Significance of long-term environmental and physiological records for understanding and predicting forest ecosystem function

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Overarching question

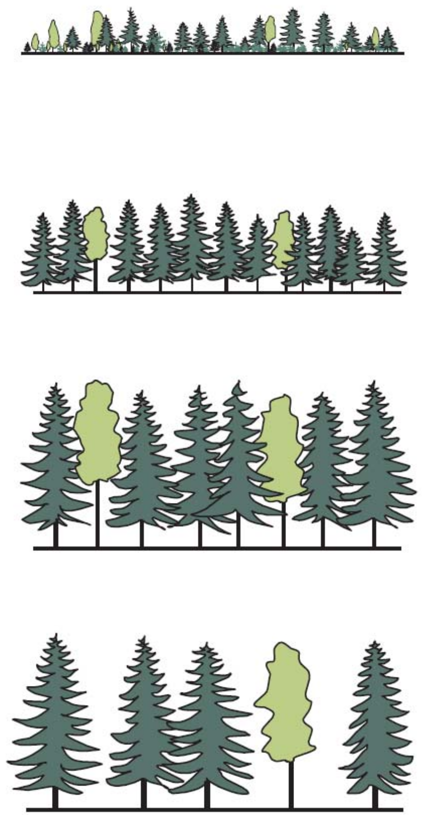
- How do we gain understanding about forest ecosystem functioning?
- Interaction of data and models?
- What data are available?
- How do models relate to them?
- Where are we going?

Outline

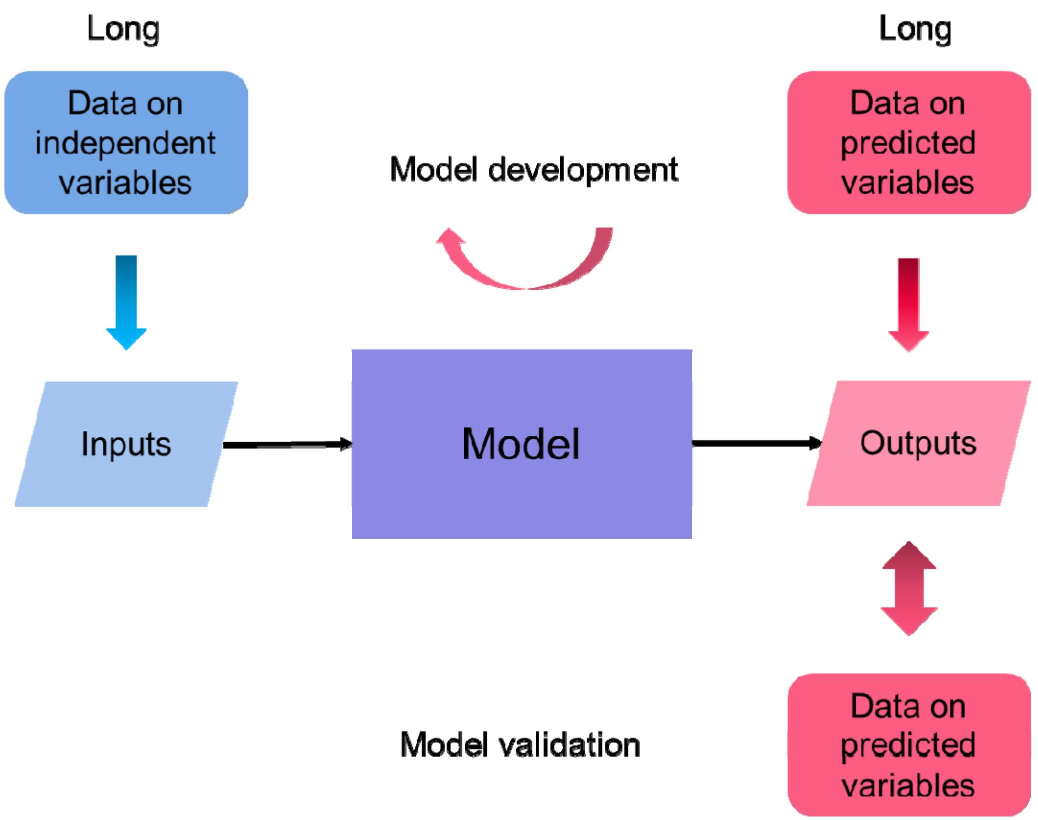
- Data and modelling paradigms in forest science
- Where are we now?
- Current and recent trends in models and data
- Conclusions

Forestry data

- Why collected?
  - Predict growth potential
  - Recommendations for management
  - Monitor growing stocks
- What time scale?
  - Lifetime ≥ 50 – 200 yrs
  - Standard time step ≤ 5 yrs
- Data sources?
  - Permanent sample plots > 20 yrs
  - National forest inventories > 50 yrs



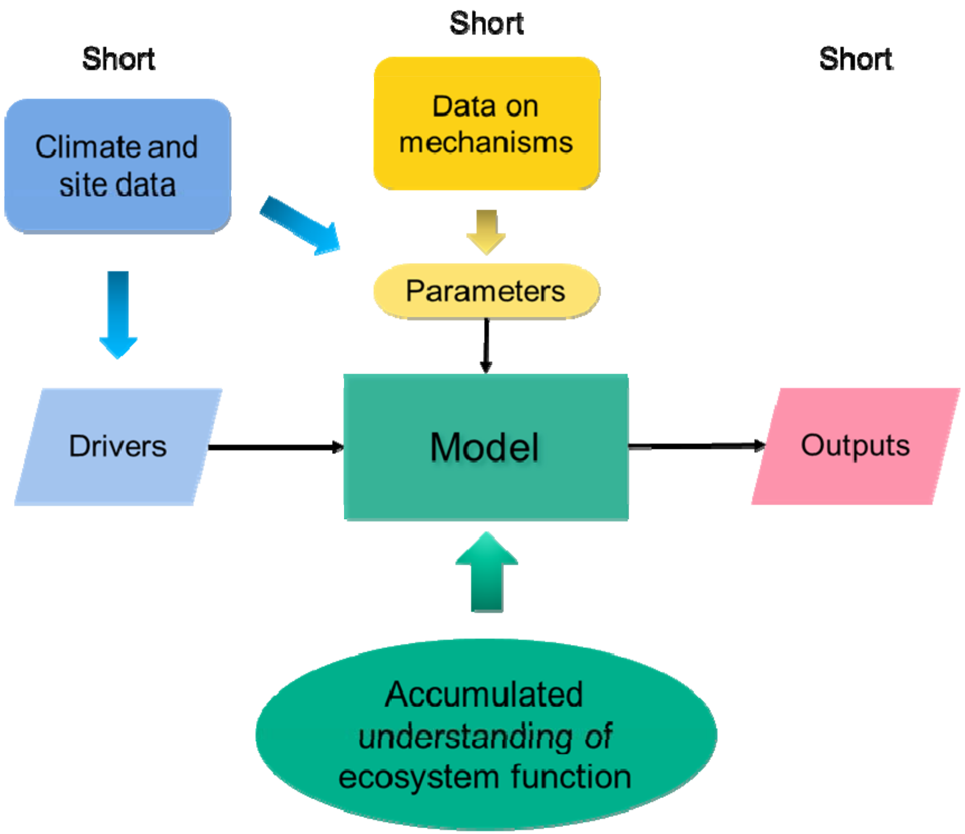
Forestry data: Empirical model paradigm



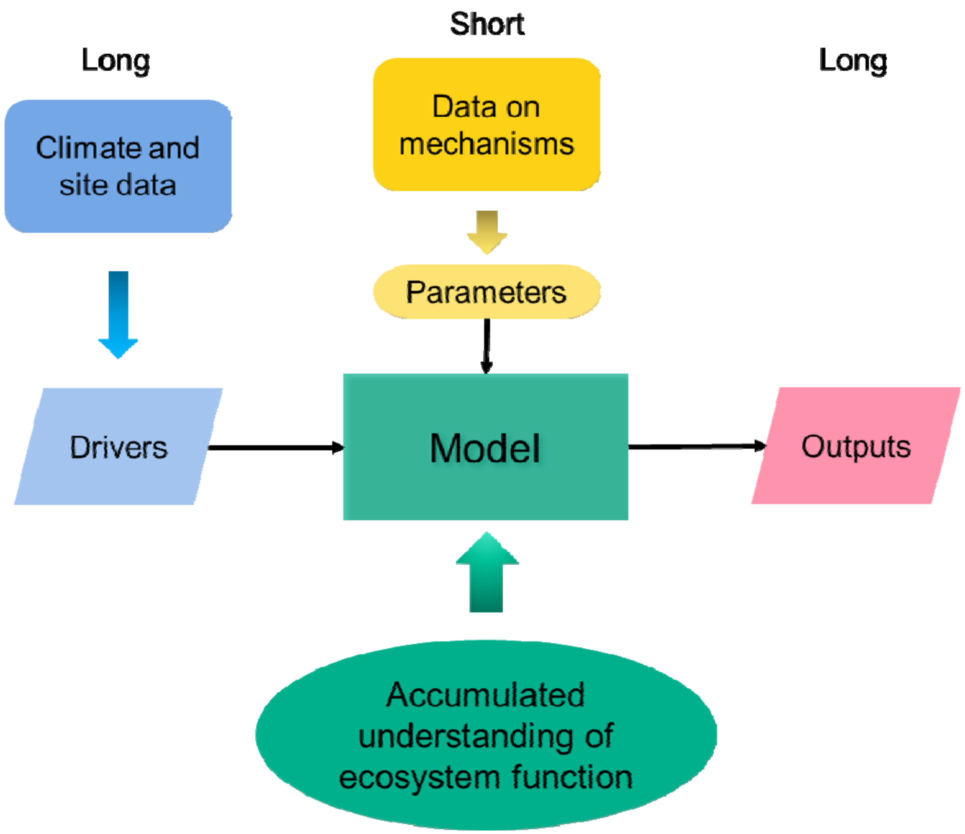
Eco-physiological forest data

- Why collected?
  - Derive growth from physiology
  - Understand responses to environment
  - Understand tree as a system
- What time scale?
  - Weeks to yrs
  - Standard time step ≤ 1 day
- Data sources?
  - Ecological research sites
  - Climate impact research
  - Experimental and monitoring
  - Harvard forest, SWECON, SMEAR,…
  - Often in connection with eddy tower
  - > 3 yrs

Eco-physiological forest data: Process model paradigm



Process model paradigm
- model projections

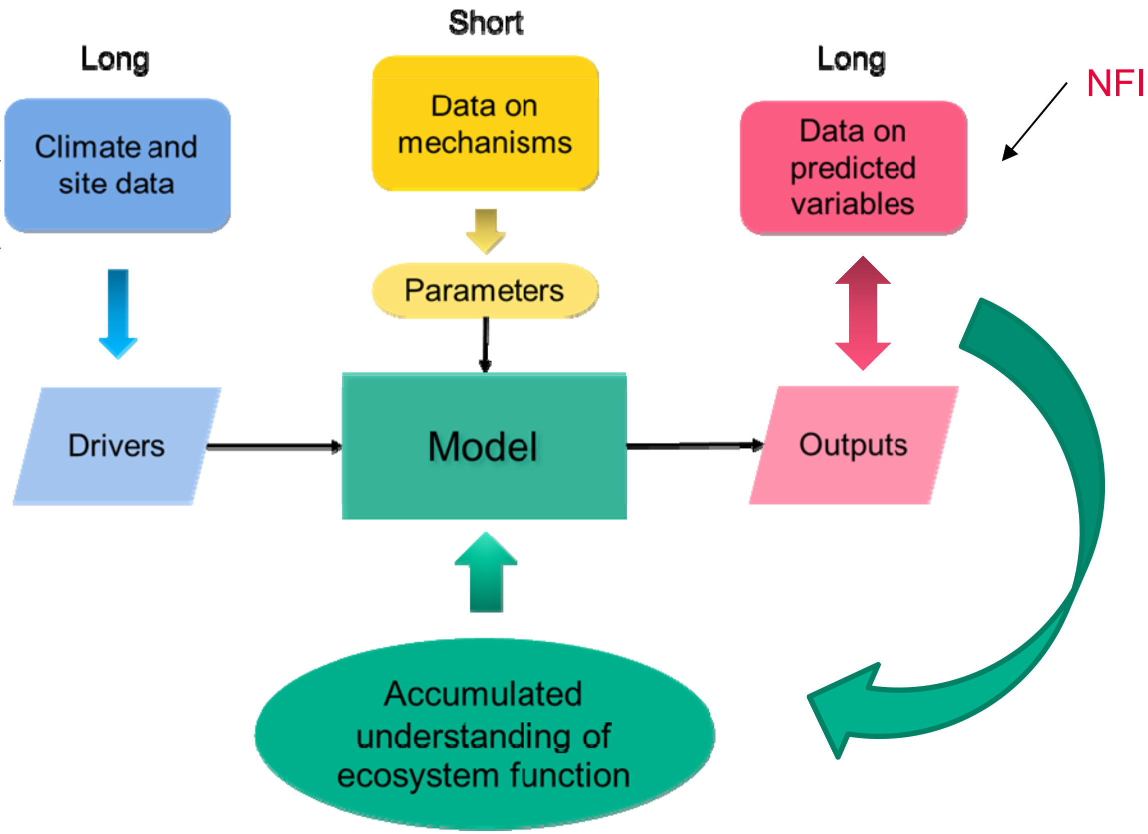


Process model paradigm
- model testing and theory development

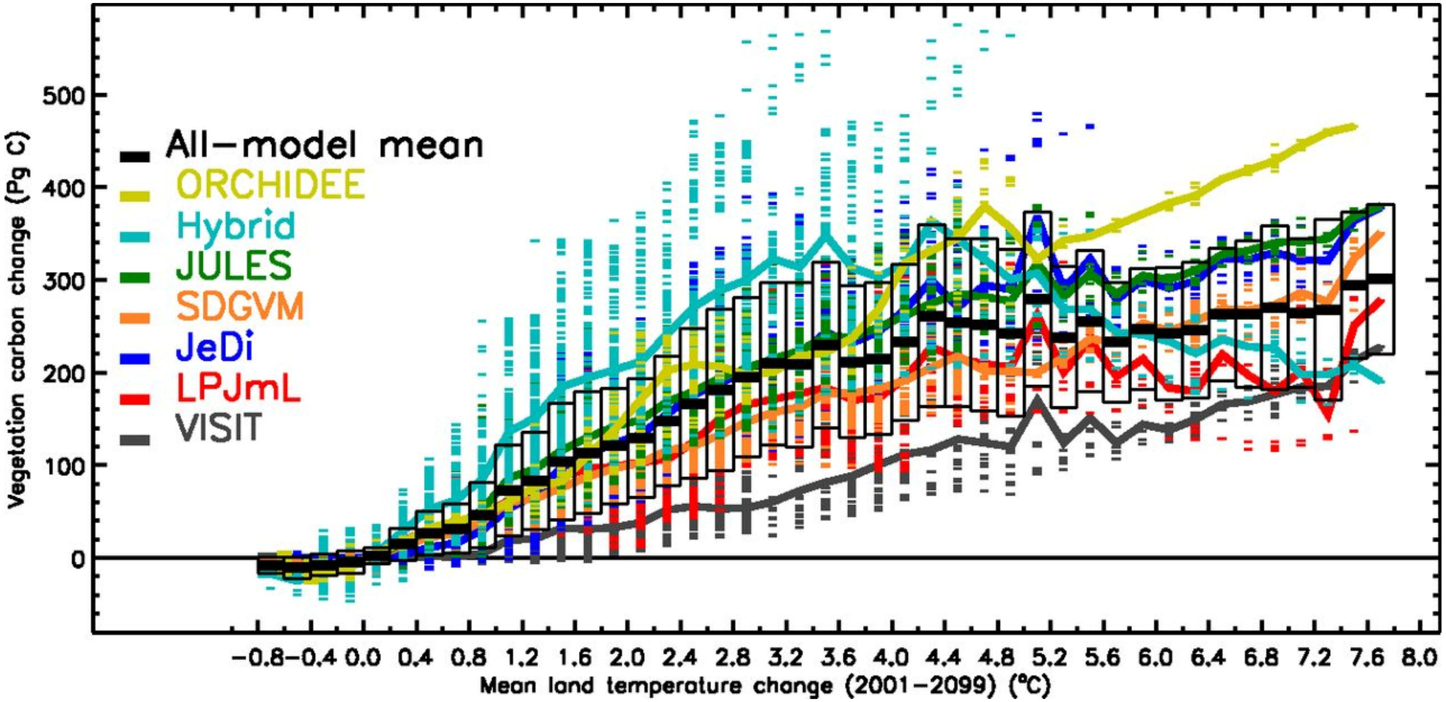
Soil properties maps
e.g. FAO

Gridded climate data
Appropriate scale

Vegetation maps
e.g. JPI, RS



Where are we now?
Challenge of changing climate persists



Andrew D. Friend et al. PNAS 2014;111:3280-3285

How to make our predictions more plausible?

- Environmental change

  => acclimation

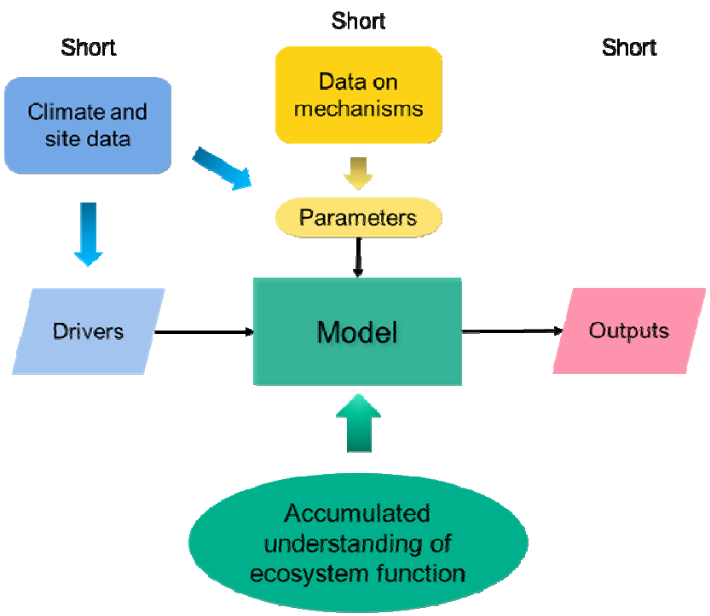
  => shift in balance between parallel processes

  => gradual shift in process model parameter values

- Eco-evolutionary models to account for the parameter shift

- Longer term and larger scale response data

- Better data-model assimilation



Eco-evolutionary models

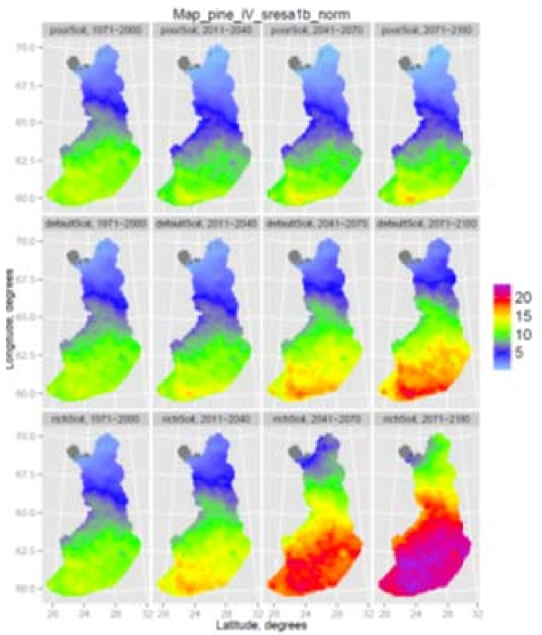
- Process-based models with evolutionary optimisation
- Optimise processes with trade-offs in new environments

  Mäkelä et al. 2000 SF, Dewar et al. 2009 BioScience, Franklin et al. 2012 Tree Phys

- Stomatal control (Prentice et al. 2015)
- Carbon – nitrogen coallocation (Mäkelä et al. 2012 NP)
- Plant-microbe relationships and priming (Franklin et al. 2014)
- New generation of DGVM

- Slower responses
- Downregulation

Optimal co-allocation of N and C at different sites under climate change

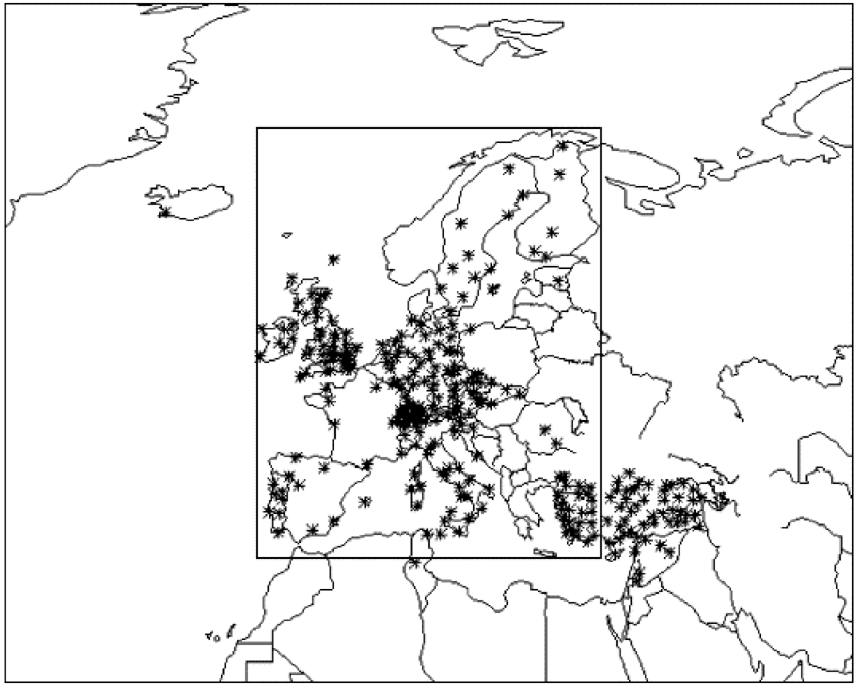


Mäkelä et al. 2014 AGU

Longer term and larger scale response data

Ecosystem experiments

Ecosystem monitoring



Longer term and larger scale response data: Ecosystem experiments

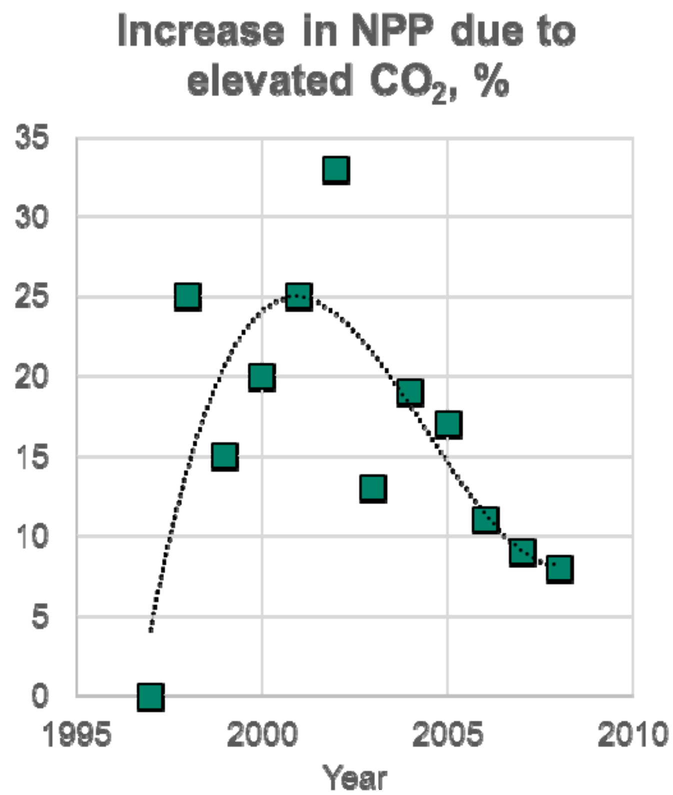
Whole tree chambers & optimal nutrition Flakaliden, Sweden

FACE experiment, Duke, USA

Longer term and larger scale response data: Ecosystem experiments

Findings from FACE experiments corroborate gradual acclimation hypothesis

- Increased photosynthetic capacity
- Increased water use efficiency
- More growth directed belowground
- Shorter lifetime of foliage and fine roots
- If nutrients are sufficient, growth may increase
- Growing stock may not increase

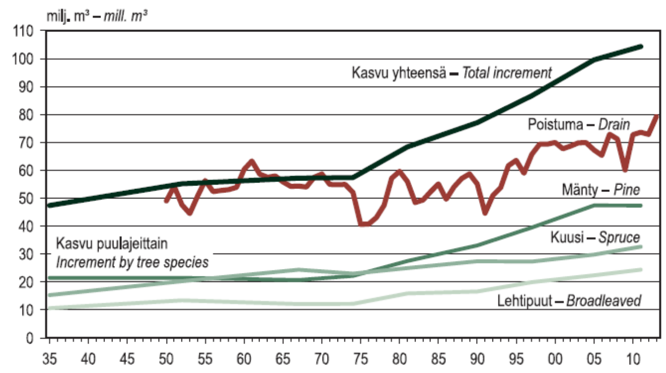


Norby et al. 2011, Ann. Rev. Ecol. Evol. Syst.
De Kauwe et al. 2013, GCB

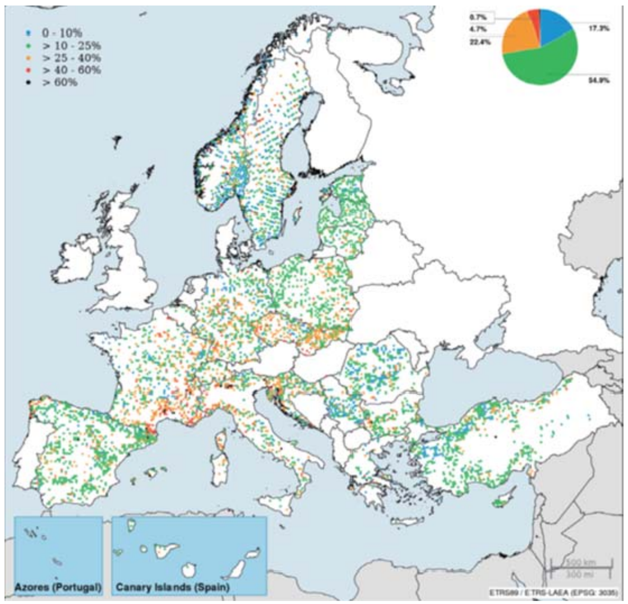
Redrawn from
Norby et al. PNAS 2010;107:19368-19373

Longer term and larger scale response data: Ecosystem monitoring networks

- **National forest inventories**
  - Growing stock, growth, forest use, damage…
  - Since <100 yrs
  - Harmonised between countries
  - An increasing nr of variables included

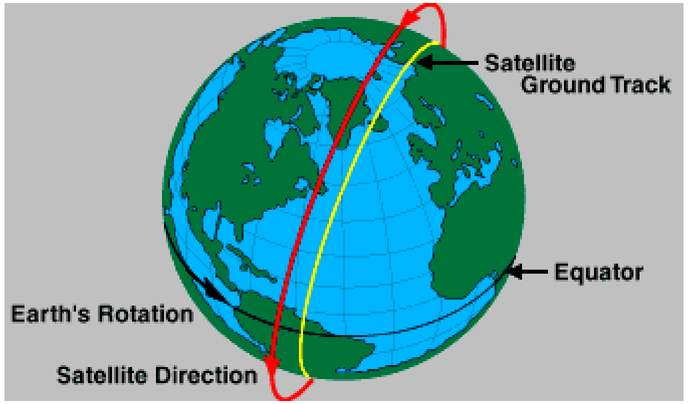


- **ICP Forest**
  - Effects of transboundary air pollution on forests
  - Since 1985
  - Forest health indicators incl. Soil
  - Europe



Longer term and larger scale response data: Ecosystem monitoring networks

- **Remote sensing**
  - Increasing nr of satellites for different purposes
  - Land cover type
  - NDVI, greening
  - NPP products (MODIS)
  - Forest fires and disturbance

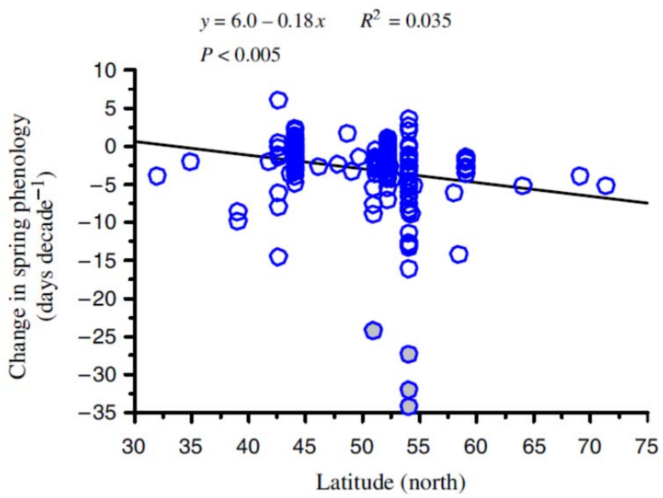


- **Eddy flux network (ICOS)**
  - Carbon and water exchange
  - Eco-physiology at ecosystem scale
  - Since 1995 >
  - Often host ecophysiological research
  - Shared protocols for combined research

Longer term and larger scale response data: Ecosystem monitoring networks

- **Detecting trends**
  - Primary purpose of monitoring
  - => inform policy decisions

- Example
  - Spring phenology change based on datasets > 10 yrs
  - 3 days per decade in the northern hemisphere
  - Parmesan et al. 2007



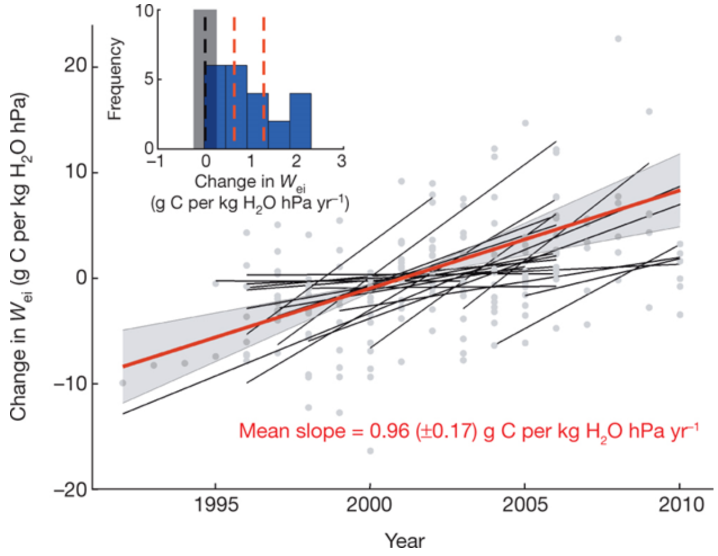
  - But mechanisms remain obscure
  - => prediction difficult

Longer term and larger scale response data: Ecosystem monitoring networks

- **Testing hypotheses**
  - Long term data on relevant processes and driving variables may allow testing of crucial hypotheses

- Example
  - Carbon and water exchange from EC flux sites > 20 yrs
  - Water use efficiency increased as a response to CO_2 concentration
  - Quantification of acclimation hypothesis!

Long-term change in forest water-use efficiency.

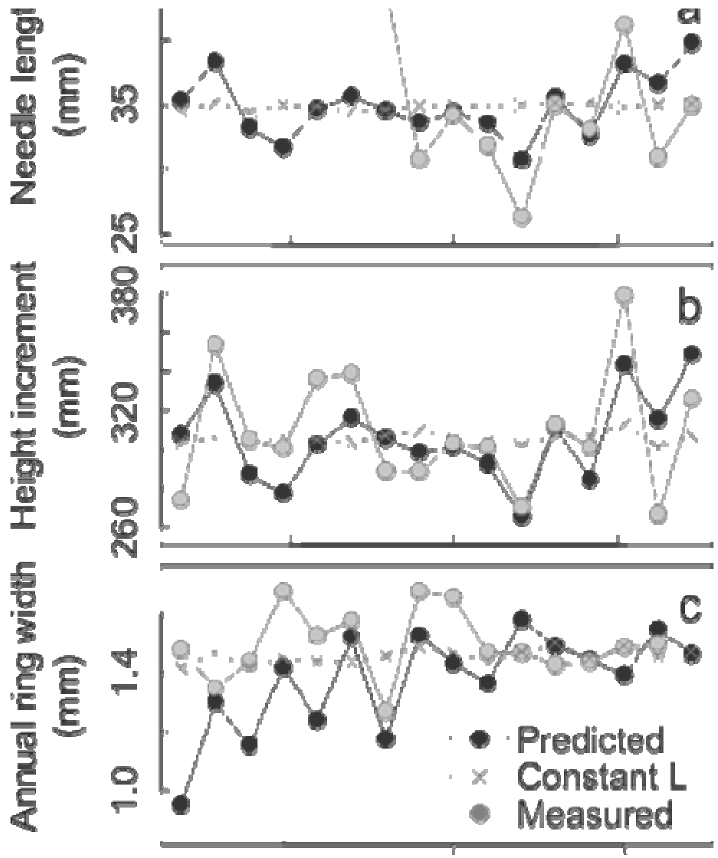


TF Keenan *et al. Nature* 2013
doi:10.1038/nature12291

Longer term and larger scale response data: Ecosystem monitoring networks

- **Testing hypotheses**
  - Combined with ecophysiological research data may become more informative

- Example
  - Carbon and water exchange from SMEAR 2 EC flux site > 15 yrs
  - Combined with tree growth data
  - Testing a model with hypotheses on carbon sink-source interactions
  - Year-to-year variations

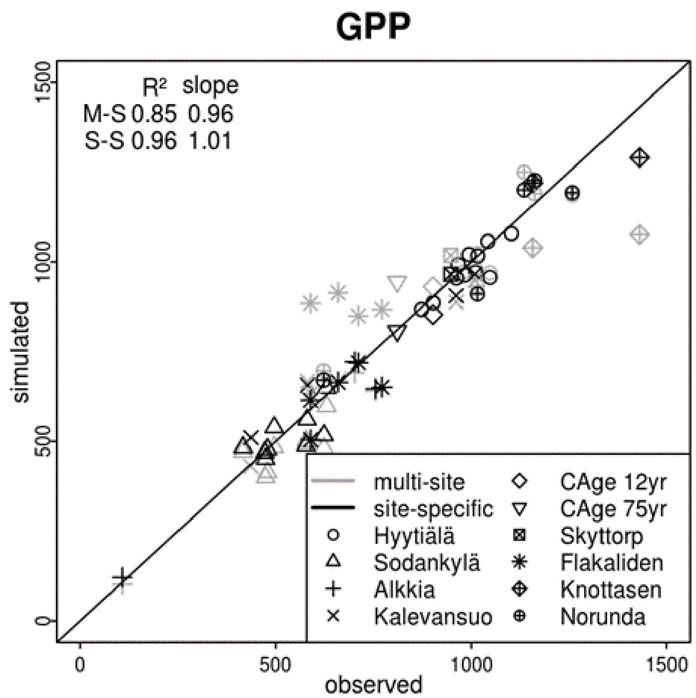


Schiestl-Aalto et al. 2015 NP

Longer term and larger scale response data: Ecosystem monitoring networks

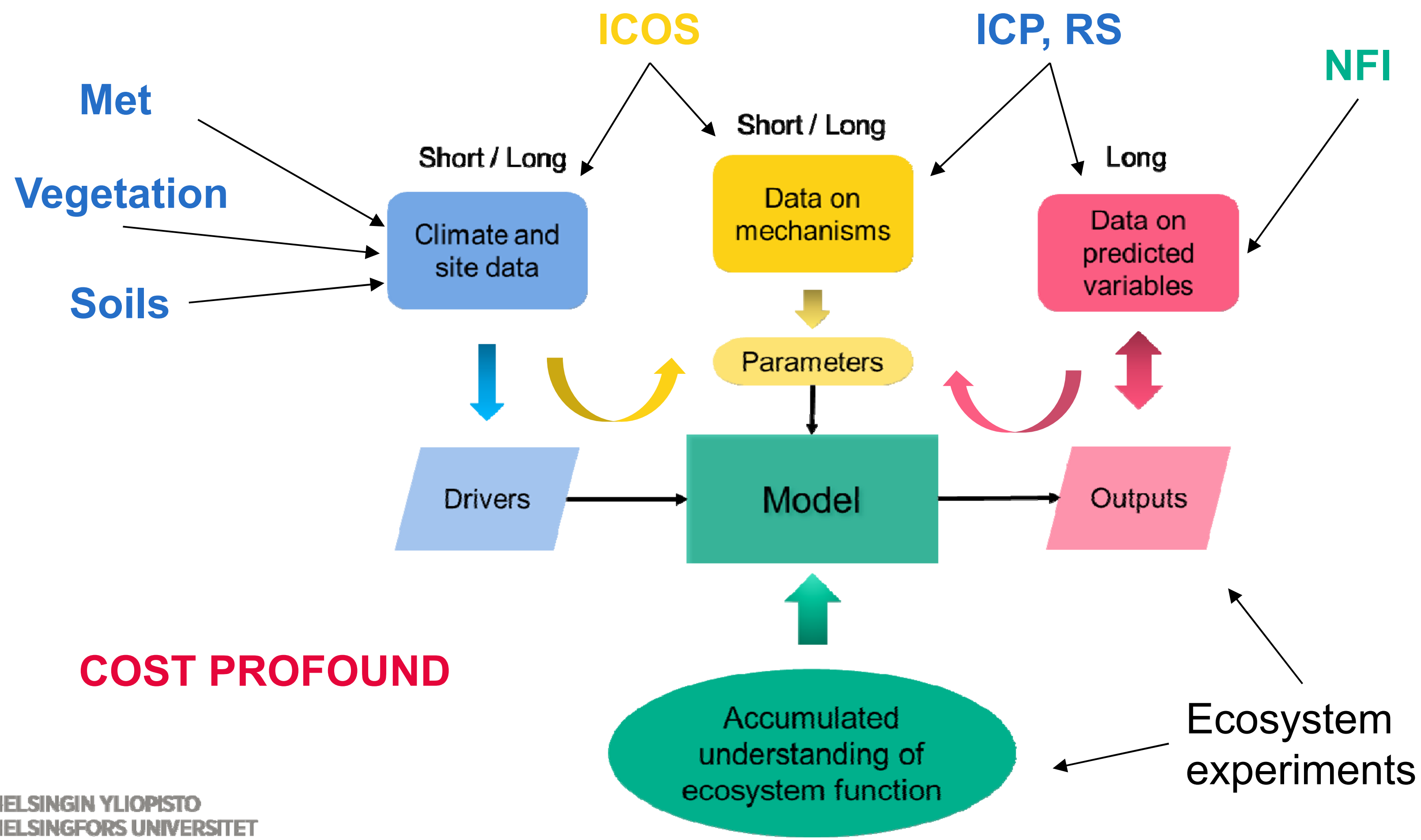
- **Model parametrisation**
  - Long-term high quality data from one site may be more poweful for parameterising dynamic processes than shorter data from variable sites

- Example
  - 10 boreal flux sites
  - Daily GPP
  - Long-term data from Hyytiälä provided better predictions for other sites than prior data from the site itself



Minunno et al. 2015 EcolMod

Data – model assimilation



COST PROFOUND

Conclusions

- Understanding and quantifying climate change impacts on forests has turned out to be more difficult than expected 20 – 30 years ago
- Acclimations and other slow processes shift the balance between functions => eco-evolutionary modelling?
- Longer-term high quality data informing mechanistic forest ecosystem models is in high demand
- The best results could be obtained by continuing to host a broad scale of eco-physiological research at ICOS sites
- Better use can be made of all existing forest ecosystem data by improved methods of data-model assimilation


Thank you for your attention!