	+2.0137°	+2.6838°	+2.5678°
UKMO-HadCM3	+4.3371°	+5.5535°	+5.6242°	+7.4081°
MIROC 3.2	+4.4283°	+4.4830°	+6.3996°	+6.6360°

	F/H	Gr. Season	F/H	Gr. Season
Mean Precipitation				
CSIRO-Mk 3.0	-0.028"	-0.190"	-0.012"	-0.027"
UKMO-HadCM3	-0.445"	-0.533"	-0.206"	-0.109"
MIROC 3.2	-0.006"	+0.086"	-0.395"	-0.303"

IPCC Emissions Scenario: Low-B1

Temperature Trends:

- All increasing
- Annual increases by 2100 from 2.68°- 6.40°F
- Growing season increases up to +7.41°F by 2100

Precipitation Trends:

- Variable and small changes across study area; larger local variations

* F/H = Flowering to Harvest (June-October); Gr. Season = Growing Season (April-October)

*All temperature values in degrees Fahrenheit, and precipitation values in inches

*Historical climate variable values for the Columbia Valley AVA:

Mean Annual Temperature:	50.05° F
Mean Growing Season Temperature:	60.47° F
Mean Growing Season Precipitation:	4.539"
Mean Flowering-Harvest Precipitation:	2.802"

Medium Emissions Scenario

	Medium Emissions Scenario			
	________2050________		________2100________	
	Annual	Gr. Season	Annual	Gr. Season
Mean Temperature				
CSIRO-Mk 3.0	+2.1044°	+2.1891°	+3.2562°	+3.1307°
UKMO-HadCM3	+5.7197°	+7.3985°	+7.9391°	+10.246°
MIROC 3.2	+5.0979°	+5.3979°	+7.8275°	+8.1939°

	F/H	Gr. Season	F/H	Gr. Season
Mean Precipitation				
CSIRO-Mk 3.0	+0.041"	+0.076"	+0.472"	+0.663"
UKMO-HadCM3	-0.791"	-0.655"	-0.482"	-0.582"
MIROC 3.2	-0.122"	-0.244"	-0.458"	-0.263"

* F/H = Flowering to Harvest (June-October); Gr. Season = Growing Season (April-October)

*All temperature values in degrees Fahrenheit, and precipitation values in inches

*Historical climate variable values for the Columbia Valley AVA:

Mean Annual Temperature:	50.05° F
Mean Growing Season Temperature:	60.47° F
Mean Growing Season Precipitation:	4.539"
Mean Flowering-Harvest Precipitation:	2.802"

IPCC Emissions Scenario:

Medium-A1B

Temperature Trends:

- -All increasing
- -Annual increases by 2100 from 3.26°- 7.94°F
- -Growing season increases by 2100 from 3.13°- 10.25°F

Precipitation Trends:

- -Variable but with larger departures from current levels
- -Growing season predicted range: -0.655”/+0.663”

High Emissions Scenario

	High Emissions Scenario			
	2050		2100	
	Annual	Gr. Season	Annual	Gr. Season
Mean Temperature				
CSIRO-Mk 3.0	+2.6883°	+2.9038°	+5.0108°	+5.1580°
UKMO-HadCM3	+4.5373°	+6.3563°	+7.8960°	+10.460°
MIROC 3.2	+4.9820°	+5.2383°	+8.3763°	+9.3081°
	F/H	Gr. Season	F/H	Gr. Season
Mean Precipitation				
CSIRO-Mk 3.0	+0.131"	+0.224"	+0.408"	+0.537"
UKMO-HadCM3	-0.736"	-0.894"	-0.876"	-1.007"
MIROC 3.2	-0.555"	-0.562"	-0.580"	-0.685"

* F/H = Flowering to Harvest (June-October); Gr. Season = Growing Season (April-October)

*All temperature values in degrees Fahrenheit, and precipitation values in inches

*Historical climate variable values for the Columbia Valley AVA:

Mean Annual Temperature:	50.05° F
Mean Growing Season Temperature:	60.47° F
Mean Growing Season Precipitation:	4.539"
Mean Flowering-Harvest Precipitation:	2.802"

IPCC Emissions Scenario: High-A2

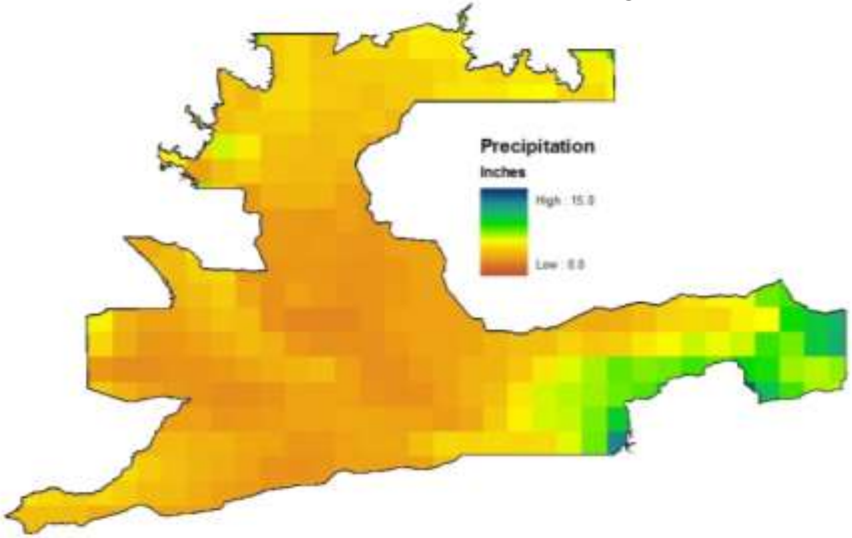
Temperature Trends:

- -All increasing
- -Annual increases by 2100 from 5.01°- 8.38° F
- -Growing season increases by 2100 from 5.15°- 10.46°F

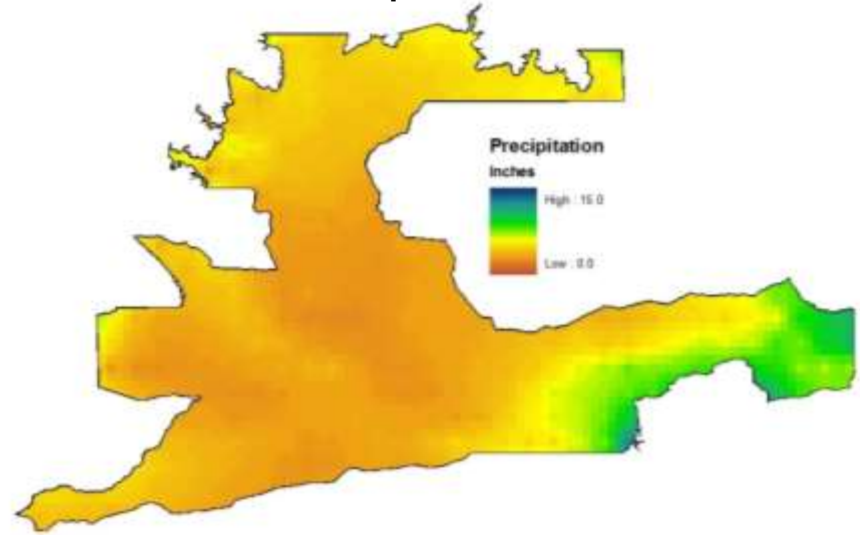
Precipitation Trends:

- -Still variable, but with greater range of changes
- -Forecasts range from -22% to +11% during the growing season
- -Growing season by 2100: -1.007”/+0.537”
- -Flowering-Harvest by 2100: -0.876”/+0.408”

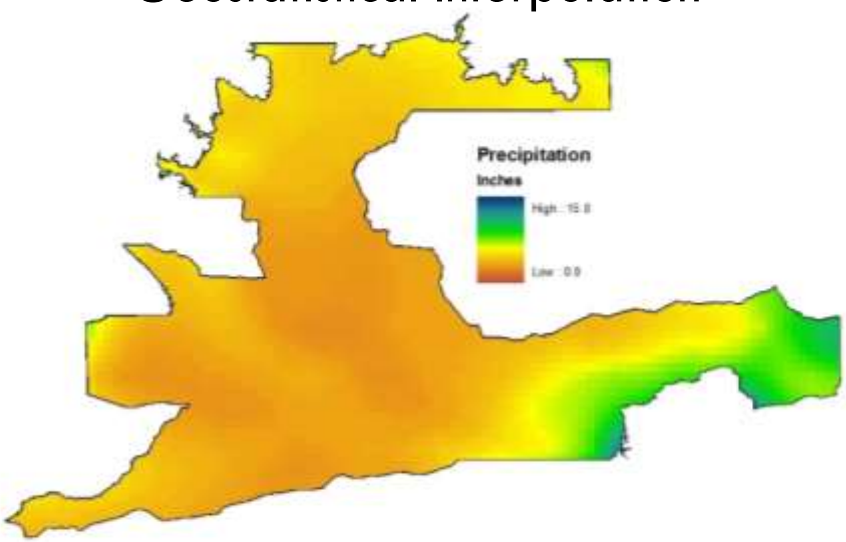
Original Dataset: CSIRO-Mk3.0,
Low Emissions, 2050 Growing Season



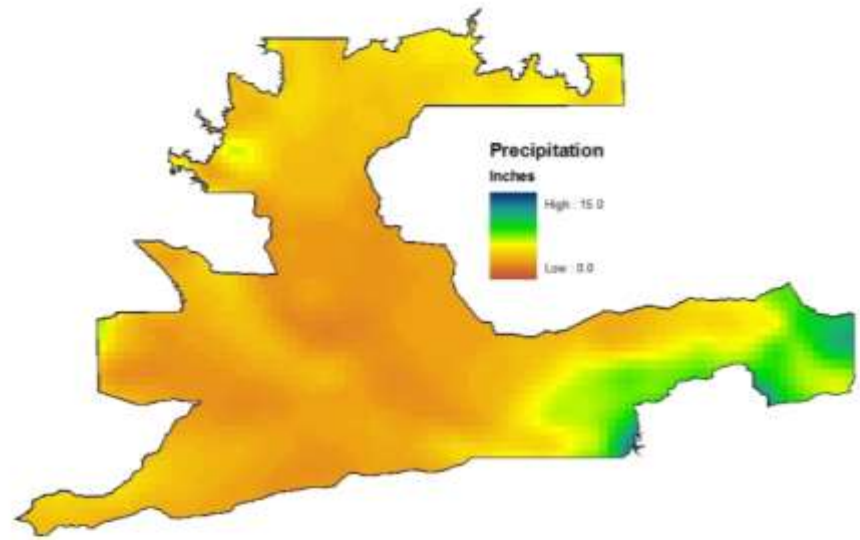
Inverse Distance Weighted (IDW)
Interpolation



Kriging
Geostatistical Interpolation



Spline Interpolation



Spatial Interpolation Results

Table 2: Spatial Interpolation Methods and their departures from model calculated temperature and precipitation levels

Control Dataset: CSIRO-Mk3.0 climate model low emissions scenario projections (growing season precipitation and annual temperature)

	Temperature Projections				Precipitation Projections			
	2050		2100		2050		2100	
	Annual	% Diff	Annual	% Diff	Gr. Season	% Diff	Gr. Season	% Diff
Datasets								
Climate Projection	51.683°	0.00%	52.592°	0.00%	4.335"	0.00%	4.498"	0.00%
IDW	51.617°	-0.13%	52.526°	-0.13%	4.394"	1.36%	4.560"	1.38%
Spline	51.729°	0.09%	52.637°	0.09%	4.325"	-0.23%	4.489"	-0.20%
Kriging	51.695°	0.02%	52.603°	0.02%	4.401"	1.52%	4.512"	0.31%

*All temperature values in degrees Fahrenheit, and precipitation values in inches

*% Diff stands for the percent difference of the mean interpolated value from the original climate projection

-Since spatial interpolation is a form of estimation, improving dataset resolution also alters the data itself, making it necessary to compare interpolated datasets to the input dataset (CSIRO-Mk3.0 Low Emissions Scenario Projections)

-Interpretation of Results: Are low departure values due to data quality, the control dataset, or the geography/climatic variation of the study area?

Conclusions: Temperature

- All of the climate models project the mean annual and growing season temperatures of the Columbia Valley AVA will increase over the next century.
- Low emissions scenario brought about least significant changes in temperature; CSIRO-Mk3.0 consistently forecast least amount of warming
- Medium emissions scenario more severe up to 2050 than the high emissions scenario
- Lowest forecasted changes in growing season temperature:
  - *2050*: **+2.0137°F** (CSIRO-Mk3.0, Low Emissions)
  - *2100*: **+2.5678°F** (CSIRO-Mk3.0, Low Emissions)
- Highest forecasted changes in growing season temperature:
  - *2050*: **+7.3985°F** (UKMO-HadCM3, Medium Emissions)
  - *2100*: **+10.460°F** (UKMO-HadCM3, High Emissions)

Conclusions: Precipitation

- Precipitation forecasts more variable, fluctuating between positive and negative changes by climate model, scenario, and time scale
- Largest forecasted decreases:
  - 2050: -0.894" → -19.6% (UKMO-HadCM3, High Emissions)
  - 2100: -1.007" → -22.2% (UKMO-HadCM3, High Emissions)
- Largest forecasted increases:
  - 2050: +0.224" → +4.9% (CSIRO-Mk3.0, High Emissions)
  - 2100: +0.663" → +14.6% (CSIRO-Mk3.0, Medium Emissions)
- No real decipherable pattern across models; as emissions increase, a higher departure from current precipitation levels observed

Conclusions: Spatial Interpolation

- Interpolated values did not stray far from predicted values
- Convincing results for interpolation functions?
- Consistent levels of departure for each model and climate factor
- Possible reasons for results
  - Lack of topographic considerations
  - Lack of varying climate zones across study area
  - Size of the control dataset
  - What is an acceptable level of departure from measured values?
- Larger geographic areas and larger datasets needed to confirm measurements

What does this mean for viticulture?

- Temperature considerations
  - Less risk of frost damage during the growing season
  - Introduction of new warmer region grape varieties
  - Increased risk of extreme heat events
- Precipitation considerations
  - Smaller changes in precipitation have little impact when considered alone
  - Continued reliance on irrigation for grape crop, water stress continues to be a problem
  - When combined with increased temperatures:
    - Vines increasingly susceptible to water stress for scenarios involved a decline in precipitation
    - Vines vulnerable to mold, diseases, and pests for scenarios with an increase in precipitation
- Application of interpolation for viticultural studies
  - Upon confirmation of the accuracy of interpolation methods, such methods could allow for currently available climate data to be used for finer scale viticultural analyses

Sources

Jones, G.V., P. Nelson, and N. Snead, 2004. "Modeling Viticultural Landscapes: A GIS Analysis of the Terroir Potential in the Umpqua Valley of Oregon." *Geoscience Canada*, 31(4): 167-178.

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