FOR 433

Classifying Models in Fire and Fuels Management

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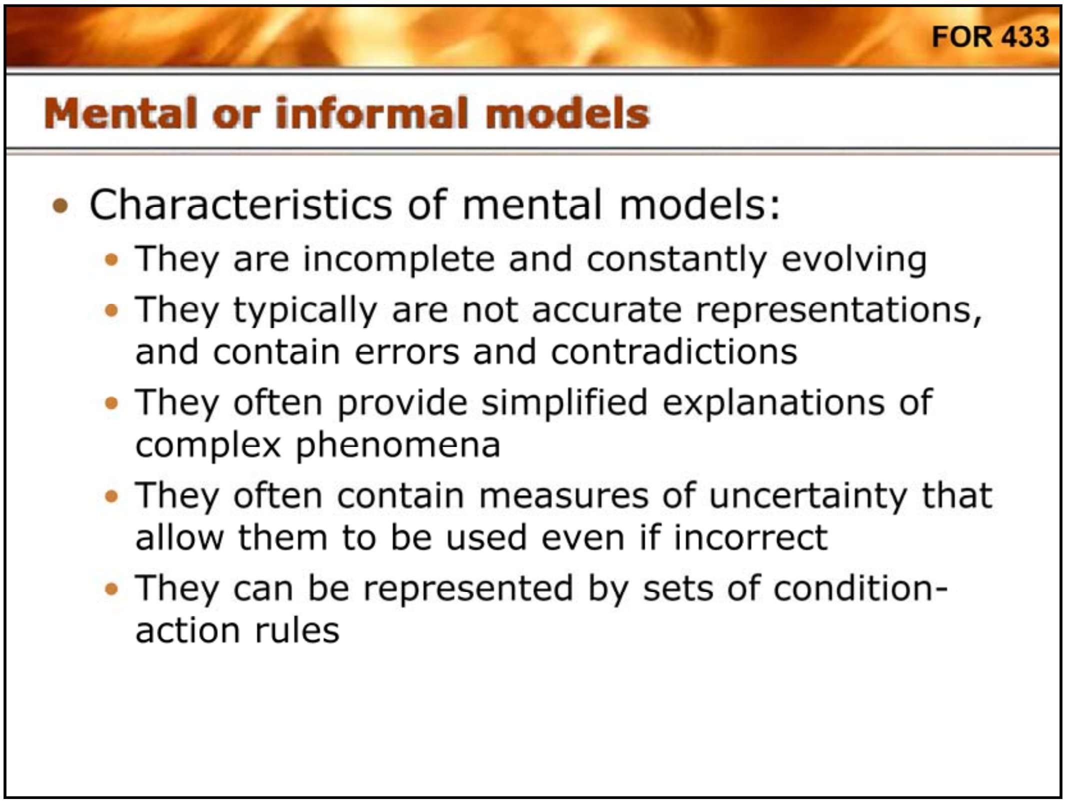
In this lecture we will talk about how models are classified. Specifically, we will focus on mathematical models but we will also discuss mental models and human perception as well.

FOR 433

Mental or informal models

- Mental models represent how we think, view the world and all the interactions in it, they are our expertise and experiences.
  - Senge (1990) defined these types of models as "deeply ingrained assumptions, generalizations, or even pictures that influence how we understand the world and how we take action."

It seems appropriate to begin our discussion about the types of models by going over mental models. Mental models are described by Holland et al (1986) as the basis for all reasoning. Others have suggested that mental models play a central role in how we represent objects, sequences of events, the way the world is and the social and physiological actions of daily life. In other words these models represent how we think, view the world and all the interactions in it; they are more commonly referred to as our expertise and experiences. Senge (1990) defined these types of models as "deeply ingrained assumptions, generalizations, or even pictures that influence how we understand the world and how we take action." Along with this type of model comes a few limitations we must consider.



The characteristics of mental models include the following:

First, mental models are often incomplete and constantly evolving (I learn more about fire behavior every time I see a fire, so my mental model changes). Second, they typically are not accurate representations and may contain errors and contradictions (this is like selective hearing). Third, they often provide simplified explanations of complex phenomena (I often explain the theory of relativity as “things change when you are going very fast”). Fourth, they often contain a measure of uncertainty that allows them to be used even when they are incorrect (or in other words I think I am right), and lastly they can often be represented by sets of condition-action rules (for example when I lose my balance I put my hand out to stop from falling).

The basic idea here is, that relying on mental models is one way we can make decision and we should recognize the knowledge and models we have all built in our minds. We should also challenge these models. Remember many early scientists thought the way to do good science was to view the world and make observations without a question in mind. But since then, others have argued that this is not the best way to improve science. It is with this thought that we will begin to leave behind mental models (although we will return to them later in the year when we look at risk adversion) and start our quest in understanding formal mathematical models used to make predictions.

Wildland Fire Models

- Fire models are oftentimes a collection of mathematical equations which provide a solution when solved.
  - Rothermel's surface fire spread model
- However, in some cases in fuels and fire management the term "model" is applied to a list of numbers which describe the natural world
  - Fuel models
- In addition, we will use the term "model" to describe decision-support systems
  - For example BEHAVE

Modeling plays an important role in fire and fuels management. In general the fire world uses the term "model" to represent one of three things: first we use the term "model" to represent a mathematical equation which, when solved, provides a numerical solution to a question, secondly, we use the term "model" to describe a set of numbers which are used to represent the natural world (an example of this would be the fire behavior fuel models), and lastly we use the term "model" to describe decision support systems such as BEHAVE. (Note: Decision support systems are a collection of mathematical fire models which are packaged together with one user interface.)

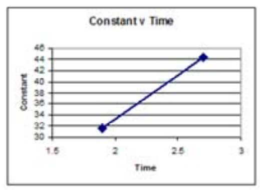
Mathematical Fire Models May Also Be Classified As…

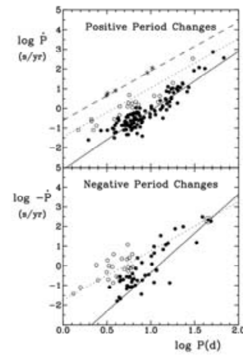
- Mathematical fire models may also be classified by the nature of the equations that are being used
  - Typically there are three types of classifications used
    - Theoretical models
    - Empirical models
    - Semi-empirical models

$$I_x = \frac{4\cos^2\theta\,(\sin^2\theta - n^2)}{(1 - n^2)\,[(1 + n^2)\sin^2\theta - n^2]}$$

$$I_y = \frac{4\cos^2\theta}{1 - n^2}$$

$$I_z = \frac{4\cos^2\theta\,\sin^2\theta}{(1 - n^2)\,[(1 + n^2)\sin^2\theta - n^2]}$$





All models can be classified based on the mathematical equations which are used to describe or represent the natural system being modeled. Typically we use three distinct classes to describe these equations: Theoretical models, Empirical models and Semi-empirical models.

Theoretical Models

- Generated from laws that govern fluid mechanics, combustion and heat transfer
- Extremely difficult to verify
- Can be extrapolated to a wide variety of situations

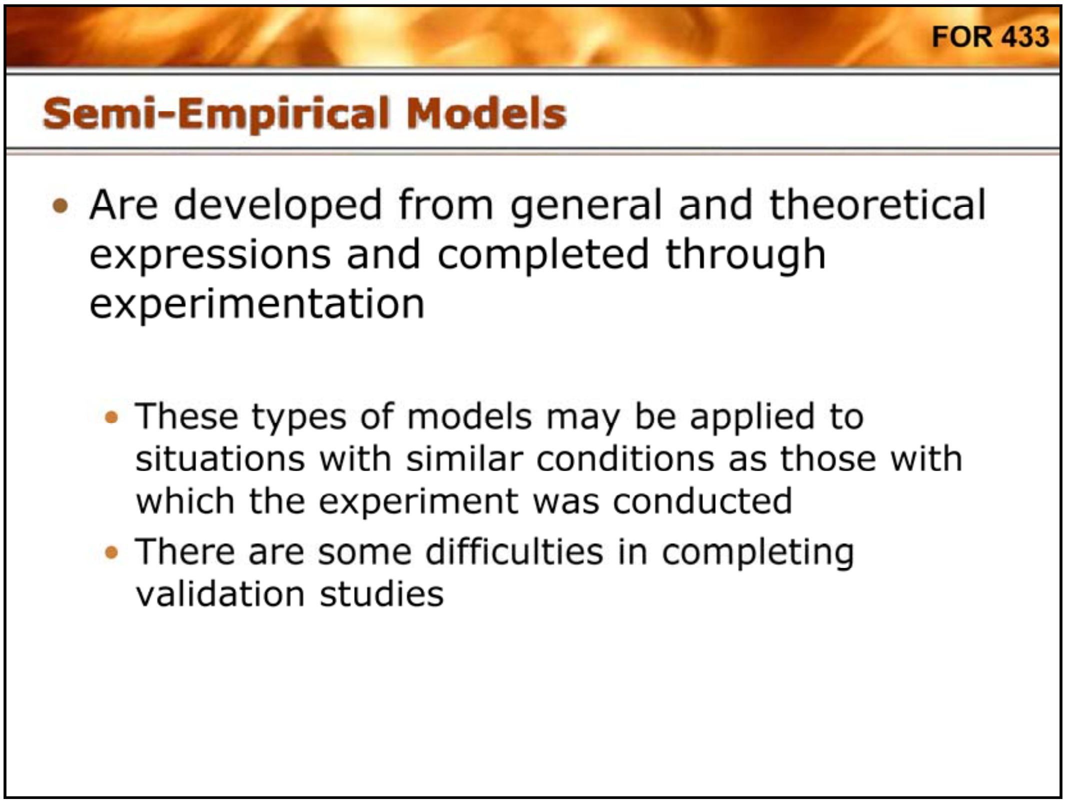
Theoretical models are based on the equations which govern fluid mechanics, combustion and heat transfer. These types of models are appealing because they can be applied to a wide variety of situations; however, they often are extremely difficult to verify. Theoretical models are similar to what many people call “mechanistic models” or “first principle models”.

FOR 433

Empirical Models

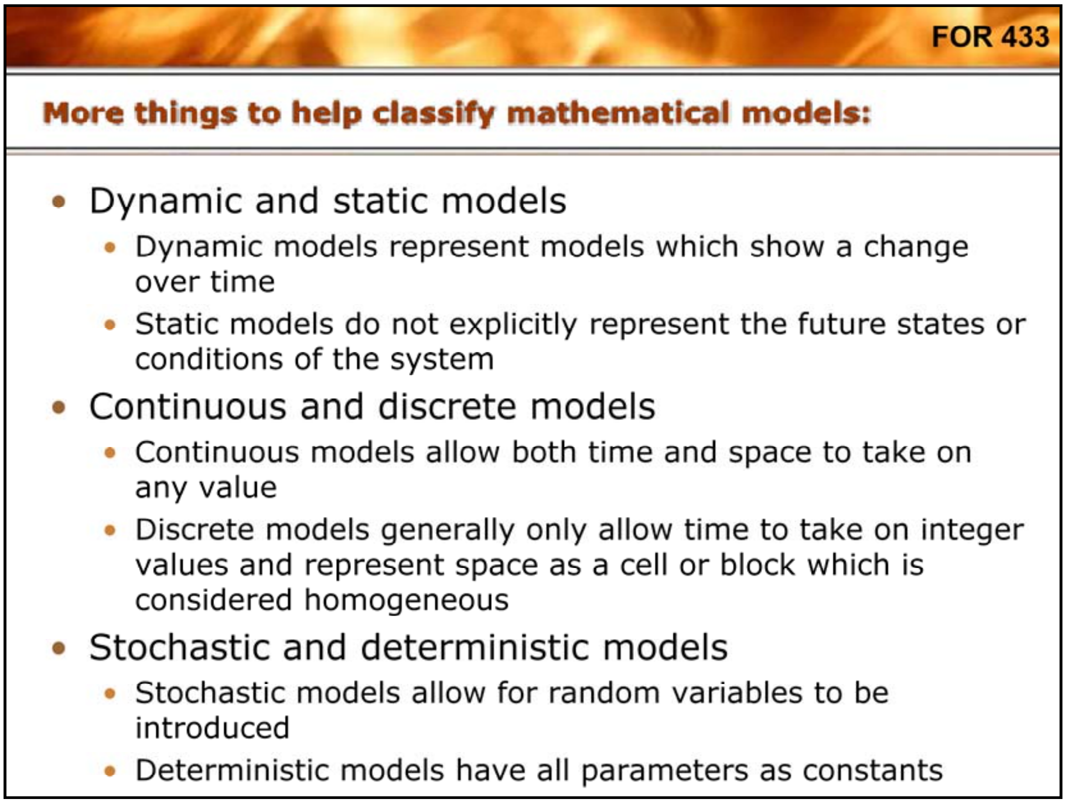
- Composed of statistical correlations based on experimental data or from historical studies.
  - These models are only applicable in the areas with identical conditions as those in which the relationship was formulated

Empirical or statistical models are composed of statistical relationships which are developed from experimental data or historical studies. These types of models can only be applied in areas with identical conditions as those in which the relationship was formed, or where verification studies have been conducted.



Semi-empirical models are developed from a combination of statistical relationships and theoretical expressions. An example of a semi-empirical model is the Rothermel surface fire spread model which is based on the laws of heat transfer but was completed through experimental data.

These types of models can be applied in situations which have similar conditions to that of the experiments used to create them, but are more limited than purely theoretical models. There are also some issues with the validation of semi-empirical models but not as many as theoretical models.



Before we move forward and talk specifically about how fire models are classified, I would like to bring up a few more terms that might help you in identifying and classifying models. First you should know the difference between a dynamic and static model. A dynamic model is one in which changes over time are explicitly shown, where as a static model is one in which the changes in the model over time are not explicitly shown.

A continuous model is one in which time and or space can take on any value. That is, we can model any point in time. A discrete model, however, is one in which either time or space must take on a integer. That is, time can be one year or two years but not 1.3 years.

Lastly you should know the difference between stochastic models and deterministic models. Stochastic models are ones which include a random variable, where as a deterministic model treats all variables as a constant. In other words, in a deterministic model if we put in the same values over and over we always get the same answer (think of Rothermels fire spread model) where as in a stochastic model we can get multiple answers with the same value.

FOR 433

Fire Model Categories

- Andrews and Queen fire model categories
  - Fire Environment
  - Fire Characteristics
  - First Order Fire effects
  - Second Order fire effects

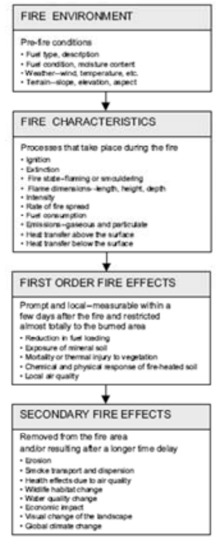
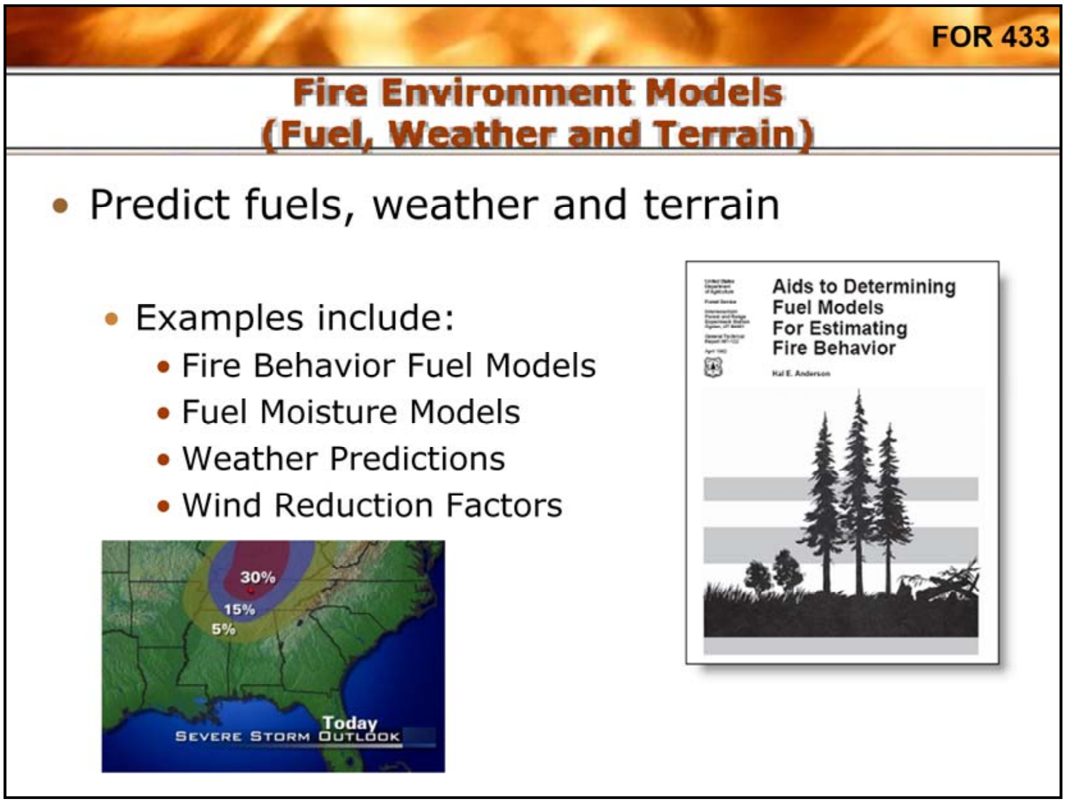


Fig. 1. Fire modeling is categorized as fire environment, fire characteristics, first-order fire effects, and secondary fire effects. Examples are given for each category.

Another common way to describe models is by the variables with which they are designed to predict. Andrews and Queen have proposed a common way to categorize fire models based on the predicted variable.

The proposed categories include fire environment models, fire characteristic models, first order fire effects models, and second order fire effects models

The rational behind these categories is that the fire environment models describe the conditions before a fire event, the results of these models are then used by the fire characteristic models, which make some prediction that is used by the first and second order fire effects models.



The first type of models that Andrews and Queen list are fire environment models. These types of models make predictions about the environmental conditions before a fire event occurs. For example, a weather prediction can tell us what the wind speed and temperature are supposed to be before we conduct a prescribed burn, while we can use a fuel model to tell us what the fuel conditions are before the burn.

Fire Characteristic Models

- Fire characteristic models predict the properties of the fire itself
  - We can further define these types of models by the variables studied
    - Wildland Fire Spread Models – predict the main physical variables directly related to the fire perimeter
      - Typically includes fireline intensity, rate of spread and fuel consumption
    - Fire Front Properties Models – Describe the features of the flame
      - Typically includes flame height, length, depth and angle

The next model category that Andrews and Queen discuss are fire characteristic models. Fire characteristic models make up the bulk of our fire behavior models. These types of models predict the properties of the fire its self. We can further categorize these models by the variables they intend to predict.

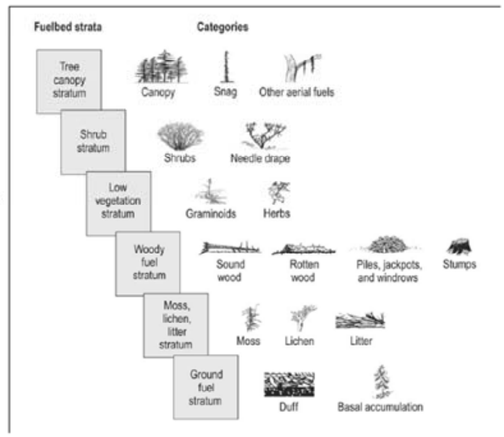
Typically there are two general categories of predicted variables. First there are fire spread models and second there are fire front properties models. Fire spread models predict the main physical variables related to the fire perimeter such as fireline intensity, rate of spread and fuel consumption

Fire front property models are used to predict features of flames such as height, length depth and the angle of the flame.

FOR 433

Fire Characteristic Models

- We can also describe fire characteristic models by the physical system modeled
  - For example:
    - Surface fire models
    - Crown fire Models
    - Spotting models
    - Ground fire models
    - Fire transition models



In addition to describing fire characteristic models by the variables studied we can describe them by the system with which they deal. For example, we can look at surface fires, crown fires, spotting, ground and fire transition models.

Examples of Fire Characteristic Model

- Linn 1997 developed a theoretical surface fire spread model
  - Linn, R.R. A transport model for prediction of wildfire behavior. PhD Thesis, New Mexico State University, 1997.
- Rothermel 1972 developed a semi-empirical surface fire spread model
  - Rothermel R.C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA Forest Service Res. Pap. Int-115

Here are two examples of fire characteristic models. The first model developed by Linn (1997) is a theoretical surface fire spread model and the second model Rothermel (1972) is a semi-empirical surface fire spread model. Based on these classifications we can tell a lot about each of these models.

For example we know that both of these models predict the rate of spread of surface fires. So we know what physical system they are attempting to model (surface fire) and we know what variable they are attempting to model (rate of spread). In addition we also can see that the Linn model is a theoretical model and the Rothermel model is semi-empirical. From this information we know that the Linn model may be applied to many different areas but may not have been validated due to its theoretical nature, where as the Rothermel model is semi-empirical and is limited to the experimental conditions it was developed with or where extensive validation has been undertaken.

So you can see that, by knowing a model's classification, we can learn a lot of information about the model, and it can lead us into other important considerations.

First-Order Fire Effects Models

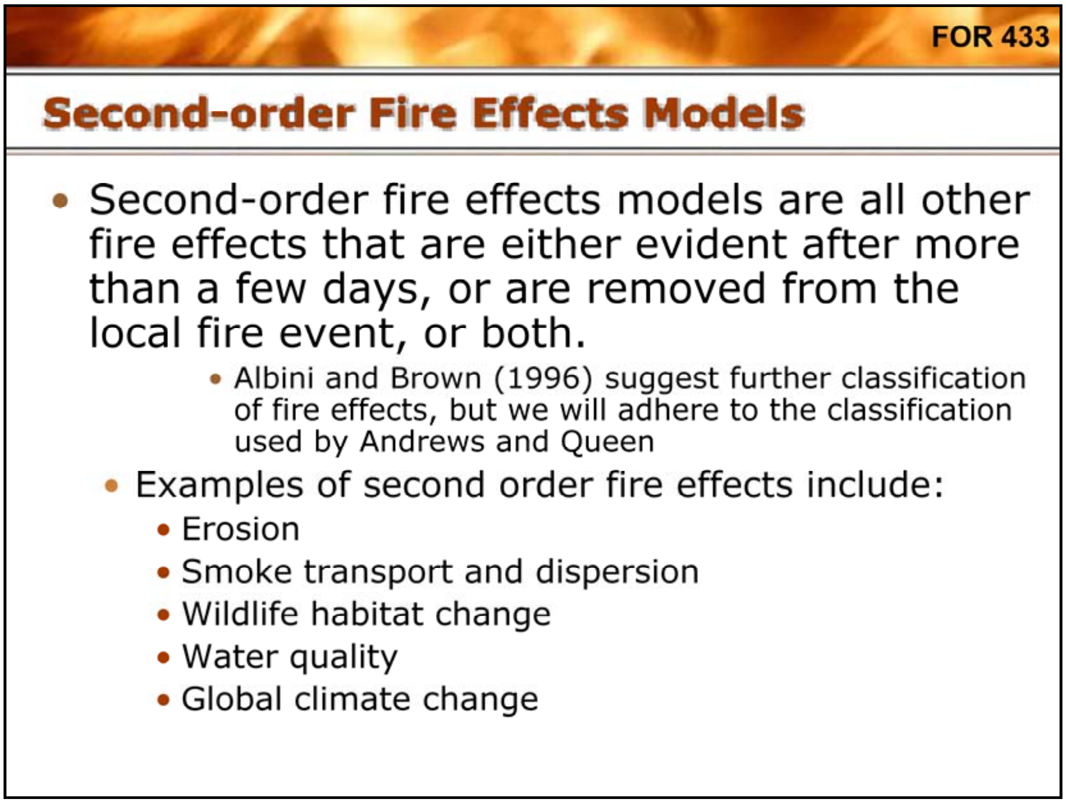
- First-order fire effects models are those which predict the effects of a fire event within a few days of the fire event and are restricted almost locally within the fire event
  - Typical first-order fire effects include:
    - The total fuel consumed
    - Tree or vegetation mortality
    - Local air quality

Tree mortality

USDA Forest Service Archives, USDA Forest Service, www.forestryimages.org

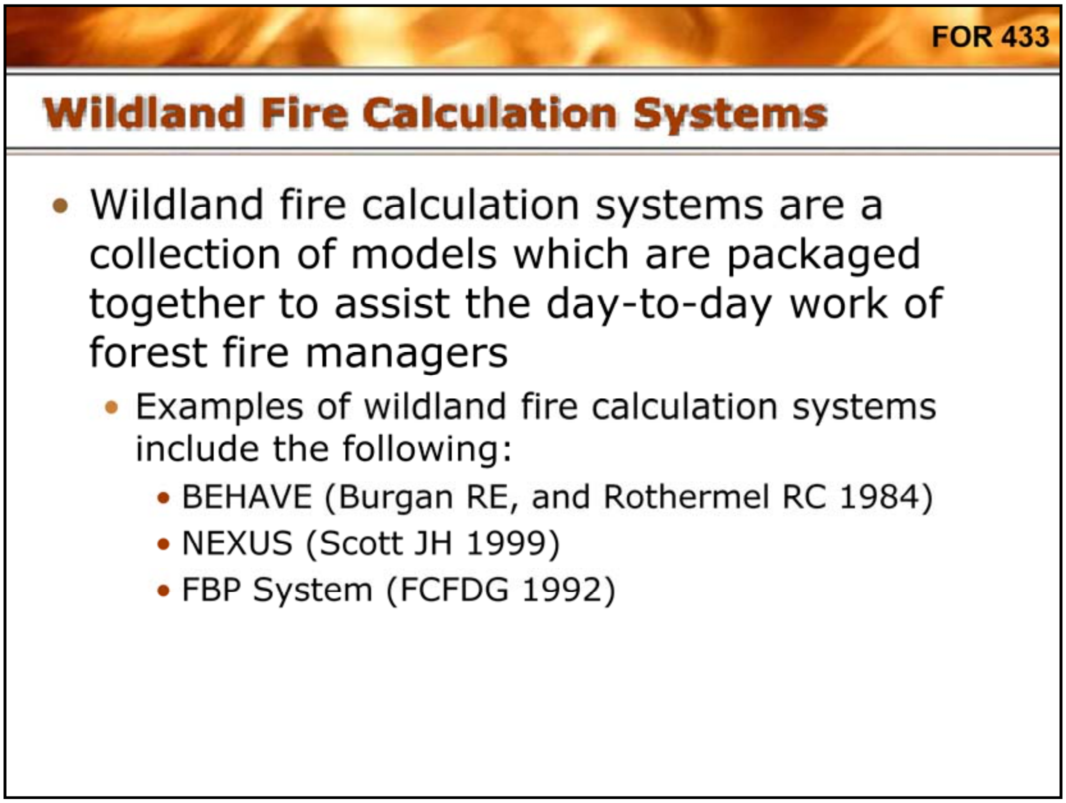
The next model classification based on the Andrews and Queen criteria is first-order fire effects. First order fire effects models predict the effects of a fire event within a short period of time (such as a few days) and are contained within a very local area.

Examples of typical first order fire effects models are the prediction of the total fuel consumed, tree or vegetation mortality, and local air quality. Please do not confuse the term “first-order fire effects models” with the modeling system called First Order Fire Effects Model (FOFEM). This system combines several first order fire effects models together in a software package.

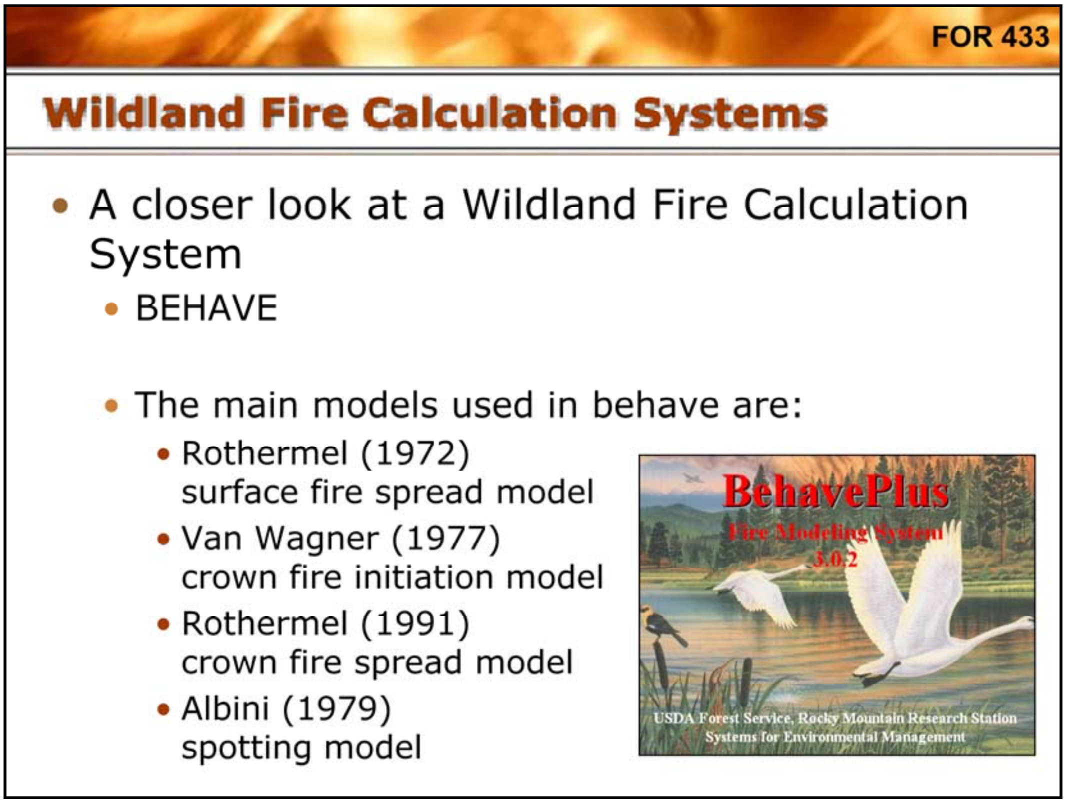


Second-order fire effects models are all other models which predict the effects of fire that are either evident after more than a few days, or are removed from the local fire event, or both. Albini and Brown (1996) suggest further classification of fire effects, but we will adhere to the classifications used by our reading from Andrews and Queen.

Some examples of second-order fire effects include erosion, smoke transport and dispersion, wildlife habitat change, water quality and global climate change.



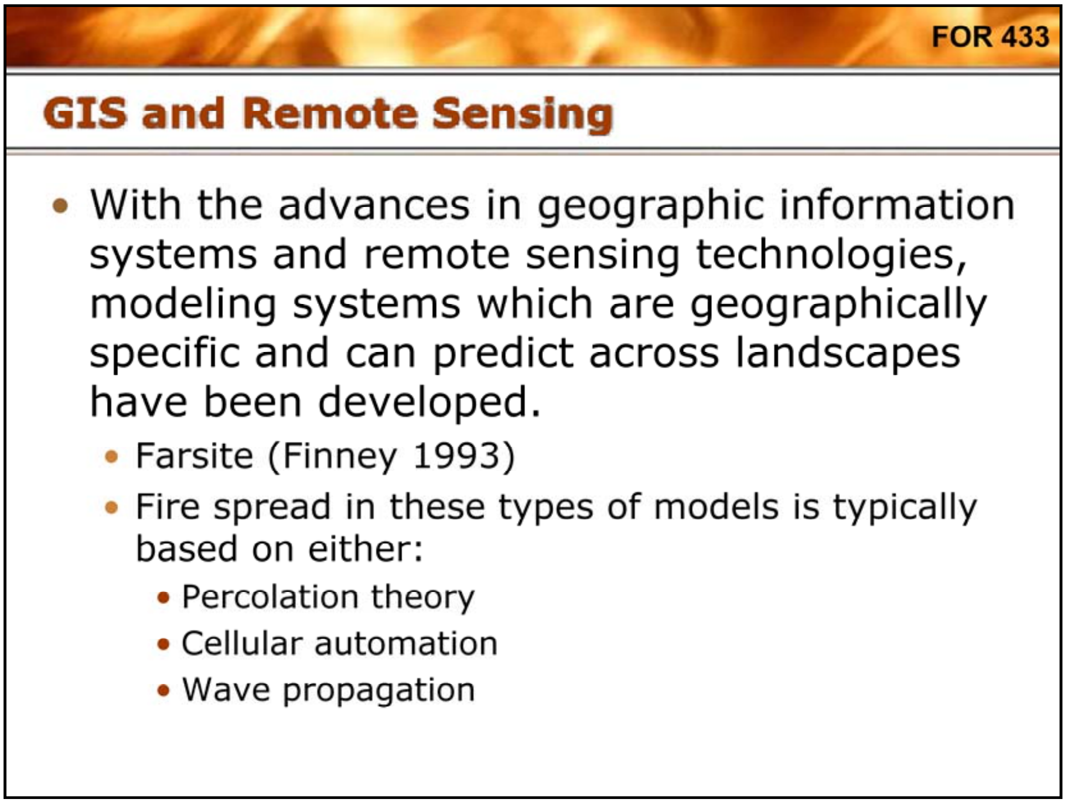
I mentioned earlier that, when we typically use the word "model" in fire management, we are often referring to a collection of models. These collections are technically refereed to as "wildland fire calculation systems" or "fire modeling systems". The idea here is to tie together multiple models to assist the day-to-day work of fire managers. Some common examples of fire modeling systems include BEHAVE, NEXUS and the Canadian FBP system.



As an example of a fire modeling system we will look at the BEHAVE fire behavior prediction and modeling system. There are four main models utilized in the BEHAVE system: the Rothermel (1972) semi-empirical surface fire spread model, the Van Wagner (1977) semi-empirical crown fire initiation model, the Rothermel (1991) empirical crown fire spread model and the Albini (1979) theoretical spotting model.

Based on these classifications you can see that the BEHAVE system will be limited to predicting surface fire spread and crown fire initiation under conditions similar to the those used in the development of the Rothermel (1972) model and the van Wagner (1977) model. In addition, it will be limited even further when predicting crown fire spread to the conditions under which the Rothermel (1991) model was developed. Due to the Albini (1979) model being theoretical in nature, we will assume that we can apply this model to many different conditions.

We could also look for verification studies to help assist us in deciding if we can apply this modeling system to our current question.



Current advances in geographic information systems and remote sensing technologies have allowed fire managers to collect landscape level data, and then apply a model to this data. A common fire modeling system which uses GIS technology is Farsite developed by Mark Finney (1993).

The incorporation of GIS technologies allows us to model fire characteristics and fire effects across large geographic areas. However, just like in other model types, there are different techniques which we can use to classify GIS-linked fire models. The differences in these models are in how the landscape is represented. There are three main ways in which fire spread can be represented in a landscape: bond percolation, cellular automation and wave propagation.

FOR 433

Landscape Fire Spread

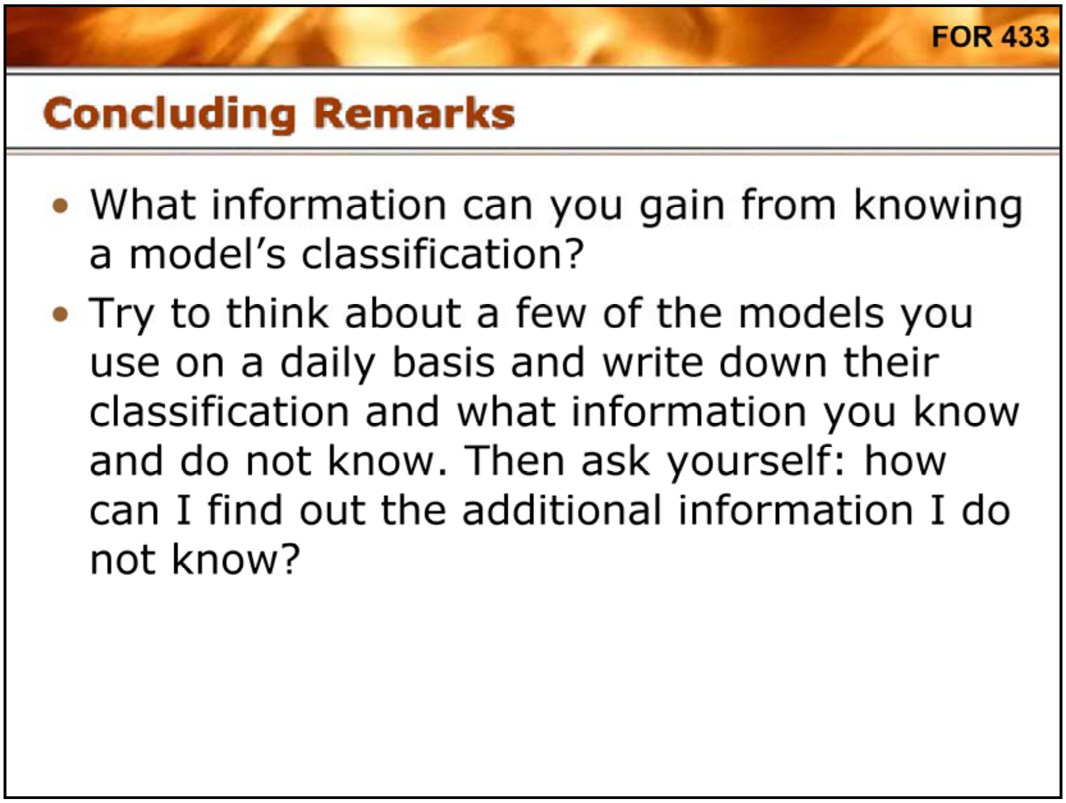
- Bond percolation technique
  - The landscape is represented by a lattice of square, triangles or hexagonal divisions
  - Fire spreads from one area to its neighbors based on a given probability of ignition and spread
- Cellular automata simulations
  - The landscape is also represented by a lattice of grid cells
  - Fire spread is based on a set of rules
- Wave propagation
  - The landscape is divided into a finite number of segments
  - Fire spread is modeled by a series of small ignitions which when combined mark the main fire parameter

Models developed using the bond percolation technique represent the landscape as a lattice of cells. Each cell is assumed to be homogenous. Fire spread is from one cell to its neighbors using assigned probabilities of ignition and spread.

Cellular automata simulations also represent the landscape with a lattice of cells which are assumed to be homogenous. Fire spread in CA models is based on a set of rules.

Wave propagation assigns a finite number of segments to the landscape each of which is assumed to be homogenous. Fire spread is then simulated by a series of small ignitions which when combined mark the main parameter of the fire.

The main components of main fire modeling/GIS systems are the same as that of the BEHAVE system. However, there are many differences between them such as including fire effects predictions.



You should now be able to recognize the importance of model classification in your ability to understand models. I would like to leave you with a few questions to think about.

What information can you understand from knowing a model's classification?

Try and think about a few of the models you use and write down their classification and all the information you know and do not know about these models. Then you should be able to think about how to locate additional information which you do not know from the model classification.