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Speaker 1: I work with this group, we call ourselves WECLIMA, Weather Extremes and Climate Impacts Analytics at Scripps Institution of Oceanography, and everybody is working on some aspect of extreme weather and how it's related to climate variability and climate change. How to use those relationships to understand predict impactful weather patterns better, and we're also very interested in the impacts of extreme weather on society and ecosystems, like Steve said. That's a list of the things that we work on. I'm just going to go over a few of these and maybe at first describe what climate change is about, and then how it may be impacting the impactful events that we actually feel and care about. Because climate change is a pretty abstract idea, if we just look at it as a warming of a few degrees averaged over the globe, then what does that mean in my backyard? We're working on those connections. Here's the background. Obviously, the world has been warming, and the warming has been accelerating over the last few decades. It used to be that we had globally warmer periods and cooler periods, warmer and cooler. Now that doesn't really happen that way anymore. We just have this warming trend, and sometimes it slows down. When it used to be cooler, now just the warming trend slows down. There's a low in it, and then it keeps warming again, typically at an accelerated rate. You can see that the years that set the records, typically, this is 82, 83, probably in El Nino year. If you look at all of these that stick out, they're all El Nino years. We're not really going to talk about El Nino unless you want to talk about it afterwards. But that's a large-scale warming of the Tropical Pacific, and it's such a large-scale feature of the global climate. It's a regional feature, but it impacts global temperatures. Typically, when El Nino events happen on top of this warming trend, that's when we set the records. You can see, here's the 15, 16 El Nino. This is 23, 24. You can bet that the next time we have an El Nino event, we'll set a new global temperature record. Why is it warming? Well, since the beginning of the Industrial Revolution, people have been digging up fossil fuels, coal, crude oil, natural gas. These are fuels that have been fossilized in the ground for 10s and 100s of millions of years from organic material, and we dig it up in a matter of a few decades, a couple of hundred years, and basically burn it, sending carbon dioxide and other stuff that's more toxic. Carbon dioxide is not toxic to us, but does have an impact on climate. When we send that much of carbon dioxide into a really very thin layer of the atmosphere that the Earth has. It's not a surprise that it's been increasing. The greenhouse effect of carbon dioxide, for the first time, had been really hinted at, and this is the first publication related to global warming. Back in 1856, by an American woman scientist by the name of Eunice Newton Foote. Am I pronouncing that right? Foote. This was presented at the American Association for the Advancement of Science in that year, but it was presented by a male colleague of hers because women were not allowed to present there. If you read this where the big red dot is, she studied the effects of different gases, and carbon dioxide used to be called carbonic acid back then, and here she summarizes an atmosphere of that gas would give our Earth a high temperature. If at some past period, it had a higher proportion than at present of that particular gas, an increased temperature would have resulted. She's not predicting climate change quite yet. That actually came later in the same century in 1890s. A Swedish scientist by the name of Svante Arrhenius published a paper in the 1890s, really focused on the greenhouse effect, where he worked out the greenhouse effect of carbon dioxide in more detail and actually predicted a several degree rise in global temperature resulting from a doubling of carbon dioxide, which they were expecting at some point in the future, given the fact that the Industrial Revolution was well on its way by that time. Then I'm just giving you the highlights, but there was a lot of work in between. But the first long-term and continuous measurements of carbon dioxide were put together by Charles David Keeling, whom I actually met at Scripps. He worked at Scripps. I started there in 1996, and he was still around. Now his son is continuing this program. Have you invited Ralph Keeling, by the way, Steve? Yeah, he would be a good speaker here. But anyway, he's been measuring carbon dioxide on top of a dormant volcano, Mauna Loa, on the Big Island of Hawaii. The reason it's way out there is because they wanted to go to a very pristine place, far from where carbon dioxide is actually burned up and released into the atmosphere. Carbon dioxide is a very long-lived gas in the atmosphere. A molecule of carbon dioxide on average stays several decades. It's hard to process it out. But that also happens

on long timescales. But basically, it accumulates, and you can measure it anywhere in any pristine location around the globe. Very quickly after a few years, they realized that carbon dioxide had been continuously rising in the atmosphere. There is this annual cycle to that curve. Does anybody know what that annual cycle is about?

Speaker 2: Photosynthesis.

Speaker 1: Photosynthesis. Where most of the canal masses in Northern hemisphere, and so Northern hemisphere summer basically, the plants bloom and then take up the carbon dioxide, and then it's released in the winter again. But basically, that's also increasing at an accelerated rate as the burning of fossil fuels is increasing. Basically, carbon dioxide is one of several greenhouse gases, and greenhouse gases are basically gases in the atmosphere that are transparent to solar radiation. They don't interact with it. Solar radiation just passes right through. But they are opaque to terrestrial radiation. The Earth has a much cooler temperature than the sun. It releases radiation at much longer wavelengths, and those are the wavelengths that get absorbed by greenhouse gases, including carbon dioxide. When that radiation is absorbed, well, the atmosphere heats up, and it reradiates energy and heat in all directions, including back down to earth. The greenhouse effect keeps the Earth warmer than it would be without it. It's natural, and it makes the world a habitable place. But we're increasing it, and I think the greenhouse effect is a little bit of a misnomer. I think of it more as a blanket. The blanket basically keeps us warm because it absorbs the heat that's coming up from our bodies, and if you put on a thicker blanket, well, then you're going to be hotter in bed, and the same thing is happening to Earth. Basically, the Earth's temperature is rising until an equilibrium temperature is achieved where as much radiation is released out to space as what is being absorbed from solar radiation. As long as we're thickening that blanket, we're not in equilibrium, and the Earth keeps warming. That's a simple version of that story. There are also other things going on like feedbacks. For example, in a warmer climate, there's more water vapor because warmer air can hold more water vapor. Water vapor is actually much stronger greenhouse gas than carbon dioxide, and there's more of it. You've all noticed that on a dry day, like in the desert, for example, it gets super hot during the day, but it cools off very quickly at night, and that's the terrestrial radiation going out to space unobstructed by water vapor. In a place like Louisiana, for example, where it's super humid, the night isn't that much cooler than the day, and it's really the greenhouse effect of water vapor. Because water vapor is also increasing due to this initial increase triggered by carbon dioxide, we get a stronger increase. I want to talk about extreme weather. So far, I've talked about global warming. Let's talk a little bit about climate change because climate change is more than just warming. It's how does this warmer globe? By the way, a globe that's not uniformly warmer, it's warmer in the polar region. It's warming more in the polar regions than in the tropics. It's warming more over the continents than over the oceans. This is the anthropogenic signature of climate change that had been predicted by early climate models back in the '70s before this level of warming was ever observed, when it wasn't even really clear that the Earth was warming. That signature was predicted, and that's how it played out. How does it impact the things that we care about: floods, droughts, extreme storms, heat waves, storms. This is an atmospheric river. We'll actually talk about that in some detail. Wildfires, extreme weather, sea level rise. I can't talk about all of that. But let me just start with one extreme that is more impacted than the others because it's directly related to warming and that's heat waves. Let's go to California to a familiar place. California has been warming pretty much as much as the Globe has, but, of course, there's much more variability around that warming because now we're averaging over a smaller region. It's smaller sample size of observations. There's more variability. But the trend is still pretty clear. How does that impact hot and cold extremes, basically? Here's one long-term station at Bakersfield, the Central Valley. What's shown here is basically, the record started in the 1890s or '80s. This is the first decade of record, and basically, these are just counts of hot temperature records, warm temperature records broken, and cold temperature records broken. It's 50/50 in the beginning, because there's nothing to compare it to. As we go on, we see an increase in the number of hot temperatures broken and a decrease in number of cool temperatures

broken. Towards the end of the last couple of decades, basically, there are no more cold temperature records broken, but hot temperature records are broken very frequently. You can look at any station, really, almost anywhere in the world and you see the same pattern. Here's Austin, Texas, and Salt Lake City, and Colorado Springs, here's San Diego. We can still break a cold record every now and then, but it just happens very, very rarely, compared to the rate at which we break hot records. Actually, last week, I didn't check, but I'm pretty sure we broke some records for the winter because that was a very unusual heat wave. Typically in the summer, our coastal heat waves are associated with Santa Ana winds. Well, that was not a Santa Ana wind. That was a different pattern. Another thing that we can see in California is that if we break this into daytime maximum temperatures which typically occur in the afternoon and minimum temperatures which typically occur right at sunrise, we see that the minimum temperatures have been rising more at a faster rate than daytime temperatures. This is reflected in heat wave activity. This is actually heat wave activity for all of California. There are two time series in here. One is heat wave activity quantified according to maximum temperatures. The blue one is minimum temperatures. When the maximum temperature heat wave activity exceeds that of the minimum temperatures. This is relative to itself, basically how unusual the maximum temperatures are, how unusual the minimum temperatures are. We see that traditionally, heat wave activity in California is it's a daytime issue. It gets super hot during the day, but then it cools off at night. But lately we've been getting nighttime accentuated heat waves. This was the event that really raised a red flag or blue flag, in this case. This was the 2006 July heat wave, which was unprecedented in California, not just in daytime temperatures but especially nighttime temperatures. Minimum temperature records were broken all over the state, and some daytime temperature records were broken, too. But really another thing that was super unprecedented about this is that people were dying in large numbers. It was healthcare professionals that were asking the question, what is so unusual about this heat wave? Because usually a few people may die from the heat during a heat wave especially sometimes it happens to tourists who drive into the desert without enough water. That happened to some German tourists a couple of decades ago. But typically, it's a few people. This was like dozens 147 people died from hyperthermia, specifically from overheating, according to coroner's report. That's when I started studying heat waves and put together this record and very immediately saw that, well, there's this change in the flavor of heat wave. But does this uptick mean a trend or, well, since then, we certainly see that it was the beginning of a trend in heat wave activity. Not only is it increasing in frequency, magnitude, intensity and duration as heat waves are all over the world. But here, they're also changing flavor. They're becoming more humid. And for health impacts, specifically, that's a double whammy because not only is it harder to weather a day of humid heat when you're not associate, I should have said, but I didn't, that the reason, but you probably gathered that from what I said before. The reason that it's the maximum temperatures that are actually increasing or heat waves not cooling off as much as they used to is because there's more humidity in the air. But humidity also prevents us from sweating efficiently. In humid conditions, sweat just runs off and we're wet but doesn't cool us off. What cools us off is when moisture evaporates. We've all felt that. You come out of the shower or swimming pool, the ocean, if there's wind, for example, and it's dry, you feel much colder because the water is evaporating at a higher rate. It takes energy to evaporate water. Going from a less energetic to a more energetic state, it takes energy, and that energy is taken up in the heat. It makes us feel cold. The same thing happens on a global scale when water evaporates from the ocean, from a wet surface, it cools that surface off. It's another way of cooling by evaporation, by sweating the greenhouse effect, it interferes with cooling by radiation, a different kind of cooling. Humidity interferes with our cooling. Like I said, 147 people died from hyperthermia, according to coroner's reports. That was absolutely unprecedented. But excess mortality was more like 600 over the state. Excess mortality counts deaths from other causes, too, because a lot of the heat related deaths occur from exacerbation by heat of preexisting conditions like cardiovascular disease, diabetes, respiratory illness, and things like that make us more susceptible to heat. This is a more accurate figure. Anyways, another thing to say about this type of impact is that most of these people who died, mostly in the Central Valley, but also in the hottest

places, there were actually way more hospitalizations and emergency department visits along the coast. Fewer people died. It wasn't as hot. But compared to what it normally is, the coast is much cooler. Those impacts were much larger. But most of these people who died were elderly and living alone, some had functioning air conditioning but didn't turn it on. Maybe they were expecting it to cool down as often as it typically does, and it didn't during that event. Some of these people, maybe about 30 or so, were young and healthy and guess why they were susceptible. Farmworkers. We have started an art collection at Scripps, where the art to be in the collection, it has to be inspired by the science that we do. Here's an art piece inspired by heat wave research and drought research, too. It's absolutely beautiful. Would be happy to show it to you. It's a mosaic made from stuff found in the environment. Makes me feel parched when I look at it. I'm not going to dwell on this, but this actually shows the impacts from heat start at much lower temperatures at the coast compared to inland locations and especially desert locations because at the coast and the impacts are basically assessed through telling hospitalizations and emergency department visits from heat related causes. They started much lower temperatures at the coast because at the coast we're just not acclimated to the heat nearly as much, neither physiologically nor technologically. There's very little air conditioning at the coast. That's the story about heat waves, short version of that story. If you look at just San Diego County, you also see this increase, especially in humid nighttime heat wave activity. Let's switch gears and talk about water a little bit. Well, for one thing, California has a very distinctive wild hydroclimate. It's very rare to have a normal or average year, extremely rare. Most of our years are either very dry or very wet. When we do have big storms sleepy river like this in Northern California, in this case, can become a raging torrent. Here's the quantification of this. This shows these circles are long term weather stations. Basically, it shows counts over about a 50-year period, in this case, of precipitation events that accumulated 15 inches or more in three days or less. This is huge. These events always lead to floods. You can see that the Gulf Coast, Florida, some of the Eastern seaboard gets these types of events, and they're from hurricanes, typically associated with hurricanes. But California doesn't get any hurricanes, especially northern California has more than its share of huge events like that. You can also notice that they tend to be tethered to the mountain ranges, to the coastal ranges, the transverse ranges, and the Sierra Nevada. What do you think? What kind of storm produces this amount of precipitation in California? What are our hurricanes in terms of precipitation amounts?

Speaker 2: Atmospheric rivers.

Speaker 1: Atmospheric rivers. Let's talk a little bit more about that. But first, I want to show you how volatile this hydro climate of ours really is. These are the same weather stations and basically what's done here by a long term colleague Mike Denger he basically took precipitation, just annual total precipitation, and he computed the standard deviation, basically, a measure of how variable it is from year to year, divided that by the mean. It's relative to the mean climate. In the East, the hydro climate is very stable. You see it's between 0.1 and 0.2. That means that the variance around the mean that you typically get there is within 10 or 20% of the mean. It's not too variable. As you go west, in the Great Plains, it becomes more variable. Now it's between 20 and 30% of the mean. As you keep going west and especially to California and especially Southern California, you see that our normal variability around the mean is between 40 and 60% of the mean or even more than that. We can easily get half of our expected precipitation amount or twice the normal precipitation amount. That's normal amount of variability for us. Makes managing water resources very challenging. What really explains this variability is the wettest 5% of the wettest days. If you look at just the 5%, the wettest days and you accumulate the precipitation annually, just on those days, you get this red curve, and you can see how correlated it is with the variability in total precipitation. This is in Northern California where our water resources mostly come from, California water resource. This is the 95% of the other days. This is actually more precipitation overall. It's 95% but not the most extreme. This does not explain the variability. What explains the variability are the extreme events. Those extreme events, by far, are atmospheric rivers here. Basically, whether we get a couple of big atmospheric

rivers per year or not makes the difference between a wet and a dry year in California. An atmospheric river is basically a jet of moist air that's moving tropical moisture to higher latitudes. When a jet of moist air, which doesn't really rain out that much over the ocean, they're pretty stable atmospheric conditions. When it hits a mountain range like the coastal mountains, that air is forced to rise, it cools. Then, basically, at a cooler temperature, the air cannot hold as much moisture. That's a very saturated jet of moist air. It's close to 100% relative humidity. If you cool it down, that colder air cannot hold that much moisture. Then you get condensation and a cloud and eventually through a series of process that leads to precipitation of the type we call or graphic precipitation because it's the mountains that squeeze the moisture the precipitation out of these storms. Then you get more into somewhat of a rain shadow. Then the Sierra Nevada basically, these mountains squeeze a bunch of precipitation out of these particular storms. They're very orographic, and they're also warmer than other storms. The snow levels are higher associated with atmospheric rivers, and higher snow levels means there's more rain at lower elevations and mid elevations, which runs off and you get these winter floods. Other winter storms that tend to be colder. They're not as wet and the snow levels are lower. When you get snow instead of rain, well, it doesn't run off. It actually stays in that mountain reservoir, the natural reservoir that we have, that's the snow pack that stores winter precipitation into the dry summer. Actually, our engineer reservoirs are designed to capture that snow melt mostly. This is what atmospheric rivers look like when you look at a snapshot of water vapor in the atmospheric column, basically, it's called precipitable water. It's measured in millimeters, typically, because it's the amount of water vapor that if you condense it and all of it rains out, you get that many millimeters. You can see that really most of the water vapor is in the tropics because that's where the trade winds evaporate water vapor from the surface of the ocean. They converge it into this meteorological equator that's called the intertropical convergence zone. Then it's all moved here over this, Steve knows all about that as a sailor. The Western Pacific warm pool where the same trade winds basically blow on this huge ocean surface, and they move the surface water from east to west. Typically, even the elevation of the water surface over here is a couple of meters higher than it is over here because of the action of these winds. A lot of warm water converges is collected here. That's where the ocean gives a lot of energy into the atmosphere. You have a lot of convection, storm activity. When there is an El Nino, by the way, this warm water slashes back into the central tropical Pacific causing a big warming right here. But we're just looking at a snapshot on a particular day of water vapor. You can see that there are these filaments right here that move this tropical water up to higher latitudes. When an atmospheric river like this hits a mountainous coast, especially a coast where the mountains are perpendicular to the average direction of the flow, that's when you get the big rain events. California has perfect topography and it's in a perfect location to get a lot of precipitation out of atmospheric rivers. Chile is also in that situation. Atmospheric rivers actually really big ones happen over all of the West Coast of the mid latitudes. But if the mountains are not there, much less precipitation is going to be produced. In California, you can see this is the contribution of atmospheric rivers, the total annual precipitation. You can see how tethered to the mountain ranges it is. You can see here this is from a paper of ours where we quantified this and you can clearly see the mountain ranges. Then there's this area here that's the bull's eye for strong atmospheric river landfalls in Northern California and Southern Oregon. Here, a couple of atmospheric rivers. Actually, they happened both in the winter of 2019, which was a very wet winter with strong atmospheric river activity. This is the Valentine's Day event. This is a little bit later, the same months. I'm going to show you what happens to an actual river, the Russian River in Northern California, which is a rain fed river. As that storm was about to hit as it was starting, here is the Russian River as seen from Gurnville in Northern California. Second day of the event, the water rises. Third day it overflows its banks. This is a very flood prone river because of atmospheric river. A colleague of ours, Tom Corringham who is a economist, PhD from UCSD Economics Department works with us on the economic impacts of extreme weather. He did this study of quantifying the dollar amounts associated with flood damages from the National Flood Insurance database. This is the proportion of flood damages associated with atmospheric rivers. You can see that at the coast it's way above 90%, except when you get down to

very southern California, we have fewer atmospheric rivers. But still, the lion's share is accounted for by atmospheric rivers. When you get into the rain shadows of the mountains, it's way less. If you look at what climate models project, in terms of atmospheric river behavior, no matter what variable we look at, climate models project an increase in atmospheric river activity, specifically in the amount of moisture in atmospheric rivers. Well, that's not a surprise. It's really simple thermodynamics. Basically, I mentioned it already. Warmer air can hold more moisture. When you have a near saturated storm like an atmospheric river near 100% relative humidity, well, if it remains saturated, it will hold 7% more moisture per every degree centigrade warming. That's according to a chemical relationship that had been worked out probably over a century ago by two scientists named Clausius and Clapeyron, they called Clausius-Clapeyron relation. This is a variable that is most intimately connected with extreme precipitation. It's the intensity of atmospheric rivers, basically, how much moisture are they moving. We can detect them in observations. We can also detect them in climate model climate models basically show a slow increase in the amount of moisture that's moved by atmospheric rivers and that hit the mountain ranges that are not moving anywhere on these timescales. With more burning of fossil fuels, we expect more. But if you look at any particular model realization, you don't necessarily see a trend even up to now. In fact, in the observations, we don't see that trend. We don't see it yet. The confidence in this result is very high because the physics are really simple. That's why the models agree that atmospheric rivers will become wetter. As that happens, this is the historical contribution of ARs to precipitation. Here, in the models, we can do the same analysis. Basically, in the historical days, this is the contribution. It looks very similar. In the future, in the last half of this century, it increases, as you would expect and this is the difference. Basically, we expect atmospheric rivers in the last half of this century, if climate change continues unabated to increase by about 15-20%. Because we know that atmospheric rivers are really responsible for this extreme volatility of the hydroclimate, that means it will get even more volatile. Here's another reason why. Here's another type of analysis where these dots basically show in these bins. The bins are by precipitation intensity, so wet days are binned by precipitation intensity. Here are dry days, zero precipitation. Here's drizzle, the 10% of the smallest precipitation amounts. As you go to the right, basically, the intensity increases. The dry days become a little bit more frequent at the expense of normal precipitation, run of the mill precipitation events which become less frequent. Then when you get to the extreme, the heavy precipitation, the wettest 10% and the wettest 1% of the precipitating days, that's where you see the increase. The dark shading represents atmospheric river caused precipitation. The light shading is other storms. We see that we're actually projected to lose precipitation frequency, and that's mostly associated with mid latitude cyclones that are expected to move a little bit forward. Because of that non-uniform warming of the globe that I mentioned before, and then the atmospheric rivers that produce more extreme precipitation amounts in a warmer climate because they just contain more water vapor. The physics are pretty simple. But what this means, they're basically two signals, and we did this for three coastal flood prone river basins. They all show the same pattern. Basically, it means that there are more dry days, more longer dry periods. But when precipitation occurs, it will be more likely to be more intense. Here is that contribution again and here is the variability. This is that standard deviation divided by the mean in the second half of the previous century, in the second half of this century and the difference. Basically, the hydroclimate is projected, is expected to become even more variable. That's what that looks like on the ground. That's the volatility that we have. This is back in February 2017, Lake Orville, the second biggest reservoir in California, was almost overflowing. The hillside was eroded here. Actually, they had to stop using the main spillway, so they couldn't empty the reservoir because of this erosion. They were using it too much. Also, there were some technical engineering problems going on at the same time. They were afraid that this emergency spillway, which is just an earth and dam that overtops when the level gets too high. If that overtops, then this hillside could get eroded and the dam could break, so they evacuated 188,000 people downstream. That's an impact. Then a few years later in the summer in July, the level of Lake Orville was at a record low. In fact, so low for the first time since its construction in 1963, I think, that they couldn't run the electric power plant anymore. There was a

power supply impact from this, as well. But this is what that volatility looks like. That's why it's so challenging to manage water resources here. Here's a summary of that. This change in precipitation that we expect, really two signals, less frequent, but more intense precipitation. The two signals cancel each other out. When you look at total annual precipitation, average precipitation, we don't really see much of a change. Moreover, the models don't agree on whether it's going to get wetter or drier, but they all do agree that the precipitation will be less frequent and more extreme. That means a more volatile hydroclimate. In a place, luckily, we're actually used to extreme volatility, and so we know how to deal with it. California is being very proactive in terms of using results like that to prepare for an increasing volatility in the future. Which means more opportunity for droughts and more opportunity for floods. We've all experienced floods during droughts.

Speaker 2: For example, when was it 2014, January? The first storms that we got southern part of San Diego County flooded Charis Creek, especially. That was actually in the middle of a very dry period. There are many other examples. This is another installation in the Scripts art collection. It's the Atmospheric Rivers Globe, and John is familiar with this one. It was right outside of his office. Here we have contents made out of bicycle sprockets, and atmospheric moisture made out of the bottoms of bottles or depicted by the bottoms of bottles. Here's that Western Pacific warm pool. Here's the intertropical convergence zone. Here's an atmospheric river making landfall on the coast of California. Do I have another 5 or 10 minutes? Let's just go a little bit further, and I'm going into impacts that are further away from the warming itself. But now, let's get a little bit into wildfire, which is another big part of our life here. That actually has to do a lot with both precipitation and temperature. Here are the observations. Unfortunately, somehow this got cut off, but these peaks got cut off. They're increasing peaks. In the years since then it's been increasing only more. This is basically acres burned by wildfires every year in California. The different colors represent different regions. The red is the Montane forest. There are actually two fire regimes in California. I mean, they're basically two fire regimes. The fuel wildfire, I'm talking about wild land fire, fuel-dominated regime where there are abundant fuels. These are forests, thick forest. The fuel is always there. In order to have big wildfires, the fuels have to be dry and they get dry from less snow, earlier snow melt, higher snow lines which leads to less soil moisture, less moisture for the trees, warm summers, and especially heat waves that suck the moisture out of the trees. Basically, those ecosystems experience the largest trend in wildfire activity. They're most directly impacted by the temperatures themselves because snow lines, the melting of snow, summer heat, and heat waves all related to global warming. But in this part of California, we experience a different type of wildfire regime. Those fueling wildfires typically occur in the summer, and they're natural sources of ignition. I mean, they're human sources, too, but the natural sources of lightning. But we experience a different type of regime here in coastal California, especially in Southern California. That's the wind-dominated regime. The fuels are not quite as abundant. We're talking about hillsides covered in woody shrub, chaparral, and coastal sage scrub, plus other species, invasive species and grasses and so on. Not a heck of a lot of fuel. It's thick, but it's modest. To get that burning, not only does it have to be dry, there has to be dry, gusty wind. That's the Santa Ana. Santa Ana's actually start cold in the Great Basin in this elevated desert surrounded by mountains. When there is a high pressure out here and low pressure here, basically that cool air over the Great Basin gets pushed over the mountain range. As it encounters warmer air on the other side, the cold air accelerates down the slopes. By the force of gravity because it's colder, denser, heavier. These are called downslope winds. It's one type of downslope wind. The winds that accelerate down the slopes of the mountains. As they move down from about 1,200 meters in the Great Basin to sea level, they warm up by about 11, 12 degrees. They're warm when they get here. Plus, no, it's very dry, the sun is blazing and so there's warming from that, too. But as the winds rush down the slopes of the mountains, they're desert winds. They started in the desert. They were dry to begin with. As they warm up, they dry even more. They warm and the relative humidity decreases, and it's typically in the single digits. If a wildfire starts and dry vegetation, under those conditions, in winds blowing, 20,30 miles an hour and gusting to 40, 50, 60 miles an hour, there isn't much you can do to extinguish a fire once, if you don't get to it immediately. That's our story here. This is what

happens with our Santa Ana winds. Actually, the temperature, this is the temperature anomaly associated with Santa Ana winds. They lead to coastal heat waves, and these are not summertime conditions. These are fall, winter, and spring conditions. We actually have heat waves here that can send people to the hospital even in the wintertime. We've done studies with epidemiologists on that. This region is also unique as far as that goes. In fact, in the winter, it can frequently get much hotter than it almost ever gets in the beginning of summer when we start getting the low level marine layer clouds. It's a very interesting climate. When I came here when I was 12-years-old, I thought, It's so boring. No seasons. But actually, it's just more subtle, but it's amazing. This is the seasonal cycle of Santa Ana winds. You see them here because there were wildfires. This is in 2003, I believe there was over a dozen wildfires burning across Southern California in an extreme long lasting Santa Ana wind event. You can see the smoke being blown out from these wildfires. But basically, we because these wildfires, we typically associate them with October. I mean, how many of you think that Santa Ana winds are a fall time> But actually, they start up typically. Sometimes in September, typically in October, we get a couple of Santa Ana wind events on an average October. But they ramp up and they really peak in December and January. It's a wintertime phenomenon. It's just that by December, January, typically, we've already had enough rain to moisten the fuel so that the fire danger goes down. But actually, the Santa Ana wind activity goes up. In December, we get about five Santa Ana wind events on average. Sometimes when there hasn't been any rain in December or January, like last year, we can get wind-driven wildfires even that late in the year. That's when they tend to be the largest, actually, because that's when you tend to get back to back San Anna wind event. If a fire is not extinguished, it gets picked up by the next San Anna wind event, and the next one, that's what happened, for example, in the Thomas fire in 2000 December 2017. It burned into early January, spread by consecutive Santa Ana wind events. Then its smoldering remains were extinguished by an atmospheric river that caused extreme precipitation in Montecito in Santa Barbara County that caused a debris flow that killed 22 people from the fire's scar. Because actually fire makes this intense fire it not only burns off the vegetation that holds the ground together, whose roots hold the ground together, it also makes the surface hydrophobic. It basically repels water. A high intensity burn results in a burn scar that repels water, so whatever water falls in it just runs off doesn't get absorbed. That's what causes a lot of the debris flow. Santa Ana wind actually is one type of weather pattern that is not expected to increase with climate change. It's actually expected to decrease in frequency, not in intensity, but in frequency, and especially in the shoulder seasons in the fall and in the spring. Not really that much in the winter in the peak of it. Basically, in the future, I would still expect, way more Santa Ana wind events than ever occurred, I mean, in December, for example, than ever occurred in October. But, warming is expected to decrease the number of Santa Ana winds, but it's also expected to make them warmer and drier. What that means for wildfire season is not as clear, but, I mean, for our wildfires not Montane. Montane fuel-dominated fires are increasing. They will continue to increase with more warming. Our coastal fires here, the wind-dominated fires, I think what's going to happen most likely is that the fire season will extend. It might actually decrease somewhat in October, but it will increase in November and December because really the timing of our wildfire season. This is the seasonality, the number of Santa Ana wind events per month in red. In green is the number of significant rainfall events. These are the rainfall events that can actually end the fire season for a little while, anyways, as long as it doesn't keep raining again. But see, the Santa Ana winds ramp up their season starts up a little bit before the rainy season. That's the sweet spot for, when you have the first Santa Ana winds before the first rainfall events of winter, that's when the fuels are dry, after a long, dry Mediterranean summer, and that's why our wildfire season is in October, typically. But as I will show you, in a sec, I showed you this change in precipitation regime, but I didn't mention until now that a lot of this decrease in precipitation frequency is expected to occur in the fall and spring. Basically, that means that these rain events, the big rain events, they just get concentrated more in the peak of winter, and the rain season starts later. When the rain season starts later, there's more opportunity for the increasing number of Santa Ana wind events into the winter to fan wildfires. There's it gets more and more complicated.I better stop with this. Oh, here, let me show

you some wildfire. Some wildfire behavior. Okay, this is Region 6, that's Coastal California. These are the different regions. These are Montane forests. Wildfire activity has been increasing there. This is the central coast. This is the South Coast, Region 6. The trend is not as clear as in Montane forest, but there's just much more variability. By the way, there are no natural sources of ignition. They're all human caused. Here's what that looks like. This is the number of fires, and this is the number of acres burned in red. You see that in most other regions, the acres burned kind of follow the fire frequency. Here, the number of fires is still more in the summertime, but the acres burned really ramp up in October. What I think is going to most likely happen is that this is going to move further, into November and December and maybe even January sometimes, and it might increase because of the more frequent Santa Ana winds later in the season. Their impacts, obviously, impacts on health from Santa Ana wind from these wind-driven fires are typically far away from the fires themselves. Well, the local impacts are devastating. But there are very few people who live in the sloping topography, where the winds blow the hardest. The downslope winds that accelerate down the slope blow the hardest. That's where the wildfires typically rage. Of course, the population is pushing into that sloping topography constantly. But really a much larger population, coastal population is impacted by the air quality, by the smoke that gets blown from those inland, no, wildfires in that sloping coastal ranges and it gets blown over to the coast. I think I should just stop here and just basically end with some examples of the art that that was motivated by some of the science that we do. I talked about this. This was by the same artist was motivated by research into atmospheric rivers and sea level rise. It's beautiful. Does make me feel like I'm drowning when I look at it. It helps us show how the art does, help us show human impact on global climate then gets translated to the scales that we actually feel down to the very personal human scales. This is actually from a art exhibition that we organized back in 2017. Now some of these art installations are scripts, but we're trying to grow the art collection also and give other scientists besides climate scientists a chance to work with artists and have their work represented in this, very digestible way that's understandable to everybody across ages, cultures, languages that we speak. Thank you.