Confronting terrestrial ecosystem models with forest inventory data

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Introduction

- In ecosystem models, vegetation responds to variation in temperature, water, etc. primarily via fast time-scale physiological mechanisms (e.g., stomatal conductance).
- In contrast, real vegetation responses include the longer time scales of acclimation, species turnover *within* functional types, and evolution.
- Forest inventories can constrain how long-term rates of carbon accumulation vary with respect to temperature, water, etc.
- We developed inverse analysis methods to fit the GFDL-LM3V terrestrial ecosystem model (Shevliakova et al. 2009, *Global Biogeochemical Cycles*) to inventory data.

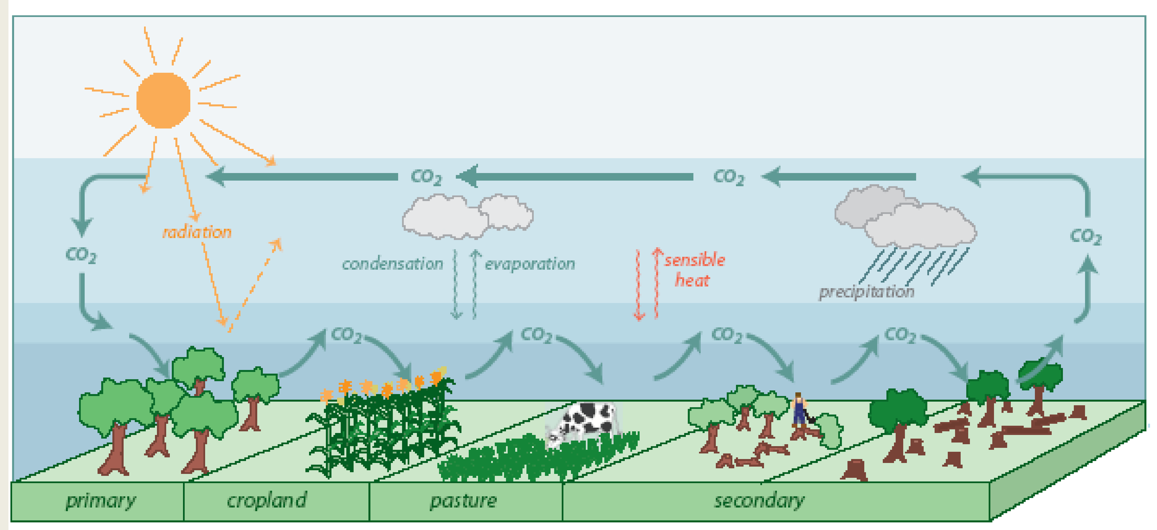

Fig. 1. LM3V simulates ecosystem dynamics and exchanges of water, energy, and CO_2 between land and atmosphere. LM3V tracks forest age structure, which facilitates comparisons with inventory data.

Baseline LM3V model vs. FIA data

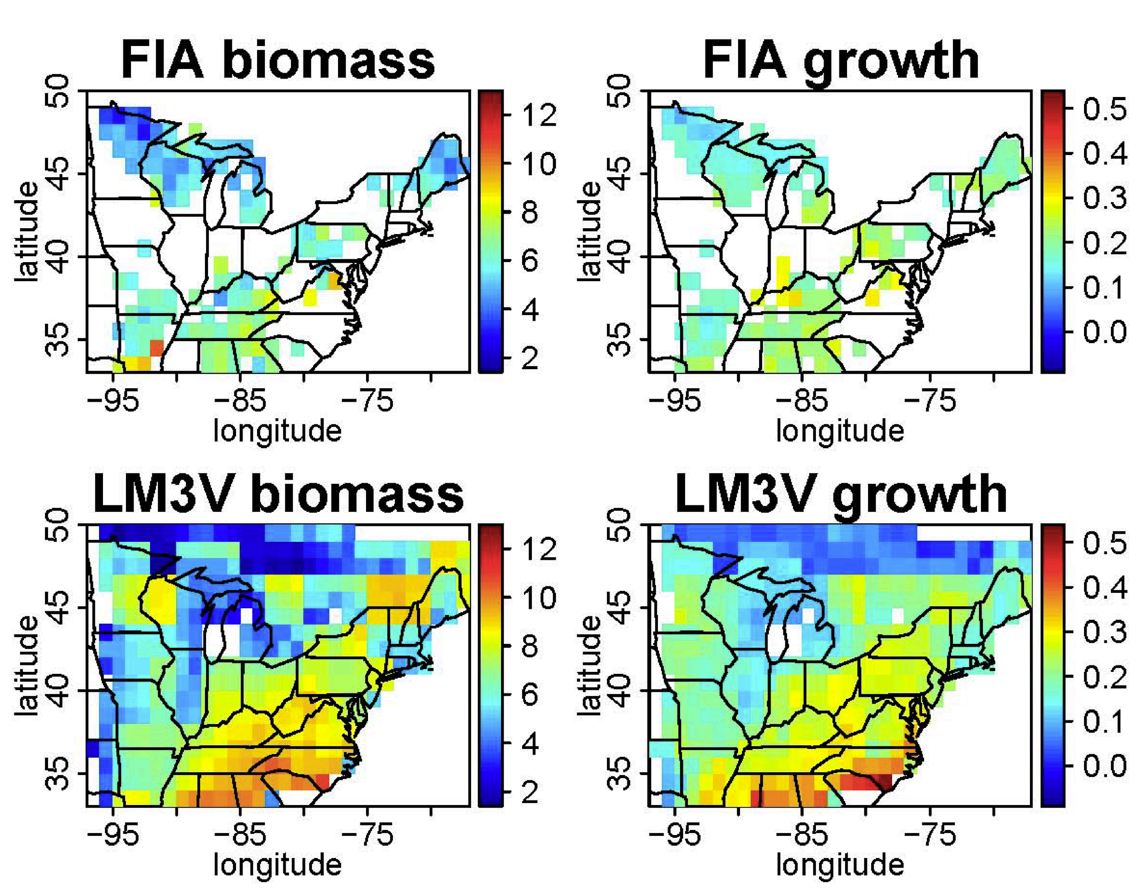

Fig. 2. Aboveground biomass (kg C m^{-2}) and woody growth (kg C m^{-2} yr^{-1}) of 50-year-old forest in U.S. Forest Service FIA inventory data and the LM3V model. The study is restricted to the 'temperate deciduous forest' LM3V functional type in the eastern U.S. Each FIA grid-cell value is the mean of ≥ 10 inventory plots (age 40-60 years old).

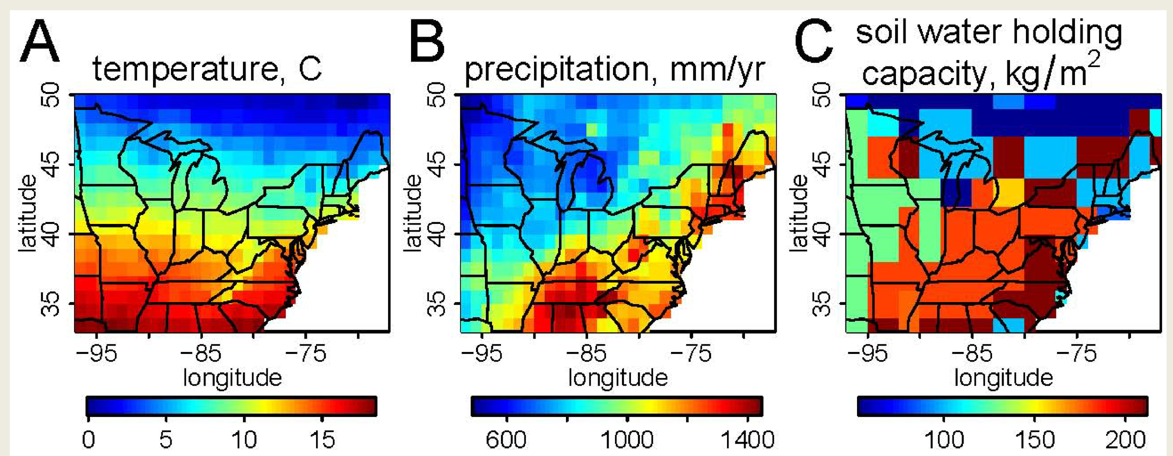

Fig. 3. Forcing data for LM3V. Temperature and precipitation are shown as annual means.

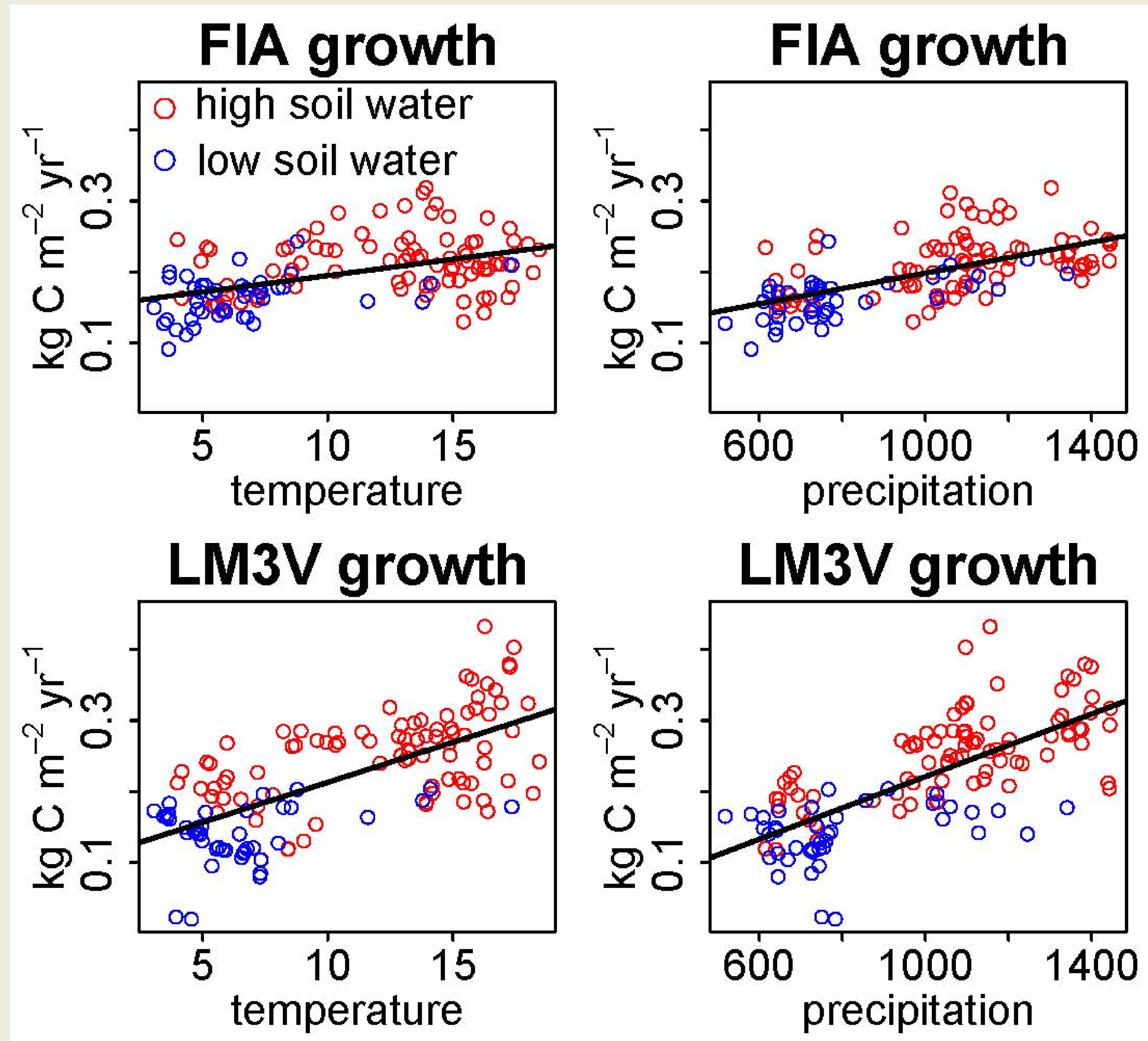

Fig. 4. Grid cell values in Fig. 2 vs. mean annual temperature and precipitation. Blue/red points have relatively low/high values of soil water holding capacity (Fig. 3C). Compared to FIA data, LM3V is too sensitive to temperature, precipitation, and soil water holding capacity. Only cells where both FIA and LM3V values were available are shown. Biomass patterns (not shown) are similar to those for growth.

Over-sensitivity of the LM3V model to temperature and water

Mismatches between model and data may be due to:

- **Parameter values.** Model performance could be improved by parameter optimization without altering model structure.
- **Model structure.** Even with optimal parameter values, model performance may be poor if key mechanisms are missing; e.g., acclimation and within-functional-type plant diversity.

We developed inverse analysis methods to improve LM3V parameter values and model structure. Here, we present preliminary findings.

Optimization

- We optimized three parameters: allocation to leaves and fine roots, and maximum carboxylase velocity (V_{max}). Optimization was performed by iteratively comparing LM3V output to FIA data using the Gauss-Newton algorithm.
- To assess the importance of model structure, we performed a second optimization in which we replaced the baseline soil map (Fig. 3C) with a uniform map (all grid cells assigned the mean value). This 'thought experiment' corresponds to the extreme case where vegetation has no sensitivity to variation in soil depth and texture.

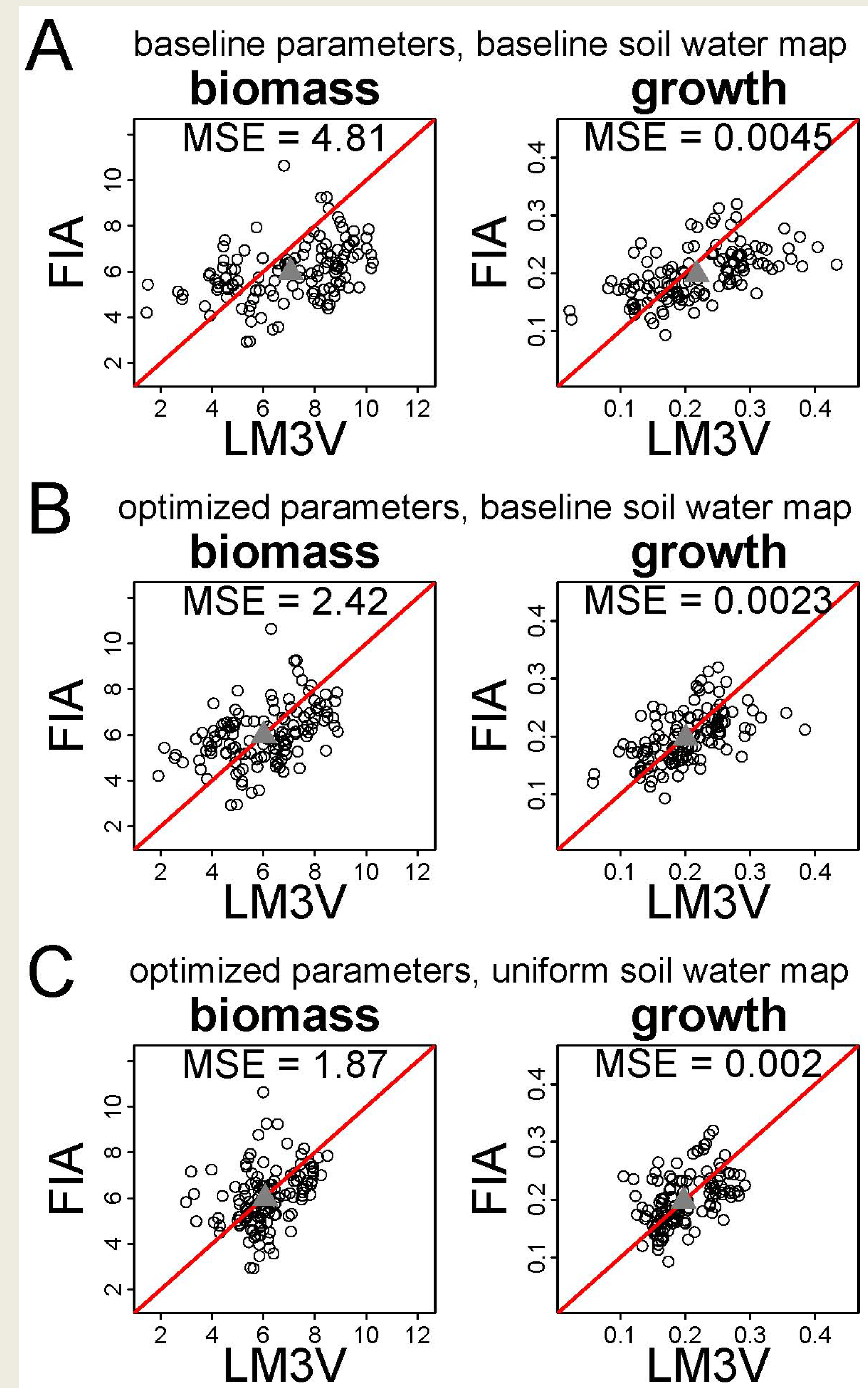

Fig. 5. Observed (FIA data) vs. predicted (LM3V) grid-cell values for aboveground biomass and woody growth in the baseline (A) and optimized (B and C) LM3V models. Optimization reduced the mean squared error (MSE) by 50% and eliminated bias in predicted means (grey triangles). The 1:1 line is shown in red.

Table 1. Parameter values in baseline and optimized models. Leaf and root fractions refer to allocation at equilibrium biomass. V_{max} is maximum carboxylase velocity (μmol CO_2 m^{-2} s^{-1}) at 15°C.

	leaf fraction	root fraction	V_{max}
baseline model	0.52	0.25	40
optimized parameters, baseline soil map	0.26	0.47	17.7
optimized parameters, uniform soil map	0.37	0.30	11.5

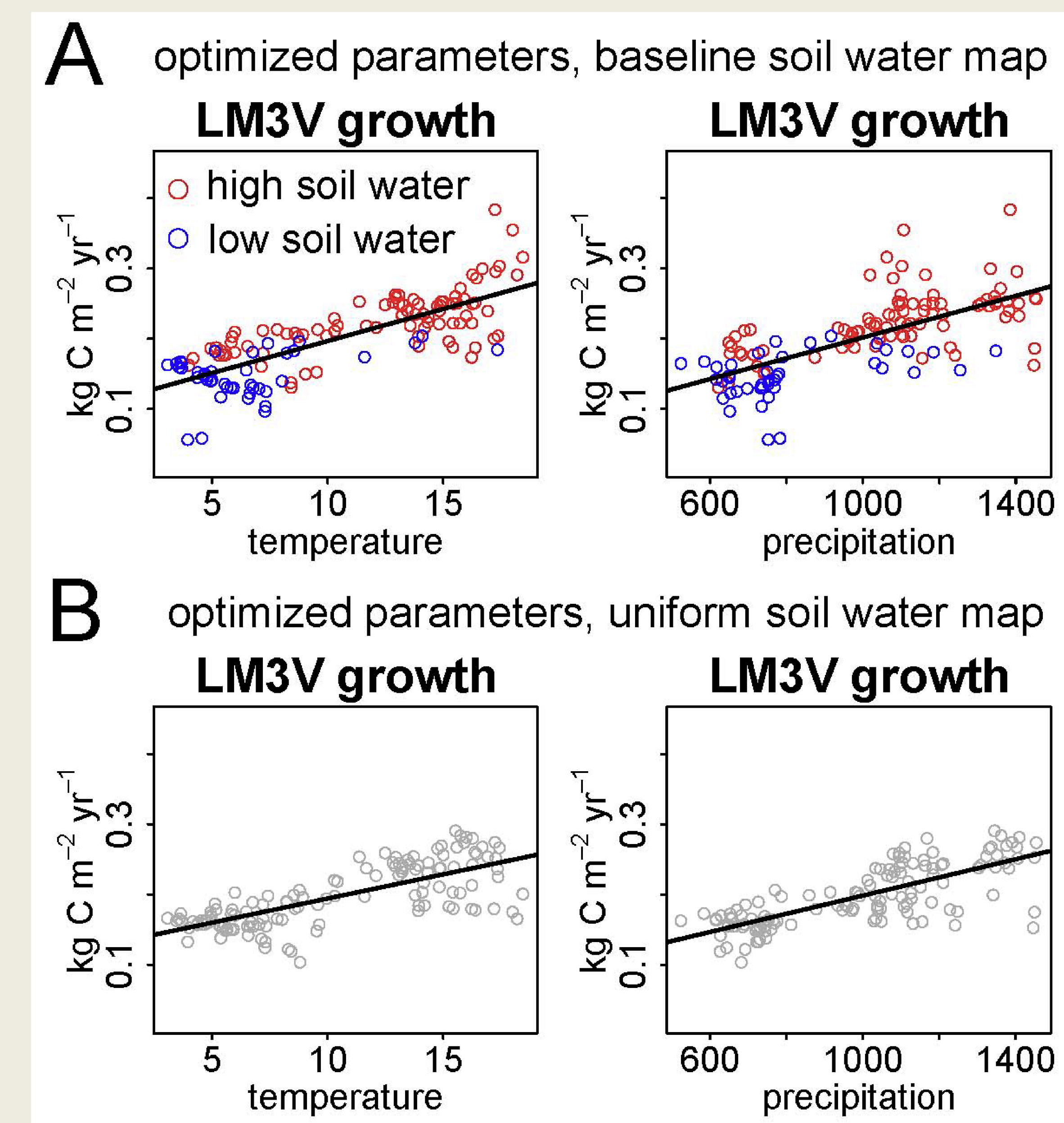

Fig. 6. **(A)** Optimization with the baseline soil water map yields soil and climate responses that are similar to FIA data (Fig. 4), but implausible root and leaf allocation values (Table 1). **(B)** Optimization with the uniform soil map yields climate responses that are similar to FIA data and reasonable root and leaf allocation values (Table 1).

Conclusions

- Temperate forest growth in LM3V is too sensitive to spatial variation in temperature and water. This result (1) may also apply to temporal environmental variation, other vegetation types, and other ecosystem models; and (2) is likely due to the absence of biological processes not represented in most models (e.g., acclimation and species turnover within functional types).
- Inverse analysis of forest inventory data could facilitate the incorporation of additional, key processes into ecosystem models.