



“What’s in store for trees in North America with climate change?”

BC FFEI Seminar November 20, 2008

Dan McKenney

Natural Resources Canada, Canadian Forest Service, Sault Ste Marie
(with John Pedlar, Kathy Campbell)

- Introduction – what we do
- Context - climate change
- Our work – “Plant hardiness” Project
- Climate change and trees analysis
- Discussion points and Conclusions

“Geospatial tools and economic analysis”
NRCan-CFS, Great Lakes Forestry Centre
Sault Ste Marie, Ontario

Primary activities

- **Spatial climate modeling**
 - the development of various models (data) that cover Canada and the US; being used by us, other researchers and various agencies (e.g. Env Can, Ag Can, Health Can., OMNR, FLUXNET ORNL, Woods Hole,...)
- **Species modeling (distribution, productivity, abundance)**
 - “Plant hardiness”, pest risk assessments, growth potential, climate change studies
- **Bioeconomic modeling (spatial and non-spatial cost-benefit and trade-off models)**
 - the economics of wood production, carbon, bioenergy, biosolids, non-commercial values; alien species spread and impact assessments

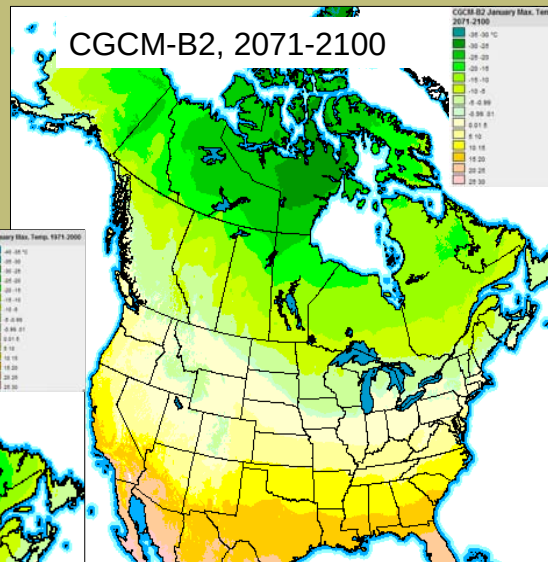
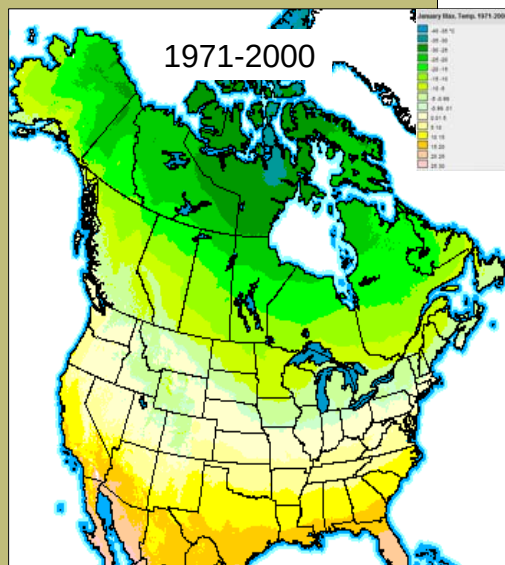
ANUSPLIN



Spatial Climate Modeling (a generic driver of ecological systems)

Models for Canada and North America

- Many variables and time steps
- Point estimates and grids
- Ongoing improvements
- Numerous journal articles and Tech Notes



Climate change scenarios

- CGCM2, A2, B2
- HadCM3, A2, B2
- CSIROmk2, A2, B2
- More underway

Data freely distributed to many agencies, researchers, planners, etc.

<http://cfs.nrcan.gc.ca/subsite/glfc-climate>

1000's unique hits each month...latest – Photovoltaic power potential



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Regional, National and International Climate Modeling

Regional, National and International Climate Modeling

Selected References

Long term mean climate grids for Canada and United States

Historical monthly climate grids for North America

Climate Change Scenario

Crop Heat Units (CHU) for the Maritime provinces

Other Miscellaneous surfaces

Bioclimatic Parameter definitions

Other bioclimatic variables

Proactive Disclosure

Proactive Disclosure

Regional, National and International Climate Modeling



We have been applying the thin plate spline smoothing algorithms (ANUSPLIN) developed by Dr. Michael Hutchinson of The Australian National University (<http://fennerschool.anu.edu.au/>) to Canadian and U.S. climate data. This work is in partnership with Dr. Hutchinson and The National Archive and Data Management Branch of Environment Canada. We thank them for access to data and for encouraging the development of our spatial climate models. We also would like to thank Tim Owen at the US National Climatic Data Center (<http://www.ncdc.noaa.gov/oa/ncdc.html>) for his assistance with US data for our North American models.

Thin plate splines should not be confused with simple univariate cubic splines. They can be thought of as a non-parametric, multi-dimensional curve fitting technique for application to noisy multi-variate data. ANUSPLIN offers an operationally efficient means to develop spatially continuous climate models ("surfaces"). This is especially important to many forest applications because weather station data are rarely available in remote forest locations.

The approach is also useful for mapping climate. Gridded climate data is often used for running spatial process models and other ecological applications. Many articles are available which describe the methods and applications in detail. [View list](#).

Our aims are to support climate impact and climate change analyses in forestry including species modeling, exotic species risk assessments and productivity studies. This page will be updated on an ongoing basis.

Our work includes the following.

1. Long term mean surfaces and grids for Canada and the United States
2. Monthly historical surfaces and grids dating from 1900 for North America
3. Climate change scenarios
4. Surfaces and grids of GCM and RCM climate change scenarios to support climate change impact studies.

Visit the Transient High Resolution Data link to download data at:
http://www.cics.uvic.ca/scenarios/index.cgi?Transient_High_Resolution_Data

Also see the Climate Change link at the Atlas of Canada for some maps and animations developed with partners. <http://atlas.gc.ca/site/english/maps/index.html>

5. Daily surfaces for parts of Canada from 1961 (contact Dan McKenney if interested)
6. Crop Heat Units (CHU) for the Maritime provinces
7. Other miscellaneous surfaces

Many of our climate grids are available for downloading, others require special permission because they have not been completely tested and/or peer reviewed. Point estimates at specific locations (eg. research plots, field locations) may also be available upon request from [Dan McKenney](#).

Frontline

Forestry Research Applications



Canadian Forestry Service - Sault Ste. Marie

Technical Note No. 108

Customized spatial climate models for Canada

Dan McKenney¹, Pia Papadopol¹, Kevin Lawrence¹, Kathy Campbell¹, Michael Hutchinson²

¹Canadian Forest Service – Sault Ste. Marie, Ontario

²Centre for Resource and Environmental Studies, The Australian National University;
Canberra ACT 0200 Australia

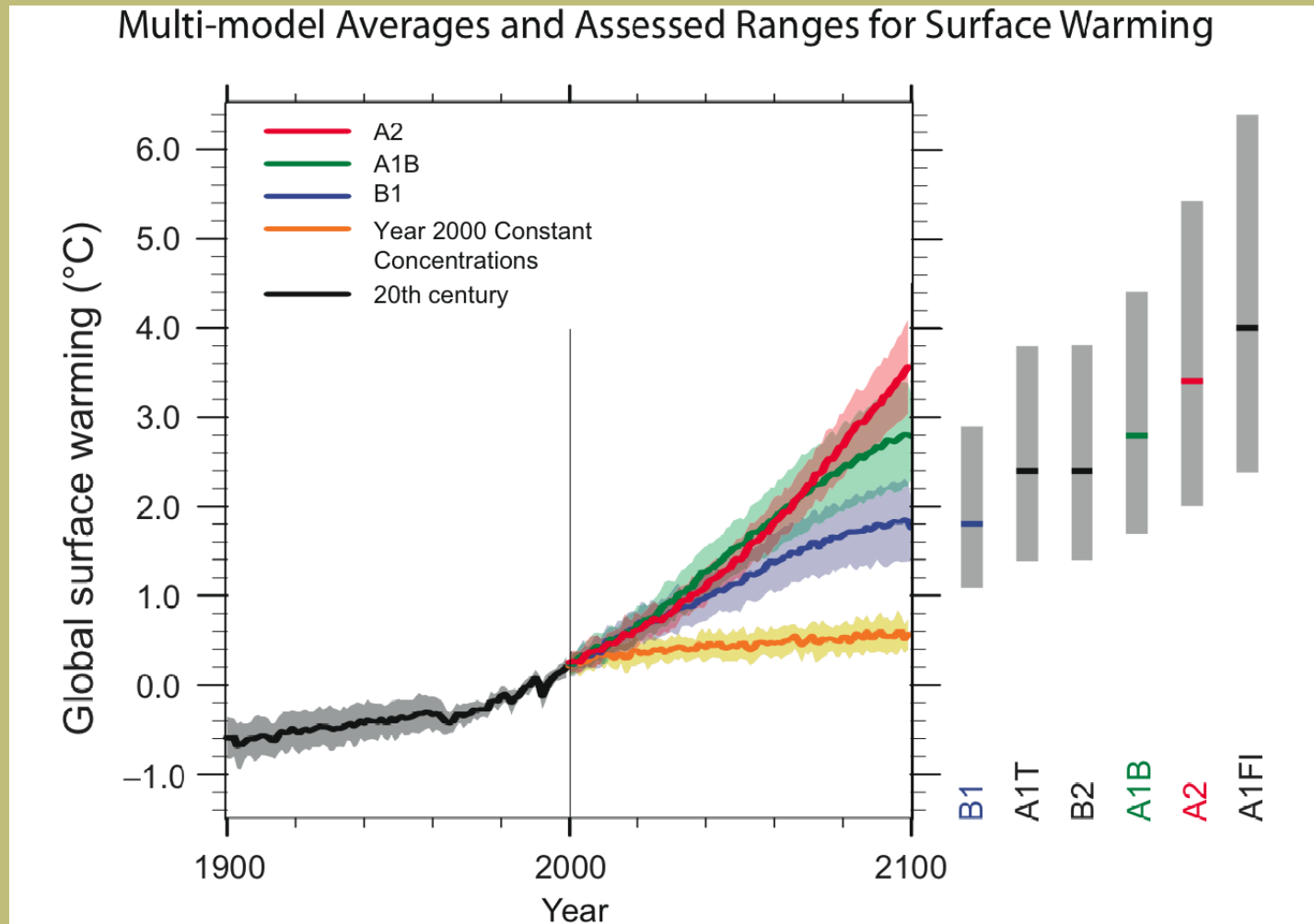
Introduction

The influence of climate is pervasive. At broad scales it drives plant/animal distributions, relative abundance and productivity. Weather – extreme heat and cold events – can affect human health. Precipitation affects hydroelectric power generation opportunities. Solar radiation affects plants but is also increasingly used as an energy source through photovoltaic panels. The list goes on. Thus there is a great need for high quality (read reliable) estimates of climate away from weather stations. This information can typically come in two forms – point estimates at specific locations such as research plots, farms, etc., and, secondly, point estimates at regular grid locations

The ANUSPLIN model

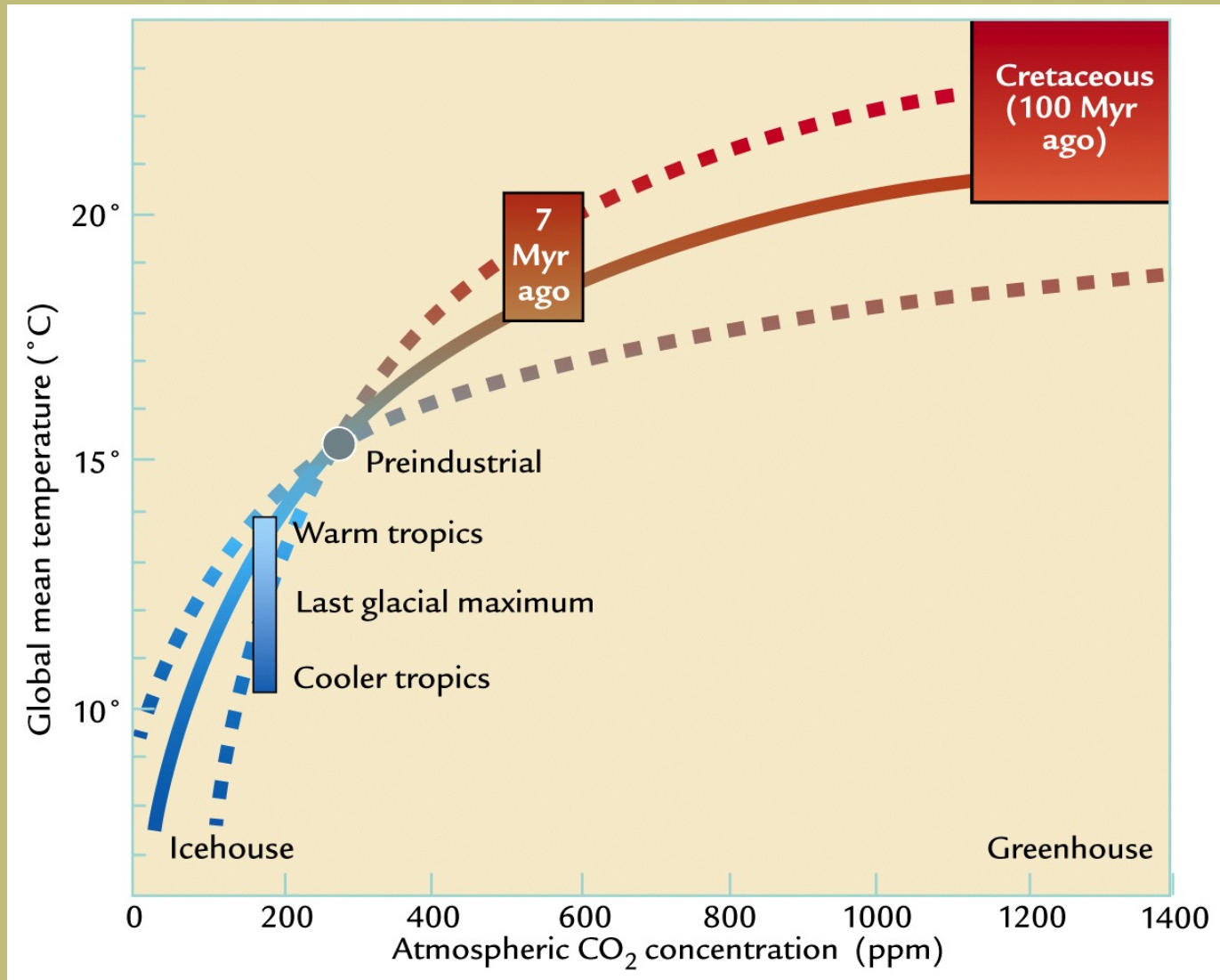
ANUSPLIN is a multi-variate non-parametric surface fitting approach to developing spatially continuous climate models. It makes use of thin plate-smoothing splines, which are a true multi-variate generalization of univariate splines, as described by Wahba (1990). They should not be confused with simple cubic polynomials. Earliest applications were described by Wahba and Wendelberger (1980) but the methodology has been further developed and made operational as a climate mapping tool by Professor Michael Hutchinson at the ANU over the last 20 years or so (e.g., Hutchinson and Bischof 1983; Hutchinson, 1995, 1991; Hutchinson and Gessler 1994). There are

Predictions of global climate trends



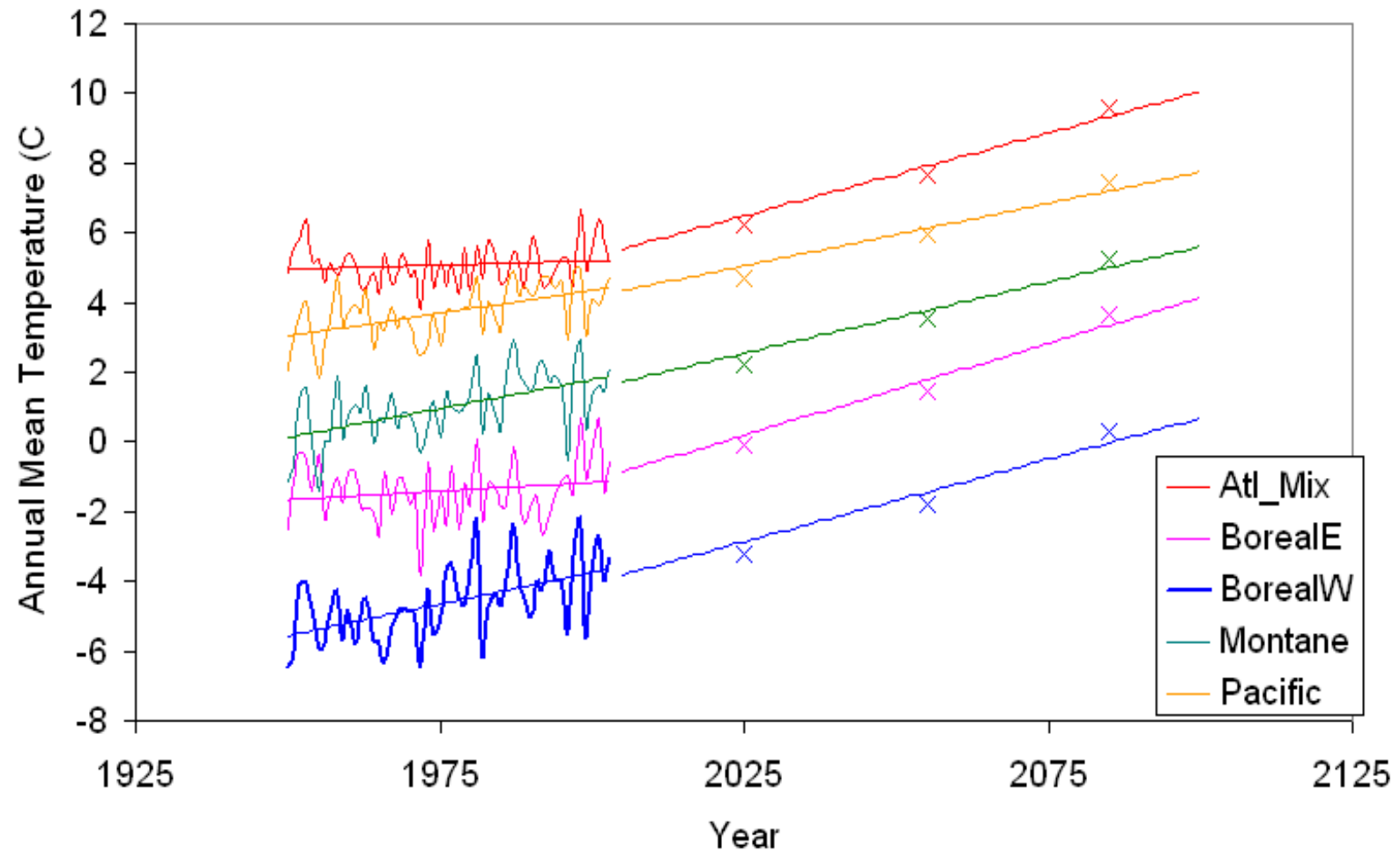
Source: International Panel on Climate Change, 4th Assessment Report 2007.

Estimates of CO₂ and temperature sensitivity from Earth's history



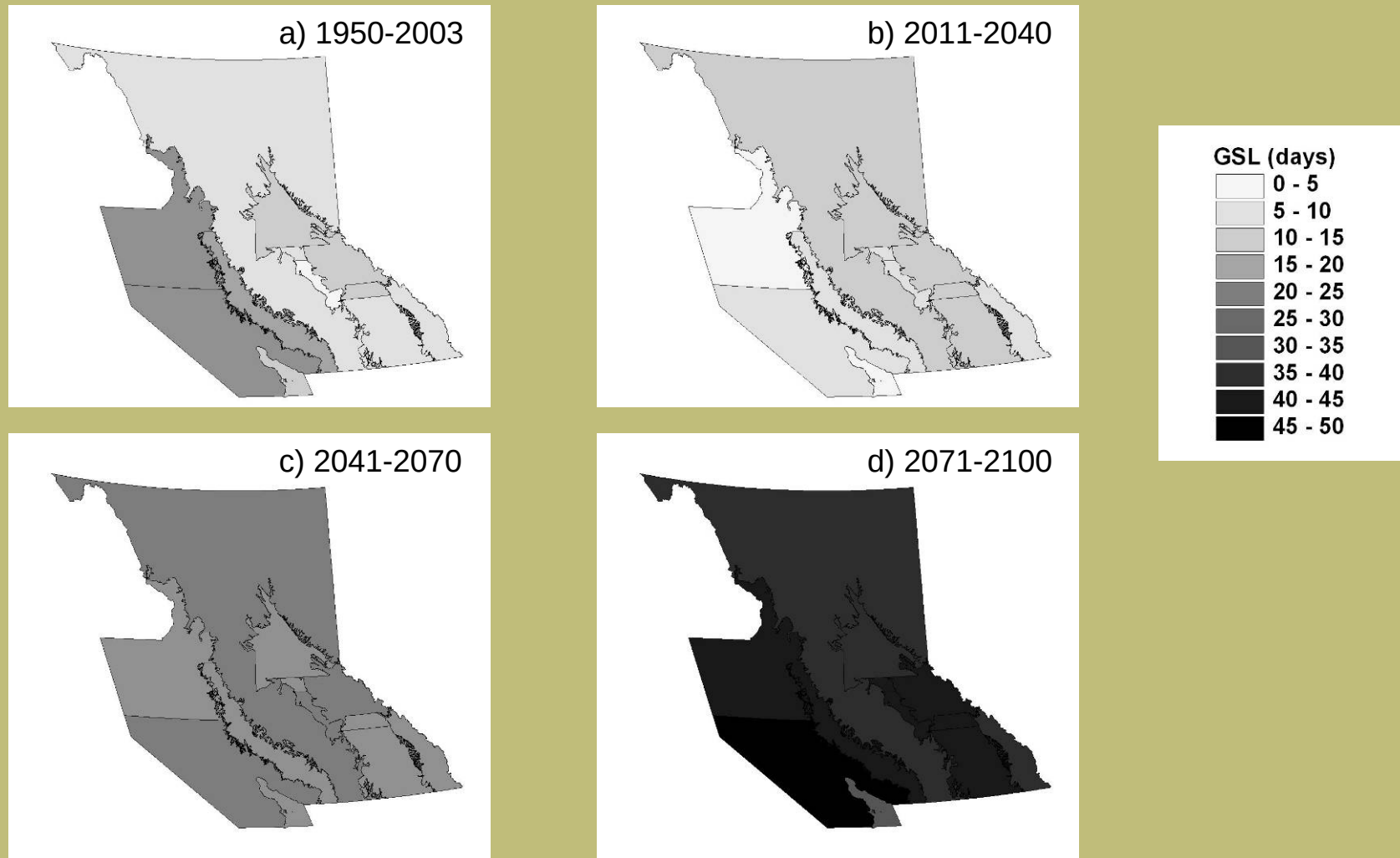
Past and projected trends in selected Canadian ecozones

- Annual Mean Temperature -



Changes in growing season length (days) across BC seed zones for 4 time periods (some collaborative work with Greg O'Niell, BC MFR)

Note we have included non Douglas-fir seed zone parts of the province for completeness.



What's in store for trees in Canada?

Will the Sault be our bread basket?

Local peach tree bucks the odds: bears fruit

By **RACHEL PUNCH**
The Sault Star

It doesn't belong here and it shouldn't be producing fruit, but a peach tree in a Wallace Terrace backyard has been defying the odds for five years.

Vito and Natalina Muzzi's tree is full of the fuzzy fruit, even though Sault Ste. Marie is well north of the peach tree line.

"Everyone comes over and says 'I've never seen peaches over here,'" said Vito Muzzi with a grin.

"It shouldn't be here and it shouldn't be producing fruit," said Chuck Davis, forest mycology technician at the Canadian Forest Service of Natural Resources Canada.

The Sault's harsh winters are not a friendly climate for growing peach trees, said Davis.

"They like it a lot warmer. If you get really lucky, they'll grow," said Davis.

Davis said that the Niagara Region and Traverse City, Mich., are the closest places that have the climate to grow the fruit trees.

He said that the Muzzis' tree has survived because we haven't had a bad winter for about seven years.

"They've been really lucky because it's been so warm," said Davis.

The tree was given to Vito Muzzi by his daughter for Father's Day five years ago.

"My husband likes plants," said Natalina Muzzi. "It makes him very happy."

The Muzzis, who came to the Sault in 1957 from Catanzaro, Italy, have peaches, plums, flowers, peppers, tomatoes and other vegetables growing in their backyard.

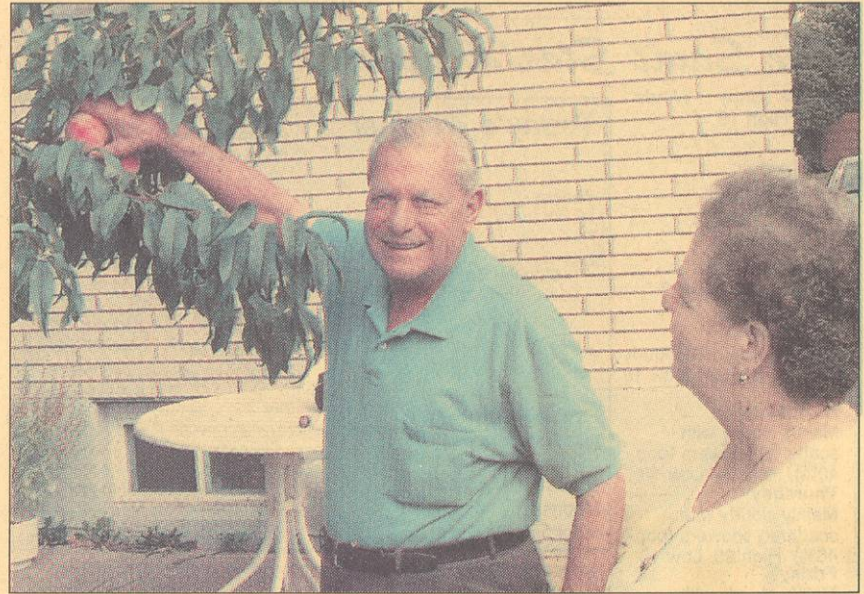
The yard is sheltered. Davis said that probably helps the tree survive.

The Muzzis have been giving away a lot of the fruit to friends and relatives.

"I try to give them to everybody," said Natalina Muzzi.

Davis, who knows of at least one other peach tree in town, said the Muzzis should hope that we don't get any cold winters.

He said that if we get a winter with



RACHEL PUNCH

VITO MUZZI picks a peach from the tree in his backyard on Wallace Terrace as his wife Natalina watches.

temperatures around -40 C for a few weeks in a row, the tree will die.

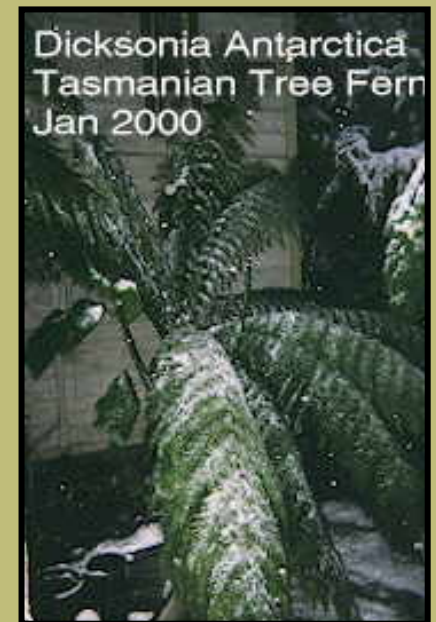
"It kills the flower buds and kills the

tree," said Davis.

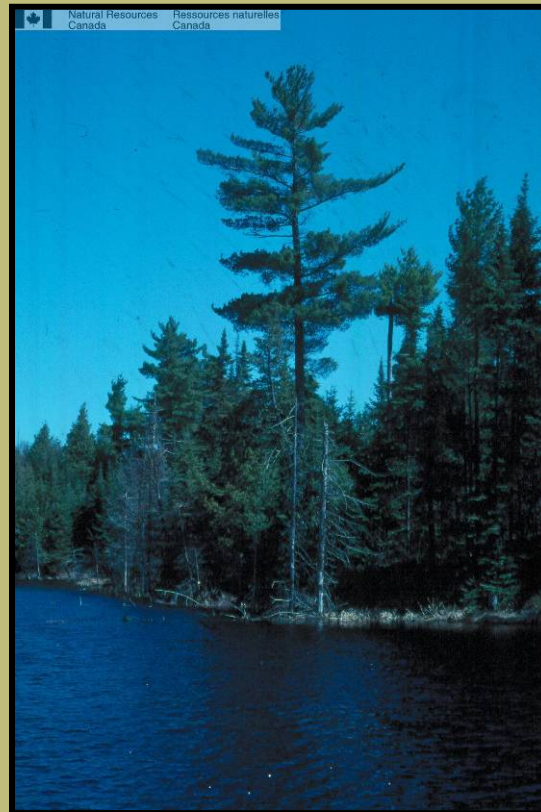
However, he said: "Miracles happen and I am wrong sometimes."



- We already grow palms in Canada!
(Salt Spring Island, B.C. - Canada's Hawaiian Island)



What can grow where?



Sometimes trivial, sometimes not!

“The Plant Hardiness Project: Connecting plants and climate”

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Plant Hardiness

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[Plant hardiness map - Natural Resources Canada.](#)

[Plant hardiness site - Agriculture Canada.](#)

[Technical details about why and what we are doing.](#)

[Climate maps and hardiness indices used to develop the new plant hardiness zones.](#)

[Canadian equivalent to the USDA hardiness zones map.](#)

[Climate change and future climate habitat of plants species](#)

Proactive Disclosure

[Proactive Disclosure](#)

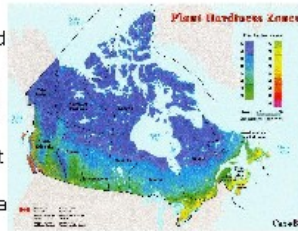


Canada's plant hardiness map ([view details](#)) provides insights about what can grow where. It combines information about a variety of climatic conditions across the entire country to produce a single general map. The original map was developed in the 1960's for trees and shrubs. It has also been used for perennials but it was not originally developed for that purpose.

Why should you help and how?

Our aim is to go beyond a single general map and develop potential range maps for individual species of trees, shrubs and perennial flowers. Our approach is to develop a climatic profile for each plant using new continent-wide climate models. These climatic profiles will be mapped giving an indication of the possible range of each species.

To do this we need participation from experts and the public all over Canada, and ideally the United States as well. Contributors need to identify what plants, from a comprehensive list, survive at their location. Once enough data are entered to develop a climatic profile the range maps will be generated. These range maps will be continually updated as more data are submitted.



Plant search

(scientific or common name keyword search)

Select by family

[A](#)[B](#)[C](#)[D](#)[E](#)[F](#)[G](#)[H](#)[I](#)[J](#)[K](#)[L](#)[M](#)[N](#)[O](#)[P](#)[R](#)[S](#)[T](#)[U](#)[V](#)[W](#)[X](#)[Z](#)

Select by genus

[A](#)[B](#)[C](#)[D](#)[E](#)[F](#)[G](#)[H](#)[I](#)[J](#)[K](#)[L](#)[M](#)[N](#)[O](#)[P](#)[Q](#)[R](#)[S](#)[T](#)[U](#)[V](#)[W](#)[X](#)[Y](#)[Z](#)

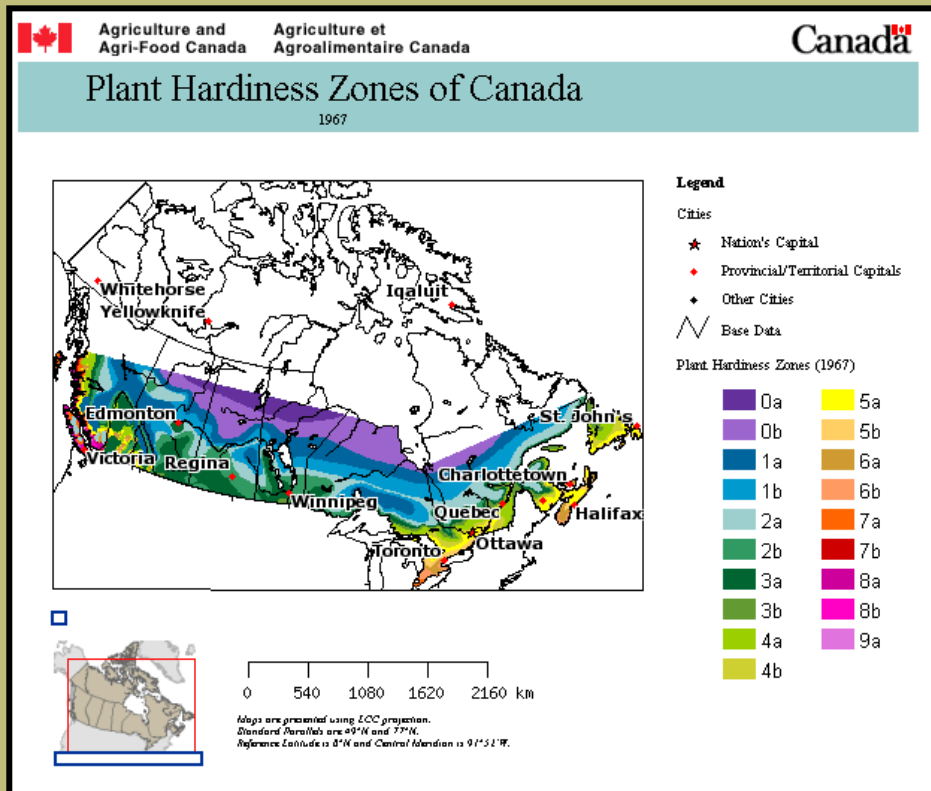
Mapping what can grow where...

Four important points:

- 1) Continent-wide
- 2) Climate-envelop based
- 3) Expert and public contributions
- 4) Maps for trees, shrubs, grasses, vines and perennial flowers

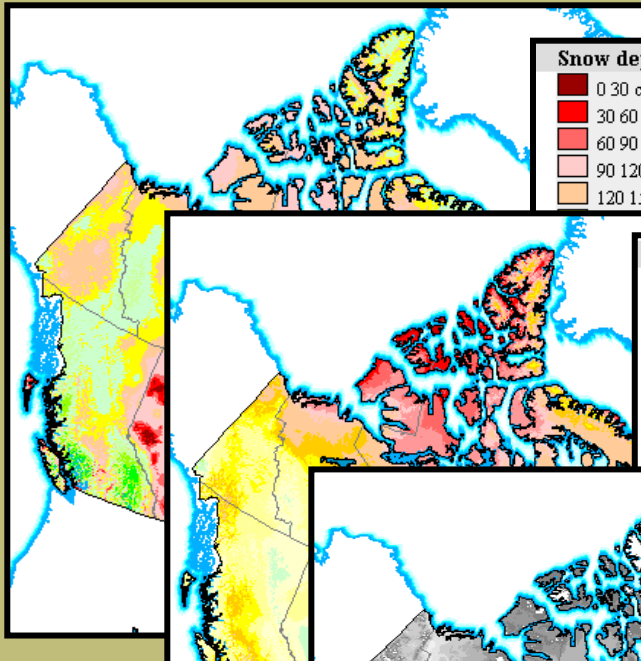
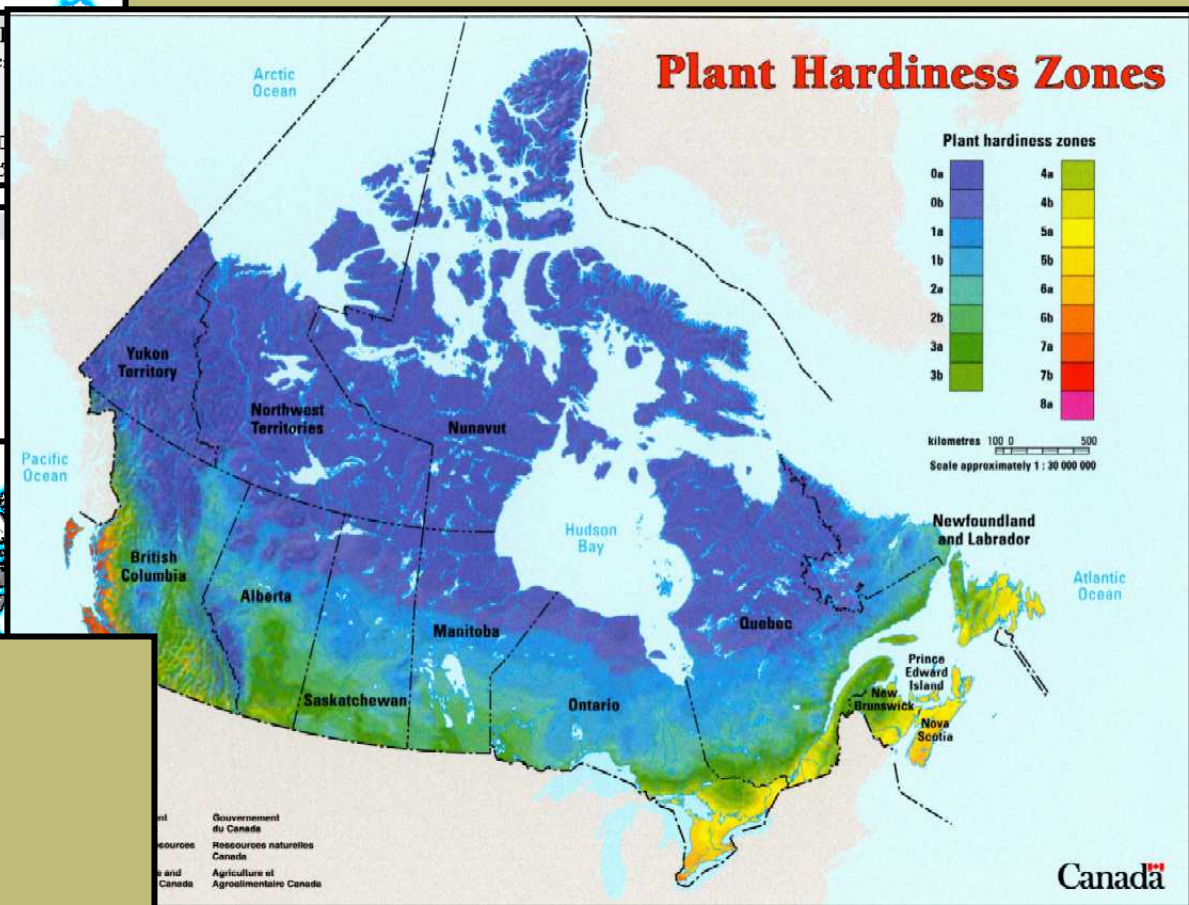
Original Plant Hardiness Map (Oullet and Sherk,1967)

- Based on 1931/60 values for:
 - minimum winter temperature,
 - length of the frost-free period,
 - summer rainfall,
 - maximum summer temperature,
 - snow cover,
 - January rainfall and maximum wind speed.
- Survival of 174 ornamental trees and shrubs at 108 locations
- Calculated a hardiness index between 0-100
- Mapped index by hand interpolation of 640 weather stations.



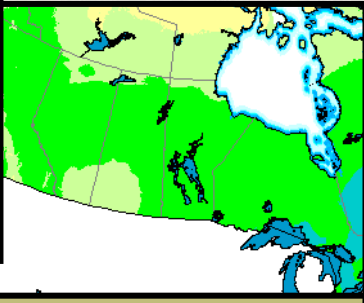
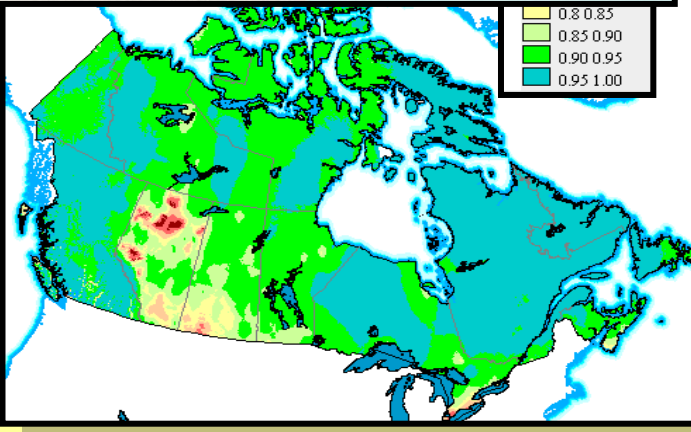
Source: McKenney, D., Campbell, K. 2002. Getting into the Zone – what does Canada's new plant hardiness zones map really mean? CFS Tech. Note. 103.

http://www.glf.cfs.nrcan.gc.ca/landscape/PDF/Tech_Note103_E.pdf



New PH map (2001):

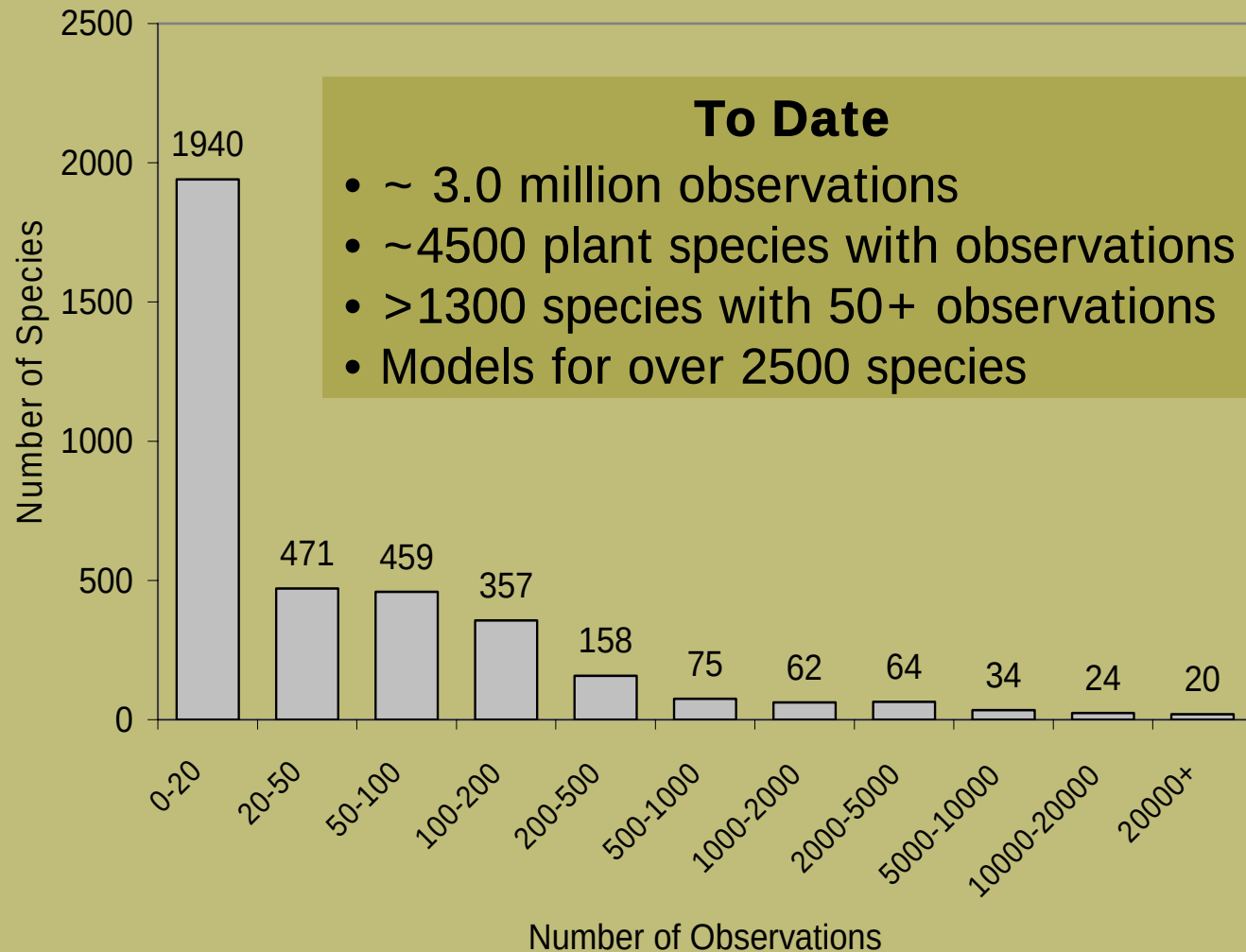
- updated climate data,
- 2 km grid
- some controversy in Vancouver Island and deep Southern Ontario
- map is only a guide



Oullet and Sherk (1967) PH formula

$$Y = -67.62 + 1.734X_1 + 0.1868X_2 + 69.77X_3 + 1.256X_4 + 0.006119X_5 + 22.37X_6 - 0.01832X_7$$

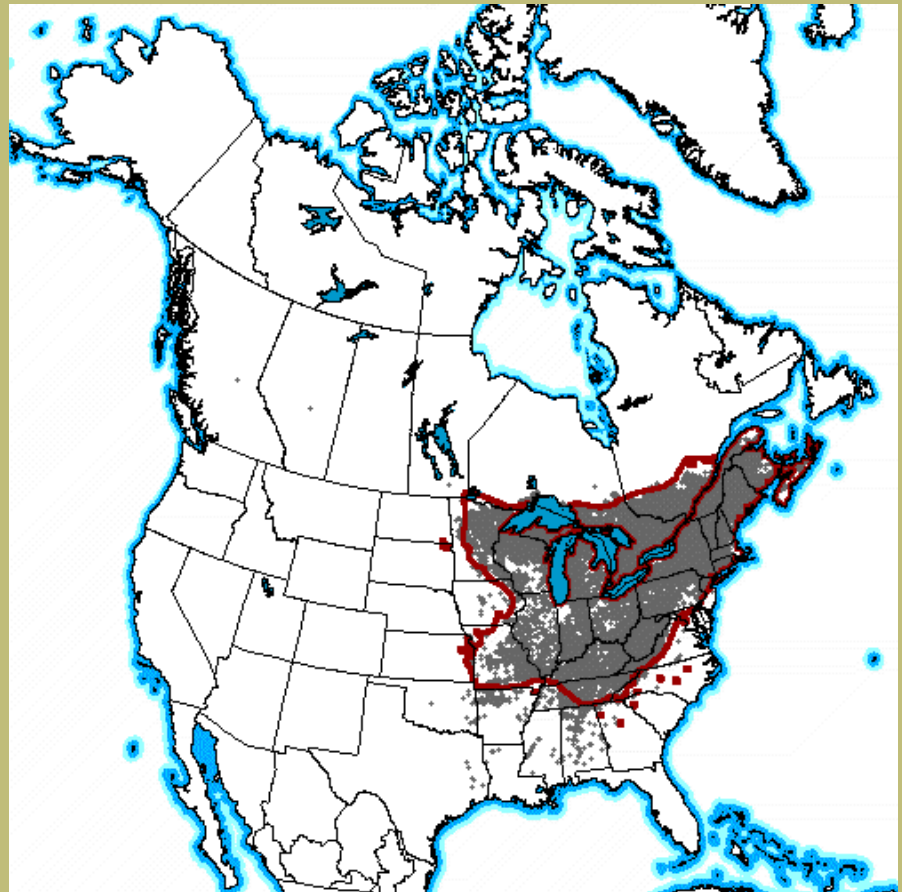
Data to Date



A climate change experiment

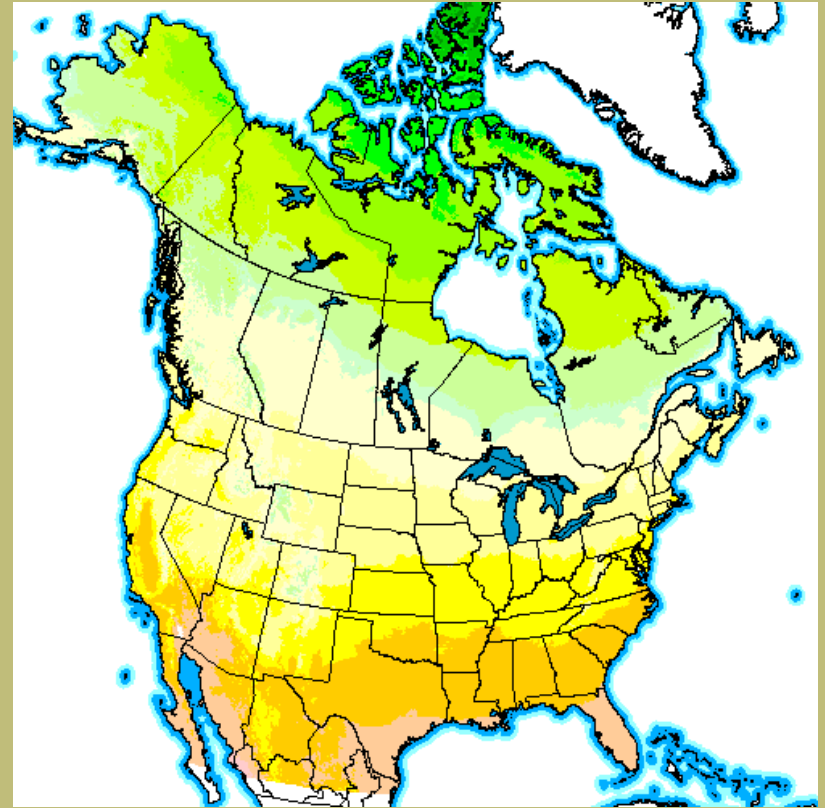
Tree Data: which species to include?

- Data exists for 286 tree species that also have digital range maps
- Not all species have complete coverage
- Species were pre-filtered using range maps
- 130 species chosen for analysis



Climate Data (Current)

- 30-year averages for the period 1971 to 2000
- 6 variables used in analysis:
 - 1) Annual mean temp;
 - 2) Min Temp coldest month;
 - 3) Max temp hottest month;
 - 4) Annual precip;
 - 5) Precip during coldest month;
 - 6) Precip during warmest month



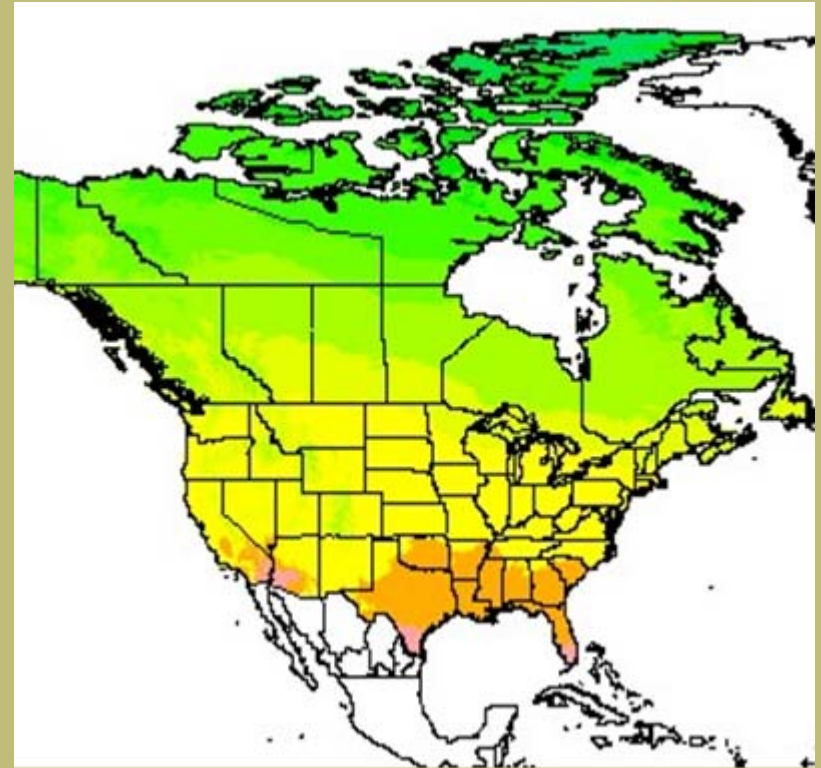
Mean Annual Temperature
(1971-2000)

Regional, National and International Climate Modeling

http://www.glf.cfs.nrcan.gc.ca/landscape/climate_models_e.html

Climate Data (Future)

- Generated using 3 GCMs:
 - CGCM2
 - HadCM3
 - CSIRO Mk2
- 2 climate change scenarios:
 - A2
 - B2
- Estimates from GCMs are appended to current values for 3 time periods:
 - 2011-2040
 - 2041-2070
 - 2071-2100



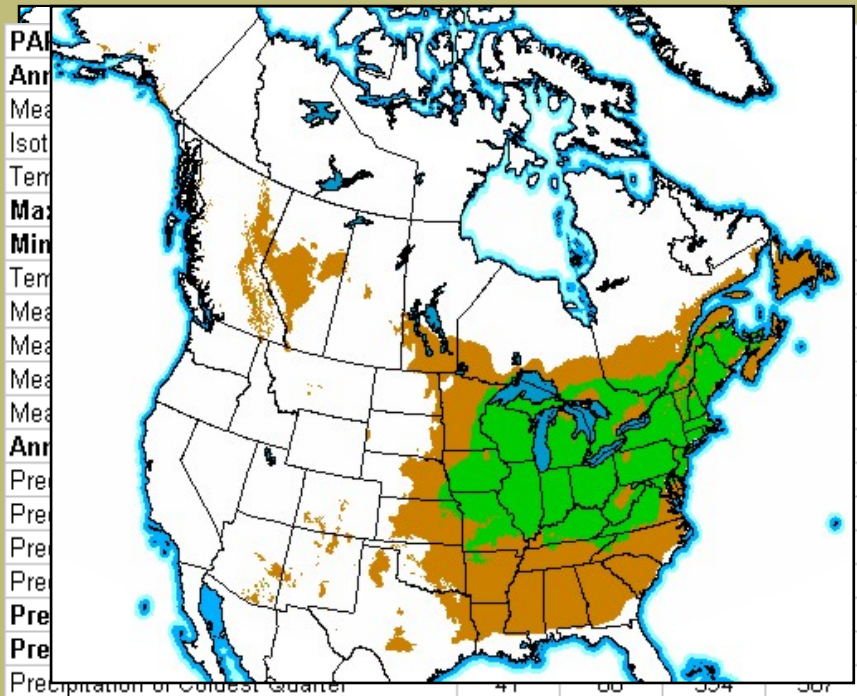
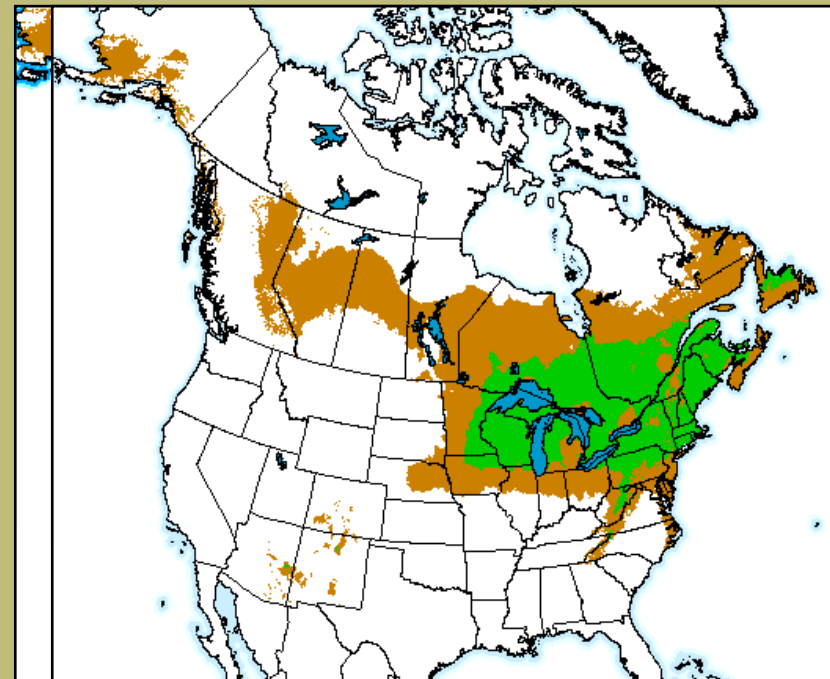
Mean Annual Temperature
(2071-2100)



*Sugar Maple (*Acer saccharum*)*



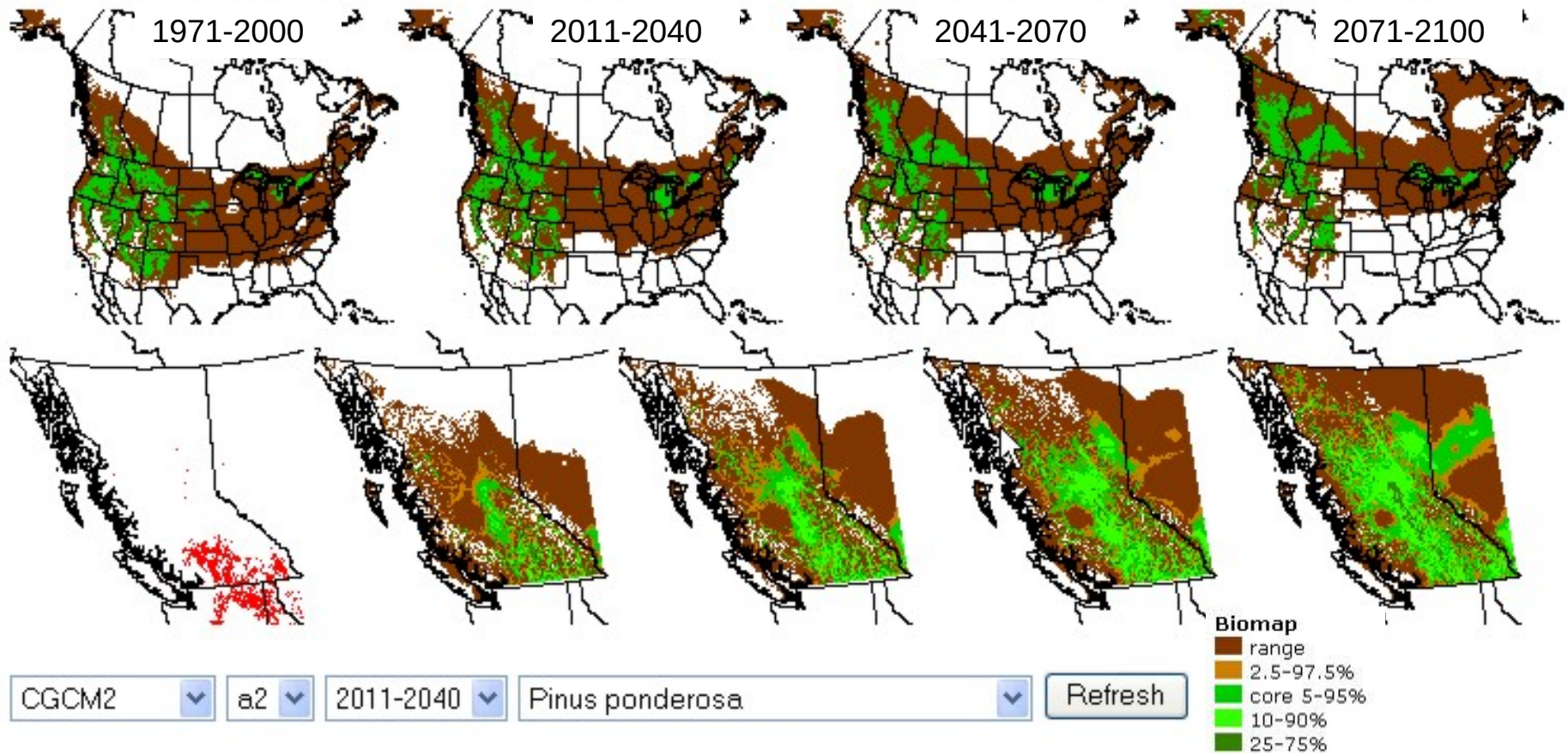
Climatic Range (1971-2000)



Future Climatic Range (2041-2070 and 2071-2100, CGCM B2)

Collaborative work with BC Ministry of Forests and Range

Pinus ponderosa



Model influences

- the accuracy of climate models, variable selections
- the accuracy and distribution of plant observation data (including georeferencing and plant identification)

Migration issues....

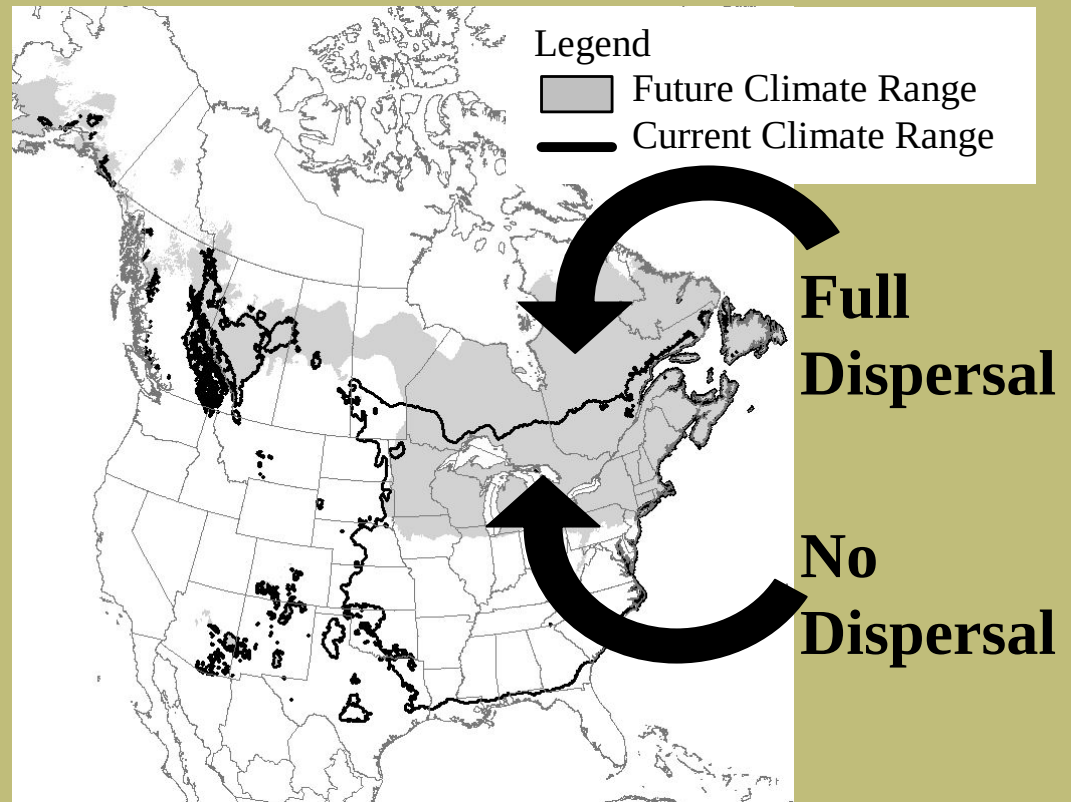
Mostly from Neilson et al, 2005; McLachlan et al 2005, 2007

- Vegetation change due to climate change: a) *in situ* conversions; b) movement of species from other locales – “fronts and jumps”
- Four components: a) fecundity; b) dispersal; c) establishment; d) growth to reproductive age; (all this varies tremendously between species and possibly between populations of the same species)
- We learn from pollen studies and more recently “Chloroplast DNA” studies: Migration rates 100 - 1000m/yr or maybe much less!
- Dynamic Global Vegetation Models (eg Neilson et al, 2005)

Migration and Climate Change

- “the” great unknown -

- the extent to which plants will be able to shift with climate is unknown
- many methods have been developed to try to model migratory patterns
- we have defined 2 “extreme” scenarios to bound the problem:
 - 1) full dispersal
 - 2) no dispersal



Results

- Change in Climate Habitat Size -

Full Dispersal Scenario

- average decrease in climate envelope size of about 12%
- Of the 130 species, 72 showed a decrease in future CE size

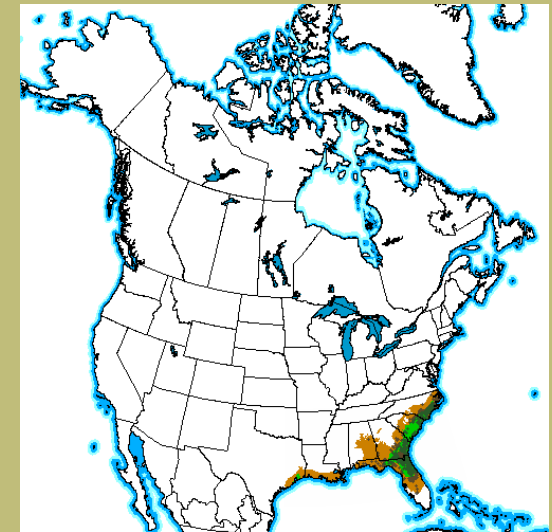
No Dispersal Scenario

- future CEs decline sharply in size – by 58% on average
- all species showed declines

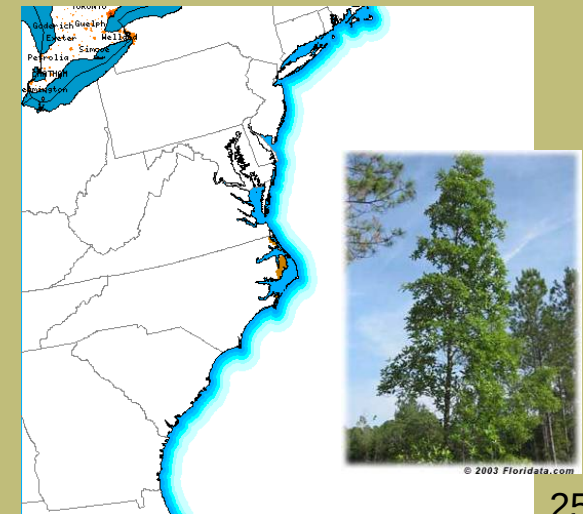
Results

- Species showing greatest declines in Climate Habitat size -

Scientific Name	Common Name	Change in Climate Envelope Area (%)	
		Full Dispersal	No Dispersal
<i>Gordonia lasianthus</i>	Loblolly-bay	-93.3	-98.3
<i>Chamaecyparis lawsoniana</i>	Lawson's false cypress	-64.5	-97.9
<i>Nyssa ogeche</i>	ogeechee tupelo	-71.9	-96.1
<i>Quercus virginiana</i>	live oak	-81.8	-95.4
<i>Magnolia macrophylla</i>	bigleaf magnolia	-70.5	-93.6
<i>Acer barbatum</i>	Florida maple	-61.7	-92.4
<i>Chamaecyparis thyoides</i>	Atlantic white-cedar	-58.9	-92.3
<i>Magnolia virginiana</i>	sweetbay magnolia	-62.1	-92.2
<i>Quercus imbricaria</i>	shingle oak	-60.8	-91.0
<i>Abies magnifica</i>	California red fir	-76.8	-87.5
<i>Nyssa aquatica</i>	water tupelo	-64.3	-87.2
<i>Taxodium distichum</i>	baldcypress	-61.2	-83.0
<i>Celtis laevigata</i>	sugar hackberry	-45.2	-81.1
<i>Quercus phellos</i>	willow oak	-55.2	-80.8
<i>Pinus virginiana</i>	scrub pine	-57.3	-80.7
<i>Quercus coccinea</i>	scarlet oak	-50.1	-80.7
<i>Ilex opaca</i>	American holly	-55.8	-80.4
<i>Quercus nigra</i>	water oak	-54.7	-79.8
<i>Pinus echinata</i>	shortleaf pine	-51.0	-79.3
<i>Pinus taeda</i>	loblolly pine	-57.2	-79.2
<i>Fraxinus quadrangulata</i>	blue ash	-33.8	-77.9
<i>Fraxinus latifolia</i>	Oregon ash	-33.9	-77.2
<i>Abies procera</i>	noble fir	-1.8	-75.7
<i>Liquidambar styraciflua</i>	sweetgum	-45.8	-74.8
<i>Magnolia acuminata</i>	cucumbertree magnolia	-36.2	-74.1



Loblolly Bay (current)



Loblolly Bay (2071-2100)

What other studies have found

- Habitat Size -

Reported effects of climate change on climate habitat size are quite variable in the literature:

- 41 of 42 UK species showed declines (Brereton et al., 1995)
- about half of western US species showed declines (Shafer et al. 2001)
- ~ 40 of 135 US species showed declines (Iverson et al. 2005)

Results

- Change in Latitude -

Full Dispersal Scenario

- shift northward by 6.4 degrees latitude (~700 km) on average
- all species showed northward shift
- $700\text{km}/70 \text{ years} = \sim 10\text{km/year}$

No Dispersal Scenario

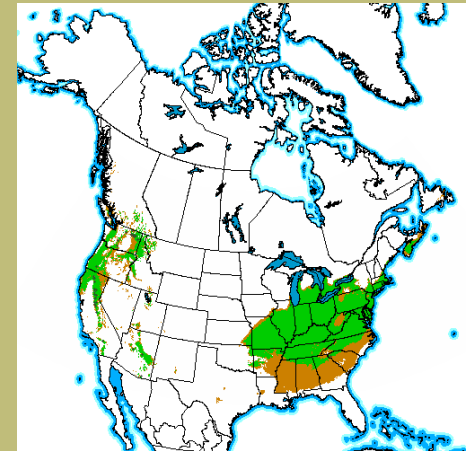
- shift northward by 3.0 degrees latitude (~330 km) on average
- all species showed northward shift

Results

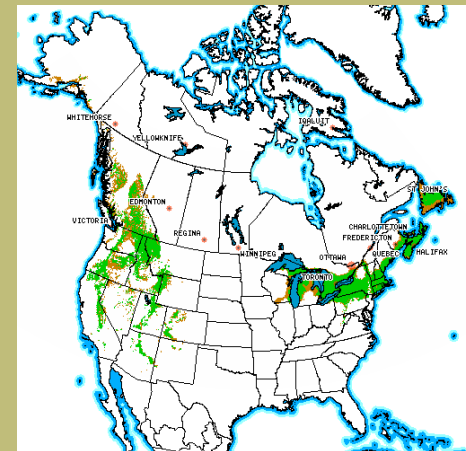
- species showing greatest northward shift -



Scientific Name	Common Name	Northward Shift in CE Latitude (°)	
		Full Dispersal	No Dispersal
<i>Alnus rhombifolia</i>	white alder	-9.7	-5.0
<i>Tilia americana</i>	American basswood	-9.2	-4.1
<i>Salix nigra</i>	black willow	-9.0	-3.6
<i>Acer saccharum</i>	sugar maple	-8.9	-3.3
<i>Ostrya virginiana</i>	ironwood	-8.7	-2.9
<i>Acer saccharinum</i>	silver maple	-8.7	-3.3
<i>Quercus rubra</i>	red oak	-8.7	-3.3
<i>Prunus serotina</i>	wild black cherry	-8.5	-2.7
<i>Ulmus rubra</i>	red elm	-8.4	-2.9
<i>Fraxinus americana</i>	white ash	-8.4	-3.1
<i>Quercus alba</i>	eastern white oak	-8.4	-2.4
<i>Betula alleghaniensis</i>	yellow birch	-8.2	-3.9
<i>Pinus strobus</i>	eastern white pine	-8.2	-3.4
<i>Populus deltoides</i>	eastern cottonwood	-8.2	-3.2
<i>Juglans nigra</i>	black walnut	-8.2	-3.0
<i>Juglans cinerea</i>	butternut	-8.1	-3.5
<i>Celtis occidentalis</i>	sugarberry	-8.0	-2.8
<i>Quercus palustris</i>	pin oak	-7.9	-3.4
<i>Quercus macrocarpa</i>	bur oak	-7.9	-3.5
<i>Betula nigra</i>	river birch	-7.8	-1.9
<i>Acer spicatum</i>	mountain maple	-7.8	-3.7
<i>Juniperus virginiana</i>	eastern red cedar	-7.7	-2.5
<i>Magnolia acuminata</i>	cucumbertree magnolia	-7.6	-4.0
<i>Robinia pseudoacacia</i>	black locust	-7.6	-3.2
<i>Acer rubrum</i>	red maple	-7.6	-2.0



White Alder (current)



White Alder (2071-2100)

What other studies have found

- Latitude Shifts -

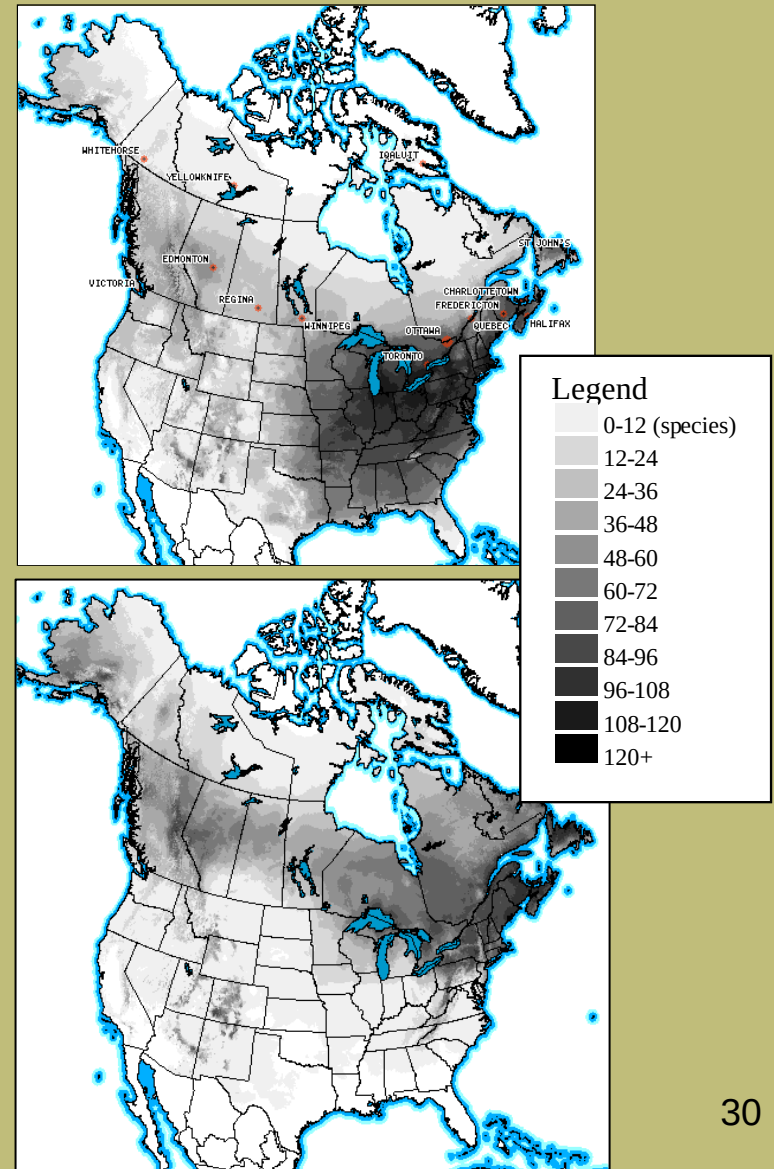
The magnitude of the latitude shifts reported here is at the high end of that reported in the literature:

- 100-500 km (Overpeck et al., 1991)
- 'hundreds of kilometres' (Shafer et al. 2001)
- 100 – 300 km (Prasad et al. 2006)

Results

- Northward shift in climate habitat richness -

- Climate in much of the southern US not within the climatic tolerances for any of the 130 tree species in this study by end of century (~700 tree species in NA)
- Alaska, the northern Prairie provinces, Ontario, Quebec, and the Maritimes are predicted to experience future climate that is favourable for a wide variety of tree species – with potential increases of more than 60 CEs



Close to Home

- Results for some familiar Canadian species -

Common Name	Full Range		Overlap Range	
	Change in Area (%)	Change in Latitude	Change in Area (%)	Change in Latitude
Deciduous Species:				
Sugar Maple	20.0	-8.9	-49.2	-3.3
White Ash	7.4	-8.4	-52.6	-3.1
Trembling Aspen	-2.7	-4.5	-24.7	-2.4
Red Maple	19.6	-7.6	-42.3	-2.0
Silver Maple	12.0	-8.7	-53.9	-3.3
White Birch	2.5	-5.2	-28.7	-2.2
Red Oak	5.6	-8.7	-52.7	-3.3
Basswood	11.2	-9.2	-52.7	-4.1
Ironwood	-0.3	-8.7	-57.4	-2.9
Beech	-10.6	-7.4	-53.7	-3.3
Black Cherry	4.1	-8.5	-53.7	-2.7
Black Walnut	7.6	-8.2	-55.5	-3.0
Coniferous Species:				
White Pine	14.4	-8.2	-49.3	-3.4
Black Spruce	-5.8	-4.0	-28.0	-1.9
White Spruce	-10.6	-3.3	-24.5	-1.7
White Cedar	9.9	-6.2	-48.3	-2.9
Balsam Fir	-8.4	-4.0	-36.1	-1.7
Jack Pine	5.0	-5.5	-32.8	-3.5
Average	3.7	-6.9	-44.6	-2.8

Some discussion points

- GCM models – what path, what model, how good are they?
- Fundamental vs realized niche....fundamental niche larger and unknown making modeling actual and even potential distributions (and relative abundance) VERY difficult
- Effects of extreme weather/climatological events and other “errors in variables”?
- Other biotic and abiotic interactions....lots of complexity!
- Spatial data for resolving models a big challenge – eg soils in the north
- Ethics and risk preferences – Assisted migration or not? (McLachlan et al 2007)
- Financial resource constraints – who and how will we pay for large migration efforts?

Concluding comments

- Major biogeographic pressures in store by mid-century **if** you believe the GCMs
- Ontario/Quebec species...may not be as heavily impacted, **relative** to other parts of NA. Climate envelop maps for more than 2500 species can be viewed at the Plant Hardiness page (plus metadata on climate tolerances) – a higher resolution BC project in the works with Will MacKenzie and Del Meidinger
- Future efforts likely to include: alternative modeling strategies; different GCM scenarios, explicit migration and intervention strategies tied to climate envelopes, land use change inclusive of economics; climate and growth rate linkages; etc...