C. Peterson: Okay. So, kind of following the theme that Alison used this morning, this will be Tree Fall 101, I suppose, and unfortunately, I can't talk to you for three hours, but I'd like to, but we'll try to fit it into 20 or 25 minutes. And so this is the outline of what I'll be saying. Just say a little bit about geography of windstorms, compare the Central Valley area to other parts of the US. Then, move into a little bit about the biomechanics of windthrow. I do that with some trepidation. I know all the engineers in this audience and I'm not. So, I'll do that with quite a bit of care.

And then talk a little bit about the influences on windthrow, tree characteristics, characteristics of the sand or the other vegetation, if you will. I hesitate to say forest because we're usually not talking about a real forest on the levees here. Plate characteristics are topographic or soil non-biotic characteristics of a particular location, and then of course storm characteristics are an influence, as well, and I'm not going to address those so I'll just concentrate on the first few, and to kind of follow-up with something somebody said a few minutes ago, there's some great research opportunities here so, in terms of trying to answer some questions.

And the first thing I'll mention is just some preliminary comments, just basics. There's a whole lot more I can go into. Most of the existing and maybe all the existing data that I know of come from [Porid], okay, and so I was really clear when folks contacted me about coming out here and said well, look, I don't -- I'm not aware of any study anywhere that has been published on tree fall from levees. So, we're extrapolating a little bit, and I ask you to kind of bear that in mind.

Also, none of the information that I could find bears on the particular species that we're probably mostly talking about here today, the cottonwood and sycamore and live oak and valley oak here. I've been unable to find any tree fall information on these particular species. That said, most of the trends that I'll mention are pretty well established. A lot of it comes from my own work, and so I'll show you some real data, and they've been developed across a number of studies, and then finally as I mentioned, there are great research opportunities. Foresters in windy places such as Scotland are very concerned about tree stability, and have made great strides in developing mechanistic models to predict when a tree is likely to fall over or blow over or not. So, it strikes me as this is a situation where such models could be directly applicable to trees on levees.

So, geography of wind, you can -- probably this is no surprise to anybody. Okay. So, this is showing the distribution -- geographic distribution of tornados in the US. Of course, we've all heard of the tornado alley in the Great Plains area, and tornados decrease sort of slowly to the east. There's a little bit of an oddball or anomaly in Florida. There are lots of very weak tornados in Florida, and then, of course, the bigger issue for this audience is that there are very few out here, right. So, that's something that one need not worry about.

A type of windstorm you may not be so familiar with are [unintelligible]. The meteorological community has become much more aware of these. These are quite large storms. They may be 20 to 30 percent the size of a hurricane, but they occur in the middle of continents, and typically we see one or two per year in North America. Maybe one every couple of years in Europe, and they can be quite large. This map here shows the distribution of forest damage. Anybody here ever heard of the Boundary Waters Canoe Area? Okay, wonderful place. You should go there if you can. A 30 mile by 10-mile damage area here shown in the red from this windstorm, so 400,000 acres from a single storm. So, these are large-scale events. Happily for the Central Valley, they don't occur here, either, and the same thing is true of hurricanes, although we've heard a lot about Katrina today so I need to show this.

And as you're all aware, hurricanes form over the ocean. The ones that we're mostly concerned about with in America are the ones that come off the Atlantic and strike the East Coast or the Gulf Coast. Although, they also do form in the Indian Ocean and in the Pacific Ocean and so, Japan and China and other areas of Southeast Asia are affected. Here in Sacramento, I'm sure there are many people in this audience that could say a whole lot more than I could about the wind climate here.

One good way of getting an idea of what the wind climate is, is to look at wind [unintelligible] And so here we see some from December and April and this is quite a long time span from 1961 to 2000 or something like that, and they show the direction that winds are coming from in a particular time period. And the different colors show what percentages of the winds are of different wind speeds, and so the dark green on the outer age are the highest wind speeds. So, not an extreme wind climate here, compared to a lot of other parts of the US. So, that's maybe the underlying take-home message in terms of wind climate relative to other areas for the Central Valley.

All right. So, what happens when wind damage happens somewhere? I've picked the most extreme example that I could find. This is the result of an F4 tornado in Pennsylvania. We can see a lot of different things have happened. Of most concern here are the two most severe types of damage, trees either breaking off or uprooting. Of course, they have very different consequences, particularly in light of the issue of vegetation on levees. Uprooting, presumably, would have a much more dramatic and important effect on levee integrity.

Trees seem to fall in the direction of the wind blowing. That's probably no great surprise. You can see in the photograph here, the wind was blowing from the right towards the left, and of course the trees are all leaning over towards the left, and this illustrates, also, a -- it's a good illustration of the root ball idea that we've heard talked about. Allison talked about that. We've heard a number of other people speak to that.

Okay. So, a little bit about the biomechanics of windthrow. So, it occurs when there is a turning moment -- in engineering terminology, that exceeds either the strength of the trunk or the strength of what we call the root-soil plate. Okay. And that turning moment can be sort of approximated or modeled in the simplest way by just thinking of the tree being a lever arm, which is more or less the trunk, with a force at the end of that lever. Okay, the force is the wind pushing against the crown of the tree, and I think Don this morning was using the term sail area and sometimes the book -- people use the word sail to talk about the crown area of the tree that's exposed to the wind.

Okay. For the engineers in the audience, so the drag force on a tree crown can be calculated, and so I'm using just the letter D. Calculated from air density. Usually, in the most calculations I've seen, that's assumed to be constant. The things that we're more concerned with are the drag coefficient, which is the dimensionless number, the wind velocity, of course in meters per second, and the frontal area of the crown. So, this gives you an immediate idea of what sort of factors are going to be important in influencing tree vulnerability to windthrow. Larger trees because they have a larger crown are more likely to be wind thrown, even though they are bigger and have stronger trunks and stronger root-soil plates, the impact in terms of high wind -- the impact on the sail area increases faster as the tree gets large. It increases faster than the trunk strength does.

And the turning moment at the base of the stem, you simply multiply the drag times the length of the lever arm or the length of the -- which is more or less the height of the tree. So, another prediction is that trees with -- that have a crown mass concentrated near the top are more vulnerable because the lever arm is out at the end of the trunk, rather than at some lower point, and we'll come back to a few things like that in a second.

What I just told you is sort of the static picture. Of course, when trees are blown on by wind, they are dynamic entities and things change. They're not just static. There are a number of things that do change. I'll just mention a couple of them. The frontal area changes because twigs and branches will -- in fact, the whole crown will bend and present a smaller area to the wind. All right. This is called streamlining. So, that increases the value of A in this equation right here, and at the same time, the drag coefficient will change, as well, because leaves and needles and twigs are going to become more streamlined, as well.

So, drag coefficients and the area changes dynamically at increasing wind speeds, and the diagram here on the side is meant to demonstrate also that once a tree is deflected from being vertical in addition to the drag induced by the wind, itself, you have actually the weight of the crown of the tree that is off-centered. And that's going to tend to pull the tree in whatever direction its leaning. It's more or less an extension of what Allison was saying earlier about if you have an asymmetric crown that's leaning or loading a trunk and root plate in a certain direction.

All right. So, I just said this. So, this is the idea of streamlining. Streamlining can be pretty important, okay. So, one calculation that was done with cottonwood is that a frontal area -- if you've got a 20-meter per second wind, is only 28 percent of the frontal area of the tree in still air, right. So, the streamlining can be pretty significant. As a result, this power that we saw back here in this slide, the U2 actually is not quite accurate, and the more accurate number is drag increases with the power of 1.8 rather than 2.

And of course as you might imagine, as with everything else I'll say here, it differs from specie to specie, okay. So, we can talk a lot about the sizes of trees, but species are important in almost any kind of calculation in terms of windthrow. Species are different. They have different properties. Okay, trunk breaks -- it occurs if the bending moment exceeds the strength of the trunk, and here's the formula for the critical bending moment for a knot-free trunk, meaning a clear wood with no knots in it. And the main factor is the module could rupture, which is highly correlated with wood density, which was an easier thing to measure, and it increases with the cube of the diameter. Deviates is the forestry or ecology terminology for diameter [breath] type. That's the diameter of the trunk at one point for meters, and, of course, trees are weakened if there are defects in the wood. So, in reality this formula is applied with a knot factor as part of the formula, which decreases the wood strength.

Anchorage is comprised of four factors: The weight of the root plate, and we've heard a little bit about that already here today. So, the root plate or the root ball is the soil plus the roots -- the large root. The soil sheer strength -- the tensile strength of the windward roots, which is what this diagram is trying to illustrate, and then the resistance to bending and compression of the deep roots in the leeward group. All right. So, those are the four major components.

And people that have calculated this have found it very difficult to get accurate data on the second, third and fourth factor, and so they've come up with sort of a fudge, and that's what this formula is here. The critical [unintelligible] used in field measurements is just number one here, but it's assumed -- and empirical studies actually bear this out, it's assumed that that's a constant component of the total turning moment -- or the critical turning moment. So, we have the first part of the formula, and that's just divided by the FRW, which is sort of the fudge factor.

Okay. So, three different categories of influence on types of damage. The biggest issue with trees is the size, right. So, this graph shows the probability of tree fall from some of my studies, as a function of tree diameter, 1.4 meters, and in almost all cases, the probability increases with size. That's no surprise. The more important thing is that it increases at different rates and different places. Okay. So, in some places it increases very dramatically from very small to not-so-small trees, such as the Cathedral pine, the diagram here. The other one, the [unintelligible] to a 1994 shows a very gradual increase, so it's a very sight specific . . .

As trees get bigger, a bunch of things are happening. The trunk is getting stronger, generally. The root plate weight increases. But the overpowering issue is that this sail area or the crown area increases, typically faster than those other things can keep up with, and also trees that get bigger tend to be more exposed. Okay, so if you're bigger than your neighbor -- regardless of your absolute size, if you're bigger than your neighbors, you're going to be more likely to blow over than your neighbors are, all right.

And then find larger trees tend to be older, and so therefore there's more likely decay or knots or some other sorts of defect in the roots or the trunk and so that will make the tree more likely to go down. Of great interest to this group, of course, is the fact that if a tree uproots, it creates this hole in the ground, which is what some of us call the root pit, and there is the strong relationship between size of tree and size of root pit, and this increase differs with species. I've only shown one pulled sample here, but it differs from species to species.

Other species' influences are -- think characteristics of the wood of species. As you might imagine, species with weaker wood are more likely to break off, all other things being equal. So, we've got some pictures of aspens from Northern Minnesota, some pines in Southern Sweden, and you can see that not very many of these uprooted. The overwhelming pattern in both of these cases was trunk breakage, rather then uprooting because these are weak-wooded species.

Another species of fact is, as we've already heard, species differ in wooding depth. Okay, so a more shallowly rooted species are more vulnerable to uprooting. So, things such as Spruce, which is the Latin name as picea shown here in the right-hand side of the -- right-hand photograph, and, in general, conifers tend to be more shallowly rooted than a broadleaf tree. All right. So, therefore, they are more vulnerable for both uprooting and trunk breakage.

One of the frustrating things is that the relationship between vulnerability and size changes among species, all right, and it is also site-specific. So, there's a lot of difficulty in making really broad generalizations here. So, species differ in vulnerability for a particular size, so if you look at the upper two lines, they're showing -- from one particular site, we're comparing Hemlock and Beech in the east, and you can see that the Hemlock is more vulnerable in the size range from about 15 to 30 centimeters than the Beech is.

If you look at the diamond symbol line, you see a very different sort of story. These are the same two species across the same size range, but a different storm that was only about 5 kilometers away. All right. So, the relationship of species to each other and vulnerability to size can be very site and storm-specific. So, that creates us -- gives us a real difficulty in making -- sweeping a broad generalization.

What about stand characteristics? There's a number of stand characteristics that influence vulnerability. The two ones -- two that I'll mention the most here are the density and presence of edges. So, low-density stands allow more wind to penetrate in amongst the trees. Trees that are at low density do not have mutual support with each other. When you have a high-density stand, the trees actually bleed off some of the energy that might knock them over by crashing into their neighbors, okay.

You have a low-density stand where the trees are far enough apart when they wave back and forth, they can't run into or lean on anybody else, okay. So, at lower density, trees are more vulnerable.

Now, the flip side of that is that trees are adaptive organisms, and I think Allison mentioned something about this, this morning. Trees that have been growing in an open circumstance will do their best to develop a wind firm root structure and trunk, as well. All right. So, there are some complexities there, as well.

And then the other sort of stand effect I'll mention is related to this, and that is trees on edges are more vulnerable than trees that are further into a stand. Again, because the leaning on each other effect and because the trees on the edge are attenuating. They're taking the brunt of the wind, if the wind is coming off of an open area.

Fight characteristics, there's a whole bunch of them, as many as you undoubtedly realize. Topography is a big one so damage is usually greater at higher elevations. I spent a semester in Finland on sabbatical a couple of years ago and heard a lot about the winter storms they have other there, which are kind of like temperate hurricane, and so in 1999, they had Hurricane Lothar or what they called hurricane. And it caused an immense amount of damage across France, Germany, Austria, very large areas, and so this picture is from there.

And this had wind speeds of, you know, 150 to 160 miles an hour or kilometers per hour in the valleys, but up on the mountaintops was 230 kilometers per hour. So, there's a very strong topographic effect. Windward sides of hills and ridge tops are the most vulnerable topographic positions. And so here's just a little cartoon that illustrates that. If you've got a hill that's perpendicular to the flow of the wind, the wind tends to speed up over the crest of the hill. You typically get turbulence if it's steep enough on the leeward side, and that turbulence can, itself, be a major cause of windthrow, as well.

Now, one key question that's in my mind, which I'm not enough of an airflow person to know this, is whether the levees in this particular area are big enough to sort of qualify for this sort of scenario. They may just be too small to have this sort of thing happen, and then, of course, there's soil characteristics as we've heard a little bit about from various people today. The two key factors are depth of root penetration and saturation. So, saturated soils have much lower sheer strength and so roots can pull out of them and soils that restrict root growth, that cause you to have a very shallowly rooted tree of course are going to increase the vulnerability to wind throw as well. Okay, so those are some of the major factors. There are a whole bunch of other ones we can go into if we want to talk more later, but I do want to mention that there are some great research opportunities, especially after I heard things just a few minutes ago, you know, about what are the questions that we can address -- well, there are mechanistic models that have been developed by foresters, particularly in England and Scotland and Northern Europe that take all these factors into account. So, there's a couple of them -- one is called Forest Gales and one called H Wind and these are models that calculate the critical turning moment needed to overturn or break off particular trees if you know characteristics of the tree, so the size, diameter and so on. What the next step is after doing that is to merge those models with site features like soil conditions and topography to get a site specific estimate of wind speed -- the wind climate in a particular location, and then finally overlay that in a GIF sort of context to sort of bring all these factors together and this could be done of course in levee context and come up with particular predictions for particular stretches of levee if you know the site characteristics of soil, topography, exposure and the trees that are on it.

So, there is a great research opportunity. And then finally, I'll just make a few of my suggestions. These sort of echo what Don was saying earlier. There are things that can be done if one is concerned about wind throw that aren't maybe as drastic as completely removing all of the trees. So, removing part of the crown area reduces the length of the lever arm if you cut off the top 20% of the tree. Many trees will survive it. Some certainly will not, but many of them certainly will. You can reduce the wind velocity on your Heritage Oaks or whatever by having additional upwind trees or you can defect the wind upward by having sort of a stepping stone of small shrubs, large shrubs, small trees, that will just push that wind up over the trees that one might be concerned with saving. And, then down the road, there is certainly the opportunity if the public desire for it is to have trees on the levees, is to have species that are much less vulnerable. Okay, so, there is a great deal of variety among species and their wind firm in planting. Wind firm species as opposed to weak species would be the solution for 20 or 30 years down the road. Thank you very much.