Integrating Climate Change and Forest Vegetation Models for Adaptation Planning

Tools for managing uncertainty in a changing climate

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Jeremy Littell
Research Scientist
UW Climate Impacts Group

Samuel Cushman
Research Landscape Ecologist
USFS Rocky Mountain Research Station
Acknowledgements

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Material for the webinar is based on the paper:

Webinar Tips

- Mute phones to reduce background noise (*6 or “mute” button). Do not put call on “hold” if your organization has hold music.

- Type questions in the chat box (lower left). We will track the questions and answer as time permits at the end of the presentation.

- Additional opportunities for Q&A:
  - Post presentation Q&A session (11:00 – 11:30)
  - Post-webinar Q&A write-up of remaining questions (if needed)
  - Email CIG: cig@uw.edu

- Presentation will be posted at:
Adaptation Challenges

- Climate is changing and impacting many ecosystem components.
- Past experiences will be a less useful guide to future conditions.

Key climate impact pathways

- **Ecophysiology**
  - Species ranges
  - Plant Assoc.

- **Disturbance Regimes**
  - Fire
  - Insects
  - Disease, pathogens

- **Ecosystem Function**
  - Hydrology
  - Biogeochem. cycling
Adaptation challenges cont’d

• Many present-day planning decisions have time horizons that will be affected by climate change.

• Combining climate models with vegetation models can help better define plausible future conditions. Use in planning has been limited, however:
  
  – Decision makers have limited experience with models, model output, and integrating output into decision making processes;
  
  – Developing scenarios can be expensive (both in terms of time and $) and therefore require tradeoffs when implementing, and
  
  – Integrating vegetation models and climate models brings a new level of complexity to traditional modeling activities.

Example of time horizons: Forest management plans = decades; outcomes and consequences of planting, thinning, fire suppression = many decades.
Adaptation Planning

The goal is to use best available science to:

1. Inform understanding of current priorities and vulnerability to climate change;

2. Evaluate how climate change will impact those priorities; and

3. Develop management strategies for increasing resilience of priorities given likely impacts.

But, at what scale, and with which tools??
There is increasing attention to combining climate models and vegetation models for planning purposes. That builds off of longer term experience with vegetation models (e.g., sometimes decades of GAP, DGVM and SSM experience with explicit influence of climate).

We want to specifically focus on some key points this audience may want to consider when thinking about how to incorporate future climate and vegetation modeling in adaptation planning.

Note: The goal here is considerations from a climate and vegetation modeling perspective, not how to construct an adaptation plan – that is not something for which a specific recipe exists. There are ongoing efforts regionally to do this, and they continue to evolve. Examples include the Olympic Case Study effort led by Dave Peterson and others like it.
Global Climate Models (GCMs)

- More than 20 GCMs developed by modeling centers around the world.

- GCMs break the world into large (~60 to 180 miles) grid sizes and model complex interactions between the atmosphere, ocean, etc. within each grid cell.
Global Climate Models (GCMs) cont’d

GCMs respond differently to the same emissions because they have different ways of characterizing components of the climate system, including:

- sensitivity to greenhouse gas concentrations;
- how physical processes that affect climate are constructed and described (e.g., viscosity of the ocean);
- how feedbacks between the processes are modeled (e.g., how fast the ocean worms once ice cover diminishes past a certain point)

Some things are common to most or all models; others are treated differently from model to model.

Other comparisons can be made, for example, for the regional seasonal cycle of precipitation, the fidelity of models to pressure patterns in the north Pacific and north America.

Until the mid 21st century, the differences between models are greater than the differences between emissions scenarios!!
Ideally, we would downscale every GCM with the most sophisticated methods, run each downscaling through a hydrologic model and/or vegetation models, and plan based on a range of outcomes we expect to be within the realm of the “plausible”.

Usually resources (computing, personnel, money) limit what we can do to some subset of that. The goal is to get as much information out of some lesser effort as we can.

How we choose depends on what we are willing to assume about the global climate models and their performance in the region we are concerned with. If we only have resources to use a couple of models, we can select models according to their fidelity to regional climate, or as “bracketing” models that give a range, or some combination.

AVERAGES (ensembles) of many models are a good approach to the “agreement” of multiple models.

“Ensembles”, or groups of several different models, can improve estimates of uncertainty

- **Advantage**: capture a broader range of possible futures
- **Disadvantage**: integrating multiple GCM results can be computationally intensive

For a more robust analysis, bracket the ensemble mean with:

- worst case scenario (e.g., warmest/driest GCM/emissions combination)
- best case scenario (e.g., least warm/wettest combination)

Which GCM/emissions scenario combinations represent the worst/best case scenarios will vary with the planning context.
Note that A1B is higher than A2 until at least 2050!! By the end of the 21st century, the ranges overlap but the mean temperature change fits the storylines we commonly associate with the scenarios.
Choosing Greenhouse Gas Emissions Scenarios

- No one emissions scenario is considered more likely than another.

- Choice of scenarios is in large part a function of risk management: are you risk tolerant vs. risk averse?

- Alternative: Model the “ensemble mean” of multiple climate models for one to a few emissions scenarios (B1, A1B, A2)
  - Advantage: helps address computational limitations; reduces influence of internal model variability in any single model
  - Disadvantage: Future may not look like the “mean”; natural variability in the climate system diminished by using only the mean change
A Note About Timing and Emissions

Differences in scenarios, and thus changes in climate and related impacts, do not strongly diverge until after mid-21st century.

Multi-model Averages and Assessed Ranges for Surface Warming

Projected Warming for the Pacific Northwest

This is true at the global scale and, as a result, at the regional scale as well.
Choosing GCMs/Scenarios

1. Are multiple scenarios and multiple GCMs needed for impacts modeling, or is an ensemble mean sufficient?

2. Do the models and emission scenarios selected match the risk framework (risk tolerant vs. risk averse)?

3. Do the models chosen have good fidelity to 20th century observations using a regional focus?

4. Is the spatial and temporal scale of the climate information appropriate to planning or decision making?

1) Pertains to a low- to moderate- risk tolerances – e.g., worst and best case scenarios aren’t so important as understanding the mean conditions across many models. Tradeoff: have assumed that the mean is more robust, when in reality that may or may not be the cases. Hence (2):

2) If the application is necessarily highly risk averse (e.g., plan for the worst possible scenario) then the ensemble mean may not be all that useful.

3) One (and NOT the only) test of models is there performance in giving us back what we know to already have occurred: a model that matches the observations during the historical record is probably doing something right. This is no guarantee that it will project climate correctly in the future, but it is one way of emphasizing models we know to work reasonably well in a given region and to de-emphasize models we know do some things poorly already.

4) Are regional average sufficient for planning purposes? Sometimes yes and sometimes know. Is it enough to know models on average suggest the future will be a few degrees warmer and seasonally both wetter and drier? Or does the planning require finer scale information? For most impacts modeling, the answer is “yes”. For general planning purposes, the answer is not always yes.
Scale and Statistical Downscaling

Global climate models do not project climate at a scale as fine as we would like for impacts studies, so we “downscale” them.
Scale and Statistical Downscaling

To do this we:

- Take historical climate and map it to a grid (~3.5 mi)
- Compare each grid cell to a climate model’s grid cell (~100 mi)
- Use the difference between them to adjust the future projections at the same coarse grid

Downscaling Methods

- Different applications have driven the development of downscaling methods.

- The method you choose should be informed by the process you are trying to understand in the future.

- Two general approaches:
  - Statistical downscaling (e.g., composite delta, BCSD, hybrid delta)
  - Dynamical downscaling (i.e., Regional Climate Modeling)

Statistical downscaling
Statistical Downscaling

- **Composite delta:** Simple, easy to explain “snapshot” of average future conditions.
  - Suitable when you want to know the mean change at a monthly time step.
  - *Ex: Changes in future vegetation distribution by biomes*

- **Bias Corrected and Spatially Downscaled (BCSD):**
  Produces a transient (i.e. continually varying) daily time series.
  - Suitable when you want to model the change in variability around monthly mean, changes in extremes at a monthly time step, or frequency of extreme events.
  - *Ex: Changes in phenology*

*Other methods that pull features from both methods (e.g., hybrid delta) are available*
Dynamical Downscaling *(Regional Climate Modeling)*

**Advantages:**
- Modeling of the climate system at finer spatial scales (5-50 km, or 3-32 mi resolution);
- Can represent major topographic features, land surface effects;
- Can simulate small extreme weather systems.

**Disadvantages:**
- Computationally demanding
- Adds to uncertainty from GCMs - GCMs constrain outcomes

*Suitable for processes driven by local feedbacks.*

Suitable for processes driven by local feedbacks, e.g. Snow in a very small watershed. Time scale variations subject to those feedbacks, or weather conditions that drive a fire, extreme precip at daily to hourly time steps; feedbacks that are weather dependent.
Caveat on Scale

- A finer scale does not necessarily mean the projections are more realistic or better constrained.

- Generally, all methods can be stepped down from the monthly to a daily or finer time step but you have to make certain assumptions that can add to uncertainty.

- Additional key questions:
  - Is more to be gained by finer downscaling?
  - Is it worth the additional cost and potential uncertainty?
  - How does the scale of information match the detail of the ecosystem impact model being used?

At some point local topography and vegetation take over how regional climate appears at finer scales. If you can extrapolate data reasonable at that scale, then ok.
For vegetation modeling, it is also important to consider how climate is interpolated across topography in which there are no climate stations. In particular, this has consequences for future climate and vegetation modeling because this interpolation forms the basis of the relationship(s) between the GCMs and finer scale processes.

It is worth asking the question, “Do I think climate estimates at 100m interpolated from climate stations that are tens of kilometers apart represent conditions that actually occurred historically?” The answer for most people depends on the scale at which interpolation is done, and less so for the variable in question. Temperature tends to be much more predictable as a function of topography and basic meteorology and atmospheric science than precipitation, particularly when it comes to the temporal and spatial patterns of precipitation.
For example, note the difference between the two temperature variables, and then compare to the precipitation variables below. Rehfeldt et al used all the available climate stations they could. The fits they show are quite linear, but for any given place the discrepancies from the regional fit can be important. It’s also worth noting that the length of the record at these stations varies. These are a couple of key reasons why interpolated climate has limitations – what likely happened and its interpolated estimate vary in how well they track each other.
Different interpolation procedures have historically used different methods and assumptions to attempt better interpolation given local information from weather stations, topography, lapse rates, etc.

Limitations of Interpolated Climate Models

- Current methods of predicting temperatures in mountains rely on existing weather stations
- Most stations located in cities, valleys and at low elevations, so we have to interpolate.
- DAYMFT uses constant lapse rate (6.5 deg C/1000 meters); PRISM is refining lapse
- Thin plate spline models (e.g. ANUSPLIN) fit the data to elevation locally, using differences between nearby stations.
Challenges of Predicting Temperatures in Complex Topography

Variations in temperature variability are known to exist, but are not captured by current models.

• Variable lapse rates
• Cold air pooling at night
• Mid-slope thermal belts
• Inversions
There is ongoing work to better understand how temperature varies in complex terrain.

Data and analytical approach time consuming, but in a nutshell, they show us that interpolation at very fine scales requires very fine scale data. This project put out dozens of small, inexpensive temperature sensors in mountain watersheds of northernmost Idaho to better understand how topography influences cold air pooling and other topographical “exceptions” to the rule that elevation and aspect are linearly related to temperature.
During the day time, temperature is generally a function of elevation, though mid slopes are warmer than valley bottoms and ridge tops are warmer than their neighboring cooler high elevations.

These relationships are driven by the different temperatures of air masses caused by topographic variability. Averaged over time, they can create serious departures from interpolated values based solely on elevation.
Such differences are especially obvious at nighttime.

At nighttime, high elevation and narrow canyons become areas of concentrated cold air pooling, and mid slopes are on average warmer than both the valley floor and the canyons.

Jessica Lundquist and Nick Pepin have done similar work focused on cold air pooling and snowpack variation, and they have some very interesting results that suggest locally driven topographical controls on “climate” at really fine scales must be considered past a certain scale. This points to a huge information gap that can really only be filled by more rigorous observation and monitoring.
Implicit and Explicit Models

Climate information can be incorporated into ecosystem impacts models explicitly or implicitly.

- Explicit models: climate is a direct predictor of an ecosystem response. Direct relationships reduce uncertainty.

- Implicit models: climate impact on ecosystem response is indirect (e.g., model predictors are elevation, lat/long, or site index, not temp or precip directly)

Models based on direct relationships between climate and ecosystem response are one way to reduce uncertainty in projections – reduces the risk for false assumptions about causation vs correlation
Scale and Modeling Approaches

- Mechanistic
- Empirical
- Stochastic

Approaches focus on specific scales in time and space.

Bob Keane
<table>
<thead>
<tr>
<th>Year</th>
<th>Stand</th>
<th>Watershed</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decades</td>
<td>FOFEM Consume Burnup</td>
<td>FARSITE Flammmap</td>
<td>NWS Models</td>
</tr>
<tr>
<td></td>
<td>FVS Gap Models</td>
<td>SIMPPLLE FETM</td>
<td>RCM’s</td>
</tr>
<tr>
<td>Centuries</td>
<td>Gap Models</td>
<td>RMLANDS Landis LANDSUM</td>
<td>CRBSUM MAPPS DGVM’s</td>
</tr>
</tbody>
</table>

Bob Keane
Statistical Species Distribution Models

Goals:

- Develop predictive models that relate species distributions with their climatic drivers

- Use models to extrapolate future potential species distributions based on future climate projections

QUANTIFYING THE ABUNDANCE OF CO-OCCURRING CONIFERS ALONG INLAND NORTHWEST (USA) CLIMATE GRADIENTS

GERALD E. REEVELEY, DONALD E. PESCHUK, AND NICHOLAS L. CHIROMINO

Rocky Mountain Research Station, USDI Forest Service, Southern Research Laboratory, 1775 S. Male, Moscow, Idaho 83843 USA
Predicting Shrub Species Distributions with Topoclimatic Data in Complex Terrain

Holden, Cushman, Evans, submitted.
### Statistical Species Models

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Conceptually simple</td>
<td>• Some methods numerically difficult</td>
</tr>
<tr>
<td>• Explicit incorporation of climate and implicit individualistic response of species</td>
<td>• Ecological controls on species distributions not considered explicitly</td>
</tr>
<tr>
<td>• Validation probabilistic and expression of model error quantitative</td>
<td>• Physical and physiological processes responsible for relationships not modeled explicitly*</td>
</tr>
</tbody>
</table>

*Future projections assume these are captured in statistical relationships that are the same as in the past*
Gap Models

Goals:

- Develop process models that describe stand development as growth of individual trees.
- Use models to extrapolate stand composition, tree growth, mortality, structure as a function of stand state and limiting factors including climate.

Shugart and Noble, 1981
## Gap Models

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual tree and stand level provides detailed response applicable to management problems</td>
<td>Require local calibration; limits use by managers</td>
</tr>
<tr>
<td>Can be linked to spatially-explicit landscape scale models</td>
<td>Most gap models are not spatially explicit</td>
</tr>
<tr>
<td>Include physiological processes that can be linked to climate drivers explicitly</td>
<td>Ecophysiology is limited compared to BGC models</td>
</tr>
<tr>
<td></td>
<td>Not prognostic for shorter term analysis of response to management interventions</td>
</tr>
</tbody>
</table>
Forest Vegetation Simulator (FVS)

FVS is an individual-tree, semi-distance-independent growth model.

Inputs include an inventory of site conditions and a set of measurements on a sample of trees (e.g., tree size, species, crown ratio, recent growth and mortality rates).

Outputs include summaries of tree volume, species distributions, and growth and mortality rates that are often customized for specific user needs.

Spatial scales range from a single stand to thousands of stands.

The temporal scale has traditionally been about 200 years (400 years maximum).

Figure 2 - FVS Program Execution
## Forest Vegetation Simulator (FVS)

FVS extensions represent disturbance agents and provide additional capabilities to the base model.

<table>
<thead>
<tr>
<th>Extension</th>
<th>What is represented</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western root disease model</td>
<td><em>Phellinus weirii</em>, <em>Armillaria</em> spp., Heterobasidion annosum</td>
<td>Frankel (1998)</td>
</tr>
<tr>
<td>Douglas-fir beetle impact model</td>
<td><em>Dendroctonus pseudotsugae</em></td>
<td>Marsden et al. (1994)</td>
</tr>
<tr>
<td>Douglas-fir tussock moth outbreak model</td>
<td><em>Orgyia pseudotsugata</em></td>
<td>Monserud and Crookston (1982)</td>
</tr>
<tr>
<td>Dwarf mistletoe impact model</td>
<td><em>Arceuthobium</em> spp.</td>
<td>Hawksworth et al. (1991)</td>
</tr>
<tr>
<td>Mountain pine beetle</td>
<td><em>Dendroctonus ponderosae</em></td>
<td>Crookston et al. (1978), Cole and McGregor (1983)</td>
</tr>
<tr>
<td>Mountain pine beetle hazard rating system</td>
<td><em>Dendroctonus ponderosae</em></td>
<td>McMahon and Smith (2002)</td>
</tr>
<tr>
<td>Southern pine beetle</td>
<td><em>Dendroctonus frontalis</em></td>
<td>Courter et al. (2002)</td>
</tr>
<tr>
<td>Spruce beetle risk rating</td>
<td><em>Dendroctonus rufipennis</em></td>
<td>FHTET (2002)</td>
</tr>
<tr>
<td>Western spruce budworm model</td>
<td><em>Choristoneura occidentalis</em></td>
<td>Crookston et al. (1990)</td>
</tr>
<tr>
<td>White pine blister rust</td>
<td><em>Cronartium ribicola</em></td>
<td>McDonald et al., in preparation</td>
</tr>
<tr>
<td>Biogeochernical physiology growth model</td>
<td>Northern Rocky Mountain tree species</td>
<td>Milner et al. (2002), McMahon et al. (2002)</td>
</tr>
<tr>
<td>Canopy and shrubs extension</td>
<td>Northern Rocky Mountain shrubs (limited coverage)</td>
<td>Moeur (1985)</td>
</tr>
<tr>
<td>Fire and fuels extension</td>
<td>Snags, down wood, fire, and fire effects</td>
<td>Reinhardt and Crookston (2003)</td>
</tr>
<tr>
<td>(FFE-FVS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The parallel processing extension</td>
<td>Interactions of stands in a landscape</td>
<td>Crookston and Stage (1991)</td>
</tr>
</tbody>
</table>
Climate “Smart” FVS

Addressing Climate Change in the Forest Vegetation Simulator to Assess Impacts on Landscape Forest Dynamics --- Crookston et al. in press Forest Ecology and Management

- Forest Vegetation Simulator (FVS) adjusted to account for expected climate effects.

- This was accomplished by:
  1. Adding functions that link mortality and regeneration of species to climate variables
  2. Constructing a function linking site index to climate and using it to modify growth rates
Biogeochemical Models

Goals:

- Develop process models that describe earth system biogeochemical cycles (e.g., carbon, nitrogen) – but, necessarily, also vegetation (forest) productivity

- Use models to extrapolate future pools of carbon as a function of plant photosynthesis, respiration, which are in turn functions of nitrogen, water, energy
# Biogeochemical Models

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• track climate controlled processes (e.g., hydrology, gas exchange) in forests and account for their interactions</td>
<td>• variables used by managers (e.g., stand structure) are not available or are limited</td>
</tr>
<tr>
<td>• carbon budgets are a natural component</td>
<td>• sensitive to downscaling: some processes operate at very small scales OR are generalized (applies to other model classes as well)</td>
</tr>
<tr>
<td>• ecosystem process focus makes them flexible for different vegetation types</td>
<td></td>
</tr>
<tr>
<td>• can identify process- and rate-limiting factors in different regions</td>
<td></td>
</tr>
</tbody>
</table>
Landscape
Vegetation Models

Goals:

- Model spatially dependent and spatially contagious processes at multiple scales

- Use models to extrapolate future vegetation structure, disturbance interactions, in real world complex topography

Source: Cushman et al 2008

Source: D.Urban
## Disturbances Simulated

<table>
<thead>
<tr>
<th>Model</th>
<th>Fire</th>
<th>Insects</th>
<th>Disease</th>
<th>Wind</th>
<th>Harvest</th>
<th>Climate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDDT/TELSA</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>SIMPPLLE</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>LANDSUM</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>potential veg. climate modifier</td>
</tr>
<tr>
<td>RMLANDS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>LANDIS</td>
<td>X</td>
<td>X</td>
<td>?</td>
<td>X</td>
<td>X</td>
<td>LANDIS-II</td>
</tr>
</tbody>
</table>

Eric Gustafson
**Spatial Dynamism:**
How spatially dependent processes are modeled

<table>
<thead>
<tr>
<th>Spatial Dynamism</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDDT/TELSA</td>
<td>SIMPPLLE</td>
<td>RMLANDS</td>
<td></td>
</tr>
<tr>
<td>LANDSUM</td>
<td></td>
<td>LANDSUM-fire</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LANDIS</td>
<td></td>
</tr>
</tbody>
</table>
**Strengths & limitations of various LDSMs**

- **VDDT/TELSA**
  - Relatively easy to use, flexible, portable, conceptually simple
  - Less scientific & analytical rigor, limited dynamics.

- **LANDSUM**
  - Minimal inputs, flexible, portable
  - Does not use spatial context, limited spatial dynamism except for fire

- **RMLANDS**
  - High spatial dynamism, good analytical capabilities
  - Computationally intensive, requires high level of developer support, documentation limited

Eric Gustafson
Strengths & limitations of various LDSMs

• SIMPPLLLE
  – Captures ecological details, accounts for interactions
  – Not very portable, limited spatial dynamism, uncertainty in parameter specifications (black box)

• LANDIS
  – High spatial dynamism, accounts for interactions, portable, can account for climate change, superior where successional pathways are less predictable, open-source
  – Computationally intensive, steep learning curve, many process parameters required, separate analytical software required

Eric Gustafson
**Landscape Models**

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• explicit representation of multiple spatial processes</td>
<td>• some models have limited mechanistic approach</td>
</tr>
<tr>
<td>• can encompass strengths of gap models within each cell if processes embedded</td>
<td>• multiple scales of interactions difficult to model well – data dependent</td>
</tr>
<tr>
<td>• many available models, for different applications</td>
<td>• data intensive: spatially explicit requirements</td>
</tr>
<tr>
<td>• applicable to forest and non-forest settings</td>
<td>• steep learning curve for use</td>
</tr>
<tr>
<td>• can explore links across different scales from local to landscape</td>
<td>• some are highly dependent on model developers / experts</td>
</tr>
</tbody>
</table>

Like landscape models, DGVMs are spatially explicit (though at coarser scales of hundreds of meters to km) and provide a platform for integrating the climate-control of ecophysiology, disturbance, and ecosystem processes.
## Dynamic Global Vegetation Models

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• based on physiological mechanisms or relationships</td>
<td>• based on functional types rather than species</td>
</tr>
<tr>
<td>• sensitive to changes in CO(_2), H(_2)O and temperature</td>
<td>• data intensive, difficult to use and learn</td>
</tr>
<tr>
<td>• applicable to forest and non-forest settings</td>
<td>• use is highly dependent on model developers / experts</td>
</tr>
<tr>
<td>• can identify process, rate, and structural limiting factors in different regions</td>
<td>• usually not down-scaled to spatial level useful to managers</td>
</tr>
</tbody>
</table>
Climate in Vegetation Models

Implicit: climate or mechanism
- Site index in growth and yield models (climate implied)
- Statistical species models (mechanisms implied)
- Landscape models sometimes use elevation, latitude, longitude as surrogates for climate

Explicit: climate and mechanism
- Climate in gap models
- Climate in statistical species models
- DGVMS, BCMs have vegetation and ecosystem processes directly a function of climate

Worth noting that models’ ability to capture transience of climate and affect future impacts on vegetation depends on how climate is incorporated – means vs. extremes, scale of climate information, method of downscaling etc.
In many ways, the uncertainty we talk about with respect to climate models and vegetation models is no different than any other – the sources of uncertainty are the same. For example, scientific information is lacking and so we can hedge, or there exist surprises, and so we can be flexible and focus on resilience.
What are the biggest uncertainties?

- Climate models don’t simulate decadal variability very well
- Vegetation models don’t simulate disturbance interactions very well
- Global politics and economics don’t constrain future emissions very well
- None of that is going to change tomorrow.
- What can change tomorrow is how we plan around that fact. Vegetation and climate models are one piece of that.

The biggest uncertainty is not that a chain of models with many, many steps has an unknown cascade of internal uncertainty.

The biggest uncertainties are surprises – thresholds, nonlinearities, things we didn’t anticipate and don’t currently model. There are several known uncertainties that can help us in our planning though, because they are contingencies.

Climate models don’t simulate decadal variability very well: this could mean, in the PNW, that precipitation could be above and temperature below projections for a climatology – 30 years. Or it could be the reverse. But the range of GCMs is much like the decadal variation we have witnessed in the historical record.

Vegetation models don’t simulate disturbance interactions very well: the combination of insects, fires, direct mortality, and management actions in a novel climate has the potential to change how forests look and work dramatically, or not very much. We need to know much more about these interactions.

Global politics and economics don’t constrain future emissions very well. We are on a pace that is consistent with A2 and A1FI over the last few years – will that continue?

None of that is going to change tomorrow.

What can change tomorrow is how we plan around that fact. Vegetation and climate models are one piece of that.
Questions?

Additional opportunities for Q&A:

- Optional Q&A period
- Email CIG: cig@uw.edu

CIG Website:
http://cses.uw.edu/cig/

WWETAC Website:
http://www.fs.fed.us/wwetac/

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Western Wildland
Environmental Threat
Assessment Center