Challenges in modeling disturbance effects on terrestrial carbon cycling

Ben Bond-Lamberty
JGCRI/Pacific Northwest National Laboratory
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Intro

- “How does disturbance affect ecosystem modeling?”
- Some disturbances, in some places, increasing
- Modeling capabilities growing
- Scientists are being asked to give answers with high temporal and spatial precision

Spinup: the modeler's dilemma

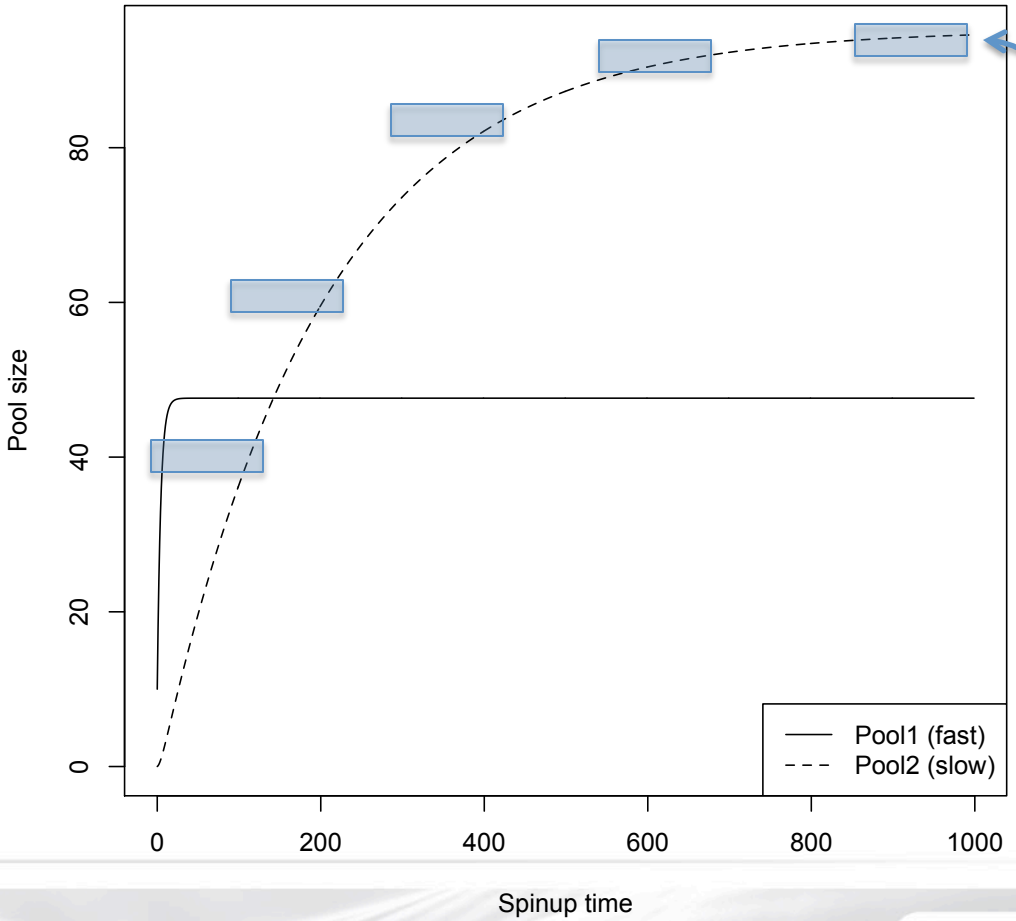
Initial value problems

- The trick is to estimate $\underline{X}_0$
- For complex models, analytical solution not possible
- Spinup attempts to solve this under non-disturbed (steady-state) conditions
- Unfortunately "non-disturbed" is rarely true

$$\begin{cases} \dfrac{d\underline{X}}{dt} = \zeta \underline{AX} + \underline{Bp} \\ \\ \underline{X}(t=0) = \underline{X}_0 \end{cases}$$

Notation follows Yuo et al. (2003)

Definitions



Note
x = window of time

and

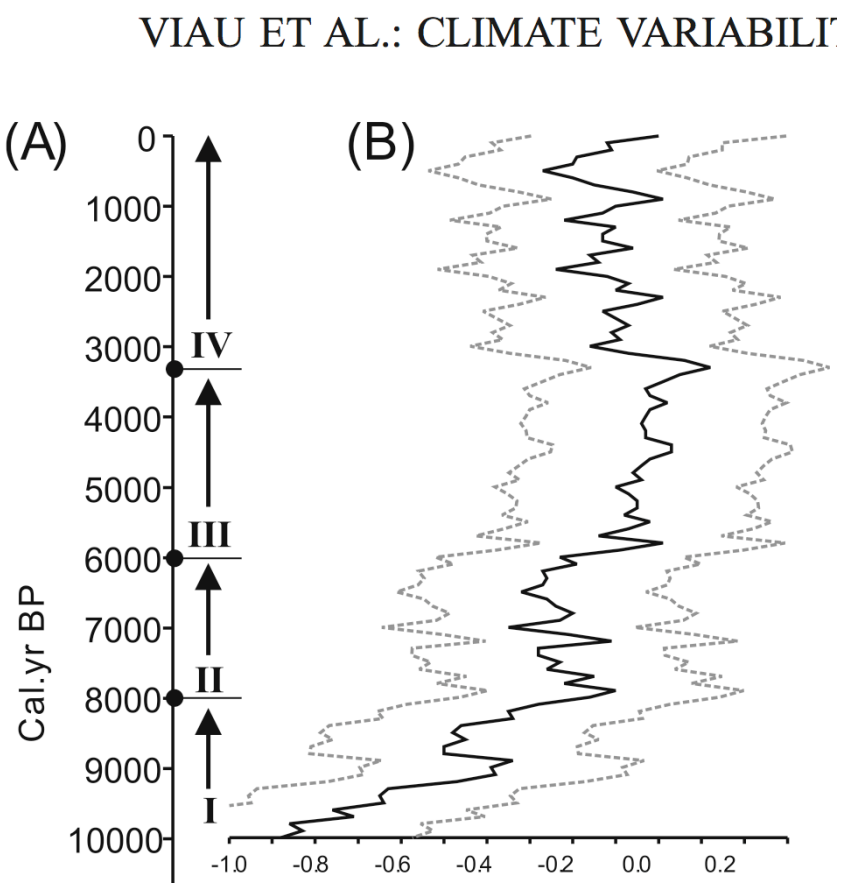
y = allowable change

Steady state stringency = xy

Fairly expensive

Not steady state

- The cooling Holocene
- Retreat of northern trees
- Expansion of peatlands
- Major shifts in fire frequency



From Viau et al. (2006)

Beware of the Mongols

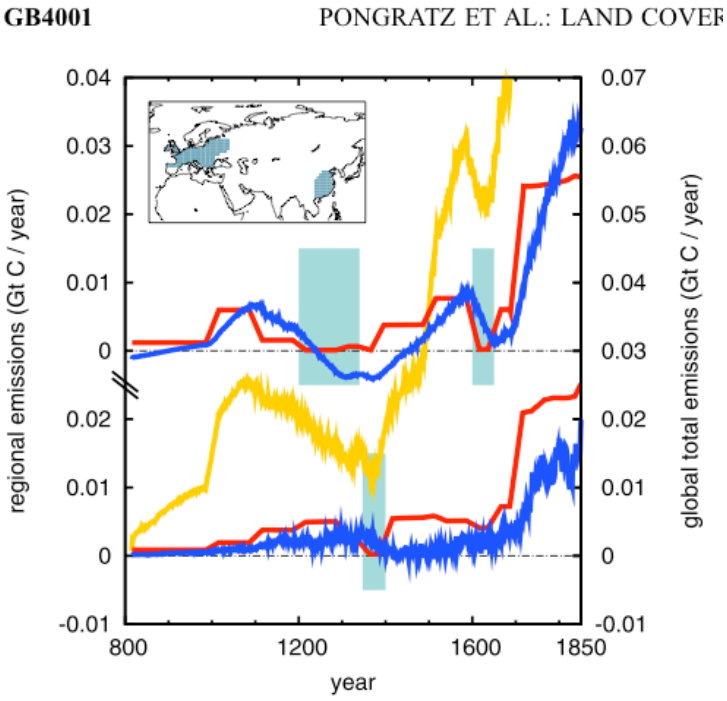
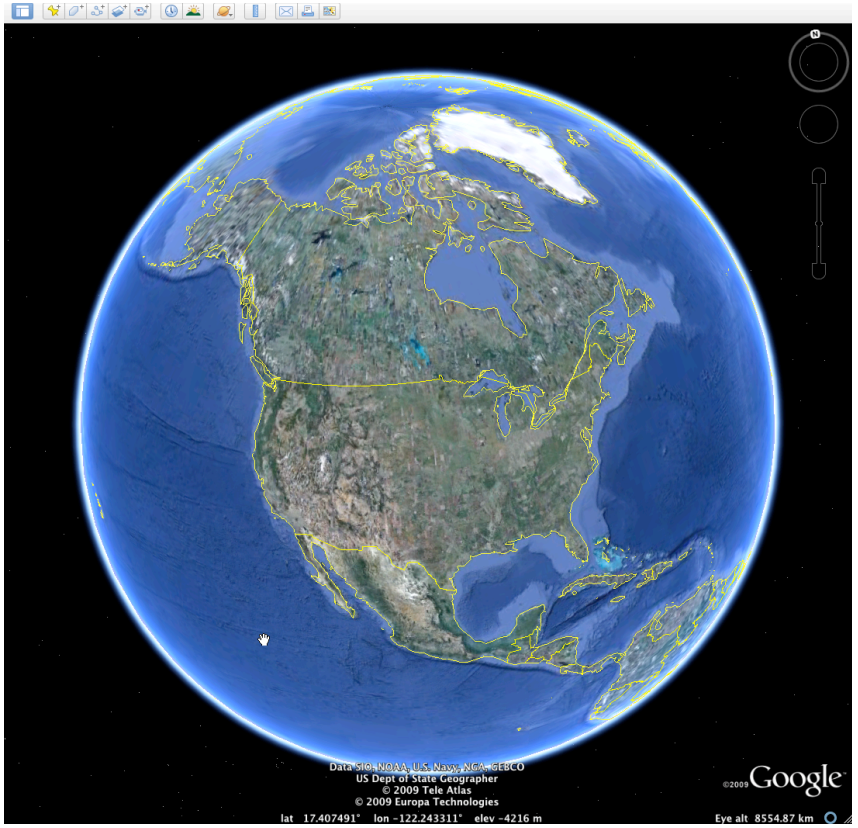


Figure 7. Direct emissions (red) and indirect emissions from changes in NEP (blue) for China (top) and Europe (bottom). The gray boxes indicate the time periods of decreasing regional population. On the right axes in yellow, global total primary emissions are given. Values are 30-year running means.

- Anthropogenic disturbances may be non-obvious
- Mongol Invasion and Black Death both resulted in large C perturbations
- Steady state in the mid-19th century *not* a safe assumption

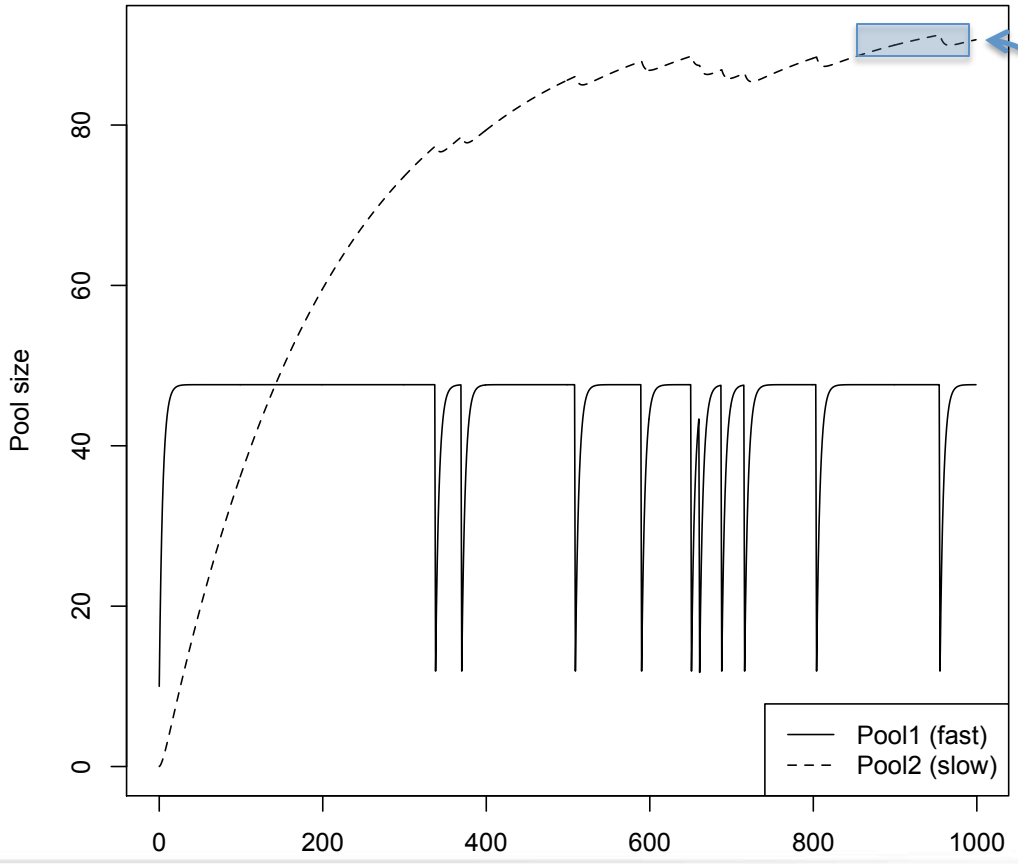
A belowground problem

- This is a *belowground* (soils) problem
- We'll soon be able to count the trees*
- But belowground is much harder, *and* it's where the carbon is stored, *and* we can't model its C losses well at all



*Every single tree, on the entire globe. "Hadoop."

Spinup and disturbance

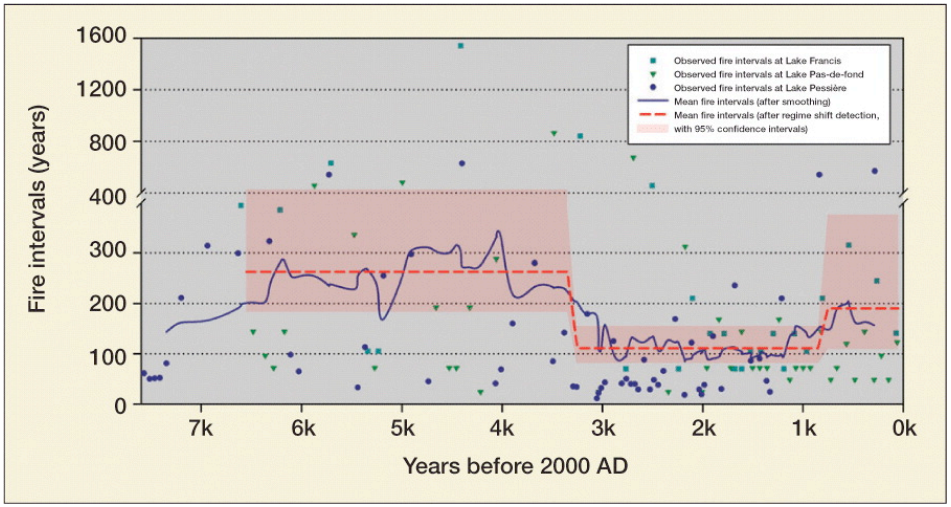


Compared to undisturbed case:

- Lower
- Less stable
- (Probably) longer to steady state

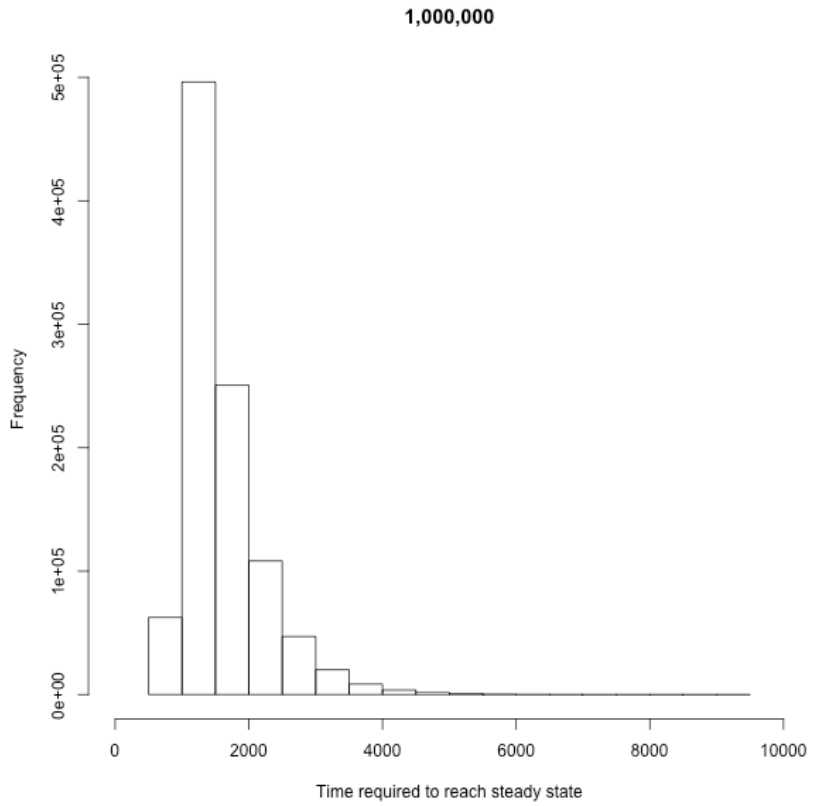
Disturbances in spinup

- Recycle disturbance history
  - but which parts?
- Reconstructed history
- Backcasting based on FRI
  - random disturbances
  - constant disturbances
- Long-term averaging



From Cyr et al. (2009)

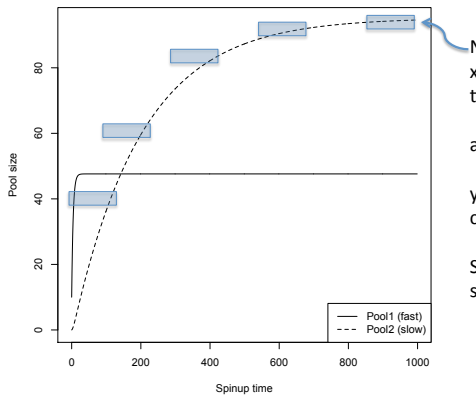
Landscape-scale spinup



- Given a large enough area (or number of trials) and randomness in the system, some cells will fail to stabilize
- Run longer?
- Have to deal with (typically) a post-spinup C surge at both cell and region level

Rethinking definitions

- Variable-size window
  - Carvalhais et al. (2007)



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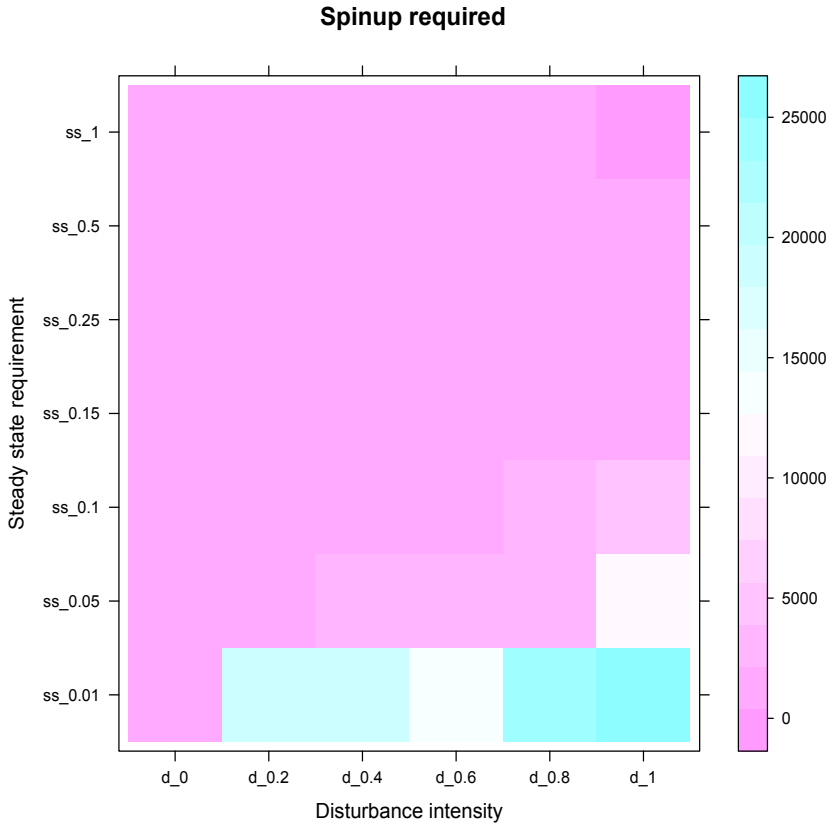
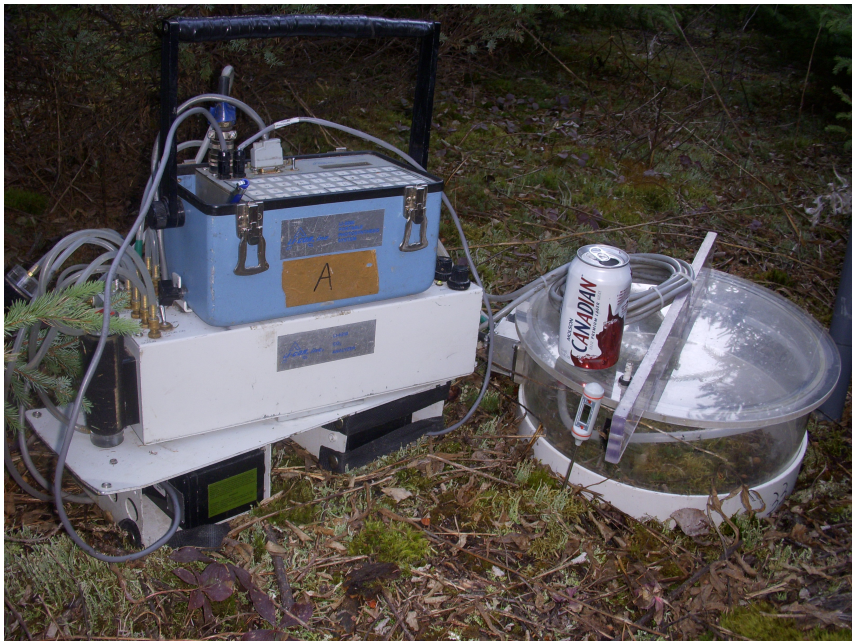


- Define stability at region level?
  - Cell stability implies regional stability, but the converse isn't (well, doesn't have to be) true

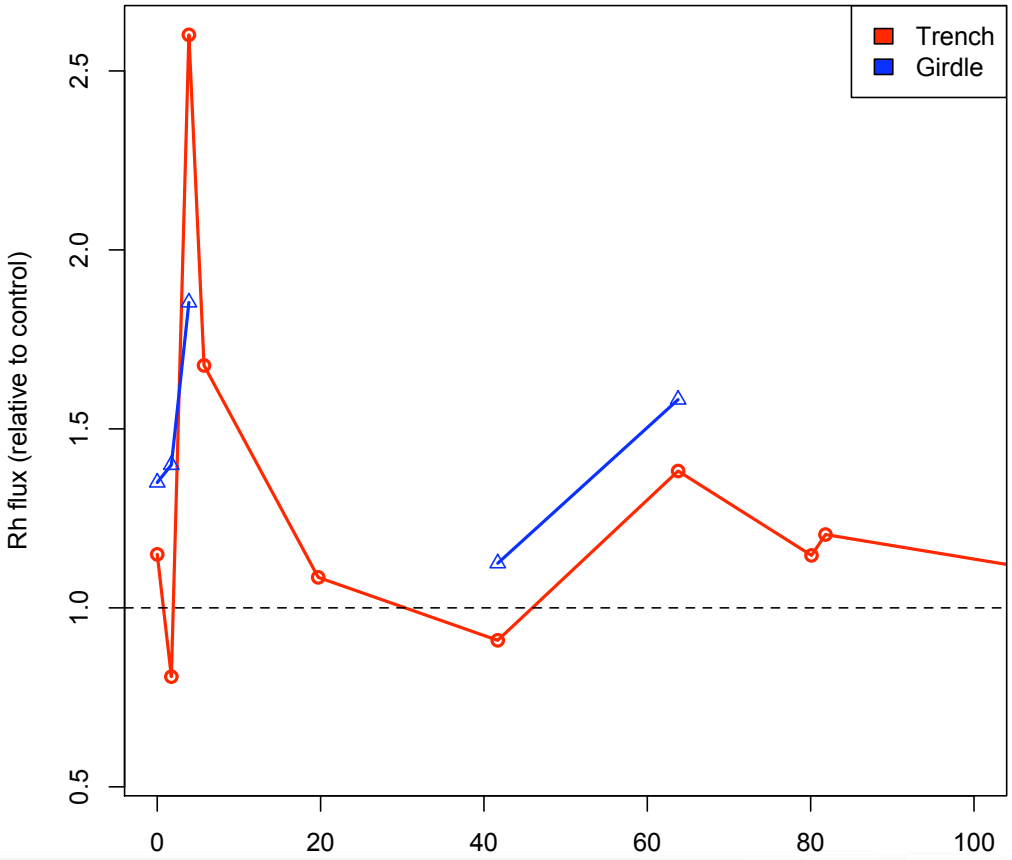
Song of the heterotrophs

Heterotrophic respiration (R_H)

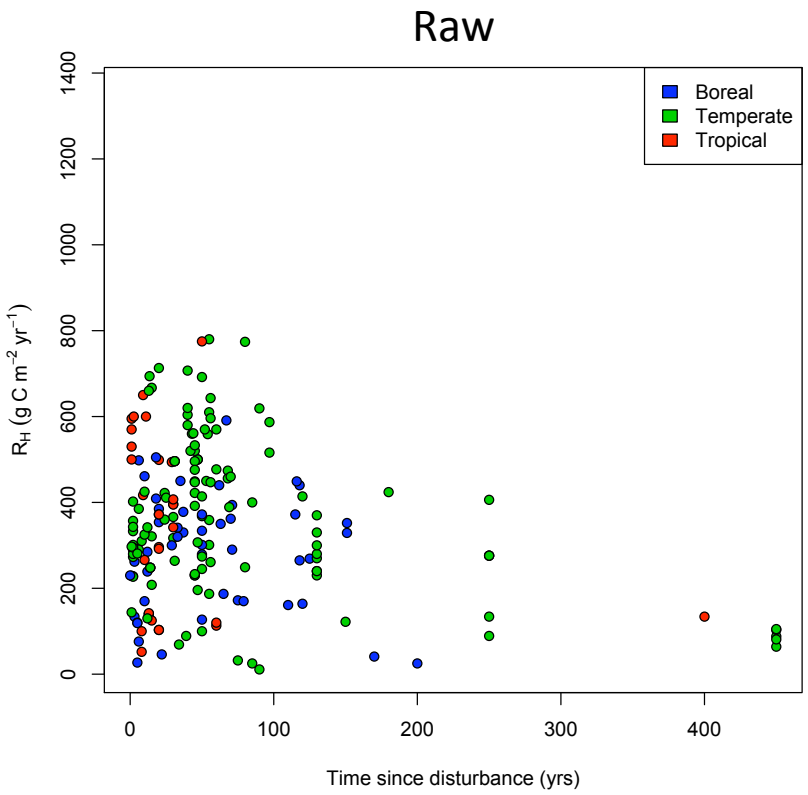
- The big, least well understood C pools are underground
- Aboveground C pools much smaller but turnover higher
- R_H is the key process
- Very poorly constrained in the field

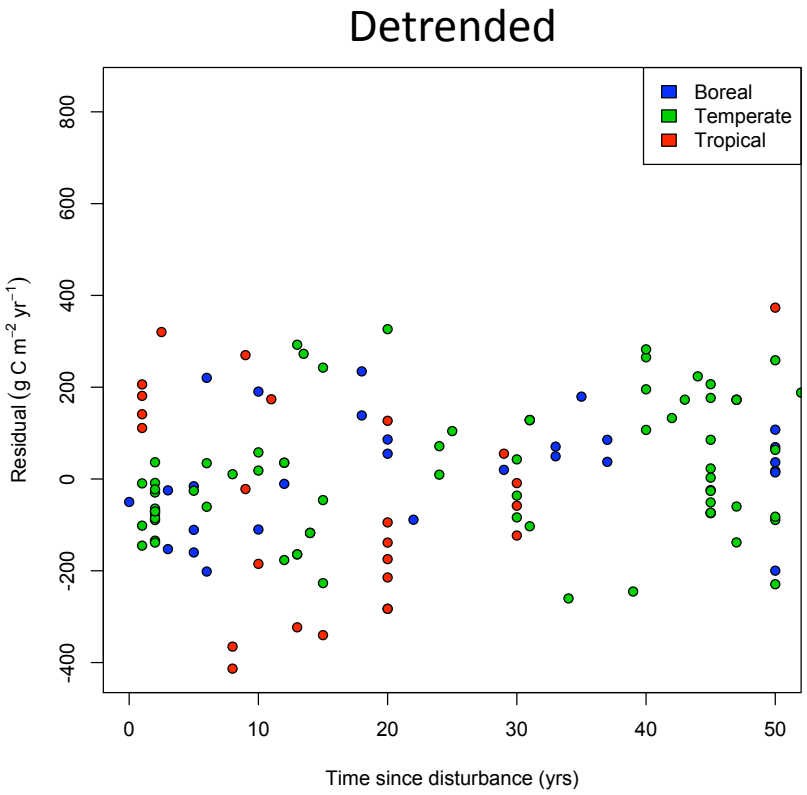


Disturbances perturb R_H



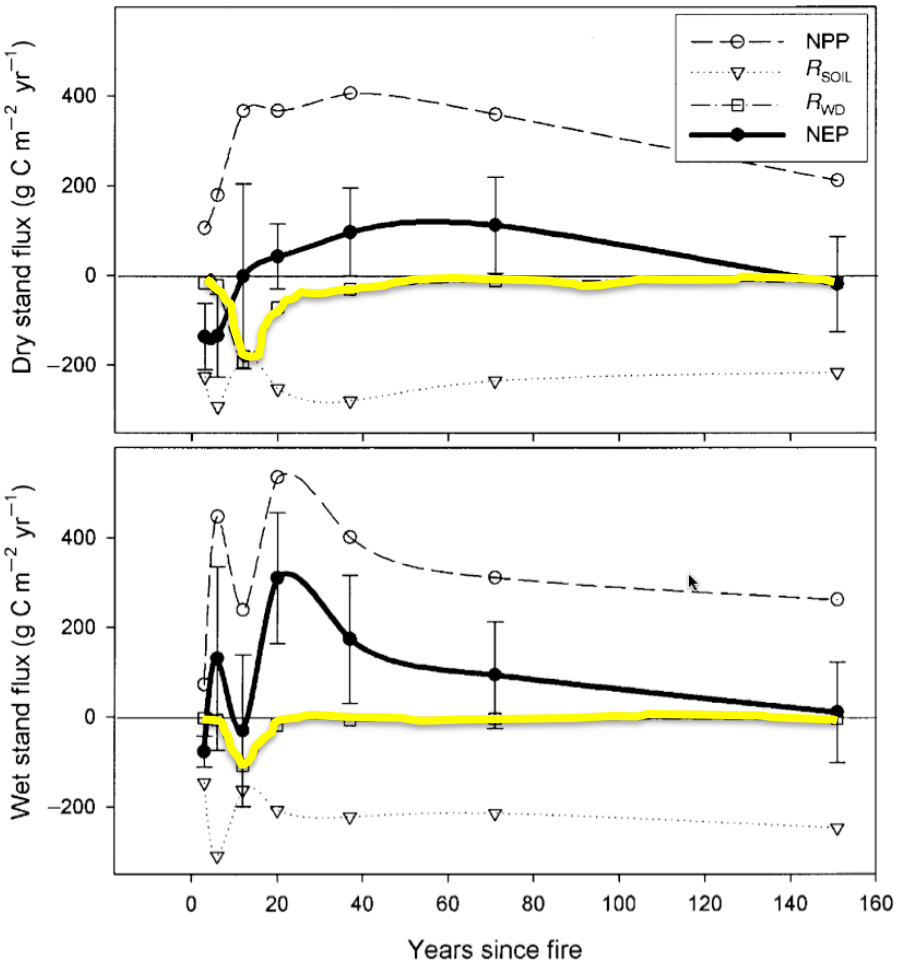
Where's the soil R_H signal?



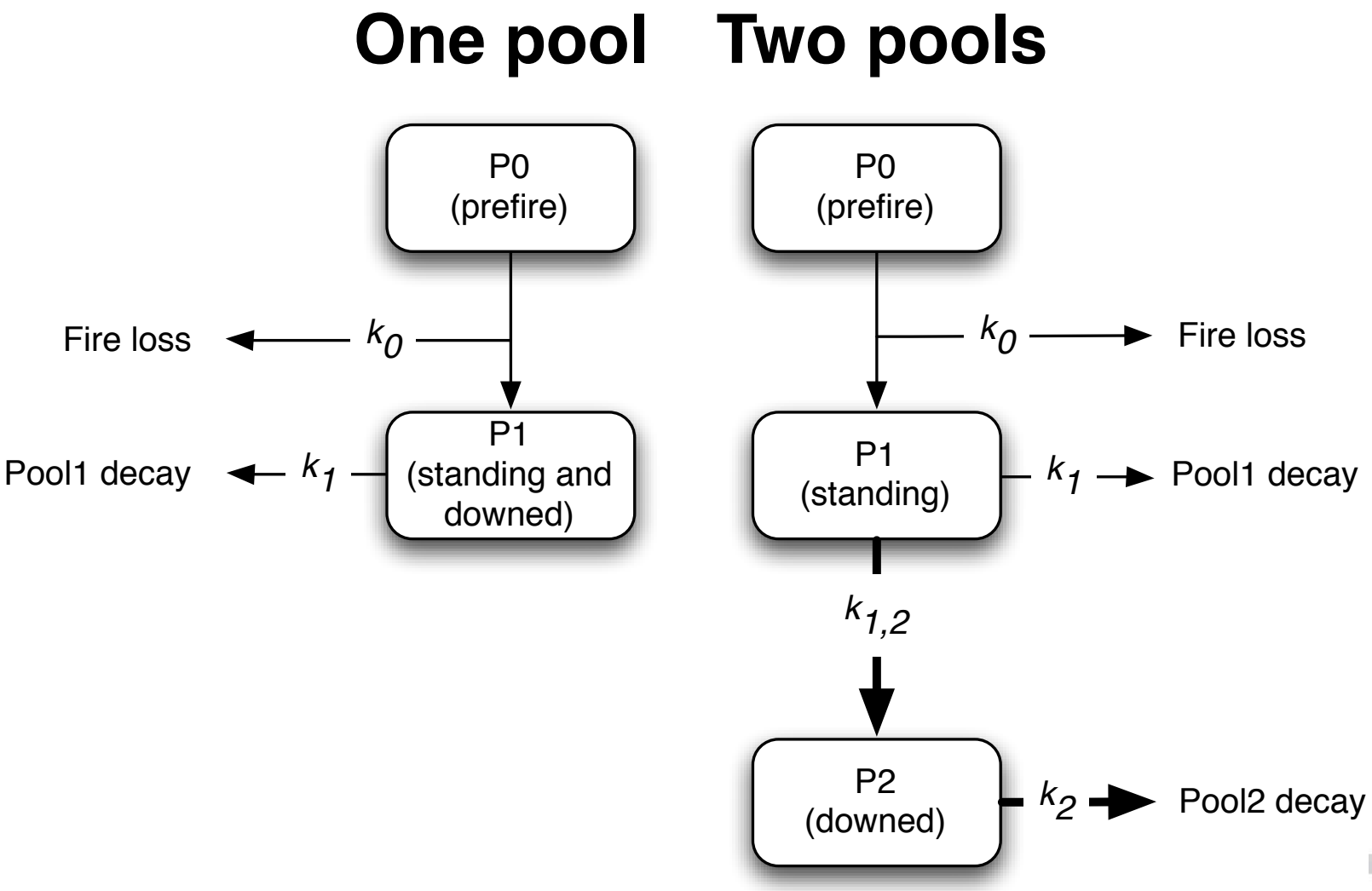


How trees (don't) fall down

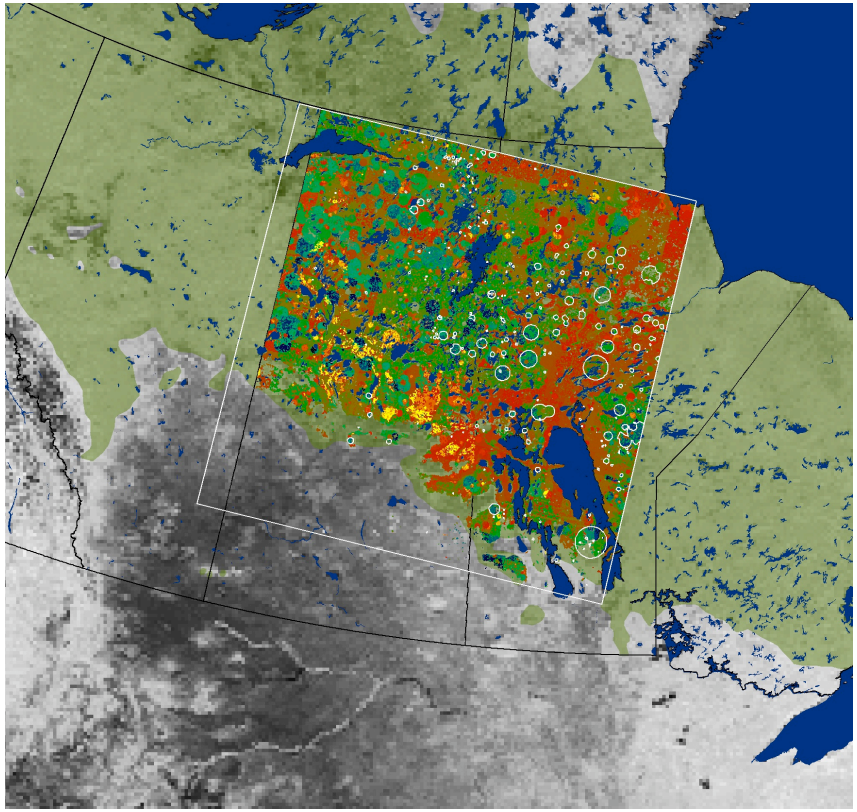
- In a disturbance, most of a tree's carbon doesn't burn, or get eaten
- It just hangs out, dry and suspended
- Until it falls
- This results in a C pulse, several decades* after disturbance



What if we don't get this right?

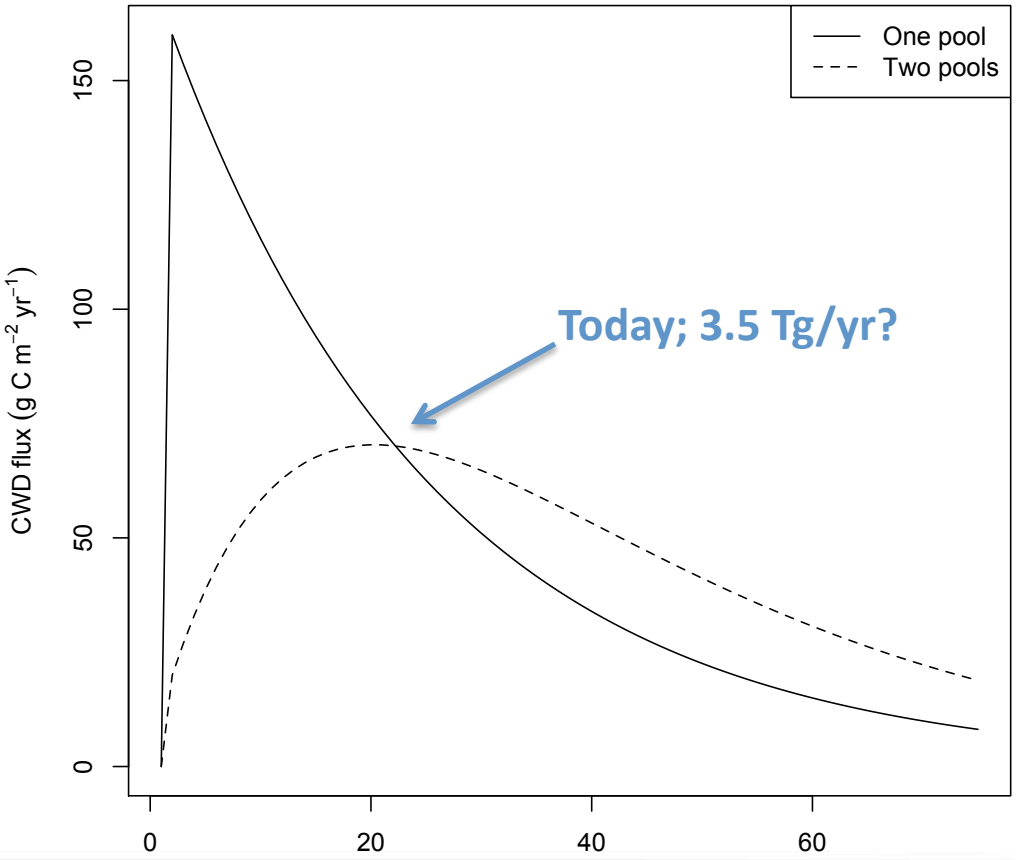


Does this really matter?

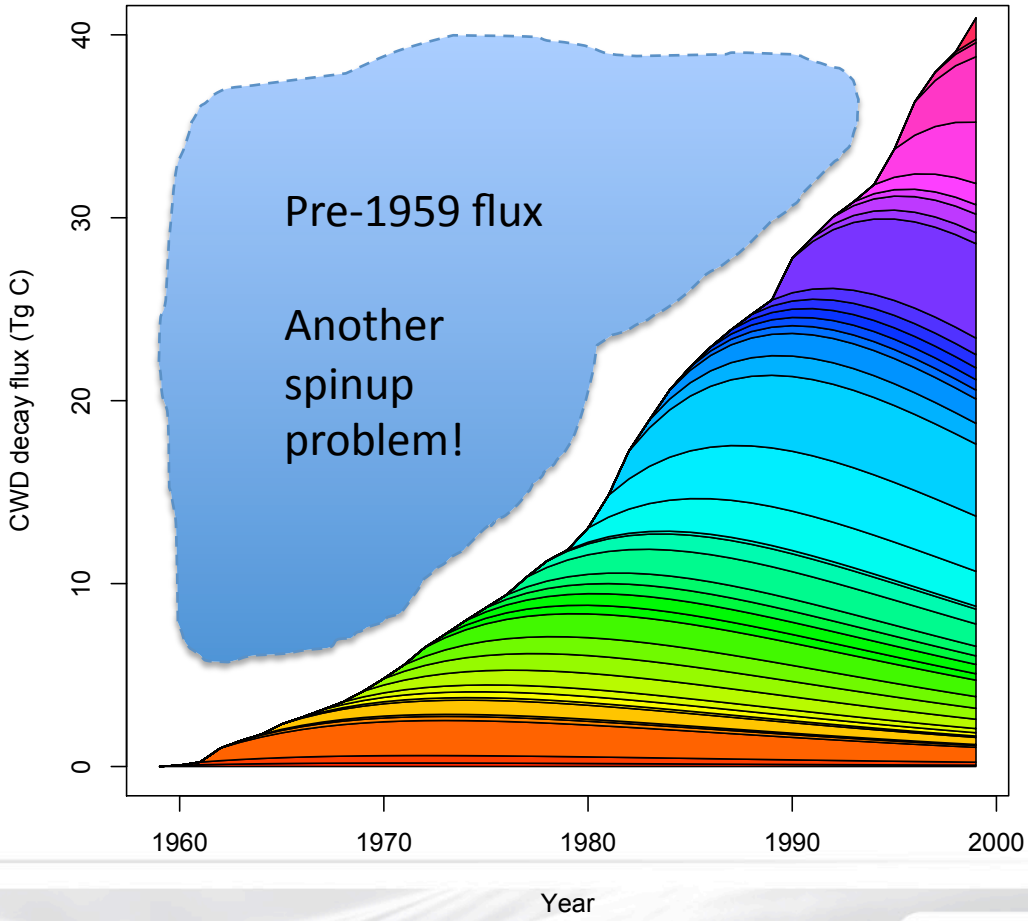


- 1989 was a *big* fire year in Canada (7.5 million ha burned)
- Twenty years later, all that suspended woody debris is coming down fast
- This provides a good test of potential importance

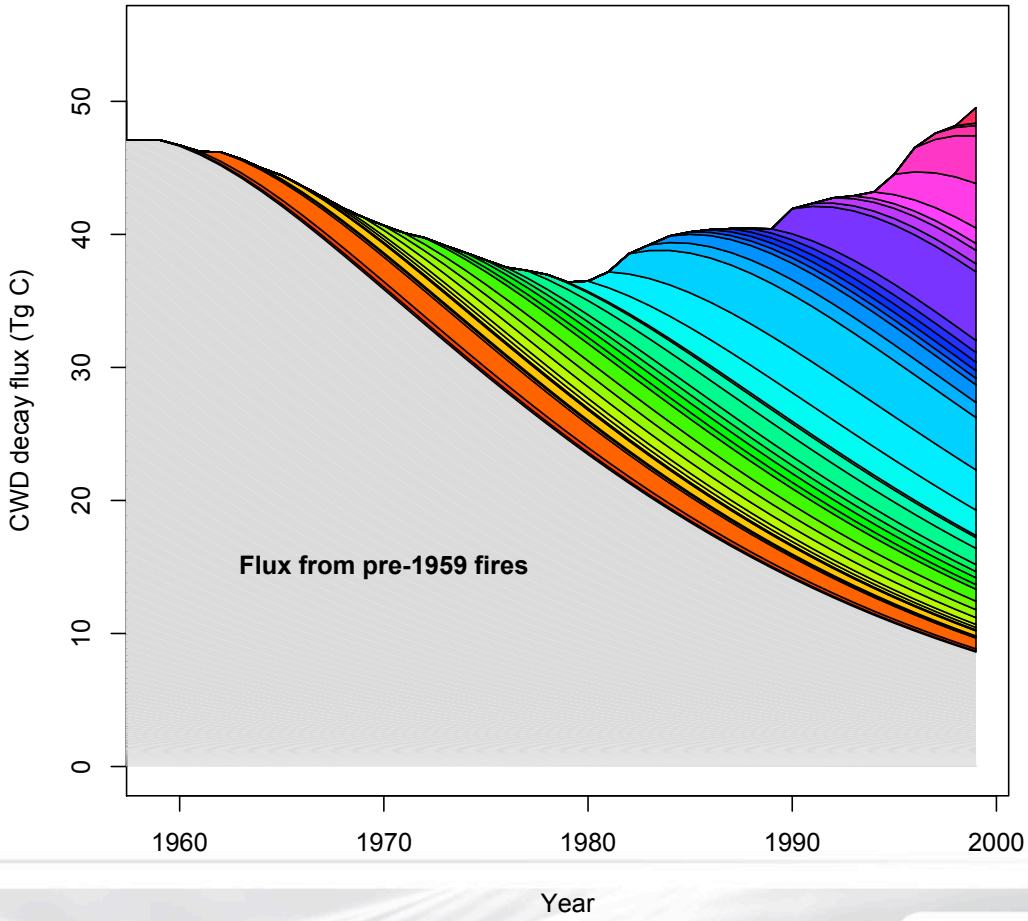
The 1989 fires today
(back of envelope)



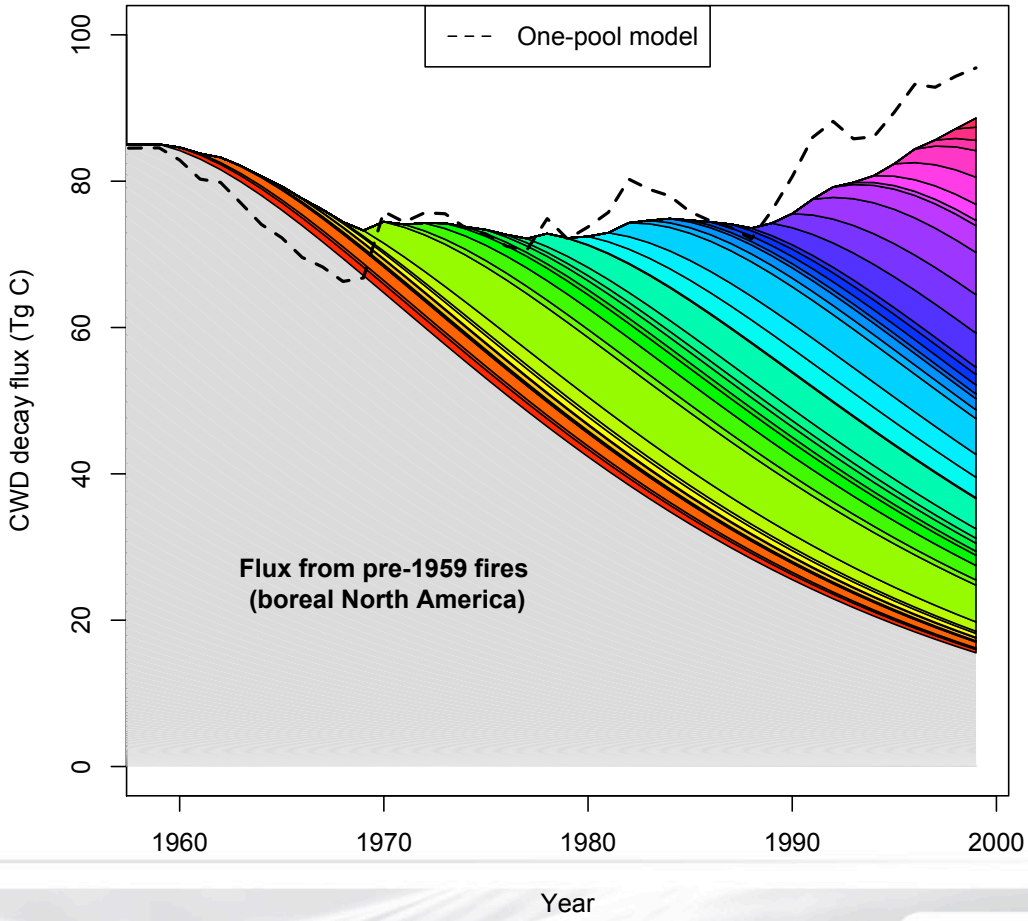
The 1989 fire flux in context



Canada

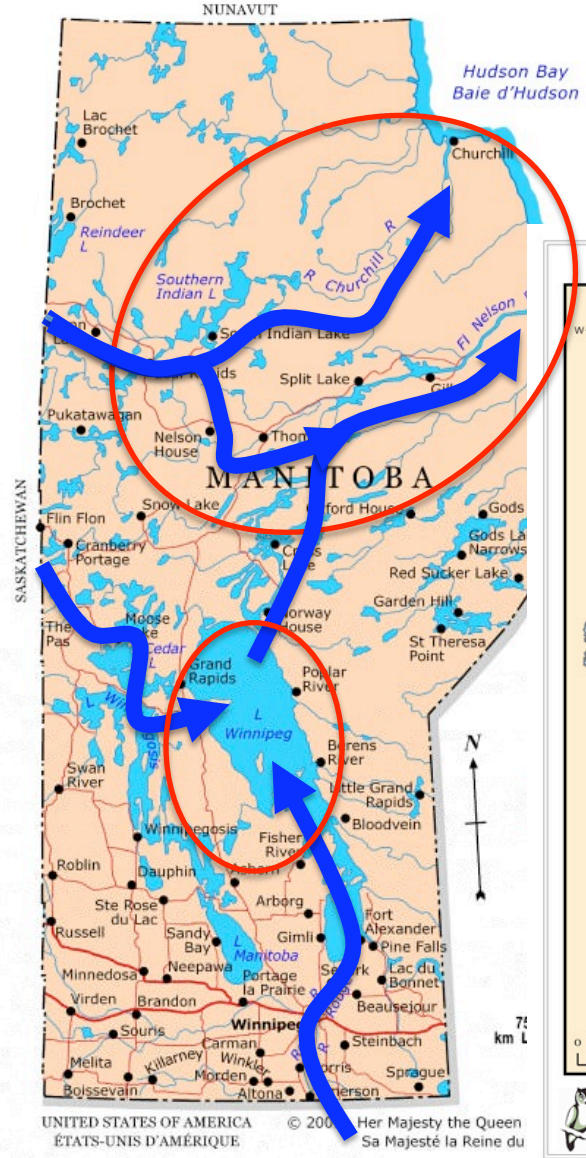

CWD decay flux (Tg C)
0
10
20
30
40
50
Flux from pre-1959 fires
1960
1970
1980
1990
2000
Year

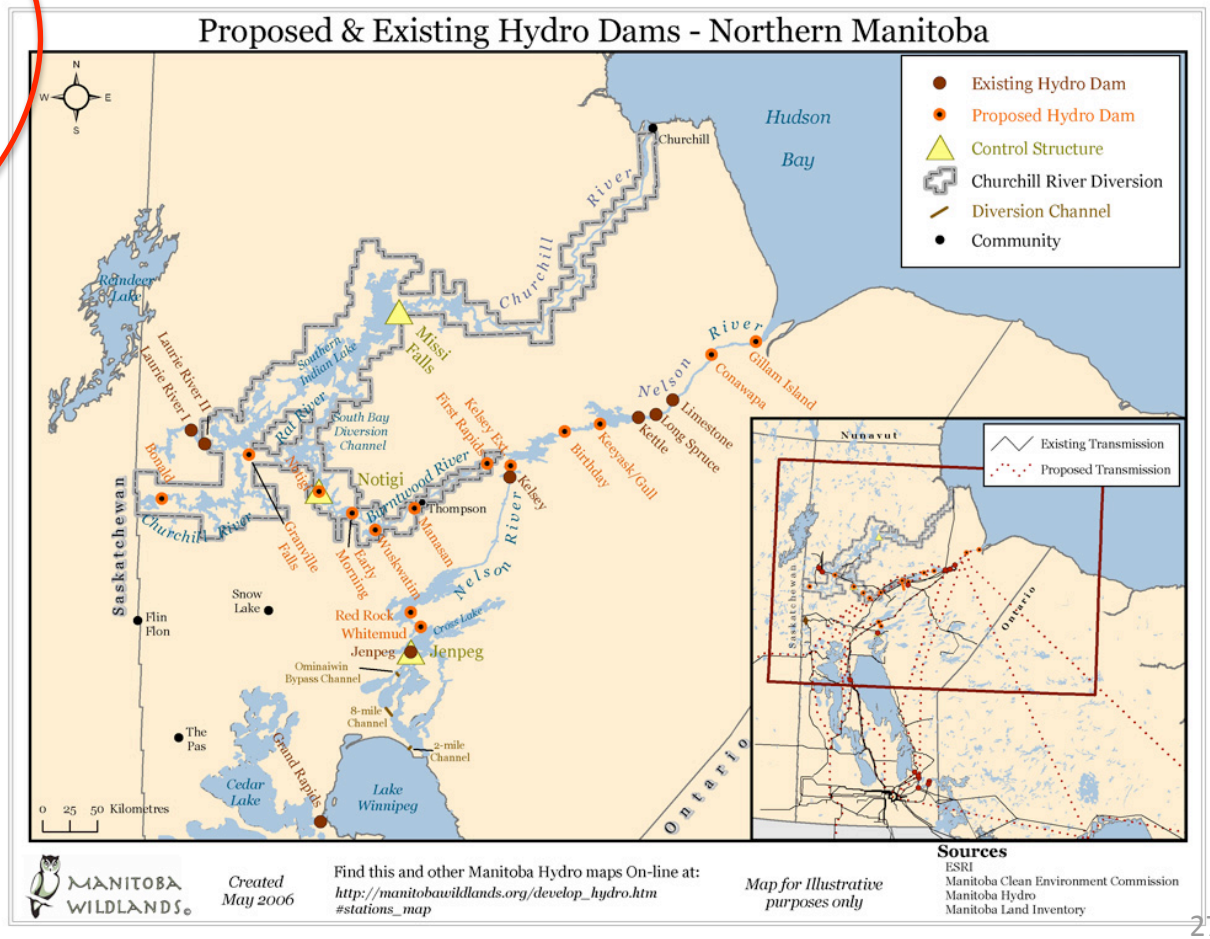
North America



Of watts and wildfire

The Churchill River diversion





Hydro generation

(Effectively, a 900-km long firebreak)

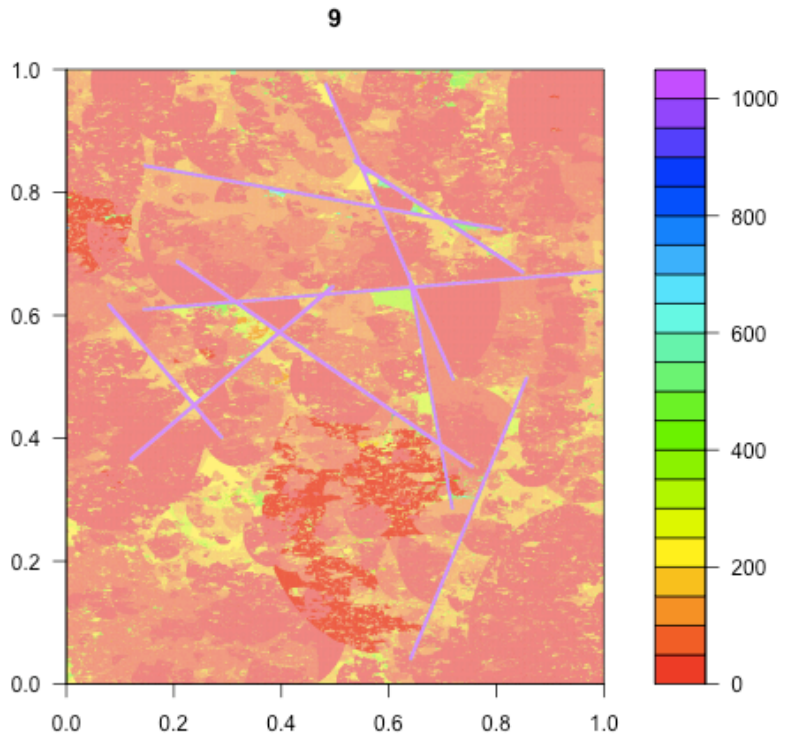
http://www.hydro.mb.ca/corporate/facilities/gs_kettle.shtml

Bipole III

- Electricity demand (both Canada and U.S.) climbing
- Bipoles I & II are saturated; Bipole III in planning stages
- Need fire suppression to protect the line

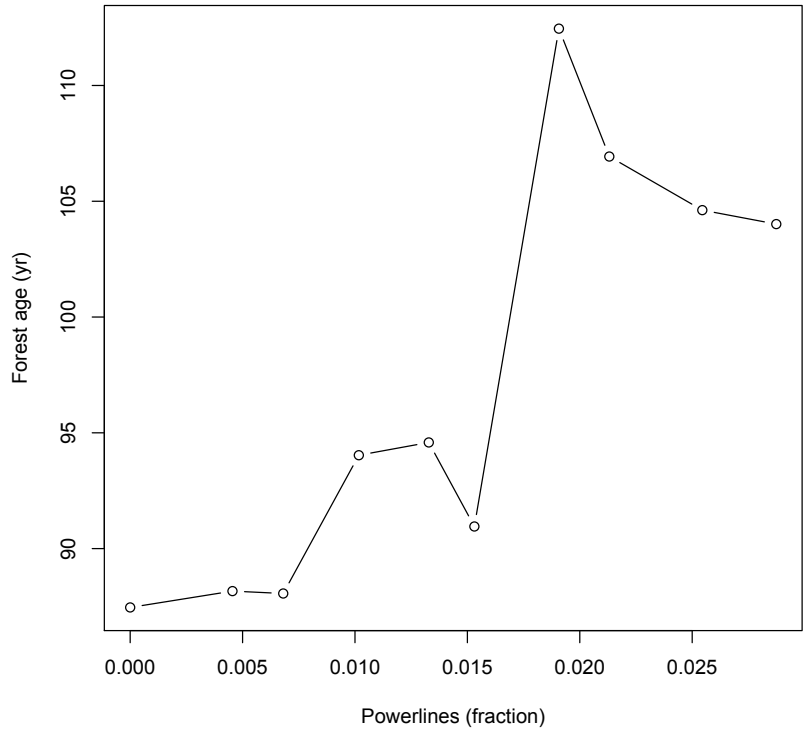
Fire and forest age

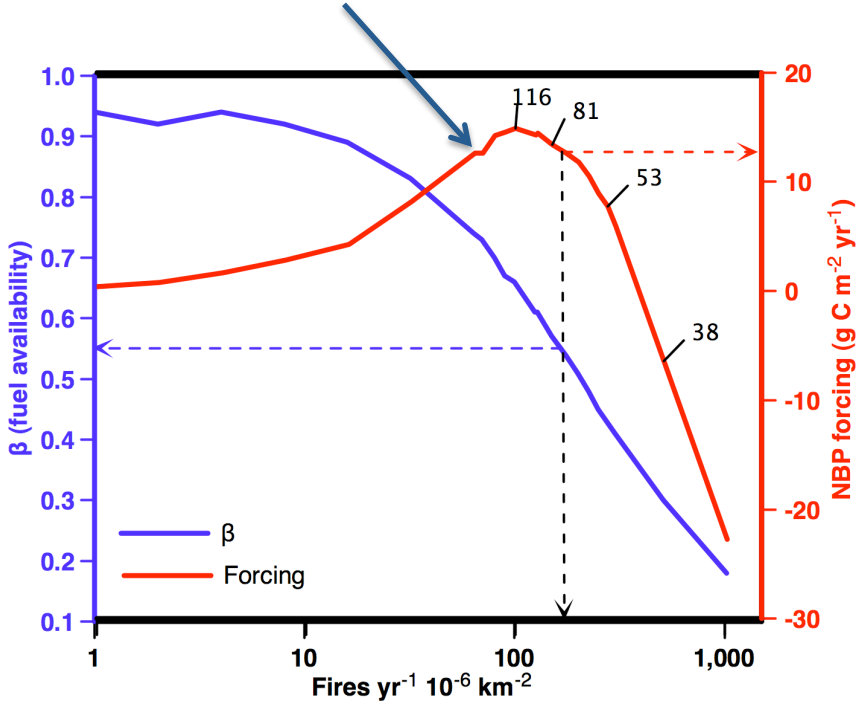
- What are the consequences for forest and C models of a new 1000-km firebreak?
- Observed fire distribution and occurrence data, pretend landscape
- Add fire breaks and observe consequences on area burned, stand age, and C sequestration



More fire breaks mean older forests

Spinup assumptions determine starting location on this curve;
CWD decay characteristics help determine speed of change!





A series of problems

- Spinup
- Initial value problem
  - Absolute versus relative numbers
- Woody debris decay
  - 3-5% of C sink at large scales; much larger at small
- Power lines (i.e., land-use change)
  - 10% of C sink in example
  - Can swamp everything else
- Forest succession

In conclusion

- Nonlinearity—both in the real world and in models—exposes questionable assumptions and empirical simplifications in our models
- Experimental disturbances are difficult
  - Modelers have a real opportunity for hypothesis generation
- Increasing need for spatially and temporally explicit modeling: challenges won't go away!