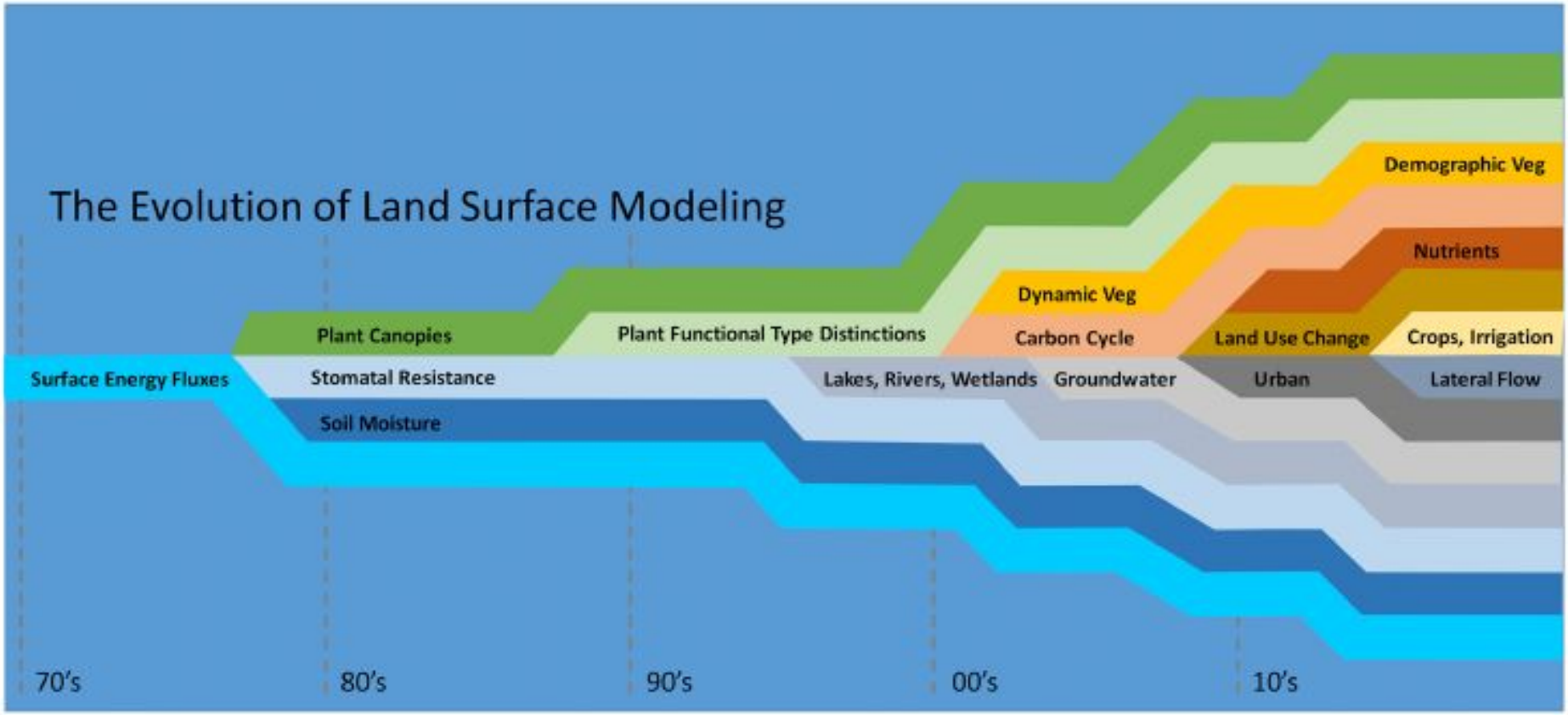
Model complexity: the why, the how, the good and the bad

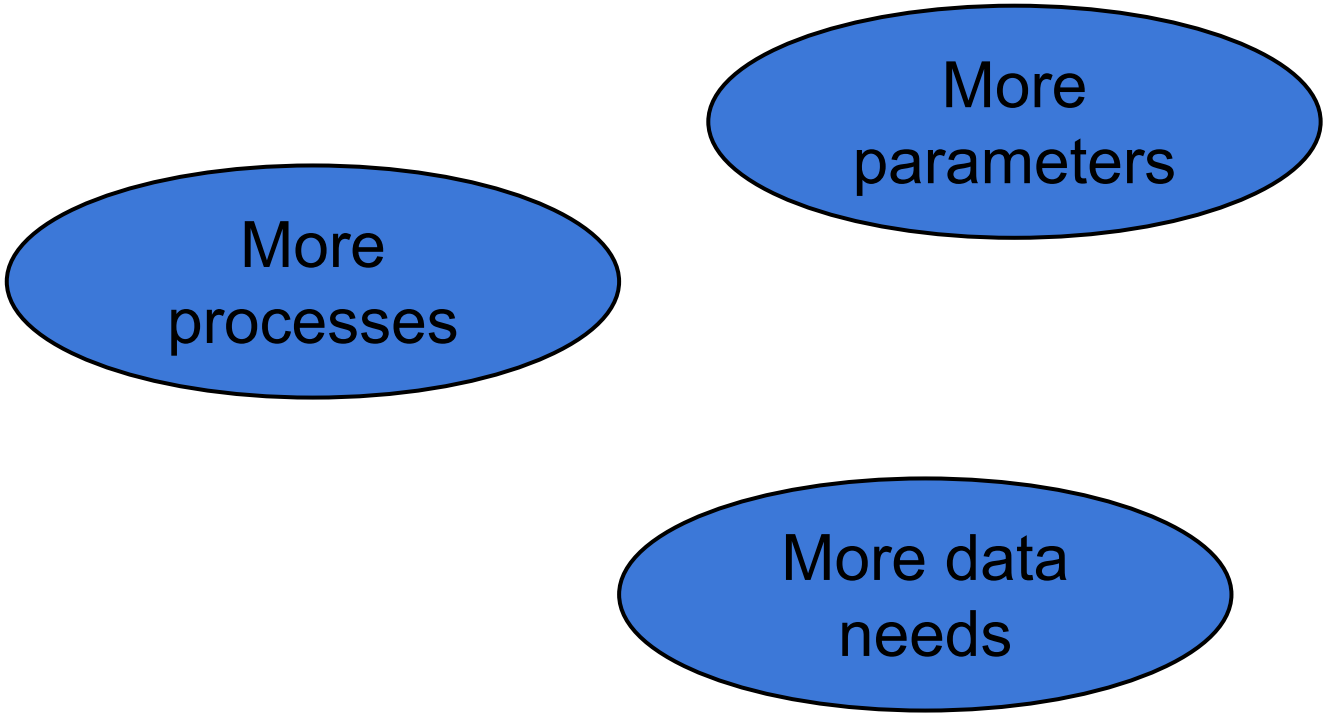
Silvia Caldararu
Max Planck Institute for Biogeochemistry
Email: scaldra@bgc-jena.mpg.de
Twitter: @SCaldararu

Max Planck Institute
for Biogeochemistry



Fisher & Koven, 2020, JAMES

What is model complexity?

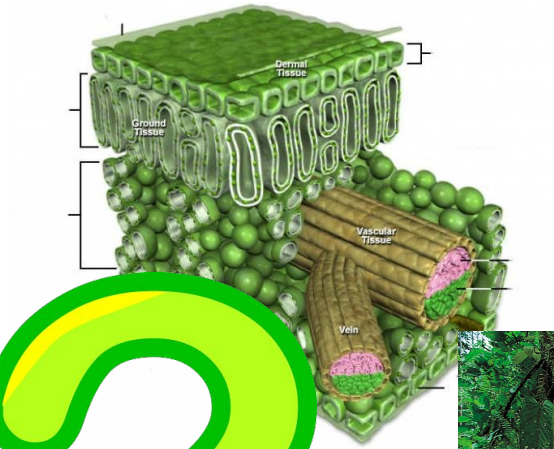


Why do we need more complex models?

The Earth system is a complex system

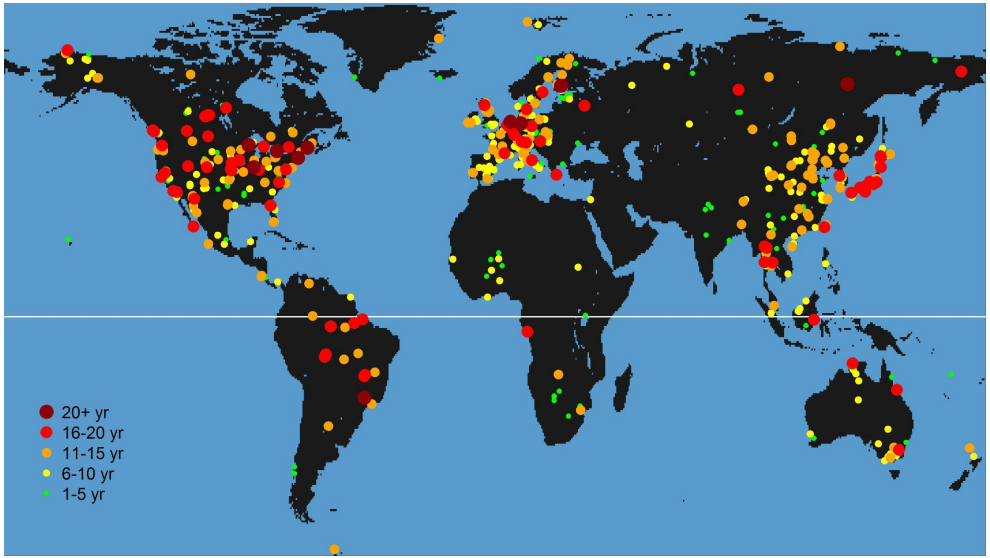
Great! So what is the problem?

Lack of process knowledge



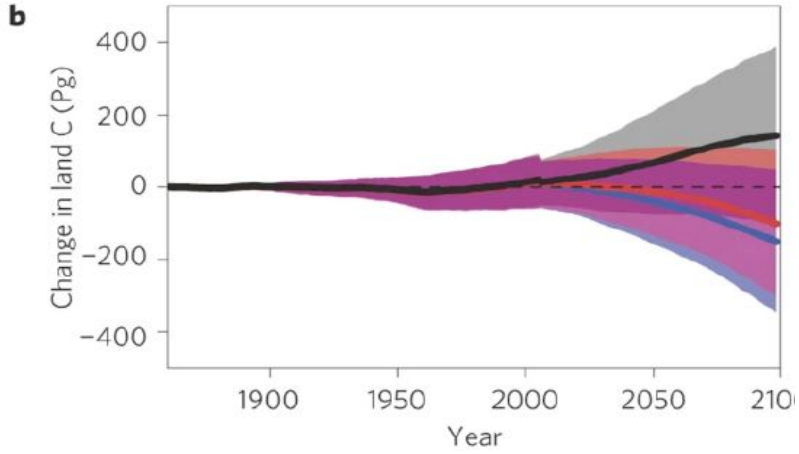
Great! So what is the problem?

Insufficient data



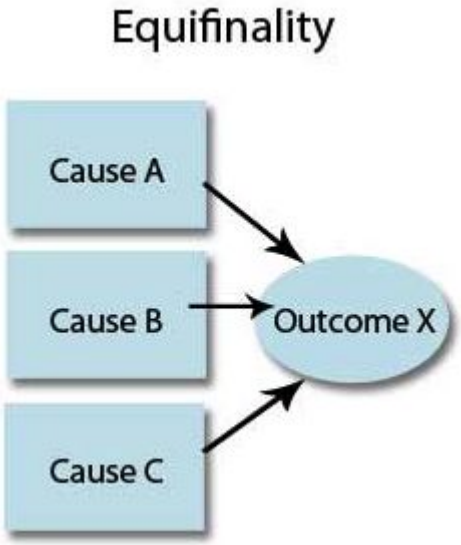
Great! So what is the problem?

More uncertainty



Great! So what is the problem?

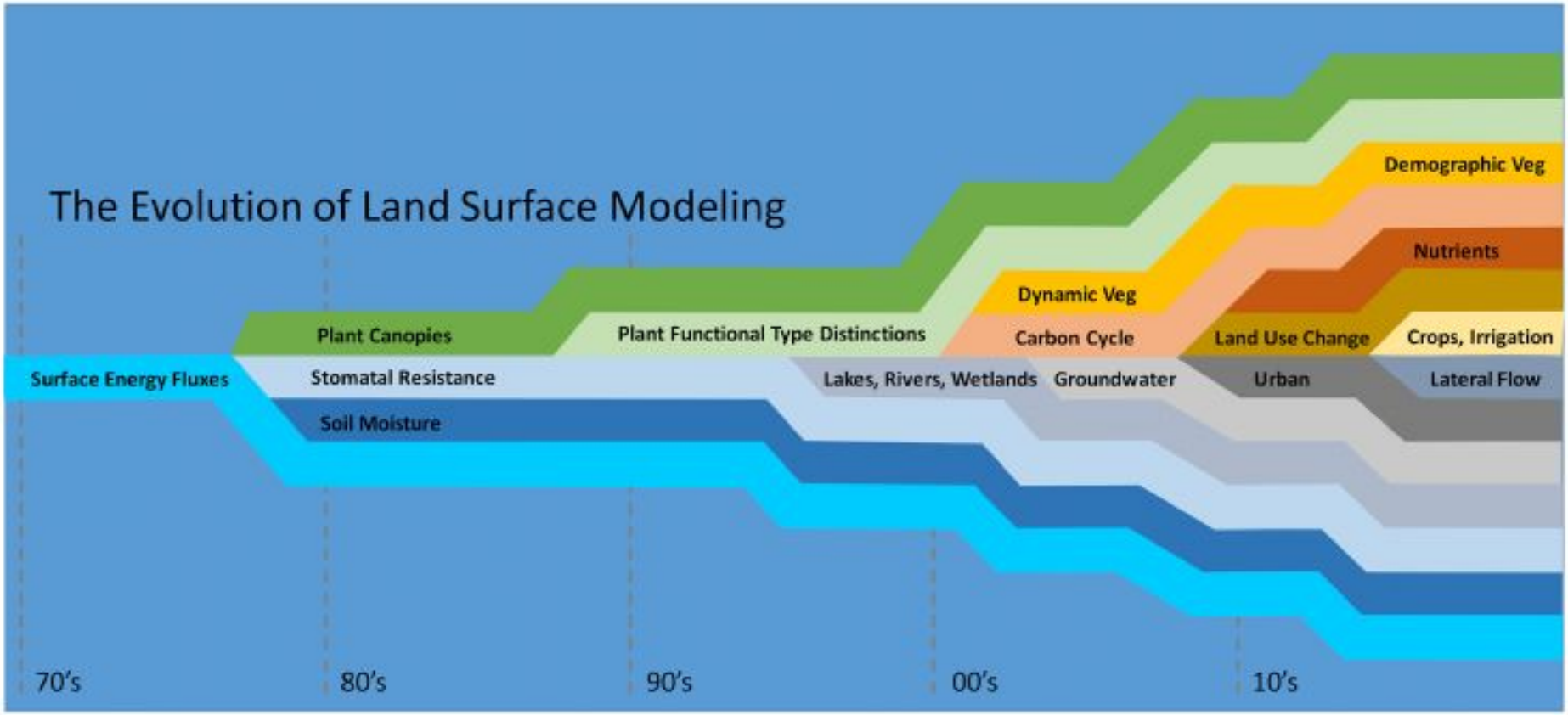
Mathematical complexity



Great! So what is the problem?

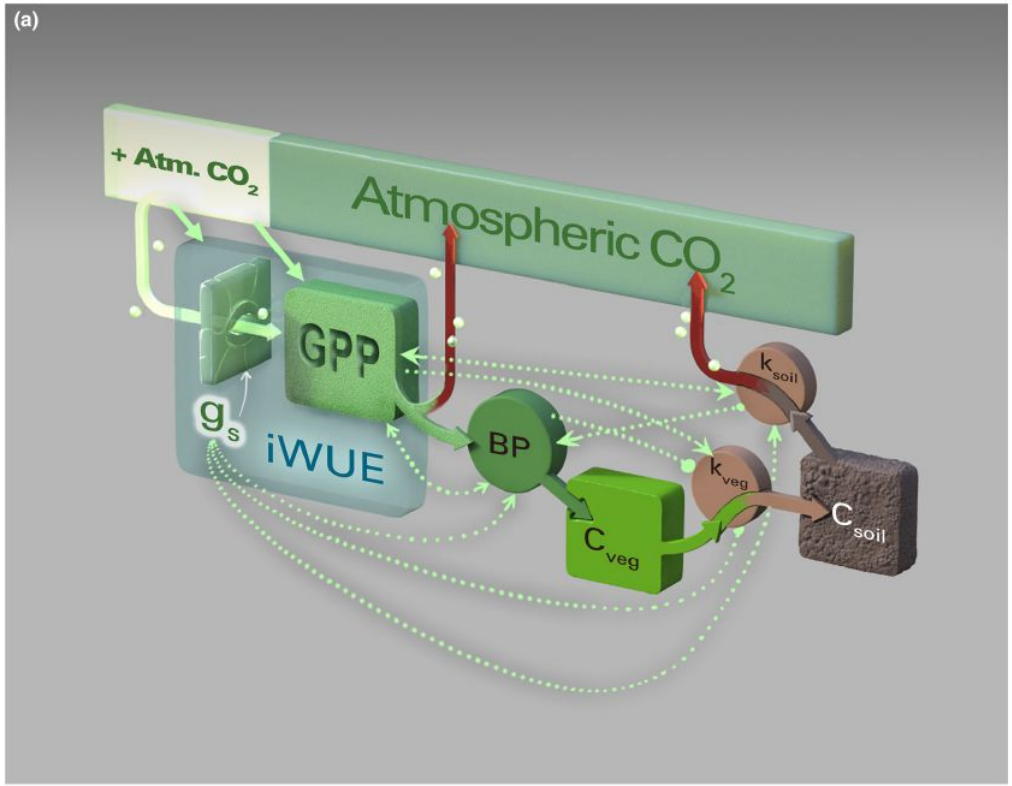
Computational demands

Example 1: the need for complexity
The nitrogen cycle



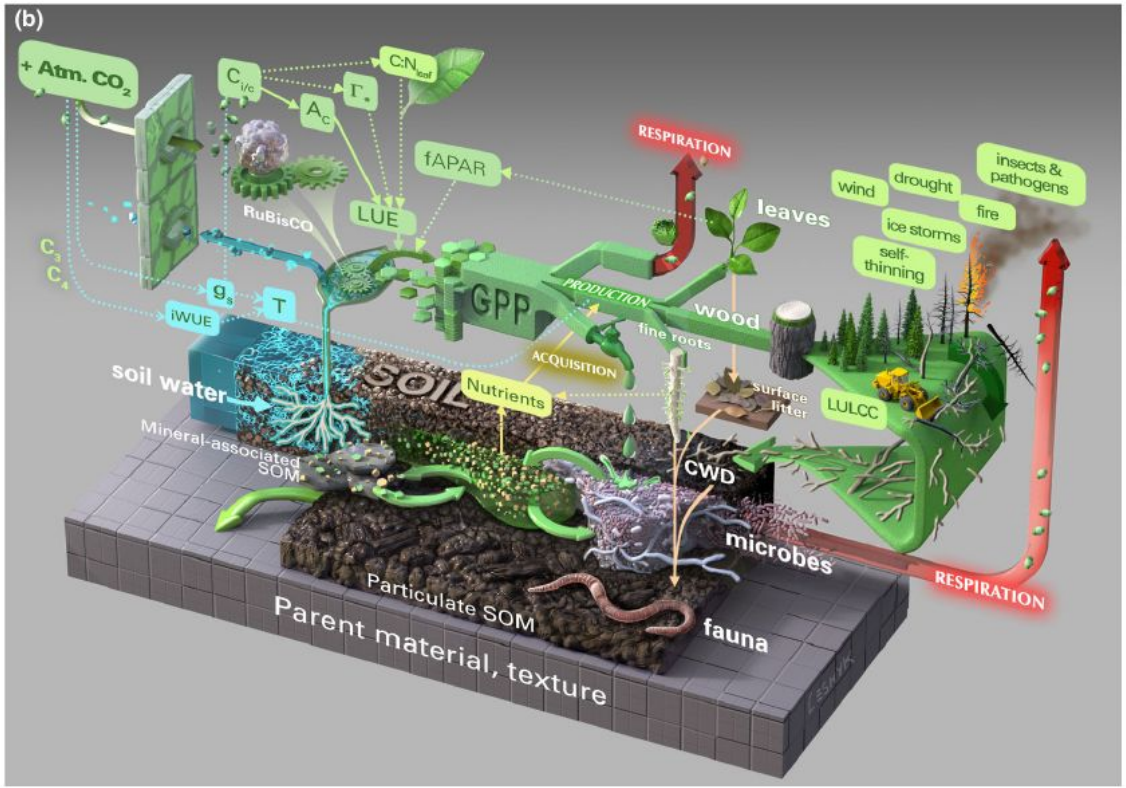
Fisher & Koven, 2020, JAMES

Why nutrients: The carbon only perspective



Walker et al., 2020, New Phyt.

Why nutrients: Things are a bit more complicated



Walker et al., 2020, New Phyt.

Why nutrients: observed effects of nutrient limitation on terrestrial carbon storage

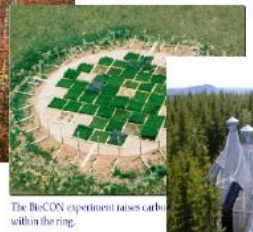
Pop-
Euroface

Rhinelander

Duke

Florida Scrub Oak

Oak Ridge National Lab.



Minnesota BioCON

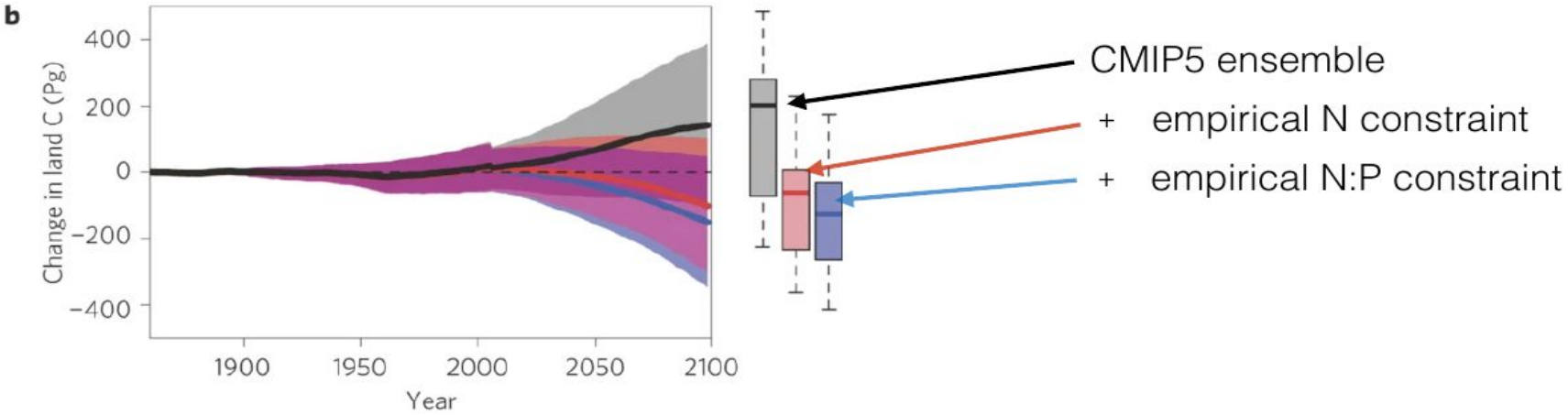
Flakaliden
Boreal Forest

SETRES,SC
Costal Plain

strong,
ongoing
effect on growth

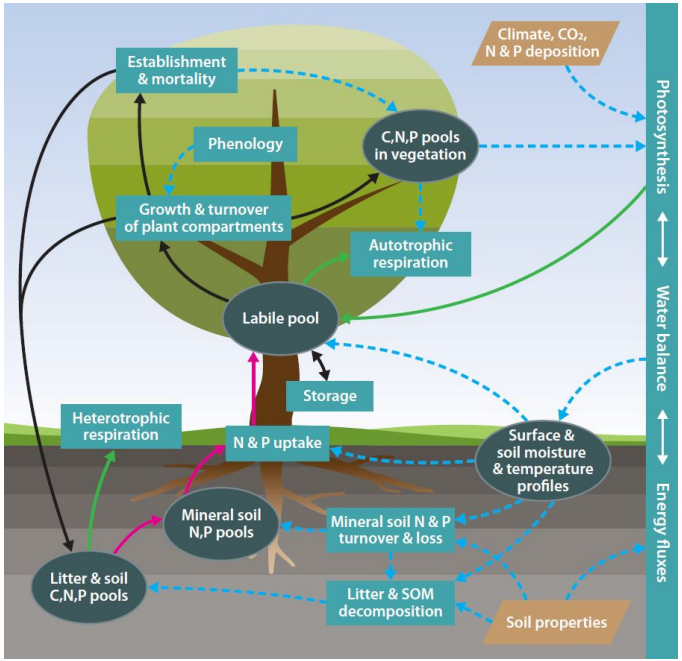
rapid loss or no
CO_2 effect

Why nutrients: predicted effects of nutrient limitation on terrestrial carbon storage



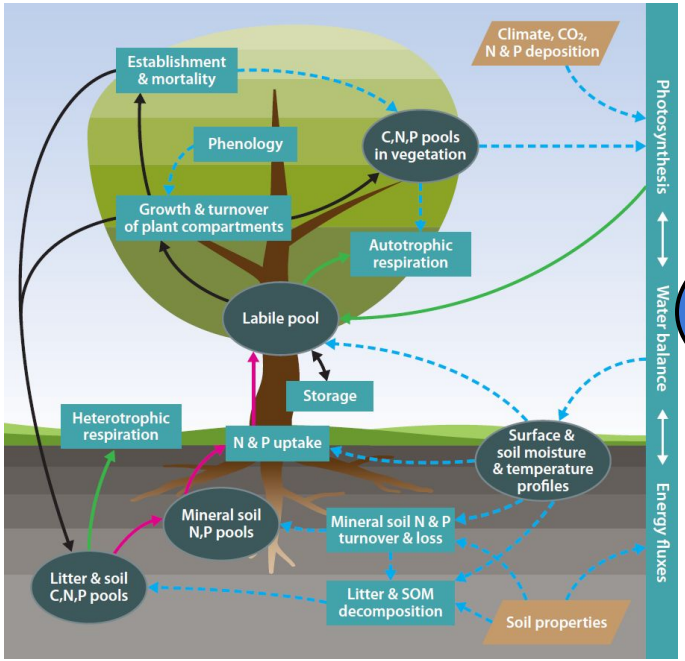
Wieder et al. 2015, Nat. Geosci.

What does this mean for model complexity?



How much N for every gram of C?

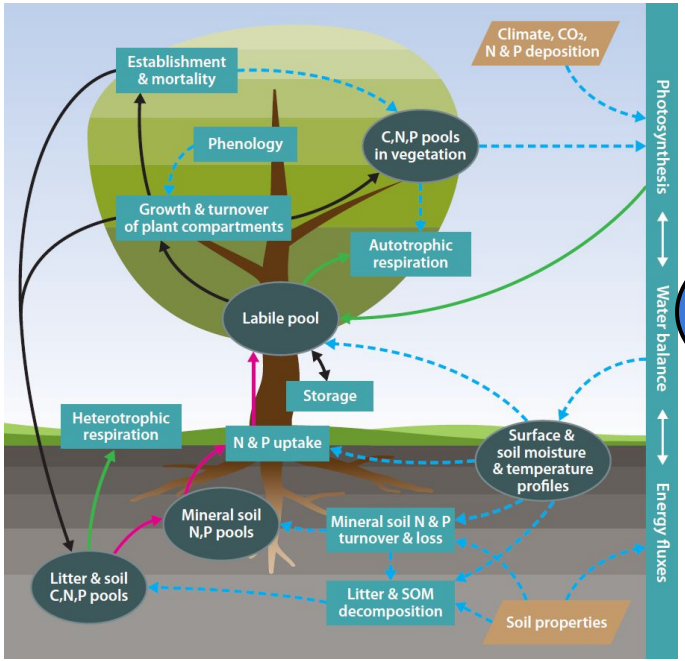
What does this mean for model complexity?



How much N for every gram of C?

What's the function of N?

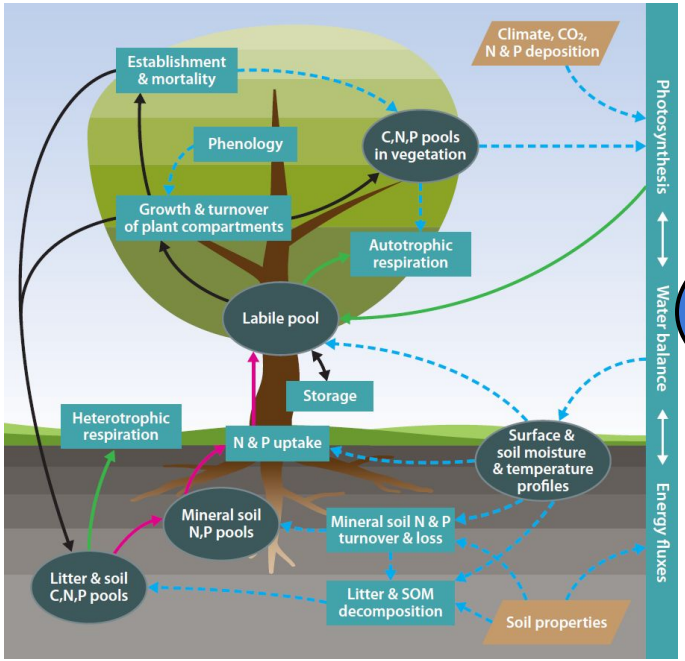
What does this mean for model complexity?



How much N for every gram of C?

What's the function of N?

What does this mean for model complexity?



How much N for every gram of C?

What's the function of N?

N uptake from the soil

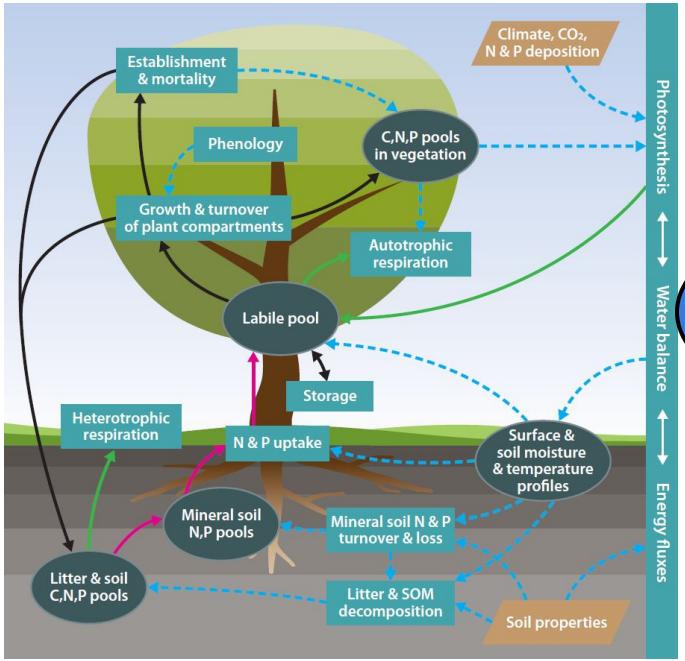
What does this mean for model complexity?

How much N for every gram of C?

What's the function of N?

N uptake from the soil

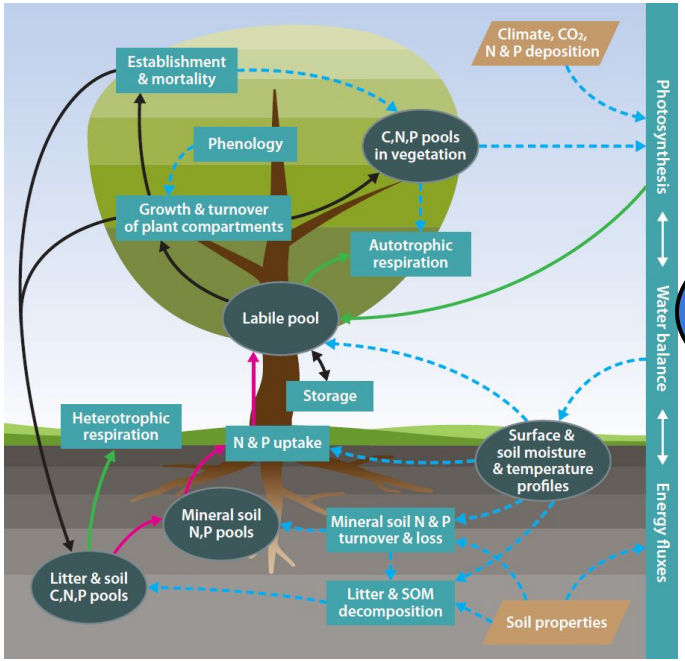
Soil microbial processes



What does this mean for model complexity?

Varied plant uptake strategies

Soil microbial processes



How much N for every gram of C?

What's the function of N?

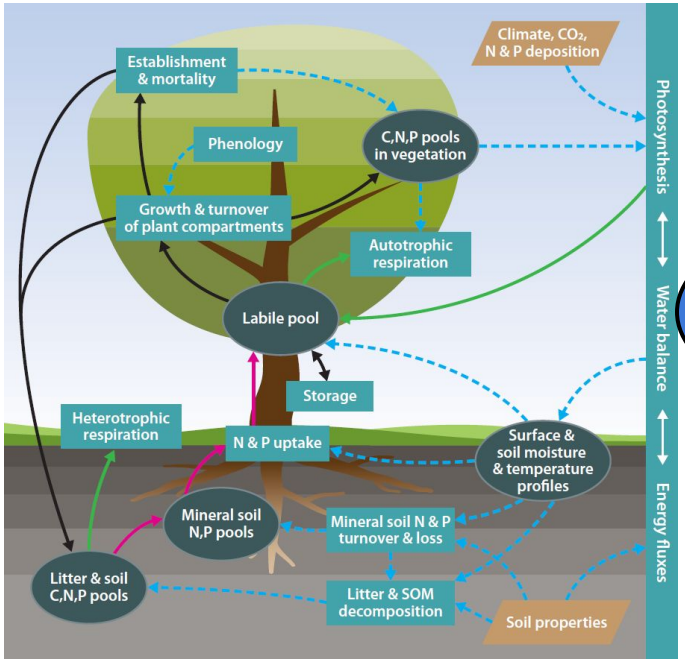
N uptake from the soil

What does this mean for model complexity?

Biological nitrogen fixation

Varied plant uptake strategies

Soil microbial processes

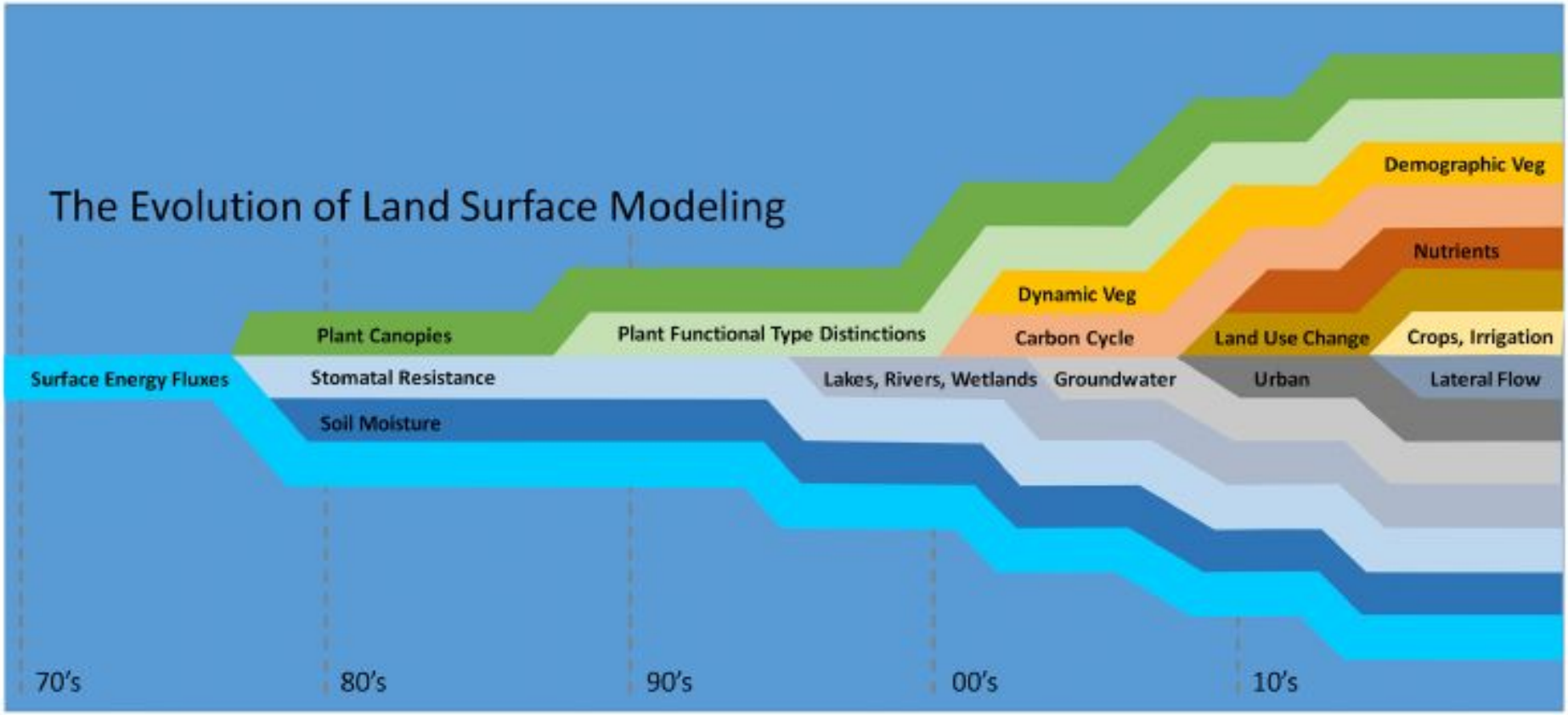


How much N for every gram of C?

What's the function of N?

N uptake from the soil

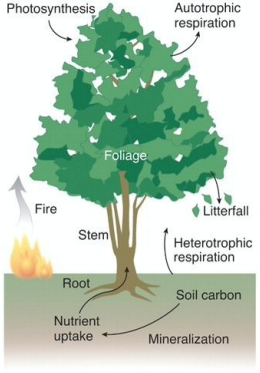
Example 2: alternative levels of complexity
Canopy structure and competition

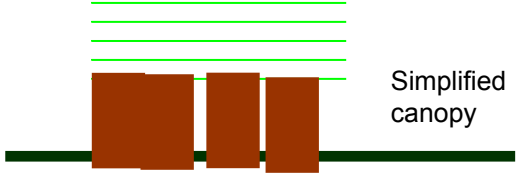


Fisher & Koven, 2020, JAMES

The need for more complex canopies

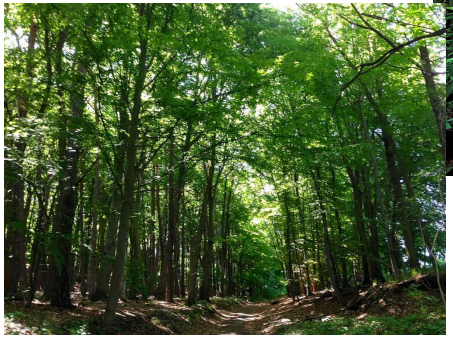
Models



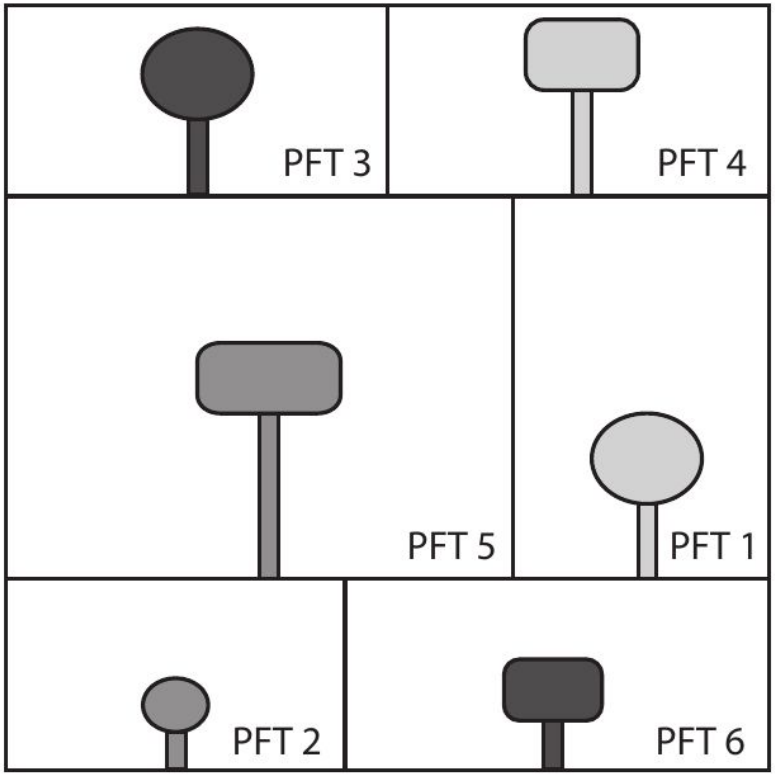


Simplified canopy

Real ecosystems

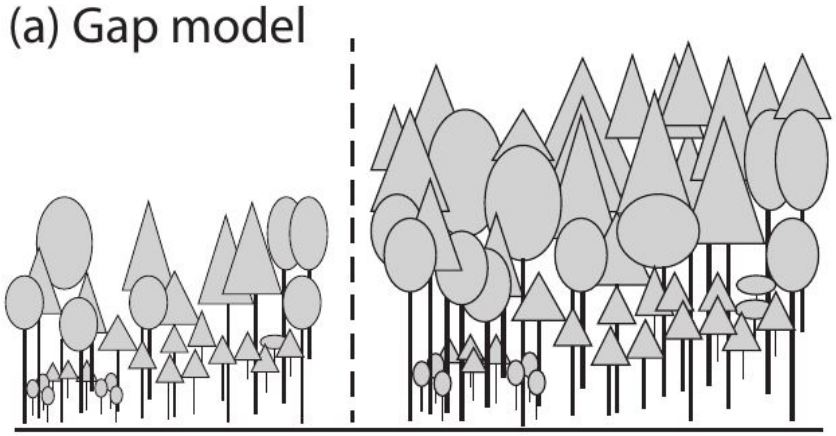


Representing multiple PFTs in one place (grid cell)



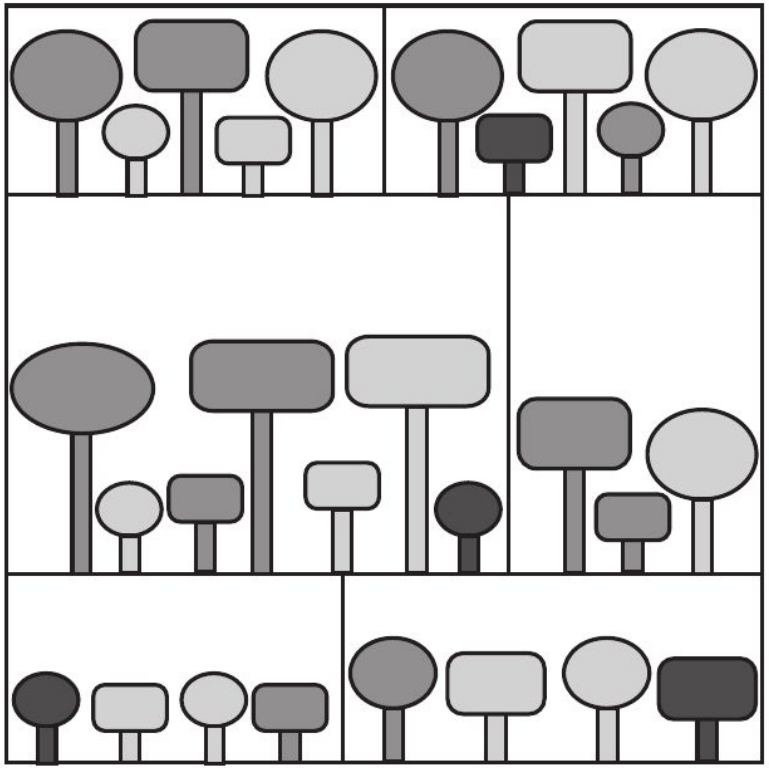
Landscape heterogeneity through representing more than one PFT together, with various degrees of interaction

Individual based gap models



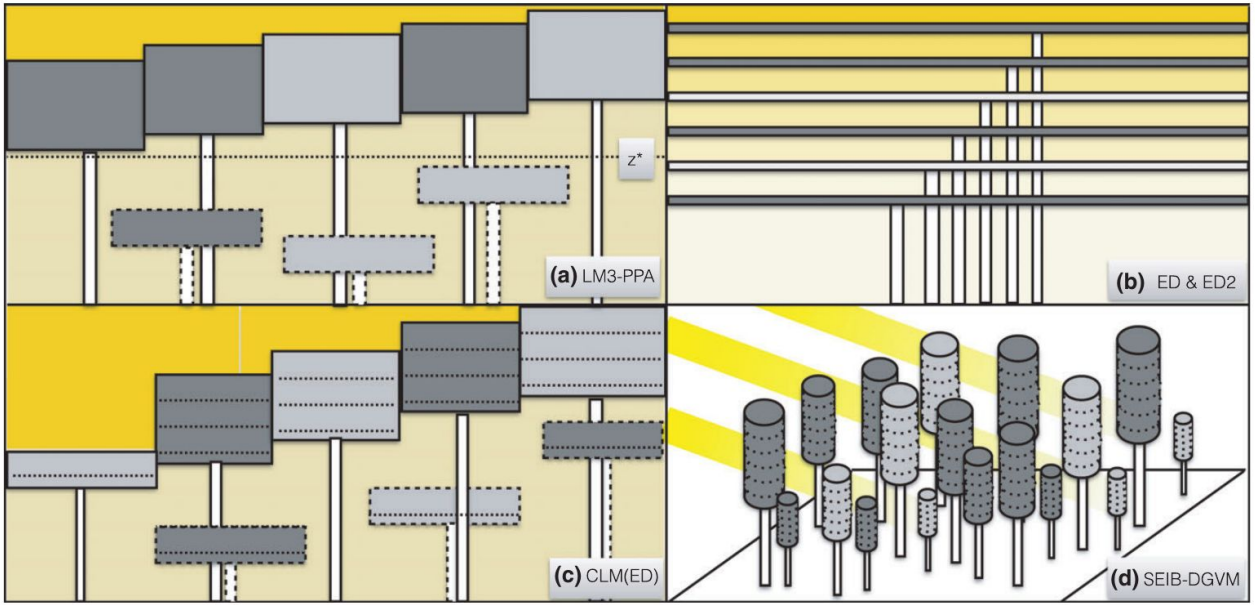
- Represent dynamics of individual trees within a stand
- Very computationally intensive
- Difficult to use beyond stand level

Cohort based ecosystem demography models



- Groups of individuals with similar characteristics (parameters)
- Can represent more details than a PFT based model but is less computationally intensive than an individual based model

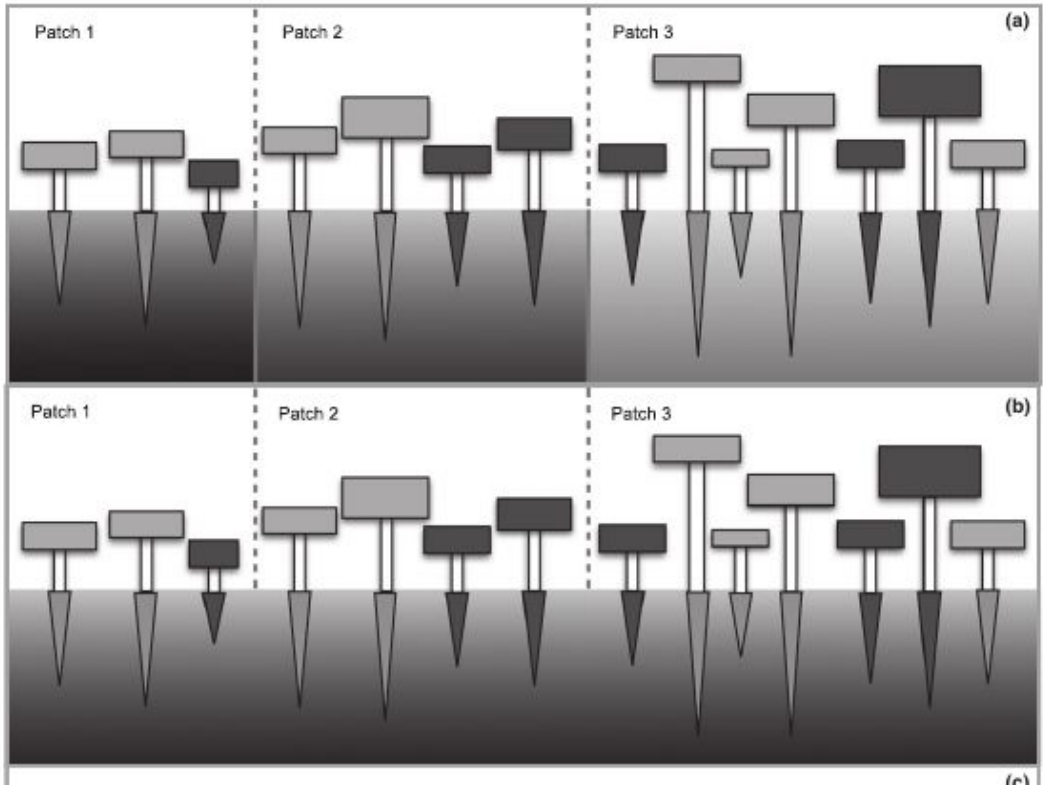
Competition for light



- A more complex case of canopy structure and radiative transfer models
- The amount of light each individual or cohort receives determines its growth

Fisher et al., 2018,
Glob. Change. Biol.

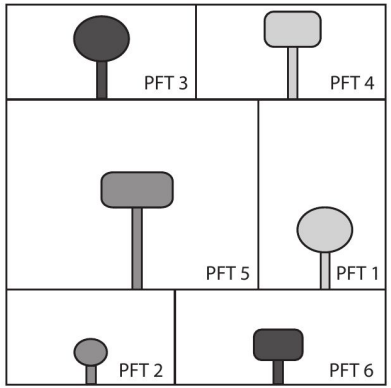
Competition for water and nutrients

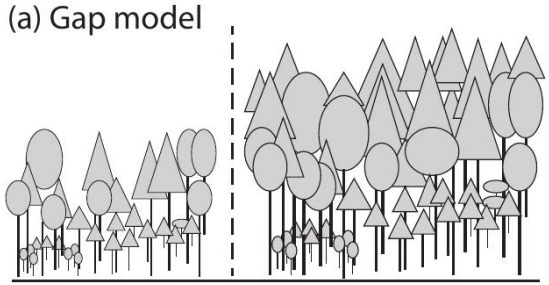


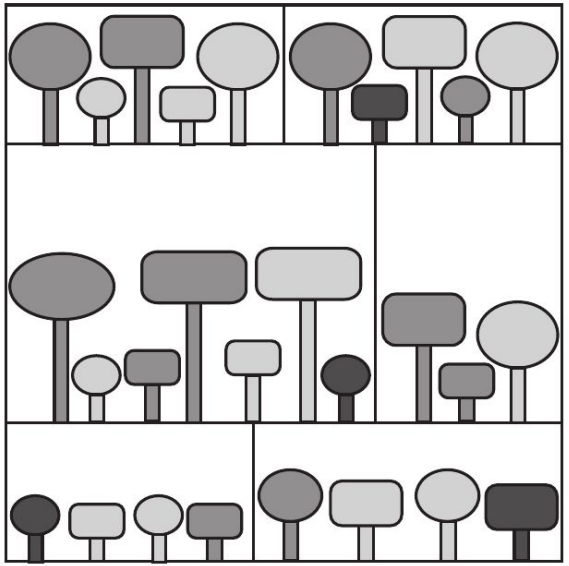
- Less well studied than light
- A more complex problem due to heterogeneity of belowground resources

Fisher et al., 2018, Glob. Change. Biol.

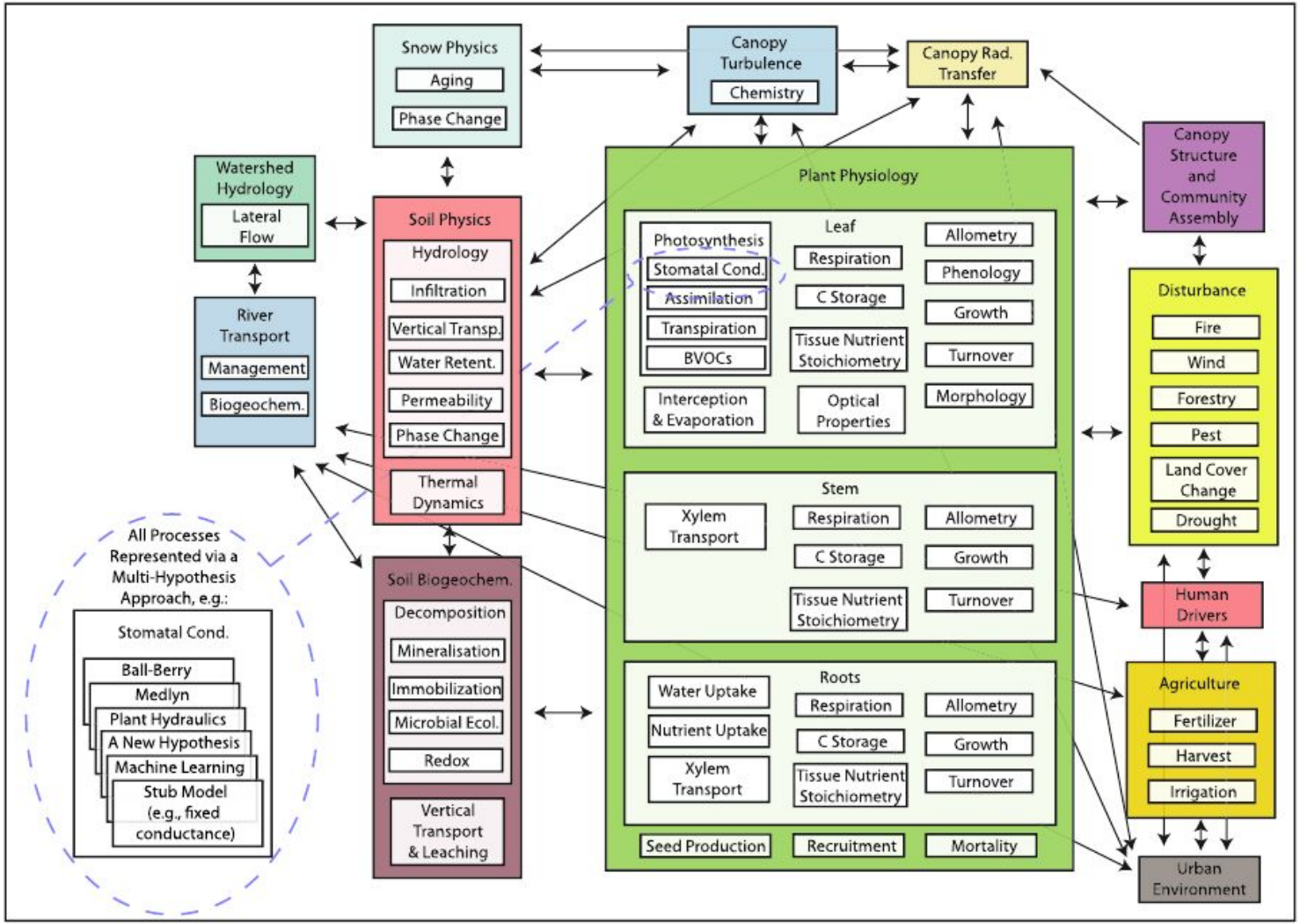
Alternative representations of the same process allow us to choose the level of complexity





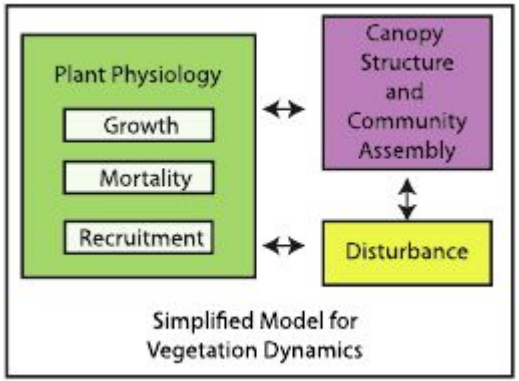


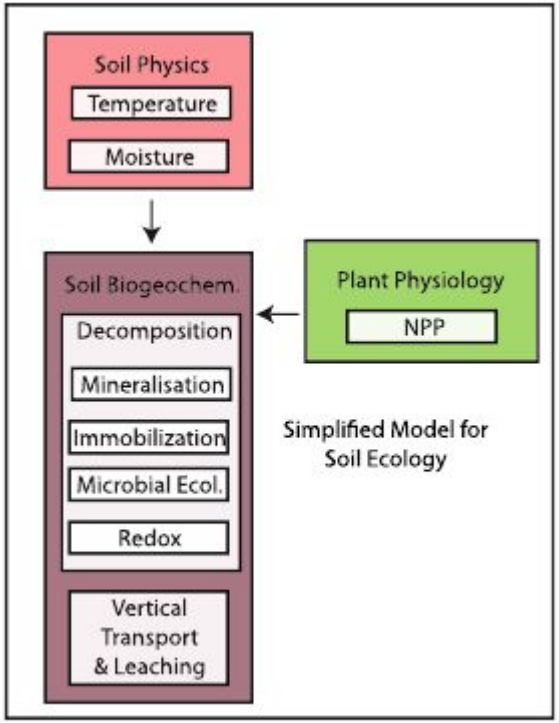
Some solutions:choosing the required level of complexity



Fisher & Koven, 2020, JAMES

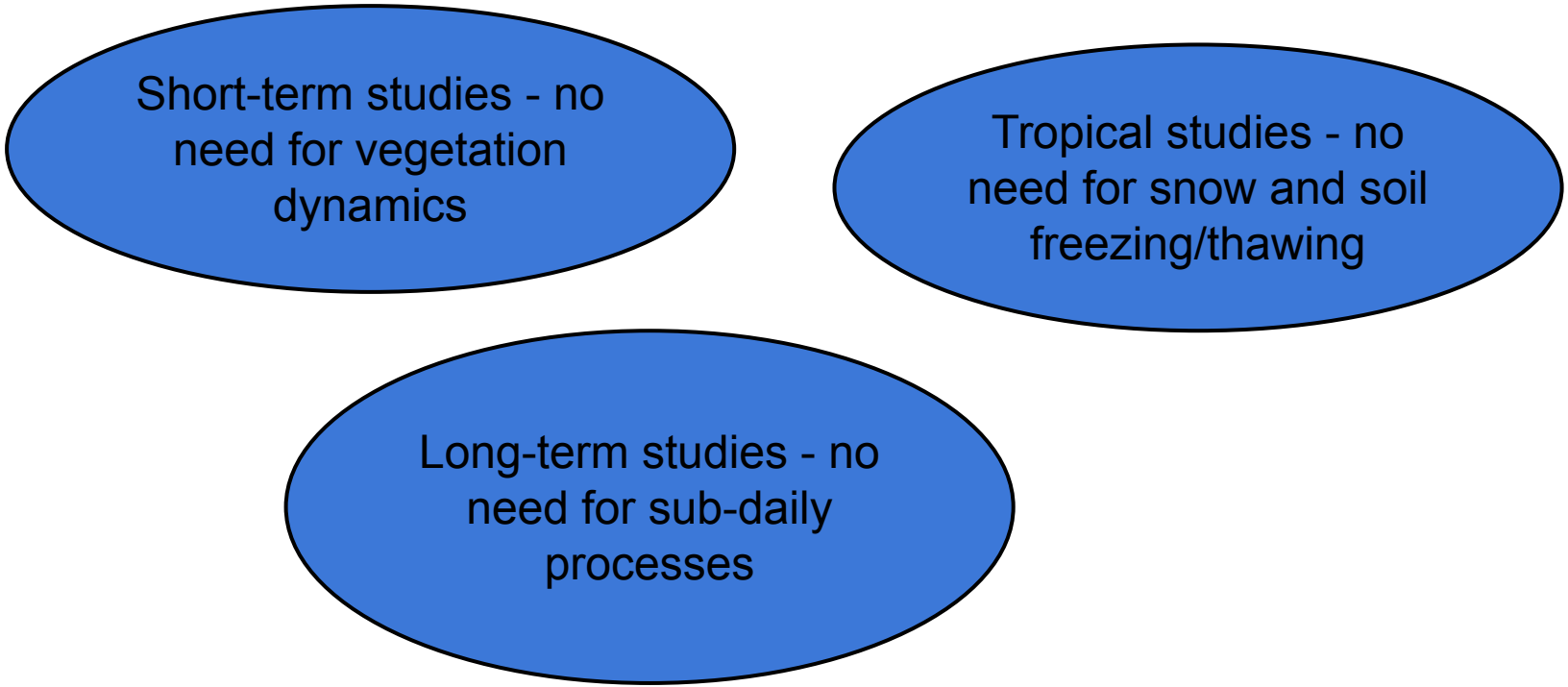
Reducing complexity based on research question



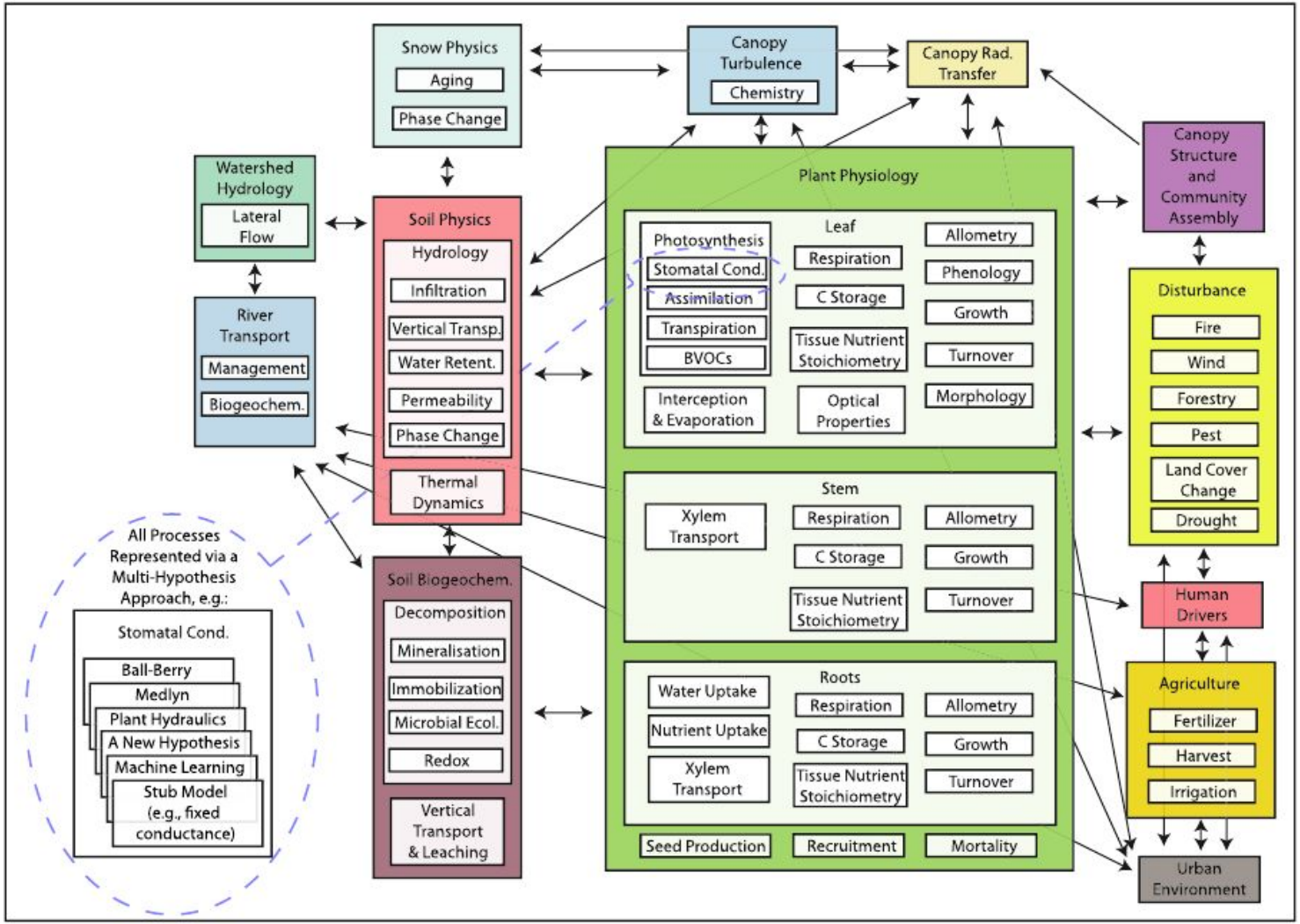


Fisher & Koven, 2020, JAMES

Reducing complexity based on temporal and spatial scope



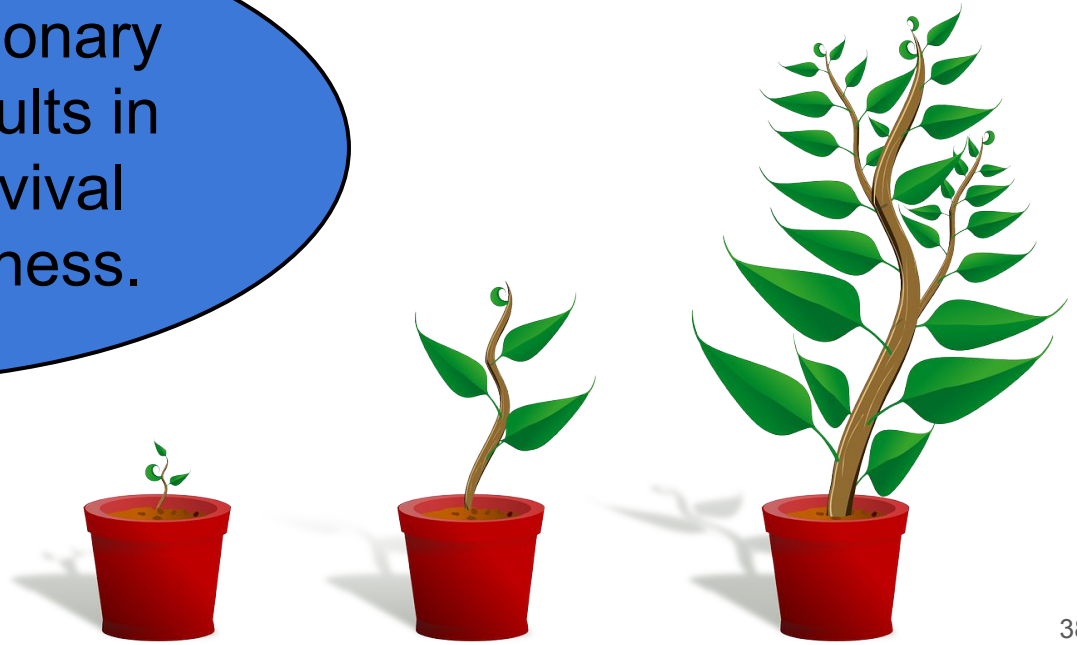
Some solutions: maintaining complexity with optimality principles



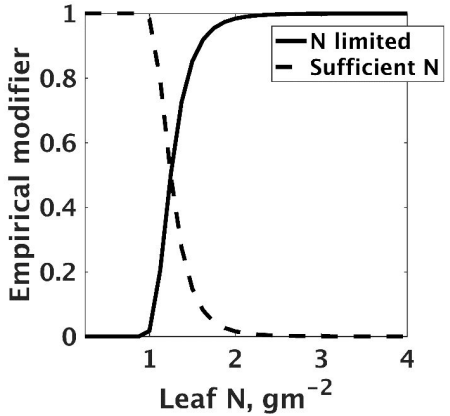
Fisher & Koven, 2020, JAMES

Optimality theory: an elegant solution to the complexity problem

The plant evolutionary strategy that results in maximising survival and offspring fitness.

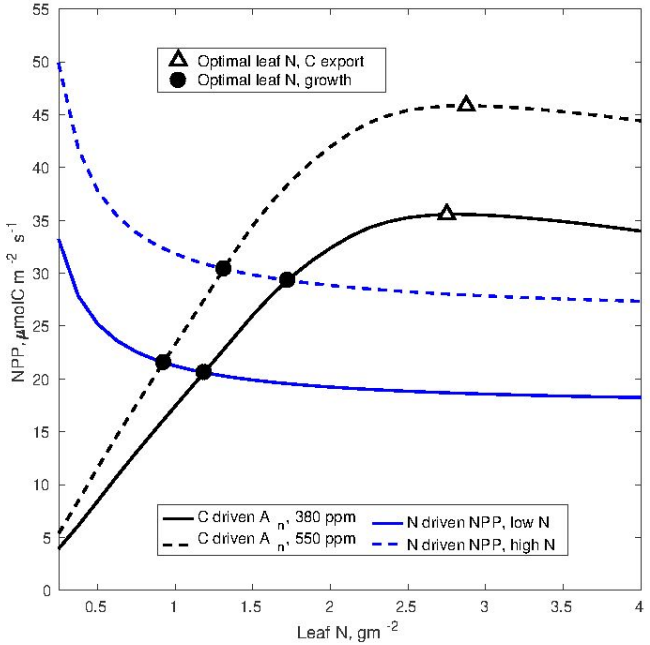


Plants vary the amount of N in their leaves. But how do we show this in models?



Change in response to N availability according to an empirical function

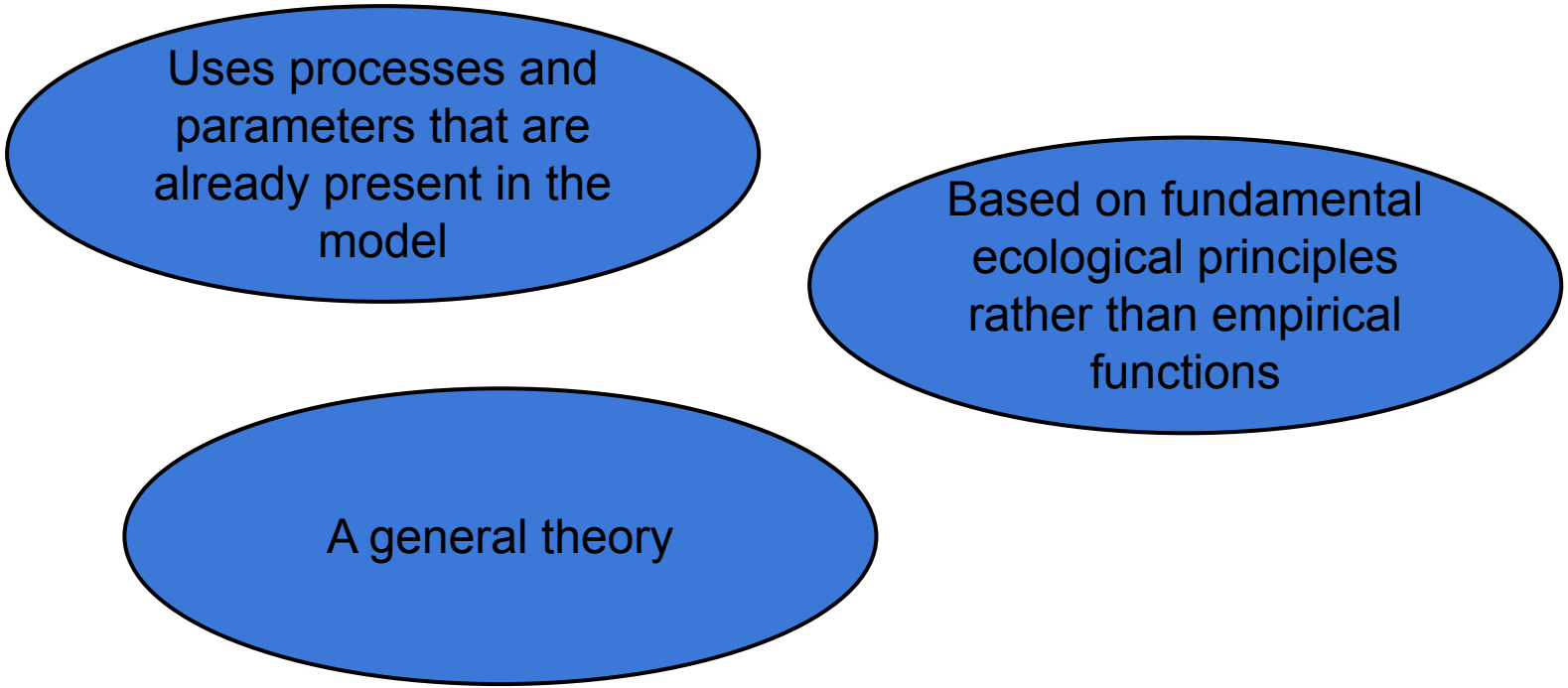
Optimal variation in leaf N based on physiological understanding



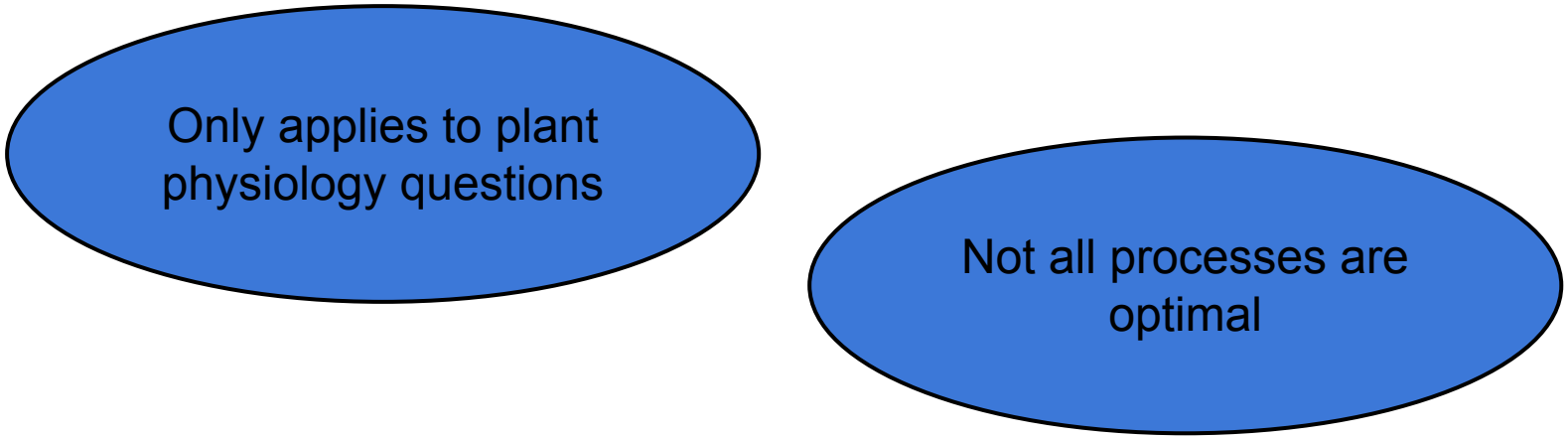
Maximising C gain: higher leaf N means higher photosynthesis but also higher respiration

Increased leaf N also means more N demand for growth, so the optimal leaf N needs to be adjusted for N availability

Advantages of optimality theory



Disadvantages of optimality theory



Take home messages

- A certain degree of complexity is necessary
- Model complexity, and the kind of model used, can be adjusted based on the needs of each project/question
- Fundamental (ecological) understanding can help maintain process complexity without more equations and parameters
- Is model complexity good or bad? There is no right answer!

Discussion points

- Are there key components of land surface models that are essential to all research questions?
- Should we have more complex models the more knowledge/data we have?
- What comes first, process understanding or modelling needs? Should we only model the things we understand?

Bibliography

Fisher, R. A., & Koven, C. D. (2020). Perspectives on the future of land surface models and the challenges of representing complex terrestrial systems. Journal of Advances in Modeling Earth Systems, 12(4). https://doi.org/10.1029/2018ms001453

Walker, A. P., De Kauwe, M. G., Bastos, A., Belmecheri, S., Georgiou, K., Keeling, R. F., McMahon, S. M., Medlyn, B. E., Moore, D. J. P., Norby, R. J., Zaehle, S., Anderson-Teixeira, K. J., Battipaglia, G., Brienen, R. J. W., Cabugao, K. G., Cailleret, M., Campbell, E., Canadell, J. G., Ciais, P., … Zuidema, P. A. (2020). Integrating the evidence for a terrestrial carbon sink caused by increasing atmospheric CO2. The New Phytologist. https://doi.org/10.1111/nph.16866

Wieder, W. R., Cleveland, C. C., Smith, W. K., & Todd-Brown, K. (2015). Future productivity and carbon storage limited by terrestrial nutrient availability. Nature Geoscience, 8(6), 441–444. https://doi.org/10.1038/ngeo2413

Fisher, R. A., Koven, C. D., Anderegg, W. R. L., Christoffersen, B. O., Dietze, M. C., Farrior, C. E., Holm, J. A., Hurtt, G. C., Knox, R. G., Lawrence, P. J., Lichstein, J. W., Longo, M., Matheny, A. M., Medvigy, D., Muller-Landau, H. C., Powell, T. L., Serbin, S. P., Sato, H., Shuman, J. K., … Moorcroft, P. R. (2018). Vegetation demographics in Earth System Models: A review of progress and priorities. Global Change Biology, 24(1), 35–54. https://doi.org/10.1111/gcb.13910