ETH
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Forests in a Greenhouse Atmosphere: Predicting the Unpredictable?

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Overview

- The nature of the problem
- Models for simulating long-term forest dynamics
- The power of data:
  Testing models – forest inventories
- The power of models:
  Upscaling of information – the vanishing CO_2 effect
- Conclusions

The nature of the problem

“Predict”?

Merriam-Webster Dictionary (http://www.m-w.com):

- *Predict*
  implies inference from facts or accepted laws of nature:
  <*astronomers predicted an eclipse*>

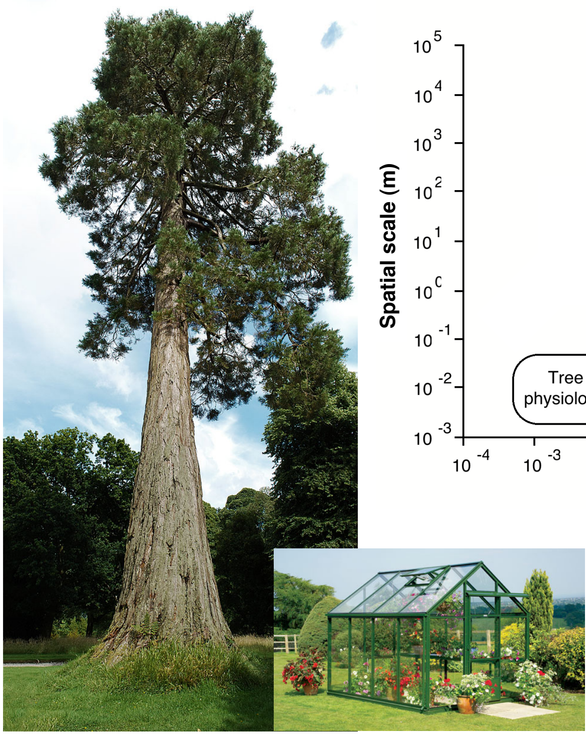
- *Forecast*
  adds the implication of anticipating eventualities and differs from predict in being usually concerned with probabilities rather than certainties, i.e. it indicates that something is likely to occur:
  <*forecast snow*>

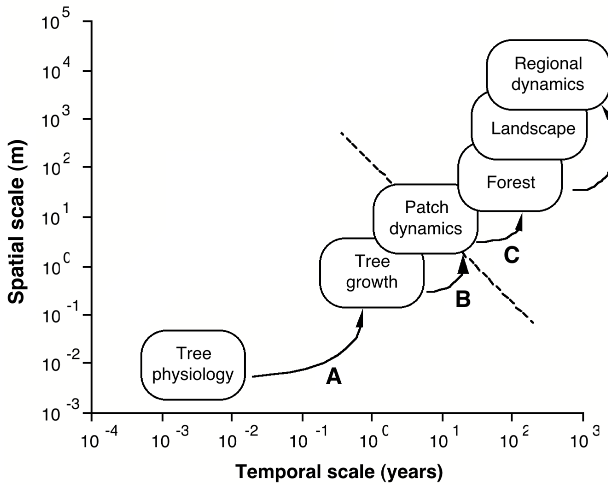
- *Projection*
  an estimate of future possibilities

- *Scenario*
  an account or synopsis of a possible course of action or events

Bugmann (2003), *Princeton U Press*

Forests don’t fit into greenhouses





Bugmann et al. (2000), *Clim. Change*

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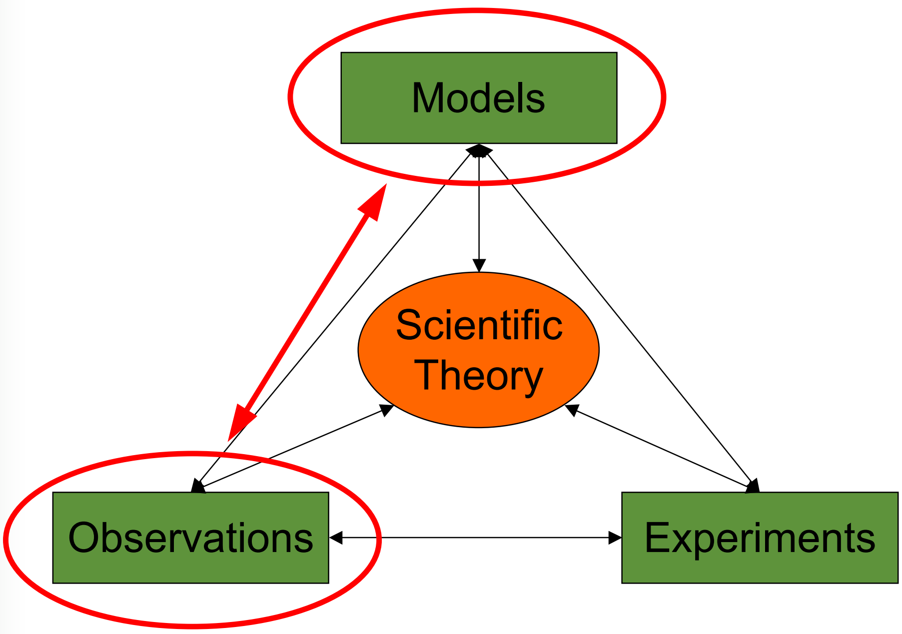
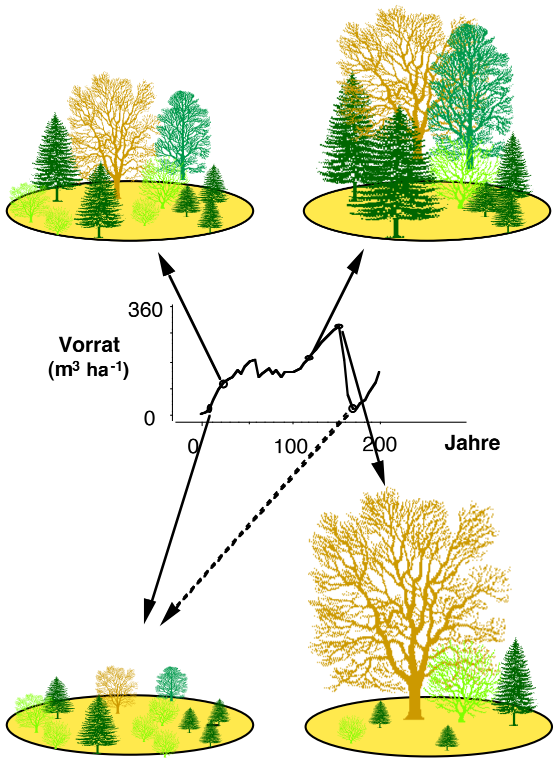


Models for projecting long-term (>100 yrs) forest dynamics

Forest succession models: approach

- Concept of small-scale mosaic of successional patches (Gleason, Botkin, Shugart): so-called „Gap model“
- Quantitative description of tree population dynamics:
  - Establishment
  - Growth
  - Mortality
- Sensitive to climatic factors
- Here: FORCLIM model, stand-scale (≈ a few hectares)



Criteria for model construction

- As complicated as real forests? No...
- As simple as possible? Yeah... but... how simple is that??
- The concept of allometric relationships:

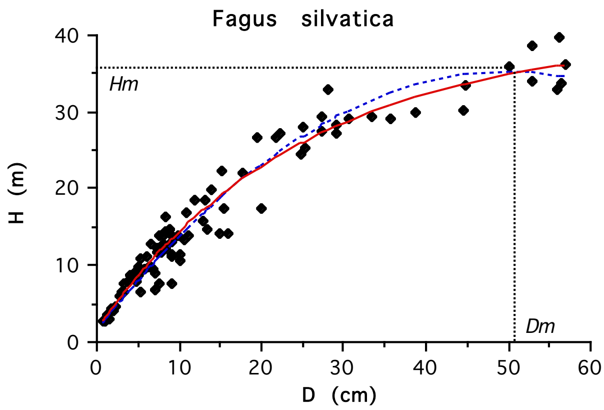
Forest succession models: growth

- Volume change of a tree:

$$dV/dt = r \cdot L - m \cdot V$$

Photosynthesis ($r \cdot L$) Respiration ($m \cdot V$)

- Allometric relationships (D = tree diameter at breast height):
  - $L = f_1(D)$
  - $V = f_2(H,D)$
  - $H = f_3(D)$



- ...from which follows (after some math):

$$\frac{\mathbf{dD}}{\mathbf{dt}} = \underbrace{g \cdot \mathbf{D}}_{\text{exponential}} \cdot \underbrace{\left(1 - \frac{\mathbf{H}}{H_{max}}\right)}_{\text{asymptote}} \cdot \underbrace{\frac{1}{\mathbf{b(D)}}}_{\text{allometry}} \cdot \underbrace{f(\mathbf{e})}_{\text{environment}}$$

Moore (1989), *Ecol. Modelling*

Towards higher model accuracy

- Height-diameter allometry
  Case study Swiss National Park (Risch et al. 2005)
- Self-pruning in dense stands
  Case study Stotzigwald UR (Wehrli et al. 2005)
- Autecological parameters: height, drought response
  Case study Valais (Weber et al. 2007)
- More self-pruning & browsing response
  Various case studies (Didion et al. 2009)
- Tree mortality
  Various case studies (Heiri 2009)
- Forest management
  Various case studies (Rasche *ongoing*)

The power of data

Rigorous tests of the models are needed...

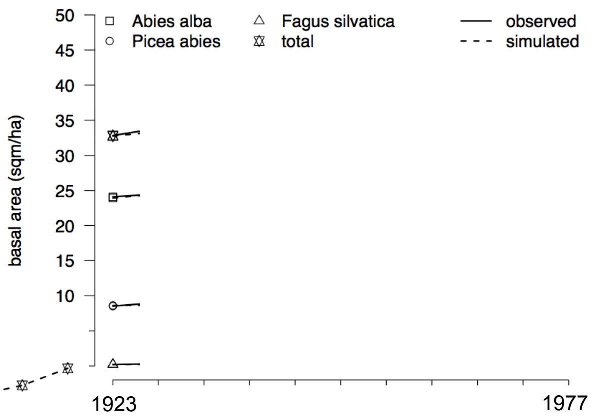
- Long-term Growth-and-Yield plots (Swiss Federal Res. Institute WSL)
  - 50+ stands
  - Partly dating back to 19th century
  - Inventories every 5-15 yrs
  - Mostly (strongly) managed stands
  - Tree positions known
  - Small, uniform plots

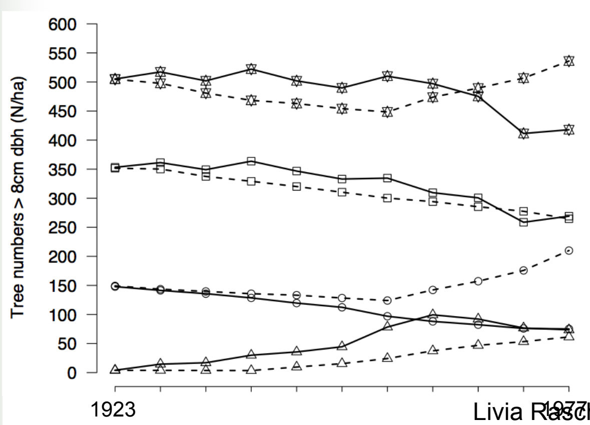
http://www.wsl.ch/forschung/forschungsunits/walddynamik/waldwirtschaft

- Network of Swiss forest reserves (ETH Zurich, WSL)
  - 48 reserves
  - Dating back to 1950s
  - Inventories every 5-15 yrs
  - Unmanaged for 50+ yrs
  - Tree positions unknown
  - Small permanent plots
  - Full cruises on larger areas (compartments)

http://www.waldreservate.ch

Model test against Growth-and-Yield data





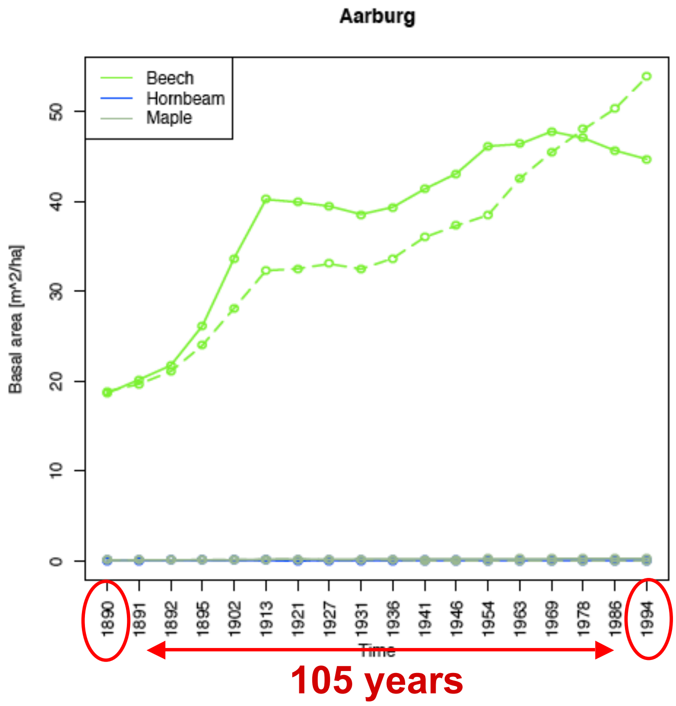
Niederhünigen (BE)

Δt = 54 yrs

Livia Rasche, *last week's work*

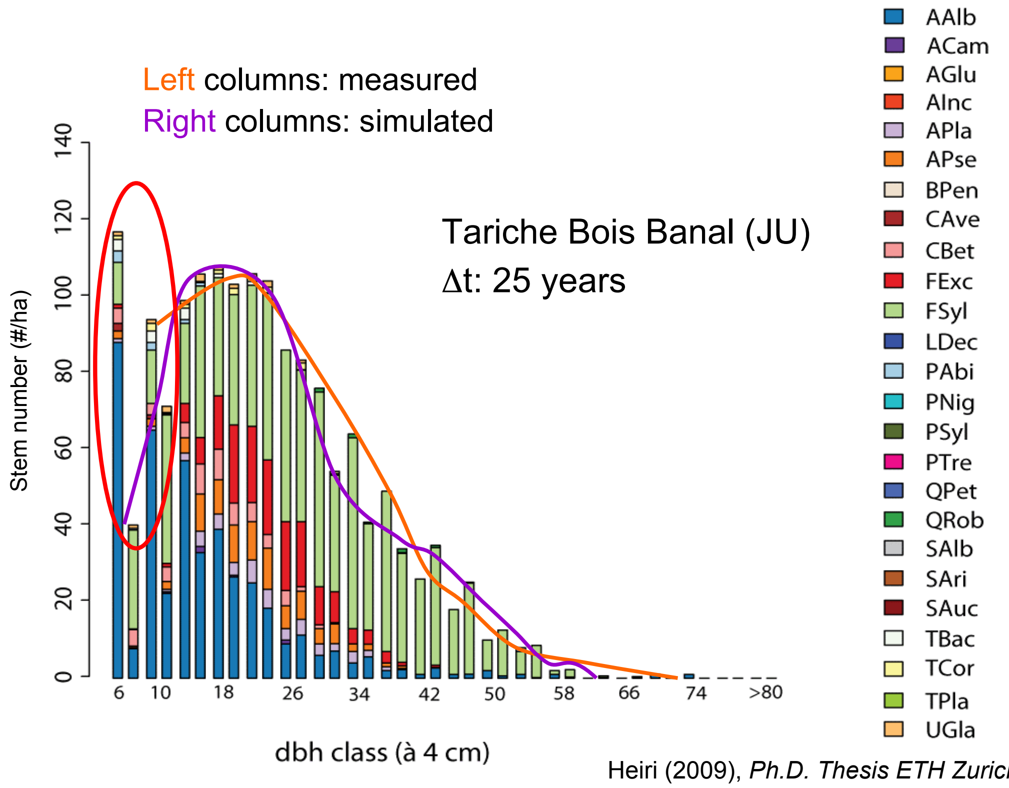
Didion et al. (2009) *CJFR*

Model test against Growth-and-Yield data



Livia Rasche, *last week's work*

Model test against reserve data

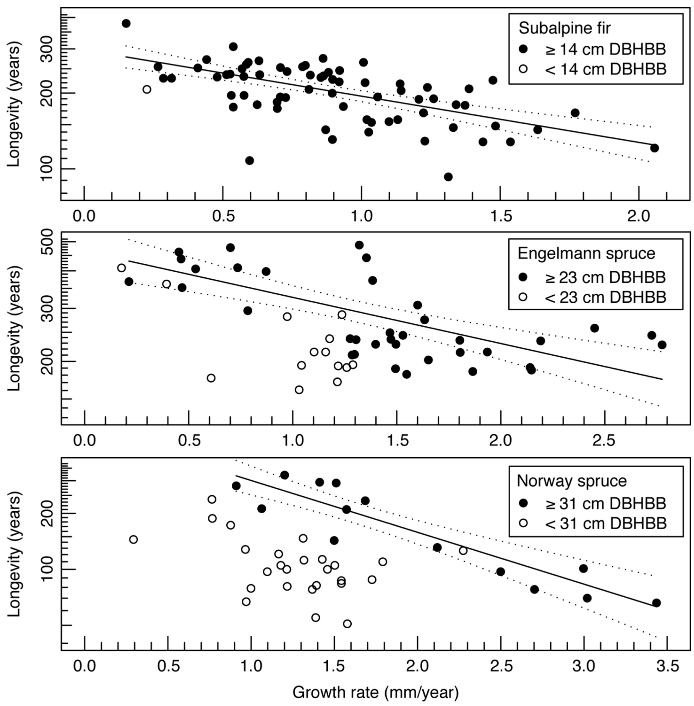


Heiri (2009), *Ph.D. Thesis ETH Zurich*

The power of models

“Grow fast, die young”

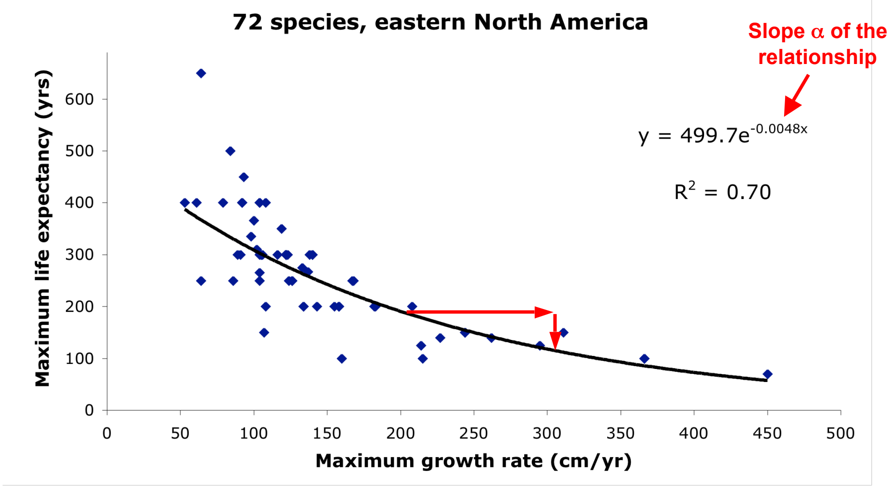
- Study of growth rate vs. longevity:
  – 3 species
  – 2 continents
- Negative exponential relationships: slope α in range [-0.35…-0.64]
- Implications? e.g. CO_2 fertilization, long-term forest dynamics & biomass?



Bigler & Veblen (2009), *Oikos*

Generalizing the finding

- Data on maximum growth rate (at young age) and maximum longevity of 141 temperate & boreal species

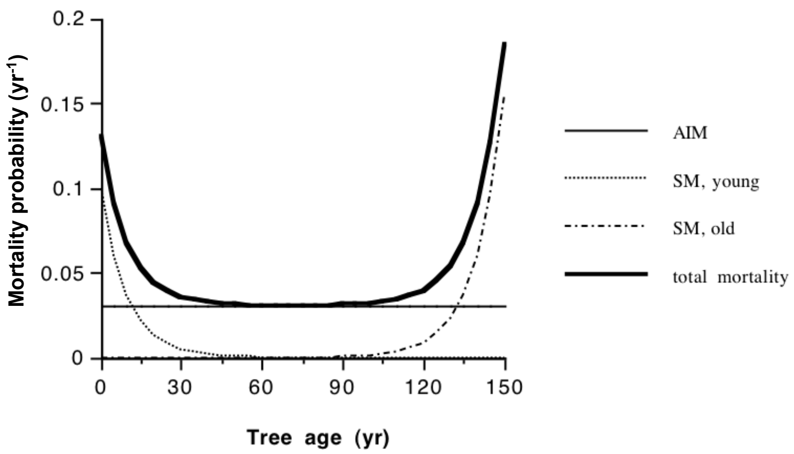


- Slope α (scaled to Bigler & Veblen units): [-0.31...-0.61]

Bugmann & Bigler (*under revision*)

Forest succession models: mortality

- Combination of
  - "background" mortality that is constant across tree life, tied to ***maximum tree age*** kA_m): small fraction of trees survives to kA_m ("age-independent" mortality = AIM)
  - growth-related mortality ("stress-related" mortality = SM)
- Overall effect:



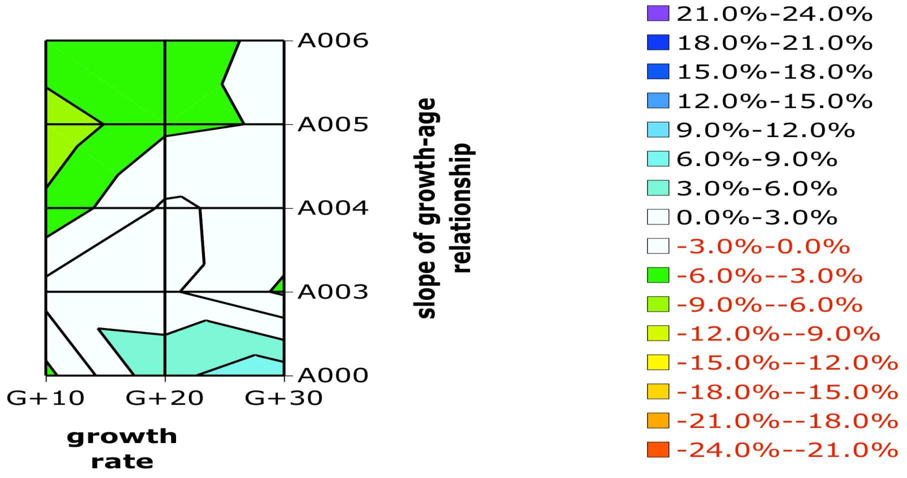
- CO_2 fertilization:
  - Reduced SM (higher growth rate)
  - Higher AIM (reduced longevity)

Bugmann (2001), *Clim. Change*

Exploring the effect using FORCLIM

- Net effect of growth stimulation vs. reduced longevity unknown
- Simulation study at 6 sites along climate gradient

Davos, change in total aboveground biomass

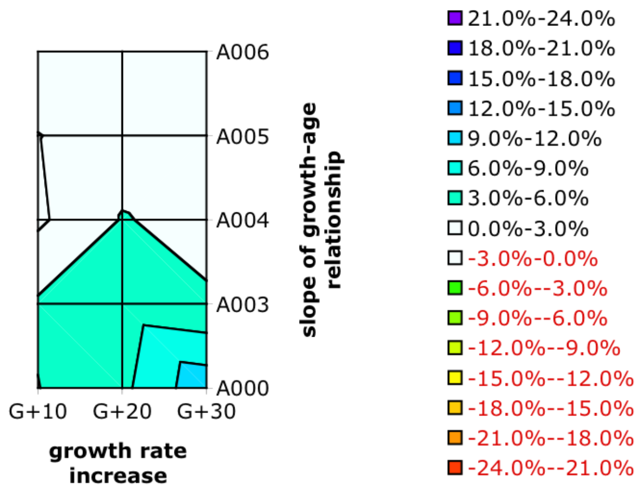


Bugmann & Bigler (*under revision*)

Exploring the effect using FORCLIM

- Results averaged over all sites (multi-species case):

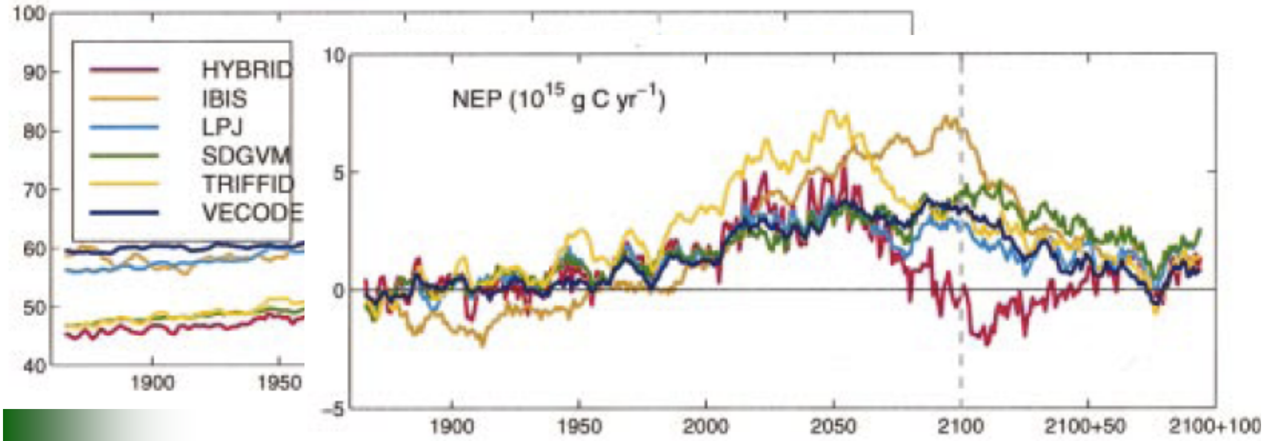
All sites, multi-species, Δbiomass



Bugmann & Bigler (*under revision*)

Taken together...

- Lack of growth-longevity relationship (& emphasis on source limitation) explains strong CO_2 effects in the “mechanistic” global vegetation models



(Short term) reality – (long-term) artefact?

Cramer et al. (2001), *GCB*

Conclusions

- Estimating future forest dynamics is a challenge, but not a hopeless endeavor
- Seemingly “boring”, old data (forest inventories) are invaluable for testing model behavior in the long term and along strong climate gradients … and these data collection efforts must be maintained
- Selection of processes to be modeled is crucial and non-trivial
- Example CO_2: taking into account reduced longevity may well cancel any growth stimulation
- Few (if any) models of biosphere dynamics are taking this into account: we may overestimate the biospheric C sink in the 21st century