

# Effects of inclusion of wind-driven seed dispersal in modeling the plant migration, and estimating future terrestrial surface albedo from polar vegetation

Eunjee Lee

with C. Adam Schlosser, Xiang Gao and Ronald G. Prinn

MIT Joint Program on the Science  
and Policy of Global Change



# Why is plant migration important?

- Previous studies stress that the plant migration has to be explicitly represented in simulating vegetation dynamics (Neilson et al., 2005; Midgley et al., 2007).
- Ignoring plant migration potentially could lead to:
  - Estimation of unrealistically fast forest expansions of the future (Chapin and Starfield, 1997; Skre et al., 2002).
  - Overestimation/underestimation of terrestrial carbon sequestration capacity (IPCC WG2; Neilson et al., 2005).
  - Less realistic representation of net radiation and hydrologic changes due to terrestrial vegetation change

# How to model plant migration?

- Plant migration depends upon (Sauer, 1988):
  - (1) Environmental influence
    - Climatic rules for survival and establishment
  - (2) Dispersal capacity of the population by seeds
    - How many seeds are transported and become available
    - But, current \*DGVMs assume ubiquitous seed availability and FREE plant migration process. A plant type can migrate freely in any land part of the globe and grow if the climate condition becomes favorable to the type
- Seed dispersal mechanisms for Tree PFTs
  - Meteorology-driven (boreal trees and temperate trees)
  - Other vehicles (tropical trees)

Missing!

(Note) Grass PFTs are allowed to migrate freely

# Wind-dispersed seeds (Temperate & Boreal Forests)

Broadleaf Deciduous Temperate tree  
(BDT temperate)  
e.g. Maple tree



Broadleaf Deciduous Boreal tree  
(BDT boreal)  
e.g. Willow tree



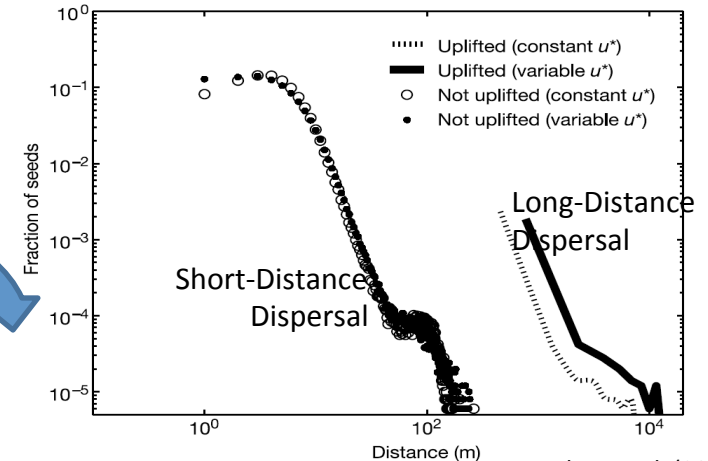
(Note) For tropical forest and herbaceous plants,  
wind-dispersal is not a dominant mechanism

Above: <http://www.flickr.com/photos/86953562@N00/150700450>

Below: Natural Resources Canada/ Canadian Forestry Service  
[http://www.atl.cfs.nrcan.gc.ca/frontliners/Bernie\\_Daigle/images/catkins.htm](http://www.atl.cfs.nrcan.gc.ca/frontliners/Bernie_Daigle/images/catkins.htm)



# MIT-SEED: Probabilistic approach



Nathan et al. (2002)

Flowering and ripening to give out seeds  
Oct-Dec (3 months)

Long Distance Dispersal (LDD)  
(seed uplifting probability: 1%~5%)

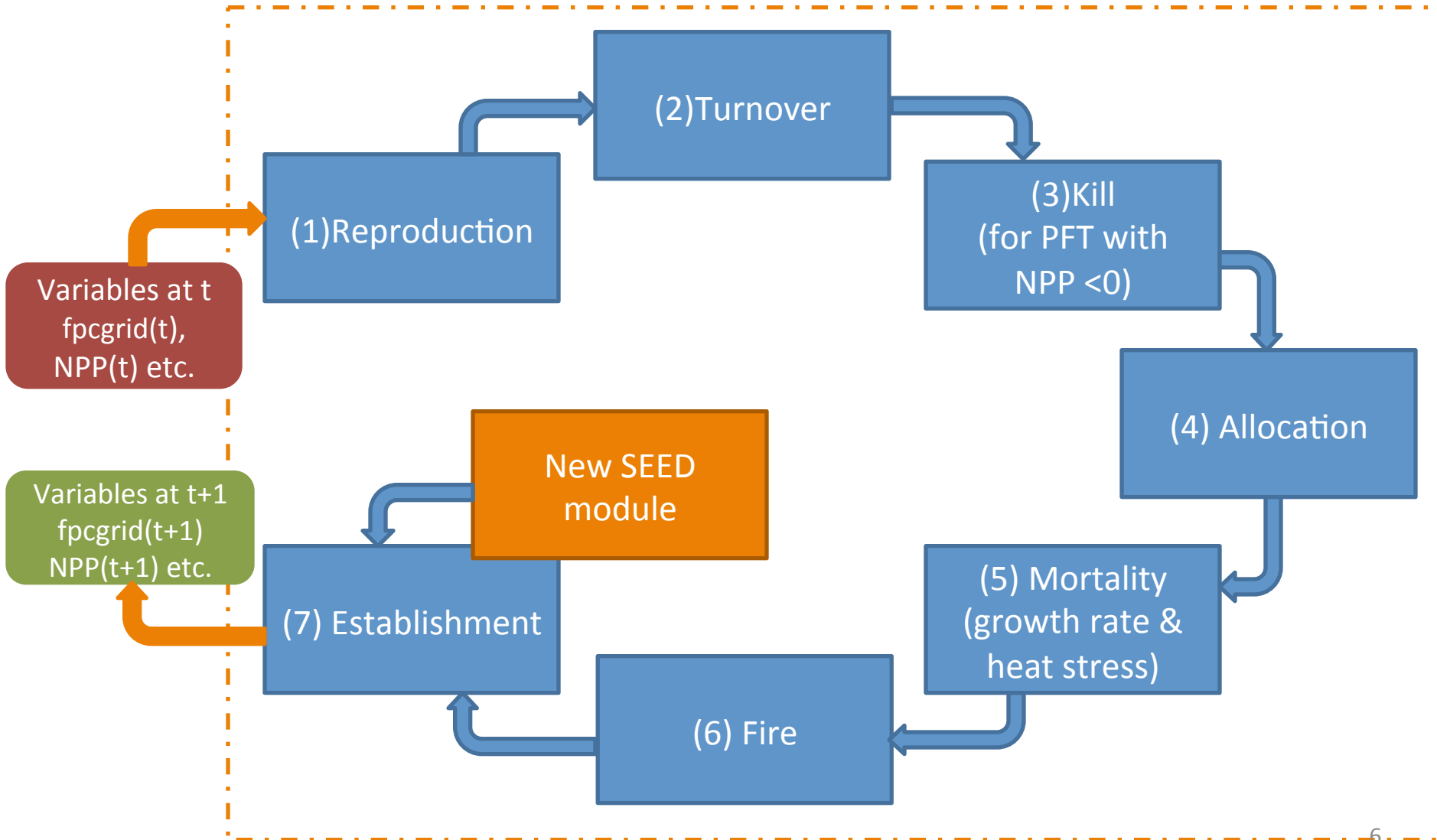
Number density of germinated seeds dispersed by wind ( $D_{seeds}$ ) [number of seeds / m<sup>2</sup>]

$$D_{seeds} = f \times POP_{Neighbor} \times \varepsilon_{disp} \times \frac{\text{Days of favorable wind}}{\text{Total days in autumn}} \times germ$$

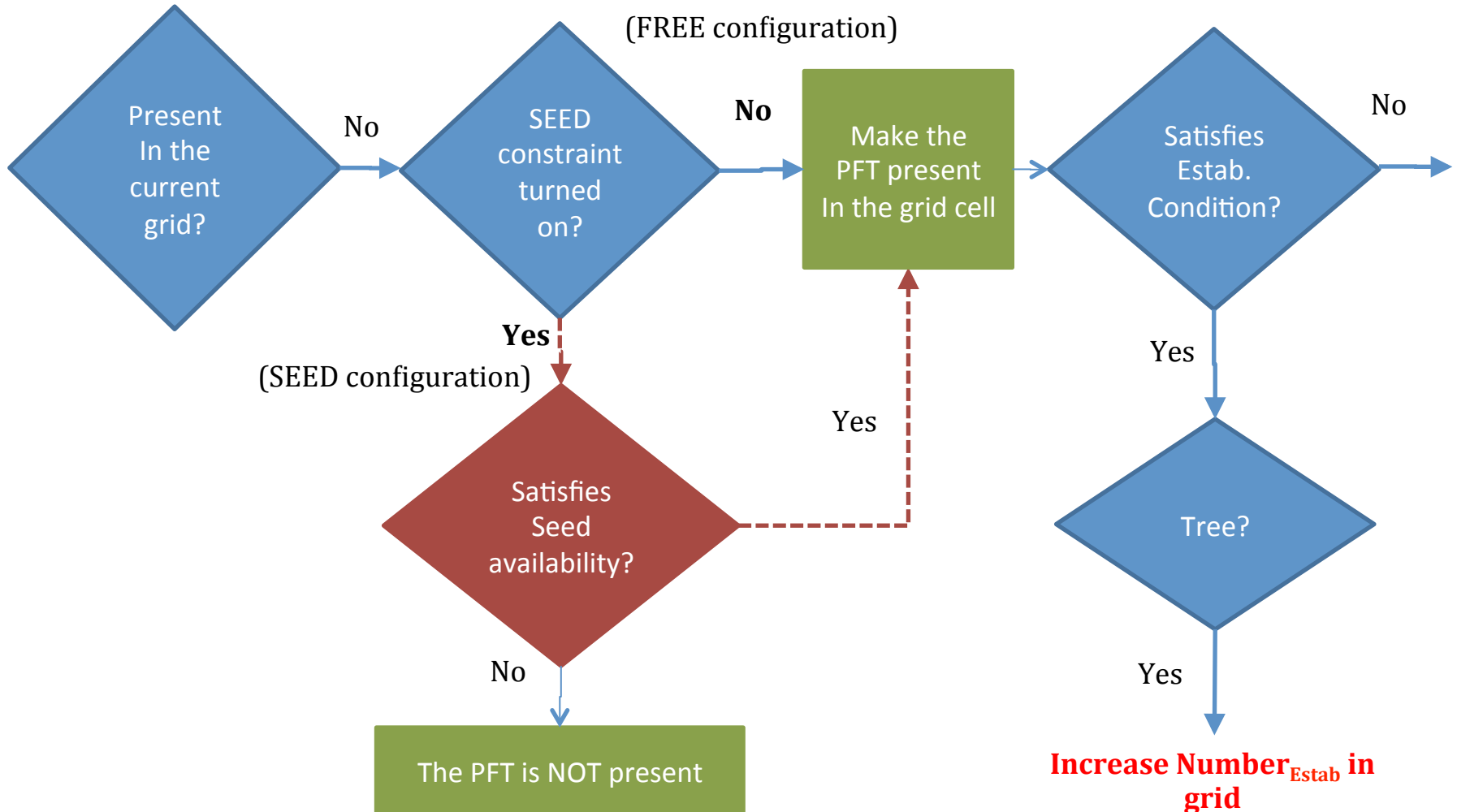
$f = 10^4$  seeds per tree per year ,  $POP_{Neighbor}$  = Number of trees x foliar projective cover on a grid cell ,  
 $\varepsilon_{disp} = 0.01 \sim 0.05$  (LDD efficiency),  $germ = 0.7$  (germination fraction)

Threshold of  $D_{seeds} = 10$  seeds / m<sup>2</sup> for establishment

# Seed dispersal into CLM-DGVM

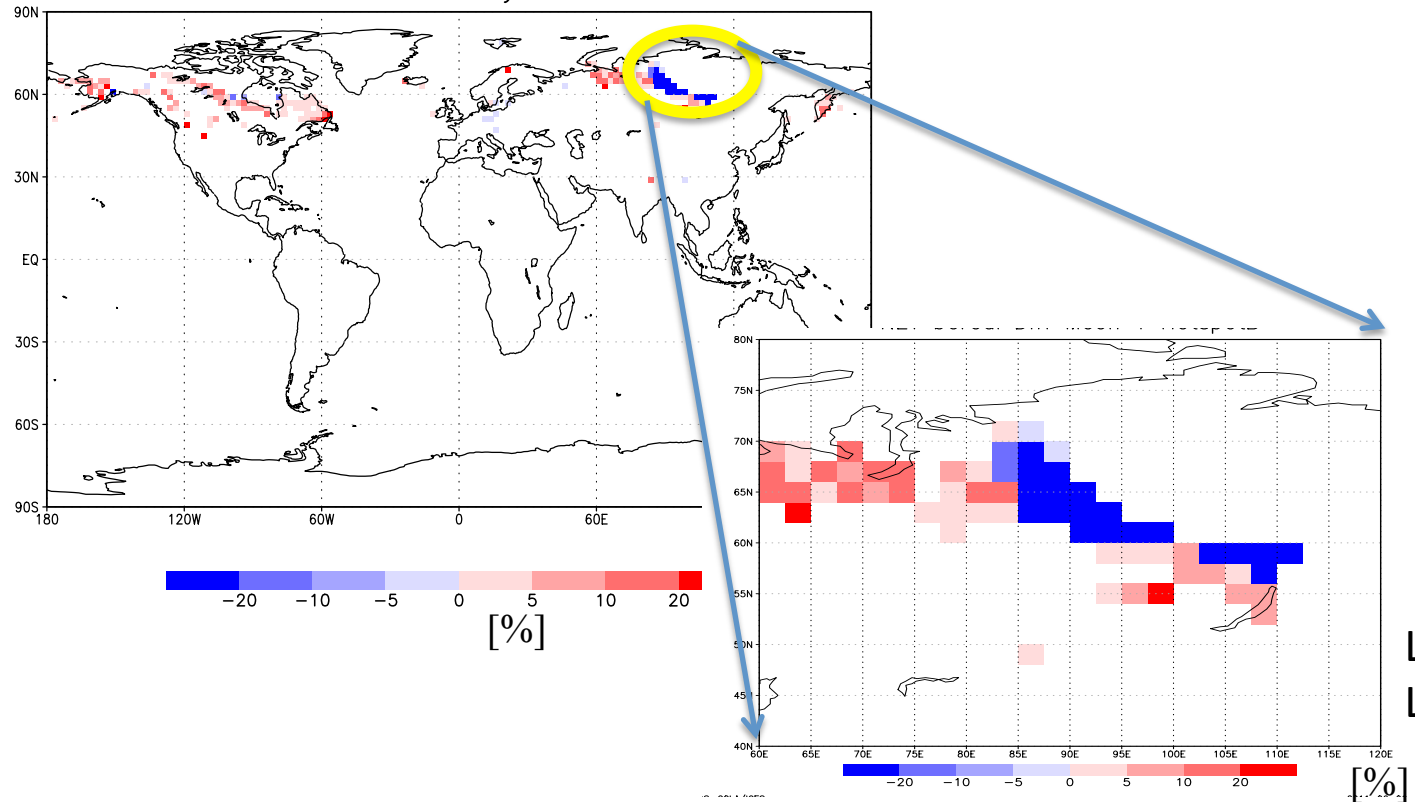


# MIT SEED configuration



# Altered competition among PFTs (1)

Difference in NET boreal forest percent cover [SEED – FREE]

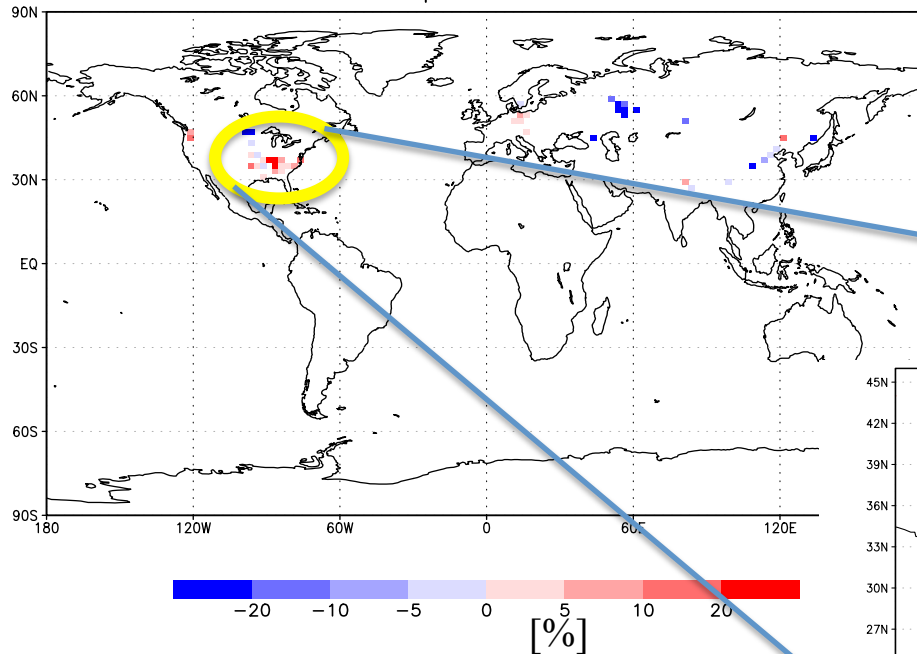


(Mechanism 1) Not enough seeds are transported. Migration of a tree PFT is forbidden due to the prevailing wind.

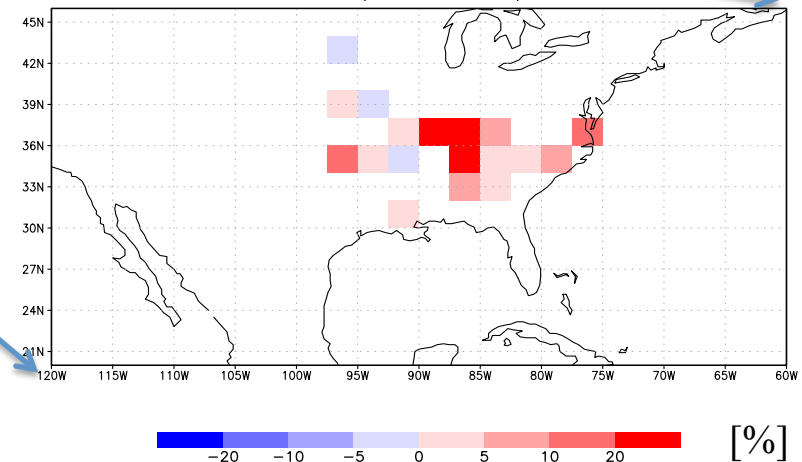


# Altered competition among PFTs (2)

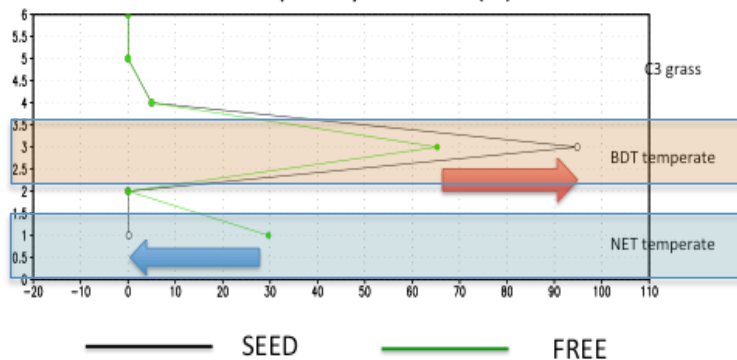
Difference in BDT temperate forest percent cover [SEED – FREE]



Lat 30N-40N  
Lon 90W-80W



Area occupied by each PFT (%)



(Mechanism 2) As a tree PFT is prohibited due to seed constraint, another tree PFT prospers

# Validation with AVHRR tree cover

- Regional representation improved (compared to AVHRR tree cover dataset). Some regions (e.g., boreal forests in Western Siberia, and temperate forests in Eastern Europe) show improved representation of vegetation using the SEED.

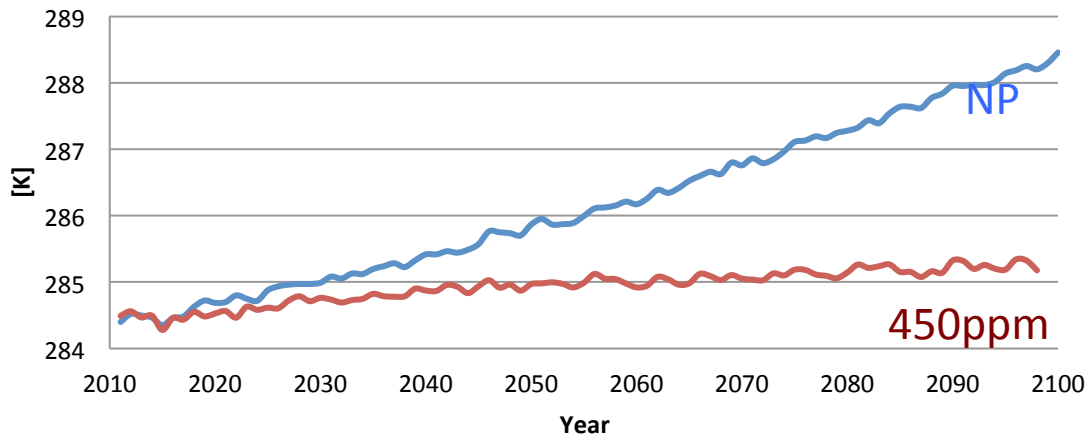
					Spatial correlation coeff	
					SEED vs AVHRR	FREE vs AVHRR
NET boreal	Gain	60N-70N	60E-80E	Evergreen	<b>0.48</b>	0.45
				Needleleaf	<b>0.55</b>	0.49
	Loss	60N-70N	80E-110E	Evergreen	<b>0.78</b>	0.62
				Needleleaf	0.63	0.70
BDT temperate	Gain	30N-40N	90W-80W	Deciduous	<b>0.80</b>	0.79
				Broadleaf	<b>0.80</b>	0.79
	Loss	50N-60N	50E-60E	Deciduous	<b>0.72</b>	0.59
				Broadleaf	<b>0.72</b>	0.59

# Simulating future vegetation

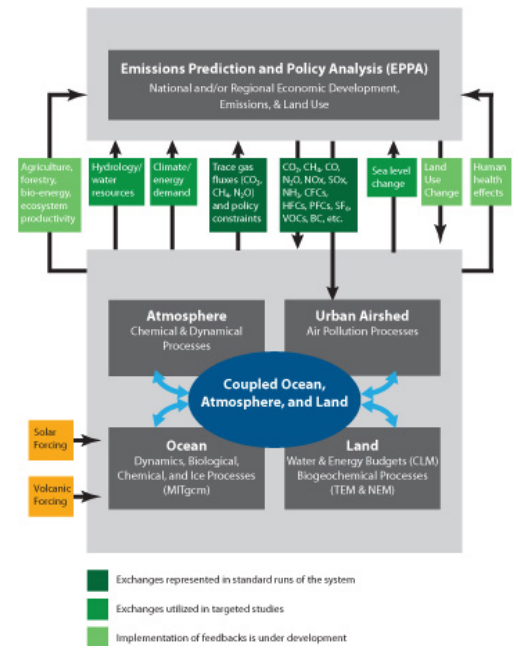
## No-policy (NP) vs. 450ppm CO<sub>2</sub> stabilization

- MIT-IGSM climate with GFDL CM2.1 precipitation pattern
  - Climatological mapping of precipitation and temperature
  - Zonal distribution patterns do not change over time; but the trend changes over time

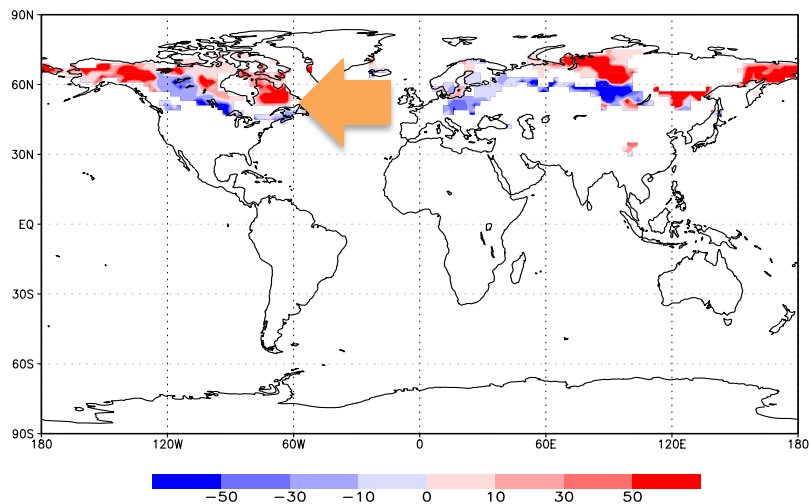
Annual global average atmospheric temperature over land



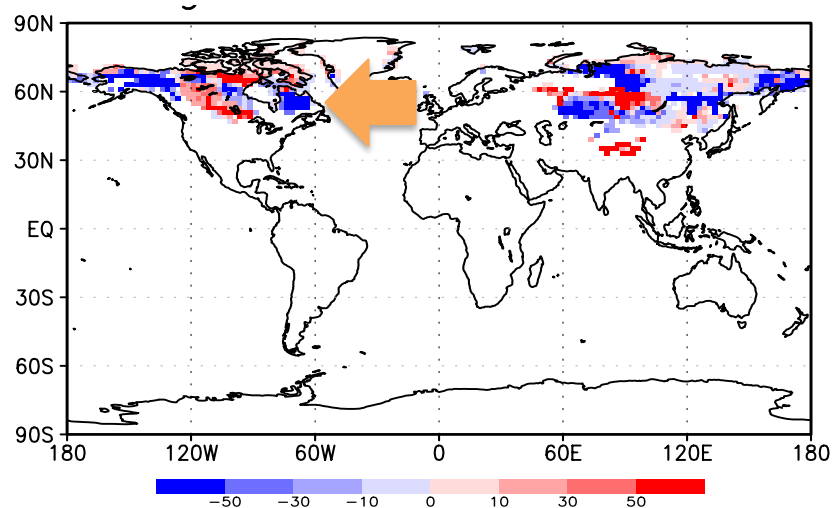
- Wind profiles are obtained from the AR4 archive
  - GFDL CM 2.1 simulated A2 wind for the NP
  - GFDL CM 2.1 simulated B1 wind for the 450ppm



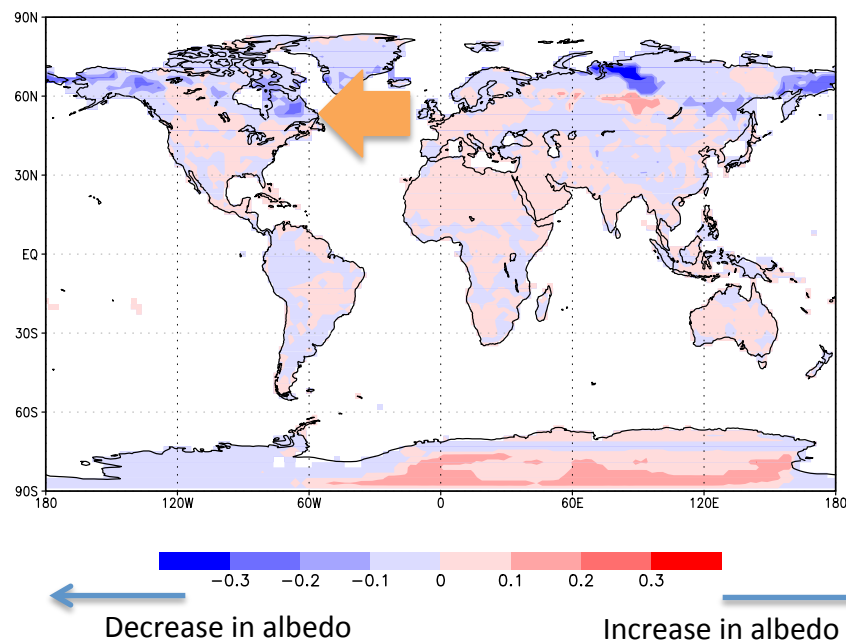
Change in areas occupied by boreal forest (%)  
from the early 21<sup>st</sup> century to the end of 21<sup>st</sup> century



Change in areas occupied by Arctic grass (%)  
from the early 21<sup>st</sup> century to the end of 21<sup>st</sup> century



Change in terrestrial surface albedo  
from the early 21<sup>st</sup> century to the end of 21<sup>st</sup> century



# Future terrestrial surface albedo

Induced albedo change due to vegetation may either accelerate or alleviate the vegetation-albedo feedback in the high latitudes, depending upon the mitigation scenario

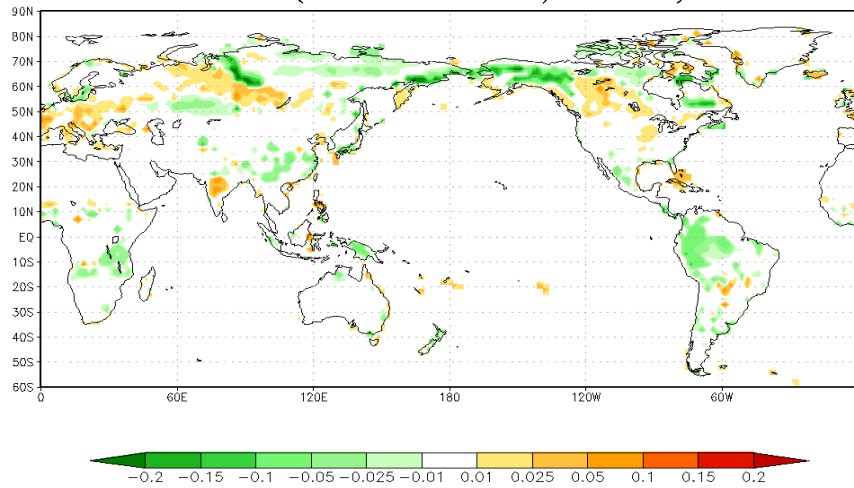
Region	Latitudes	NP			450ppm		
		* C+V+R	# C+R	V	* C+V+R	# C+R	V
High latitude	50N-90N	-0.0357	-0.0187	<b>-0.0171</b>	-0.0145	-0.0187	<b>0.0042</b>
Mid latitude (NH)	23.5N-50N	0.0013	-0.0013	0.0025	-0.0007	-0.0013	0.0006
Tropics	23.5S-23.5N	0.0002	0.0008	-0.0005	-0.0014	0.0008	-0.0021
Mid latitude (SH)	50S-23.5S	0.0005	0.0016	-0.0011	0.0008	0.0016	-0.0008

$$\begin{aligned}
 * C + V + R : & \quad \boxed{\frac{\partial X}{\partial C} \cdot \frac{dC}{dt}} + \boxed{\frac{\partial X}{\partial V} \cdot \frac{dV}{dt}} + \boxed{\frac{\partial X}{\partial t}} \\
 \# C + R : & \quad \boxed{\frac{\partial X}{\partial C} \cdot \frac{dC}{dt}} + \boxed{\frac{\partial X}{\partial t}}
 \end{aligned}$$

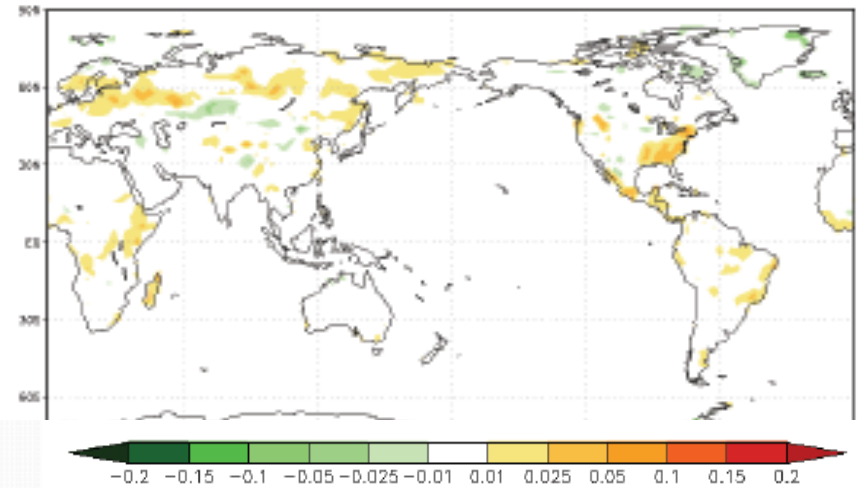
## Ongoing work:

Comparison of biogeophysical impacts  
(Natural vegetation vs. Land-use)

albedo (2050 minus 2015) No Policy



WITH BIOFUELS



Courtesy of Willow Hallgren

Magnitudes of change in albedo from early 2000s and 2050 from both cases are comparable, and none of them is negligible. We are investigating the biogeophysical impacts of both natural vegetation and human land-use.



# Conclusion

- MIT SEED configuration incorporates the seed dispersal mechanism in simulating vegetation dynamics, and regionally improves the representation of natural vegetation distribution.
- Future vegetation is likely to lead the biogeophysical change (e.g., albedo), especially in polar regions by boreal expansion and C3 grass Arctic retreat.
- The scale of Impacts on albedo by future natural vegetation change is likely to be as large as the impact by human land-use for biofuels, implying although we decide not to do deforestation, the response of natural system to changing climate will be significant.



Massachusetts Institute of Technology



# Backup slides

# Changing climates will lead changes in forest structure

- Changing climates may lead to significant changes in regional biogeography in the 21<sup>st</sup> century if no mitigation policy is implemented.
  - In high latitudes, the area occupied by boreal forests will proliferate at the expense of Arctic grass.
  - Changes in natural vegetation structure in some regions (for example, Greenland, Tibet, South Asia and Northern Australia) are expected to be more extreme if no mitigation policy is implemented, compared to a stabilization scenario.

# Change in biogeography may induce change in Earth's energy budget

- Change in future vegetation may induce more rapid change in terrestrial surface reflectivity if no mitigation policy is implemented
  - More boreal forests and less Arctic grass => Increase in darker spaces => Decrease in albedo
  - Induced albedo change due to vegetation may either accelerate or alleviate the vegetation-albedo feedback in the high latitudes, depending upon the emission scenarios.