PERSPECTIVES AND COMPARISONS OF SMOKE EMISSIONS FROM HISTORIC AND MODERN FIRES: TAKING THE ELEPHANT OUT OF THE CLOSET AND PUTTING IT IN THE STADIUM

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Dr. Kevin Robertson: Our next speaker is Dr. Michael Stambaugh, presenting some of the research that he has done in conjunction with Dr. Richard Guyette, both of whom are at the University of Missouri in Columbia's School of Natural Resources.

Dr. Guyette's primary research emphasis has been dendrochronology, or the use of tree rings and tree chemistry to study fire history, in which he has over 30 years of experience. He's currently working on pre-settlement fire frequency in oak–pine forests and also reconstructing long-term climatic records from the chemical signatures that are stored in tree rings.

Dr. Stambaugh is a Research Associate at the University of Missouri, and he's also studying fire history and disturbance ecology and dendrochronology. His dissertation has focused on the assessment of fire risk across the western-central hardwood forests, and he has authored over 20 papers in the last six years. He is currently working on several projects relating to fuels management, fire ecology, fire history, and paleoclimatology. So this morning Mike is going to help us put smoke and particulate emissions in their historical context. So let's welcome Mike Stambaugh.

Dr. Stambaugh: Thanks for inviting me to give this talk. This is very much a work in progress, so what I am going to talk about in general terms is the problem, some of our research objectives, how you might estimate historical emissions, how we try to estimate emissions over long time periods, a model we are working on called the PC2FM, and why we think that emissions can be described as an elephant in a closet.

Essentially, stricter emissions standards could limit the future of prescribed burning. Information is needed that addresses ecosystem differences in natural levels of emissions from vegetation fires. However, from our perspective, there is a lack of information about what historic or natural levels of emissions really were. For instance, how many of you are familiar with the 1780 dark day that darkened almost all of New England, caused the Connecticut Legislature to dismiss, and caused widespread fear? This event was caused by fires throughout Canada and the northern U.S. I don't think we have these kinds of emissions levels on our radar. One can look at smoke emissions as a kind of a tug of war or balance, where on one side you are trying to maintain air quality standards and, on the other side, you're trying to maintain fire regimes. What we don't know is where we are within this balance. Are we somewhere in the middle or somewhat on one edge, or is there even a balance in this issue?

So what our work is trying to describe is what might be a fire emissions standard for a particular place, and there are lots of different perspectives about how you get to this. One might use what historic emissions were. One might use what the current emissions are. Or maybe it is totally independent of the ecosystem and it should be strictly based on policy. So as a problem statement, what is the basis for using historic emissions? The primary reasons are for understanding the earth system's emission potential and having long-term perspective. For instance, how would we know that we're experiencing global warming if we didn't have some idea of what it has been in the past? From historic fire information we also can estimate how much smoke emissions contributed to greenhouse gases. These emissions are directly related to what the fire frequency was that created those communities that, through prescribed burning, we yearn or burn to achieve. Estimates of historic fire frequency and emissions also could be used to gauge how much suppression is actually minimizing emissions in certain areas.

Here are some of the most recent data about how fire has varied in the past. These data are from Marlon and others, 2008, published in *Nature*, based on charcoal sediments around the globe. Basically, the amount of biomass burning declined from about 2,000 years ago up to about 1700, after which we went through a couple of dips and bumps strongly related to human influences. As you can see, the peak in burning at about the turn of the 20th century is about the same level that was occurring about 2,000 years ago. These long-term data give us a really good idea of where we are with respect to emissions levels. Is this a lot, or is this a little? How does it compare?

Leenhouts and others in 1998 and other papers describe where we are today compared to historically. These graphs show acres burned across the United States. Where historically it may have been in the area of 200 million acres, we are currently somewhere around 20 million, about a tenfold decrease. However, to apply this to specific places, it is very difficult. This information is not spatially explicit. So how do we use these data to determine emission standards for individual states? And that's really our idea here. The objective of this talk is to demonstrate the relevance of using the PC2FM model to estimate historic emissions. I'm going to show a comparison of what historic and current emissions might be and then discuss the scale of variability and try to explain this play on words, the "elephant in the closet."

For single fire events, typically one would use some kind of model, such as Consume, that would estimate emissions from the amount of fuel consumed, an emissions factor, and the area burned. I'm not sure how many of you are familiar with Consume, but it is a publicly available model developed for estimating the amount of CO_2 or particulate matter that is coming off a fire.

Of course, over long time scales this information is likely not available. Information on fuels may not be as important for characterizing the long-term emissions at a certain place compared to information on how frequently fires occurred, the rate at which fuels accumulated between fire events, and what kind of vegetation changes may have occurred to the site.

We deal a lot with retrieving fire-scarred trees and reconstructing fire histories around the states based on tree-ring-dated fire scars. We commonly look at these data as fire disturbance frequency, but one could also think of them as rate-of-emission information. This is an example of a study conducted at Devil's Tower National Monument showing this type of data. Here is a cross section of a ponderosa pine. The fire-scar history from this area shows a fire frequency of about 25 years, so the rate of emissions here is about 25 years. However, rates of emissions vary across the United States, which I'll talk about more. Here are examples from Oklahoma, one from the Wichita Mountains, and one from the Ozark Highlands. These are studies that we are just completing, showing that the rate of emissions is much different, somewhere between three to five years.

I talked a little bit about the rate at which fuels accumulate between fires. This is very important for understanding amount of emissions. This is an example of some of our work estimating the rate and amount of litter accumulation following a fire. Following a fire event we want to know the rate of litter accumulation and when this accumulation reaches some kind of equilibrium. This accumulation model can be used with knowledge of how frequently a place burned. Here are examples from four sites in Missouri showing how litter loading varied through time based on how frequently fires were burning.

And then lastly, we want to know what the vegetation was like historically. Has it changed in composition? Has it changed in structure? All of these things are important for determining what the differences might be between historic and current emissions.

As I said, we're working on a model that estimates what the fire frequency would have been historically. We call the model the PC2FM, which is just an acronym for the Physical Chemistry Fire Frequency Model. The PC2FM predicts historic mean fire intervals at a coarse scale based on temperature, precipitation, and information about people. We have done a lot of work testing lightning as a predictor, but as of now, there is no lightning component within this model. The logic of the model is based on the Arrhenius equation, which is a fundamental equation in understanding fire combustion. The rate of a reaction is an exponential relationship that has temperature as a major component. The PC2FM model substitutes landscape variables into Arrhenius' reaction-rate equation to predict fire frequency. Instead of predicting the rate of reaction (Arrhenius equation), the PC2FM predicts fire frequency of a particular site.

The model is validated using fire-scar data from over 150 sites throughout the U.S., and this is an example of what site data look like. This graph shows data from the Upper Peninsula of Michigan, a red pine site where all of these horizontal lines represent the tree-ring record of trees we sampled, and all of these vertical tick marks crossing the lines represent the fire-scar years on those trees. At the bottom you can see how the fire frequency has varied through time, here covering about three centuries. This is typical of all of the data that are used in the PC2FM model. The red dots on this map are the locations of sites that we worked on, and the black dots are from other investigators. You can see it's important that the data come from many different locations because the contributions of temperature and precipitation at these different places have very different roles. Probably the reason that the climate variables are showing up to be so important is that they play key roles in many parts of the fire environment, such as in the production of fuels, the actual serial reaction rate, the length of the fire season, and how quickly fuels are accumulating and decomposing.

There haven't been a lot of statistics mentioned at the conference yet, so I'm going to try to avoid them as much as possible here. This is the general model that we're using. It includes temperature, a moisture index, human population, and annual precipitation, each represented spatially as a GIS layer. Right now I think we have a very surprisingly robust model to many people. It's relatively powerful for the time period that we're dealing with as well as the many different sites that we have included. Essentially, spatial data layers can be plugged into the PC2FM and be used to map coarse-scale historic fire frequency. This is the PC2FM estimates of historic fire frequency for the conterminous United States just prior to a European contact, and the period here represents 1650 to 1850. Many of the high-frequency intervals are located here in the southeastern United States, where the entire Coastal Plain has fire intervals of less than four years. The Pacific Coast is very complex. Here in Tallahassee, the PC2FM estimates fire frequencies of about every two to four years.

These are some examples of fire frequencies at different locations. Southern California has very spatially complex fire regimes and the model picks that up. You have semiarid to desert areas burning somewhere between a hundred to 300+ years. We have made maps for specific locations such as national parks and forest units. Here is an example of the estimated fire frequency of Yosemite National Park, where fire return intervals range from about two years in the Great Valley to over 40 years in the vegetated upper elevations. These are data from studies that we have held out of the model in order to verify model predictions. Here is a study by Gassaway in 2005, and here is a study by Swetnam et al. in 1990, showing what fire intervals they generated locally using fire-scar history methods, and they agree very closely with our model.

Now that I have summarized long-term emission factors and fire frequency, what I want to do is use the PC2FM model to get some idea of what emissions were compared to what they are today. Essentially, I clipped out fire frequency estimates for a couple of states where we know quite a bit about the fuels environment, and this example is for Arkansas. Arkansas is a state of about 34 million acres. If you look at the modeled coarse-scale fire frequency across Arkansas, the average fire frequency would have been about seven years, and I'm going to compare that to a hundred thousand acres of prescribed burning today. If you include wildfires and other types of burning, this might go up to, say, four hundred thousand, but in this particular example I focused on prescribed burning. I then used the Consume model to estimate emissions based on three model runs. One is under current conditions where fire is applied to a site that has undergone fire suppression and fuel buildup, then two other runs are for a seven-year mean fire interval under a scenario of current fuel conditions and under a scenario of historic conditions with natural fuels. Although the fuel loading and emissions per acre are about the same for the latter two, the biggest difference here is how many acres we're burning. In recent years, Arkansas has about a hundred thousand acres burning annually, whereas historically the model estimates somewhere around five million acres burning annually.

When you look at consumption on an initial burn of a long-fire-suppressed forest land, it is reasonable to expect somewhere around 20 tons per acre are consumed. Once some maintenance phase is achieved from repeated burning, we estimate a reduced consumption of around 13 tons. That is also a reasonable loading for historic conditions under a fire frequency of seven years. However, just based on the total number of acres burning, we estimate annual fuel consumption of somewhere around 2.2 million tons versus 63 million historically. When you consider the percentage change, we're talking about the current amount of consumption being about 3 percent of historic. So, if we're burning about 3 percent of the historic acreage, then that equates to about 3 percent of the historic emissions. I did similar kinds of runs for Missouri, which resulted in current consumptions of about 1.5 million tons per year, where historically it was somewhere around 52 million. Again, about 3 percent of historical annual emissions have occurred in recent years.

So, to estimate historical emissions characteristic of states or ecosystems, we think it is reasonable to consider what the fuel type was, how much fuel was consumed, the area burned, and the long-term fire frequency. Fire frequency is something that is very much overlooked in terms of its importance to understanding historic emissions and developing emissions standards for different regions. For example, expected levels and rates of emissions from vegetation fires should be different for states with largely fire-dependent ecosystems compared to those without. What we'd like to do in the future is determine how much this map actually reflects what the historical emissions were. For example, did Florida naturally have much higher emissions compared to, say, Iowa or the Olympic Peninsula?

Because fire was such an important historic disturbance and is a large component in understanding regional differences in emissions, it is analogous to an elephant in the closet. One can think of fire frequency as the elephant. That is, it is an issue that is often unknown, disregarded, or overlooked. The scale of historic emissions is potentially very large, contentious, and just too big of an issue to get out of the closet door. As an elephant in the closet, fires have the potential to break their confines (e.g., wildfires, megafires), but being in the closet effectively hides its potential and features. By illuminating fire histories and using them to develop this model and map, we hope that fire regimes and their diversity (the elephant) are being placed into a stadium where many different people with perhaps diverse fire interests can see the features, see the differences between the fire frequency of, let's say, Florida or Oklahoma or Maine, estimate how emissions may have varied spatially as well as temporally, get an idea of how much the agencies might be reducing emissions from what they historically would have been, and potentially use this information to weigh against the noted decline of species, consequences of megafires, or forest mesophication.

From my examples of model runs and emissions estimates, you can certainly see that there are state-level differences between current emissions and historic emissions. These differences are potentially large and varied from place to place, such that our view of current-day emissions standards for vegetation fires might also consider this variability.

With that, I'd like to thank all of the people who allowed me to use their data to develop the PC2FM model, researchers at Oregon State University associated with PRISM data that provide temperature and precipitation data, and the many agencies who have funded our fire history research, including the Joint Fire Science Program, the Forest Service, state agencies in Missouri, and the Ontario Ministry of Fish and Game. Thanks.

Audience Member: I'm curious, in the determination of the historic frequency of the prairie fires, do you feel that that's as accurate as the forest fires, given that you don't have the trees to depend on? What do you use as your paleo evidence?

Dr. Stambaugh: Right. Well, like I said, there are not a lot of good tree data in the grasslands. We're trying to collect as much as we can. For instance, in the Cross Timbers forest region, there were oak savannas within a large complex of grasslands. We have several sites like that where we are trying to get forest lands that, based on their locations, would reflect the grassland fire frequency. However, one thing to consider is that fire scars on trees may not be perfect recorders of fire frequency. They may show something at the longer end of the intervals. Fire events could have been more frequent than this. That's not always the case, although some people think it's always the case. Sometimes they can be really good recorders, but oftentimes they may not be perfect, particularly over many centuries or different fire types (e.g., very low severity, very small fire sizes).

Audience Member: Have you had an opportunity to present these results to any of the groups who are advocating a return to air quality that presumably existed before [European] settlement?

Dr. Stambaugh: No, I haven't. Actually this is the first time I have presented these results. And I don't know about any of these groups, so that is interesting to hear. But one thing that's clear, looking through historic information, is that the tree rings tell us from all different types of sites that the landscape was burning a lot. It was burning much more than I think many of us really considered, so there was a lot of smoke. It's really interesting that smoke was not commented on more in historic journals and in travel documents, even though personally I think, based on fire-history knowledge, that it was commonplace. Smoke was something that was commonly there and it was part of life.

AUDIENCE MEMBER: You included temperature and precipitation in your model. Have you thought about using it for forecasting based on some of the climate change models?

DR. STAMBAUGH: Yes, we have. We've done a little bit of this work. We actually have a proposal submitted to do that exact thing using some of the temperature predictions, putting them into the model and seeing how different places are predicted to change according to our model in terms of temperature increases or precipitation differences.

AUDIENCE MEMBER: Using your analogy, there looks to be only one elephant in all of Florida, that is, only one fire-history study based on your maps. I'm wondering what you used as data to input into your model predicting historical patterns in Florida.

DR. STAMBAUGH: Okay. You're right. There are very few data from Florida. There are actually no fire-history sites from fire scars in the model from Florida, and when we were initially developing this study, there were only two or three dots in the eastern United States. And we've gotten some Joint Fire Science Program support to increase the number of fire histories in the eastern United States.

Before we developed the model, we didn't have this site in southern Louisiana, and the model predicted that fires burned there every two to four years. Coming from the Ozarks and spending a lot of time in the western United States, it was really hard for me to believe that someplace burned on average every two years historically for hundreds of years, but we have fire scars showing that it in fact did burn that frequently. And there is some difficulty in getting fire histories out of Florida, especially with some of the species that are here. Many are fire adapted, so they don't scar very well. I certainly think that the vegetation that was here historically is a really good indicator of what the fire frequency had to have been to create those conditions, and this should become more clear as we continue to monitor the longer-term vegetation responses to fires. Thanks a lot.

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