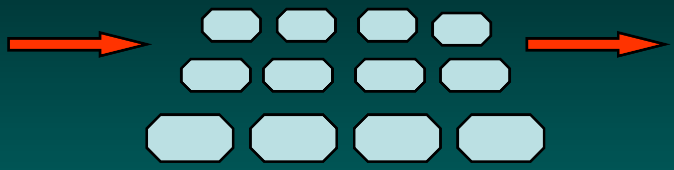
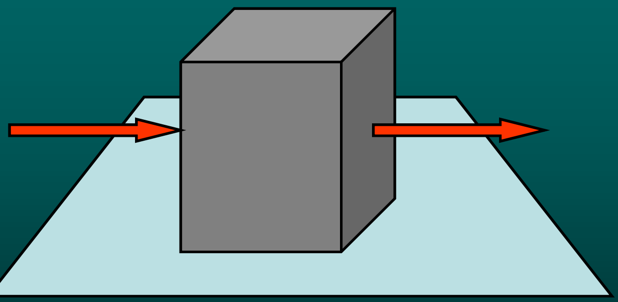
Ecosystem Models

H.H. Shugart,
Ralph Dubayah,
George Hurrt and
Sassan Saatchi

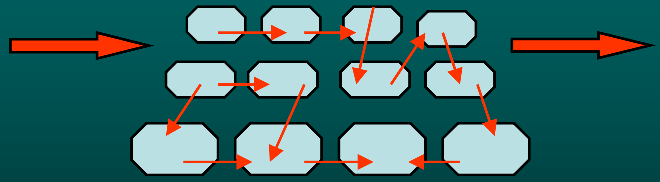
Landscapes as represented in different types of landscape simulators.



Mosaic Landscape Models



Homogeneous Landscape Models



Interactive Mosaic Models

Material Flow Models

Canopy Process Models

Farquar *et al.* Model

Dynamic Global Vegetation Models or

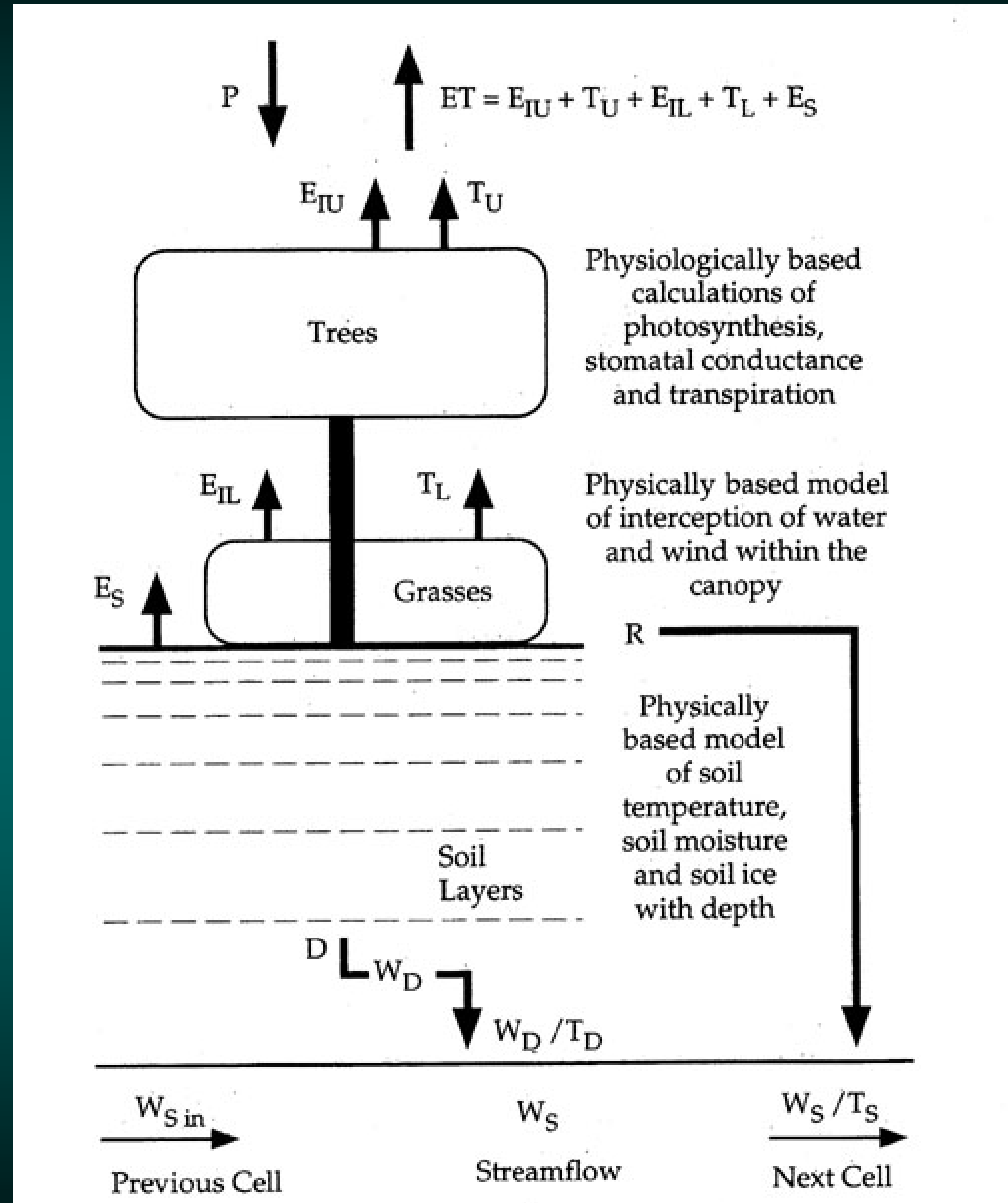
DGVM's

Biogeographic Approaches

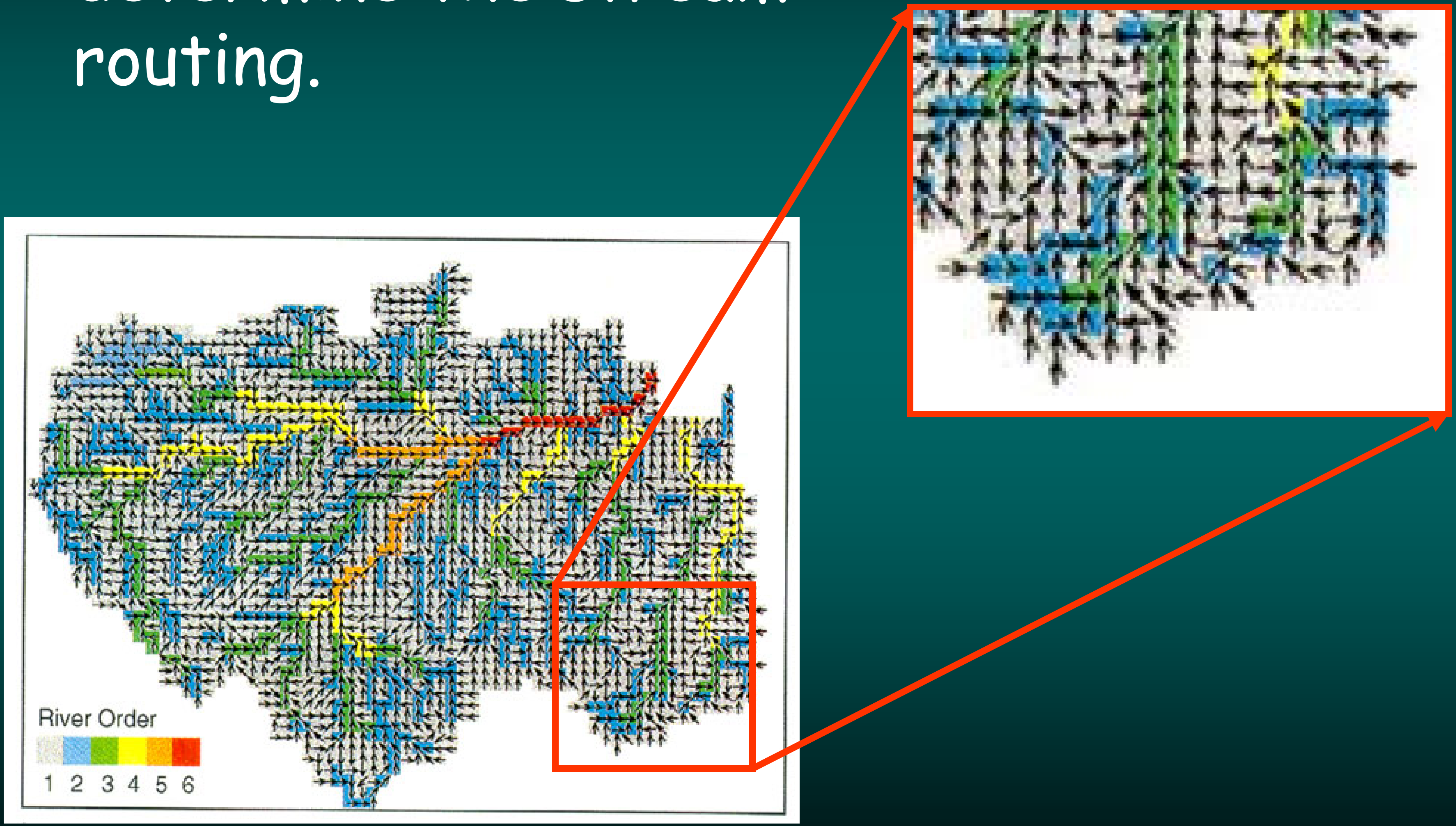
An Example: The IBIS Model

Canopy Process Models

Material Flow Models



Using a terrain map of the Amazon Basin determine the stream routing.



Biogeographic Approaches

Material Flow Models

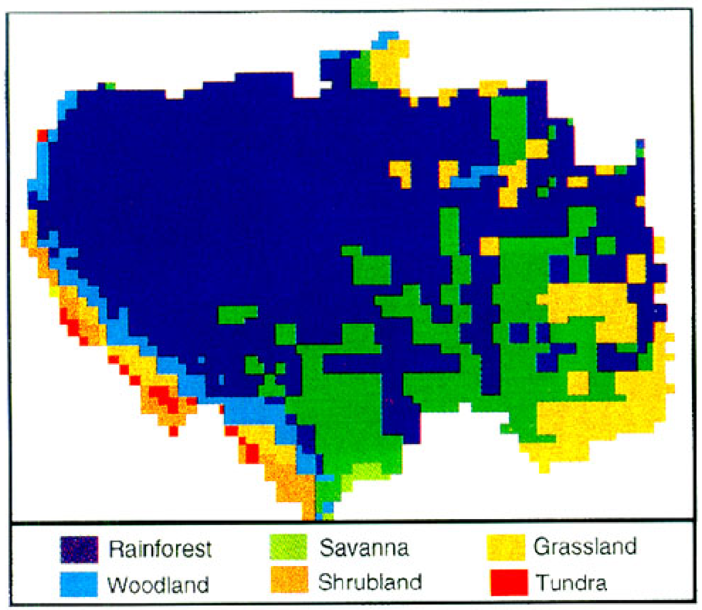


Plate 3. Vegetation cover of the Amazon Basin. The geographic distribution of vegetation types is specified from the *Olson et al.* [1985] database, where we simplify the Olson types into several general categories: forest, woodland, savanna, shrubland, grassland, and tundra.

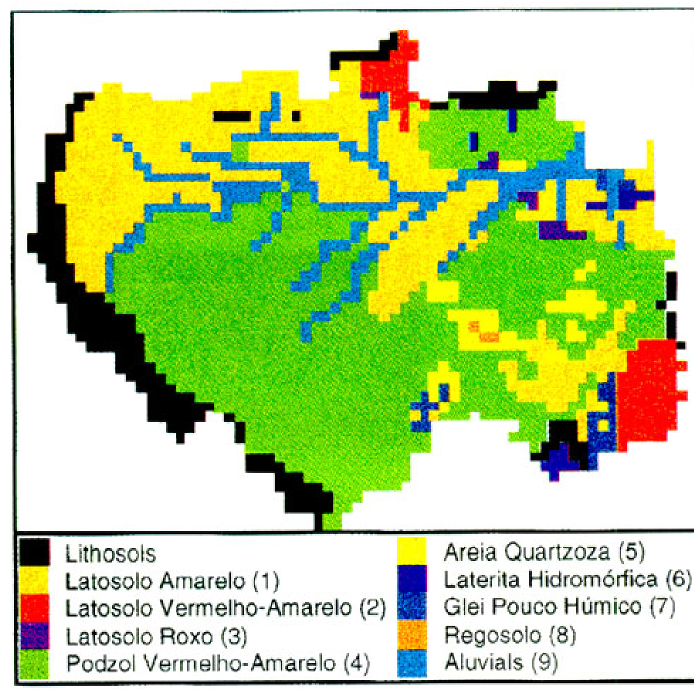


Plate 4. Schematic soil map of the Amazon Basin, as represented on a 0.5° latitude by 0.5° longitude grid (adapted from *Vieira* [1975]).

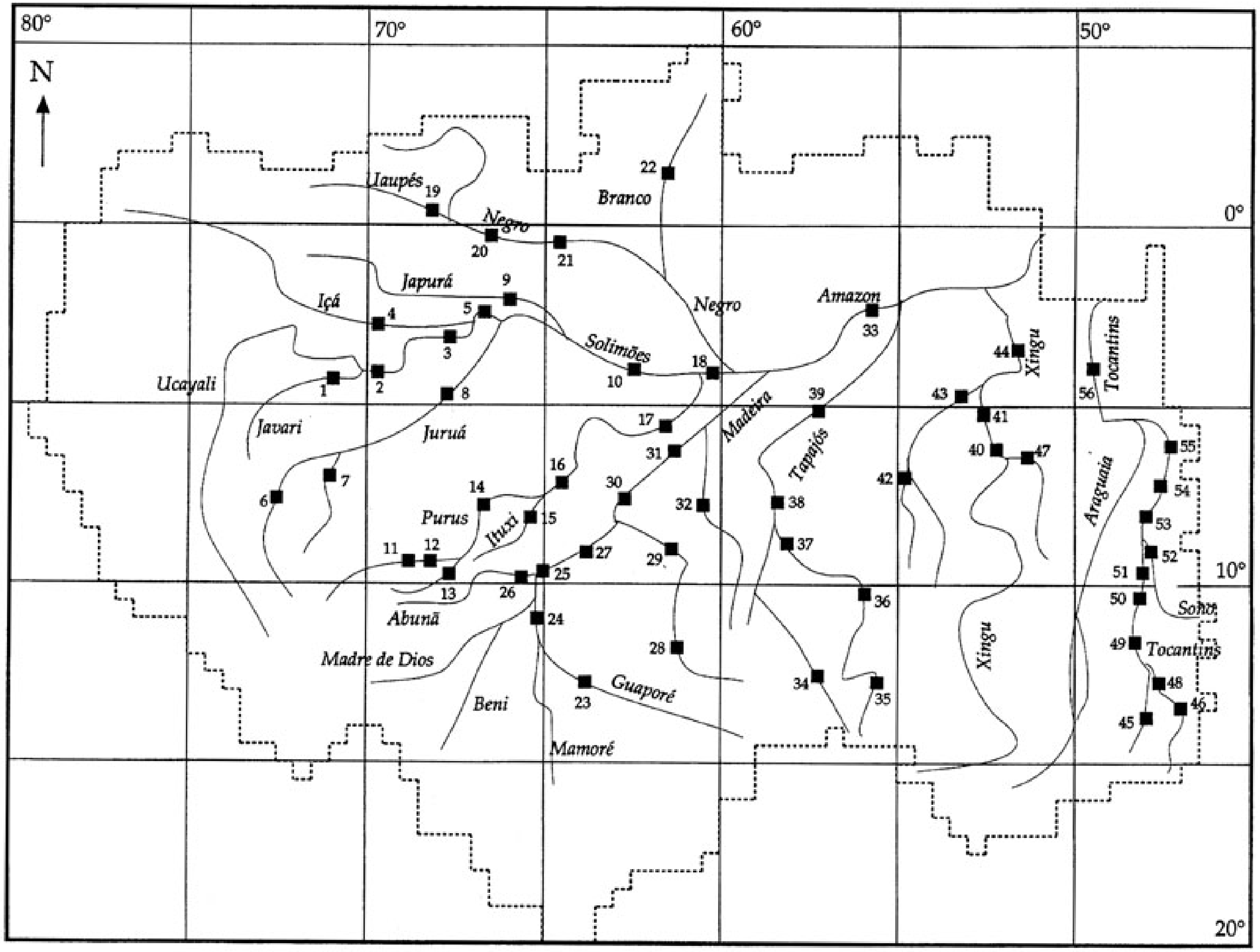
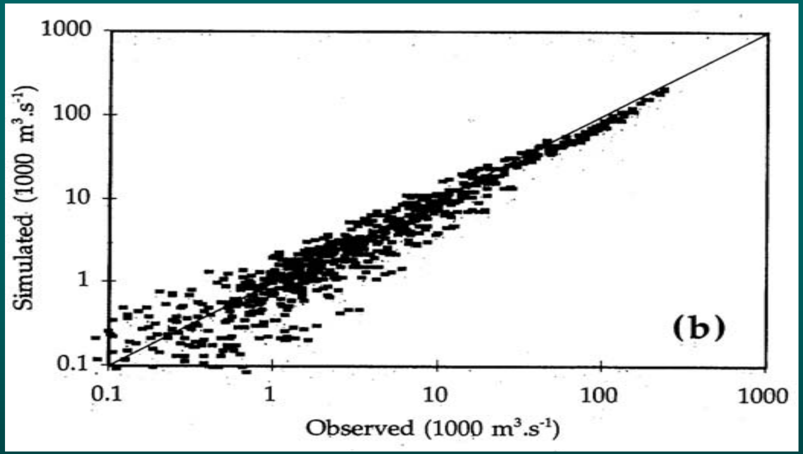


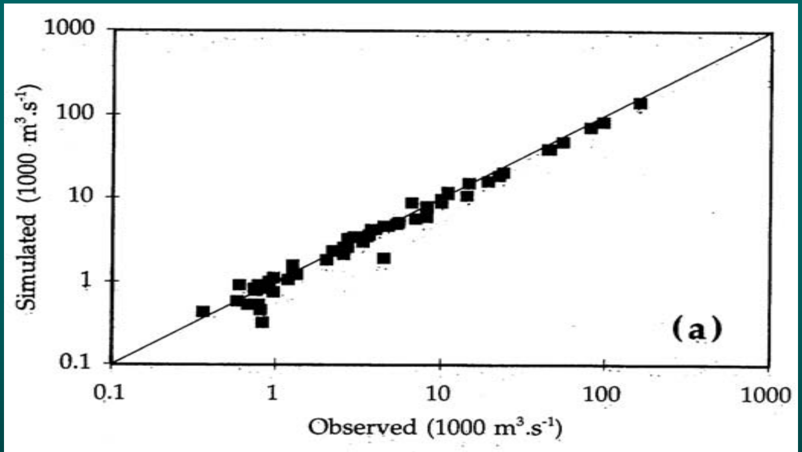
Figure 2. Location of fluviometric stations in the Amazon Basin. In this study, we utilize a network of 56 fluviometric stations provided by the DNAEE (Brazilian National Department of Water and Electrical Energy).

Test for Prediction of Runoff from the Amazon Basin

Monthly



Annual



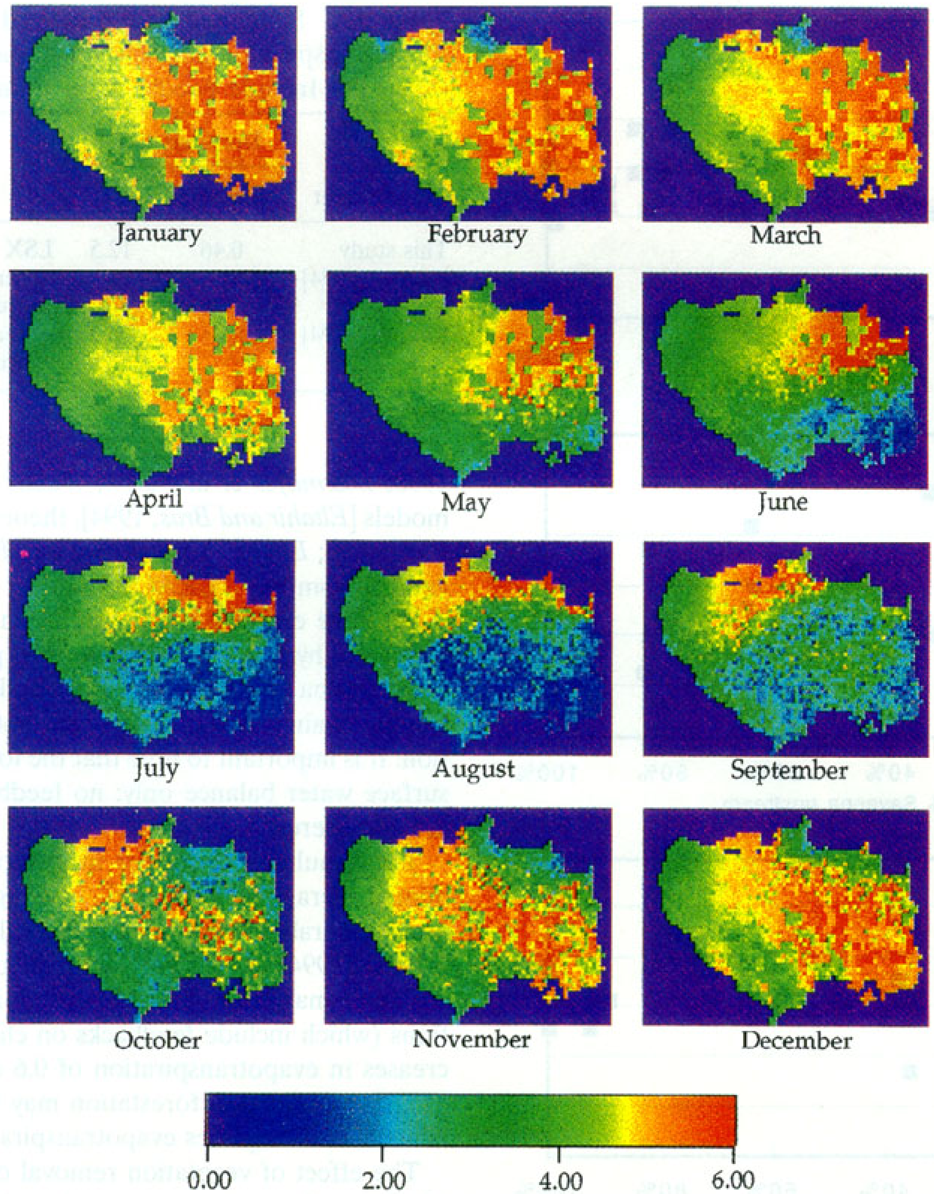
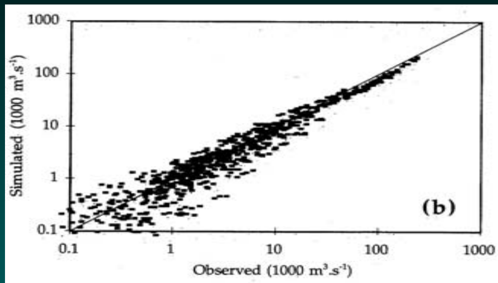
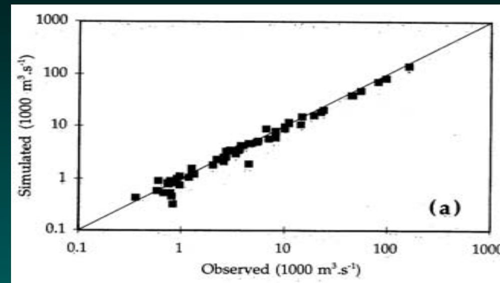


Plate 5. Simulated monthly mean evapotranspiration rates (mm d^{-1}) over the Amazon Basin.

Model Testing





Application

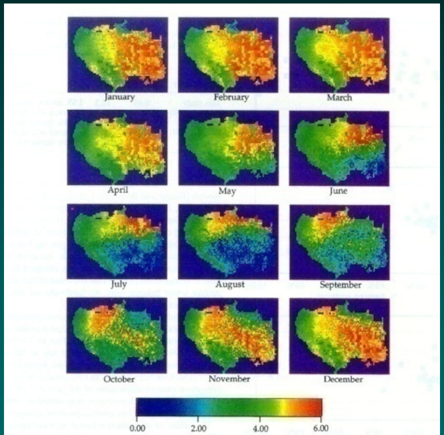


Plate 5. Simulated monthly mean evapotranspiration rates (mm d^{-1}) over the Amazon Basin.

Global Change Prediction

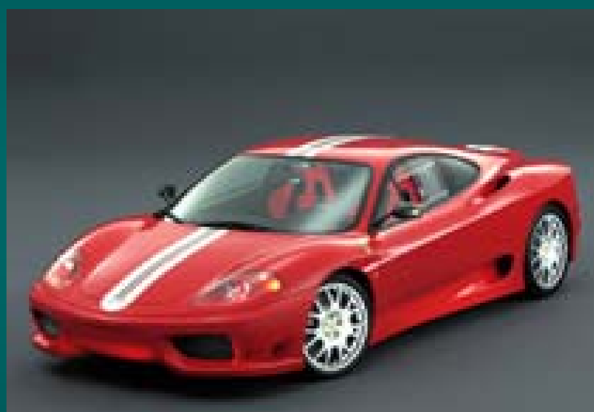
Table 15. Annual-Mean Evapotranspiration by Vegetation Cover Simulated at 325 and 650 ppmv CO_2

Vegetation Cover	Evapotranspiration at 325 ppmv, mm d^{-1}	Evapotranspiration at 650 ppmv, mm d^{-1}	Change in Evapotranspiration	
			mm d^{-1}	%
Rainforest	4.18	3.99	−0.19	−4.5
Savanna	3.62	3.49	−0.13	−3.8
Grasslands	3.54	3.45	−0.09	−2.8
Basin	3.66	3.51	−0.15	−4.1

Dynamic Global Vegetation Models or

DGVM's

The Ideal



The Prototype

One important step in improving our models of global ecosystem dynamics is to incorporate the effects of structure.

Of course, the importance of structure to predict the amount of wood in a forest has been known for generations of foresters.

This inspires a brief discussion of height and structure as a variable to predict biomass

Mature spruce forest in Winterthur, Switzerland, undated.

Traditional "German" Forestry

I'm a lumberjack
and I'm OK …

Eidg. Anstalt für das forstliche Versuchswesen
Institut fédéral de [illegible]ches forestières

FICHTE

Ertragstafel für hochdurchforstete, gleichförmige Reinbestände
14 m Oberhöhe im 50. Jahr

EPICEA

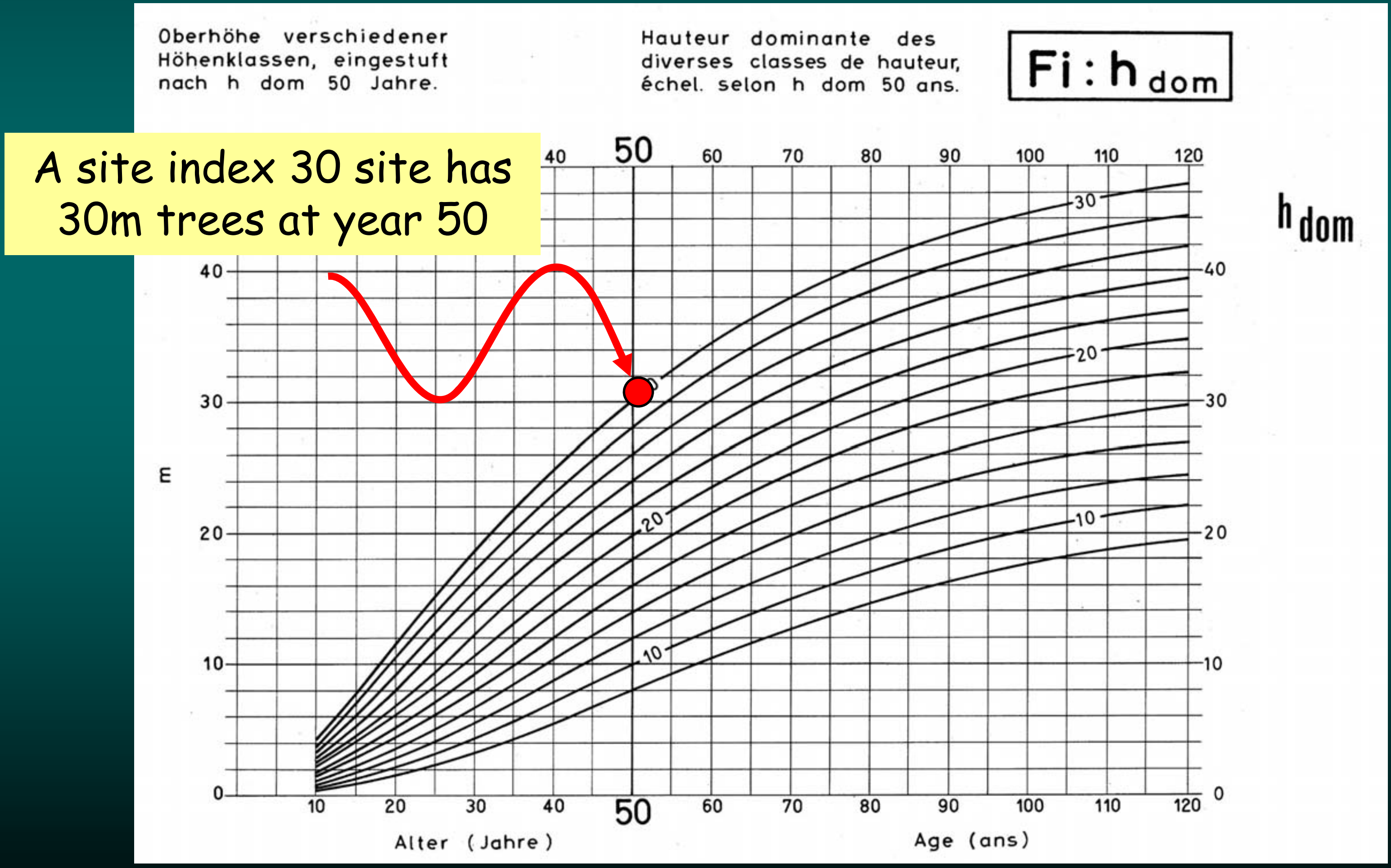
Table de production pour des peuplements purs et uniformes éclaircis par le haut
14 m de haut. dom. à 50 ans

ET

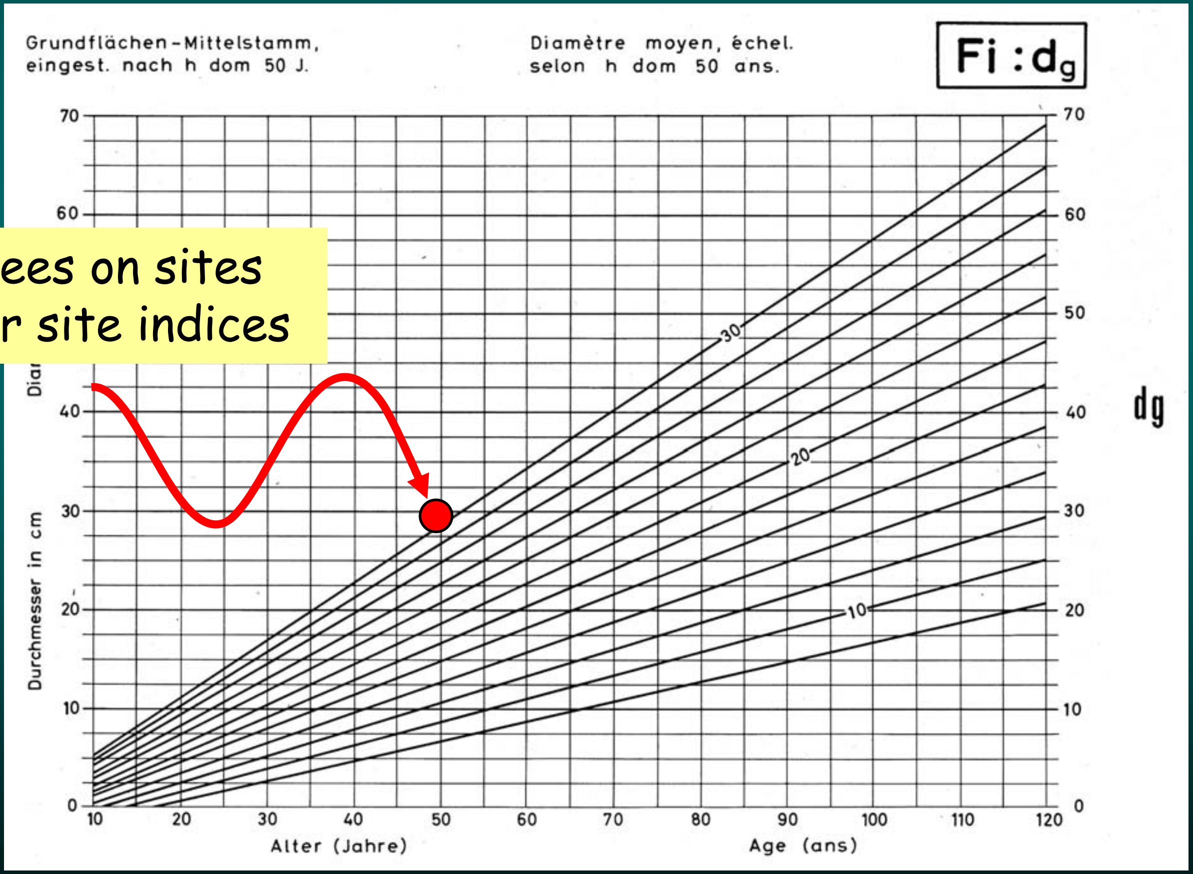
Alter Age	Verbleibender Bestand / Peuplement restant sur pied: Stammzahl Nombre de tiges	Ober- (Mittel-) Höhe / Hauteur dominante (moyenne)	Basalfläche Surface terrière	Mitteldurchmesser Diamètre moyen	Vorrat Derbholz Matériel bois fort	Ausscheidender Bestand / Eclaircie: Stammzahl Nombre de tiges	Mittelhöhe h_L Hauteur moyenne h_L	Basalfläche Surface terrière	Mitteldurchmesser Diamètre moyen	Derbholzmasse Volume bois fort	Laufend jährlicher Zuwachs / Accroissement courant annuel: Basalfläche Surface terrière	Derbholzmasse Volume bois fort	Gesamtleistung an Derbholz / Production totale de bois fort	Hievon Vornutzungen / Production prise en éclaircie	Altersdurchschnitts-Zuwachs / Accroissement moyen annuel depuis l'origine: Verbleibender Bestand / Peuplement restant	Total Total	Alter Age
Jahre Ans	n	m	m²	cm	m³	n	m	m²	cm	m³	m²	m³	m³	%	m³ Derbholz / m³ bois fort		Jahre Ans
20																	20
30																	30
40	2'94[illegible]	10,[illegible] (6,[illegible])	2[illegible]	[illegible]5	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4,7	4[illegible]	–	1,2	1,2	40
50	1'1[illegible]	14,[illegible] (9,[illegible])	2[illegible],5	1[illegible],5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	1'[illegible]5[illegible]	17,[illegible] (12,[illegible])	2[illegible],6	1[illegible],[illegible]	169	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
70	1'[illegible]0[illegible]	19,[illegible] (15,[illegible])	2[illegible],2	1[illegible],[illegible]	218	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80	[illegible]7[illegible]	[illegible]1,[illegible] (17,[illegible])	2[illegible],2	2[illegible],[illegible]	260	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]0[illegible]	[illegible]3,[illegible] ([illegible]0,[illegible])	29,0	2[illegible],6	296	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100	[illegible]495	25,2 (22,3)	29,8	27,7	324	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
110	407	2[illegible],2 (2[illegible],8)	30,[illegible]	30,7	343	88	22,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	110
120	339	2[illegible],9 (2[illegible],8)	30,[illegible]	3[illegible],[illegible]	35[illegible]	68	23,0	3,6	26,0	40 / 285	0,38	5,2	640	45	3,0	5,3	120

Volume of Wood

The basis for “German” yield tables is registration of a site by a “site index” — the height a tree on the site should grow in a given number of years

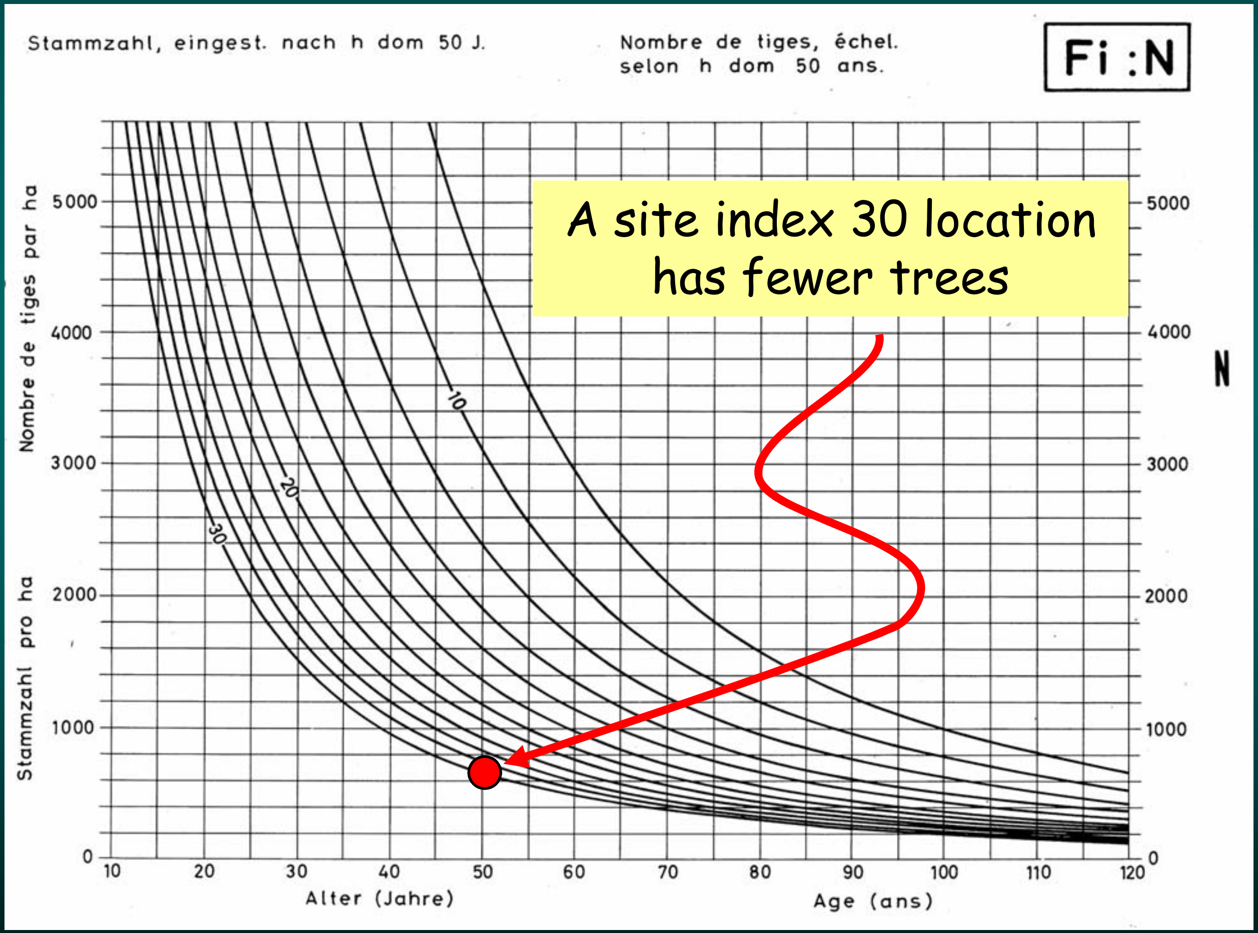


The larger the site index, the greater the average diameter on a site.

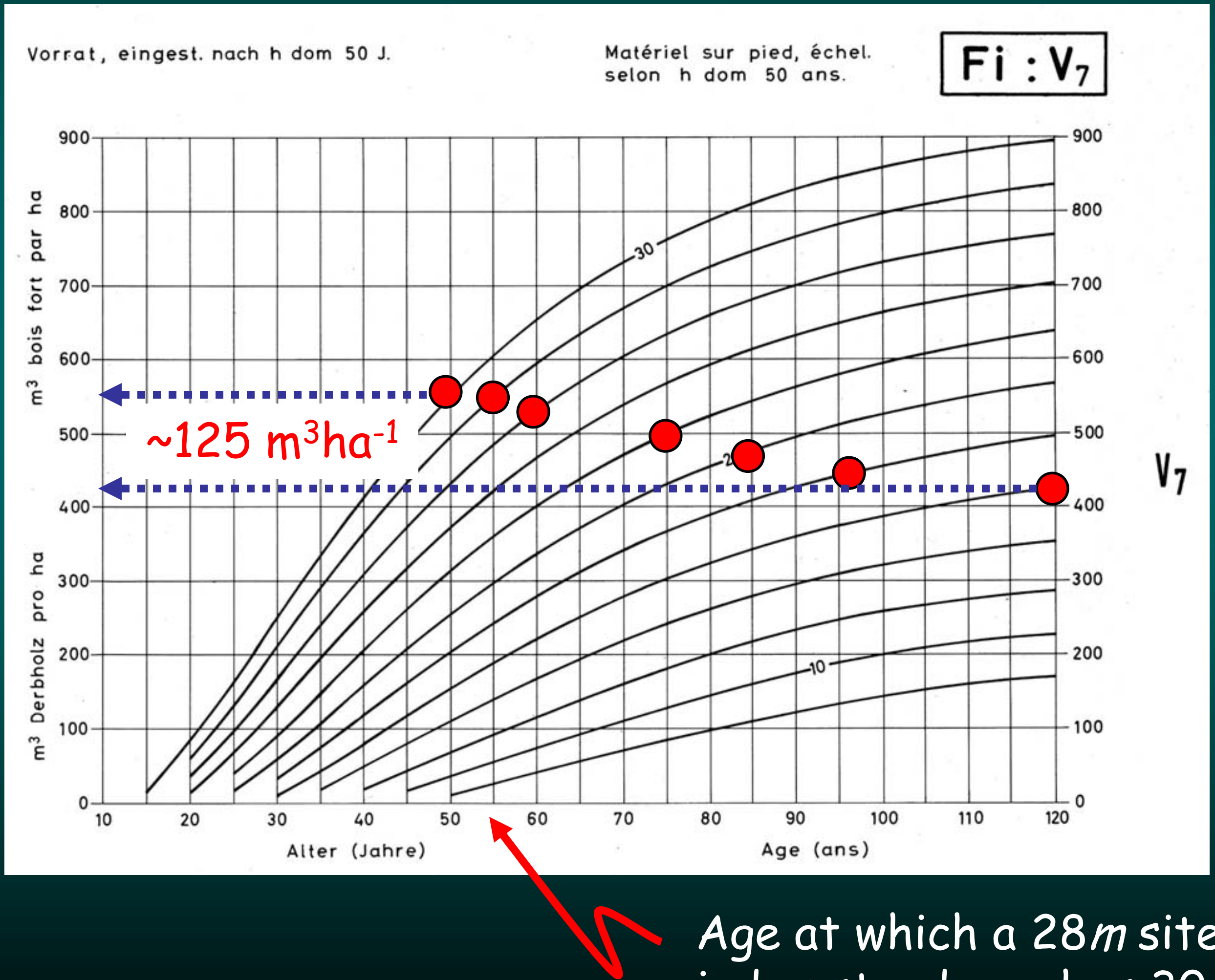


Bigger trees on sites with higher site indices

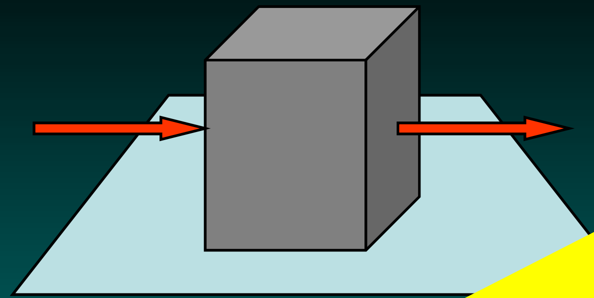
The larger the site index, the **greater** the mortality on a site.



The larger the site index, the greater the biomass or volume on a site.



Age at which a 28*m* site index stand reaches 30*m*



Homogeneous …

Immediat…

•D… …oss

… Initial

…tion of Physical Parameters

…n Physical Climate Models

…ved Representation of Internal

…ocesses

We are already seeing greater incorporation of structure in this class of models … even with a lack of global data bases.

Canopy Process Models

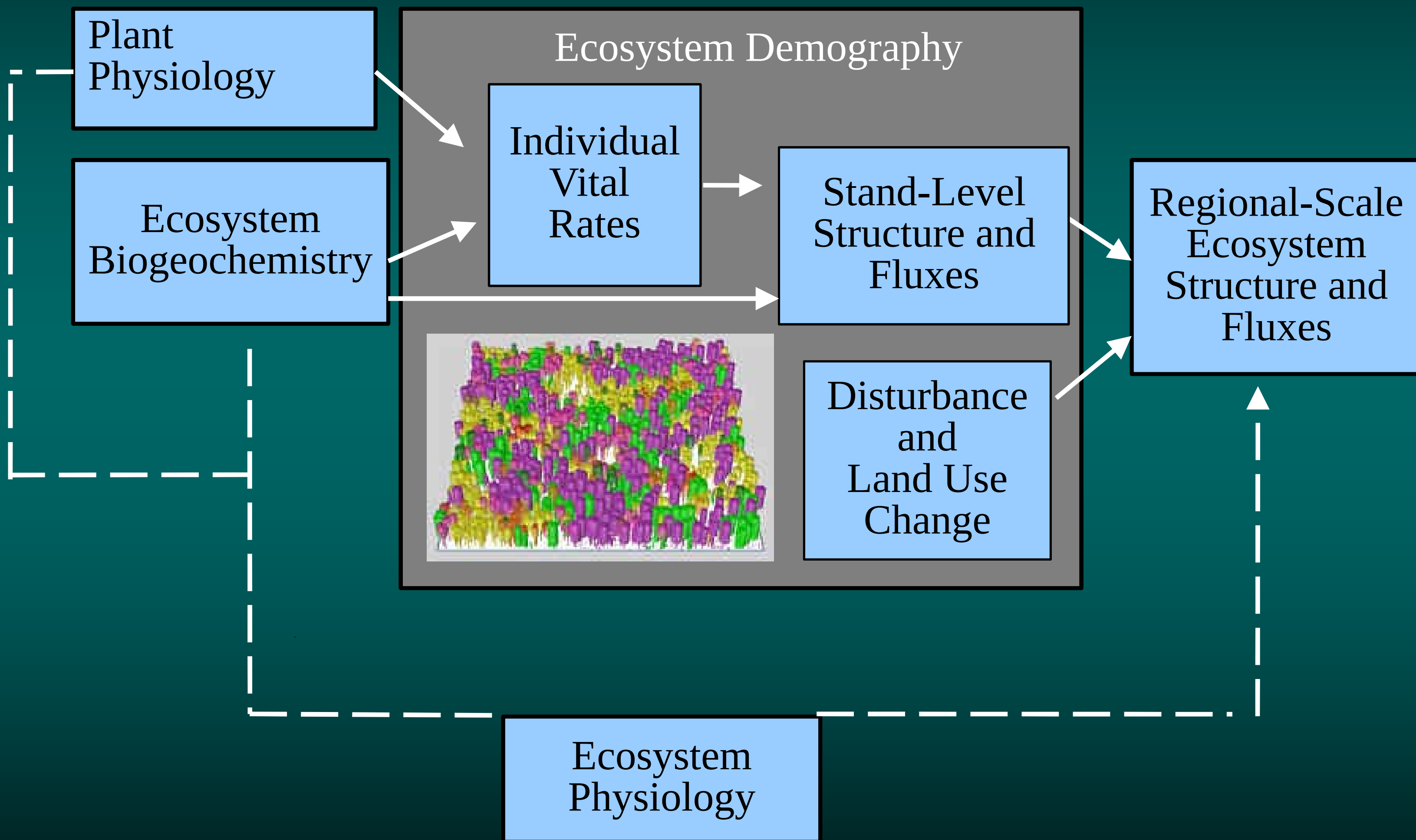
New Dynamic Global Vegetation Models or

DGVM II's

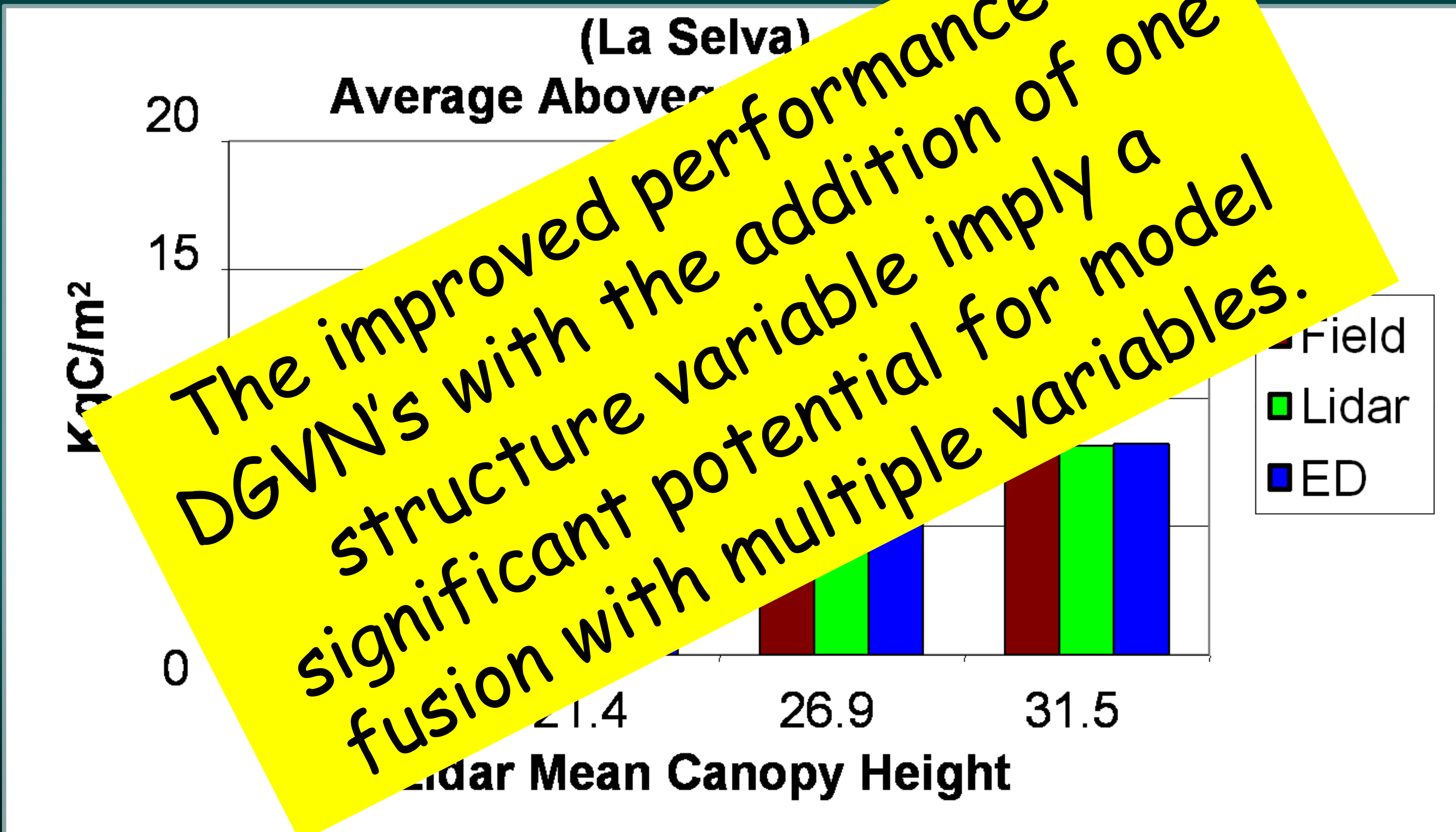
Material Flow Models

Mosaic Models IBM's

Height-structured Ecosystem Model (ED)

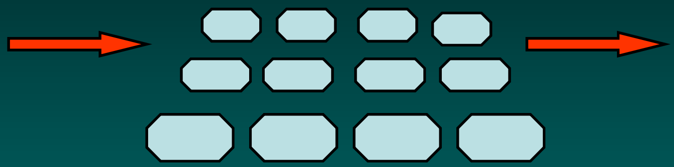


Height-structured Ecosystem Model (ED)

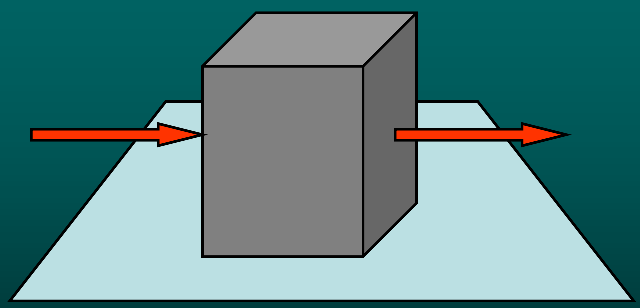


The improved performance of DGVN's with the addition of one structure variable imply a significant potential for model fusion with multiple variables.

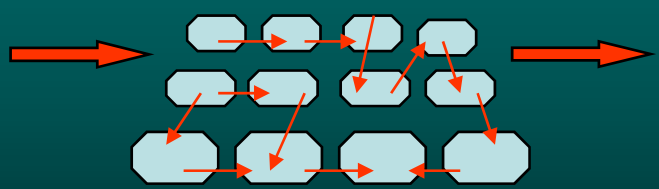
Landscapes as represented by different types of landscape simulators.



Mosaic Landscape Models

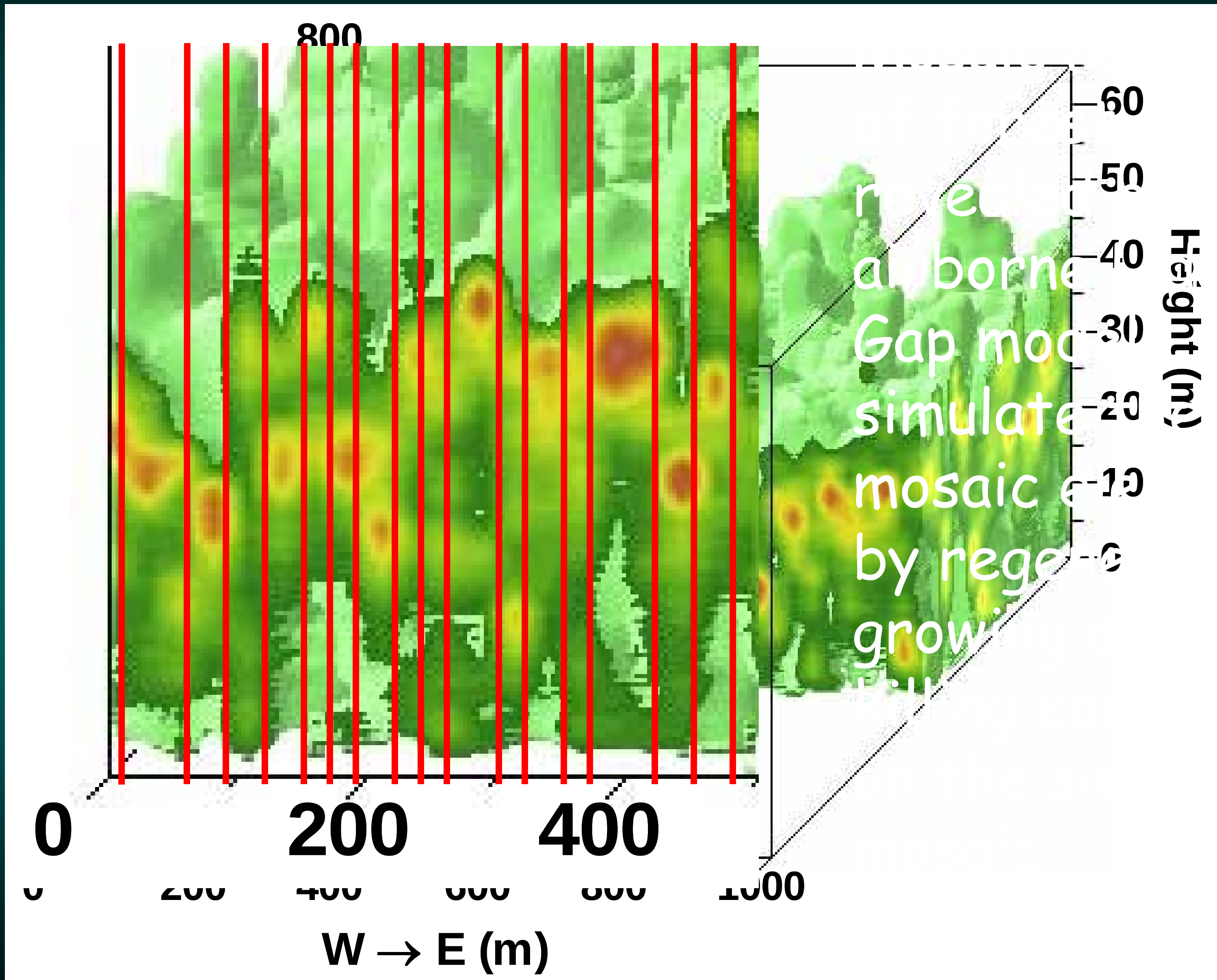


Homogeneous Landscape Models



Interactive Mosaic Models


Not Exactly a Lawn



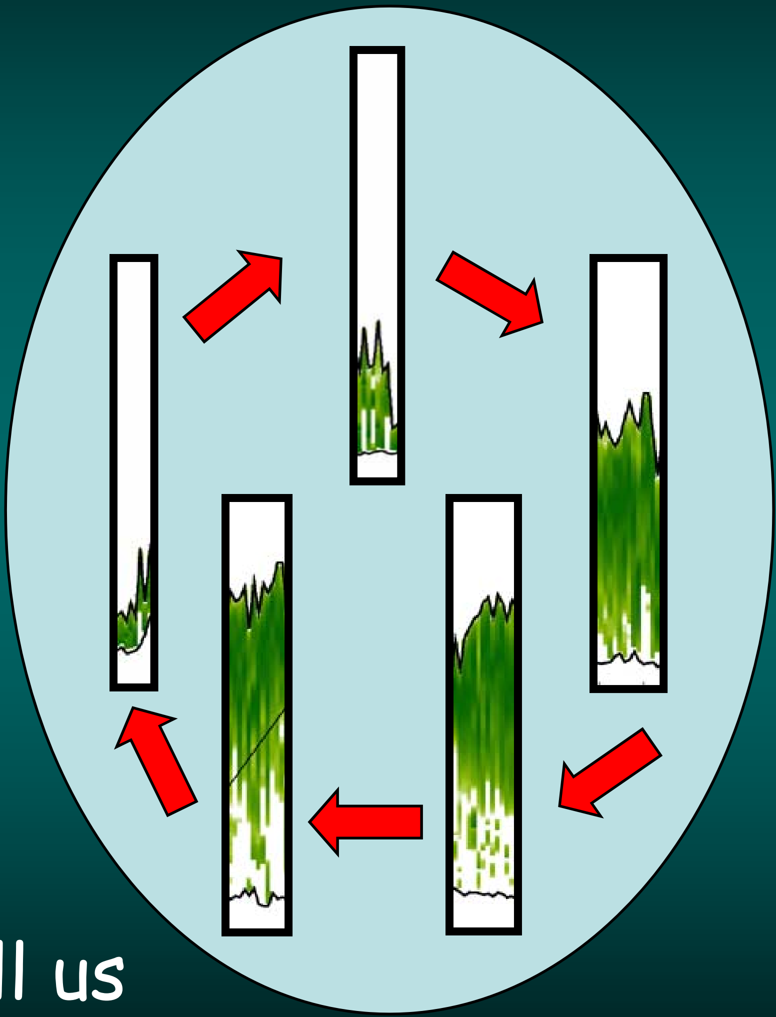
e
opy
r
ai borne r.
Gap moc
simulate e
mosaic e nts
by rege ing,
growi
ree
ted

LANDSCAPE FOREST BIOMASS DYNAMICS

Mature Amazonian Rain Forest Canopy

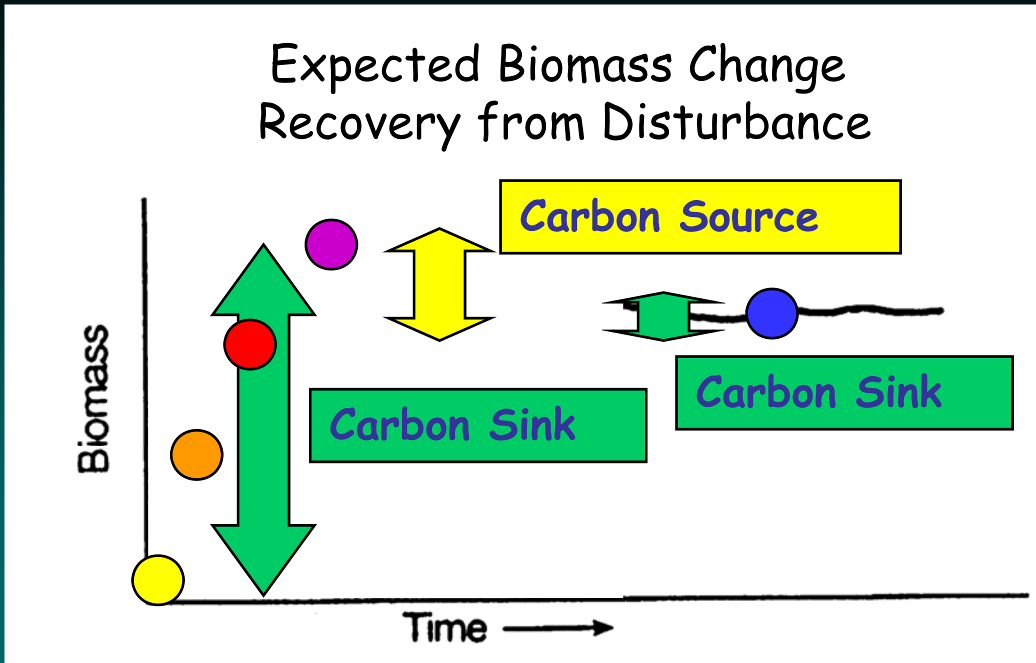
In a mature forest, one expects the canopy to be a mosaic of spatial elements about the size of a large tree crown. These elements go through a cyclical recovery cycle.

Forest Gap-Dynamics Cycle



Lidar Image of Mature Tropical Rain Forest

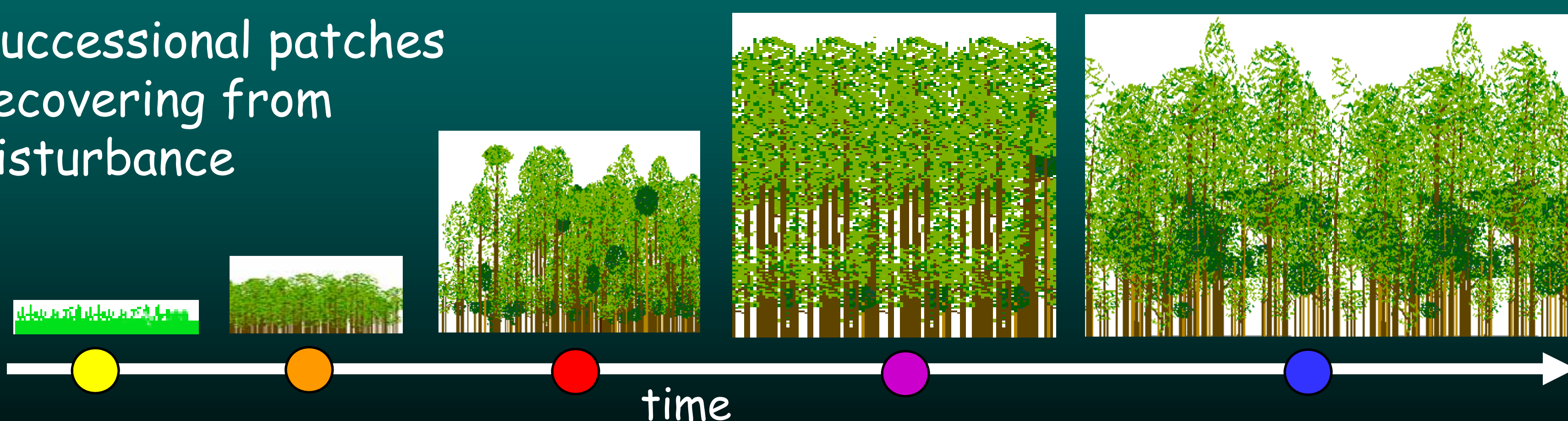
What do gap dynamics tell us about forest biomass dynamics?



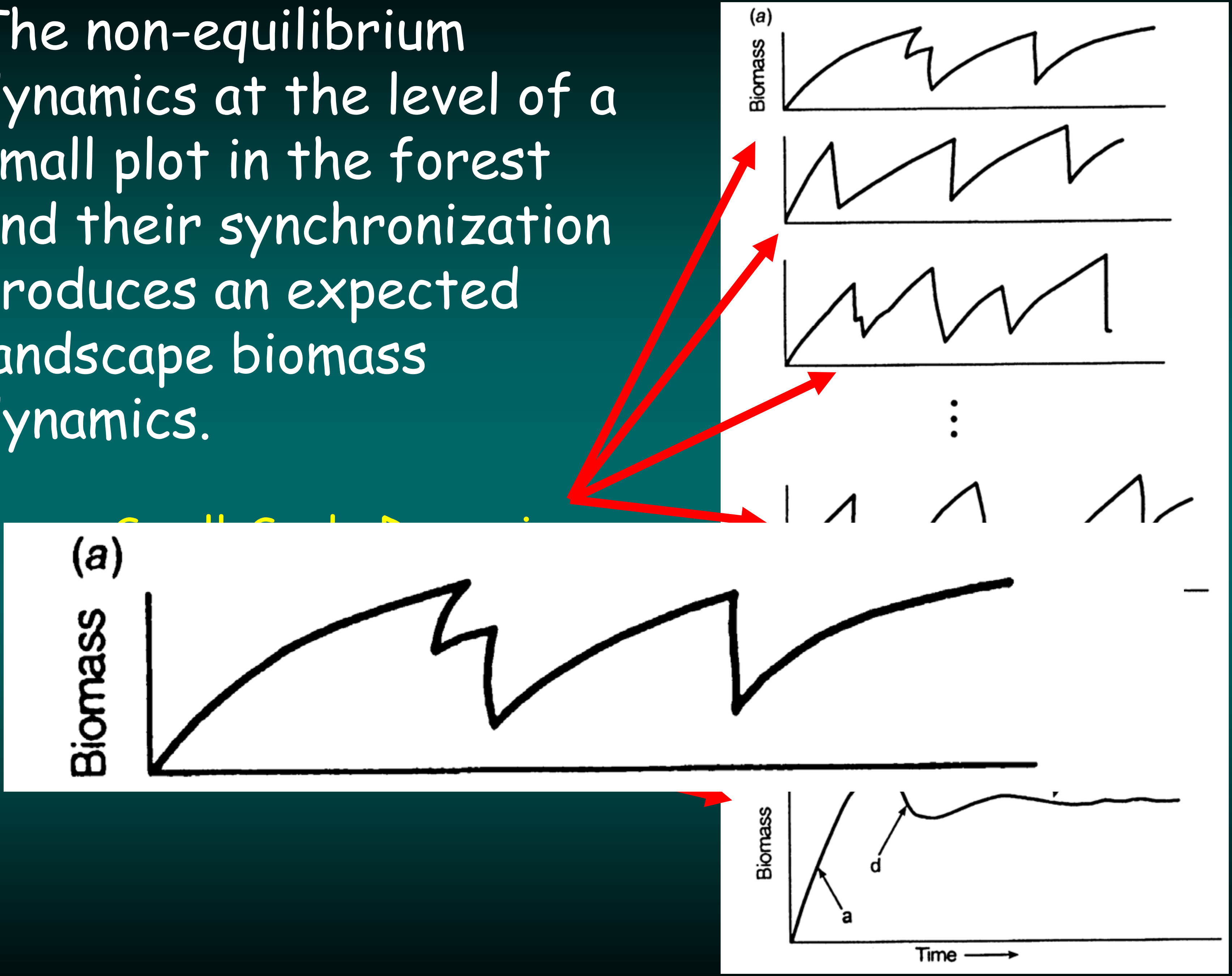
Carbon disturbance recovery dynamics are non-linear as the all-aged successional patches become desynchronized to produce the mixed-aged mature-forest mosaic.

Mature forest is a mosaic.

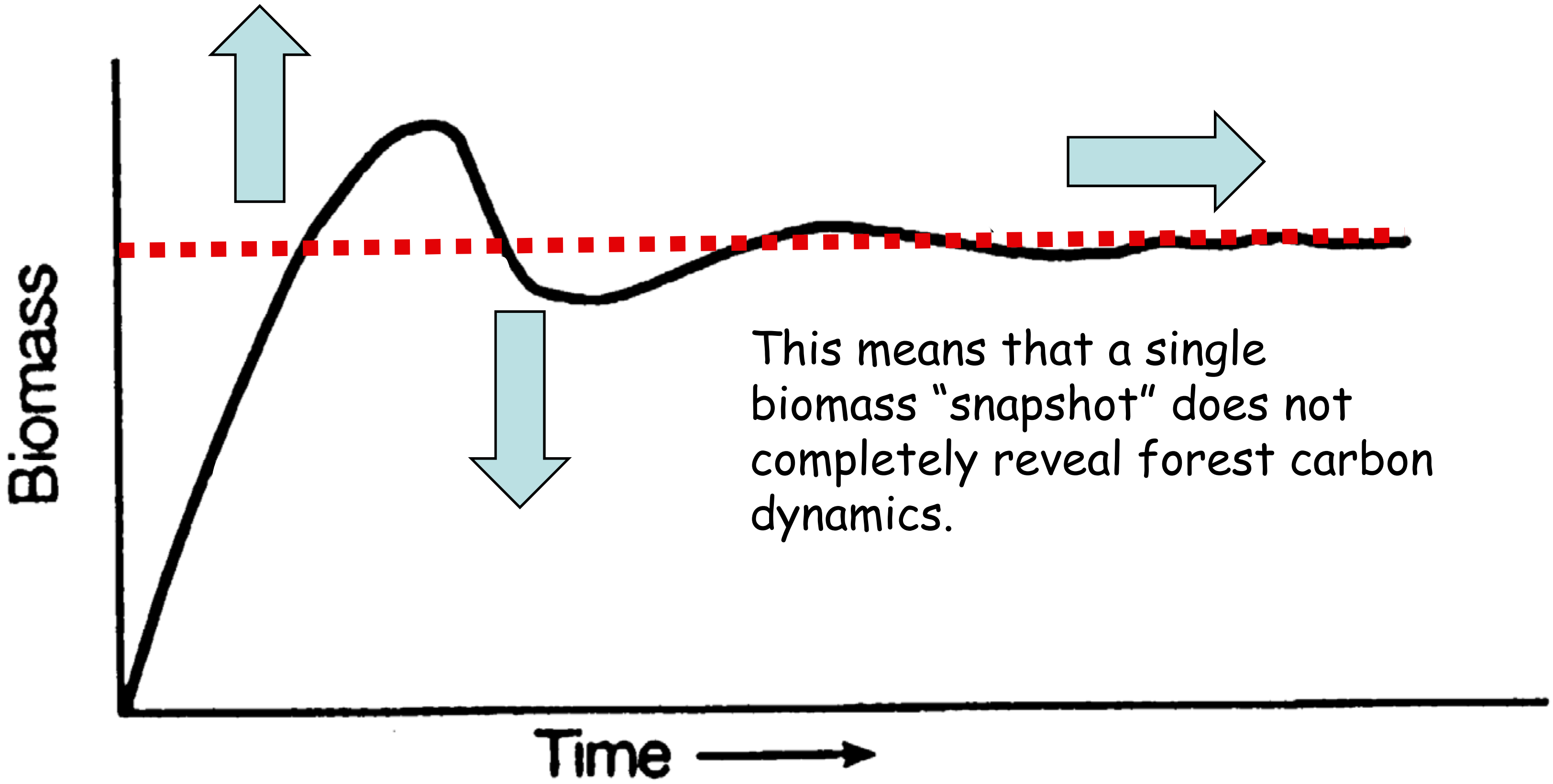
Successional patches recovering from disturbance



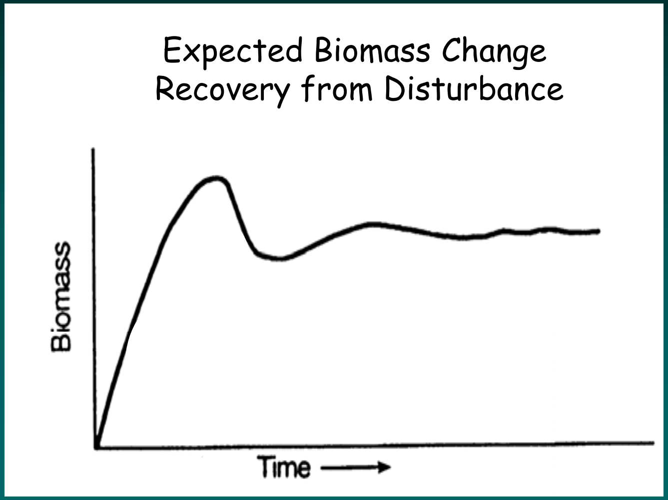
The non-equilibrium dynamics at the level of a small plot in the forest and their synchronization produces an expected landscape biomass dynamics.



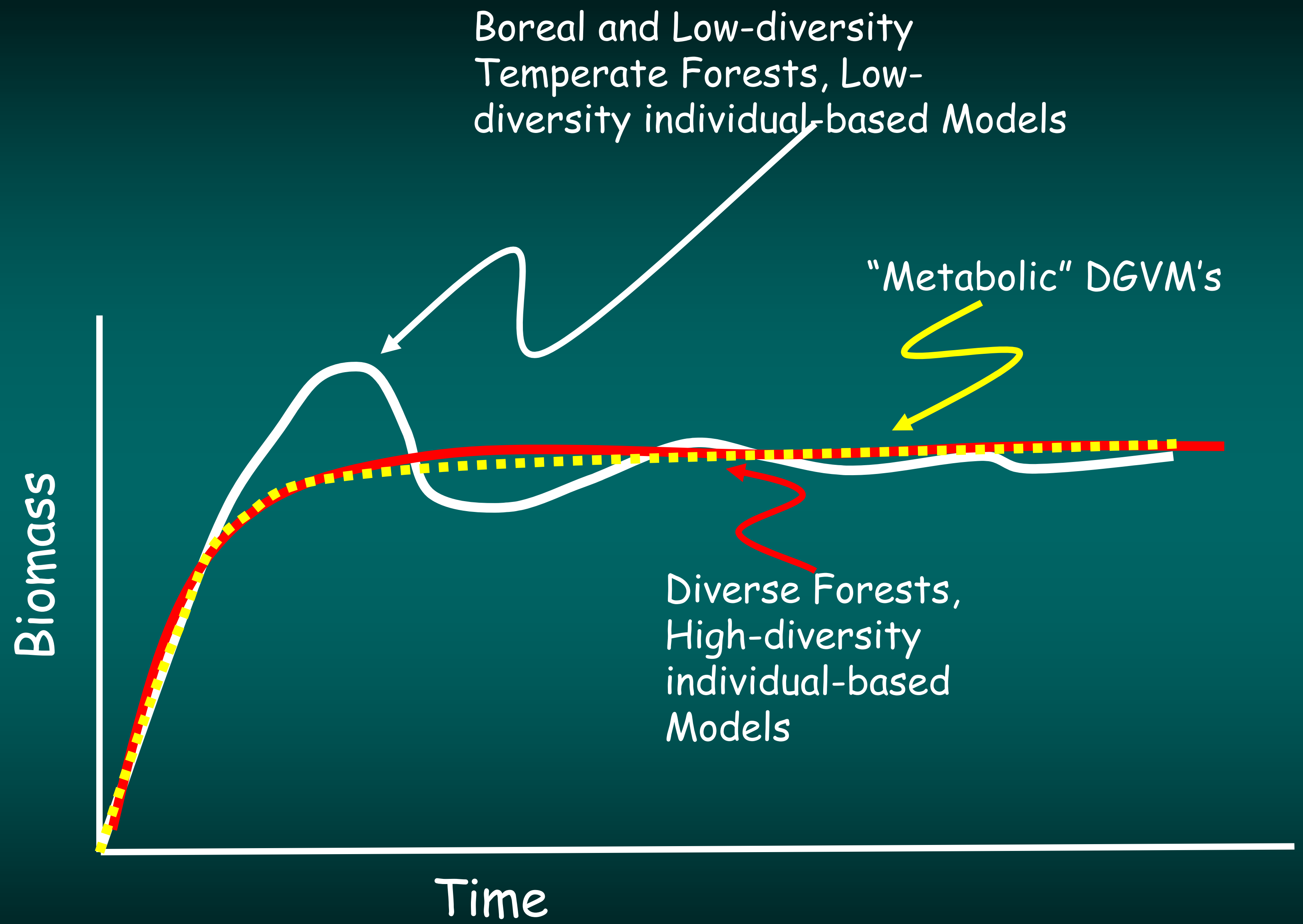
Depending on antecedent history, a forest with the biomass level associated with a mature forest, could be storing carbon, losing carbon or staying the same.



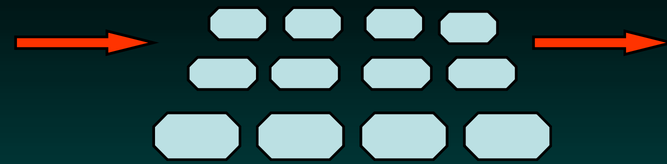
This means that a single biomass "snapshot" does not completely reveal forest carbon dynamics.



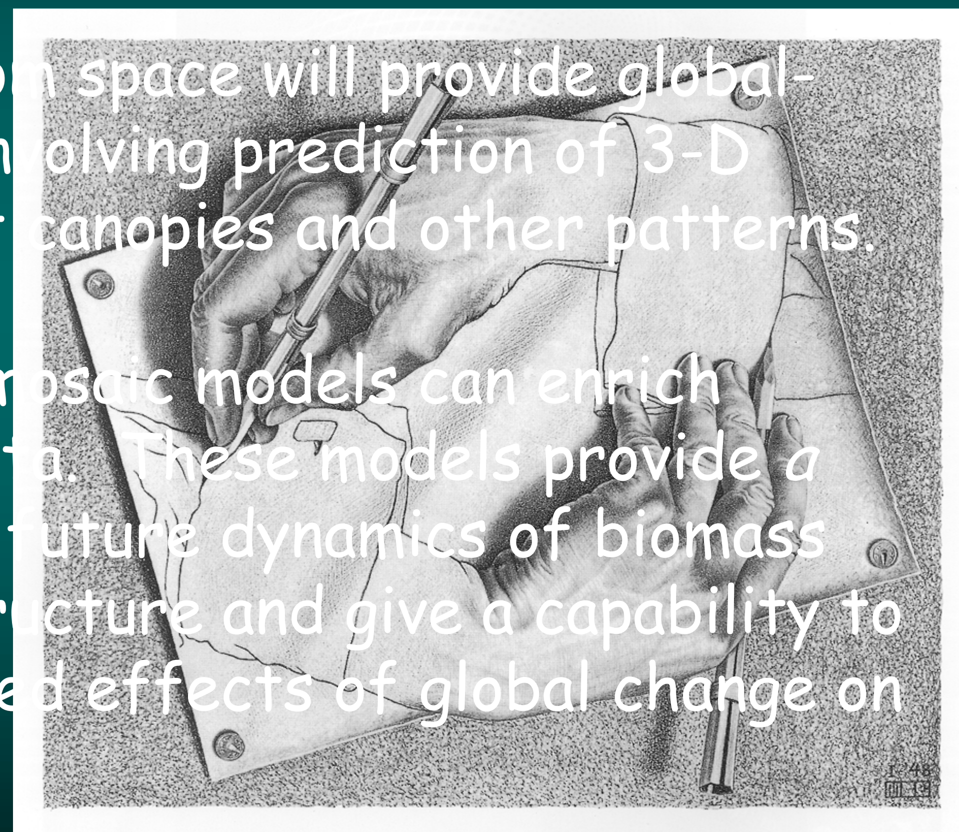
Prediction of the 3-D structure of forests is essential to the predictive capability needed for ecosystem sustainability.



Boreal and Low-diversity Temperate Forests, Low-diversity individual-based Models
"Metabolic" DGVM's
Biomass
Diverse Forests, High-diversity individual-based Models
Time



Mosaic Landscape Models

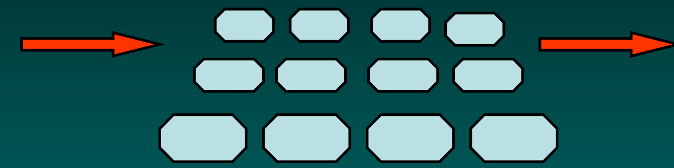


Structural data from space will provide global-scale model tests involving prediction of 3-D statistics of forest canopies and other patterns.

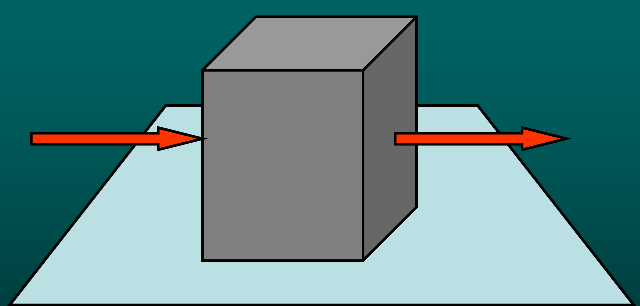
At the same time, mosaic models can enrich remotely sensed data. These models provide *a priori* estimates of future dynamics of biomass based on forest structure and give a capability to explore the expected effects of global change on forest structure.

This is a class of models that has significant synergism — using and interpreting 3-D data

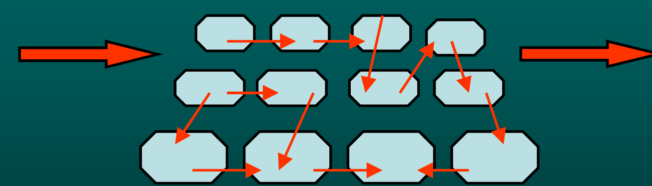
Landscapes as represented by different types of landscape simulators.



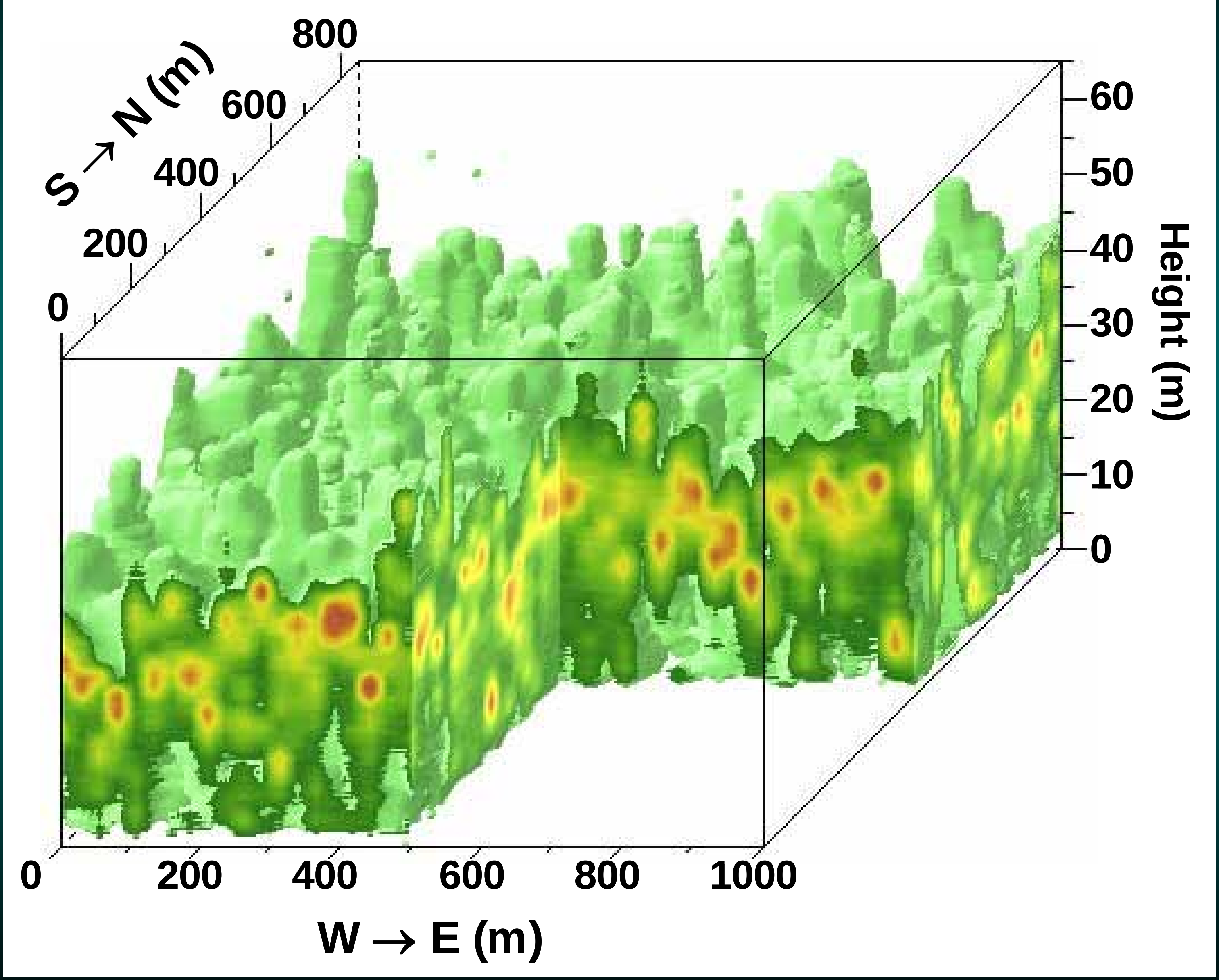
Mosaic Landscape Models



Homogeneous Landscape Models



Interactive Mosaic Models

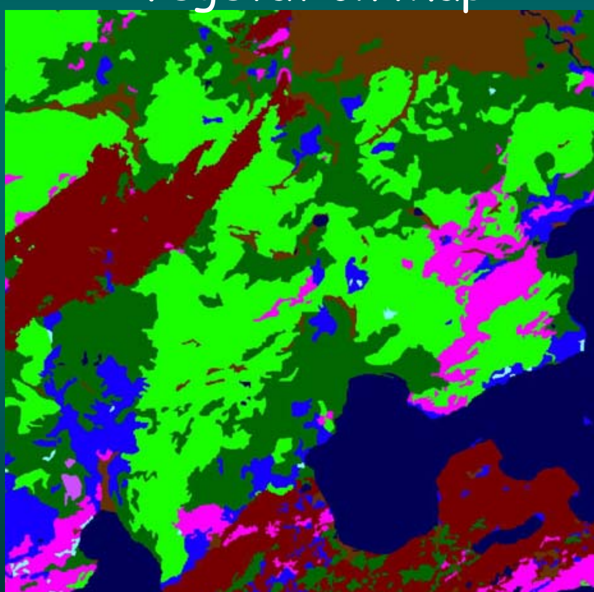


S → N (m)
800
600
400
200
0
60
50
40
30
20
10
0
Height (m)
0
200
400
600
800
1000
W → E (m)

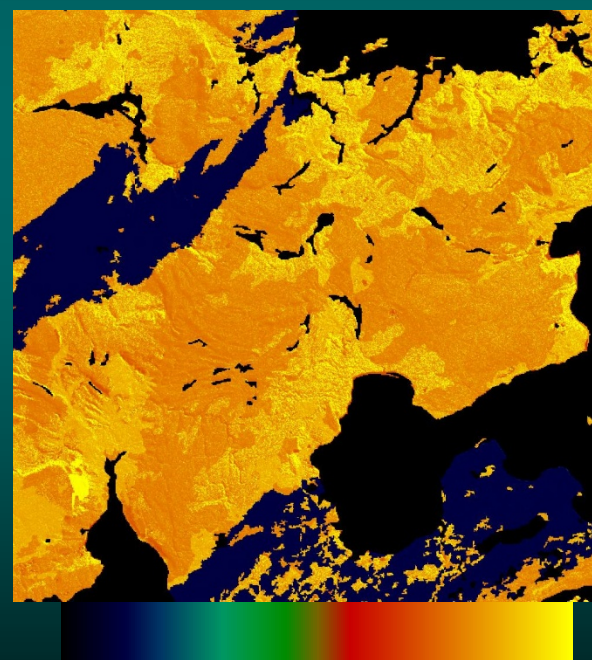

Photo - John McColgan BLM Alaska Fire Service

Measuring Wildfire Fuel

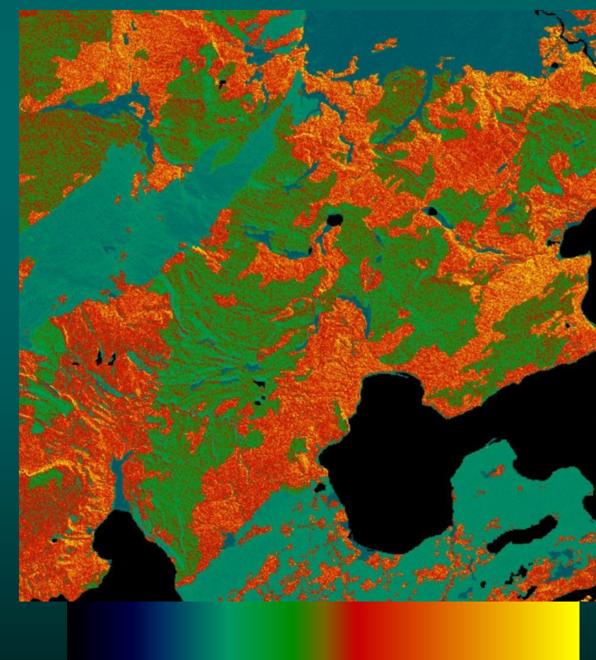
Vegetation Map

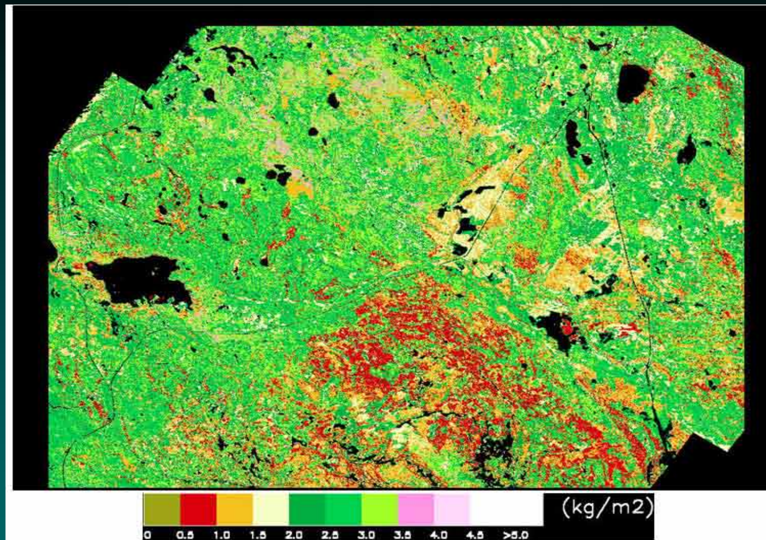


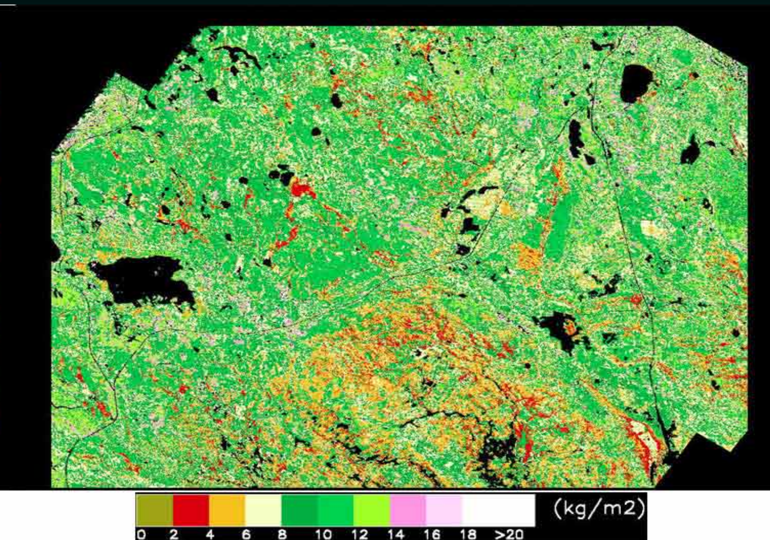
Stem Biomass

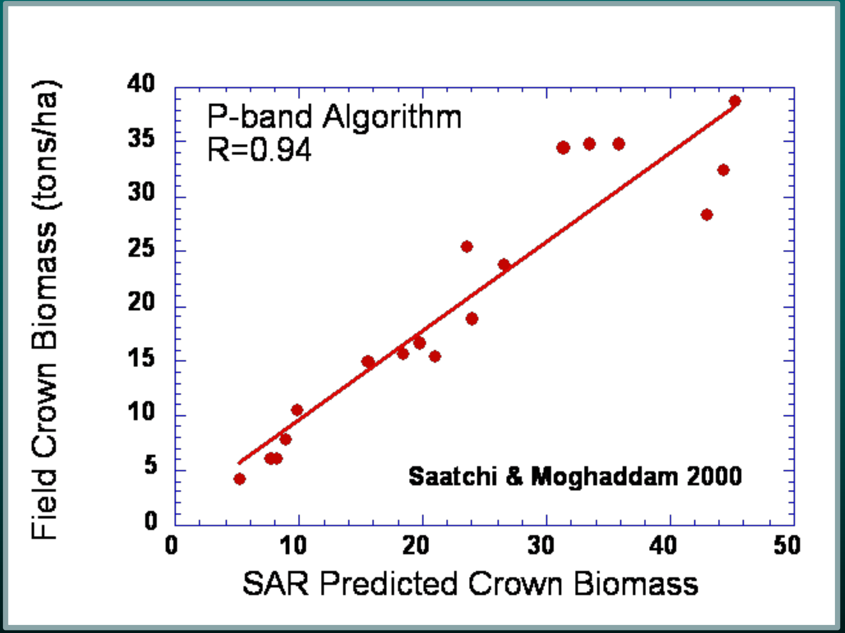


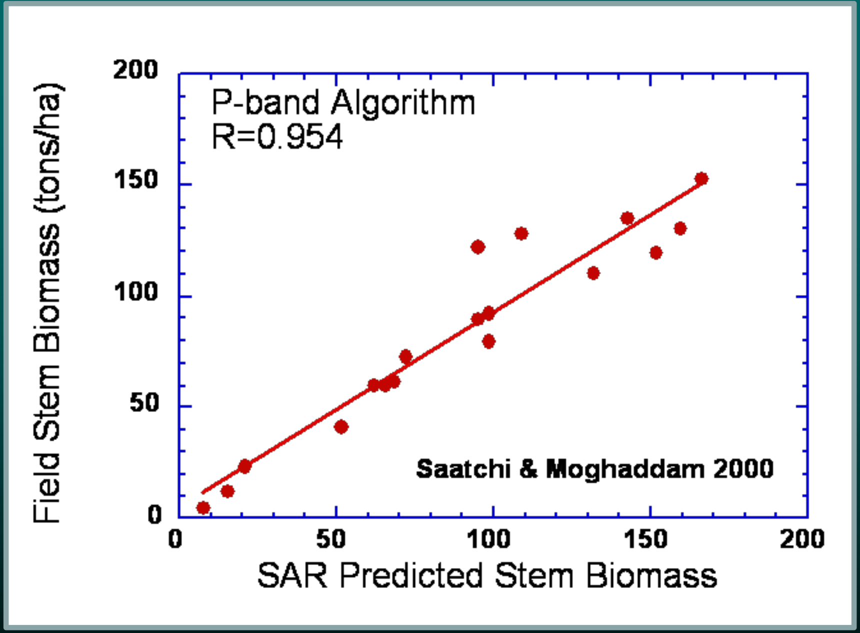
Crown Biomass

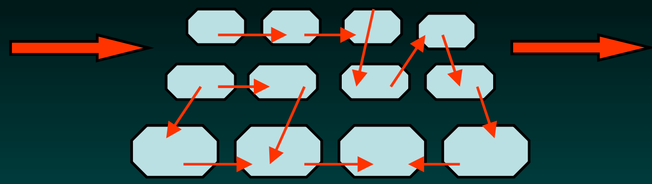



(kg/m2)
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 >5.0


(kg/m2)
0 2 4 6 8 10 12 14 16 18 >20


P-band Algorithm
R=0.94
Saatchi & Moghaddam 2000
Field Crown Biomass (tons/ha)
SAR Predicted Crown Biomass
0 5 10 15 20 25 30 35 40
0 10 20 30 40 50


P-band Algorithm
R=0.954
Saatchi & Moghaddam 2000
Field Stem Biomass (tons/ha)
SAR Predicted Stem Biomass
0 50 100 150 200
0 50 100 150 200



Interactive Mosaic Models

For models of spatially propagated phenomena (insect pests, wildfire, dispersal of species), the availability of global structural data for forests would lift one of the principal limitations to the large area applications.

It is significant that these spatial phenomena and their dynamics could be expected to change with global change, notably climate change. Our characterization of these spatial dynamics are a major source of uncertainty in our predictive capability.

The End

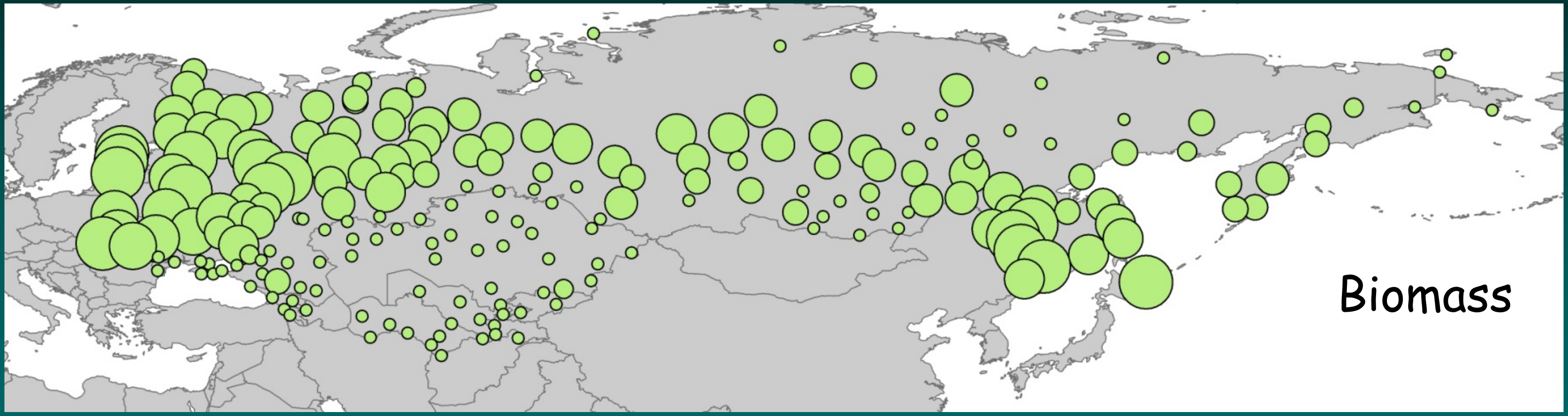
FAREAST: An Example Individual-based Boreal Forest Simulator

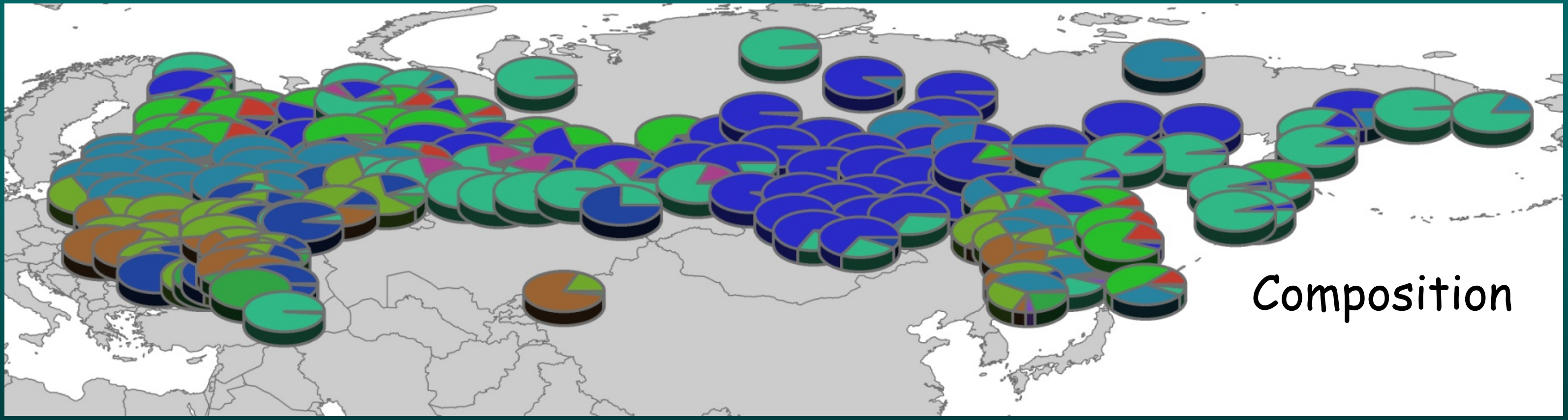
Growth:
- Available Light
- Soil Moisture
- Site Quality
- Growing-Degree Days
- Depth of Thaw
- Diameter
- Age
- Height

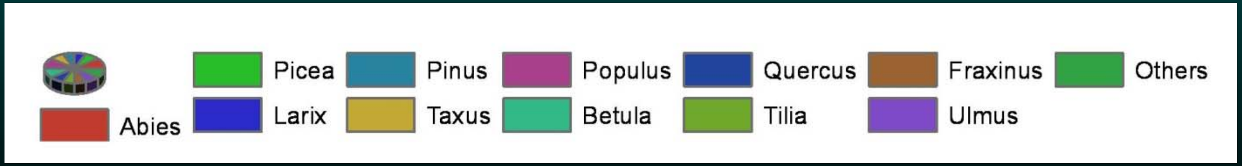
Mortality:
- Stress
- Fire
- Insects
- Age

Regeneration:
- Available Light
- Soil Moisture
- Site Quality
- Depth of Thaw
- Seed Bed
- Seed Availability
- Sprouting
- Layering

Individual-based Models can be Applied over Large Areas







Dynamic Global Vegetation Models or

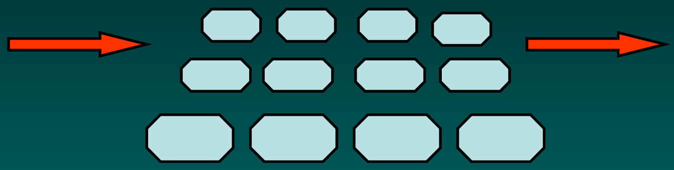
DGVM's

The Ideal

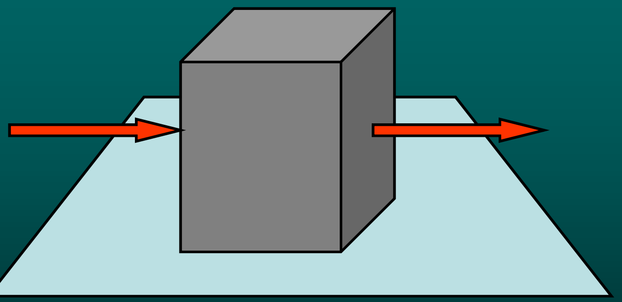
The Prototype

One important step in improving our models of global ecosystem dynamics is to incorporate the effects of structure.

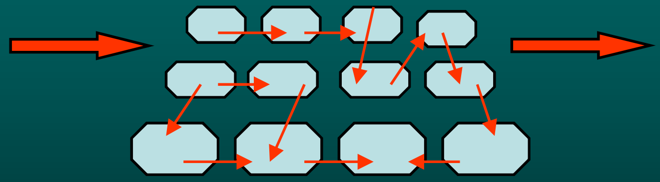
Landscapes as represented by different types of landscape simulators.



Mosaic Landscape Models

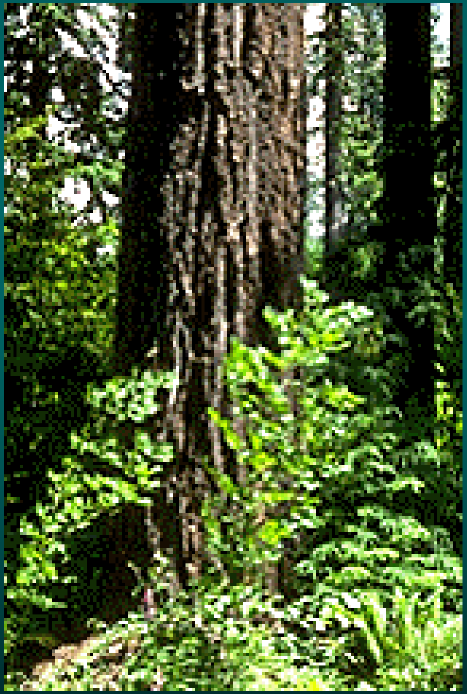


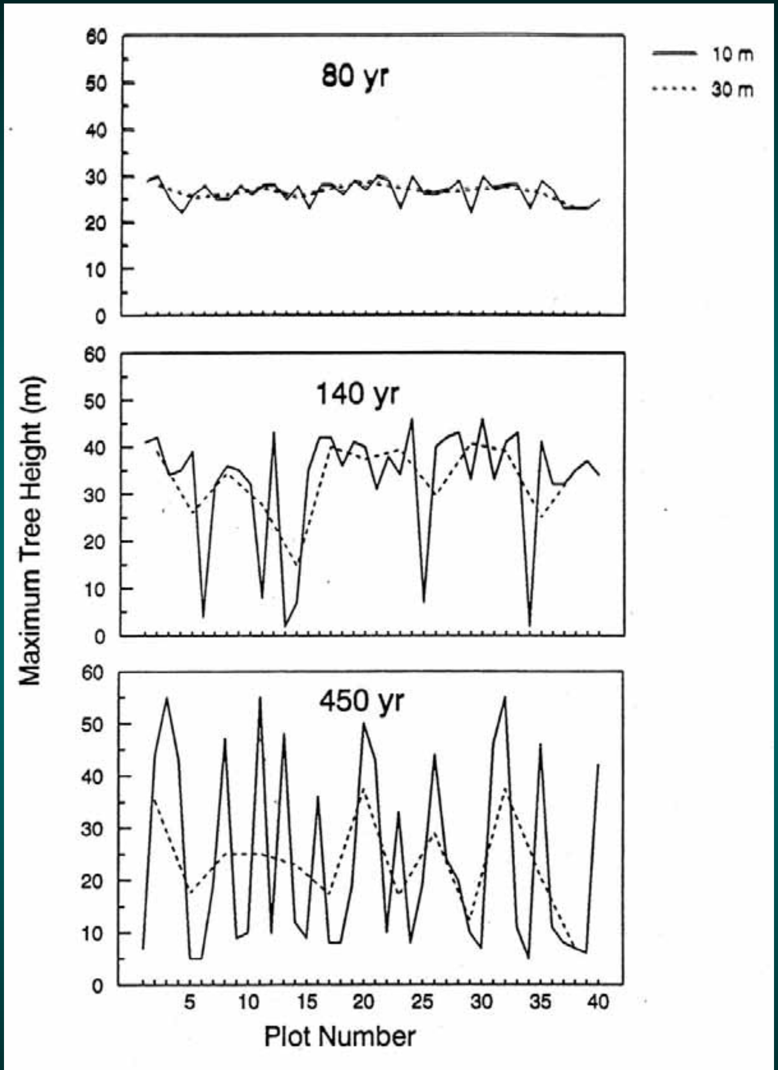
Homogeneous Landscape Models



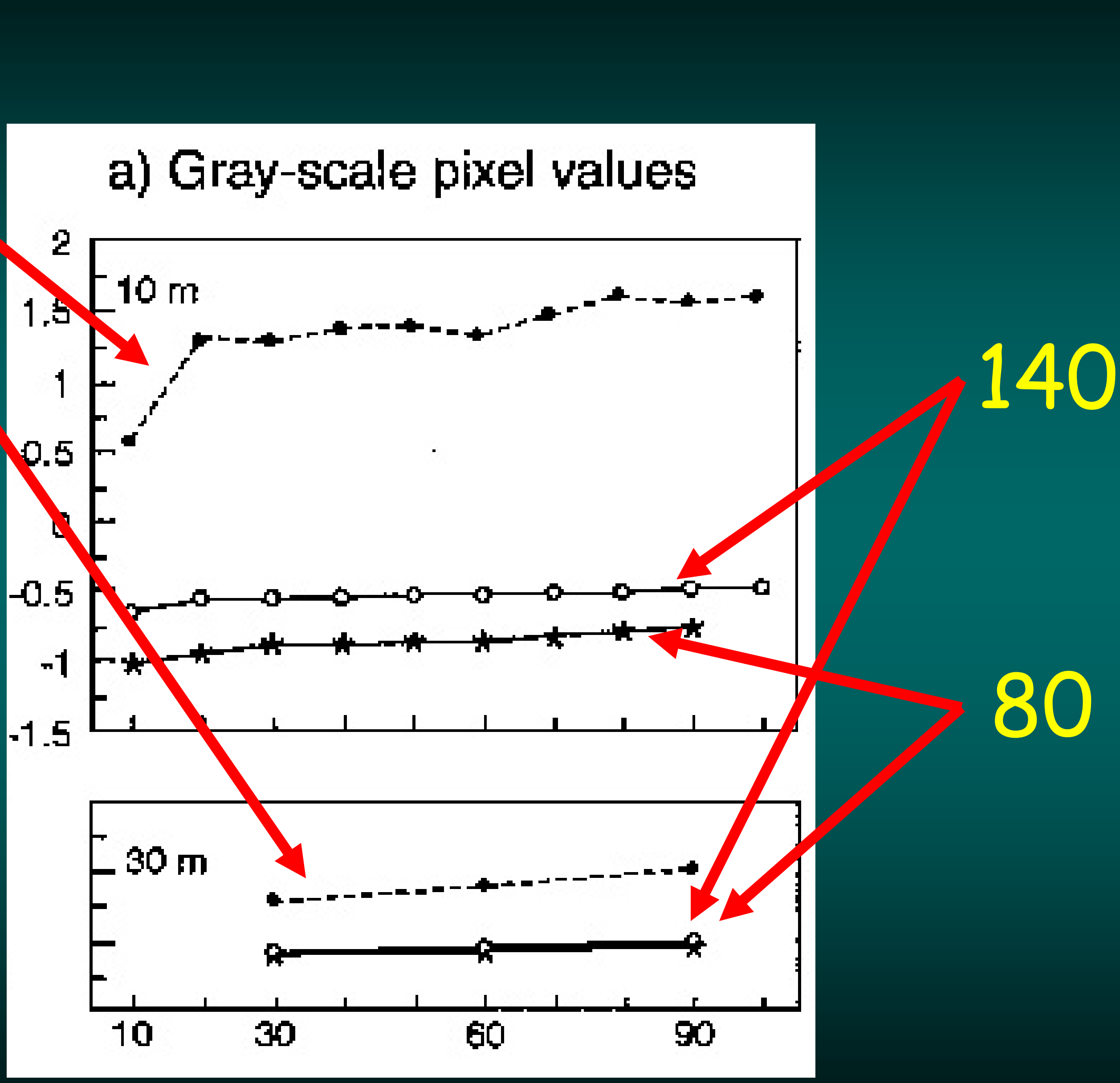
Interactive Mosaic Models

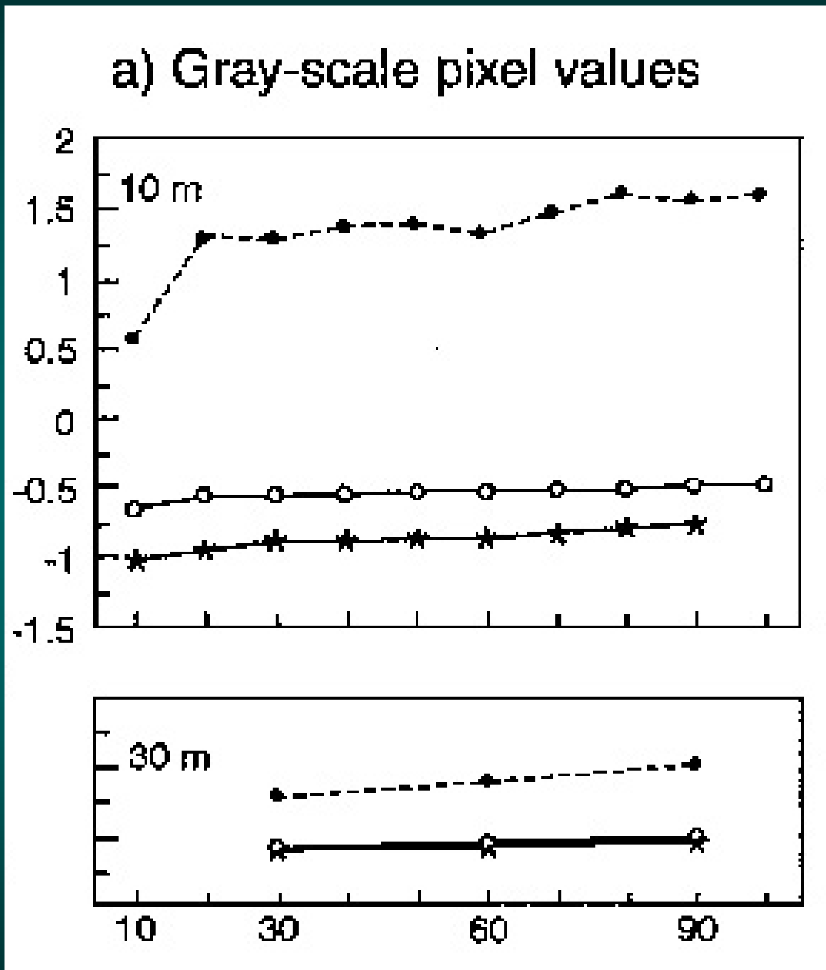
Spatial Pattern in Douglas-fir Forests

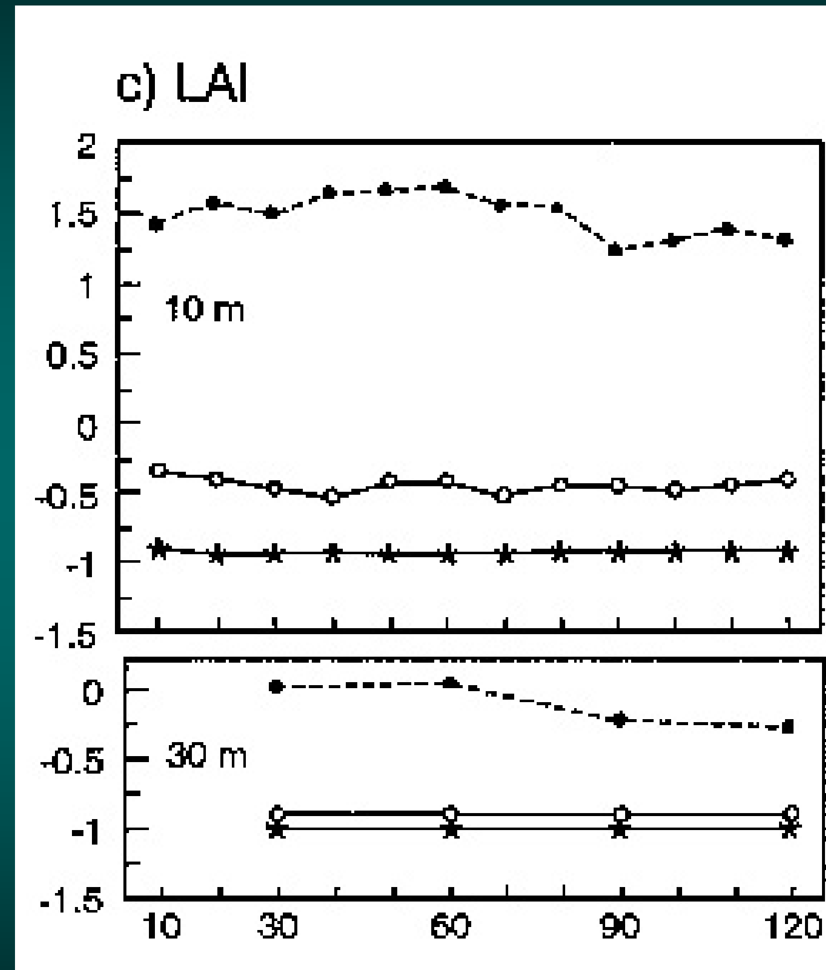




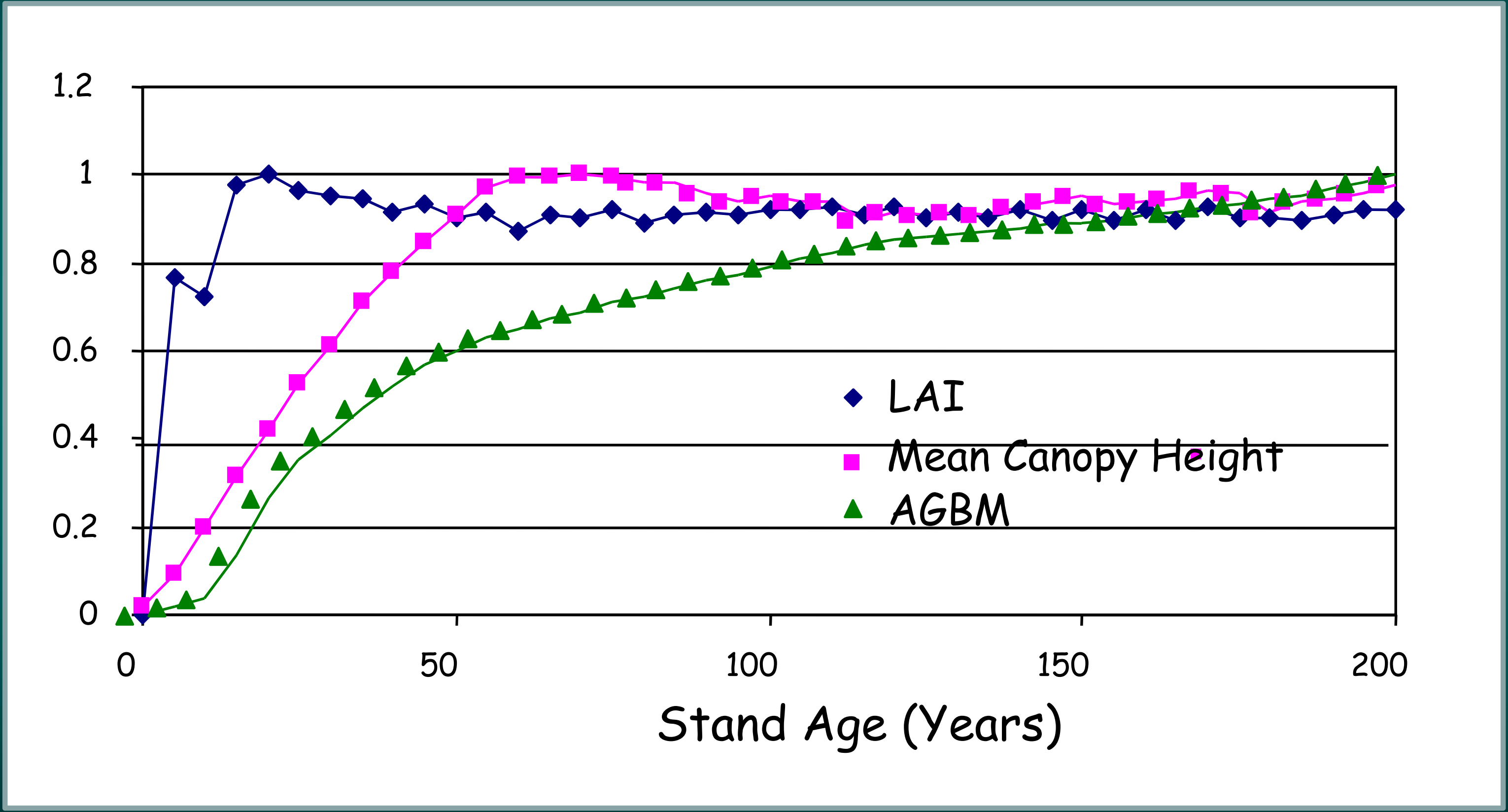
450+ year-old forest



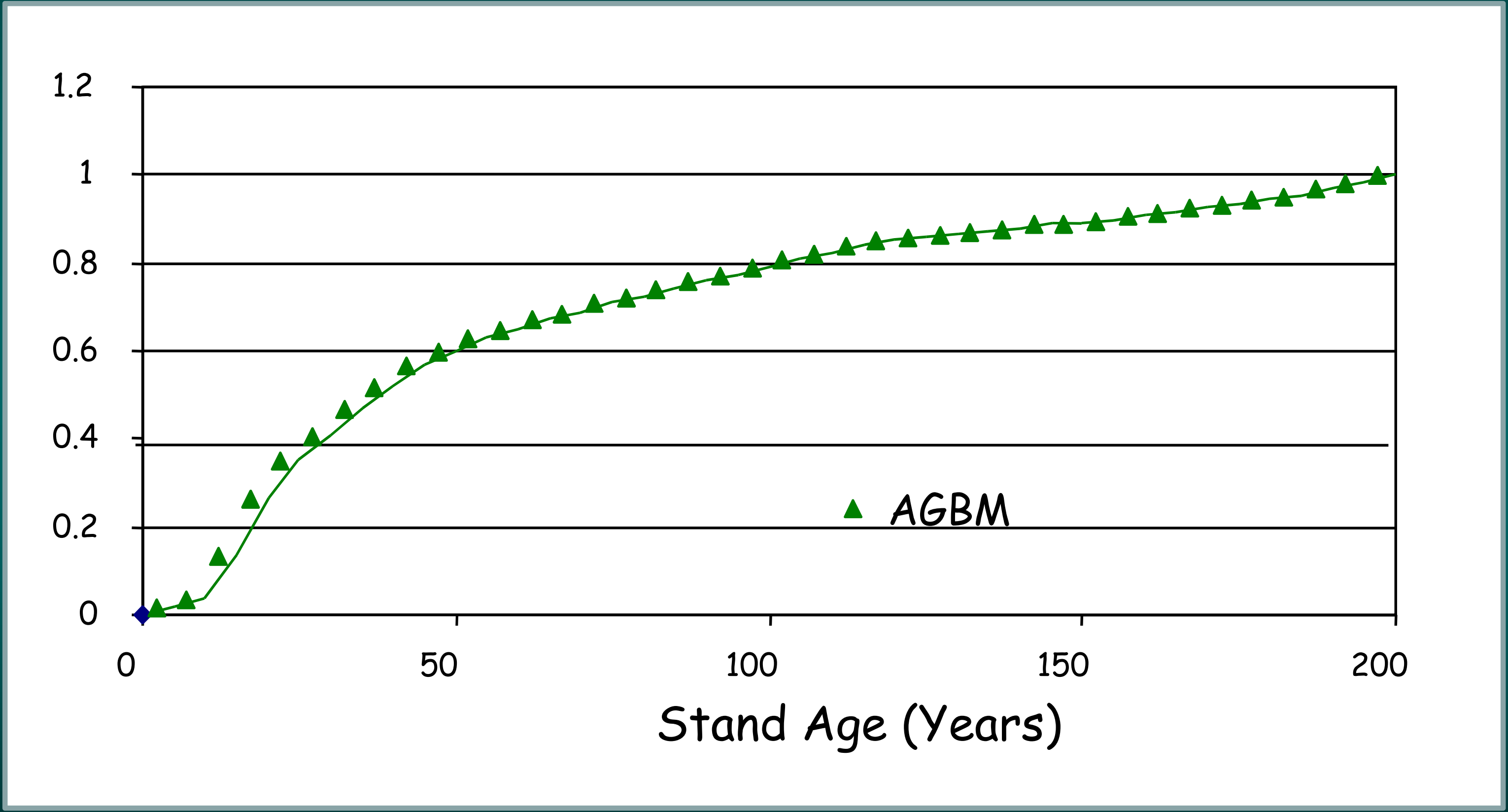

a) Gray-scale pixel values
10 m
30 m
2
1.5
1
0.5
0
-0.5
-1
-1.5
10
30
60
90


c) LAI
10 m
30 m
2
1.5
1
0.5
0
-0.5
-1
-1.5
10
30
60
90
120

Successional Patterns Simulated by the ED Model



Successional Patterns Simulated by the ED Model



Talk to follow by Ralph Dubayah will provide more details