PETER MOLNAR: Thank you, Randle. The next person who is going to come up to speak is Dr. Gregory Jones from the Southern Oregon University. He's a professor there and a research climatologist, and will go into some of the climate at altitude.

GREGORY JONES: Okay. Well, first of all, thank you very much, Peter. I really, truly appreciate you putting together this type of meeting. It's an interesting conversation to have.

I have to tell a little story. I was asked by Erica Lundquist about a year ago to do this. And when she first ask me, I said, 'Well, what do you really mean by high elevation?' And I went ahead and said okay, because I had a year to figure it out. So I'm hoping that that year has proved fruitful.

I'm going to talk about a lot of different kind of characteristics of climate that I know are probably very germane to kind of what you do, but try to put it in the context of what we know that's happening at elevated environments, and talk about a lot of the different characteristics as a broader set of issues. So we're going to look at weather and climate influences and hazards; what do they truly mean at different elevations. I'm going to talk a little bit about what defines this, as best I can, because there really are a couple of different ways of looking at it. Look at some of those influences that weather and climate end up producing in upland zones. And then while this says 'Conclusions,' I'm not sure I will conclude, other than to say that more research is needed. So I'll say that upfront.

So we know as grape-growers and winemakers that there are a whole series of influences with weather and climate and even hazards that are tied in to these. In some locations, we can have extreme winter temperature issues that are very problematic, we can have spring and fall frosts or the length of the growing season sets of issues that really influence a whole series of things going on in the vineyard and in canopy and in the fruit zone. Growing season temperature characteristics, averages, extremes, heat accumulation, diurnal temperature ranges—all of those are very interesting both at any elevation kind of characteristic. Ambient moisture and precipitation with growth potential, disease potential issues, disruption of flowering and/or splitting of berries during harvest—all of these being issues. Also, extreme events during this time period, whether they be hail, wind, heavy rain. So while these are a set of continuum of climate and weather issues that know that exists in viticulture, I think what the real question is, is how do uplands zones influence some of these characteristics? Are they different, and how do they differ? And I'm going to try to get to some of that in this talk.

So if we look broadly at the kind of geographical factors, characteristics of weather and climate are really influenced by four main things—latitude, continentality, altitude, and topography. And if you look at these four it's really tied… two of them are intimately tied to what we are about here today, altitude and topography. The big issue behind this is, is that altitude and topography are influenced by latitude and continentality. So there are some real intimate ties between all four of these, and you can't really look at any one characteristic in and of itself, and you have to look at how it varies. High latitude environments operate very different at altitudes and do low latitude environments. So we kind of have to consider that there's a lot of variation going on.

If we look at terrain's effects on weather, there are really three kind of broad things that are characteristic. Those three things drive immediate and downwind type of environmental characteristics. The very first one is the modification of kind of the synoptic flow, what the weather system looks like around that region. It's both looking at dynamic and thermodynamic kind things going on that actually work at considerable depth in the atmosphere. If any of you are pilots, you know what the boundary layer is in the atmosphere because that's where you ride of a plane into the bumpiness. And the idea is that mountainous terrains have a depth structure that's very important relative to how air flows around that. So mountain or upland areas tend to produce that kind of environment.

There are also producing reoccurring and very distinctive regional weather kind of conditions, whether it be local winds, cloudiness, or precipitation patterns. All of those become distinct virtually anywhere, and it has to do with the orientation and structure of the mountainous area.

The other one is slope and aspect variations operate on much smaller scales within most environments, producing, typically, a fairly strong mosaic of what are called topo climates or site climates over a given area.

And so these three things tend to work together to kind of produce some very unique kind of characteristics in weather and climate.

So the question really comes down to what defines high elevation. And I kind of asked this question of Erica and others when I first started thinking about this. And as somebody who kind of works in this environment quite a bit, to me, I came down and I asked the question, 'Is it a vineyard planted in Argentina at 7,000- 8,000 feet, like Randle was telling us, or is it the difference between being planted in Carneros versus Amador County in California, or is it the difference between the bottom block or the upper block of this vineyard?' These are all very, very different kind of issues, and I think they drive very different kind of weather and climate issues. Arguably, the person at this very steep slope vineyard on the right here, they would say that they have elevational differences that really need to be looked at. And so we have to really think about that there's a wind range of what really defines high elevation or mountainous type of climate structures.

You can look a lot of different types of vineyards out there—I know these pictures are small, but just kind of walk through this here. The upper left is Stone Mountain Vineyards in Virginia at 1,700 feet. To the right is Alta Seca Vineyard in Oregon at 2,450 feet. Terra Creek Vineyard in Colorado at almost 6,500 feet, Vineyard in Argentina at 5,500 feet. We can go to Central Otago in Chile, 1,400, 1,500 feet. Douro Valley in Portugal, 2,000 or more. Madrona Vineyards up in the foothills, 3,000 feet or more. And then Chateau Aigle in Switzerland at 3,100 feet. So all of these are very different kind of environments, and the mountainous areas around them will determine kind of what climate really does in those regions.

So when we look at this, we have to define this, really, in two basic frameworks—relative relief, which is just simply the difference in elevation between the highest and lowest points in a given area; and absolute relief, the difference in elevation between a given location and sea level. And this is just a little diagram that kind of shows that. And so when we talk about elevation parameters, we really need to say, ‘Are we talking about it in an absolute sense, or in a relative sense?’ because they really do mean slightly different things.

In most vineyard areas, relative relief is the most important aspect of what we really look at from elevational differences. This produces topographical effects on all characteristics of weather and climate that really are site issues that we know that we try to maximize.

In a very high absolute elevation relief, though, we really need to know that there are some pretty significant things that go on in weather and climate compared to similar low elevation vineyards at the same latitude. So we really need to think about these as kind of two different things.

So I’m going to walk through both of these from a relative relief standpoint and an absolute, and talk about some of the differences that we know exist. So from the local or topographical influence kind of characteristic, first of all, elevational differences do drive temperature differences. On average, the atmosphere cools at about 3.6 degrees Fahrenheit per thousand feet, or one degree Fahrenheit for 275 feet. So that’s a very basic average number. It varies quite a bit, depending on characteristics of the environment, but this idea is, is that slope aspect diurnal temperature characteristics, proximity to the coast, all can vary this just by small amounts. We can also have latitudinal, seasonal, and moisture level differences as well. And if you look at… this is a diagram looking at how temperature changes in the atmosphere, and I know you probably can’t see some of the situations here, but if you’re in a tropical environment versus a mid-latitude environment versus an arctic environment, you’re going to have very different kind of changes and temperature with height. And so you really need to know that there are large-scale variations that occur in how temperature does change.

On average, though, mid-latitudes, this rule of thumb of one degree Fahrenheit per 275 feet is pretty good.

When we move off to the next effect, we know that slope effects really are very important in terms of air movement. This varies by aspect a little bit. We know that there are diurnal wind characteristics, inversionary characteristics, thermal zones—all of those kind of things become very important. This is a picture from a vineyard area up in Oregon, and we know that air flows up the valley and up into the mountainous areas during the daytime, and we know it turns around and flows downhill at nighttime. Knowing the strength of that, and the direction of it is very important for any given local relief kind of a framework. These are all thermally-driven. Sometimes they're very driven by the local landscape. Other times they're driven by the greater kind of macro-scale kind of a flow of the atmosphere around you. So there's some very different things that can go on from one region to another.

There's also thermal zone characteristics, and I think this is one that's very important, and everybody here knows that in an inversionary environment in a valley we have typically an area where cold air pools and there's a warmer environment aloft. You need to know a little bit about the width of the valley and the openness of that air flow that will determine the depth of that thermal environment. And, honestly, I don't think we've really done enough to establish in many regions. Randle saying the idea that you need to have weather stations in many locations, I think this is important to understand, really, where of that thermal zone is on an average basis. And so being able to figure that out, and knowing the shape of the valley that you're in is very important.

The one I associate with this is, of course, isolated terrain. We know that if you grow grapes within isolated terrain feature you have very little cold air source left behind when it drains away, and so that could produce a very advantageous situation. But you need to know where that cold air source is around… in any mountainous area.

Another one, slope and aspects on heat loads and retention. We know that aspects tend to produce very differential heat loading. You can look at any set of the landscape and actually calculate it out pretty easily today about heat loading relative to that based on solar potential. You can also, of course, look at what the heat loads are per slope characteristic… I'm sorry, aspect characteristics, knowing, of course, that, you know, southerly-facing slopes, of course, give more than the northerly-facing slopes, but know that is very important, and within a relative relief kind of scenario. This both affects air temperature and soil temperature, and I think that there are some very prominent things there that really should be looked at a lot harder … understanding what is the tie between air and soil temperature that drives early growth in vines. I think that's probably some real important aspects of it.

The other one is high latitude effects. When you get up into a higher latitude, some of these become much more pronounced than others. And so you have to think about there's latitudinal changes that come about.

The next one here is proximity to bodies of water. Of course, this is a dry year, and our proximity is getting less and less to this body of water back here, but those are all very, very important because they deal with latent heat retention and buffering of temperatures from place to place. Bodies of water, depending on their size, can have very, very different kinds of effects overall.

This is a piece of research that I think really needs to be repeated in other areas. This was actually done in the L.A. Basin, and I know it's not the, you know, wonderful viticultural environment, but the idea here is that it shows that as you move from the coastal zone inland there's a point at about seven, or so, maybe eight miles inland, which the change almost kind of bottoms-out. There's really no more change after that. Knowing what those temperature changes are from the coastal zone inland as you move over mountainous terrain are very important, and even though this is for a non-viticulture environment, I think it tells a story that would be worth kind of repeating and understanding.

So moving from… these more local kind of topographical issues, moving to more absolute, kind of getting into the real extremes of what elevation potentially does, temperature differences are virtually the same. I don't really need to make any difference there, other than to say that we know at the highest elevation locations we typically have lower averages, lower heat accumulation, and a higher diurnal temperature range. This diurnal temperature range issue could be something very different for different varieties, and we need to know that connection between varieties to their diurnal temperature needs.

I did something, I hope everybody can see this, I kind of played around with this last week, and I went on as close as I could get to a transect going from the coast to the mountains. And I went across from Fort Bragg, through Ukiah, Clear Lake, Willows, Marysville, Auburn, Placerville, Blue Canyon, and Truckee, and I basically calculated out the shape of the degree-day curve for each one of those locations over the course of the year. And one of the big stories there, of course, is that you can see that Marysville and Willows and Auburn all achieved slightly higher units than the others, and then when you look at some of the colder locations, the shape of those curves are very, very different. Fort Bragg doesn't receive as much as anywhere else, but it gets more on the shoulder months, in terms of heat accumulation.

So these curves are all very, very different and elevation plays a role in that. But you can't discount distance to the coast in terms of that, and so you have to look at kind of both of them together as very important features. And if you look at the absolute numbers for the degree days for these locations, and you guys all probably know these, you start off at the coast at Fort Bragg at 1,340, and… in Marysville you hit nearly 5,000, 4,900, and then in Truckee you get back to get back to 1,100 again. So it's kind of an interesting kind of framework or transect of just degree-days across this region.

So elevation definitely plays a role, and you can just see the difference between Ukiah and Clear Lake, but also we have distance to the coast issues that need to be really kind of brought into play as well.

So going from there to pressure and density differences. I think everybody in here knows that gravity, of course, causes us to have a higher density, and, therefore, a higher pressure environment at sea level. As you move upward in the atmosphere, we have a lower density of all constituents in the atmosphere, everything. From oxygen to carbon dioxide to water vapor, everything decreases in a fairly well-known rate. If you look at the average density structure as we move up in the atmosphere, at 3,000 feet, we're roughly at 89% of what we are at sea level. At 9,000 feet we're roughly 60%. So you can see, we don't have to go up very high. Randle, your 9,000-foot environment, you're at 60% of the atmosphere at sea level—a very, very different kind of environment in terms of how any kind of plant would deal with that.

One of the issues that comes into play with this I think is important is carbon dioxide, because we know that when we look at water, nitrogen, and carbon dioxide, those are three very limiting issues for plant growth. And so if we look at this, CO2 in the atmosphere follows very similar kind of structures as other constituents do, that the relative concentration or percentage at altitude is about the same thing as at sea level, about .03%. However, the abundance of CO2 to O2, oxygen, at high elevations decreases, and this is very important about uptake. Uptake are carbon within the photosynthetic process. So it's a very important component of it.

CO2 update is going to be less at higher altitude, typically limits photosynthetic activity and productivity at ambient solar radiation. It also produces something called nanism, it's essentially dwarfing and/or stunting. And I would really like to see some research over the long-term to see something about internode links, leaf sizes, berry sizes, those kinds of things that if you can start measuring that, it would be interesting to see what happens between, say, 6,000 and 9,000 feet in Argentina, because I think that that's definitely a piece of the puzzle.

The gradient of CO2, of course, is less because there's less of it in the air, so plants have to physiologically adapt. I don't know what the timing is of that for grapevines, but it does have to occur. You have to be able to, from a plant systems standpoint, be able to adapt to that by increasing stomata size and/or number to be able to deal with it. So my thoughts here are, is that we have some research on this, but there's really not a good integrated overall full impact on grapevines or wine, specifically, known, and we really need to do some more research in that environment.

Again, looking at going from, you know, differences at elevation relative to carbon dioxide and density, the radiated differences are also very important. Higher elevation surfaces both gain and give off radiation or heat very quickly. This produces a pretty dominant sun/shade effecting kind of issue. You have higher intensity and more ultraviolet radiation. Now, I don't know how many of you are familiar with this here, but the ultraviolet band is divided out into basically three areas—UVC, UVB, and UVA. And we're very fortunate that we have enough ozone up at high elevation in our stratosphere that keeps most of the UVC and UVB away from the surface. But as you get further and further up in elevation, the ability for UVB, especially, the biologic reactive component of that, to get down near the surface, it increases pretty dramatically. And so those are the kinds of things that we need to be aware of. If you look at it, the terms is called rarefaction. Rarefaction just basically says as density decreases as we get up into higher altitude, the thinner atmosphere filters less ultraviolet radiation. The numbers hold pretty good at low-level elevations and high elevations at about 3-4 percent per thousand feet. Now, what that equates to, exactly, in wine issues is another story. I don't know if we really have enough information on that. But, typically, UV exposure should increase the [...unintelligible...] and color level—should.… there's some research out there that does indicate that. But other factors may lessen their influence, and we have to look at how these competing interactions come about in that environment. Recent research does show that some diseases in grapes are due to a combination of both water stress and high UVB environments at high altitude, so it will be kind of interesting to see that relationship, how it plays out.

Chlorophyll degradation in leaves and berry skins also occurs more rapidly in high-radiation environments. And that goes back to something that Randle mentioned, the idea of shading, dappled shading instead of pulling leaves to keep that from occurring.

When we look at UV radiation levels across the globe, they're mostly stable, meaning they haven't changed dramatically. However, some regions in the southern hemisphere in some locations and in Europe, we see increasing UV levels that are kind of interesting. But other places it's actually showing decreasing trends, and there's a term out there called 'global dimming,' that the atmosphere is not allowing as much in. But there's a lot of kind of effects that are very, very spatially variable across the globe.

Moisture patterns: Marked spatial and temporal variability with moisture happens. Just about right. Marked spatial and temporal variability happens with moisture patterns. And I know you guys know most of this, but we have orographic rainfall characteristics, valley fog characteristics. This is a diagram from California—extremely complex orographic rainfall structure. It depends on orientation of mountains and airflow patterns across that area. Valley fog, how deep valley fogs can get. Again, it gets back to the idea of inversion depths, as well. However, when you get up to the highest absolute relief influences, we have, typically, drying winds and fairly low humidity and so there is a tendency to have higher rapid dehydration issues in some regions. However, it's not consistent, and you can look at other places where there are potential increases… or decreases in ET rates at high altitude. So you really need to look at every place individually just to kind of see where are the dominant factors coming into play with moisture, because some environments, while you would expect them to be wetter, are not always wetter, and actually can be dryer.

Some of the mechanisms that go into this… I know that everybody can't see this here, but from a meteorologist's standpoint, I think this is very important. Methods of orographic precipitation vary by the mountainous regions, what kind of general climate is found in that area, and how the airflow characteristics vary between winter and summer in those areas. You can have a whole range of scenarios that go on. We typically have more of the B scenario here for orographic precipitation, just upslope condensation occurs as airflow moves over a mountain. But you can have conductive processes in parts of Italy. I mean, this is very, very important for uplift of air over mountainous areas producing conductive processes, and, therefore, greater hail frequency and things like that. So we need to think about all of the different types of ways in which mountainous areas influence that rising of air and can influence precipitation as it goes on.

One of the other things, and this is, again, a small diagram—I wish I had a big screen to kind of show all this here—but this is a very important one: Complex terrain equals complex inversion. This is very, very important because when you look at inversion depths, the strength of inversions, and also how they break during the daytime, a mountainous region can produce some very interesting characteristics. How the air flows into those mountainous valleys produces some very different kind of structural inversion depth, it can produce one that breaks at a given time in mid-morning versus one in late morning, so we have some very big differences that occur across the terrain. And we can also get some fairly big differences in rising air as the inversions break. And so complex terrains will produce very large differences across a given area.

Wind characteristics, just real quickly, I'll kind of go through this. I think this is some of the very important issues, you know, getting back to the idea that at any one location you need to know what those wind flow characteristics are. We talk about it being channeled flow, turbulent blow, or desiccation potential from the atmosphere itself flowing around. Typically, what happens is, is that if the main air flow comes perpendicular to the mountainous area that you're in, you typically have the greatest vertical development of air flow. You can also have the strongest turbulent structure on the downside of it. If your mountainous area is at an orientation such that it deflects it in a non-perpendicular way, you likely could have a much lessened environment in terms of vertical air flow and turbulence. So there are some differences where you need to know where airflow characteristics are, and looking at kind of those dominant flow paths is pretty important.

We also have in many places, and this seriously… it happens throughout my region in Oregon, and I know it happens here—you get forced channeling of the atmosphere that produces some very dominant wind kind of flow characteristics. The typical one is, is that forced channeling will take a relatively benign 10-mile-an-hour flow and increase it to a 30-mile-an-hour flow over a very short distance. And knowing where you are with that, that flow, that jump from 10- to 30-miles-an-hour through a mountainous area could really drop growing degree day potential down quite a bit, and so you need to look at that as an overall issue.

One of the other ones—this is a map from Northern Oregon and Washington—pressure-driven channeling. This is very important, I think, as we get into summer, when we have heating going on in the Central Valley of California and you get pressure differences between that Central Valley area and offshore. Then you can get some pressure-driven kind of channeling, as well, in the atmosphere.

This is a whole range of things that goes on over elevated terrain, and let me just kind of walk through this, because you have to really look at the sum total of everything that happens relative to the air movement around you. Of course, there's upslope flow during the daytime that leads to what's called mountain venting, just the air moving off the top of the mountain pretty effectively. And this is more evident in a south-facing, or southeast-to-southwest-facing area where you have strong venting that goes on during the daytime. There's also convective mixing that goes on. If you're close to an urban environment, you can have urban divergence/convergence of air flow that's very important, so you have to consider that. There's also the idea that isolated hill areas produces divergence and convergence. There's a vineyard up in my region that exists on a south-facing zone of an isolated hill, but it has a convergence of air that goes around it and diverges right… or converges right into the vineyard, and the airflow characteristics in that vineyard are always 15 to 20 percent greater than they are on the other side of the mountain because of the way the air comes together there.

You need to look at other things. We fortunately live in an environment here where we have large-scale substance, meaning that the atmosphere, in general, above us is subsiding in our high-pressure environment during the summertime. This holds some of this airflow characteristics at bay, even though we do have mountain venting that goes on. Fortunately, we have subsiding air, which keeps us from having large-scale convective processes going on. Not every environment in the world has that, you know, so you can really get some big differences from place to place.

So just to conclude off of this, and, again, like I said, this is really not conclusive, but what I've tried to do is show that elevated climates are fairly distinctive; they have a distinct combination of temperature, radiation, wind, rainfall patterns that varies quite a bit over the nature of the landscape. There is large climate variability that occurs, as well, at both temporal and spatial scales, depending on where you are. There's many complex interactions, and I think this is very important, being able to kind of tie those together and understand them as best you can in your own individual environment. However, they're kind of hard to isolate overall.

Growing seasons tend to be shorter at higher elevations, but plant growth can be intense. So understanding kind of what happens in a more favorable radiation environment and these marked contrasts between day and night temperatures is pretty important. I think if we look at it, and I think that if you look at some of the research that the students pulled together that's in your… I think it's in a CD in the book—is that right?—I think what you'll find in there is that most of the research is pointed to radiated and CO2 effects at high elevation being the most important characteristics. But I think that overall we clearly need to do more research to be able to figure this out, not so much just on how weather and climate vary with high elevation, but that influence on vine growth characteristic, fruit composition, and wine. And I think that's kind of a fruitful area for us to kind of move forward in the future.

So thank you very much.