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What are the Major Climate Risks for Agriculture in the U.S. Pacific Northwest?

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There are many types of risk for agriculture, including risks of droughts, floods, and declining commodity prices. Risk is exposure to uncertain consequences, particularly unfavorable consequences (Hardaker et al. 2004). Risk management implies decision-makers can act to mitigate the impact of unfavorable outcomes or influence outcomes of risky endeavors (Welch and Lamie 2013). This issues brief explores climate risks for agriculture in the U.S. Pacific Northwest (PNW) and different approaches for representing them.

The spatial and temporal variations of climate significantly affect agricultural production risk. Climate change may exacerbate water shortages in the PNW because it is expected to accelerate snowmelt, which would increase spring flood risk and reduce summer water availability (Vano et al. 2010a; Vano et al. 2010b). At the same time, climate change may increase the demand for water from agriculture. Farmers use irrigation to mitigate crop damage from extreme climate events, such as frost, extreme heat, and drought (Olen et al. 2015), which are projected to occur more frequently with climate change (Cai et al. 2015; Cook et al. 2015). Improving the understanding of agricultural adaptation to climate change hinges on advancing the understanding of agricultural climate risk.

In this issues brief, we develop a statistical profile of agricultural climate in the PNW, which includes detailed information about average climate and climate risk. We analyze the spatial and temporal variations of climate during the growing season over a 30-year period to assess the climate risk for agriculture in the U.S. Pacific Northwest. We find that absolute precipitation risk, fall freeze risk, and spring freeze risk, measured by their standard deviations during the 30-year period, are greatest near the coast and that temperature risks (minimum and maximum temperature) are lowest



in these same areas. However, we do not observe much variation in temperature risks across agricultural land in the PNW. Absolute precipitation risk and fall freeze risk are greatest at high elevations. Our statistical profile of agricultural climate provides a holistic representation of average climate and climate risk for the PNW, which is a valuable contribution for empirical analysis of agricultural production and adaptation to climate change.

PRISM Climate Data

The primary data for this analysis are the PRISM climate data. The PRISM Climate Group gathers climate observations from a wide range of monitoring networks, applies sophisticated quality control measures, and develops spatial climate datasets to reveal short- and long-term climate patterns (Daly et al. 2008). The resulting datasets incorporate a variety of modeling techniques and are available online at multiple spatial/temporal resolutions, covering the period from 1895 to the present (<http://prism.oregonstate.edu>).

For this application, the PRISM Climate Group developed recent 30-year averages (1983–2012) for an array of climate statistics for the PNW (Idaho, Oregon, and Washington). The 30-year averages were developed separately for each climate statistic and month of the year. Additionally, the 30-year averages were developed separately for the entire PNW and for agricultural land only. Agricultural land was identified using the 2014 National Cultivated Land Cover Data layer from the U.S. Department of Agriculture, National Agricultural Statistics Service (U.S. Department of Agriculture 2014). The cultivated data layer is based on the most recent five years of the cropland data layer. The cultivated land cover was imported into a GIS system, a masking layer was created, and the agricultural masking layer was used to extract the relevant data from the climate grids.

The monthly averages were in turn averaged to develop 30-year March–November averages to represent the agricultural

growing season. The following climate statistics were calculated: mean total precipitation, mean maximum temperature, mean minimum temperature, mean date of first fall freeze, and mean date of last spring freeze. We also developed standard deviations of these climate statistics.

Our representation of agricultural climate assumes that agricultural producers' behavior is driven by spatial and temporal expectations about climate and other factors. We assume that agricultural land (cultivated land) is the best spatial representation of agricultural producers' climate expectations because this is where production has occurred. We assume that climate during the growing season is the best single representation of agricultural producers' temporal climate expectations. We assume this for two reasons: 1) producers respond directly to ambient climate, and 2) the connection between winter climate and agricultural production behavior is less clear. The latter reason is particularly applicable in the western United States because of the significant influence of dam, reservoir, and aqueduct management on agricultural water supply. The growing season for most crops in the PNW (difference between usual planting and harvest dates)

Figure 1. Major PNW Mountain Features

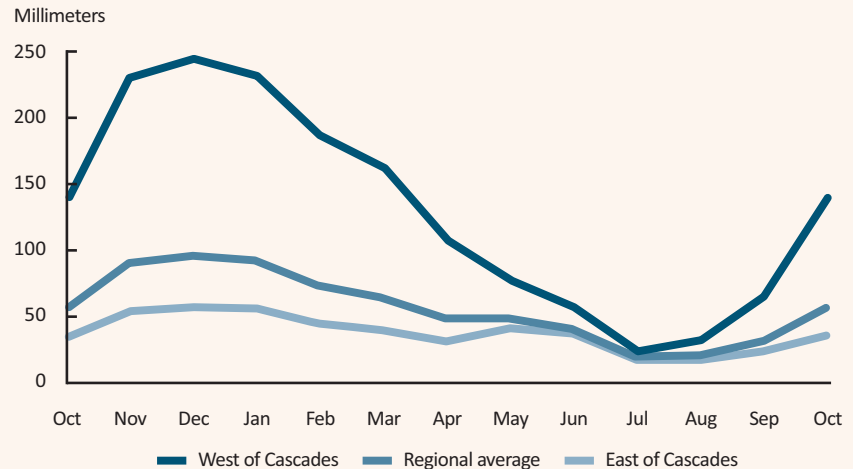


Source: Climate Impacts Group

occurs between March-November (U.S. Department of Agriculture 2010), which we use to represent the growing season. Our statistical profile of agricultural climate can be used to analyze the effects of climate on many production decisions that occur on agricultural land during the growing season, including agricultural water demand and land use.

There are many types of risk. For example, there is absolute risk and relative risk, and there is more than one way to represent each of these. For this application, we use the standard deviation of climate statistics to represent absolute risk. In statistics, moments are used to describe the probability distribution function. The zeroth moment is the total probability (i.e., one), the first moment is the mean, the second moment is the variance, the third moment is the skewness, and the fourth moment is the kurtosis. The variance measures the spread of the probability distribution. The square root of the variance is the standard deviation, so it also measures the spread of the probability distribution. If the standard deviation of climate is relatively high, the climate is relatively variable from year to year and the probability of extreme weather is relatively high. Thus, the standard deviation and variance are appropriate representations of absolute risk because they represent exposure to uncertain consequences, particularly unfavorable consequences. Also, we can interpret risk in terms of upside risk and downside risk. Upside risk is exposure to uncertain increases, and downside risk is exposure to uncertain decreases. An alternative approach, which we explore briefly, is using the coefficient of variation (standard deviation divided by mean) to represent relative risk.

Figure 2. Average Monthly Precipitation for the U.S. Pacific Northwest, 1900–1998



Source: Climate Impacts Group

Table 1. Statistics for Average Climate on Agricultural Land During the Growing Season in the U.S. Pacific Northwest, 1983–2012

	PNW	West-PNW*	East-PNW*	OR	WA	ID
Total precipitation						
Mean (inches)	14	26	8	17	17	9
Standard deviation (inches)	8	14	5	9	9	6
Maximum temperature						
Mean (°F)	66	65	69	67	66	66
Standard deviation (°F)	3	3	4	3	3	4
Minimum temperature						
Mean (°F)	41	45	41	42	43	38
Standard deviation (°F)	2	2	3	2	2	3
First Fall Freeze						
Mean (date)	Oct 13	Nov 7	Oct 2	Oct 21	Oct 25	Sep 27
Standard deviation (days)	13	16	12	15	13	12
Last Spring Freeze						
Mean (date)	Apr 28	Apr 2	May 10	Apr 23	Apr 14	May 17
Standard deviation (days)	15	19	13	17	15	13

Note: Statistics for agricultural land are aggregated at the county-level.

*East-PNW is agricultural land in counties east of the Cascade crest. Hood River County, Oregon is included in West-PNW.

Broad Climate Patterns in the PNW

Climate in the PNW is largely driven by interactions between seasonally varying atmospheric circulation and spatially varying elevation (Climate Impacts Group).

Approximately two-thirds of the region's precipitation occurs in just half the year (October–March) when the PNW is on the receiving end of the Pacific storm track. During the other half of the year, the PNW is fairly dry due to high pressure systems to the west. These weather patterns are related to changes in large-scale atmospheric circulation occurring over the Pacific Ocean, such as the El Niño/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) phenomena. In their warm phases, both ENSO (i.e., El Niño) and PDO increase the odds for a warmer than average PNW winter and spring and decrease the odds for a wetter than average winter. The opposite tendencies are true for cool phases, both ENSO (La Niña) and PDO increase the odds that PNW winters will be cooler and wetter than average.

There is a wide variety of microclimates in the PNW, due in part to the region's diverse topography (Figure 1). For example, the Cascade Range creates a barrier between the maritime climate influences to the west and the continental climate influences to the east. Prevailing westerly winds draw warm and moist air toward the Cascades, where it condenses and precipitates before crossing the Cascade crest. The relatively dry air advances past the crest, which creates a drier side called the "rain-shadow". The Olympic Mountains create a significant rain-shadow effect on the Puget Sound area.

West of the Cascades, temperatures are generally mild year-round, winter precipitation is abundant, and summers are dry. East of the Cascades there is more sunshine and larger daily and annual variation in temperature. Winters are colder, with snow more common at lower elevations, and summer days are hotter (though nights are cooler) than areas west of the Cascades. The mountains east of the Cascades, including portions of the Rockies in eastern Idaho, the Okanogan Highlands in northern Washington, and the Blue Mountains of northeast Oregon and southeast Washington, receive much less precipitation than the Cascade and Olympic Mountains. For areas

east of the Cascades, a higher share of precipitation falls in the dryer half of the year, particularly in May and June (Figure 2).

The mean climate statistics in Table 1 provide insights about spatial variation in average climate for agriculture in the PNW. Mean total precipitation and mean minimum temperature are both higher for agricultural land in Oregon and Washington than in Idaho. The mean date of the first fall freeze is later for agricultural land in Oregon and Washington than in Idaho. The mean date of the last spring freeze is earlier for agricultural land in Oregon and Washington than in Idaho. There are not significant differences in mean maximum temperature for agricultural land in each state. However, mean maximum temperature is significantly lower for agricultural land in west-PNW (west of the Cascades) than in east-PNW.

The standard deviation climate statistics in table 1 provide insights about spatial variation in climate risk for agriculture in the PNW. The standard deviation of total precipitation for Oregon and Washington agricultural land is higher than for Idaho, mainly a result of lower mean precipitation in Idaho. Standard deviations of first fall freeze and last spring freeze are similar across the PNW, but with a tendency for them to be slightly lower in Idaho. Agricultural lands in western Oregon and Washington have mild winters, where the dates of first and last freeze can vary significantly from year to year, whereas freezing conditions in Idaho and eastern Oregon and Washington are more consistent and predictable.

Spatial Variations in Climate in the PNW

Mean total precipitation, mean maximum temperature, and mean minimum temperature during the growing season across the PNW are shown in Figures 3, 4, and 5, respectively. Mean total precipitation is greatest at higher elevations exposed to moisture from the Pacific Ocean. The relatively dry areas east of the Cascades and Olympic Mountains are consistent with rain-shadow effects. Mean maximum temperatures are lowest at high elevations and near the coast. For example, some of the highest mean maximum temperatures for agricultural land are in the Columbia River Valley and the Snake River Plain. Mean minimum temperatures are highest at low elevations and near

the coast. For example, some of the highest mean minimum temperatures for agricultural land are in the Willamette Valley, eastern shore of Puget Sound, and Columbia River Valley. Thus, diurnal temperature variation is lower near the coast.

Figure 6 shows the location of agricultural land in the PNW, as well as mean total precipitation there. The figure shows that there are many agricultural microclimates in the PNW. The major agricultural production regions in the PNW are the Willamette Valley in northwest Oregon, Columbia River Valley in eastern Washington and northcentral Oregon, and the Snake River Plain, which loops from western to eastern Idaho. There are also smaller production niches, including areas scattered across eastern Oregon, southwest Washington, the eastern shore of Puget Sound in western Washington, and the Palouse region of southeast Washington and northeast Idaho.

Mean first fall freeze and mean last spring freeze dates across the PNW are shown in Figures 7 and 8, respectively. The average first fall freeze is latest at low elevations near the coast. In other words, low-elevation coastal locations, such as the Willamette Valley and Puget Sound area, tend to have later first fall freeze dates. The opposite tends to be true for mean last spring freeze. Low-elevation coastal locations tend to have earlier last spring freeze dates. The difference between mean date of first fall freeze and mean date of last spring freeze represents the length of the mean agricultural growing season. The longest mean growing seasons in the PNW are west of the Cascades from March to November.

The results indicate that producers in west-PNW tend to have a wetter and longer growing season with lower diurnal temperature variation than producers in east-PNW.

Figure 3. Mean Total Precipitation during the Growing Season in the U.S. Pacific Northwest, 1983–2012

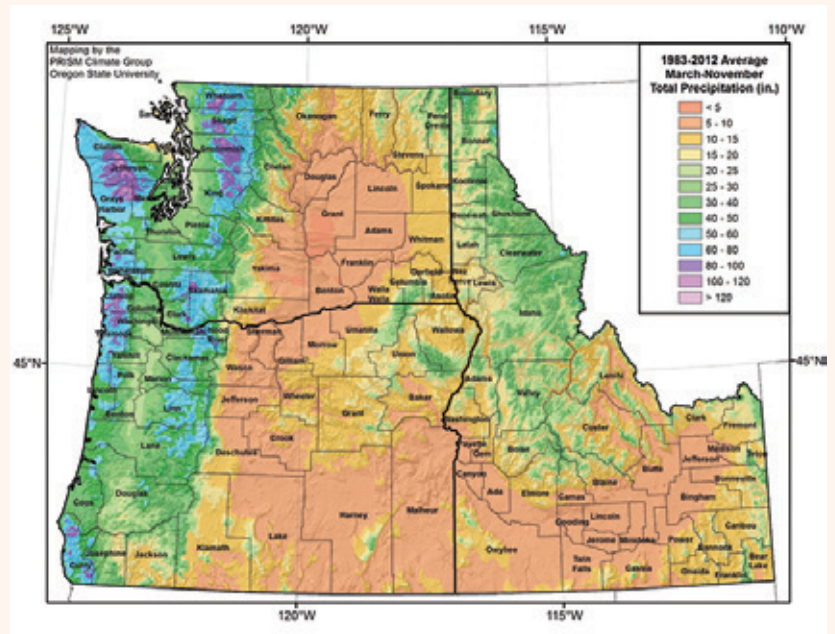


Figure 4. Mean Maximum Temperature during the Growing Season in the U.S. Pacific Northwest, 1983–2012

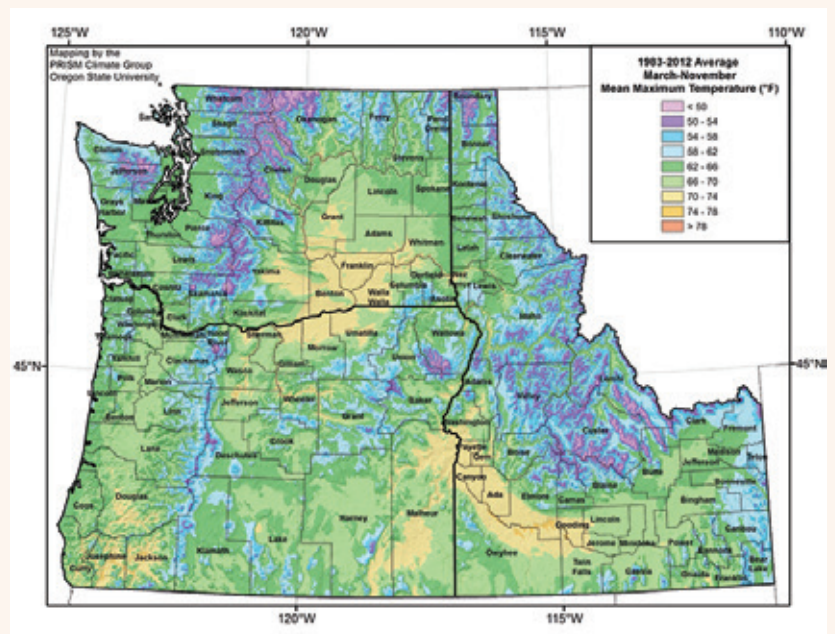


Figure 5. Mean Minimum Temperature during the Growing Season in the U.S. Pacific Northwest, 1983–2012

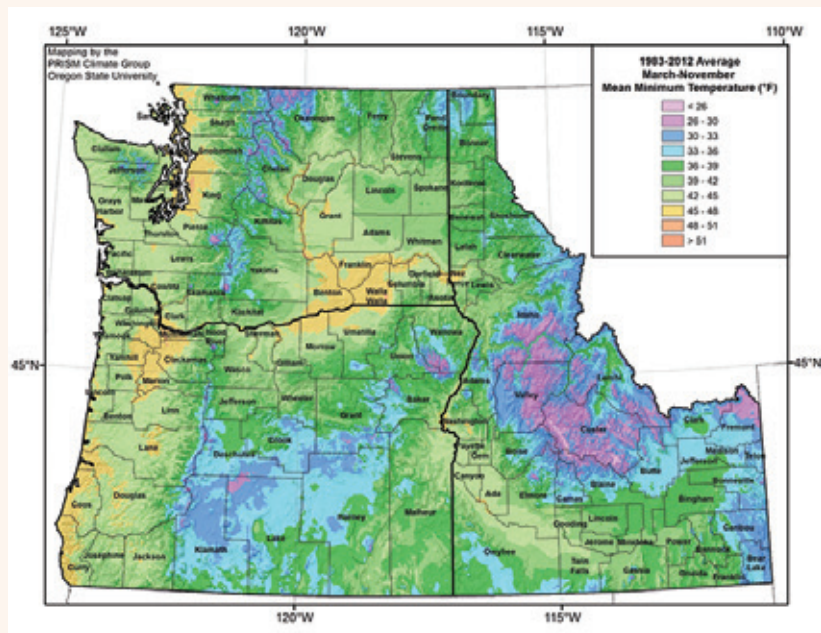
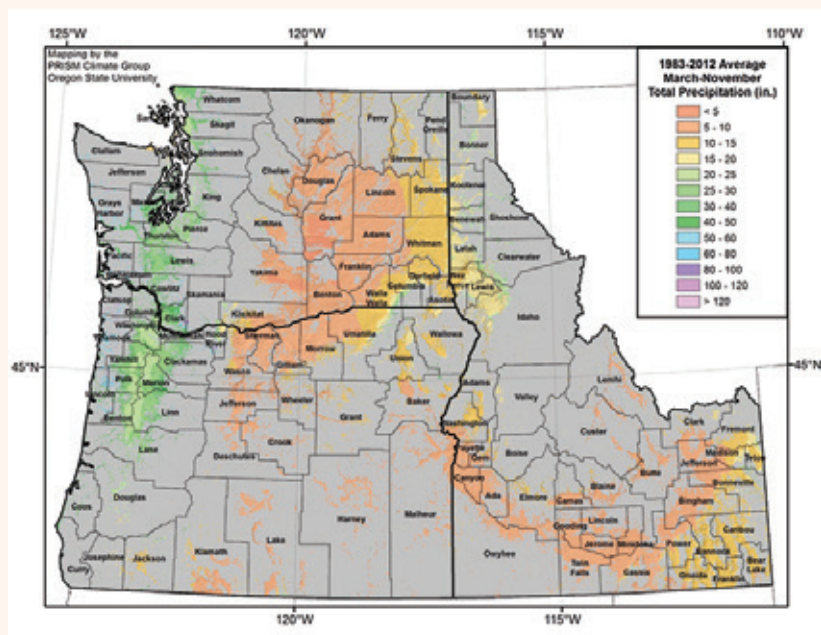


Figure 6. Agricultural Land in the U.S. Pacific Northwest (Non-grey Area) and Mean Total Precipitation during the Growing Season on Agricultural Land, 1983–2012



Spatial Variations in Climate Risk in the PNW

Climate risk is measured by temporal variations in precipitation, maximum and minimum temperatures, and first and last freezing days. The standard deviation of mean total precipitation during the growing season from 1983–2012 is shown in Figure 9. The standard deviation of mean total precipitation is greatest at higher elevation coastal locations, where the mean precipitation is highest. For example, the standard deviation of total precipitation is relatively high in wet, high-elevation coastal locations, including the Three Sisters Mountains (Lane County and Deschutes County, OR), Mount Hood (Hood River County, OR), Olympic Mountains, Mount St. Helens (Skamania County, WA), and Mount Rainier (Pierce County, WA). The coefficient of variation (standard deviation divided by mean) for total precipitation during the growing season from 1983–2012 is used to represent relative risk (Figure 10). The coefficient of variation for total precipitation is highest in low elevation areas away from the coast, where the mean precipitation is lowest. Thus, for precipitation, absolute risk and relative risk appear to be negatively correlated.

The standard deviation of mean maximum temperature and the standard deviation of mean minimum temperature are both lowest near the coast (Figures 11 and 12, respectively), but we do not observe much variation in these statistics for agricultural land in the PNW (Table 1).

The standard deviations for the mean date of first fall freeze and mean date of last spring freeze are shown in Figures 13 and 14, respectively. The standard deviation of both freeze dates is highest at low elevations near the coast. Again, this is related to

the sporadic nature of freezing conditions in the milder areas in the PNW. The standard deviation of first fall freeze is lowest in inland valleys east of the Cascades, where cold air pools in low-lying locations are common and minimum temperatures are consistently low.

These findings suggest that absolute precipitation risk, fall freeze risk, and spring freeze risk are greatest near the coast, and that absolute temperature risk is greatest away from the coast. Absolute precipitation risk and fall freeze risk also appear to be greatest at higher elevations.

Conclusion

Spatial and temporal dimensions of climate significantly affect agricultural production risk. There is a wide variety of microclimates in the PNW, due largely to the region's proximity to the coast and diverse topography. This complexity confounds one-size-fits-all climate change adaptation strategies. We can improve our understanding of agricultural production and adaptation to climate change through better climate data and deeper understanding of agricultural climate risk.

We develop a statistical profile of agricultural climate, which provides a holistic representation of climate and climate risk for the PNW. We find that absolute precipitation risk, fall freeze risk, and spring freeze risk are greatest near the coast and that absolute temperature risks (minimum and maximum temperature) are greatest in inland areas. However, we do not observe much variation in temperature risks across agricultural land in the PNW. Also, we find that precipitation risk and fall freeze risk generally increase with elevation. Absolute risk of precipitation (standard deviation) and relative risk of precipitation (coefficient

Figure 7. Mean Date of First Fall Freeze in the U.S. Pacific Northwest, 1983–2012

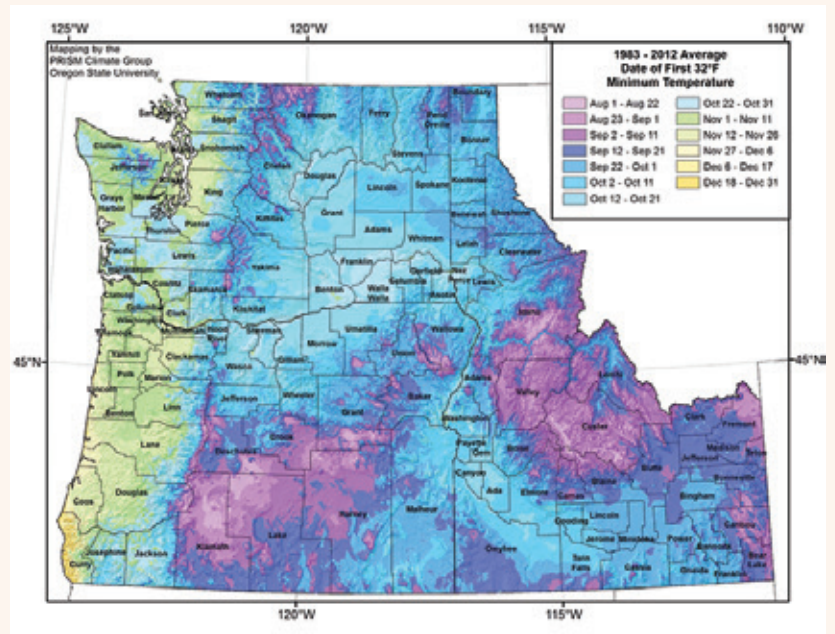


Figure 8. Mean Date of Last Spring Freeze in the U.S. Pacific Northwest, 1983–2012

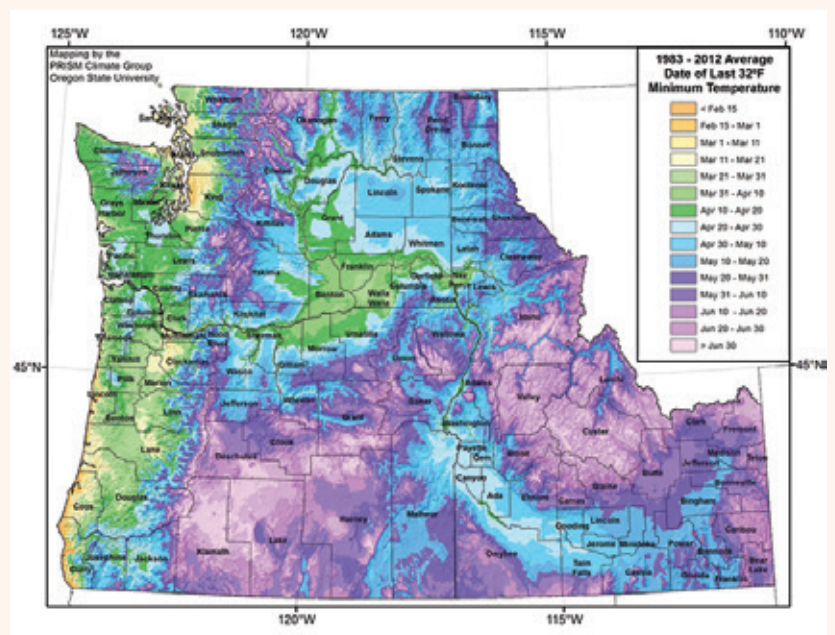
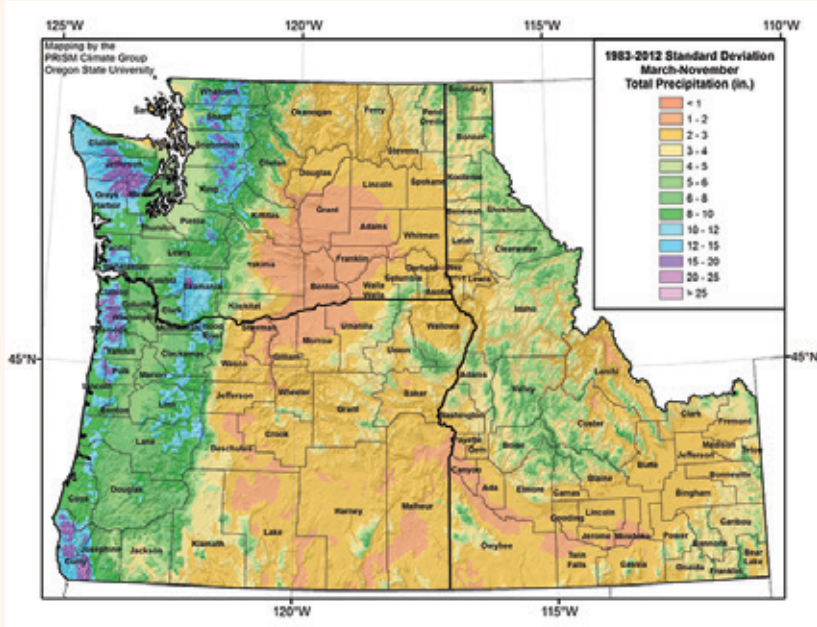


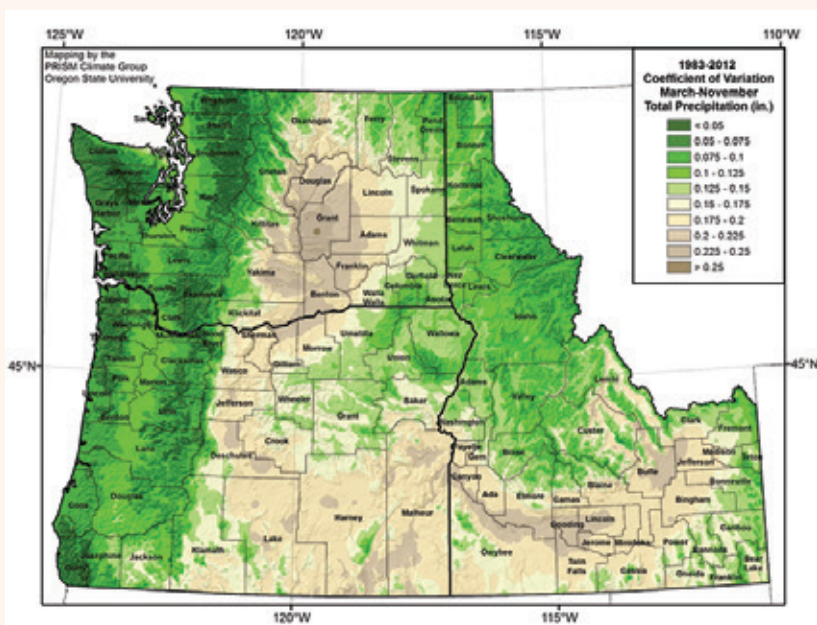
Figure 9. Standard Deviation of Total Precipitation during the Growing Season in the U.S. Pacific Northwest, 1983–2012



of variation) appear to be negatively correlated. Producers in west-PNW tend to have a wetter and longer growing season with lower diurnal temperature variation than producers in east-PNW.

Our statistical profile of agricultural climate helps explain agricultural production patterns. The major agricultural production regions in the PNW are the Willamette Valley, Columbia River Valley, and the Snake River Plain. Why is the Columbia River Valley a major producer of fruit trees such as apples, cherries, and pears? We find that in the Columbia River Valley the spring freeze risk, fall freeze risk, and precipitation risk are lower than in locations that are proximate to the coast, such as the Willamette Valley, or higher in elevation. Also, mean minimum temperatures are higher in the Columbia River Valley and Willamette Valley than in the Snake River Plain. Freeze risks are an important consideration for fruit tree growers because fruit blossoms can be damaged by *late* spring freezes, and mature fruit can be damaged by *early* fall freezes. In other words, upside spring freeze risk and downside fall freeze risk are important considerations for fruit tree producers. Freeze dates are less variable from year to year in the Columbia River Valley, which improves the effectiveness of agricultural producers' frost protection practices, including application of over-head sprinkler irrigation, wind mixers, and chemicals. Also, the relatively low mean minimum temperatures in the Snake River Plain may be conducive for frost damage to fruit trees. Precipitation risk is also an important consideration for producers, including fruit tree growers, because moisture shortage and excess can directly damage crops by reducing crop yield and product quality (U.S. Department of Agriculture 2013). For example, early summer precipitation can increase water uptake by the roots of cherry trees and increase water absorbed

Figure 10. Coefficient of Variation for Total Precipitation during the Growing Season in the U.S. Pacific Northwest, 1983–2012



directly by the cherry fruit, which both can cause cherries to crack so badly they're not worth harvesting. Rain-cracking affects fruit and vegetables besides cherries, including other stonefruit that are harvested in mid-summer (Washington State Department of Agriculture), such as plum (Milad and Shackel 1992), nectarine (Gibert et al. 2007), peach (Gibert et al. 2010) and apricot (Gulsen et al. 1995). Field trials in cherry orchards in Oregon's Wasco and Hood River counties from 2008 through 2014 showed that rainfall in late June and early July caused 10 percent to 27 percent of cherries to crack. It is uneconomical to harvest if more than 25 percent of the cherries crack. Most sweet cherry trees in the western U.S. are irrigated. Drip irrigation is typically used to avoid rain-cracking and disease hazards that can accompany overhead systems that wet the fruit (Bertelsen 1995).

Our statistical profile of agricultural climate provides a holistic representation of average climate and climate risk for the PNW, which is a valuable contribution for empirical analysis of agricultural production and adaptation to climate change. The best representation of risk would be the variability around key damage thresholds for specific crops. This paper takes some first steps in that direction by using variability of freeze dates to represent freeze risk, which is particularly well-suited for analyzing production decisions for fruit and nut tree producers. Our analysis also points to future areas for research on agricultural climate risk, including upside risk of precipitation in June and July on cherry production in the U.S. Pacific Northwest. ■

Figure 11. Standard Deviation of Maximum Temperature during the Growing Season in the U.S. Pacific Northwest, 1983–2012

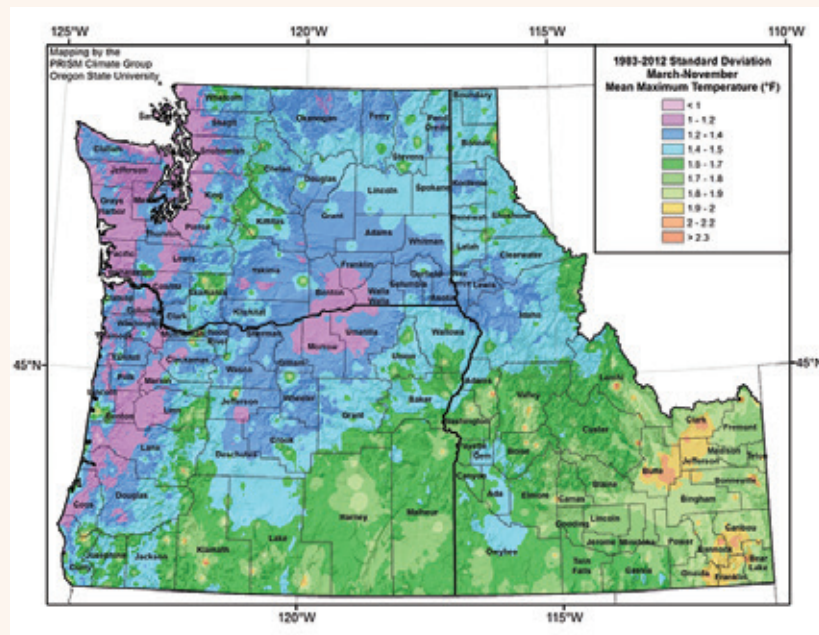
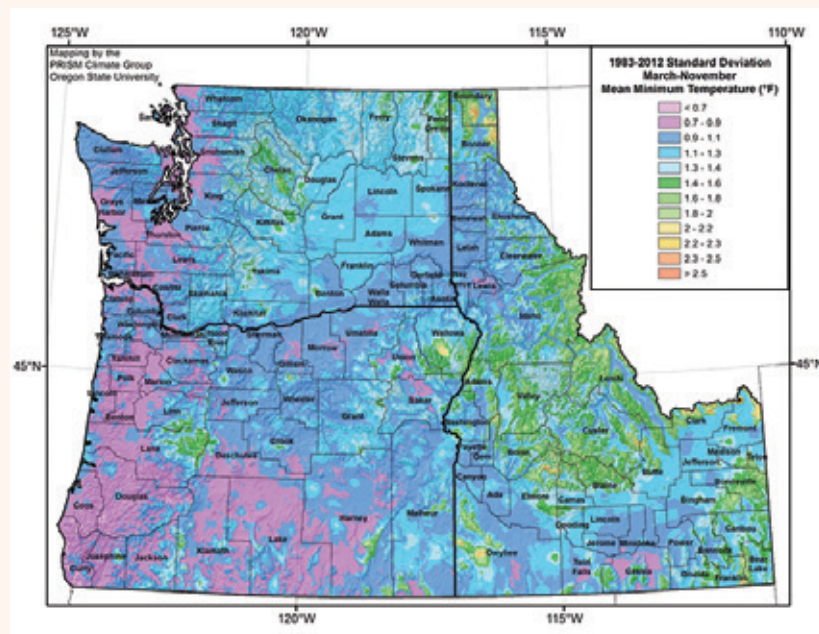


Figure 12. Standard Deviation of Minimum Temperature during the Growing Season in the U.S. Pacific Northwest, 1983–2012



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Figure 13. Standard Deviation of First Date of Fall Freeze in the U.S. Pacific Northwest, 1983–2012

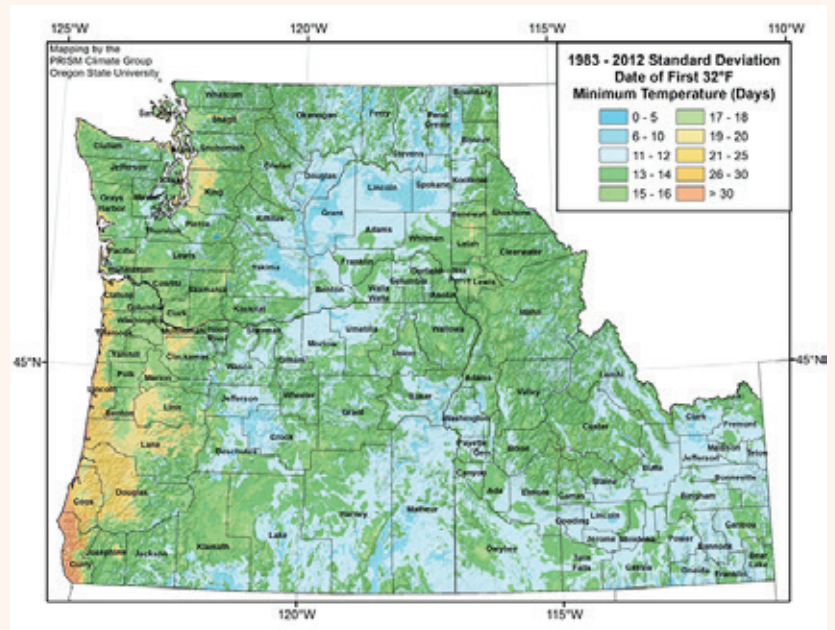
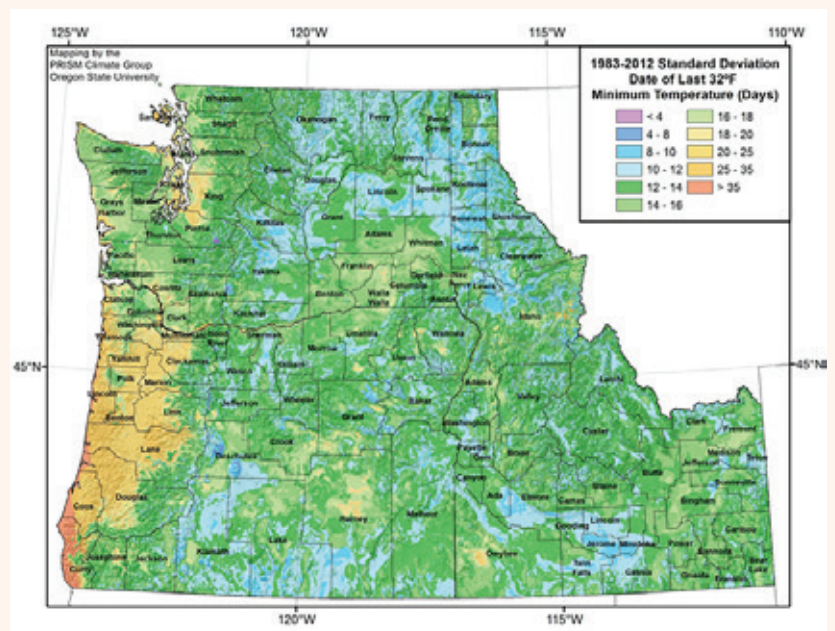


Figure 14. Standard Deviation of Last Date of Spring Freeze in the U.S. Pacific Northwest, 1983–2012



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The logo for OreCal, featuring the word "OreCal" in a white, sans-serif font on an orange rectangular background. Below the orange rectangle is a thin dark blue horizontal line.

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This material is developed with support from the US Department of Agriculture's Climate Change Program Office under Cooperative Agreement 58-0111-14-020. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of their home institutions or the US Department of Agriculture.

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