Long (and really long!)-Term Terrestrial Carbon Fluxes & Uncertainties in Ecological Forecasting with Model-Data Fusion

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Perspectives

• Bev Law
  “Long-term data are needed to calibrate models”
  “Do we have the science to inform policy makers?”

• Michael Kuperberg
  “We need a predictive understanding.”
Objectives:

– Long term trends in C cycling at Harvard Forest.

– Assess the ability of integrated data streams to constrain process-based model uncertainty.

– The propagation of model uncertainty into future projections.

How? – Using a forest C-cycle model in a Model-Data Fusion framework.
Model-Data Fusion

Model application
(fully considering uncertainties & limitations)

Scaling & Generalization
(through space and/or time)

Model Validation
(using independent data)

Model (re)formulation

Data + Uncertainties

Model characterization & state/parameter optimization
(consistency checks, uncertainty analysis, and multiple data constraints)

Optimization assessment
(plausibility and evaluation of uncertainty)

Keenan et al. (in review)
Forest Biomass Assimilation Allocation and Respiration (FöBAAR)

Drivers:
PAR
Air Temp.
Soil Temp.
VPD
CO₂

A parsimonious forest C-cycle model

6 Pools, 29 Parameters, 3 dataset harmonization parameters = 38 p’s optimized
The Six Commandments for a good model-data fusion study

<table>
<thead>
<tr>
<th>Code of best practices for model-data fusion analyses</th>
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<tr>
<td>1. Data uncertainties should be openly acknowledged</td>
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<td>2. Model structural error should be assessed</td>
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<td>3. Multiple data constraints should be implemented</td>
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<td>4. The MDF framework should be tested against synthetic data</td>
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<td>5. Validate the optimized model against independent data.</td>
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<td>6. Confidence intervals (posterior distributions) on model parameters, states, and predictions should be estimated in a transparent manner.</td>
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Constraints

– NEE (hourly, no gap filled data)
  • Distinction between day & night
  • Monthly & annual incremental values

– Soil Respiration (3 different data sets, day & night)
– LAI
– Leaf litterfall
– Carbon in wood (both measured & increment)
– Phenology – leaf out and leaf in
– % Soil respiration from autotrophic
Results:

Keenan et al. (in prep.)
Confidence in parameters...
• What have we learned?
  – The model gets it, but doesn’t get it.
  – Model structural error?
  – Lack of sensitivity to a changing climate?
  – Data error?

1. Benchmark the model – Artificial Neural Network
2. Test the data – independent gap filling
Climate-independent change in uptake
What’s going on?

• 1. Change in ecosystem climate sensitivity with respect to late ‘90s mean?
  – Can ecosystem structural changes explain the necessary ~20% increase in GPP?
• 2. Systematic measurement error?
  – If it is not the gap-filling....then?

to be continued...
Back to the Future....

FöBAAR & Ecological Forecasting
Back to the Future....

FöBAAR & Ecological Forecasting

![Graphs showing carbon stocks and carbon fluxes over time.](image-url)
Back to the Future…

FÖBAAR & Ecological Forecasting

Carbon Stocks

Carbon Fluxes

Keenan et al. (in prep.)
Conclusions

• Modeling long-term trends is not trivial
• Multiple constraints can lead to a better constrained model
• Modeled really long-term (>50 years) fluxes shows strong sensitivity to initial conditions
• Techniques such as Model-Data fusion can help reduce this uncertainty.
Thanks...

Andrew Richardson
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Eric Davidson
Kathleen Savage
Markus Reichstein
Extras.....
Artificial Neural Network

Hypothetic-deductive modeling approach

Ecosystem model with fixed equations

Parameterization and evaluation

Constrained set of parameters

Inductive modeling approach

Purely empirical model

Data

Extraction of the functional relationships and evaluation

Characterization

Hypotheses

Moffat et al., 2010 GCB
Is it the model?
Change in climatic drivers?
Is it the gap-filling?

![Graph showing cumulative NEE over years with annotations: Measured FLUX data, FörBAAR model, ANN.]

PerYear ANN
Parameter Covariance:
Phenology
Chi-square uncertainty...
MCMC Ji posterior search
Standard MCMC posteriors (Jtot exploration)