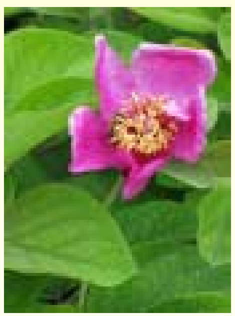
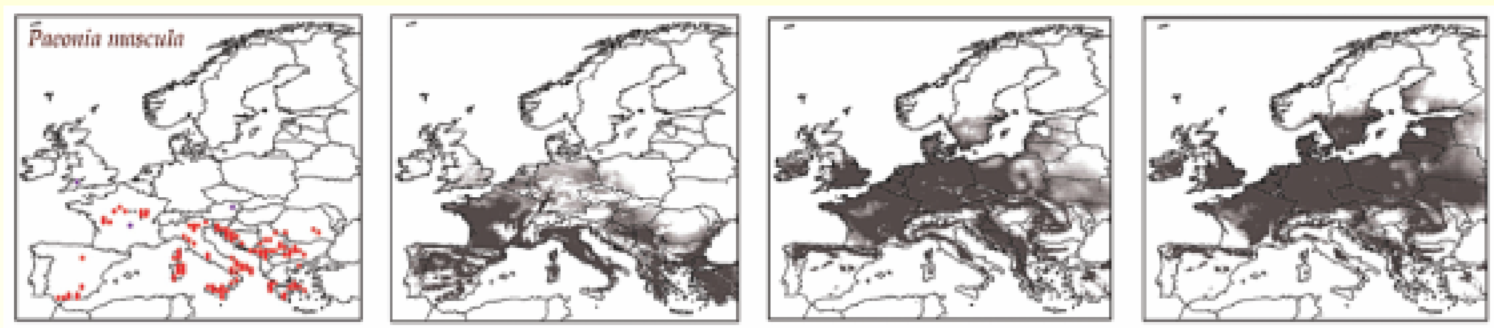
Forecasting changes in the distribution and abundance of plants in response to climate change





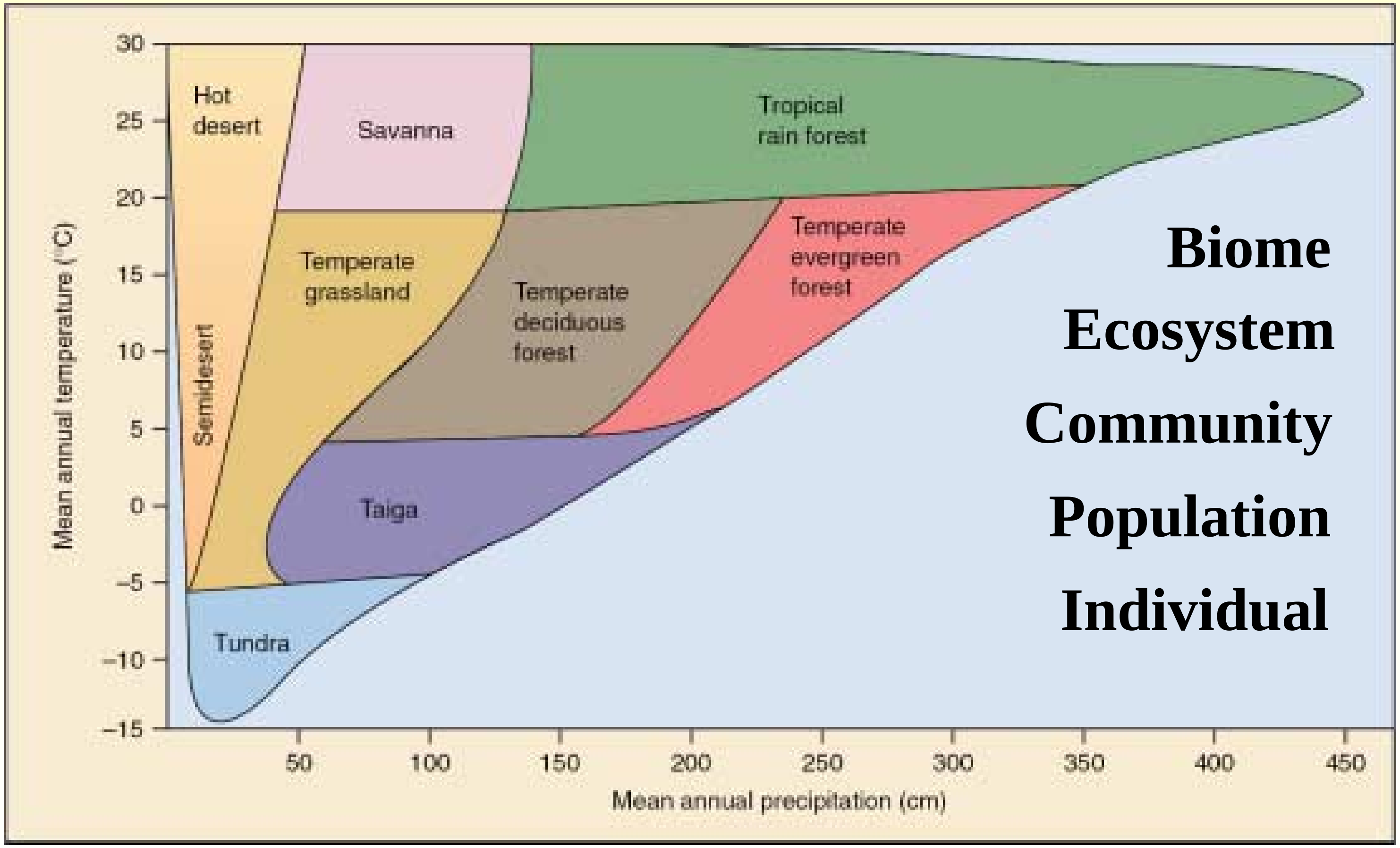
From: Skov & Svenning (2004), *Ecography*

Ran Nathan

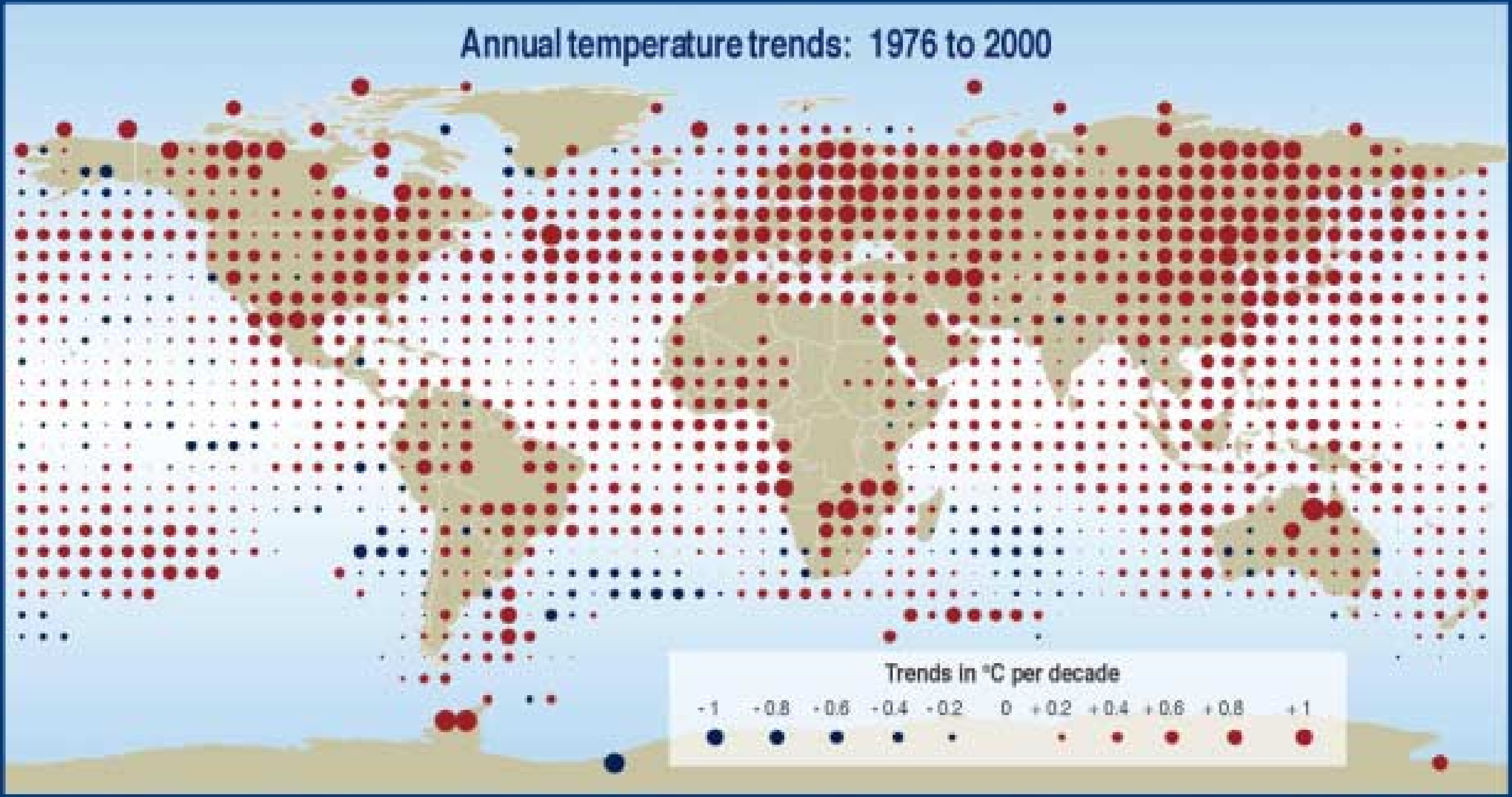
MOVEMENT ECOLOGY LAB

Dept. of Evolution, Systematics and Ecology
The Hebrew University of Jerusalem, Israel

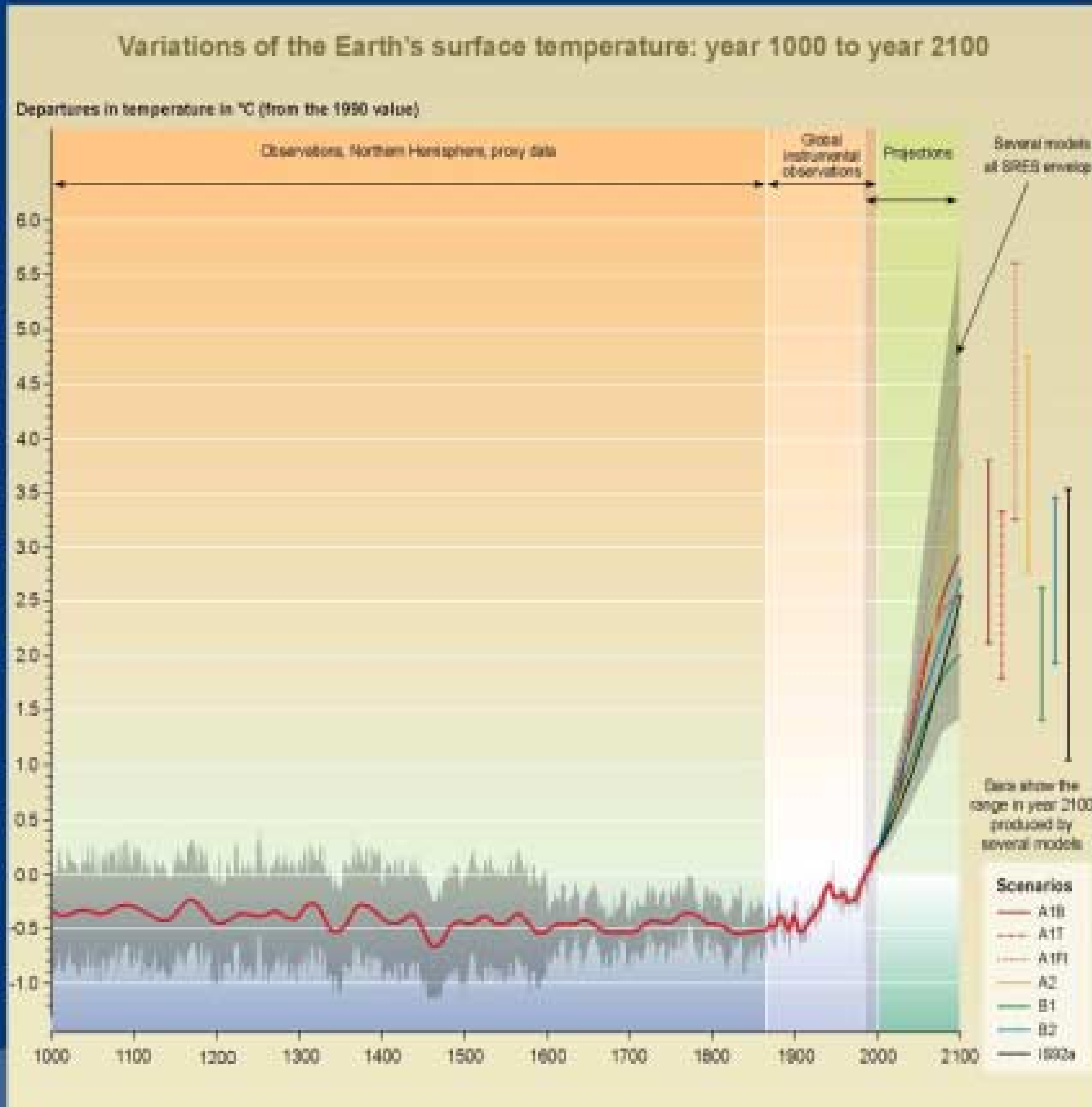
Climatic control of biomes



From Raven & Johnson (2001), *Biology;* based on Whittaker (1975) *Communities and Ecosystems*



SYR - FIGURE 2-6b



SYR - FIGURE 9-1b

How climate changes affect world's biota?

Evolutionary level

Selection for/against life-history traits, speciation, extinction

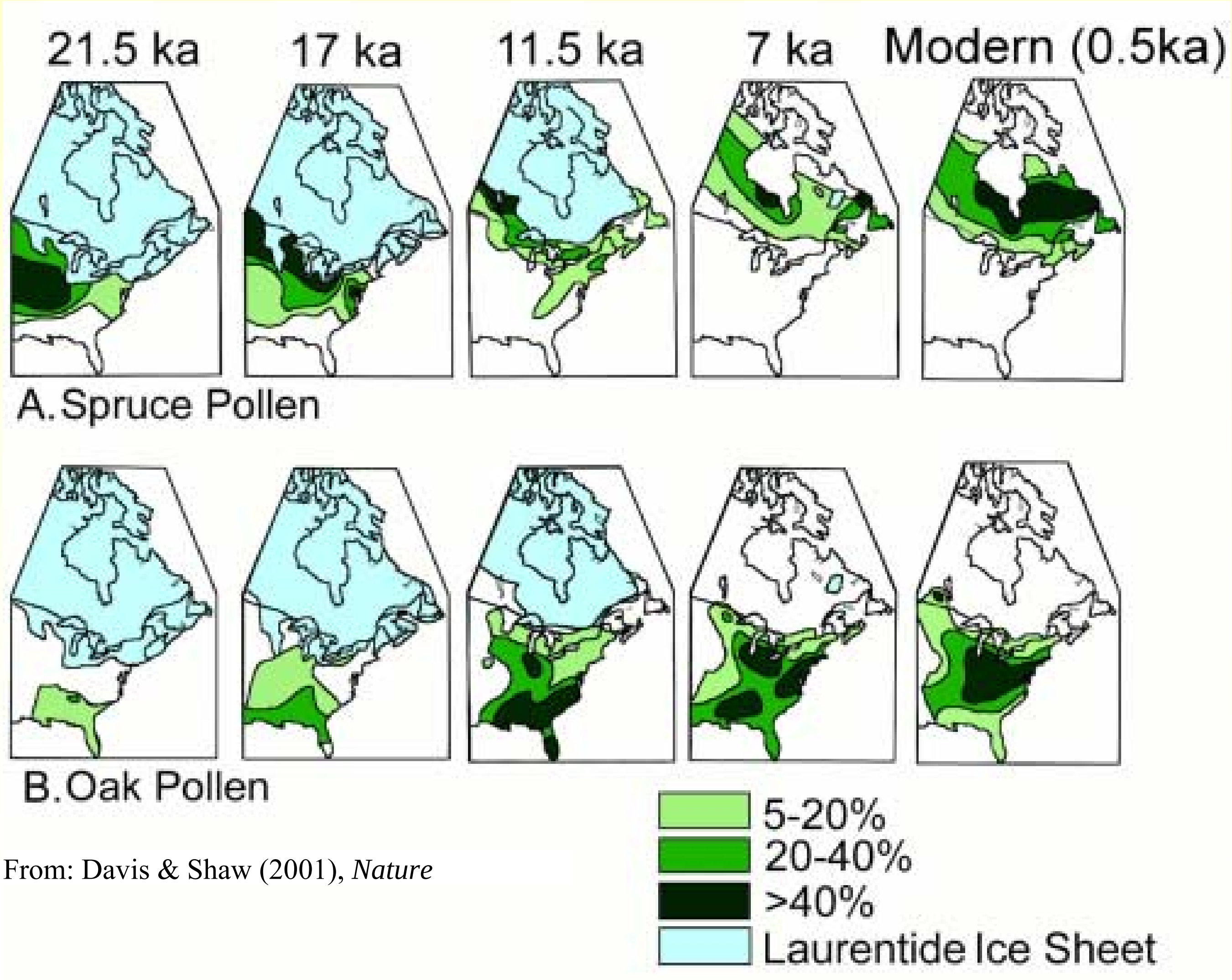
Community/Ecosystem level

Changes in diversity patterns, ecosystem processes

Species/Population level

Changes in distribution and abundance

Climatic changes alter plant distribution: evidence from the past



From: Davis & Shaw (2001), *Nature*

Climatic changes alter plant distribution: contemporary evidence

articles

A globally coherent fingerprint of climate change impacts across natural systems

Camille Parmesan* & Gary Yohe†

NATURE | VOL 421 | 2 JANUARY 2003

letters to nature

Fingerprints of global warming on wild animals and plants

Terry L. Root*, Jeff T. Price†, Kimberly R. Hall‡, Stephen H. Schneider§, Cynthia Rosenzweig|| & J. Alan Pounds¶

NATURE | VOL 421 | 2 JANUARY 2003

Type of Analysis	Changed as predicted	Changed opposite to prediction	P-value
Phenological changes **Earlier timing of spring events** Significant changes = 484/678 (71%)	**87%**	**13%**	**$< 10^{-13}$**
Distributional changes **Poleward/upward range shift**	**80%**	**20%**	
Cold-adapted species declining and warm-adapted species increasing	**85%**	**15%**	
Significant changes = 460/920 (50%)	**81%**	**19%**	**$< 10^{-13}$**

Based on data for 1598 species of trees, herbs, shrubs, marine zooplankton & invertebrates, butterflies, fish, amphibians, reptiles, birds and mammals

Based on:

Parmesan & Yohe (2003), *Nature*

Forecasting plant response to climatic changes: sources of uncertainty

Journal of Ecology 2003
91, 341–347

ESSAY REVIEW

Forecasting plant migration rates: managing uncertainty for risk assessment

S. I. HIGGINS, J. S. CLARK*, R. NATHAN†, T. HOVESTADT‡, F. SCHURR, J. M. V. FRAGOSO§, M. R. AGUIAR¶, E. RIBBENS** and S. LAVOREL††

Model Uncertainty

Key underlying processes are missing in the model

Parameter Uncertainty

Parameter estimate is likely across a wide range of values, often due to limited sampling

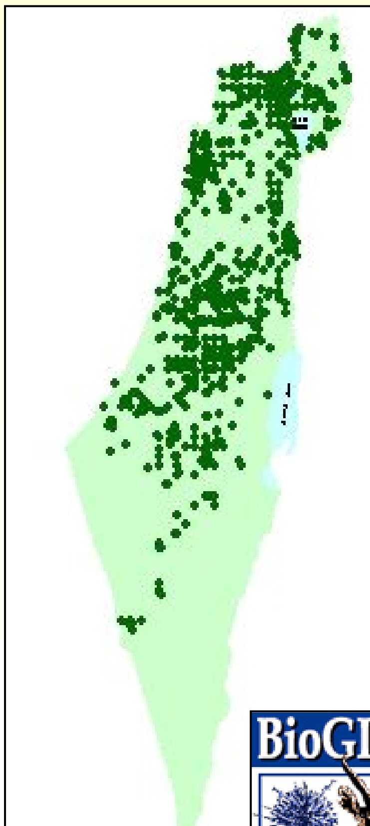
Inherent Uncertainty

The variance in the response variable induced by stochastic processes that is inexplicable by other uncertainty sources.

Forecasting plant response to climatic changes: modeling approaches

Bioclimate Envelope Models (BEMs)

Actual distribution map

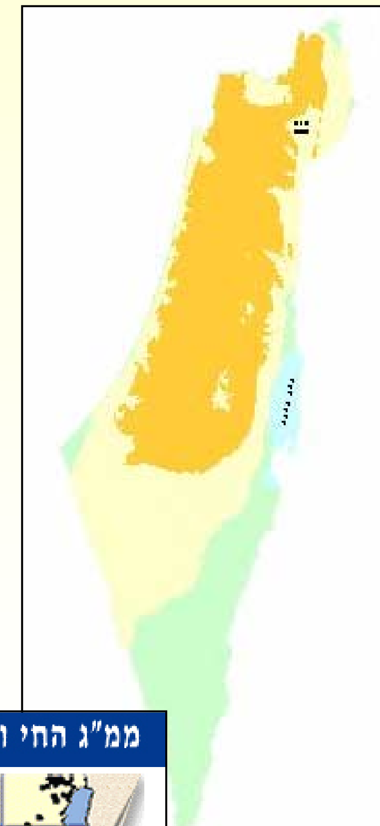


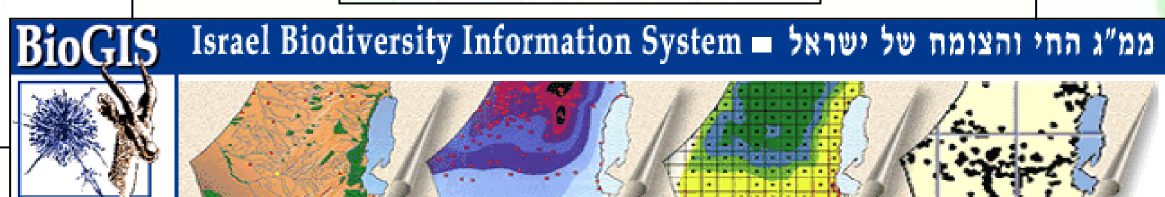
Observations

Niche profile

Variable	Minimum	Maximum	Average	Range	Standard deviation
Altitude [m]	-302.3	1090.3	349.1	1392.6	277.7
Mean annual rainfall [mm]	68.8	1074.7	517.4	1005.9	184.4
Mean January temperature [C]	4.5	13.3	10.1	8.8	1.6
Mean August temperature [C]	21.1	30.8	25.3	9.7	1.5
Minimal January temperature [C]	-1.2	4.3	2.9	5.5	1.0
Maximal June temperature [C]	26.9	39.4	33.0	12.3	2.4
Seasonal temperature range [C]	12.5	18.6	15.3	6.1	1.3

Predictive map

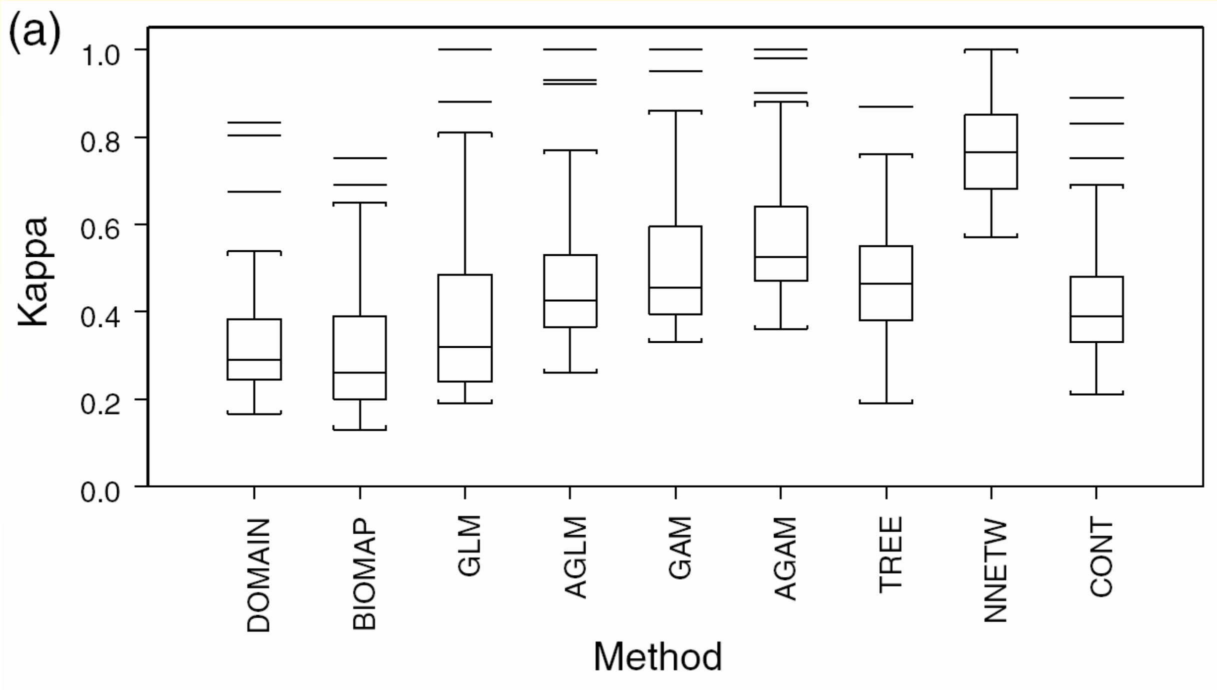




Forecasting plant response to climatic changes: modeling approaches

Bioclimate Envelope Models (BEMs)

(also called Bioclimatic Models, Niche-Based Models, Climate Equilibrium Models and alike)



From: Segurado& Araujo (2004), *Journal of Biogeography*

Forecasting plant response to climatic changes: modeling approaches

Bioclimate Envelope Models (BEMs)

letters to nature

Making mistakes when predicting shifts in species range in response to global warming

Andrew J. Davis*, Linda S. Jenkinson*, John H. Lawton†, Bryan Shorrocks* & Simon Wood†‡

NATURE | VOL 391 | 19 FEBRUARY 1998

<u>Major model uncertainty problems</u>:

BEMs do not account for

1. System Dynamics
2. Biotic Interactions
3. Evolutionary Change
4. Dispersal

Forecasting plant response to climatic changes: modeling approaches

Bioclimate Envelope Models (BEMs)

The importance of dispersal

ECOGRAPHY 27: 366–380, 2004

Potential impact of climatic change on the distribution of in Europe

Flemming Skov and Jens-Christian Svenning

Climatic variables:

Growing Degree Days (GDD)

→ **heat requirements**

Absolute minimum temperature

→ **cold tolerance**

Water balance

→ **moisture requirements**

Two climate change scenarios

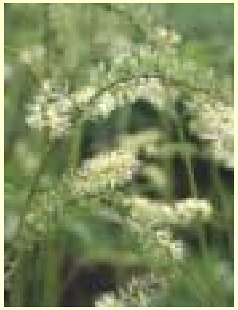
The B1 scenario - constant or gradually declining human population, rapid change toward a service and information economy, reduced use of natural resources and the use of clean and resource-efficient technologies **("optimistic"**).

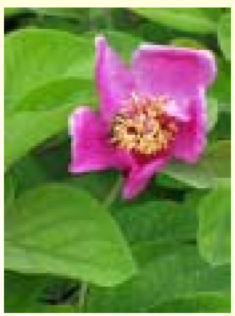
The A2 scenario - continuously increasing human population, economic development primarily regionally and fragmented (**"business-as-usual"**)

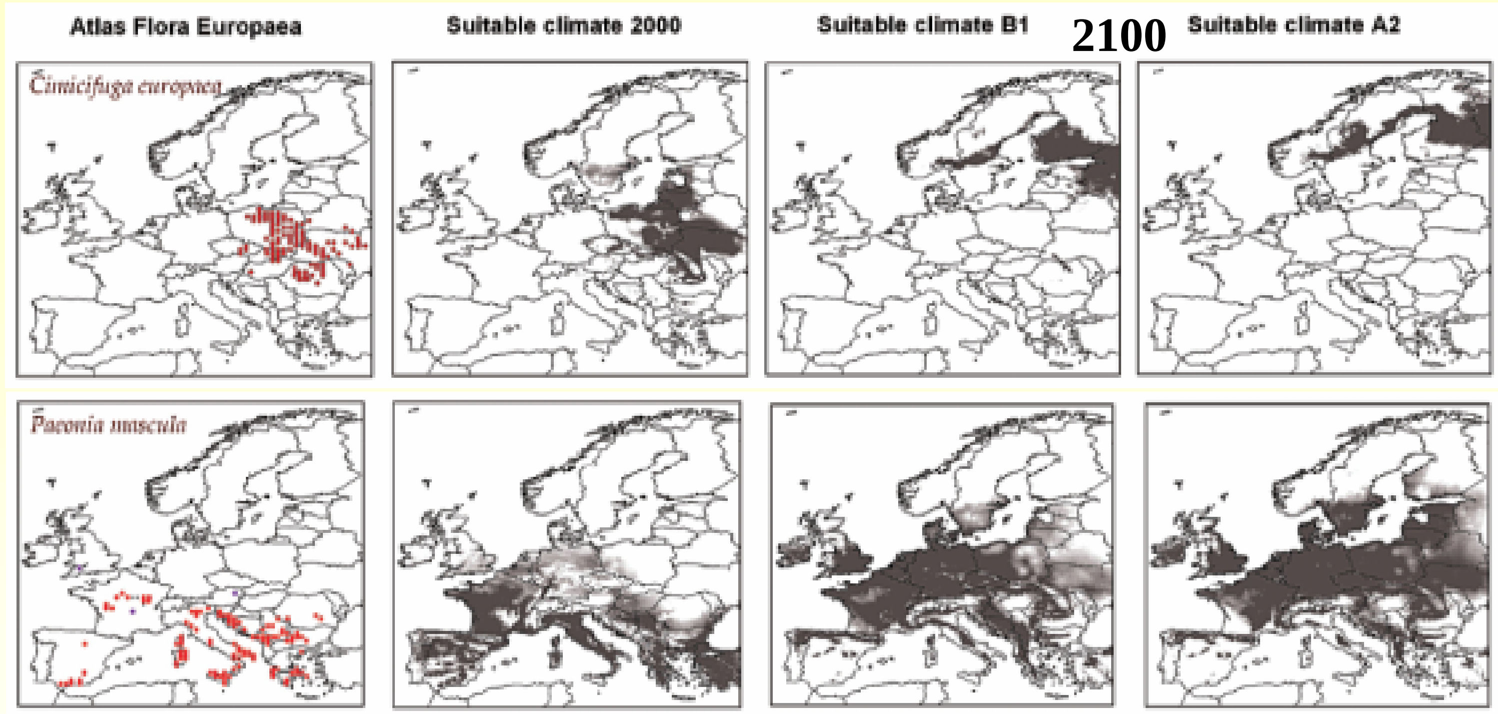
IPCC (2001)

Applied to 26 European forest herb species

Examples of distribution maps







Can plant species spread so fast?

Required minimum spread rate for tracking the potential range shift:

B1 scenario: 2.1 km/year

A2 scenario: 3.9 km/year

From: Skov & Svenning (2004), *Ecography*

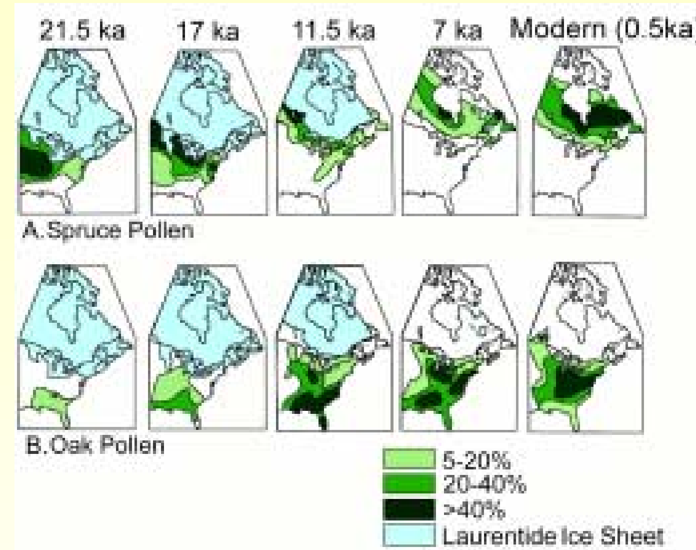
Can plant species spread so fast?

Reid's Paradox of Rapid Plant Migration

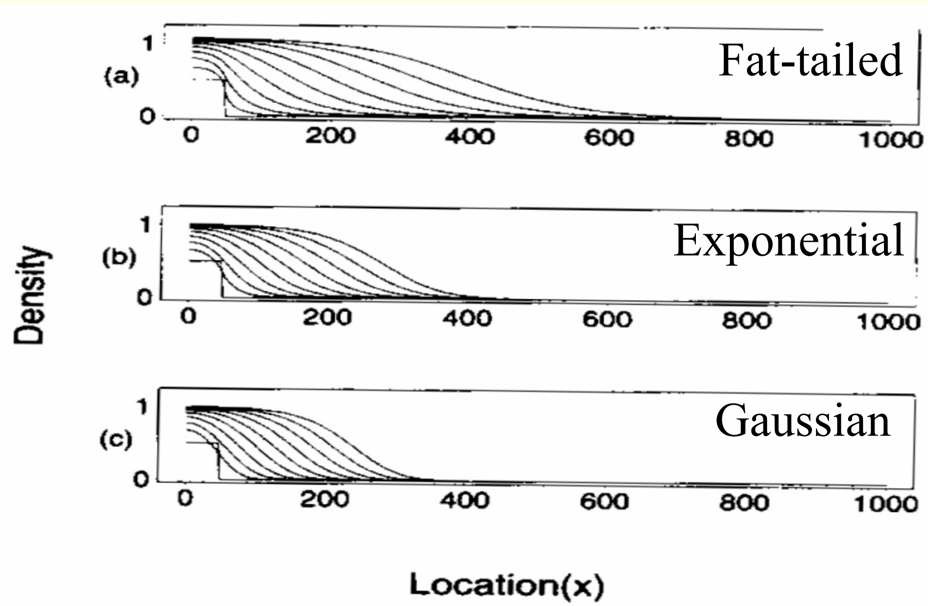
Dispersal theory and interpretation of paleoecological records

James S. Clark, Chris Fastie, George Hurtt, Stephen T. Jackson, Carter Johnson, George A. King, Mark Lewis, Jason Lynch, Stephen Pacala, Colin Prentice, Eugene W. Schupp, Thompson Webb III, and Peter Wyckoff

BioScience Vol. 48 No. 1 *January 1998*



From: Davis & Shaw (2001), *Nature*

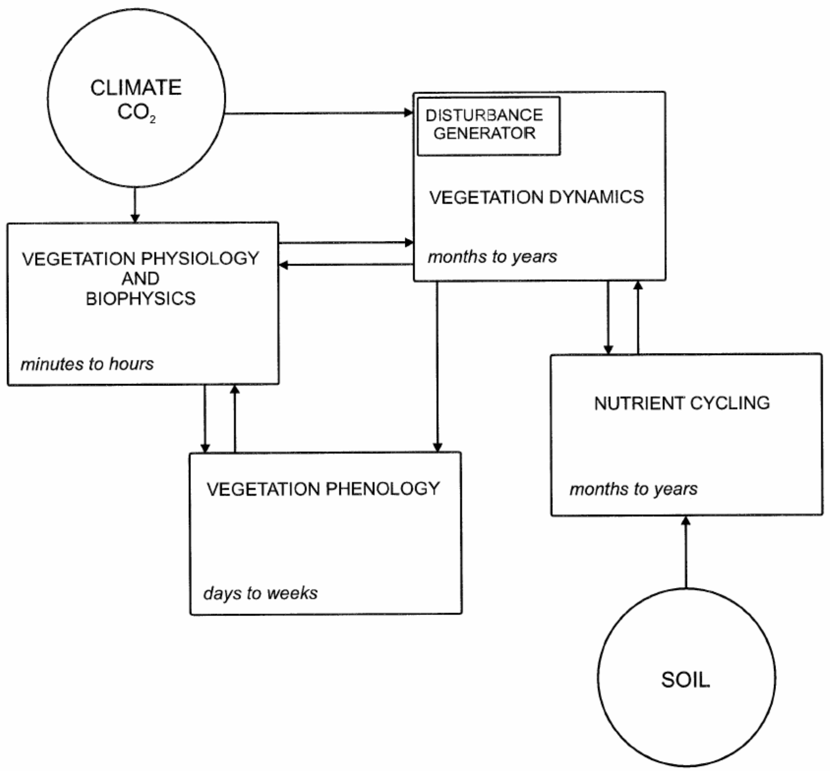


From: Clark et al. (1998), *BioScience*

→ only long-distance dispersal (LDD) events can explain the rapid spread rates of the last post-glacial!

Forecasting plant response to climatic changes: modeling approaches

Alternative to BEMs – Dynamic Global Vegetation Models (DGVMs)



From: Cramer et al. (2001), *Global Change Biology*

Major model uncertainty problems of BEMs:

✓ 1. System Dynamics
✓ 2. Biotic Interactions
?✓ 3. Evolutionary Change
X 4. Dispersal

Forecasting plant response to climatic changes:

Dynamic Global Vegetation Models (DGVMs)

Required modifications

Forecasting Regional to Global Plant Migration in Response to Climate Change: Challenges and Directions

R.P. Neilson, L.F. Pitelka, A.M. Solomon, R. Nathan,
G.F. Midgley, J.M.V. Fragoso, H. Lischke & K. Thompson

BioScience **(In Press)**

Major model uncertainty challenges:

1. **Dispersal and long-distance dispersal (LDD) in particular**
2. **Scale-dependency and landscape heterogeneity**
3. **Economic classification of Plant Functional Types (PTPs)**

Major model uncertainty challenges:

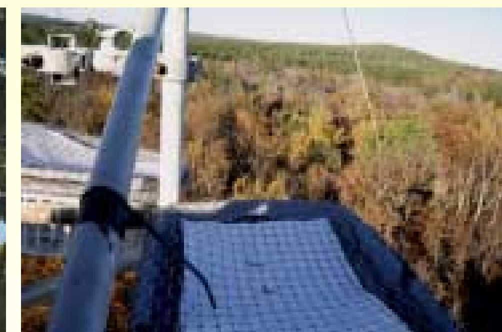
1. Dispersal and long-distance dispersal (LDD) in particular
2. Scale-dependency and landscape heterogeneity
3. Economic classification of Plant Functional Types (PTPs)

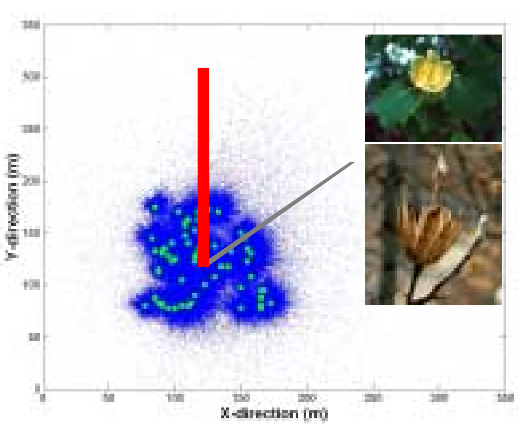
letters to nature

Mechanisms of long-distance dispersal of seeds by wind

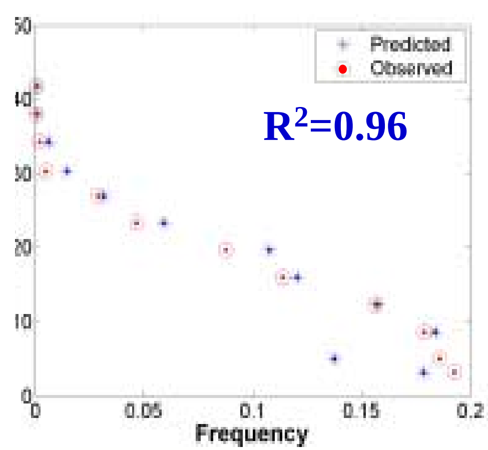
Ran Nathan*, Gabriel G. Katul†, Henry S. Horn‡, Suvi M. Thomas‡, Ram Oren†, Roni Avissar§, Stephen W. Pacala‡ & Simon A. Levin‡

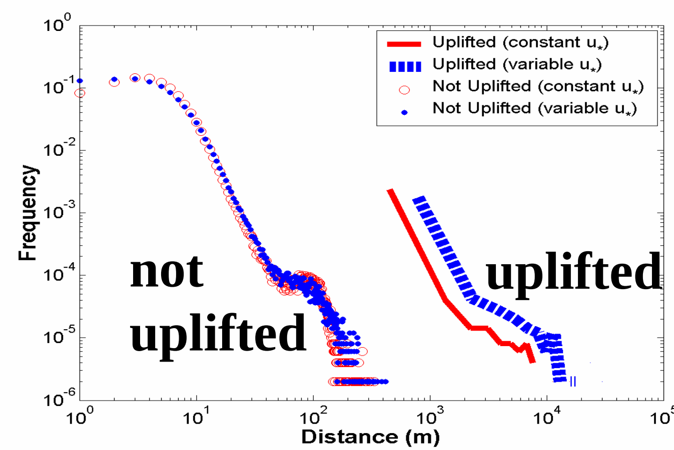
NATURE | VOL 418 | 25 JULY 2002





Liriodendron tulipifera





From: Nathan et al. (2002), *Nature*

Major “model uncertainty” challenges:

1. Dispersal and long-distance dispersal (LDD) in particular
2. Scale-dependency and landscape heterogeneity
3. Economic classification of Plant Functional Types (PTPs)

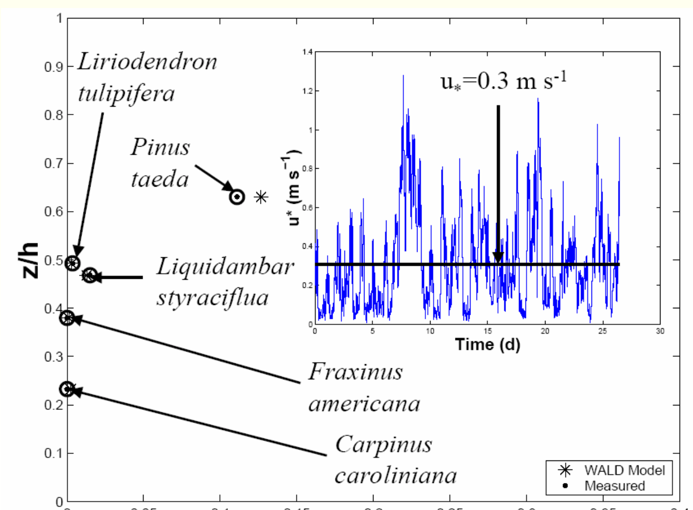
Mechanistic Analytical Models for Long-Distance Seed Dispersal by Wind

G.G. Katul, A. Porporato, R. Nathan, M. Siqueira, M.B. Soons, D. Poggi, H.S. Horn and S.A. Levin

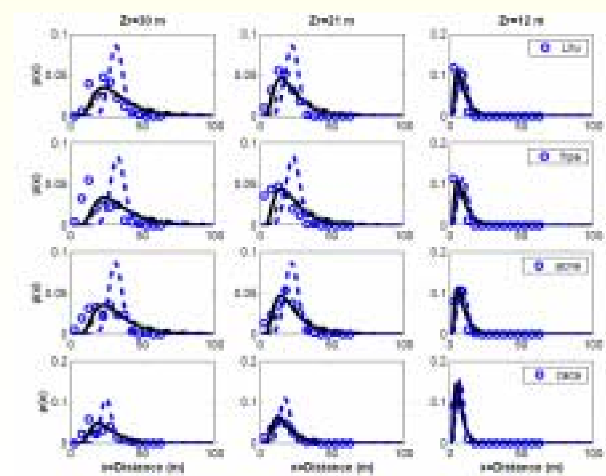
***The American Naturalist* (In Press)**

Wald **A**nalytical **L**ong-distance **D**ispersal (**WALD**) model

Standardized mean height of seed release



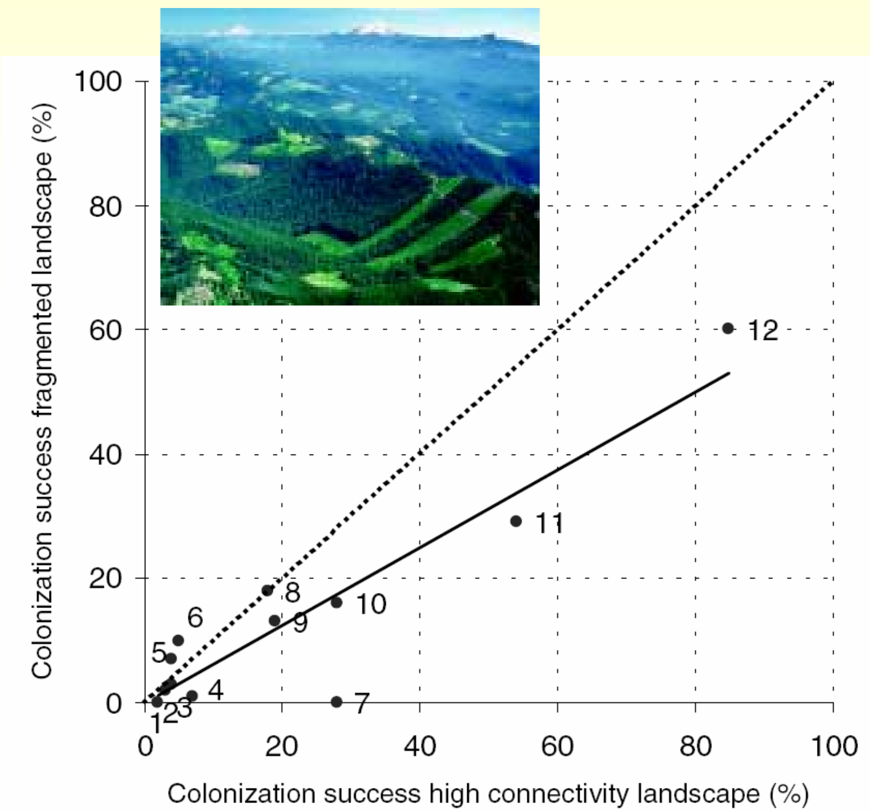
Probability of uplifting Pr(z/h>1)



From: Katul et al. (In Press), *The American Naturalist*

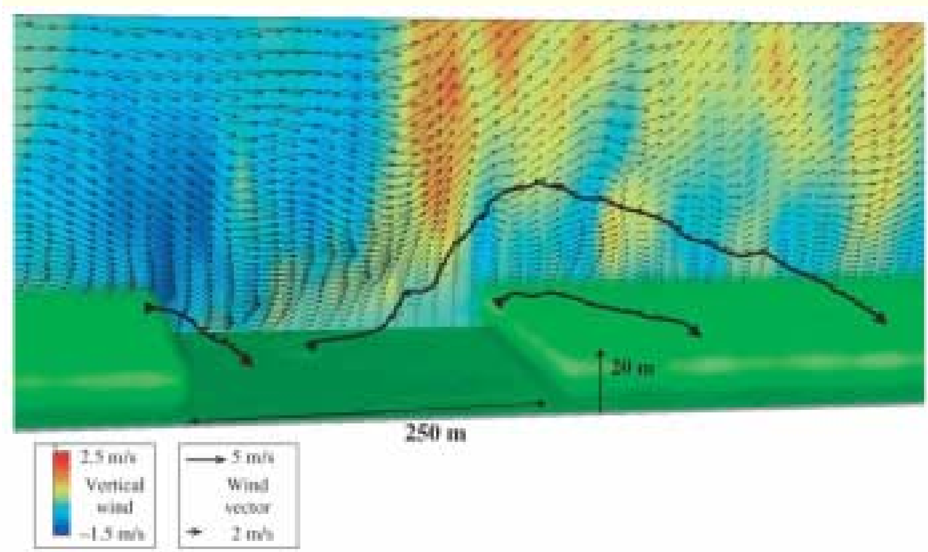
<u>Major “model uncertainty” challenges</u>:

1. Dispersal and long-distance dispersal (LDD) in particular
2. **Scale-dependency and landscape heterogeneity**
3. Economic classification of Plant Functional Types (PTPs)



From: Honnay et al. (2002), *Ecology Letters*

Large-Eddy Simulation (LES) of wind dispersal in a heterogeneous landscape (Avissar, Bohrer and Otte)



From: Nathan et al. (2005), *Diversity & Distributions*

Major “model uncertainty” challenges:

1. Dispersal and long-distance dispersal (LDD) in particular
2. Scale-dependency and landscape heterogeneity
3. Economic classification of Plant Functional Types (PTPs)

TABLE 1. The assignment of eastern North American taxa to plant functional types (PFTs). These assignments follow the work of Prentice *et al.* (1996) with the addition of *Tsuga*, *Carya*, *Celtis*, and *Liquidambar*, which are eastern North American taxa not present in Europe

Taxa	Plant functional types										
	Boreal Ever-green Conifer	Cool Tempe-rate Conifer	Eury-thermic Conifer	Boreal Summer-green	Cool Tempe-rate Summer-green	Tempe-rate Summer-green	Warm Tempe-rate Summer-green	Warm Temp. Broad-Lvd. Evergrn.	Arctic Alpine Shrub	Sedge	Steppe Forbs	Desert Forbs
Picea	x											
Abies	x	x										
Tsuga		x										
Pinus	x		x									
Betula				x								
Alnus				x	x							
Populus				x								
Ulmus					x							
Fagus					x							
Ostrya-Carp.					x		x					
Corylus					x							
Acer					x	x						
Quercus						x						
Carya						x						
Fraxinus						x						
Castanea						x						
Tilia						x						
Celtis						x						
Juglans							x					
Platanus							x					
Liquidambar							x					
Cyperaceae										x		
Prairie Forbs											x	x

PFT Classification

1. Growth form
2. Leaf form
3. Phenology
4. Climatic requirements

? 5. Capacity for LDD

From: Williams et al. (1998), *Quaternary Science Reviews*

Major "model uncertainty" challenges:

1. Dispersal and long-distance dispersal (LDD) in particular
2. Scale-dependency and landscape heterogeneity
3. **Economic classification of Plant Functional Types (PTPs)**

Ecology, 84(8), 2003, pp. 1945–1956

ARE LONG-DISTANCE DISPERSAL EVENTS IN PLANTS USUALLY CAUSED BY NONSTANDARD MEANS OF DISPERSAL?

S. I. Higgins,[1,4] R. Nathan,[2] and M. L. Cain[3]

→ the relationship between morphologically-defined dispersal syndrome and long-distance dispersal is poor, because multiple processes often move seeds in a complex way.

PFT Classification

1. Growth form
2. Leaf form
3. Phenology
4. Climatic requirements

? 5. Capacity for LDD

→ are there differences among PTPs in the distribution of dispersal capacity?

Forecasting changes in the distribution and abundance of plants in response to climate change

1. **Recognize different levels of uncertainty.**
2. **Reduce *model uncertainty* by investigating and incorporating the key underlying mechanisms.**
3. **Incorporate system dynamics, evolutionary change, biological interactions and long-distance dispersal.**
4. **Reduce *parameter uncertainty* by utilizing advances in modeling, computing and monitoring techniques.**
5. **Examine the potential of DGVMs (or modify BEMs) for forecasting plant response to climate change.**

Thanks

Supporting Agencies:
The US National Science Foundation (NSF)
The Israeli Science foundation (ISF)
The German-Israeli Foundation (GIF)
The International Arid Land Consortium (IALC)
The US-Israel Binational Science Foundation (BSF)

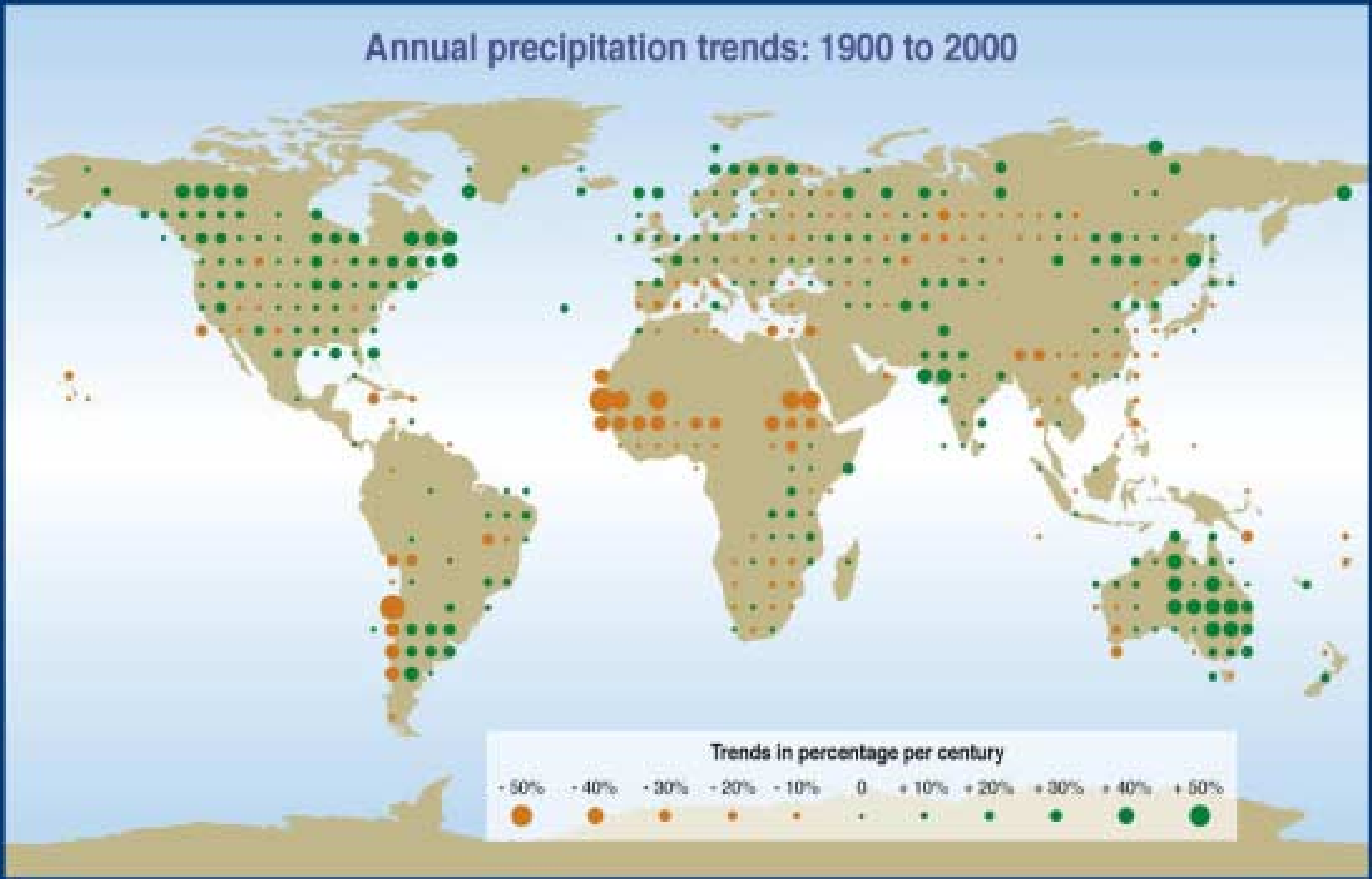
Colleagues
Gabriel Katul, Simon Levin, Roni Avissar, Henry Horn, Ron Nielson, Louis Pitelka, Steve Higgins, Helene Muller-Landau, Joe Wright, Merel Soons, Michael Cain, Amilcare Porporato, Gil Bohrer and HUJ ESE members.

My students, post-doc and assistant @ the Movement Ecology Lab, The Hebrew University of Jerusalem: Ofir Altstein, Tal Avgar, Luba Broitman, Itamar Giladi, Yoav Motro, Nir Sapir, Orr Spiegel, Ofer Steinitz, Ana Trakhtenbrot, David Troupin, Asaf Tsoar & Royi Zidon.

Aristolochia maxima

Mikania leiostachya

Photos by Steve Paton



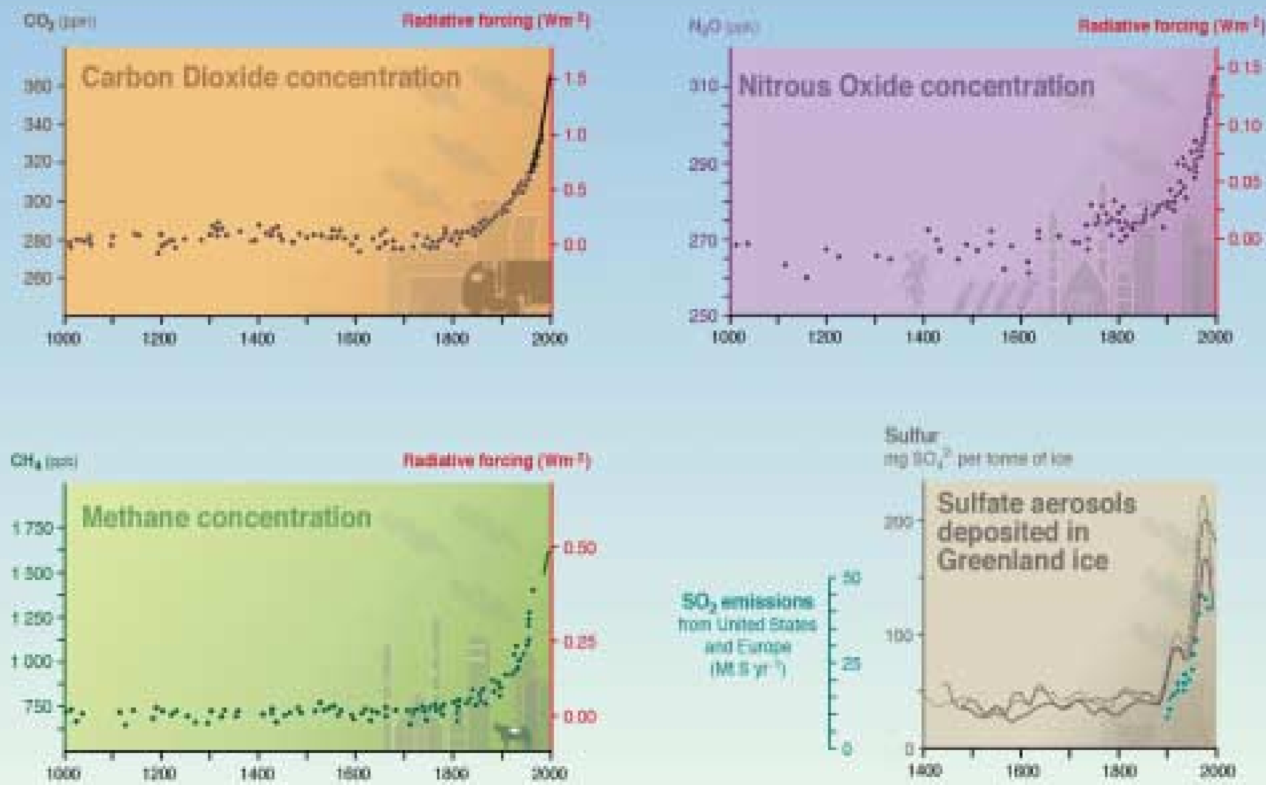
SYR - FIGURE 2-6a

IPCC

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

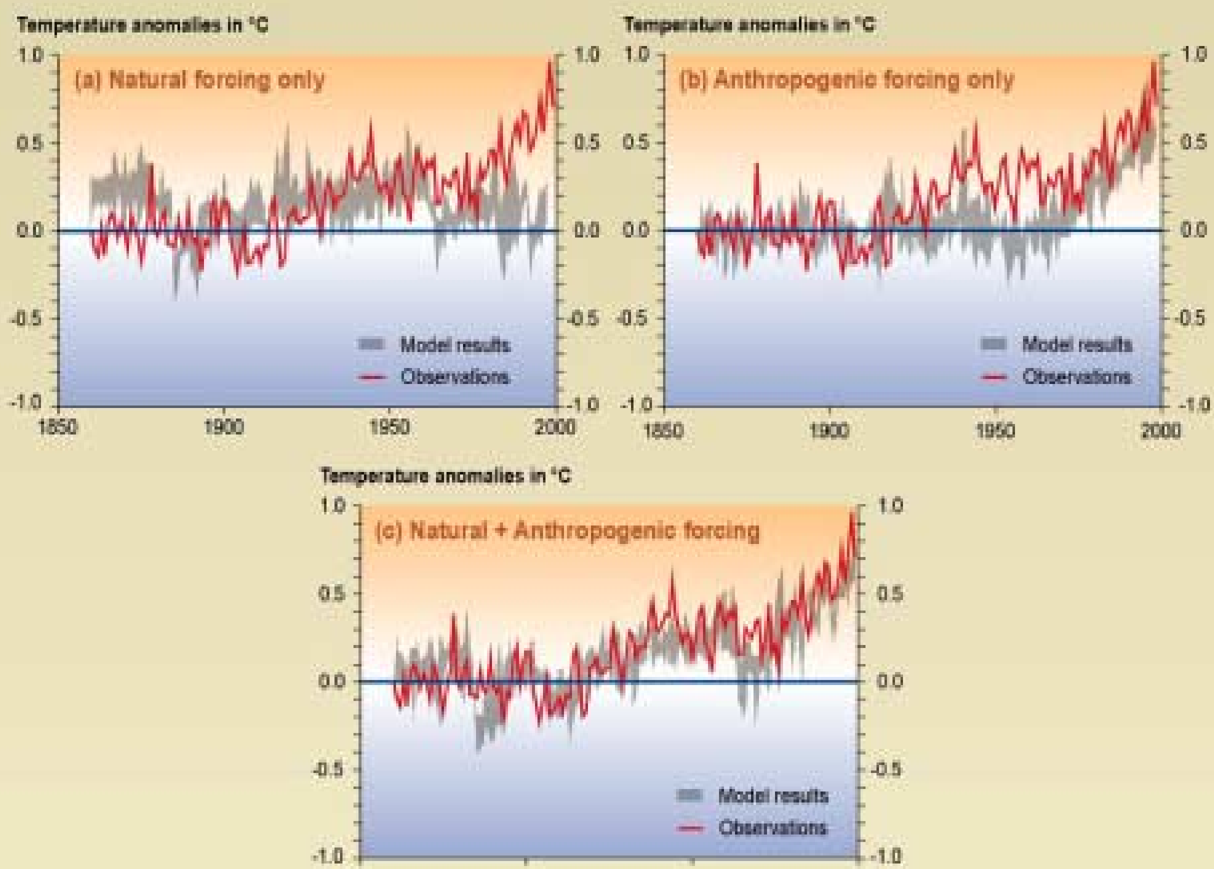
Indicators of the human influence on the atmosphere during the Industrial era



SYR - FIGURE 2-1
WG1 FIGURE SPM-2

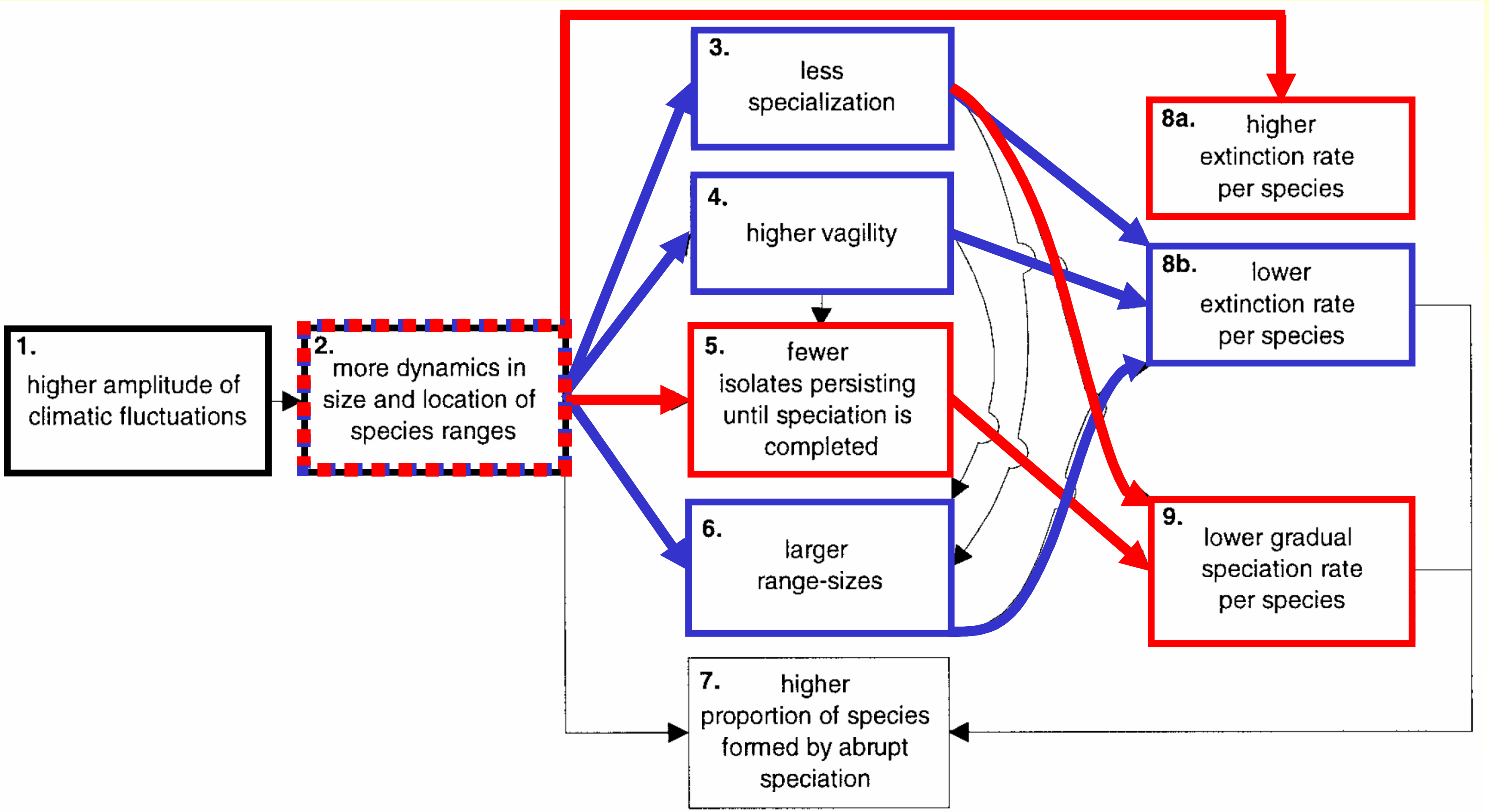
WMO UNEP

Comparison between modeled and observations of temperature rise since the year 1860



SYR - FIGURE 2-4

Inter-relationships among different levels of response



From: Dynesius & Jansson (2000), PNAS

How climate changes affect world's biota?

Evolutionary level

Selection for/against life-history traits, speciation, extinction

letters to nature

Extinction risk from climate change

Chris D. Thomas[1], Alison Cameron[1], Rhys E. Green[2], Michel Bakkenes[3], Linda J. Beaumont[4], Yvonne C. Collingham[5], Barend F. N. Erasmus[6], Marinez Ferreira de Siqueira[7], Alan Grainger[8], Lee Hannah[9], Lesley Hughes[4], Brian Huntley[5], Albert S. van Jaarsveld[10], Guy F. Midgley[11], Lera Miles[8]*, Miguel A. Ortega-Huerta[12], A. Townsend Peterson[13], Oliver L. Phillips[8] & Stephen E. Williams[14]

NATURE | VOL 427 | 8 JANUARY 2004

…we predict, on the basis of mid-range climate-warming scenarios for 2050, that 15–37% of species in our sample of regions and taxa will be 'committed to extinction'.

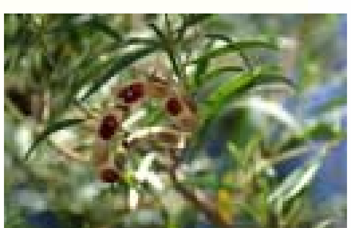
Community/Ecosystem level

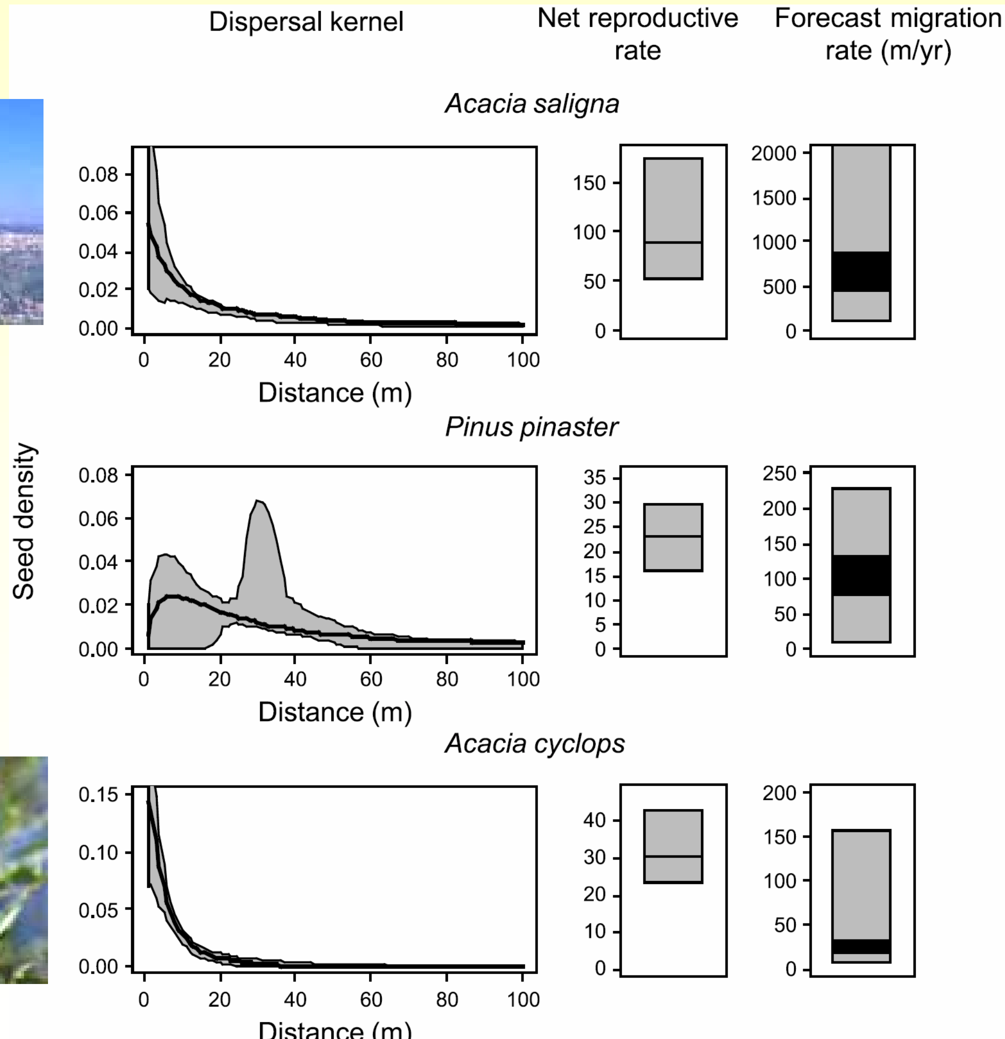
Changes in diversity patterns, ecosystem processes

Species/Population level

Changes in distribution and abundance

Forecasting plant response to climatic changes: sources of uncertainty





Uncertainty types are represented by 90% confidence intervals of the forecasts, estimated by non-parametric bootstrapping for

Parameter Uncertainty

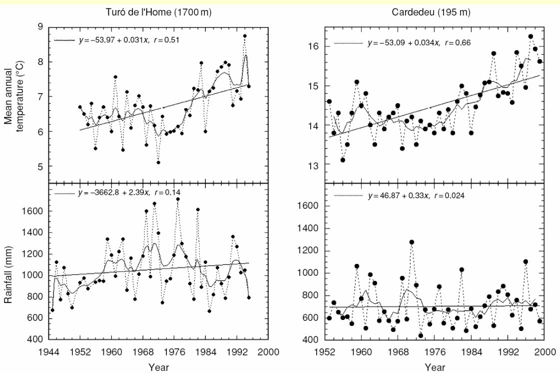
and by maximum-likelihood estimates for

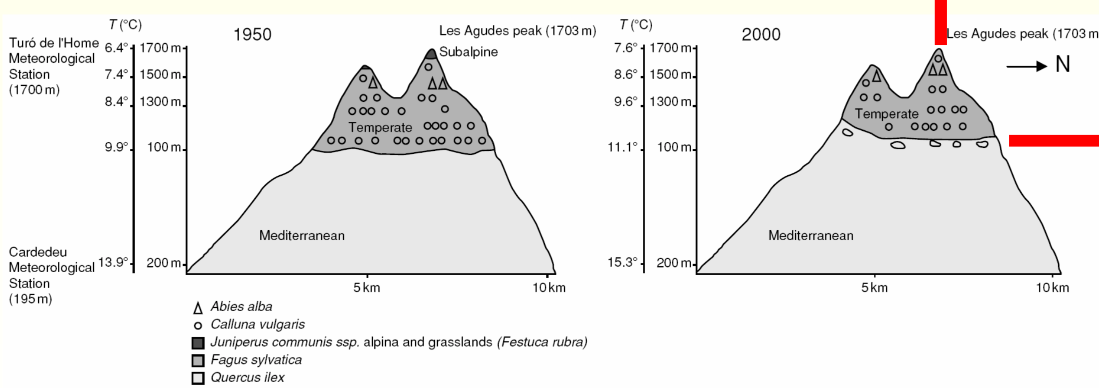
Inherent Uncertainty

From: Higgins et al. (2003), *Journal of Ecology*

Climatic changes alter plant distribution: contemporary evidence

Montseny mountains in Catalonia (NE Spain)





From: Penuelas & Boada (2003), *Global Change Biology*

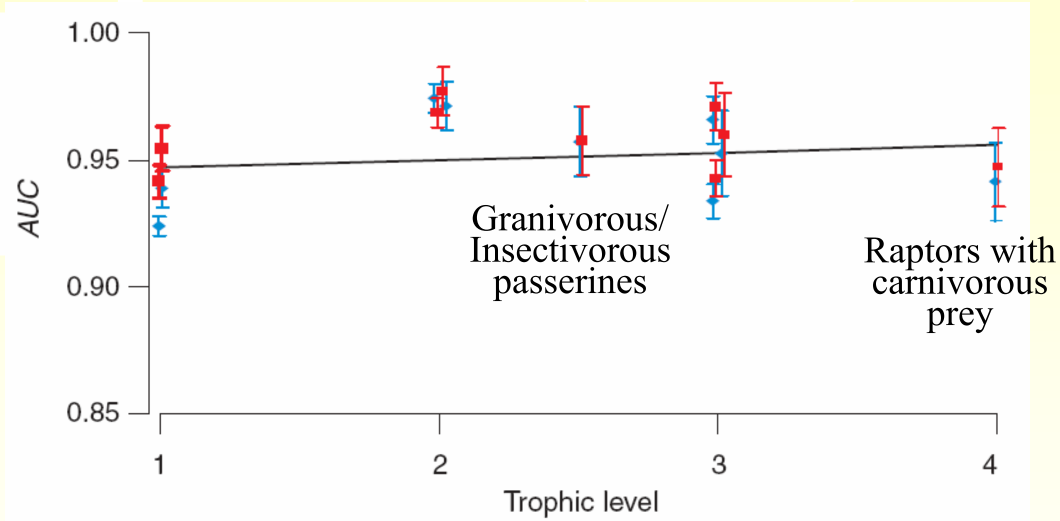
Forecasting plant response to climatic changes: modeling approaches

Bioclimate Envelope Models (BEMs)

Ecology Letters, (2004) **7**: 417–426 doi: 10.1111/j.1461-0248.2004.00598.x

The performance of models relating species geographical distributions to climate is independent of trophic level

Brian Huntley[1]*, Rhys E. Green[2], Yvonne C. Collingham[1], Jane K. Hill[1,3], Stephen G. Willis[1], Patrick J. Bartlein[4], Wolfgang Cramer[5], Ward J. M. Hagemeijer[6] and Christopher J. Thomas[1]



Higher plants

Herbivorous insects

Granivorous passerines

Insectivorous passerines

Insectivorous raptors

Raptors with herbivorous prey

By showing that such models can be applied with equal validity to species from different trophic levels, and that they generally perform well for species from disparate taxonomic groups, the present study has provided additional evidence of **the robustness and general applicability of such models**.

From: Huntley et al. (2004), *Ecology Letters*

Forecasting plant response to climatic changes: modeling approaches

Bioclimate Envelope Models (BEMs)

Robust and general applicable?

letters to nature

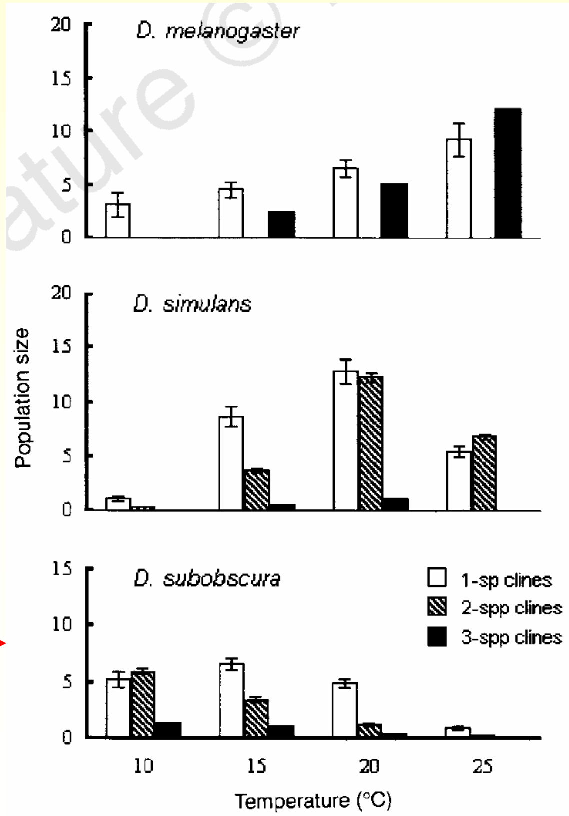
Making mistakes when predicting shifts in species range in response to global warming

Andrew J. Davis*, Linda S. Jenkinson*, John H. Lawton†, Bryan Shorrocks* & Simon Wood†‡

NATURE | VOL 391 | 19 FEBRUARY 1998

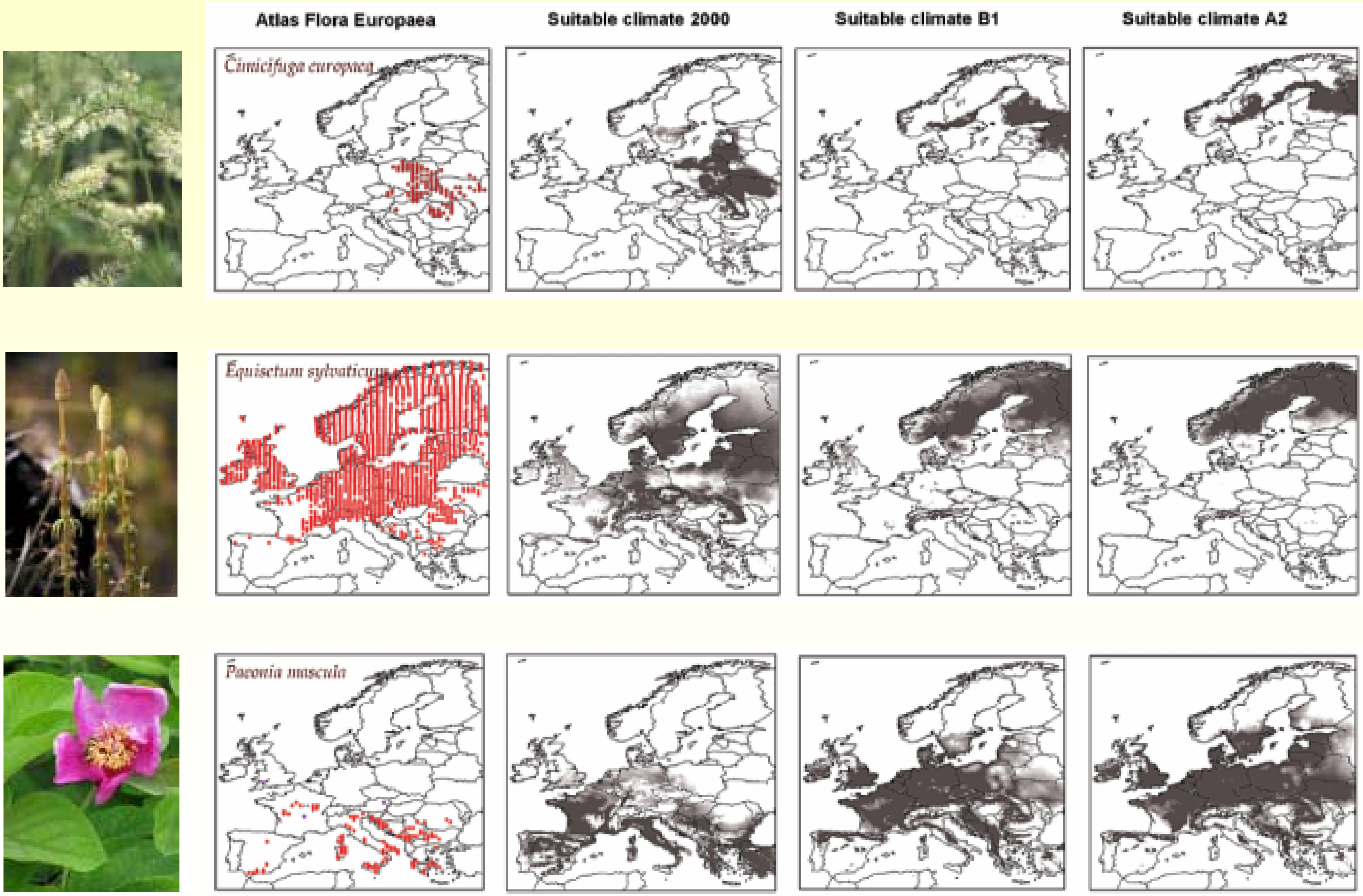
Major model uncertainty problems:

1. Biotic Interactions
2. Evolutionary Change
3. Dispersal



From: Davis et al. (1998), *Nature*

Examples of distribution maps



From: Skov & Svenning (2004), *Ecography*

Forecasting plant response to climatic changes: modeling approaches

Alternative to BEMs – Dynamic Global Vegetation Models (DGVMs)

Global Change Biology (2001) **7**, 357–373

Global response of terrestrial ecosystem structure and function to CO_2 and climate change: results from six dynamic global vegetation models

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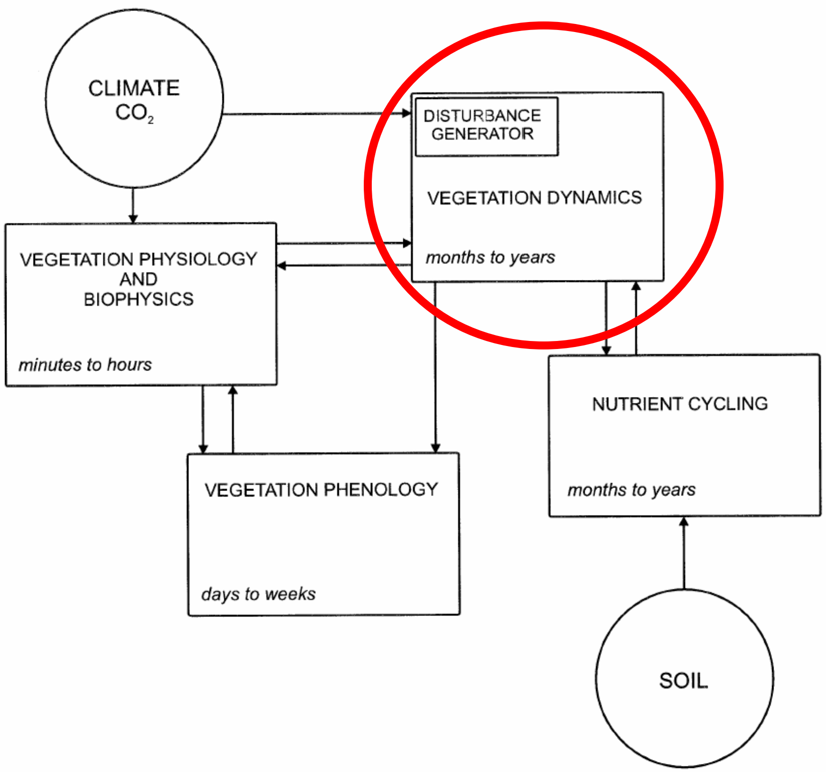


Major model uncertainty problems of BEMs:

✓ 1. Biotic Interactions

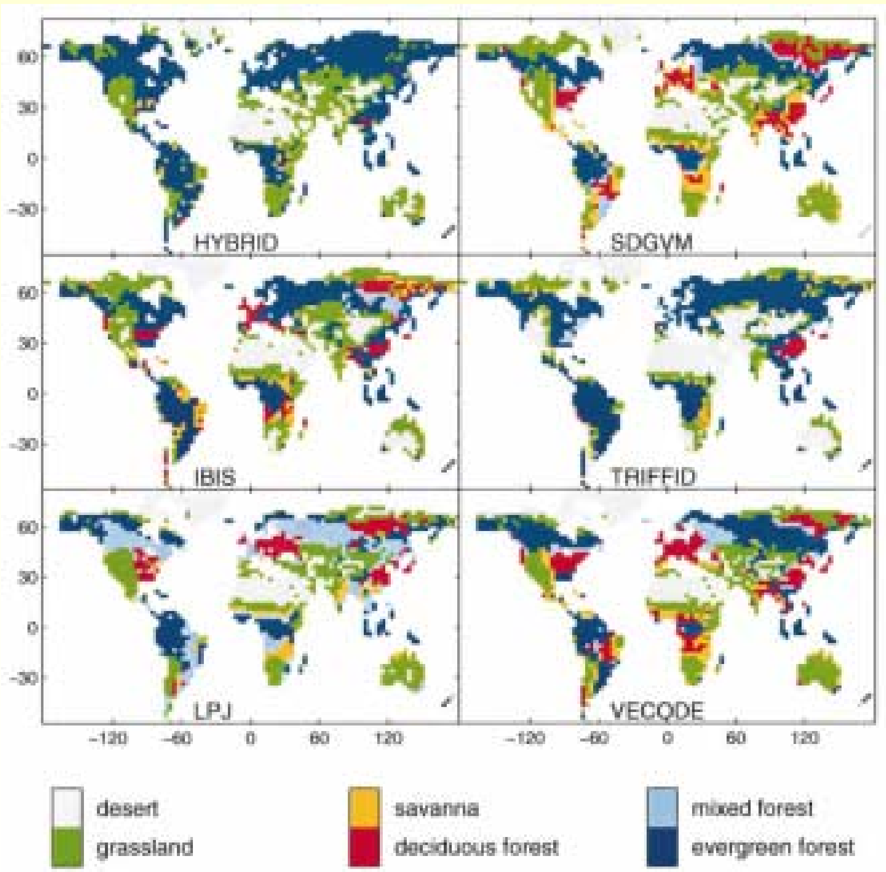
? 2. Evolutionary Change

X 3. Dispersal

From: Cramer et al. (2001), *Global Change Biology*

Forecasting plant response to climatic changes:

Dynamic Global Vegetation Models (DGVMs)



From: Cramer et al. (2001), *Global Change Biology*

Plant Functional Types (PTPs)

TABLE 1. The assignment of eastern North American taxa to plant functional types (PFTs). These assignments follow the work of Prentice *et al.* (1996) with the addition of *Tsuga*, *Carya*, *Celtis*, and *Liquidambar*, which are eastern North American taxa not present in Europe

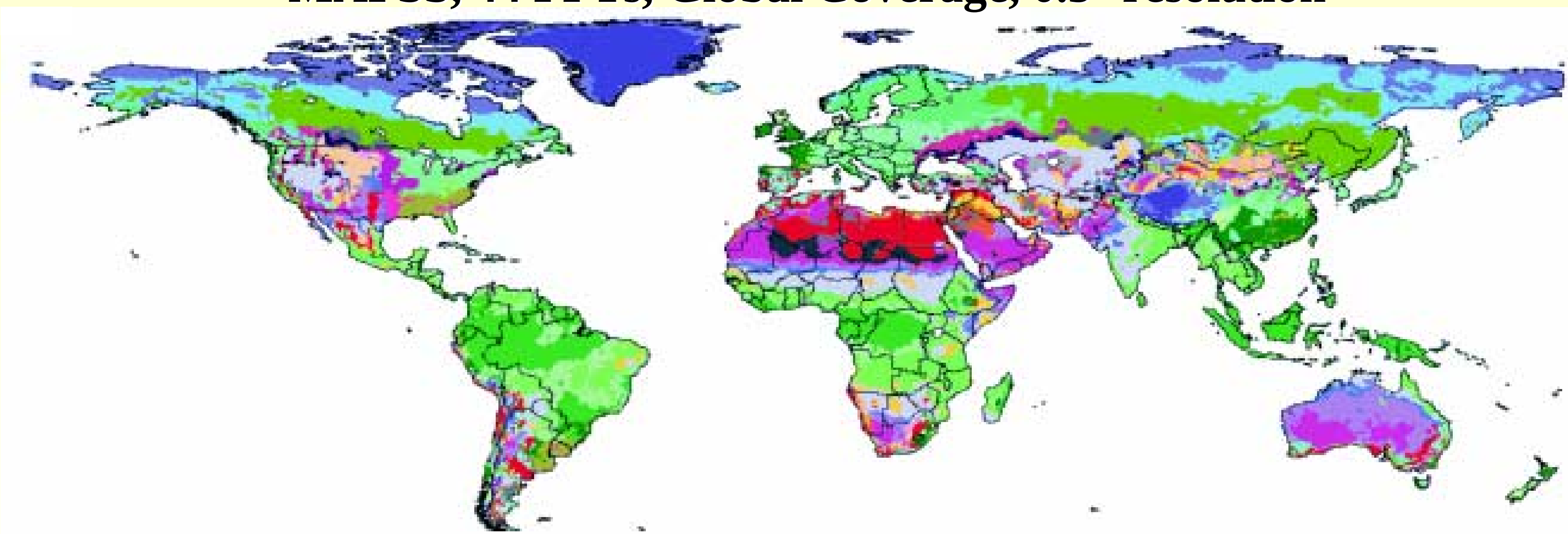
Taxa	Plant functional types										
	Boreal Ever-green Conifer	Cool Tempe-rate Conifer	Eury-thermic Conifer	Boreal Summer-green	Cool Tempe-rate Summer-green	Tempe-rate Summer-green	Warm Tempe-rate Summer-green	Warm Temp. Broad-Lvd. Evergrn.	Arctic Alpine Shrub	Sedge	Steppe Forbs	Desert Forbs
Picea	X											
Abies	X	X										
Tsuga		X										
Pinus	X		X									
Betula				X					X			
Alnus				X	X				X			
Populus				X								
Ulmus					X							
Fagus					X							
Ostrya-Carp.					X		X					
Corylus					X							
Acer					X	X						
Quercus						X		X				
Carya						X						
Fraxinus						X						
Castanea						X						
Tilia						X						
Celtis						X						
Juglans							X					
Platanus							X					
Liquidambar							X					
Cyperaceae										X		
Prairie Forbs											X	X

From: Williams et al. (1998), *Quaternary Science Reviews*

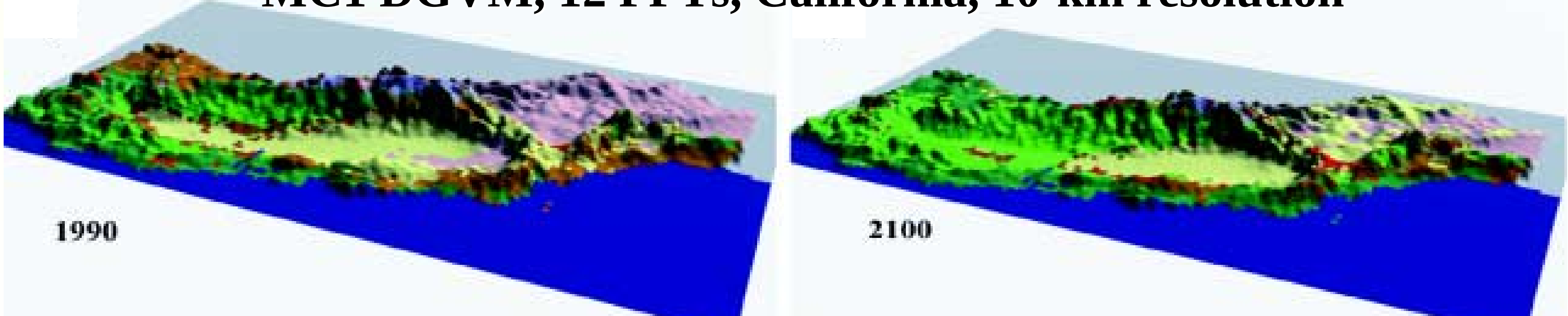
Forecasting plant response to climatic changes:

Dynamic Global Vegetation Models (DGVMs)

MAPSS, 44 PFTs, Global Coverage, 0.5° resolution



MC1 DGVM, 12 PFTs, California, 10-km resolution



From: Neilson et al. (In Press), *BioScience*

<u>Major model uncertainty challenges</u>:

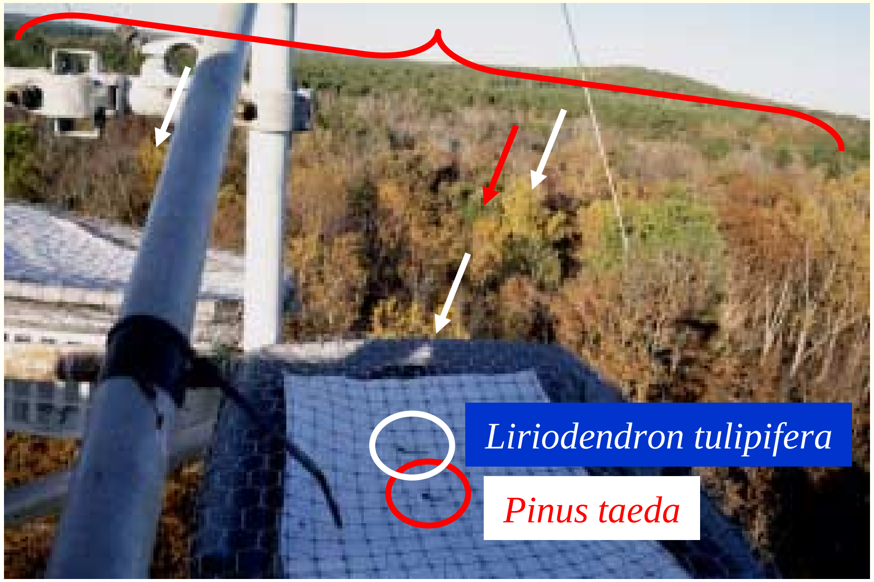
1. **Dispersal and long-distance dispersal (LDD) in particular**
2. **Scale-dependency and landscape heterogeneity**
3. **Economic classification of Plant Functional Types (PTPs)**

Photo by Nick Ledgard. From: Neilson et al. (In Press), *BioScience*

Major model uncertainty challenges:

1. Dispersal and long-distance dispersal (LDD) in particular
2. Scale-dependency and landscape heterogeneity
3. Economic classification of Plant Functional Types (PTPs)

A study of seed dispersal by wind at Duke Forest, NC, USA



Major model uncertainty challenges:

1. **Dispersal and long-distance dispersal (LDD) in particular**
2. Scale-dependency and landscape heterogeneity
3. Economic classification of Plant Functional Types (PTPs)

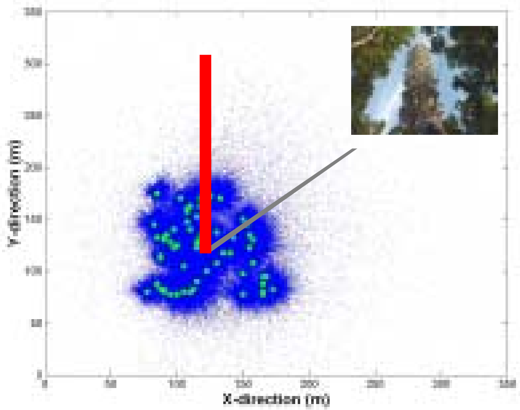
letters to nature

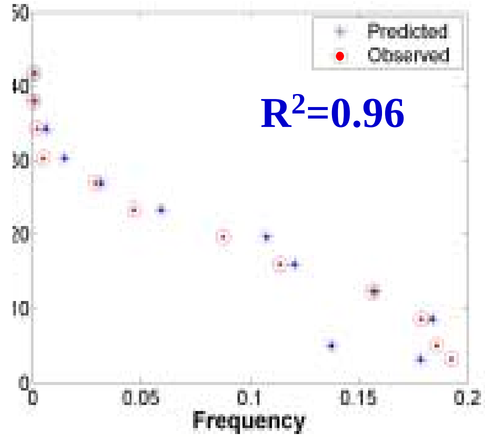
Mechanisms of long-distance dispersal of seeds by wind

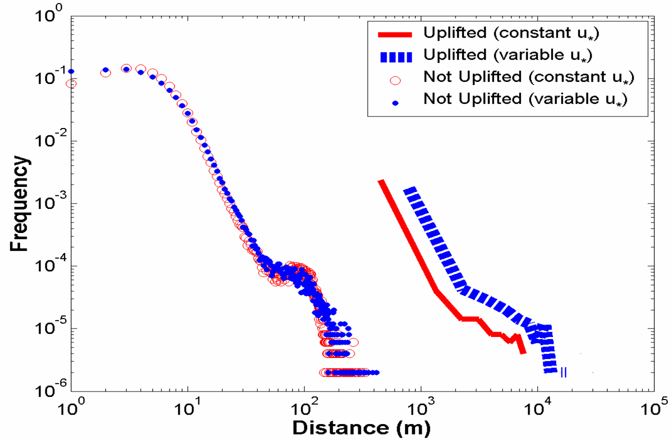
Ran Nathan*, Gabriel G. Katul†, Henry S. Horn‡, Suvi M. Thomas‡, Ram Oren†, Roni Avissar§, Stephen W. Pacala‡ & Simon A. Levin‡

NATURE | VOL 418 | 25 JULY 2002

Liriodendron tulipifera







From: Nathan et al. (2002), *Nature*

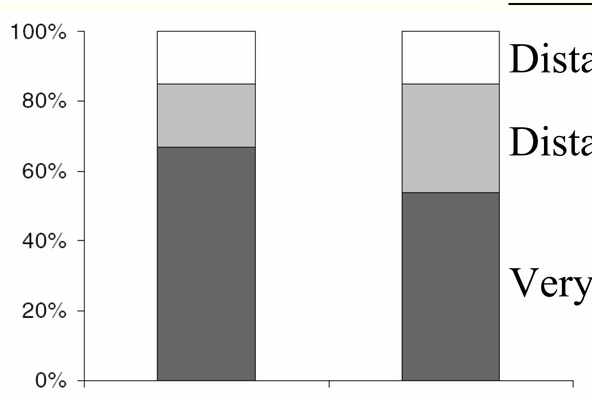
Major “model uncertainty” challenges:

1. Dispersal and long-distance dispersal (LDD) in particular
2. Scale-dependency and landscape heterogeneity
3. Economic classification of Plant Functional Types (PTPs)

Ecology Letters, (2002) **5**: 525–530

Possible effects of habitat fragmentation and climate change on the range of forest plant species

Olivier Honnay*, Kris Verheyen, Jan Butaye, Hans Jacquemyn, Beatrijs Bossuyt and Martin Hermy



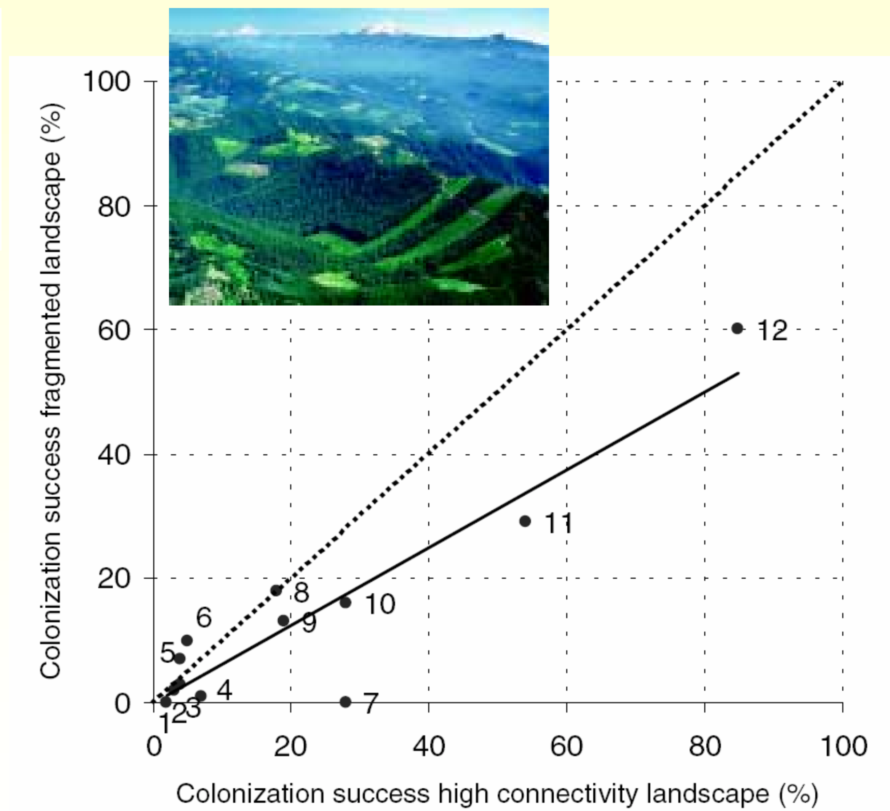
Fragmented High Connectivity

Colonization success:

Distance-independent

Distance-dependent

Very low (<5%)



From: Honnay et al. (2002), *Ecology Letters*

Major "model uncertainty" challenges:

1. Dispersal and long-distance dispersal (LDD) in particular
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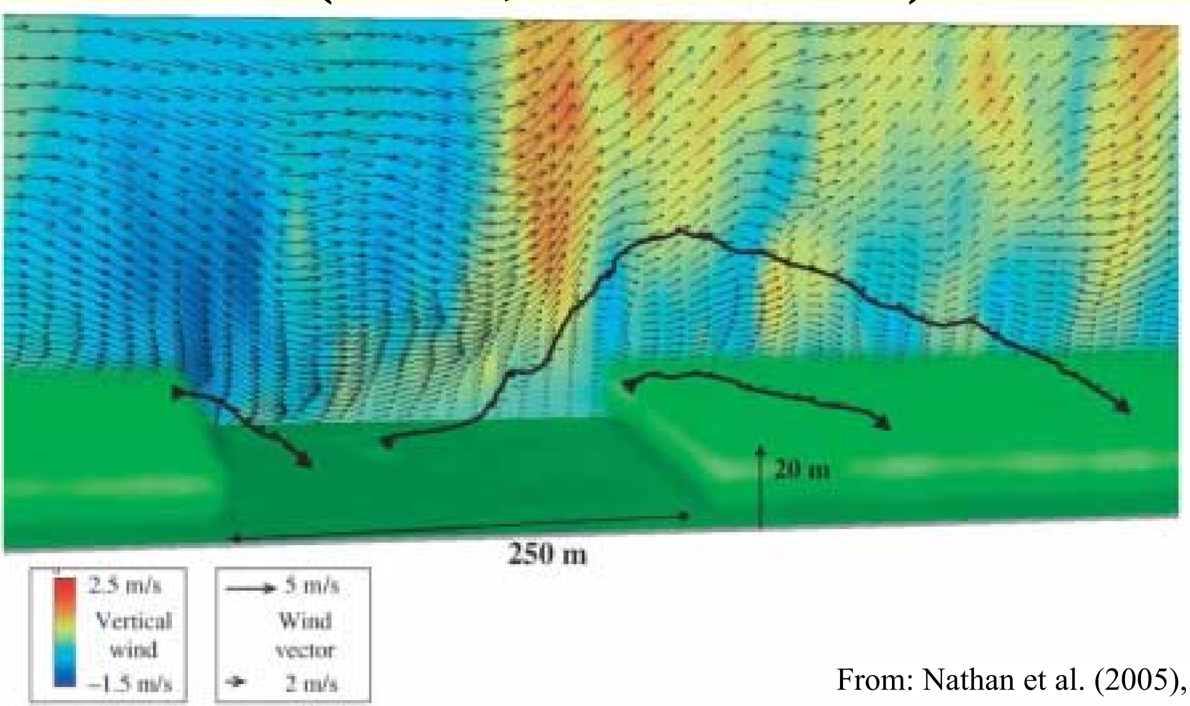
Wind dispersal in a heterogeneous landscape simulated using the Large-Eddy Simulation (LES) approach
(Avissar, Bohrer and Otte)



From: Nathan et al. (2005), *Diversity & Distributions*