
Vegetation Models and Climate Change

Workshop Results

Prepared for:

*Western Wildlands
Environmental Threat Assessment Center
USDA Forest Service
Prineville, OR*



Prepared by:

*ESSA Technologies Ltd.
Vancouver, BC, Canada*

April 21, 2008

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Gap Models	<i>Rick Busing</i>	<i>David Price</i>
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1. Introduction

National Forest managers and planners operate in an uncertain world. To be effective they incorporate a variety of forecasting tools – such as vegetation management models – to support their planning and decision-making. In the past, incorporating new kinds of disturbances in vegetation simulation models has required novel quantitative approaches. Incorporating the potential effects of climate change in vegetation simulation models also presents a significant challenge.

There exist a number of ecological models that estimate vegetation development (productivity or vegetation type) under climate change. Those models produce a variety of results based on different approaches and assumptions about the interaction between ecological processes and three key indicators of climate change: moisture, temperature and CO₂. Different models offer planners and managers differing pictures of future vegetative landscapes. Each also offers differing utility for National Forest planning needs. As a result, determining which model, if any, best suits the particular needs of a manager or planner can be daunting.

This report documents the discussion and recommendations of a workshop held January 23-24, 2008 at the Hotel Vintage Plaza in Portland Oregon. The workshop was convened to provide a forum to explore five classes of vegetation simulation model that are currently sensitive to climate change. The workshop goals were:

1. To evaluate and document the purposes, limitations, strengths, and weaknesses of different classes of models that can be used to project future vegetation with climate change.
2. To provide a forum for discussion between modelers, planners and managers on ways to increase the ease of use and effectiveness of vegetation management models in a changing climate.
3. To try to identify general patterns of vegetation change which might be independent of individual specific quantitative approaches and useful for decision making purposes in planning and management.
4. To identify the content necessary to develop a short course for National Forest System managers, planners and other decision makers using the vegetation models which are currently available, with particular emphasis on their utility for planning under climate uncertainties.

As a result of the workshop, we expected that managers and planners would have an improved understanding of the strengths, weaknesses, and limitations of the various models, including a clearer knowledge of the questions that each model can and cannot answer. Likewise, we expected that modelers would have a better sense of the questions being posed by the planning community, and would be better able to plan for the improvement of their models to accommodate those needs.

The remainder of this report is structured as follows:

- an overview of the workshop format;
- a summary the strengths and weaknesses of five classes of vegetation models, with suggestions for possible synthesis of model results;
- a summary of the management issues and needs expressed by the workshop participants;
- a summary of concepts developed and expressed by the workshop participants related to extension and professional development for climate change and vegetation management; and
- recommendations for continued progress in developing and delivering the best available science to support National Forest planning and management.

The appendices to the report contain the list of participants, the agenda and a more detailed description of the developer interviews that preceded the workshop.

2. Workshop Overview

Prior to the workshop, participants were sent a briefing document that contained two syntheses of the five model classes. Information about the model classes was derived from answers to a questionnaire and an in-depth interview with each of the lead model developers. The first synthesis provides a high-level summary of some of the main *characteristics* of each model class (Table 1, on the following pages). The second level of synthesis is more detailed and contains comments, notes and references provided in response to the questionnaire and the interview (Appendix A). Our intention in the interviews and synthesis was to focus on the features of each *class* of models. It was often difficult, however, to maintain this distinction, since every model class is an abstraction that ultimately must be represented through a specific model instance.

The workshop was structured around presentations and discussions on five classes of climate-sensitive vegetation models:

- statistical species distribution models;
- gap models;
- landscape models;
- biogeochemical models; and
- dynamic global vegetation models.

Note that although the Forest Vegetation Simulator (FVS) is a widely-used management model, it was not included in this workshop since it is not *yet* sensitive to any of the climate variables in common use, although plans are under way to change this.¹

Each presentation began with a 30 minute plenary presentation specific to the model class, delivered by a senior model developer. This presentation was followed by a 20 minute presentation delivered by an experienced model user who shared their experience working with a model of the class. The plenary session then broke into breakout groups to elicit additional feedback and ideas relevant to the strengths and weaknesses of the model class, technical enhancements that could make the model more relevant to managers and a discussion on its relevance to current management needs. The workshop participants and agenda can be found in Appendices B and C, respectively.

In addition to preparing the briefing document we collected and posted an extensive collection of model and climate literature to serve as background. This collection of papers will remain until the end of 2008, at which time it will likely be hosted by WWETAC directly:

<ftp://ftp.essa.com/pub/essa/VegetationModelsClimateChangeWorkshop>

¹ **ESSA Technologies Ltd.** 2007. Development of a Climate-Driven Forest Vegetation Simulator: the Priest River Experimental Forest Workshop Results. Prepared by ESSA Technologies Ltd., for Rocky Mountain Research Station, USDA Forest Service, Moscow, Idaho and the Forest Management Service Center, USDA Forest Service, Fort Collins, CO. 14 p.

Table 1: Synthesis of the five model classes prepared prior to the workshop.

MODEL FEATURE	STATISTICAL SPECIES DISTRIBUTION MODELS	GAP MODELS	LANDSCAPE MODELS	BIOGEOCHEMICAL MODELS	DYNAMIC GLOBAL VEGETATION MODELS
Model Names	DISTRIB SHIFT	FORCLIM, FOREL (JABOWA, LINKAGES, ZELIG, FORSKA, GUESS)	LANDSUM (over 100 other models available)	CENTURY, DAYCENT (TEM, BIOME-BGC, DNDC, EPIC)	MC1 [MAPSS-CENTURY] (S-DGVM [DOLY-CENTURY], LPJ [BIOME], ED, IBIS)
Development Objective	predict potential tree species occurrence & potential colonization using statistical models based on 7 climate, 31 site & soil variables	simulate gap dynamics and stand dynamics of forests	simulate the dynamic interactions of vegetation, disturbance, and climate in a spatial domain	simulate key nutrient cycles and fluxes: H ₂ O, C (NPP, etc.), N, P, trace gases (N ₂ O, NO _x) Water & temperature dynamics at monthly and daily scale	simulate key physiological processes to infer vegetation (grass, shrub and tree) and cover type based on monthly climatic environment, including CO ₂ .
Key Concepts	focus on statistical relationships; predicts habitat suitability based on historical and current climate/site; insensitive to CO ₂ and new competitive relationships; time-free equilibrium assumption; relict or rare species may be inaccurate	individual-based models that simulate interactions and dynamics on a small, gap-sized patch of land. Ingrowth, growth and death of individuals of one or more species on the patch are simulated	spatially explicit, dynamic interactions between modeled entities, simulation of spatial process, long simulation times with short simulation time steps	N,P key drivers of productivity in plant communities (principally grass & tree); sensitive to soil texture; relevant submodels must be correct so that the emergent behaviour is appropriate; extensively tested in agricultural systems	uses empirical and fundamental physiological processes (leaf to plot scale) to model LAI; heuristic model to assign physiognomic cover class; at extreme down scale will come to resemble a gap model; incorporating biogeochemical approaches
Model Availability	www.nrs.fs.fed.us/atlas work directly with developers Google Earth tools in development	http://www.pik-potsdam.de/topik/t6scs/safe/home/forclim.html available by request to run on user's workstation; sample input files to ease initial use	www.firelab.org Available for download. Steep learning curve, but easy gaming afterwards.	http://www.nrel.colostate.edu/projects/century source and executables for download; week-long training sessions; user community	http://www.fs.fed.us/pnw/mdr/mapss work directly with developers; study results coordinated with ORNL for better availability; goal of download, web service, 3 week learning curve
Scale & Range	20 km typical, depends on sampling scale of coarsest site variable	0.01ha – entire biogeographic province. 1 – 15,000 years	30-300m pixel. 1 – 10,000 year simulations	1-D site model, scale invariant; plot to continent; typical scale of input data is 5km	1-D site model, scale invariant; plot to continent to globe; 10km typical for recent
Biological Resolution	tree species; no time dynamic	individual trees, by species	vegetation type – structural stage – potential vegetation type combination	tree or grass components (e.g., NPP), configured to species of interest; daily, monthly, outputs	plant physiognomic group (e.g., needle leaf conifer); can be attributed to corresponding local species, annual output most common

MODEL FEATURE	STATISTICAL SPECIES DISTRIBUTION MODELS	GAP MODELS	LANDSCAPE MODELS	BIOGEOCHEMICAL MODELS	DYNAMIC GLOBAL VEGETATION MODELS
Key Components	uses a data mining statistical method (Random Forests) for robust predictive habitat models	ingrowth, growth, mortality based species-specific parameters, competition (e.g., relative height) light, temperature, soil moisture	succession: state and transition pathway models. Fire: initiation (stochastic), spread, effects (both rule based and stochastic)	focus on dynamics of plant production, water balance, nutrient mineralization, trace gases; sensitive to soil texture, water balance, temperature and CO ₂ ; monthly and daily scales	focus on physiology of photosynthesis, transpiration, water balance and competition; grass/shrub/tree plant functional types, heuristic classification to physiognomic groups (48 tree + 2 grass, e.g., needle leaf conifer); moving toward more nutrient cycling and fuel loads; ecotones an emergent property
Output	potential habitat suitability, indicated as potential species importance	Density, basal area, biomass, leaf area index by species and by stand. Information on each live tree is also available (e.g., species & DBH).	Landscape composition, disturbances, fire size	daily, monthly fluxes and pools of all components, C,N,P, NPP	annual cover classification, climate sensitive, dynamic with climate inputs
Management Uses	risk assessments for species: identification, ranking of species' sensitivity to climate; assisted migration; integrates historic disturbance and current climate	harvesting, site prep, managed fire, C-accounting, N fertilization Can be used to predict stand structure, species composition, regeneration	almost any kind of management can be simulated (but no scheduled) at the polygon level. Currently used to quantify HRV and compare management alternatives.	extensively used in agricultural sector, with daily & monthly versions; mostly in policy, but some farm-based tools are available; wide variety of management actions can be simulated (user-extensible libraries come with model)	fire hazard forecasts updated monthly; http://www.fs.fed.us/pnw/mdr/mapss/fireforecasts future cover type
Links to Climate	basic climate information: monthly min/max temperature, precipitation; uncertainty with novel climate, CO ₂	uses monthly temperature and precipitation. Sensitive to soil moisture, responsive to CO ₂ . Responds to novel climates	fires respond to precipitation and temperature. Novel climate impacts can be captured in the initialization phase.	min/max air temperature, precipitation; model is directly (physiologically) sensitive; climate link to soil characteristics; responds appropriately to novel climate	monthly min/max air temperature, precipitation; model is directly (physiologically) sensitive; climate humidity/fuel conditions can be derived for burn models; responds appropriately to novel climate

3. Synthesis of Discussions

3.1 STRENGTHS & WEAKNESSES

During discussions following each presentation, strengths and weaknesses of the various model classes were identified by the workshop participants, and are summarized in Table 2. Because of the limited time available for discussion, this summary is not exhaustive.

Table 2: Summary of the strengths and weaknesses of the model classes represented at the workshop.

CLASS	STRENGTHS	WEAKNESSES
Statistical Species Distribution Models	<ul style="list-style-type: none"> • results describe the “emergent properties” of mechanistic processes • do not have the same parameter estimation problems as the other model classes • may be useful in the immediate term to explore changes over smaller scales • understandable to managers due to the relative simplicity of the approach • provides useful range maps at regional scales • useful for identifying vulnerability of species 	<ul style="list-style-type: none"> • models provide an climate-equilibrium assessment whereas climate change represents a disequilibrium condition • lack of understory vegetation (data issue) • no explicit representation of interactions across complex ecological processes • cannot account for potential future changes in disturbance regimes that are some of the processes that led to the current species distribution • distributions predate the observed climate data • do not include invasive species (but perhaps could) • not useful at the point scale • no accounting for competition
Gap Models	<ul style="list-style-type: none"> • can be used at local levels • they work and are somewhat accurate/efficient at providing dynamic feedback • valuable when linked to spatially-explicit landscape scale models • include physiological processes that can be linked to climate drivers • model structure is flexible • individual tree level analysis provides response variables that are applicable to management issues • relative to statistical models they have more potential for prediction due their process formulation, i.e., do not have issue of trying to predict outside the domain over which a regression model is fit) • more recent models have moved from functional response curves to mechanistic process equations and provide a more realistic representation of ecological process • good class of models for looking at disturbance impacts of models for looking at disturbance impacts 	<ul style="list-style-type: none"> • require calibration – this inhibits routine use by managers • on their own, most gap models are not spatially explicit • many do not include animals, i.e., pests, herbivores • knowledge of eco-physiology is increasing but still limited • disturbance regime often needs to be assessed independently and input to the model • most do not currently include understory, e.g., grasses, shrubs • usually do not work well at the forest/shrub/grass interface • growth reduction factors in the models differ regionally (e.g., nutrients constrain in the east, water in the west) – to some degree a consequence of different limiting factors in different areas, but may also simply reflect developers bias: no overall formulation that is generally applicable (but FORCLIM is a step in this direction) • structure permits incorporation of new (invasive /exotic) species but usually not included • CO₂ interactions not explicitly represented in most existing models • not prognostic for shorter term analysis of response to management interventions
Landscape Models	<ul style="list-style-type: none"> • explicit representation of multiple spatial processes • encompasses the strengths of gap models within each cell • many available models to select from, for different applications • applicable to forest and non-forest settings • flexible for analysis of different management 	<ul style="list-style-type: none"> • existing models do not have strong mechanistic approach • internal conflicts in the scale of model components e.g., fire vs. vegetation • do not account for larger scale constraints e.g., carrying capacity • data intensive, difficult to interpret, difficult to

CLASS	STRENGTHS	WEAKNESSES
	<ul style="list-style-type: none"> questions can explore links across different scales from local to landscape outputs maps "about the right scale" for most management use 	<ul style="list-style-type: none"> parameterize steep learning curve for use some are highly dependent on model developers / experts
Biogeochemical Models	<ul style="list-style-type: none"> useful for policy and strategic studies carbon budgets are a natural component based on functional types rather than species applicable to forest and non-forest settings can identify limiting factors in different regions 	<ul style="list-style-type: none"> variables used by managers (e.g., stand structure) are not available or are limited sensitive to downscaling: different processes operate at very small scales (applies to other model classes as well)
Dynamic Global Vegetation Models	<ul style="list-style-type: none"> based on physiological mechanisms or relationships sensitive to changes in CO₂, H₂O and temperature applicable to forest and non-forest settings based on functional types rather than species can identify limiting factors in different regions useful for policy and strategic studies 	<ul style="list-style-type: none"> data intensive, difficult to use steep learning curve for use use is highly dependent on model developers / experts management, pests and herbivores not included riparian and wetland dynamics may be absent often do not account for land use change usually not down-scaled to the spatial level useful to managers; e.g. 10 km² result may not capture details such as microsite refugia

3.2 MODEL SYNTHESIS

The presentations and discussions of the five model classes during the workshop were organized so that they were roughly ordered from lower to the higher complexity. This assumption about class complexity was borne out by the later interviews (Appendix A). Although their derivation is non-trivial, the statistical distribution models are widely accessible (even through Google maps) and their results are quite easy to understand and interpret. In contrast, more complex models are more technically demanding to fully understand and are typically run by a small group of expert users and developers. The key features and trade-offs of this complexity-axis are shown in Figure 1.

Potential users of the more complex models would benefit if ways could be found to bridge the highly technical and demanding work associated with more mechanistic models. At least two solutions are possible. The first would be to promote the development of centers of excellence, with sophisticated model users devoted to supporting management application, interpretation and extension for process based models. A second and complementary approach would be to develop and make available simplified sets of outputs from complex models. These could be built upon common GIS, database and metadata standards.

Drawing upon the information in Figure 1 and Tables 1 and 2, Table 3 summarizes climate-sensitivity, usability and current applicability to National Forest decisions, all at the model-class level.

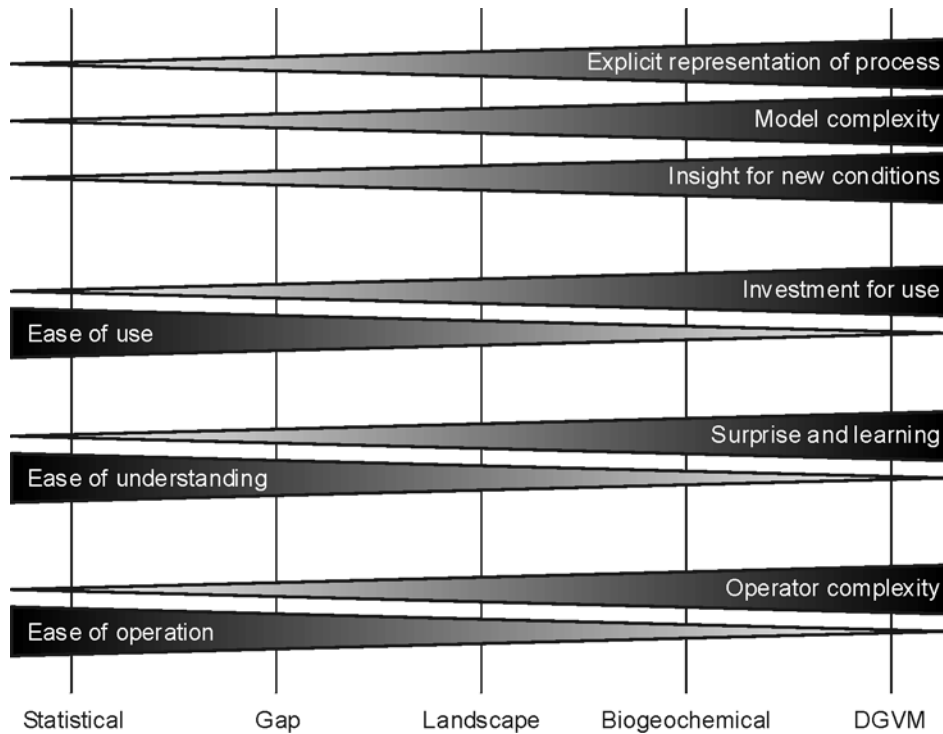


Figure 1: Simple and complex models, and those in between, come with tradeoffs for development, understanding and use. The particular location of the five model classes shown at the bottom of the figure is approximate.

Table 3: A further synthesis of some high-level features of each model class.

MODEL FEATURE	STATISTICAL SPECIES DISTRIBUTION MODELS	GAP MODELS	LANDSCAPE MODELS	BIOGEOCHEMICAL MODELS	DYNAMIC GLOBAL VEGETATION MODELS
Precipitation Sensitive	YES	YES	SOME	YES	YES
Temperature Sensitive	YES	YES	SOME	YES	YES
CO ₂ Sensitive	NO	OPTIONAL	COULD	YES	YES
Ease of Use	EASIER	MODERATE	MODERATE	MODERATE	HARDER
Ease of Interpretation	EASIER	MODERATE	MODERATE	MODERATE	EASIER
Stand Management	INFORMATIVE	YES	COULD	INFORMATIVE	INFORMATIVE
Simulate Current N.F. Management	INFORMATIVE	COULD	YES	COULD	INFORMATIVE

The availability of new quantitative tools could raise unrealistic expectations that Forest Service staff will be able to deliver improved or more extensive analyses. Such expectations may be difficult to meet as

demand grows and expertise is lost through agency downsizing or personnel retirement. In the face of this, it will be important to develop simpler approaches. For example, although it may be technically possible to programmatically link existing models, it may be easier to make use of more qualitative and comparative higher level model behaviour to support other models (Table 4). In particular, we should look for ways in which a particular model’s strengths, particularly related to simulating climate effects, can inform other models. Insights may also be gained from comparative analyses of the agreement or disagreement of different model results when simulating the same climate scenario and geographical location.

Table 4: Results from one model class may be able to contribute information that will improve simulations made by another model class. Note the inclusion of the stand- and landscape-level FVS model in this table because of its importance to managers and planners.

		FROM					
		STATISTICAL	FVS	GAP	LANDSCAPE	BGC	DGVM
TO	STATISTICAL						<ul style="list-style-type: none"> functional types, species
	FVS	<ul style="list-style-type: none"> regenerating species potentially stressed species (to inform mortality model) 		<ul style="list-style-type: none"> regenerating species inter-specific competition 	<ul style="list-style-type: none"> natural disturbance (e.g., modified rates) 	<ul style="list-style-type: none"> growth, mortality changes from climate change C,N in soils 	<ul style="list-style-type: none"> functional types regenerating species
	GAP	<ul style="list-style-type: none"> regenerating species 	<ul style="list-style-type: none"> silviculture response 				<ul style="list-style-type: none"> functional types regenerating species
	LANDSCAPE	<ul style="list-style-type: none"> regenerating species 	<ul style="list-style-type: none"> stand structure 	<ul style="list-style-type: none"> stand structure species composition succession 		<ul style="list-style-type: none"> soils (especially C, N content) grasslands information 	<ul style="list-style-type: none"> functional types regenerating species indicators of how vegetation types shift with climate change
	BGC				<ul style="list-style-type: none"> disturbance patterns, locations 		
	DGVM				<ul style="list-style-type: none"> disturbance patterns, locations 		

3.3 SUITABILITY FOR MANAGEMENT

Management and planning must span a wide range of spatial and temporal scales. Faced with planning for climate change, questions and decisions will range from the tactical “how large should this culvert be?” to the strategic “how should genetic resources be managed under a changing climate?”

During group discussions it became clear that models in all five classes currently have a fairly weak connection to stand level (tactical) silvicultural management, but could have a more important role to play in strategic decision making. The weak connection to the national forest inventory was a recurring theme among most of the model classes that were discussed and poses is a significant hurdle to routine usability for stand- and landscape-level decision making. The strongest current candidates in this area would be members of the gap model class, which have the capacity to utilize inventories as input and simulate gaps and patches at the tree scale. In addition to gap models, some coarse resolution landscape models like VDDT are also being used to provide a bridge² between stand level management tools like FVS and landscape tools like LANDFIRE.

At the strategic level, model classes that predict Leaf Area Index (LAI: gap models, biogeochemical models, and DGVMs) and species functional groups (DGVMs) may be able to produce information useful for strategic decisions involving novel climate regimes, and models that predict species suitability areas may be useful when contemplating facilitated migration. Some of these possible linkages are shown in Table 3.

None of the models discussed address genetic adaptation in a coherent way. For example, mechanistic models may not adequately represent changes in physiological parameters across the geographic range of the functional type, and statistical models may simplify species into a homogenous and uniform population when in fact, genetic provenances within the species-range may be adapted to a much more restricted range. These simplifying assumptions could result in surprises if local climate change moves a provenance out of its adaptation zone.

3.4 ASSESSMENT OF MANAGER NEEDS

While planning for the workshop an effort was made to obtain balanced representation from both modelers and managers. Both groups made valuable contributions to the discussions and the participants stressed that it would be very helpful to have more thorough *regional* discussions or workshops to clarify the decision making needs in the National Forests of each region, and how those decisions might be affected by climate change.

The plenary participants noted that managers at all levels recognize the need to be better informed about climate change impacts, but want to take an active role in designing their own professional extension, based on issues and questions that they themselves identify. Drawing on information from new or emerging Forest Plan revisions, fuel management strategies, carbon budgets, specific habitat analyses and NEPA reports, regionally based case studies would help to determine how to incorporate climate change considerations in specific management decisions and support efforts to develop realistic solutions. This would give a clearer understanding of regional management issues vis-à-vis climate change, and the appropriate scale for decisions and tactics. Without a good understanding of the specific needs of managers, a top-down effort to support management and planning could be perceived as lacking local management context.

A two-way discussion between managers and modelers – bringing science and management together – would probably result in the delivery of quite different national and regional extension programs (it was also suggested that some extension to the public should be part of the development plan). The needs of a national level group may require a training and education component that focuses primarily on the

² Moeur, M. 2008. Beyond the conceptual realm – using FVS to empirically estimate parameters and outputs of state and transition models. Third Forest Vegetation Simulator Conference: 2007 February 13-15.; Fort Collins, CO. [http://www.fs.fed.us/fmsc/ftp/fvs/conference/Presentations2007/Session1_Issues/MMoeur_FVS_021307_minimize.d.pps]

broadest scale applications to inform policy development. The results from a number of the model classes may *already* provide useful content for exploring and setting future national directions. Failing that, an analysis of the scale and content of existing results will certainly help to define the *gaps* in strategic knowledge. For example, Table 2 shows that even the most complex models appear to have gaps in their ability to portray and model future disturbances such as fire, insect outbreaks, disease epidemics and anthropogenic effects. Loose connections like those shown in Table 3 may suffice to bridge these gaps, perhaps through the development of gaming scenarios. Alternatively, further model development and tighter model integration may be required. The weak linkage between all model classes and the national forest inventory has already been mentioned in the context of usability for management.

Presentations made at the workshop clearly indicated that management decisions may be pervasively affected by climate change. While most planners have been comfortable in the past with fairly wide confidence bands on their projections, comments made in the discussions indicate that some now feel overwhelmed by the additional layers of uncertainty. These now include not just issues of model structure and parameters (as with all quantitative models), but also uncertainty in the behaviour of different GCMs plus uncertainty in the corresponding global social development scenarios. Part of the needs assessment therefore should explore ways to familiarize managers with these different kinds of uncertainty.

An assessment of user needs must also consider the ways in which regional managers might interact with modeling results and climate change data. Extraction and analysis of detailed model results requires staff with in depth knowledge about a model or with a specific skill-set. For example, skilled GIS technicians are usually necessary to support analyses that directly incorporate GCM scenarios (e.g., extraction and mapping of monthly temperature minima and maxima, and precipitation)³. The time, skills and effort required for this task made it impractical to look in detail for patterns of agreement or similarity between model classes during the workshop. However, much less detailed knowledge is required if scenario results are synthesized and compiled as a kind of “middleware” layer. A good example of such a concept is provided through the samples of output from the statistical models (www.nrs.fs.fed.us/atlas), or some DGVM results (<http://www.fs.fed.us/pnw/mdr/mapss>). Analysts with a different set of skills would be needed to contrast results from different models and scenarios⁴ to find those that may have the best chance of producing resilient management strategies and tactics. A comprehensive needs assessment would be able to determine, for different regions and managers, which of these should have priority.

3.5 SHORT COURSE DEVELOPMENT

The model participants were unanimous in their interest in finding ways to apply climate change information to the development of improved national forest management and especially to the training and mentoring of new staff. It was clear that it is not practical to invest heavily in training a large group of managers in how to run models, and that a better use of their abilities and interests would be develop (a) a middle layer of synthesis suitable to the majority of problems and solutions, and (b) a middle layer of warehoused future climate scenario data for customized analyses.

Participants also discussed constraints, either existing or predicted, that may affect the format or content of a course. Both time and budgets are an issue, with people generally having less time available to take a course and less money with which to travel long distances to a course. It was also thought that, with the awareness of causes of climate change increasing, there would be more pressure to have meetings and courses over the web (i.e., creating a smaller carbon footprint). Finally, with the issue being at least

³ **Beukema, S.J., D.C.E. Robinson, and L.A. Greig.** 2007. Forests, Insects & Pathogens and Climate Change: Workshop Report. Prepared for The Western Wildlands Threat Assessment Center, Prineville, Oregon. 39 pp

⁴ This could include, for example, the examination of ensembles, “hot spots” of disagreement and agreement and analyses of the significance of those hot spots.

national in scope, all parts of the country need to be engaged, including the Eastern Forest Threat Assessment Center; but each region may have different questions or issues that should be addressed in such a course.

Many comments were directed around the concept of 1-2 day short course focusing on managers, but many other delivery options were also discussed, including:

- a self-directed web-based course;
- a weekly, live, multi-participant web-based course that had a different focus each week (e.g., different models, different management questions, or different regions);
- a comprehensive General Technical Report to allow self-study and to serve as a reference;
- a 1-day addition to existing training or extension programs, such as landscape modelling or silvicultural certification courses either given by the USFS or other groups (such as universities);
- a weekly reading group to study current papers and discuss their applicability to management; and
- a symposium with invited expert presentations.

The suggested emphasis of regional problems and solutions has already been noted. Any method of extension should include:

- freedom from jargon;
- an introduction to the world of climate models and scenarios;
- a review of the main vegetation model classes and models (see Table 1 and Table 2), including the purpose for which the models were originally developed, key processes that are included or not included (e.g., disturbances), and the kinds of results that they produce;
- a review of risk analysis and assessment;
- a discussion of decision making under uncertainty;
- development of a practical application with examples in a National Forest *planning* setting; and
- development of a practical application with regionally appropriate examples in a *project* setting.

4 Recommendations

The WWETAC workshop provided an opportunity to begin to engage National Forest managers to find out what they need to help them develop ways to adapt their management strategies and tactics to a changing climate. Nation-wide about one quarter of National Forest Plans are currently in revision, and GAO directives mandate that the Forest Service (as well as other agencies) “consider and analyze potential climate change effects in their management plans and activities.”⁵

At the Forest Plan level, managers are faced with integrating climate change knowledge (where it exists) into the calculation of long term sustained yield, the designation of management indicator species, the estimation of water flows and runoff patterns, the development of recovery plans for threatened and endangered species, the definition of desired conditions and potential changes in species composition, possible changes in disturbance patterns (which could impact proposed practices and treatments) and suitability analyses.

If WWETAC is careful to integrate its extension and training efforts with other work groups and teams within the Forest Service and to deploy its services in both national and regional contexts, it will enhance and promote its ability to be a broker of climate change knowledge and expertise throughout the Forest Service. Efforts to develop training materials or a course stand the best chance of success if regional managers are involved from the very beginning, and if the technical details of climate and vegetation modeling receive less emphasis. Emphasis *should* be given to synthesizing knowledge in these three broad areas:

1. summaries of the range of climate changes (including greater and lesser certainty) predicted for the region;
2. summaries of expected changes in disturbance patterns for the region; and
3. summaries of the different perspectives on possible vegetation change for the region, including a range of possible changes in vegetation forms (e.g., deciduous forest to savanna or prairie) and in tree species. These summaries could be based on results from different models simulating the same scenario and region, or from extracting and summarizing results from the existing literature.

Research models are sometimes developed in isolation from managers, but this can be easily corrected by soliciting, and then paying attention to, the views offered and the questions raised by planners. The solutions may involve all combinations of education, data warehousing and support and software programming and support.

⁵ U.S. GAO. 2007. Climate Change: Agencies should develop guidance for addressing the effects on federal land and water resources. Report to Congressional Requesters GAO-07-863. Washington, D.C. 184 p.

Appendix A – Synthesis of Interviews

STATISTICAL SPECIES DISTRIBUTION MODELS

GETTING STARTED

1 – Model Class	
Statistical Species Distribution Models – Responses below are marked (D) and (S) as appropriate to indicate the DISTRIB (D) and SHIFT (S) models.	

2 – Model Name	
DISTRIB & SHIFT - These are sometime inaccurately referred to as Climate Envelope Models. These 2 models use 7 climate variables and 31 other variables in the model fitting. Therefore, barriers or conduits other than climate can restrict or enhance the changes in potential suitable habitat. Furthermore, we have a companion spatially explicit, stochastic cellular model SHIFT that ‘migrates’ the species into the new suitable habitat based on current fragmented landscapes	
Other models are available: most robust use Random Forests methods	

3 – Interviewee	
Name	Louis Iverson and Anantha Prasad
Affiliation	USFS-NRS – Delaware OH
Phone	740-368-0097
Email	liverson@fs.fed.us , aprasad@fs.fed.us

4 – Key Model Literature	
Concepts	D: Iverson et al. 2007a S: Iverson et al. 1999; Iverson et al. 2004a
Methodology & Technical	D: Prasad et al. 2006 S: Iverson et al. 1999, Iverson et al. 2004b
Application to Management Or specific ecosystem	D: Iverson et al. 2007a, 2007b S: Iverson et al. 2004a, 2004b
Current and Future Climate	As above, starting with Iverson & Prasad 1998

5 – Class View	
Model Objective	D: Model potential suitable habitat for 134 eastern US tree species S: Model potential colonization probability within new habitat in 100 yrs, based on species abundance in occupied zones and habitat quality/fragmentation in unoccupied zones.

<p>What are the key concepts of the model class</p>	<p>These models must NOT be interpreted as predictions of range change; only of suitable habitat changes. A host of factors play into whether a species will actually migrate into the newly suitable habitat. This issue is better tackled by other kinds of models including process-based models. The models also identify which species are driven primarily by climate variables.</p>
<p>Key strengths & weaknesses of the model class</p>	<p>Strengths: Risk assessments due to climate change for individual species Accounts for reality that the species exists where it is, in spite of all legacy influences over decades and centuries. It therefore integrates over all historic disturbances and climatic phenomena Need not be parameterized with a large suite of variables that are imperfectly known. Extremely robust non-parametric statistical tools using ensemble and consensus techniques are now available for prediction (DISTRIB) The reliability of individual species models can be evaluated based on the agreement among ensemble methods (DISTRIB) TRI model approach – may be useful to give managers confidence in high reliability rare species are hard for any model (Schwartz et al. 2006)</p> <p>Weaknesses: Limited in scope to modelling the <i>potential</i> current/future suitable habitats, not their actual future distributions. May predict inaccurately for species with relict populations Assumes equilibrium Does not account for competition, predation, CO₂ enrichment, or other biological phenomena except indirectly.</p>
<p>Best application examples across the class, with references</p>	<p>Ensemble forecasting of species distributions (Araújo & New 2007) Predicting climate-induced range shifts: model differences and model reliability. (Lawler et al. 2006) Endemic species and ecosystem sensitivity to climate change in Namibia: (Thuiller et al. 2006)</p>
<p>Compare/contrast this model class with the other 3 classes we are studying</p>	<p>Both process-based and robust statistical methods are necessary; there are strengths and weaknesses in both approaches. Theoretically, process modeling will be better because it can address the mechanistic nature of species interacting with their environment, if those interactions are known. Practically, however, it is highly improbable that we can mechanistically model individual species responses to climate change. The systemic character of processes is so complex and the inevitable importance of stochastic events is so large that it is infeasible to model something that might or might not occur. For example: “How would one model the occurrence and action of a yet-to-be introduced pathogen to arrive in a certain area that may or may not affect a certain tree species that is especially vulnerable due to the effects of water stress after two extremely dry summers coupled with an early season heavy frost after three weeks of springtime temperatures and, thus, will favor the spread of another invasive tree that out-competes a different tree species during a certain</p>

	<p>phase of its regeneration?" (e.g balsam wooly adelgid)</p> <p>Large assumptions must be made to model stochastic phenomena such as human interventions, natural disasters and invasions. In the end, all mechanistic models rely on physiological or other parameters that are acquired from experimentation or the literature – statistical approximations themselves! Many, if not most, of these parameters are averages and extrapolations from a very small subset of associated climatic or other environmental conditions, age and size classes, and in various conditions of competition or mutualism. Process models can also inappropriately use a species-average for physiological process estimates, which may actually vary widely across the range Parameterizations are also sometimes made with various groupings or substitutions of related (or not) species because of the lack of detailed information and fudge factors are often used.</p> <p>Every model has error, and is only a perception of reality. Uncertainty is magnified for each additional approximation or equation built into a model. Coupling models multiplies the number of these equations, potentially propagating errors into outputs. There is a tradeoff: the more complex the model, the more potential for learning and prediction, but the less accuracy (more uncertainty) in outputs (Sklar and Hunsaker 2001).</p> <p>Rather than arguing for the strengths of our favored models we should combine results of different models and estimate their central tendencies. A consensus of results from an ensemble of models would be useful for managers.</p>
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NUTS AND BOLTS

6 – General Model Information	
Lead Developer	D: Iverson and Prasad S: Prasad, Iverson, Schwartz
Affiliation	USFS-NRS, U of Cal-Davis
Model website	D: www.nrs.fs.fed.us/atlas
How to Get the Model	work with authors – no download available
Computing Requirements	D,S: PC
Documentation & User Guides	D,S: not available, internal
Support Options	D,S: we work individually with folks
Required Third Party Software	D: ArcGIS, R, ArcView Avenue, Python, Bourne shell scripts S: Fortran 95, ArcGIS, Bourne shell scripts
Number of People Able to	D: 2 S: 2-3

Run the Model	
Person-Days Required to Configure First Run	D,S: Unknown: data acquisition and formatting requires high effort
Typical Model Run Duration	D: <1 hr per species S: 20-40 hr per species
Ease of Gaming	D: medium S: very hard Google earth application has been developed but is not yet public; one idea is to make everything available this way and let managers compare/contrast the results.
How has the model been validated; at what scales	D: Map Comparison Kit: Out-of-Bag model reliability score using the 30 bagging outputs compares favorably with paleoecological data and historic vegetation data at 20km scale S: not yet done
Additional data needed to run the model	D: 38 variables: soils, land use, climate, FIA vegetation data S: FIA vegetation data, land cover at 30 m, aggregated to 1km

7 – Model Scope

Geographic Locale(s)	D & S: eastern U.S. so far (Rehfeldt et al. 2006 have done similar work in the western US)
Smallest Spatial Scale	D: 20 km S: 1 km
Smallest Temporal Scale	D: 2100 climate (so far) under a variety of IPCC scenarios with GCMs S: specific tree regeneration times until 100 yrs out models are equilibrium – time scale and temporal dynamics are absent
Largest Spatial Scale	D,S: eastern US
Largest Temporal Scale	models are equilibrium – time scale and temporal dynamics are absent
Vegetation Resolution	D: Individual tree species for 134 species, can be combined to forest type S: Individual tree species

8 – Input & Output

Input File or Database Format(s)	D,S: CSV files (as outputs from statistics and GIS processes)
Output File or Database Format(s)	D: CSV, GIS, KML, grid ASCII, SHP S: CSV, GIS
Key output	D: potential habitat suitability, indicated as potential species importance

variables	value S: potential probability that a species may occupy a 1km cell by 2100
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MODEL CONCEPTS

9 – Model Components	
What are the key processes; how are they modeled	<p>D: correlation of FIA importance values with soil, landscape variables climate (current and modeled future), modeled using Random Forests. Model reliability based on agreement among various individually modeled regression trees.</p> <p>Predictor importance based on prediction stability under permutations of data.</p> <p>Built-in bootstrap/predictor-subsetting among 1000 regression-trees to get honest out-of-bag evaluations of prediction strength</p> <p>S: colonization potential as affected by landscape fragmentation, habitat quality (%forest within each 1 km cell) and spatial abundance of the species in question. Dispersal is handled simply as an inverse distance function with climate forcing, calibrated to ~50km/century (as in Holocene) under fully forested condition.</p>
What are the key processes excluded from the model	<p>D: Since ours is a niche-based prediction model, mechanistic processes are excluded, including CO₂ enhancement effects on water balance, competition among species, pollinators, invasive plants, pathogens and insects, stochastic natural or human-caused events</p> <p>S: actual dispersal functions</p>
What does this model do best	<p>The method can identify species that are (or are not) sensitive to climate.</p> <p>D: creates a risk assessment of individual species based on potential changes in suitable habitat – not where the species will be! If a species is vulnerable to warming per se, then it should be on a watch list for additional risks from other stochastic events. It differs from straight ‘climate envelope models’ in that it takes into account ‘barriers’ to movement according to edaphic and landscape controls.</p> <p>S: estimates potential colonization probability within new suitable habitat (from DISTRIB) in 100 years for a particular species, which accounts for land fragmentation and abundance of the species near the range boundary</p>
Where is the model weakest; have the most caveats; most in need of strengthening	<p>D: model suffers from many shortcomings as listed in Iverson et al. 2007a, Pearson and Dawson 2003, Guisan and Zimmermann 2000, Pearson et al. 2006, Araújo and Guisan 2006. Many cannot be overcome in the mechanistic modeling sense – they must be used in combination with mechanistic models to maximize the value of both. We don’t have Canada properly integrated yet for lack of comparable FIA data.</p> <p>S: does not now deal with transient changes in distribution within the currently occupied zone (e.g., southern range changes) or potential changes, other than northward.</p>

	Questions about the migration capacity of species (Pearson et al. 2006). Five (or so) challenges for species distribution modeling (Araújo & Guisan 2006, Guisan & Zimmerman 2000).
Discuss case(s) where the model produced important results that were initially surprising but later shown to be correct	D: Black Rock Forest, NY –found changes over 70 years of monitoring that are consistent with our results. Paleo record also consistent with our results, especially for spruce-fir species in the NE. S: none available
Has model behavior been compared with results of other models at the same location? How do they compare?	D: very generally, changes in forest types of New England compare favorably to that of Hansen et al. (2001). They do not agree in Southeastern US, where we model many species able to survive harsh climate change and Neilson et al. model forest conversion to savanna and even grassland. S: no comparisons yet
What conditions or parameters is the model most sensitive to	D: FIA data S: fragmentation and abundance of the species near the range boundary
Discuss how the model incorporates natural variability and uncertainty about the future	D: we have 3 models, 2 emission scenarios and averages incorporated in our outputs. S: we assume the biologically constrained rate of 50 km migration per century (in fully forested condition). For the most part, this rate is much slower than the movement of suitable habitat, even in the least harsh climate change scenario. Thus uncertainty among GCMs matters little.

10 – Use For Management

How is the model currently used by land managers	D: web sites and publications have most of the information (www.nrs.fs.fed.us/atlas); special requests are granted S: few species run so far, a few in the literature
Can management actions be simulated	D: we only deal with potential suitable habitat; it is essentially a risk assessment. Species with habitat moving out of specific area of management have more risk – and various management options follow S: change in land use could alter outputs
How are model results communicated	D: via web sites and in personal contact S: literature and personal contact
Best examples of decisions that incorporate model results	D: just beginning – risk of species changes S: not that we know of yet

11 – Linkage to Climate

What processes are included in the model that respond to temperature and precipitation	D: seven climate variables: Jan T, Jul T, Ann T, Ann P, Diff between Jan and July T (seasonality), May-Sept T (growing season), precipitation May-Sept Individual species respond singly to these variables. Assuming equilibrium, the species has endured and evolved through time where they now exist with these parameters S: assumption of climate forcing in a generally northern direction
What spatial and temporal climate scale is used	D: 20 km, from 4km data S: climate not directly input; assumes a climate forcing generally north
Does the model respond directly or indirectly to changes in CO ₂	D: no S: no
Where does the model express the most sensitivity to climate	D: depends on species S: general climate forcing northward
How does the model respond to novel climates (no precedent)	D: Random Forest does not predict wildly in novel situations – stable and reasonable outputs S: general climate forcing- no difference with novel climates
Is micro-climate (below smallest scale) accounted for? If so, how? If not, why not?	D: if the FIA plot data captured the species within the 20km cell, it will be accounted for, regardless of the local scale influences on that species. So a rare species growing on specific soil/slope habitat, if in a FIA plot, will register for that cell. However, rare species in this situation will not likely result in a highly reliable model according to our reliability analysis S: Not relevant
Are disturbances modeled? Are they influenced by any climate variables?	D: disturbances are modeled only in that the species in place will have endured countless disturbances up until this point to exist in that particular place. A changed climate will not alter this legacy that is modeled S: land-use is considered (constrains dispersal)

12 – References

PDF versions of most references are found in the appropriate subdirectory at:

<ftp://ftp.essa.com/pub/essa/VegetationModelsClimateChangeWorkshop>

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GAP MODELS

GETTING STARTED

1 – Model Class	
Gap Models	

2 – Model Name	
FORCLIM stand model, FOREL (landscape model based on FORCLIM)	
Other models developed in this class: JABOWA, LINKAGES, ZELIG, FORSKA, GUESS	

3 – Interviewee	
Name	Richard Busing
Affiliation	USGS
Phone	541-757-0982
Email	rtbusing@aol.com

4 – Key Model Literature	
Concepts	Botkin et al. 1972; Shugart 1984
Methodology & Technical	Botkin 1993; Bugmann 2001
Application to management or ecosystem	Aber et al. 1982; Busing & Garman 2002; Busing et al. 2007
Current and Future Climate	Shugart & Smith 1996; Price & Apps 1996; Bugmann & Solomon 2000

5 – Class View	
Model Objective	To simulate the gap dynamics and stand dynamics of forests.
What are the key concepts of the model class?	<p>Gap models are individual-based models that simulate interactions and dynamics on a small, gap-sized patch of land. Ingrowth, growth and death of individuals of one or more species on the patch are simulated.</p> <p>Such models can simulate patch, stand and landscape dynamics. Some dynamic global vegetation models rely on the gap model framework.</p> <p>Gap models can provide species and ecosystem dynamics information for management and conservation assessments.</p> <p>The climate variables often used in gap models include the growing-degree-day sum (typically affecting species ingrowth, growth and mortality), the minimum winter temperature (typically affecting species ingrowth), and the soil moisture deficit (typically affecting species growth and mortality).</p>

<p>Key strengths & weaknesses of the model class</p>	<p>Strengths: The gap model approach has been used widely by ecologists for several decades. It relies largely on existing information about species traits. The theoretical and practical aspects of this modeling approach have been debated heavily, which has resulted in recent revisions and improvements especially in regard to climate change. The approach handles multiple species and provides information on individuals and much more. For example, forest gap models can provide information on tree bole diameters, stand composition, stand basal area, stand leaf area, stand biomass (both live and dead), NPP and detritus inputs from mortality. Gap models are well suited to forest management problems where tree population, community and ecosystem responses are of concern.</p> <p>Weaknesses: Few of these models incorporate physiological detail or consider dispersal limitations.</p>
<p>Best application examples across the class</p>	<p>Consequences of chestnut mortality in the eastern deciduous forest (Shugart & West 1977)</p> <p>Disturbance and the steady state in northern hardwood forests (Bormann & Likens 1979)</p> <p>Late Quaternary dynamics of the eastern deciduous forest (Solomon et al. 1980)</p> <p>Management effects on yield and nitrogen dynamics of northern hardwood forests (Aber et al. 1982)</p> <p>Fire disturbance and succession in a mixed-conifer forest (Kercher & Axelrod 1984)</p> <p>Potential climate change effects in Pacific coniferous forests (Dale & Franklin 1989)</p> <p>Simulation of forest vegetation patterns and dynamics within and among biogeographic regions using a simplified gap model (Bugmann & Solomon 2000)</p> <p>Merging of a gap model and a dynamic global vegetation/ecosystem model evaluated in Europe (Smith et al. 2001)</p>
<p>Compare / contrast this model class with the other classes</p>	<p>The gap model approach is well suited to multispecies dynamics of forests. It is usually assumed that species ranges are constrained by climate. Effects of changing climate and complex disturbance regimes can be assessed. However, few gap models can directly simulate the effects of ambient CO₂ levels on growth and water-use efficiency. Most gap models are point models that project forest stand dynamics under a single set of site conditions. However, landscape models with horizontal spatial heterogeneity and interactions such as dispersal have been constructed around the gap model framework.</p>

NUTS AND BOLTS

6 – General Model Information	
Lead Developer	Bugmann (FORCLIM stand model), Busing (FOREL – a similar model for stands and landscapes)
Affiliation	Bugmann (Swiss Fed. Inst. Tech., Zurich) Busing (USGS, Corvallis)

Model website	www.pik-potsdam.de/topik/t6scs/safe/home/forclim.html
How to Get the Model	Bugmann or Busing
Computing Requirements	MAC, UNIX or MS WINDOWS (FORCLIM model code is available in MODULA 2, C and C#; FOREL model code is in FORTRAN)
Documentation & User Guides	FORCLIM: version 2.9 Users guide (by H. Bugmann) FOREL: model description (USGS SIR 2007-5040 by R. Busing)
Support Options	Consult developers
Required Third Party Software	FORCLIM: C compiler is helpful FOREL: FORTRAN compiler is helpful for
Number of People Able to Run the Model	>50
Person-Days Required to Configure First Run	<5 (using existing input files)
Typical Model Run Duration	<1 hr execution time
Ease of Gaming	Moderate
How has the model been validated? At what scales?	Natural vegetation patterns Plot survey data Time series and chronosequences (see Bugmann 2001)
Additional data needed to run the model	Species pool and parameters, mean monthly temperature and precipitation of the site, soil depth of the site, water holding capacity of the site, site latitude, and slope aspect of the site are required. A climate change regime can be input. Disturbance frequencies can be input.

7 – Model Scope	
Geographic Locale(s)	Different biogeographic provinces require different species pools to be input. The FORCLIM model does not need to be altered when moved to a different location.
Spatial Scale	A forest patch ca. 0.01-0.1 ha A biogeographic province (simulated by FORCLIM as a set of many grid points).
Smallest Temporal Scale	1 yr – 15,000+ yr
Vegetation Resolution	Individual trees

8 – Input & Output	
Input File Format	Text file (space delimited)
Output File Format	Text file (space delimited)
Key output variables	Density, basal area, biomass, leaf area index by species and by stand. Information on each live tree is also available (e.g., species & dbh).

MODEL CONCEPTS

9 – Model Components	
What are the key processes? How are they modeled?	Patch processes are modeled annually. Ingrowth is based on suitable conditions (e.g., temperature) for each species. Competition for light is based on relative heights of trees and species tolerance to shade. Tree growth is reduced primarily by suboptimal light, suboptimal temperatures and suboptimal soil moisture for the species. When growth is reduced to less than 10% of the optimum for 2 consecutive years, the tree has a greater chance of mortality.
What are the key processes excluded from the model?	Ecophysiological detail such as the direct effects of ambient CO ₂ levels on tree growth and water-use efficiency is typically lacking. Dispersal limitations are often lacking. Water inputs from summer fog and summer snowmelt are usually ignored.
What does this model do best?	The dynamics of stand composition, basal area, and biomass over the long-term (>50 yr).
Where is the model weakest, have the most caveats, or is most in need of strengthening?	The internal structure of forest stands is often inaccurate (e.g., size-class distributions). The dynamics of young stands (<50 yr) is often inaccurate. This can be improved, however, with careful attention to rates of ingrowth, growth and mortality.
Discuss case(s) where the model produced important results that were initially surprising but later shown to be correct	According to Botkin (1993), gap model results contradicted “classic static stability” theory (e.g., the climax forest concept). The non-equilibrium approach of gap models supported the existence of a shifting-mosaic steady-state instead. The idea that late-successional (or climax) forests had maximal basal area and biomass was also contradicted by gap models that projected maximal levels in the 1 st or 2 nd century of successional development.
Has model behavior been compared with results of other models at the same location? How do they compare?	Yes, such comparisons have been made. A good example in North American systems is presented by Bugmann et al. 2001. Differences among models were attributed largely to contrasts in their water balance considerations.
What conditions or parameters is the model most	Simulated forests are sensitive to cooling climate and to drying climate (FORCLIM version 2.9).

sensitive to	
Discuss how the model incorporates natural variability and uncertainty about the future	The FORCLIM model accepts various climate scenarios as input files of climatic regime data or time series climate data. Alternative inputs can be used to obtain a range of outcomes. FORCLIM version 2.9 has fixed formulations, but they can be altered with the aid of a computer programmer. This would allow testing of various assumptions regarding tree responses to new climates. The FOREL stand and landscape model is designed to facilitate testing of such assumptions as well as effects of landscape-level characteristics (e.g., dispersal limitation, complex topography, spatial structure of the forested landscape).

10 – Use For Management

How is the model currently used by land managers?	Indirectly, through reports and papers.
Can management actions be simulated?	Harvesting, site preparation, managed fire, C-accounting, N fertilization and more.
How are model results communicated?	Through reports and papers.
Best examples of decisions that incorporate model results	Forestry practices to accelerate stand development to old-growth structure in Oregon (Garman et al. 2003).

11 – Linkage to Climate

What processes are included in the model that respond to temperature and precipitation?	Tree ingrowth can be limited by temperature (e.g., low degree-day sum or by winter temperature). Tree growth can be limited by low temperature and by low soil moisture. Decomposition is affected by AET.
What spatial and temporal climate scale is used?	As small as 0.05 ha. Monthly climate data are input. The simulated climate and forest data output interval is as small as 1 yr.
Does the model respond directly or indirectly to changes in CO ₂	CO ₂ effects are indirect in FORCLIM.
Where does the model express the most sensitivity to climate?	Through tree ingrowth, growth and death. Ingrowth and growth patterns respond relatively rapidly.

How does the model respond to novel climates?	It appears to do well in terms of community composition, stand basal area and biomass.
Is micro-climate (below smallest scale) accounted for?	Slope aspect and site soil characteristics are considered.
Are disturbances modeled? Are they influenced by any climate variables?	Both complete and partial-stand disturbances can be simulated. For example, regimes with severe and light fires can be simulated in a new version of FORCLIM used in the western U.S. A fire routine that includes climate effects has been developed.

12 – References

PDF versions of most references are found in the appropriate subdirectory at:

<ftp://ftp.essa.com/pub/essa/VegetationModelsClimateChangeWorkshop>

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LANDSCAPE SIMULATION MODELS

GETTING STARTED

1 – Model Class	
Landscape Simulation Models	

2 – Model Name	
LANDSUM	
Over 100 others are available	

3 – Interviewee	
Name	Bob Keane
Affiliation	RMRS USDA Forest Service
Phone	406-329-4846
Email	rkeane@fs.fed.us

4 – Key Model Literature	
Concepts	(Baker 1989, Keane et al. 2004, Mladenoff 2004)
Methodology & Technical	(Gardner et al. 1999, Agarwal et al. 2002)
Application to Management Or specific ecosystem	(Keane et al. 2007)
Current and Future Climate	(Gardner et al. 1996, Aber et al. 2001, Cushman et al. 2007)

5 – Class View	
Model Objective	Simulate the dynamic interactions of vegetation, disturbance, and climate in a spatial domain
What are the key concepts of the model class	Spatially explicit, dynamic interactions between modeled entities, simulation of spatial process, long simulation times with short simulation time steps
Key strengths & weaknesses of the model class	<p>Strengths: Models simulate important ecosystem elements in an integrated and dynamic platform. They include multiple scales of space and time, increased realism in ecological dynamics, and are most germane to management applications.</p> <p>Weaknesses: Models are generally complex, difficult to parameterize and initialize, dependent on the number and detail of the ecological processes included in the model and tend to be application specific.</p>
Best application	Computing HRV (Keane et al. 2007)

examples across the class	Comparing alternative management scenarios Ensemble comparison (Cary et al. 2006)
Compare/contrast this model class with the other classes	Higher resolution in simulated ecological processes Implemented at a scale most germane to land management Able to integrate multiple disturbance interactions

NUTS AND BOLTS

6 – General Model Information	
Lead Developer	Keane
Affiliation	RMRS US Forest Service Missoula Fire Sciences Laboratory
Model website	www.firelab.org
How to Get the Model	(Keane et al. 2006)
Computing Requirements	Any computer: code is compilable with any C++ compiler (ANSI C)
Documentation & User Guides	(Keane et al. 2006)
Support Options	None
Required Third Party Software	GIS (ARC)
Number of People Able to Run the Model	Around 20
Person-Days Required to Configure First Run	Between 10 and 30 days
Typical Model Run Duration	Overnight
Ease of Gaming	Easy
How has the model been validated? At what scales?	See (Keane et al. 2002, Keane et al. 2006) Patch distributions and vegetation composition of simulated landscapes have been compared
Additional data needed to run the model	Data layers: DEM, Potential Vegetation Type, Existing Vegetation type Simulation parameters: pathway models, fire frequency probabilities,

7 – Model Scope	
Geographic Locale(s)	Works everywhere if parameterized correctly

Spatial Scale	30 m Pixel size – 300 m pixel size
Temporal Scale	1 year - 10,000 years
Vegetation Resolution	Vegetation type-structural stage-potential vegetation type combination

8 – Input & Output	
Input file format	ARC-GRID-ASCII maps, eight space delimited summary files
Output file format	ARC-GRID-ASCII maps, eight space delimited summary files
Key output variables	Fire size, landscape composition, disturbance type.

MODEL CONCEPTS

9 – Model Components	
What are the key processes? how are they modeled?	Succession: state and transition pathway models Fire: initiation – stochastic based on probability distribution Spread – cell automata Effects – rulebase and stochastic
What are the key processes excluded from the model?	Interactions with climate
What does this model do best?	Provides a means to simulate landscape dynamics with the most parsimonious set of input values
Where is the model weakest, have the most caveats, or is most in need of strengthening?	Inability to simulate complex interactions of climate, disturbance, and vegetation.
Discuss case(s) where the model produced important results that were initially surprising but later shown to be correct	LANDSUM predicted historical landscapes had limited areas of oldgrowth in many montane forests Model showed that the simulation environment can significantly impact simulation results (Keane and Karau 2007)

Has model behavior been compared with results of other models at the same location? How do they compare?	LANDSUM was included in a model comparison exercise with five other models to determine the importance of fire in landscape simulations. Although LANDSUM was significantly less complex and less detailed than the other models, simulated results were roughly the same (Cary et al. 2006)
What conditions or parameters is the model most sensitive to?	Fire frequency parameters, landscape size (extent), fire size distribution
Discuss how the model incorporates natural variability and uncertainty about the future	It does not do this directly, however, through modification of the initial conditions, specifically the PVT map, future conditions can be modeled under the same context as the past (see (Keane et al. 2008[in press])

10 – Use For Management

How is the model currently used by land managers?	Currently, managers do NOT run the model. We have trained people at head sheds (i.e., “centers of excellence) that will run the model for managers (see www.fs.fed.us/fmi). Currently, the model is used to quantify HRV (Keane et al. 2002, Keane et al. 2007) and comparing management alternatives (Keane et al. 1997)
Can management actions be simulated?	Yes, but only at the polygon level and actions can not be scheduled, only simulated
How are model results communicated?	GIS maps, graphs, and tables
Best examples of decisions that incorporate model results	The most comprehensive application of LANDSUM is in the LANDFIRE project to compute FRCC (Keane and Rollins 2006, Keane et al. 2007)

11 – Linkage to Climate

What processes are included in the model that respond to temperature and precipitation?	Only fire size and initiation
What spatial and temporal climate scale is used?	Non-spatial

Does the model respond directly or indirectly to changes in CO ₂	No
Where does the model express the most sensitivity to climate?	Only in the initialization process
How does the model respond to novel climates (no precedent)?	It does not directly, but it can indirectly via changes in initial conditions
Is micro-climate (below smallest scale) accounted for? If so, how? If not, why not?	No, insufficient resolution in modeled entities
Are disturbances modeled? Are they influenced by any climate variables?	Yes, all disturbances are modeled if included in the input parameters but only wildland fire is linked to climate

12 – References

PDF versions of most references are found in the appropriate subdirectory at:

<ftp://ftp.essa.com/pub/essa/VegetationModelsClimateChangeWorkshop>

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BIOGEOCHEMICAL MODELS

GETTING STARTED

1 – Model Class	
Biogeochemical Models	

2 – Model Name	
CENTURY & DAYCENT – monthly and daily versions	
Others: TEM (Melillo), BIOME-BGC (Running), DNDC (ecosystem model for trace gas fluxes); EPIC (similar to DNDC; for erosion/productivity)	

3 – Interviewee	
Name	Bill Parton
Affiliation	CSU, Natural Resource Ecology Laboratory
Phone	970-491-1987
Email	billp@nrel.colostate.edu

4 – Key Model Literature	
Concepts	Parton et al. 2001 – Generalized model description
Methodology & Technical	Parton et al. 2001
Application to Management Or specific ecosystem	Del Grosso et al. 2005
Current and Future Climate	Parton et al. 2007

5 – Class View	
Model Objective	To faithfully model plant C cycling (including DOM, NPP), nutrient (N,P) cycles, trace gas (NO _x , N ₂ O, N ₂ , CH ₄ , NH ₄) fluxes, nitrate leaching, water and temperature dynamics Model was initially monthly (CENTURY) and is now daily for some applications (some calculations are done at a sub-daily scale)
What are the key concepts of the model class	Need all relevant submodels must be present and correct before the emergent properties are apparent, and it becomes possible to respond to climate Trace gases, N,P cycling are newer features of the model class (i.e., the last 20 yrs)
Key strengths & weaknesses of	Strength: Models capture and include N cycling and interactions of water, N cycling,

the model class	productivity, CO ₂ Weakness: As a class, the vegetation types are not very dynamic; grassland to forest might not switch automatically.
Best application examples across the class , with references	Del Grosso et al. 2005 – analysis of past and contemporary C cycling in grassland and pastures systems.
Compare/contrast this model class with the other 4 classes we are studying	Statistical Species Distribution – some issues with these are the transition questions: how long do changes take; what about novel ecosystems with no analog?; uncertainty about the role of CO ₂ ; with reduced water stress; there may be higher productivity and new combinations of grass/trees possible Gap – these models include C balance and water but generally don't have much N-cycle; some gap models are fully biogeochemical; their strength is inferring change in vegetation after disturbance Landscape – biogeochemical models often now work at this scale; landscape models may not include advanced processes DGV - large scale models don't have N-cycling, which is important for controlling productivity; if the DGVM vegetation type is wrong, then lots more can go wrong

NUTS AND BOLTS

6 – General Model Information	
Lead Developer	Bill Parton
Affiliation	CSU, Natural Resource Ecology Laboratory
Model website	http://www.nrel.colostate.edu/projects/century/
How to Get the Model	Model is given away (both as compiled and source code); the monthly version has many hundreds of users, and is easier to use;
Computing Requirements	PCs, Linux
Documentation & User Guides	Yes, for both (see website: CENTURY 4, CENTURY 5)
Support Options	DAYCENT – training sessions 2x/yr - 1 wk, \$500-\$1000; access to more individual support; a user community exists.
Required Third Party Software	No, could use XLS or other software to study results
Number of People Able to Run the Model	100s
Person-Days Required to Configure First Run	About a week, after training

Typical Model Run Duration	Seconds for monthly version; 10 minutes/run for daily version
Ease of Gaming	Lots of abilities here, events and actions can be scheduled Model comes with a library of plants that can grow and disturbances events that can be set up Users can develop their own libraries
How has the model been validated; at what scales	Mostly at site level; observed data sets for NO _x model Core validation data sets used regularly DAYCENT generates N ₂ O in US every year (Del Grasso et al. 2005) Model behavior rechecked when a change is made Weather and soil texture parameters change across scales; model needs to be provided with values that are appropriate to the scale being used
Additional data needed to run the model	Monthly or daily met (min/max air, precipitation); soil texture

7 – Model Scope

Geographic Locale(s)	Common code; parameterized for species e.g., one corn variety for US; but really there are different varieties at regional scale, and the model could accommodate those, if known
Smallest Spatial Scale	Plot or site
Smallest Temporal Scale	Daily (sub-daily for some numerical calculations)
Largest Spatial Scale	Continental, Global
Largest Temporal Scale	25 years typical
Vegetation Resolution	CENTURY – multiple vegetation types; but not as detailed as DGVMs; an underlying savanna paradigm is assumed, comprising grass and trees; grasses can be C3 and/or C4, but can represent species and shrubs (as small trees).

8 – Input & Output

Input File or Database Format(s)	Text files
Output File or Database Format(s)	Binary file for output at daily; can then be searched (their software) to filter Moving toward databases for big problems (regional assessments)
Key output variables	Soil C, plant C, all fluxes: N,P, NO ₃ leaching, trace gases, water (1-D mostly)

MODEL CONCEPTS

9 – Model Components	
What are the key processes; how are they modeled	Emphasis on plant production, nutrient mineralization, trace gases, N trace gases, water balance, soil temperature over time (all as a function of air temp and precipitation) Monthly and daily model are similar, but equations simplified at the monthly scale
What are the key processes excluded from the model	Direct plant competition between trees and grasses; Tree species (or groups) are not included Not modeling species change over time; main goal is biogeochemical dynamics
What does this model do best	good at trace gases, N ₂ O targeted good at water balance, C dynamics plant production
Where is the model weakest; have the most caveats; most in need of strengthening	Predicting interaction of environmental change, CO ₂ , N, water; all components are “in” most models, but <i>interactions</i> (relevant to between-model comparisons) differ; assumptions differ and the data are imprecise. For example, N could be as important as rooting depth and WUE (DGVMs). This is a valid theory but the question not settled: the CO ₂ effect is uncertain; appears to be true in grasslands but less certain in trees (conifer stomata are less sensitive, compared to grasses)
Discuss case(s) where the model produced important results that were initially surprising but later shown to be correct	In studies of biofuel impacts there is a common belief that if you plough lands that have reverted to natural (e.g., abandoned farmland) it would result in a C would decline. Actually it increases. This result can be shown in simulations where soil C increases thru increase in C inputs. Once you put it all together, it can make sense eventually
Has model behavior been compared with results of other models at the same location? How do they compare?	VEMAP with monthly (VEMAP 1995) In new work: climate change monthly model coupled to Century daily model (McMurtry) Models agree under current conditions (as expected), future is uncertain The interactions among drivers are the main uncertainty
What conditions or parameters is the model most sensitive to	Soil texture is a key variable (fine scale erosion/deposition not represented) Nutrient inputs temperature and water
Discuss how the model incorporates natural variability and uncertainty about the future	Depends on disturbances and events used in the model scenario

10 – Use For Management	
How is the model currently used by land managers	Mostly in agricultural policy sector, daily or monthly versions GHG reductions Works more at policy level than the individual farm There are some web tools for farm (simple Century, see web) Have also worked in Canadian forests (CFS), but not as much
Can management actions be simulated	Yes, through the scenario and plant species and disturbance libraries
How are model results communicated	Plenty of publications, web help and information and web tools
Best examples of decisions that incorporate model results	Adler et al. 2007 – a GHG assessment for all major cropping systems.

11 – Linkage to Climate	
What processes are included in the model that respond to temperature and precipitation	Min/max air, CO ₂ , precipitation
What spatial and temporal climate scale is used	5km datasets on ground, daily met and monthly met
Does the model respond directly or indirectly to changes in CO ₂	directly
Where does the model express the most sensitivity to climate	Top two are: soil or plant water balance, life history
How does the model respond to novel climates (no precedent)	Biogeochemical models can do this This is especially a problem for DGVM (no N) and statistical (historical and equilibrium) models Locations with strong climate gradients could be more susceptible to error
Is micro-climate (below smallest scale) accounted for? If so, how? If not, why not?	Yes – LAI, biomass, water, temperature altered by the current canopy

Are disturbances modeled? Are they influenced by any climate variables?	All capable – any form of forest disturbance or burns all can be set up through libraries; CWD management
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12 – References

PDF versions of most references are found in the appropriate subdirectory at:

<ftp://ftp.essa.com/pub/essa/VegetationModelsClimateChangeWorkshop>

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DYNAMIC GLOBAL VEGETATION MODELS

GETTING STARTED

1 – Model Class

Dynamic Global Vegetation Models

2 – Model Name

MC1 (MAPSS-CENTURY); BIOMAP (MAPSS-BIOMEBCG), MAPSS (Mapped Atmosphere-Plant-Soil System)

other models developed in this class that are available: DOLY, S-DGVM (Sheffield) (Doly offshoot-Century), LPJ (Biome) (Stephen Sitch, w/ fire model), ED (Paul Moorcroft, Harvard)

3 – Interviewee

Name	Ron Neilson
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4 – Key Model Literature

Concepts	Neilson 1995, Woodward & Lomas 2004 has a good review and comparison with other models
Methodology & Technical	Neilson 1995
Application to Management Or specific ecosystem	Lenihan et al, 2007
Current and Future Climate	Daly et al. 2000, Bachelet et al. 2003

5 – Class View

Model Objective	A climatically sensitive physiologically oriented model that predicts classes of upland vegetation
What are the key concepts of the model class	MAPSS is the ancestor: current DGVMs all derive from biogeography models all DGVMs use the grass-tree (savanna) paradigm as the fundamental unit everything moves along that continuum; two rule bases: (1) physiological characteristics of plant functional types (grass, shrub, tree), and (2) physiognomic classification (e.g., needle-leaf evergreen)

	<p>the variety of ecotones (physiognomic classification) is an emergent property of these 2 components</p> <p>water balance the key driver of productivity, model calibrated to stream gauge data</p> <p>canopy is physiologically defined (photosynthesis, wilting point, LAI), e.g., shade tolerant and shade intolerant conifers vs. pines; root habits also differ, distributed across grid cells in simulation</p> <p>8 woody functional types (as in MAPSS) and 6 thermal zones = 48 + 2 grasses (C3,C4)</p> <p>recent models are more explicit about NPP and autotrophic respiration</p> <p>fire models emerging as an important feature (Sitch et al. 2003, Lenihan et al. 2007): allometric rules for fuel, climate data (monthly) for moisture and ignition, heuristics for fire behavior)</p> <p>a few functional types possible, and roughly approximate succession: use climate rules; shrubby to savanna to forest physiognomic/functional type</p>
<p>Key strengths & weaknesses of the model class</p>	<p>Strength:</p> <p>uses empirical and fundamental physiologic-physiognomic characteristics</p> <p>implements a good theoretical physiology model that works at leaf to plot scale</p> <p>Weakness:</p> <p>at coarse scale, models do not do fire spread; at landscape scale need to include fire more explicitly</p> <p>linkage to GCMs can produce odd precipitation statistics when rainfall is low, resulting in odd results</p> <p>downscaling methods can be criticized: coarse grids are offset from reality and need to be corrected/shifted</p> <p>hydrology model is 1-D and needs to be improved to provide better representation of landscape water relations</p> <p>wetland ecosystems not yet included</p> <p><i>tacticians want species, strategists want functional types; in local domain this may not be as difficult as it seems</i></p>
<p>Best application examples across the class, with references</p>	<p>MC1: Bachelet et al. 2001, Bachelet et al. 2003</p> <p>Lenihan et al. 2007 and California references on MAPSS website</p>
<p>Compare/contrast this model class with the other 4 classes we are studying</p>	<p>regression and correlative models will always have limitations in a changing (non-equilibrium) world; there is a fundamental need for models that include physiology, disturbance regimes and interactions of plant functional type</p> <p>at the limit DGVMs combine Gap models (small scale, e.g., LPG-Guess) Landscape models (large scale) and Biogeochemical models (nutrient cycles)</p> <p>DGVMs do not presume stationarity, as CE models do</p>

NUTS AND BOLTS

6 – General Model Information	
Lead Developer	Ron Neilson
Affiliation	USFS, OSU
Model website	http://www.fs.fed.us/pnw/mdr/mapss
How to Get the Model	Not really possible for MC1
Computing Requirements	Depending on problem size, can be run on a single CPU up to multi-core clusters
Documentation & User Guides	MC1: Bachelet et al. 2001 MAPSS model now at Oak Ridge; porting of MC1 in progress data and results can be downloaded need to develop web services possible Google earth applet; movies of simulated dynamics goal is for novice user to be able to do this in 3 weeks for test data from ORNL
Support Options	willing, but constrained
Required Third Party Software	NetCDF for all data management GRASS, ArcInfo for display, analysis
Number of People Able to Run the Model	Approx 10 – rarified atmosphere requires sophisticated user Sarah Shafer, USGS: LPJ-DGVM user and supporter of landscape version
Person-Days Required to Configure First Run	>90 days (input data time), based on grad student experience 60 days for initial calibration
Typical Model Run Duration	All US – 10km – 1-2 hrs for MAPSS BIOMAP DGVM– daily 3500 cells (lower 48) 3-5 hrs, 48 node cluster
Ease of Gaming	Hard – requires expertise
How has the model been validated; at what scales	A non-trivial task: most important to get biogeography right and try to verify the lower level: NPP etc. developed at 50m resolution (Bachelet et al. 2000); implemented at 8km for all of North America; ½ degree globally Woodward et al. 2004
Additional data needed to run the model	monthly precipitation, min/max temperature; sandy loam soil default, humidity for fuel moisture (MC1); (BIOMAP – respiration) CENTURY – neither humidity or respiration Model self-equilibrates for C pools, then runs on historical conditions to give present conditions.

7 – Model Scope

Geographic Locale(s)	have run from 50m to globe; the model is “general” in sense of GCM, for ecology of all upland ecosystems
Smallest Spatial Scale	50m to ½ degree 1-D model – no intrinsic spatial dimension (leaf to plot)
Smallest Temporal Scale	Month
Largest Spatial Scale	– global historical – observed climate – routinely used for paleo data; could be any time period, with data
Largest Temporal Scale	Up to the user
Vegetation Resolution	plant functional types/physiognomic types

8 – Input & Output

Input File or Database Format(s)	NetCDF is standard; GRASS, ArcInfo for display/analysis
Output File or Database Format(s)	NetCDF is standard; GRASS, ArcInfo for display/analysis
Key output variables	Hundreds; C-pools, N-pools, vegetation type, functional type, LAI, density, fire return (flux, productivity, decomposition, state variables;); monthly or annual

MODEL CONCEPTS

9 – Model Components

What are the key processes; how are they modeled	See Neilson 1995 and Point 5, above
What are the key processes excluded from the model	does not model species wetlands, peat lands are not modeled canopy is simplified
What does this model do best	vegetation moves based on first principles includes biogeochemical cycles does drought and fire disturbance emergent properties driven by empirical physiological relationships
Where is the model weakest; have the most caveats; most in need of strengthening	weaknesses of the class are vegetation regeneration: seedling and dispersal hydrology is non-spatial evapotranspiration could be improved

	include ozone, wetlands, peat lands canopy made more realistic
Discuss case(s) where the model produced important results that were initially surprising but later shown to be correct	MAPSS: successfully predicted vegetation classes in South America, before they were verified in the field (<i>Austrocedrus</i> in a evergreen needle leaf savanna) MC1: predicted extreme fire hazard in Yellowstone NP (1988) due to the emergent properties of its sub-models; correctly predicts the behaviour of the Prairie Peninsula (interaction between savanna/forest and role of water and disturbance in maintaining prairie)
Has model behavior been compared with results of other models at the same location? How do they compare?	Phase 1: VEMAP (1995) compared biogeography and biogeochemistry; Phase 2: DGVM (MC1/LPJ) over all US (Bachelet) VINCERA (DGVM comparison) - David Price - Apples & oranges issues: could compare runoff, LAI (not published) Have tried some comparisons with Iverson Okanongan/Wenatchee NF “model shoot out”: Statistical (envelope) model: no CO ₂ effects: climate change causes ecotone to move <i>up</i> slope DGVM with CO ₂ effects sends ecotone <i>down</i> slope.
What conditions or parameters is the model most sensitive to	water cycle very important, evapotranspiration, WUE and CO ₂ relationship
Discuss how the model incorporates natural variability and uncertainty about the future	Scenario analyses future climate scenarios have a metaphor of variability; e.g 11 yr sunspot (small forcing from energy change, possible ionosphere and ozone dynamics), 5 yr ENSO, 35yr inter-decadal

10 – Use For Management	
How is the model currently used by land managers	Can be accessed through white and grey literature MAPSS website Monthly fire hazard predictions building infrastructure for tech transfer (ORNL) increasingly asked to consult in forest plans directly
Can management actions be simulated	fire disturbance, repression harvesting or grazing could CENTURY agriculture could be incorporated
How are model results communicated	Can be accessed through white and grey literature MAPSS website Monthly fire hazard predictions: http://www.fs.fed.us/pnw/mdr/mapss/fireforecasts building infrastructure for tech transfer (ORNL) increasingly asked to consult in forest plans directly
Best examples	Monthly fire hazard predictions:

of decisions that incorporate model results	http://www.fs.fed.us/pnw/mdr/mapss/fireforecasts
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11 – Linkage to Climate

What processes are included in the model that respond to temperature and precipitation	everything!
What spatial and temporal climate scale is used	50 m to globe, 1-D, one month: no cell-to-cell for water, fire or propagules
Does the model respond directly or indirectly to changes in CO ₂	yes, physiological
Where does the model express the most sensitivity to climate	water balance is key
How does the model respond to novel climates (no precedent)	guaranteed to predict a physiognomic community consisting of variable mixture of plant functional types
Is micro-climate (below smallest scale) accounted for? If so, how? If not, why not?	No at the landscape, slope/aspect below the grid-cell scale will not be seen equations will include process if the scale is small enough, e.g., at 30m resolution in watershed will have different value on N-facing slope, inferred in canopy biophysics and fire (fuel moisture)
Are disturbances modeled? Are they influenced by any climate variables?	yes, fire and drought insect models are being built

12 – References

<p>PDF versions of most references are found in the appropriate subdirectory at:</p> <p>ftp://ftp.essa.com/pub/essa/VegetationModelsClimateChangeWorkshop</p> <p>Bachelet, D., Neilson, R.P., Hickler, T., Drapek, R.J., Lenihan, J.M., Sykes, M.T., Smith, B., Sitch, S. and K. Thonicke. 2003. Simulating past and future dynamics of natural ecosystems in the United States. <i>Global Biogeochemical Cycles</i> 17:14-1-14-21.</p> <p>Bachelet, D., Lenihan, J.M., Daly, C., Neilson, R.P., Ojima, D.S. and Parton, W.J. 2001. MC1: A dynamic vegetation model for estimating the distribution of vegetation and</p>

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Appendix B – Workshop Participants

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Appendix C – Workshop Agenda

Wednesday, January 23rd

8:00	Welcome & Introduction	Jerry Beatty, Director WWETAC Tony Tooke
8:20	Goals and Relevance	Linda Joyce
8:30	Around the room - introductions, issues	
9:15	Statistical Species Distribution Models Presentation (30) Application (20) Q&A (10)	Louis Iverson Jim Thorne
10:15	Break	
10:30	Breakout Groups	
11:15	Lunch	
12:35	Gap Models Presentation (30) Application (20) Q&A (10) Breakout Groups (45)	Rick Busing David Price
2:20	Break	
2:40	Landscape Models Presentation (30) Application (20) Q&A (10) Breakout Groups (45)	Bob Keane Miles Hemstrom
4:25	Wrap & Summary of Breakouts	
5:00		

Thursday, January 24th

8:00	Overview of Day	
8:15	Biogeochemical Models Presentation (30) Application (20) Q&A (10) Breakout Groups (45)	Bill Parton Linda Joyce
10:00	Break	
10:20	Dynamic Global Vegetation Models Presentation (30) Application (20) Q&A (10) Breakout Groups (45)	Ron Neilson Dominique Bachelet
12:05	Lunch	
1:25	Synthesis of Breakouts	
2:15	Lunch	
2:35	Discussion - emergent themes - short course outline - next steps	
4:00		