Geo 873 – 001: Seminar in Human-Environment Geography

12:40 am – 3:30 pm; GEO120

1) Carbon Monitoring and Modeling
2) Globalization: Food, Energy and Water (April 5, 12, 19)

Reading

Chen, J. (2023). Unlocking the Power of Machine Learning for Earth System Modeling: A Game-Changing Breakthrough. *Global Change Biology*.

Homework 4: In the remaining 3-4 weeks, we will discuss issues on global food, energy and water (FEW). You will select a focal topic of FEW nexus and report the lessons from the lectures, reading materials, as well as your own literature search.

Due date: 12:00 am, April 19, 2023.

April 5, 2023
GEO873-001, MSU

Carbon Stories & Climate Change: measurements

Measuring photosynthesis: chamber-based at leaf level

LiCor6400 (LI6800)

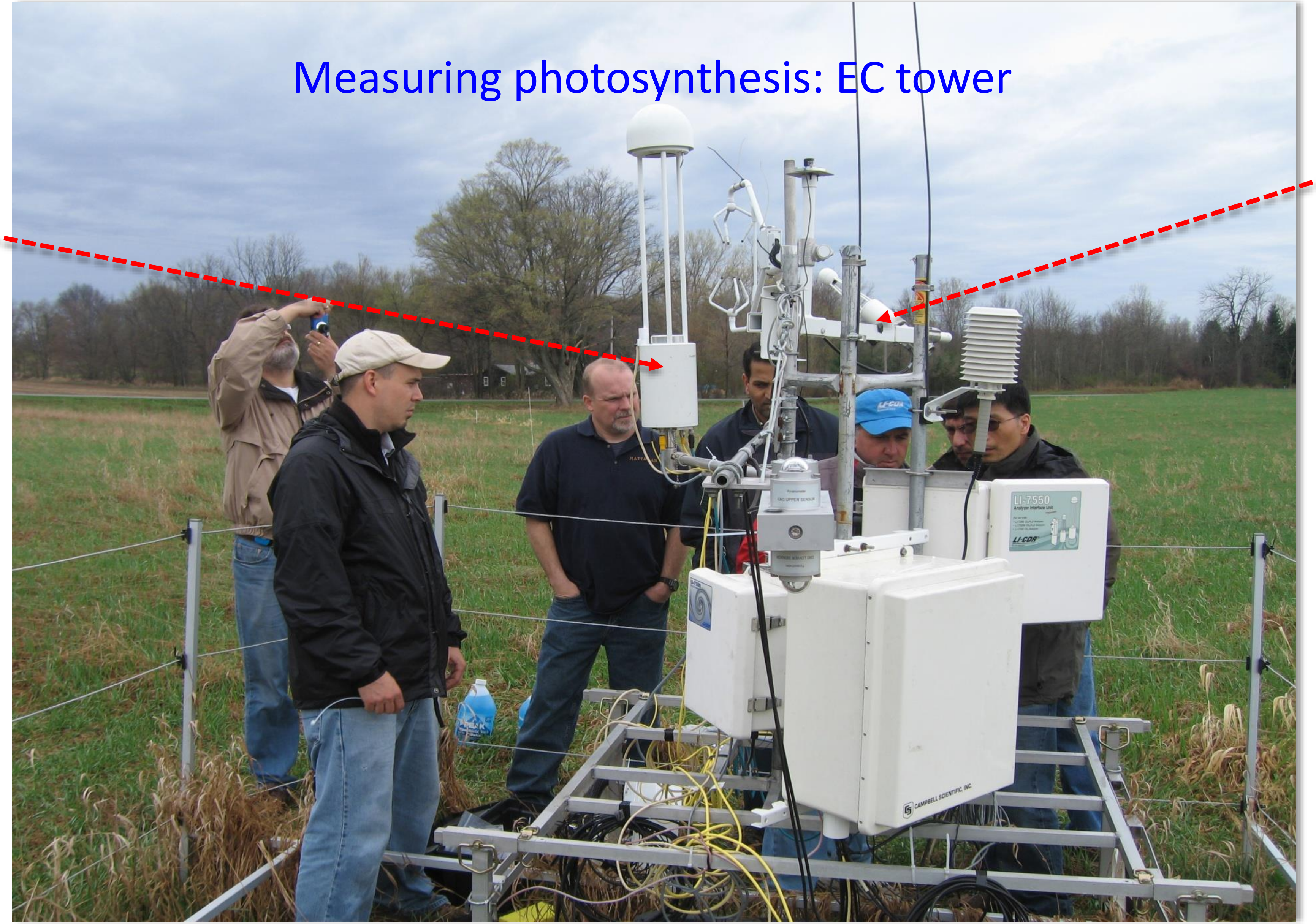
CO_2 & H_2O concentration

PAR, temperature

Carbon Stories & Climate Change: measurements

Carbon Stories & Climate Change: measurements

Open-path EC tower
daytime minus nighttime
(NEE = GEP – R_{eco})

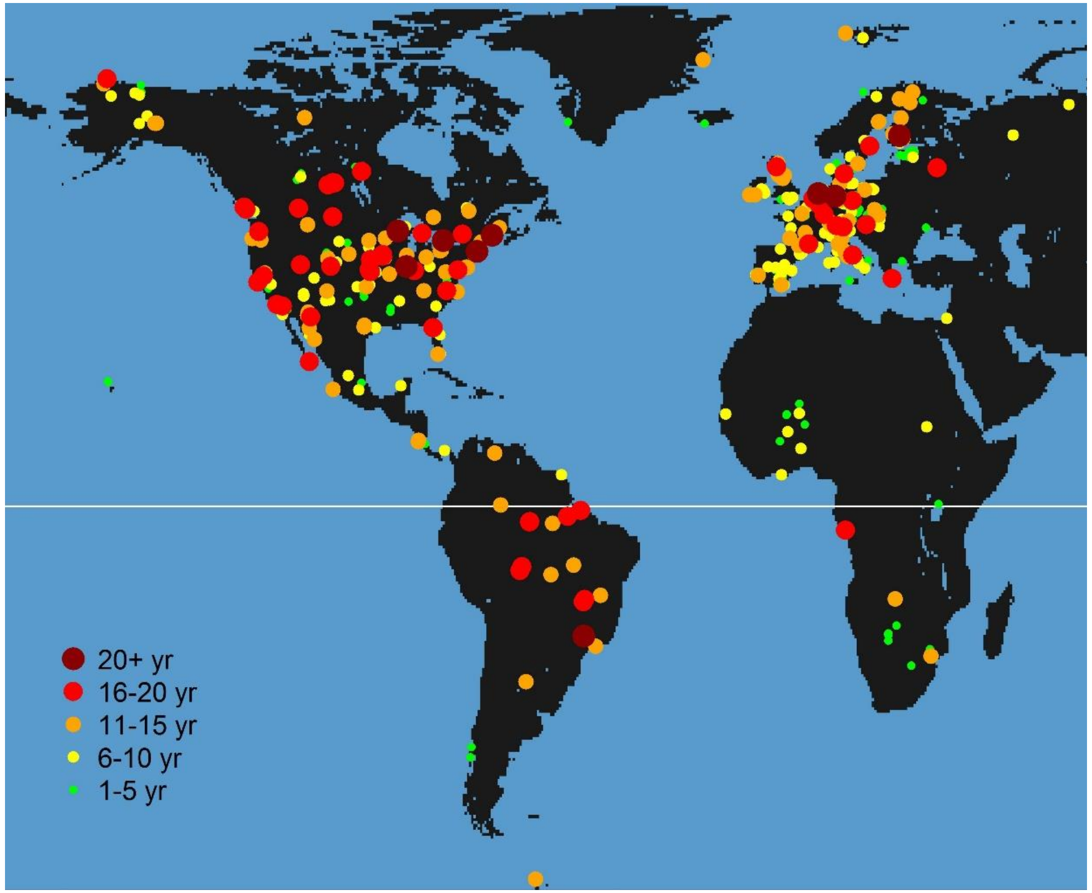


Measuring photosynthesis: EC tower

LI7700
CH_4

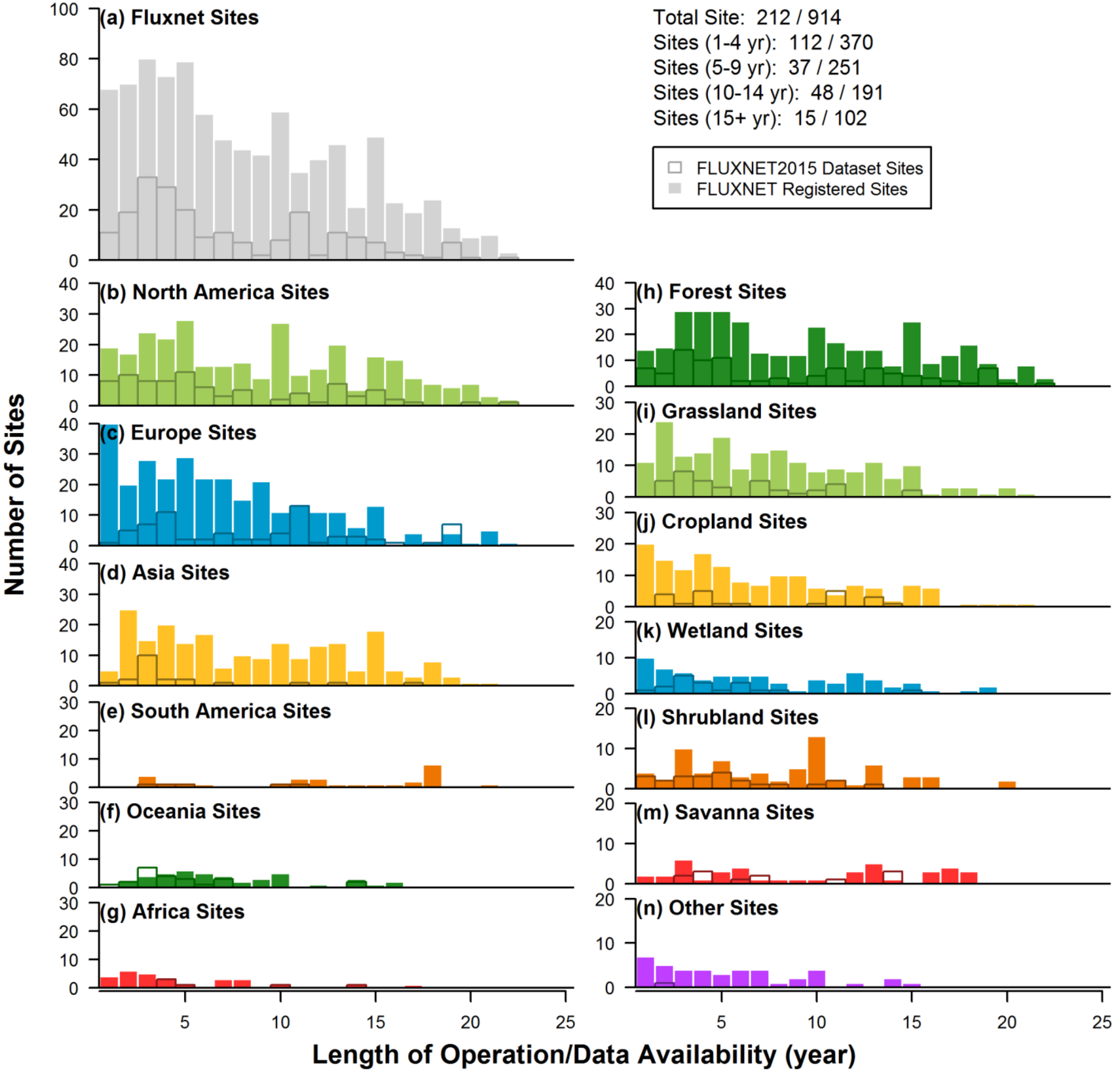
LI7500
CO_2

Carbon Stories & Climate Change:



https://fluxnet.org/sites/site-summary/

(last updated February, 2017)

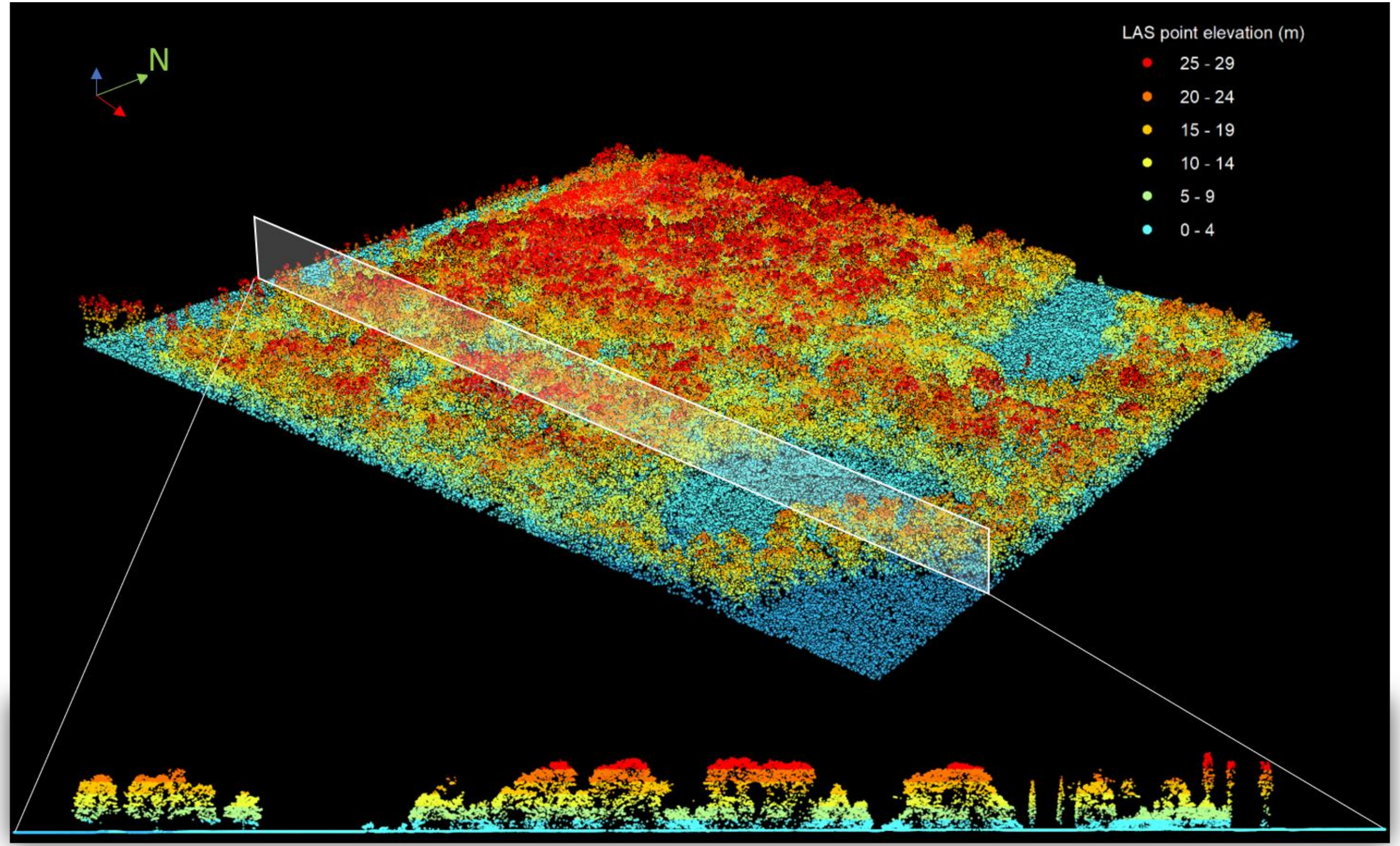


Carbon Stories & Climate Change: measurements

Measuring photosynthesis: Biometric approach (tree ring, DBH)

Carbon Stories & Climate Change: measurements

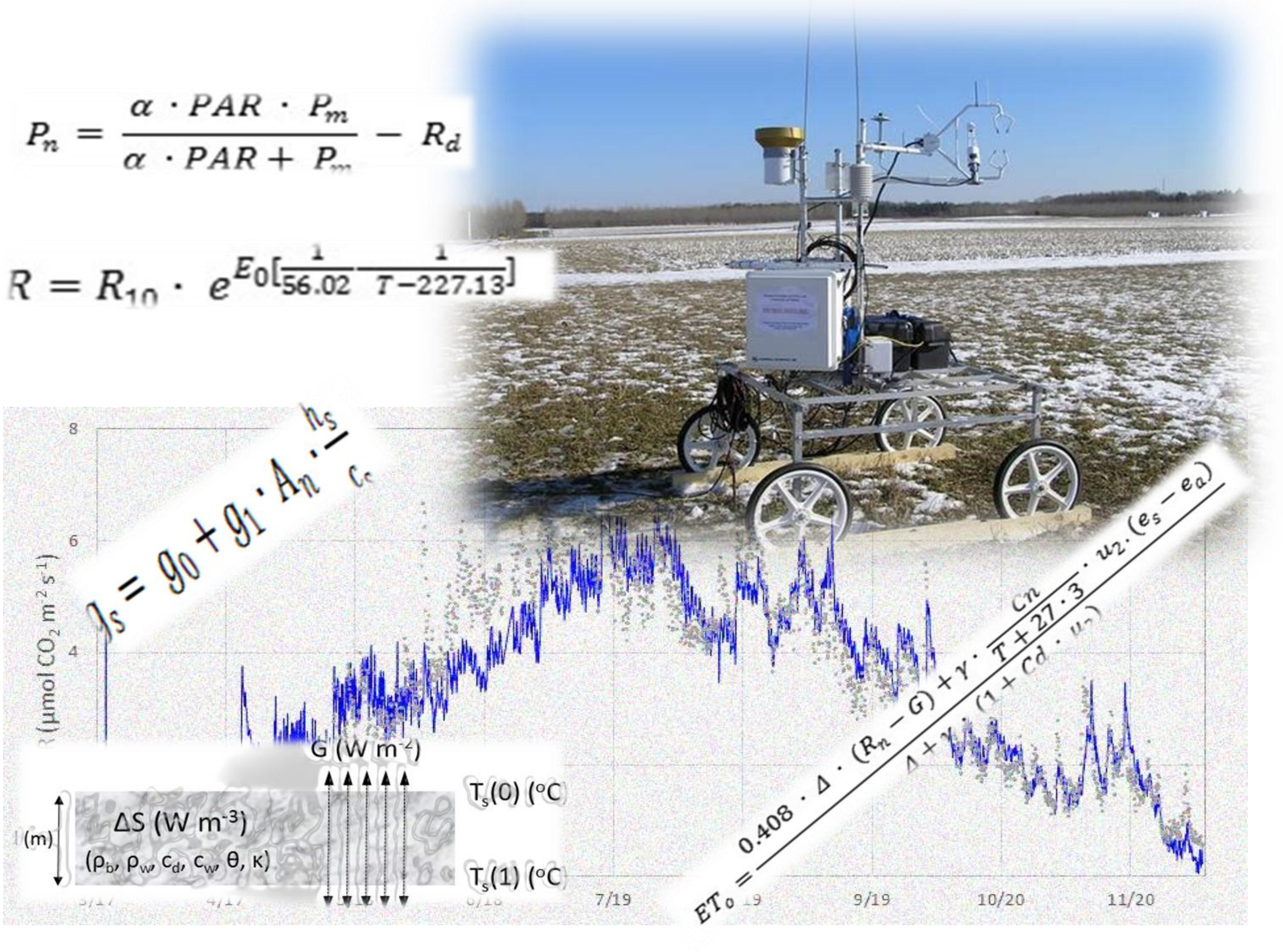
Measuring photosynthesis: remote sensing modeling



Carbon Sto

Carbon Stories & Climate Change: measurements

Measuring photosynthesis: ecosystem modeling

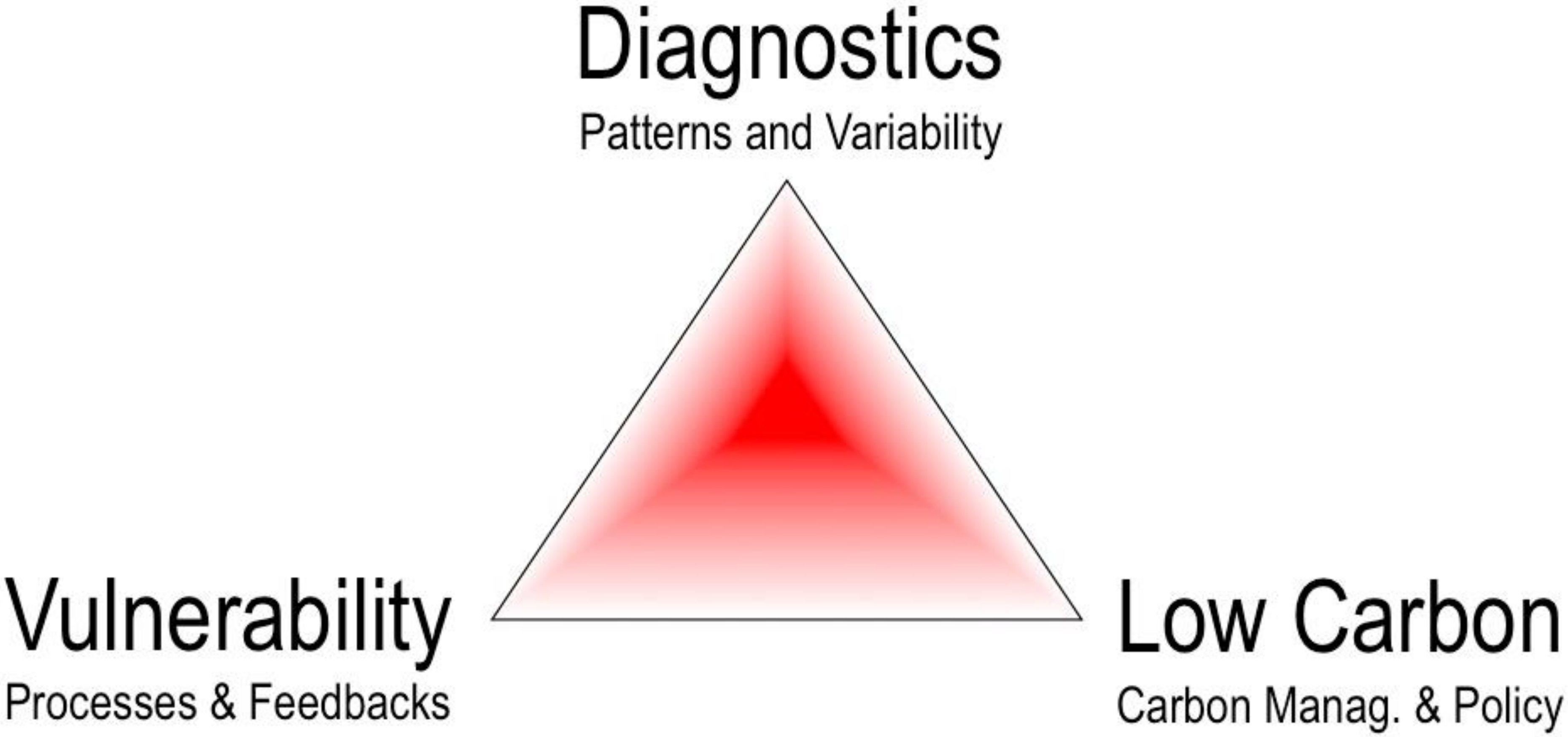


$$P_n = \frac{\alpha \cdot PAR \cdot P_m}{\alpha \cdot PAR + P_m} - R_d$$

$$R = R_{10} \cdot e^{E_0\left[\frac{1}{56.02} - \frac{1}{T - 227.13}\right]}$$

$$g_s = g_0 + g_1 \cdot A_n \cdot \frac{h_s}{c_s}$$

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{Cn}{T + 273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + Cd \cdot u_2)}$$



Diagnostics

Patterns and Variability

Vulnerability

Processes & Feedbacks

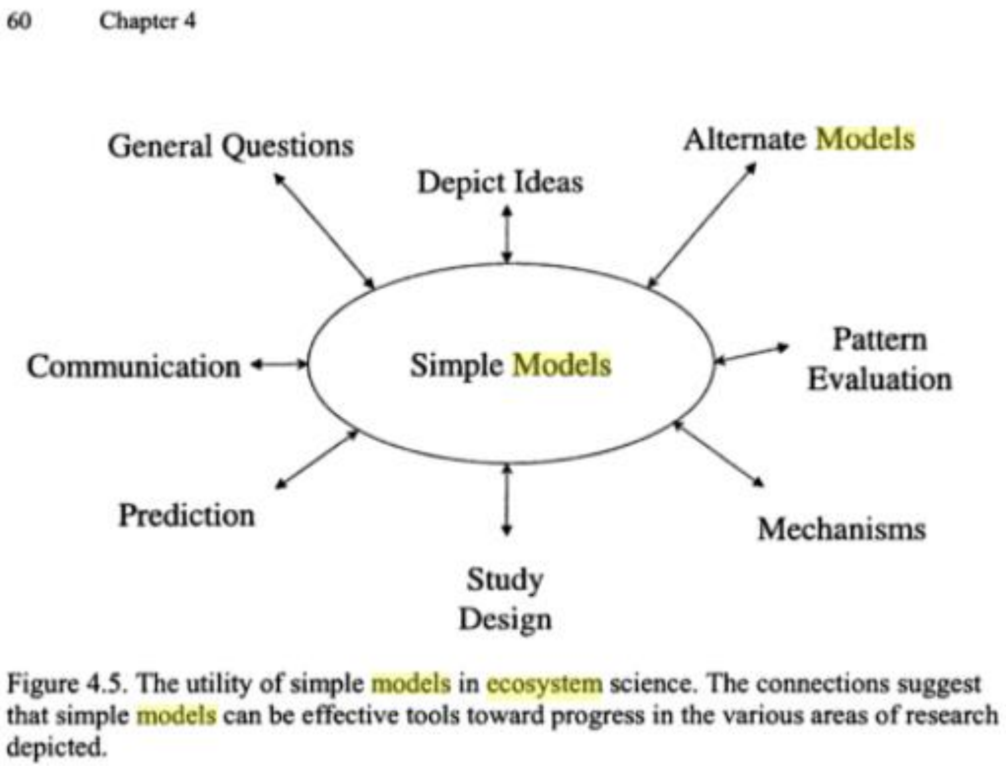
Low Carbon

Carbon Manag. & Policy

Carbon Stories & Climate Change: Earth System Models

Ecosystem Models: What? Why?

- Abstractions of real-world system or process



60 Chapter 4

Figure 4.5. The utility of simple models in ecosystem science. The connections suggest that simple models can be effective tools toward progress in the various areas of research depicted.

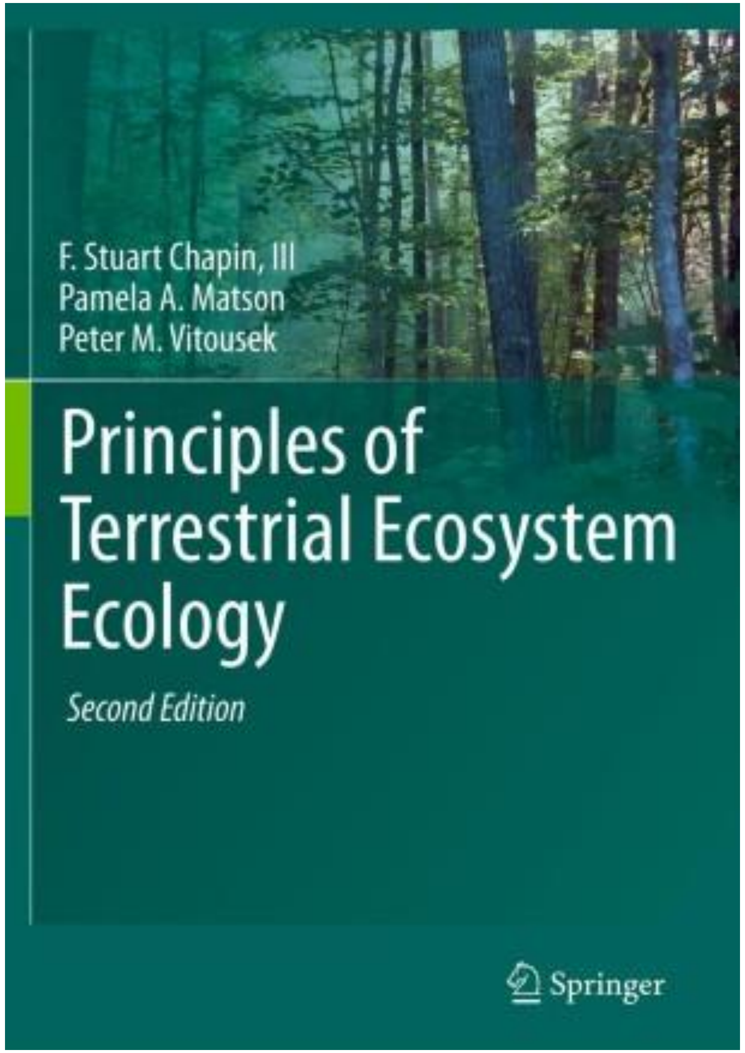
Canham, C. D. W., Cole, J., & Lauenroth, W. K. (2003). *Models in ecosystem science*. Princeton University Press.

Biogeochemical Cycles of Terrestrial Ecosystems: Carbon, Water, Nutrient, and Energy in Terrestrial Ecosystems

1) What is ecosystem ecology?
2) What are the major components of ecosystem analysis?
3) Cycles of carbon and water
4) Energy balance
5) Global Warming Potentials (GWP)

References

1) Chapin III, F. S., Matson, P. A., & Vitousek, P. (2011). *Principles of terrestrial ecosystem ecology*. Springer Science & Business Media.
2) Waring, R. H., & Schlesinger, W. H. (1985). Forest ecosystems. *Analysis at multiples scales*, 55.
3) Ågren, G. I., & Andersson, F. O. (2011). *Terrestrial ecosystem ecology: principles and applications*. Cambridge University Press.
4) Schlesinger, W. H. (Ed.). (2005). *Biogeochemistry* (Vol. 8). Elsevier.
5) Perry, D. A. (1994). *Forest ecosystems*. JHU Press.



F. Stuart Chapin, III
Pamela A. Matson
Peter M. Vitousek

Principles of Terrestrial Ecosystem Ecology

Second Edition

Springer

What is “Ecosystem Ecology”?

- Ecosystem components are cohesively connected through various processes and interactions!
- Quantify and model these interactions through computer models have been a key elements of ecosystem analysis

Example: **How Wolves Change Rivers**

https://www.youtube.com/watch?v=ysa5OBhXz-Q

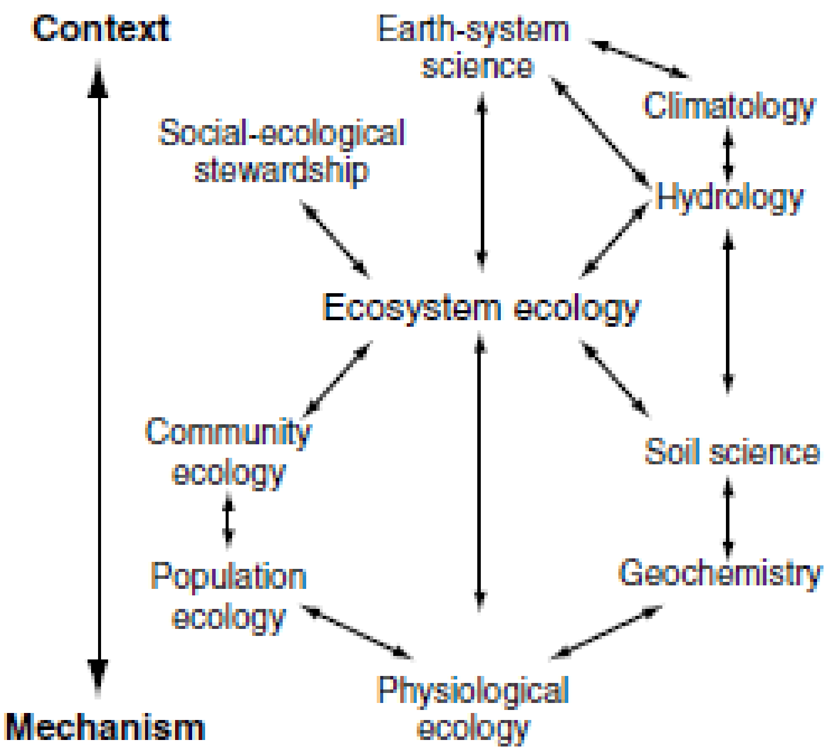
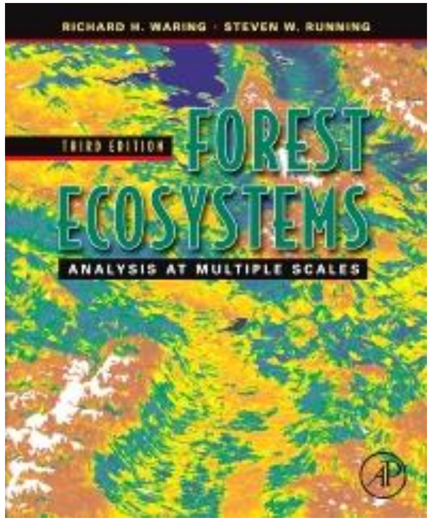


Fig. 1.3 Relationships between ecosystem ecology and other disciplines. Ecosystem ecology integrates the principles of several biological and physical disciplines, determines the resources available to society, and provides the mechanistic basis for Earth-System science

The story is about the mechanisms, suggesting that a model should also focus on the underlying processes.

Forest Ecosystems (Waring & Running 2007)



1. Forest Ecosystem Analysis at Multiple Time and Space Scales
2. Water Cycles
3. Carbon Cycle
4. Mineral Cycles
5. Temporal Changes in Forest Structure and Function
6. Susceptibility and Response of Forests to Disturbance
7. Spatial Scaling Methods for Landscape and Regional Ecosystem Analysis
8. Regional and Landscape Ecological Analysis
9. The Role of Forests in Global Ecology
10. Advances in Eddy-Flux Analyses, Remote Sensing, and Evidence of Climate Change

https://www.google.com/books/edition/Forest_Ecosystems/6YjhssXQ2AUC?hl=en&gbpv=1&pg=PA20&printsec=frontcover

In sum,

1 The Ecosystem Concept
2 Earth’s Climate System
3 Geology, Soils, and Sediments
4 Water and Energy Balance
5 Carbon Inputs to Ecosystems
6 Plant Carbon Budgets
7 Decomposition and Ecosystem Carbon Budgets
8 Plant Nutrient Use
9 Nutrient Cycling
10 Trophic Dynamics
11 Species Effects on Ecosystem Processes
12 Temporal Dynamics
13 Landscape Heterogeneity and Ecosystem Dynamics
14 Changes in the Earth System
15 Managing and Sustaining Ecosystems

Joshua M. Epstein (2008), *Journal of Artificial Societies and Social Simulation* 11(4 12); Http://jasss.soc.surrey.ac.uk/11/4/12.html

1) Explain (very distinct from predict)
2) Guide data collection
3) Illuminate core dynamics
4) Suggest dynamical analogies
5) Discover new questions
6) Promote a scientific habit of mind
7) Bound (bracket) outcomes to plausible ranges
8) Illuminate core uncertainties.
9) Offer crisis options in near-real time
10) Demonstrate tradeoffs / suggest efficiencies
11) Challenge the robustness of prevailing theory through perturbations
12) Expose prevailing wisdom as incompatible with available data
13) Train practitioners
14) Discipline the policy dialogue
15) Educate the general public
16) Reveal the apparently simple (complex) to be complex (simple)

Epstein, J. M. (2008). Why model?. *Journal of Artificial Societies and Social Simulation*, *11*(4), 12.

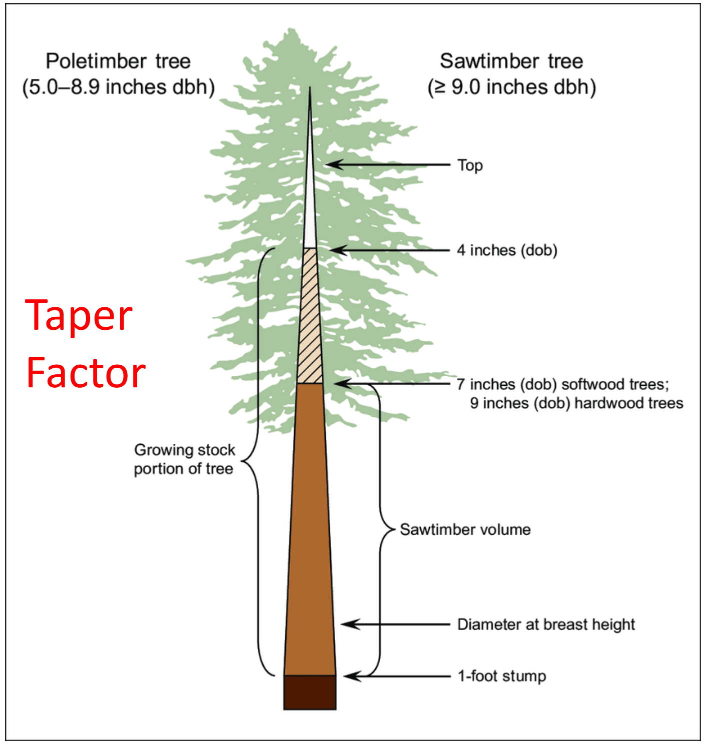
Pre-computer Era models

- Look up tables
- Simple empirical relationships

A tree

Volume= $\alpha \cdot DBH^{\beta}$

Volume= $\alpha \cdot Height \cdot DBH^{\beta}$



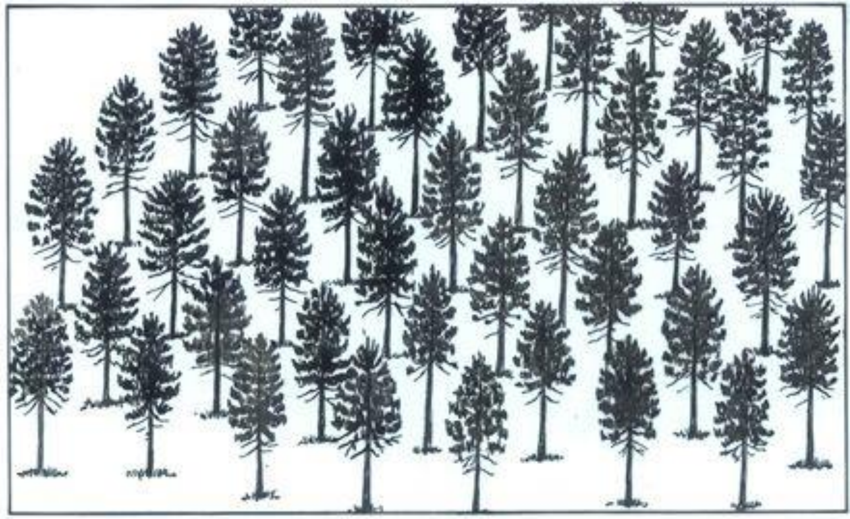
A forest

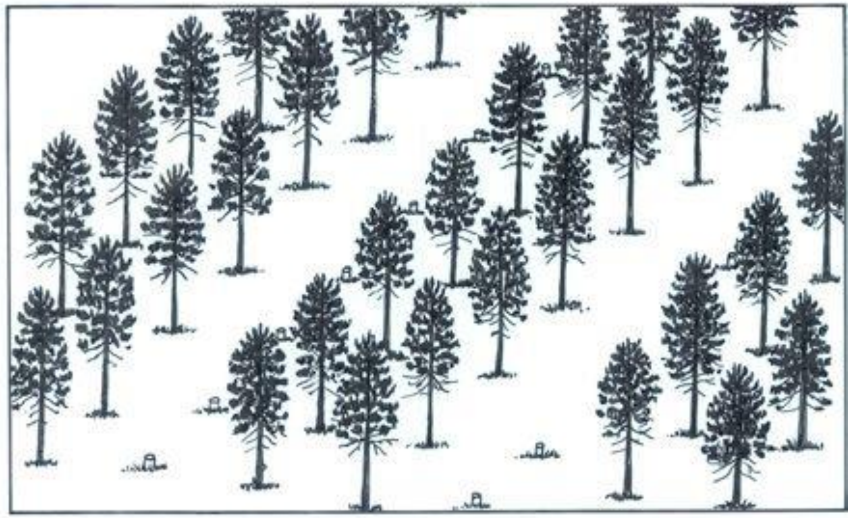
Volume= $\alpha \cdot [Height \cdot DBH^{\beta}] \cdot Density$

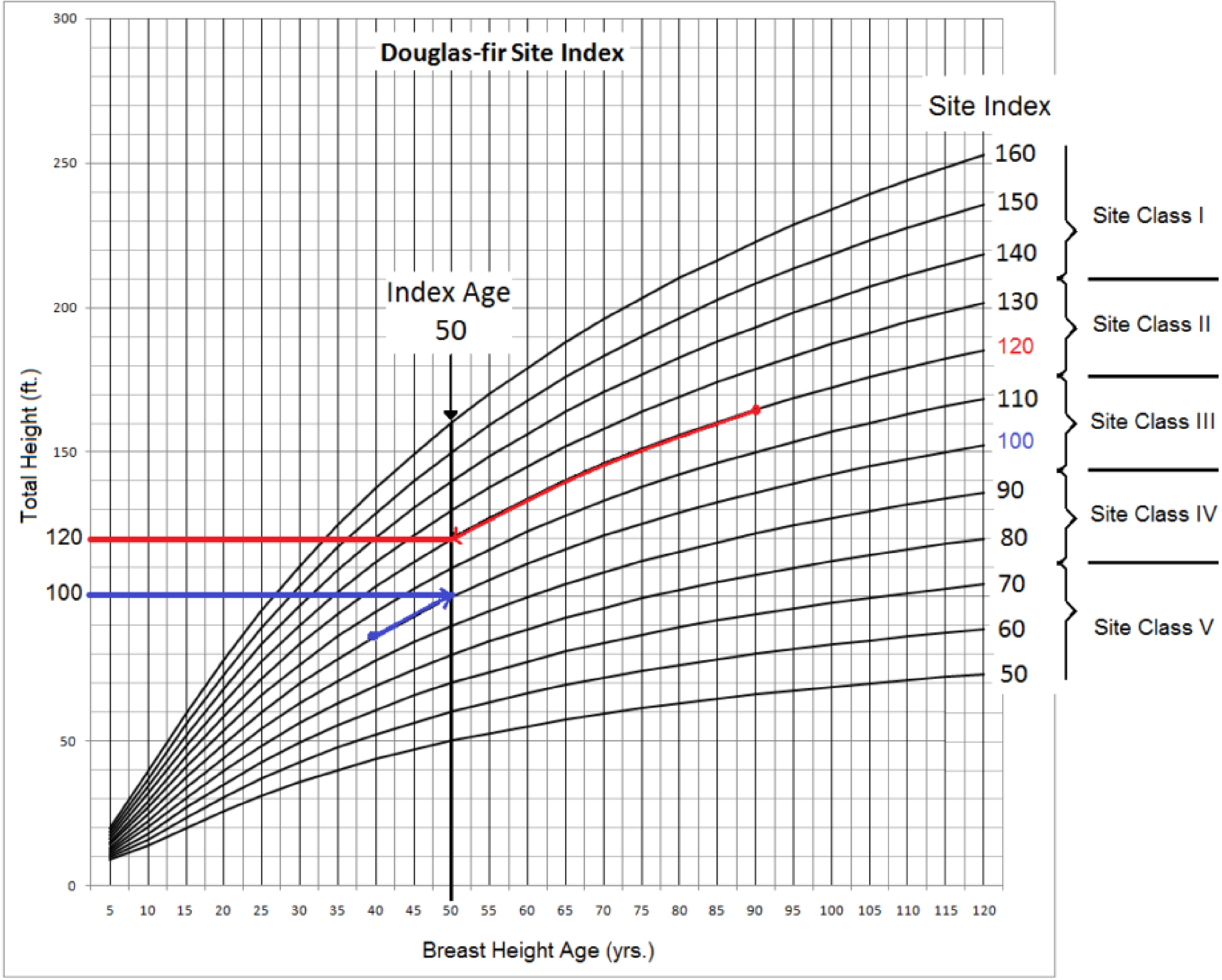
Volume= $\alpha \cdot [Height \cdot DBH^{\beta}] \cdot Density \mid Site\ Index|Species$

Volume= $\alpha \cdot [Height \cdot DBH^{\beta}] \cdot Density \mid Site\ Index|Species|management$

Biomass = Volume · Wood Density

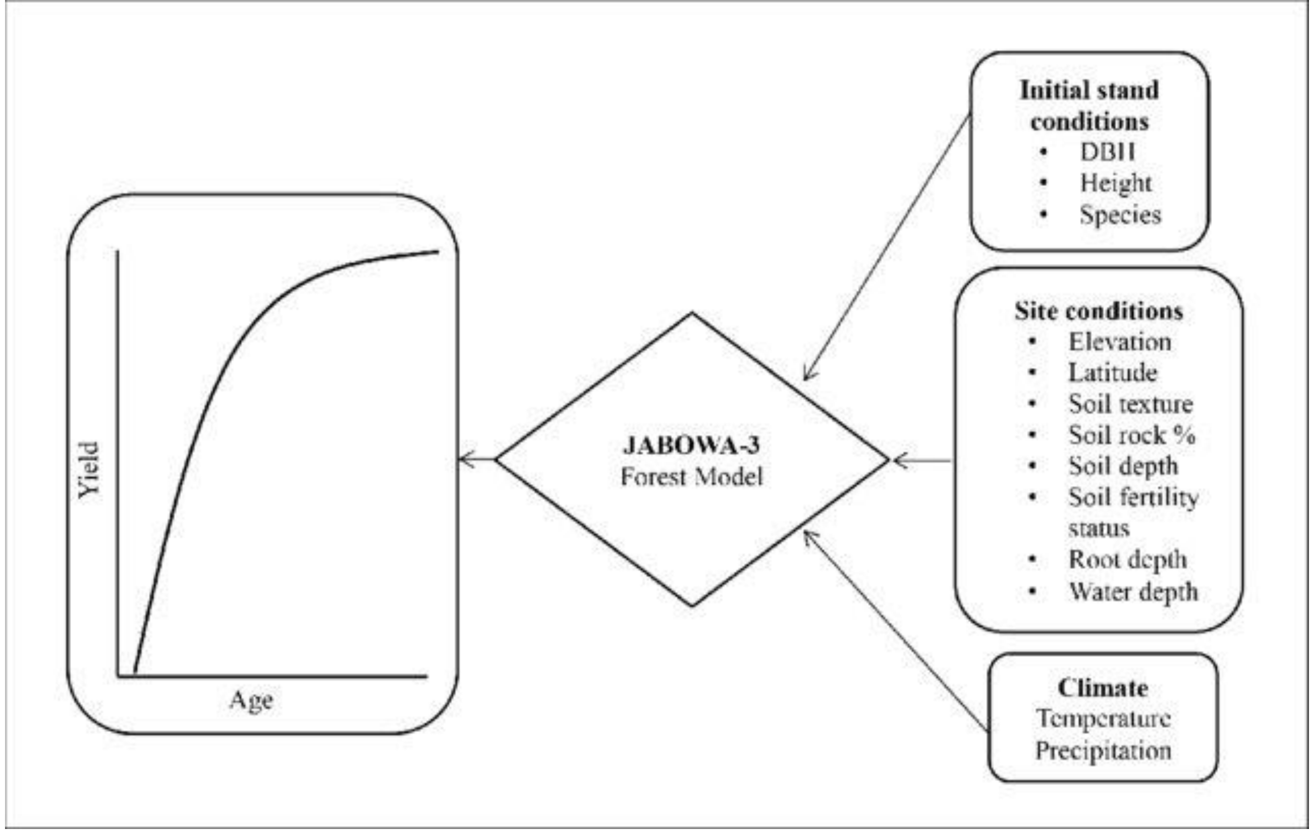


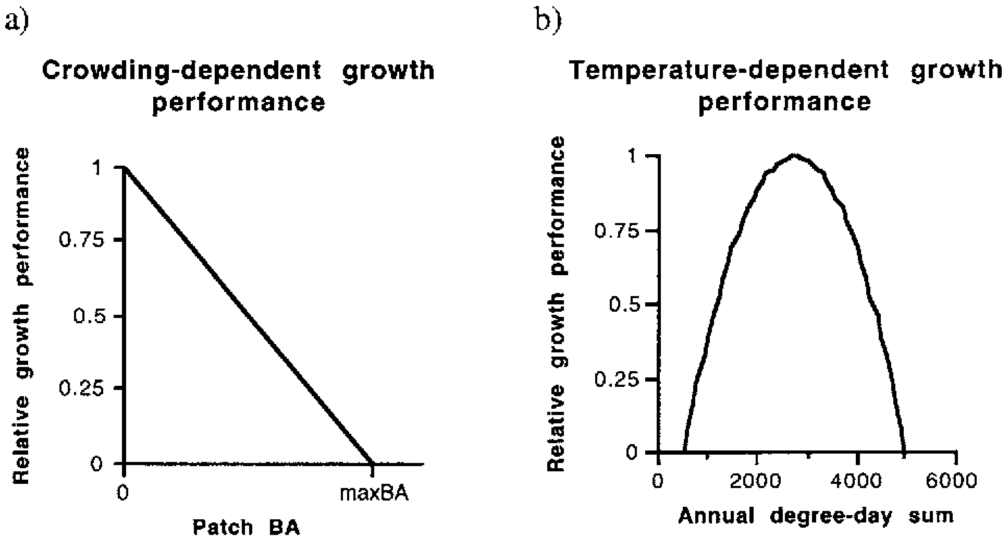



Douglas-fir Site Index
Site Index
160
150
140
130
120
110
100
90
80
70
60
50
Site Class I
Site Class II
Site Class III
Site Class IV
Site Class V
Index Age
50
Total Height (ft.)
300
250
200
150
120
100
50
0
Breast Height Age (yrs.)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120

Computer Era models

- Increasing the number of variables
- Mostly based on empirical relationships
- Climatic, soil, disturbances, management as regulators
- Interactions among components (e.g., species, soil-plants) are considered
- Example: JOBAWA, FORET models (a.k.a. GAP models)





Ashraf, M. I., Bourque, C. P. A., MacLean, D. A., Erdle, T., & Meng, F. R. (2012). Using JABOWA-3 for forest growth and yield predictions under diverse forest conditions of Nova Scotia, Canada. *The Forestry Chronicle*, *88*(6), 708-721.

Individual-based models (IBMs) of complex systems emerged in the 1960s and early 1970s, across diverse disciplines from astronomy to zoology. Ecological IBMs arose with seemingly independent origins out of the tradition of understanding the ecosystems dynamics of ecosystems from a ‘bottom-up’ accounting of the interactions of the parts. Individual trees are principal among the parts of forests. Because these models are computationally demanding, they have prospered as the power of digital computers has increased exponentially over the decades following the 1970s.

Shugart, H. H., Wang, B., Fischer, R., Ma, J., Fang, J., Yan, X., ... & Armstrong, A. H. (2018). Gap models and their individual-based relatives in the assessment of the consequences of global change. *Environmental Research Letters*, *13*(3), 033001.

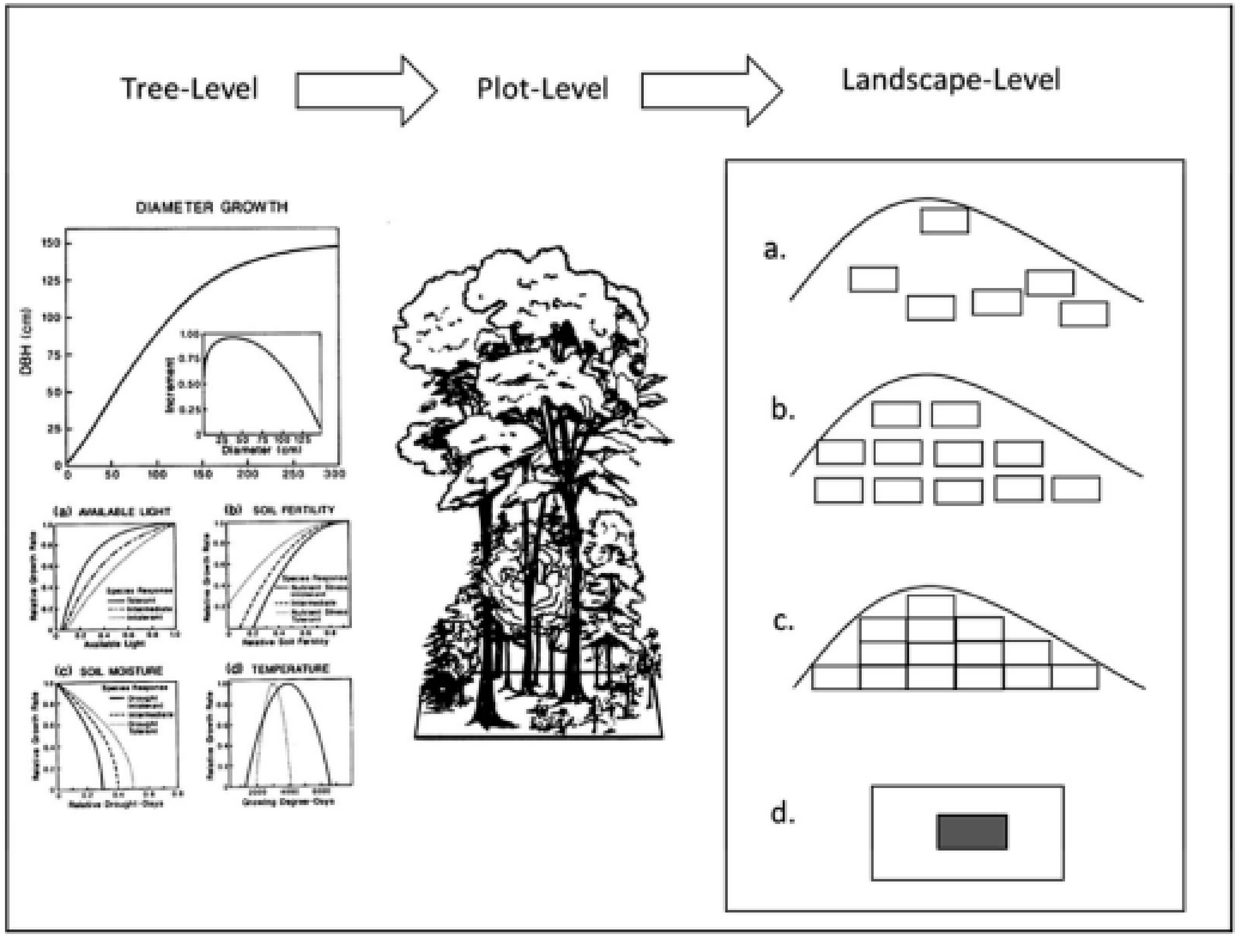
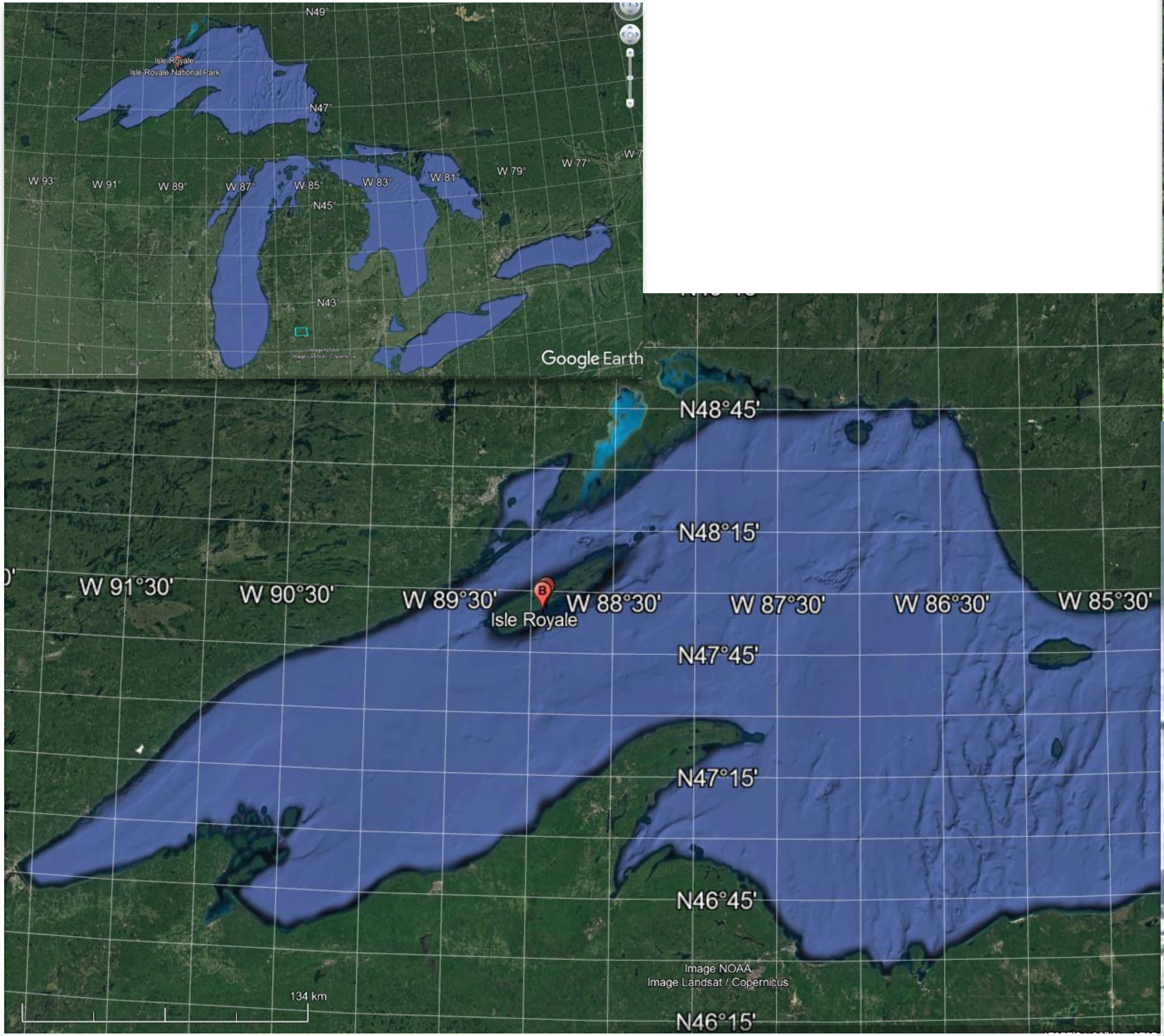


Figure 2. General functioning of a gap model. As one moves to the right to left, spatial scale increases from an individual tree to a small plot to a landscape. The tree-level response shown here is the elementary growth (or tree ring) equation from the FORET (Shugart and West 1977) model. The magnitude ot the tree-mortality probablity of each tree are also determined at the tree-level depending on tree growth as an index of vigor, species longevieties and other conditions. The form of the growth equation with no constraints is shown at the top and the decrement to this optimal growth equation is found below according to the particular controlling environmental factors (available light, soil moisture, etc). At the plot level, the vertical profile of light, available soil moisture, and other environmental and biogeochemical factors are calculated and tree to tree interactions are computed. Conditions for potential new seedlings for each year are determined factors such as the environmental conditions and seed sources. At the landscape model, a basic gap model can be used to represent the landscape as: (*a*) the summation of a Monte Carlo collection of independent random points; (*b*) gridded points at some spacing, (*c*) a tessellation of adjacent plots; (*d*) a spatially explicit landscape simulation with a spatial map of trees that is ‘windowed’ or updated for tree birth, growth and death by dropping a gap-model computational window onto the tree-stem map to solve for a subset of a new map. This is repeated to produce the new map. The size of this subset determines the resolution of the spatial map.

Population Dynamics: Predator-Prey Relationship (



Population Dynamics: Predator-Prey Relationship (Wolf-Moose on Isle Royal National Park)

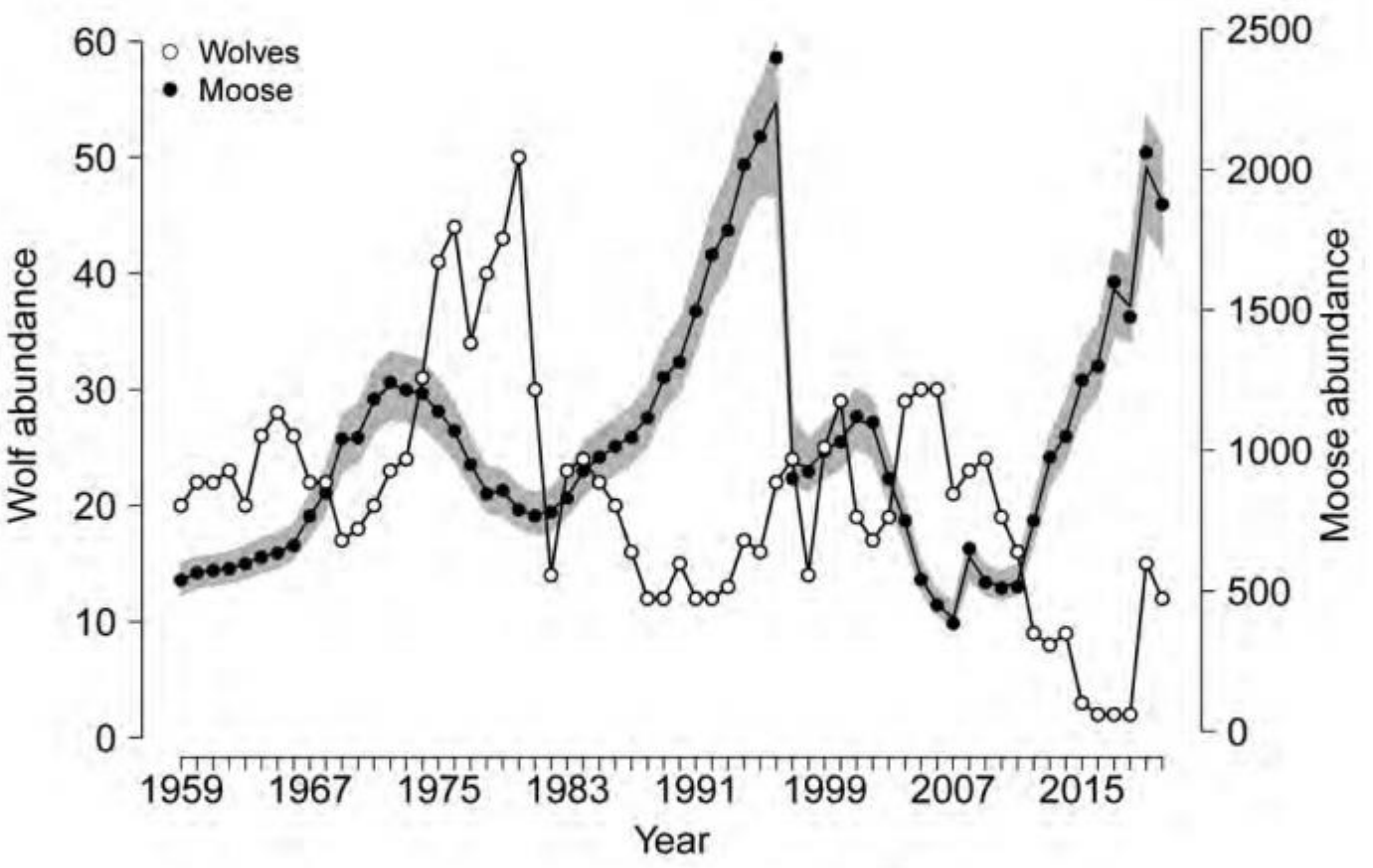


Figure 1. *Wolf and moose fluctuations in Isle Royale National Park, 1959-2020. Wolf abundances (open circles) were based on aerial surveys conducted from January to March. The sudden increase in wolf abundance in 2019 is the result of wolves being translocated by the National Park Service. Moose abundances (filled circles) during 1959-2001 are based on population reconstruction from the recoveries of dead moose, and estimates from 2002 to 2020 are based on aerial surveys. The second set of moose abundances (lines) and confidence intervals (shaded area) are results of a Bayesian state-space model that takes account of density dependence and age structure, as well as sampling error (Hoy et al. 2020, Functional Ecology). By contrast, confidence intervals reported in the main text emphasize sampling error associated with aerial surveys.*

The BIDE Model

Population = + Birth
+ ~~Immigration~~
+ Death
+ ~~Emigration~~

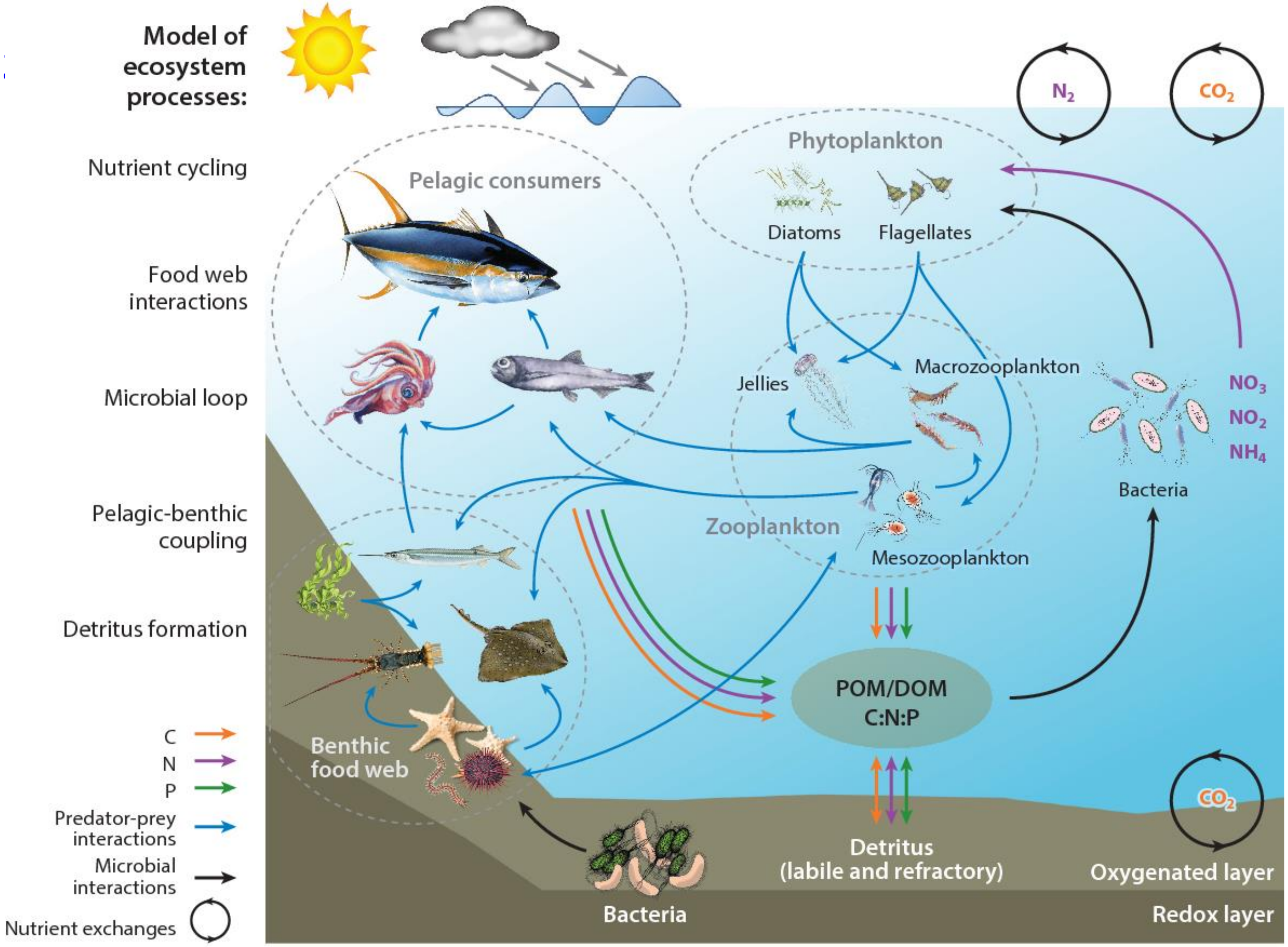
Death = function (Wolf Population)

https://www.youtube.com/watch?v=PdwnfPurXcs

Ecosystem Model

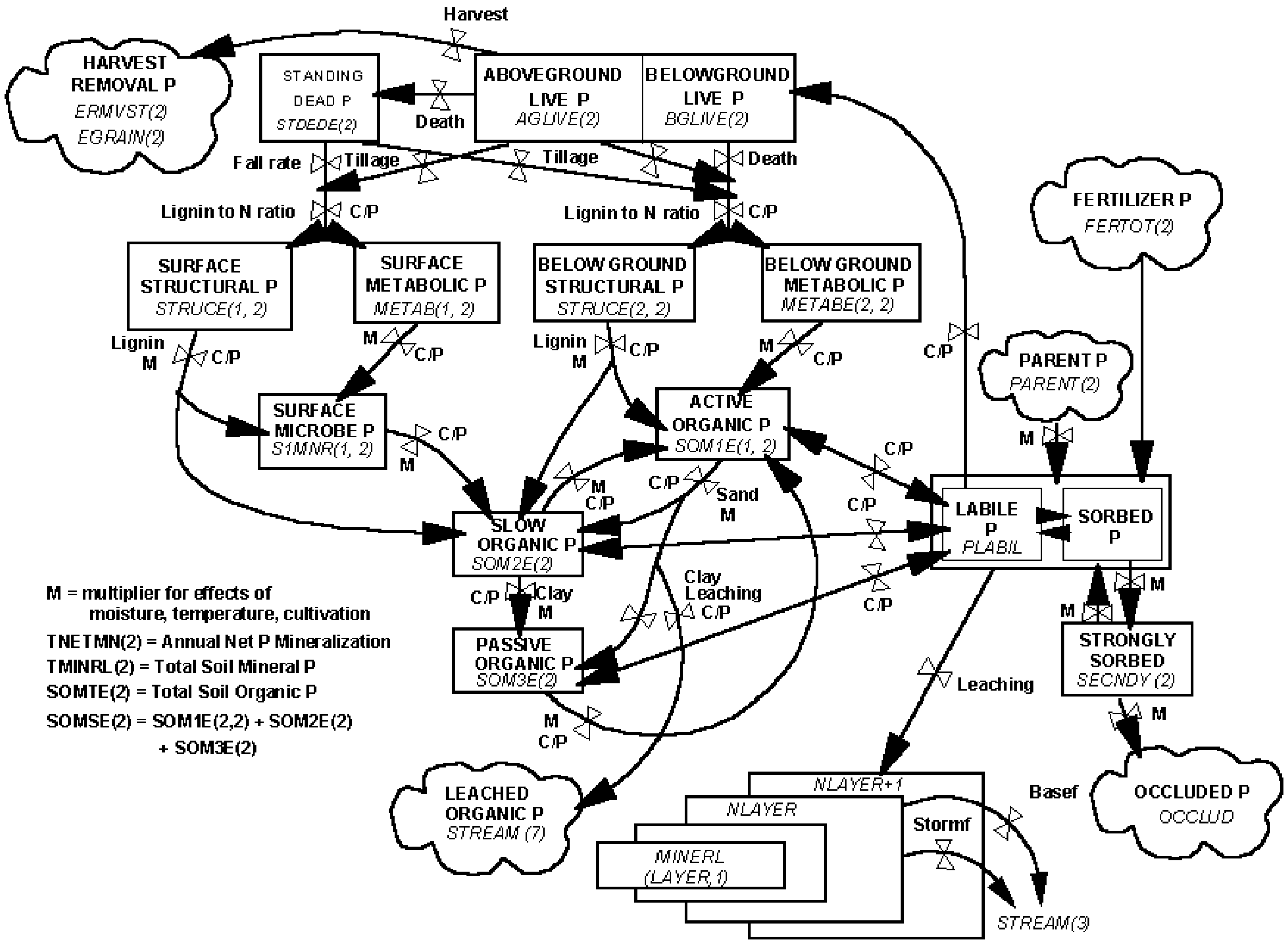
flows of mass and energy through an ecosystems

Fluxes among the components expressed as differential equations!



Pethybridge, H. R., Choy, C. A., Polovina, J. J., & Fulton, E. A. (2018). Improving marine ecosystem models with biochemical tracers. *Annual review of marine science*, *10*, 199-228.

Ecosystem Models: more examples



M = multiplier for effects of moisture, temperature, cultivation

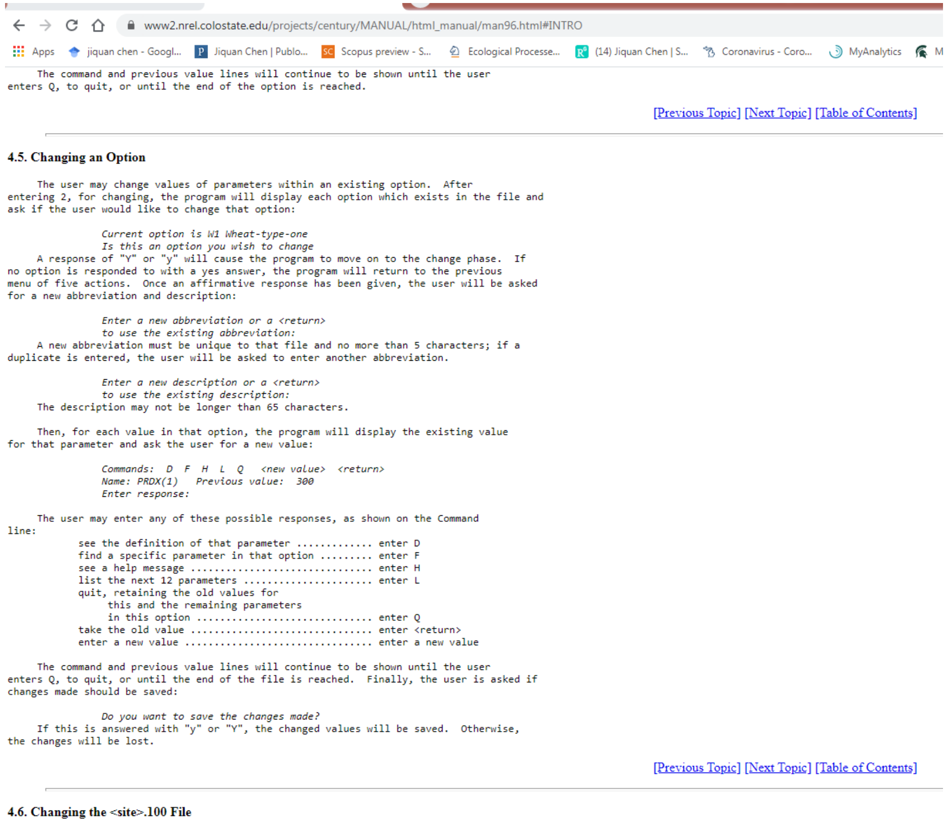
TNETMN(2) = Annual Net P Mineralization

TMINRL (2) = Total Soil Mineral P

SOMTE(2) = Total Soil Organic P

SOMSE(2) = SOM1E(2,2) + SOM2E(2) + SOM3E(2)

Open Source Codes



The command and previous value lines will continue to be shown until the user enters Q, to quit, or until the end of the option is reached.

[Previous Topic] [Next Topic] [Table of Contents]

4.5. Changing an Option

The user may change values of parameters within an existing option. After entering 2, for changing, the program will display each option which exists in the file and ask if the user would like to change that option:

```
          Current option is W1 Wheat-type-one
          Is this an option you wish to change
```

A response of "Y" or "y" will cause the program to move on to the change phase. If no option is responded to with a yes answer, the program will return to the previous menu of five actions. Once an affirmative response has been given, the user will be asked for a new abbreviation and description:

```
          Enter a new abbreviation or a <return>
          to use the existing abbreviation:
```

A new abbreviation must be unique to that file and no more than 5 characters; if a duplicate is entered, the user will be asked to enter another abbreviation.

```
          Enter a new description or a <return>
          to use the existing description:
```

The description may not be longer than 65 characters.

Then, for each value in that option, the program will display the existing value for that parameter and ask the user for a new value:

```
          Commands:  D  F  H  L  Q   <new value>  <return>
          Name: PRDX(1)   Previous value:  300
          Enter response:
```

The user may enter any of these possible responses, as shown on the Command line:

```
     see the definition of that parameter ............. enter D
     find a specific parameter in that option ......... enter F
     see a help message ............................... enter H
     list the next 12 parameters ...................... enter L
     quit, retaining the old values for
          this and the remaining parameters
          in this option .............................. enter Q
     take the old value ............................... enter <return>
     enter a new value ................................ enter a new value
```

The command and previous value lines will continue to be shown until the user enters Q, to quit, or until the end of the file is reached. Finally, the user is asked if changes made should be saved:

```
          Do you want to save the changes made?
```

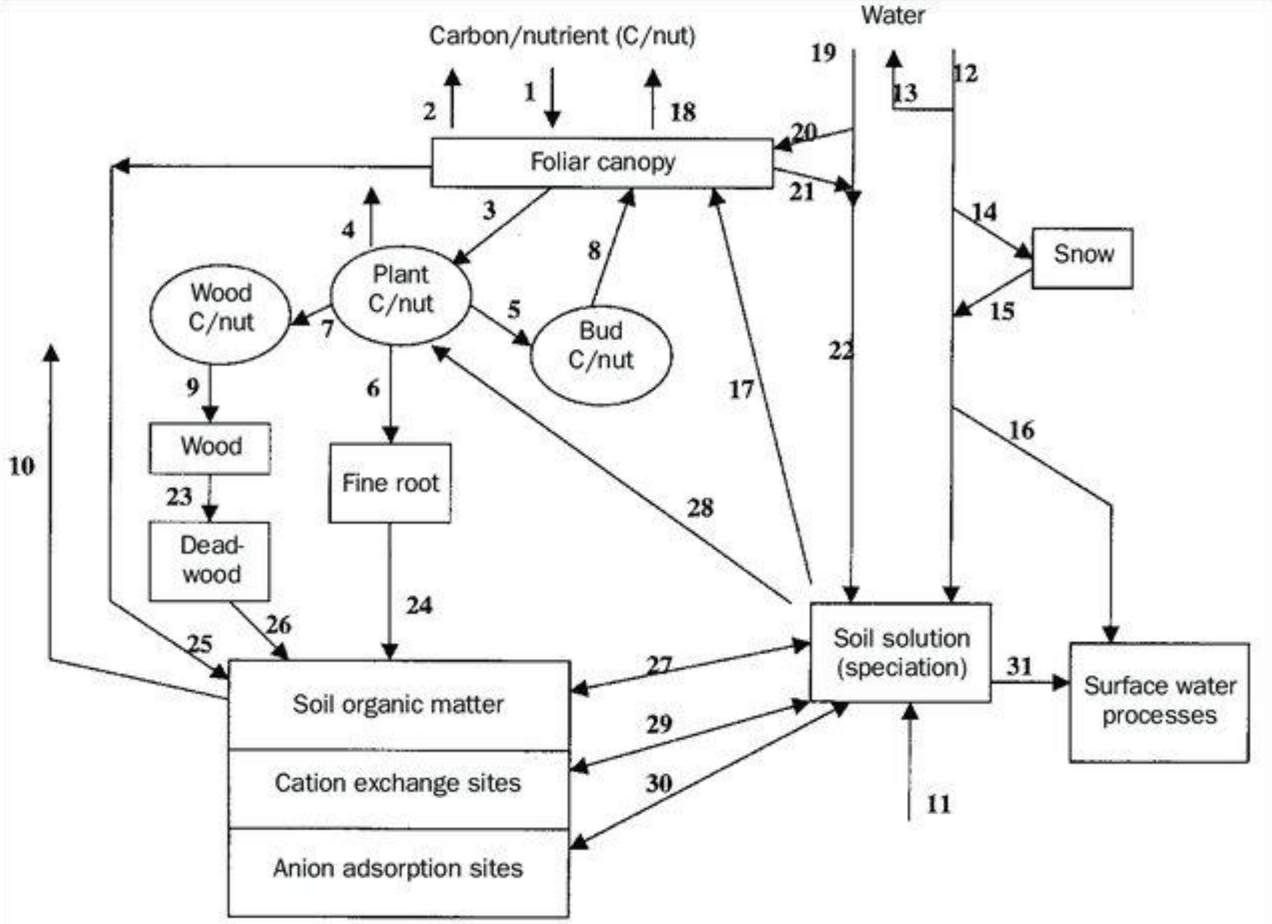
If this is answered with "y" or "Y", the changed values will be saved. Otherwise, the changes will be lost.

[Previous Topic] [Next Topic] [Table of Contents]

4.6. Changing the <site>.100 File

PnET is a suite of three nested computer **models** which provide a modular approach to simulating the carbon, water and nitrogen dynamics of forest **ecosystems**. (https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=817)

Aber, J.D., S.V. Ollinger, C.T. Driscoll, C.A. Federer, and P.B. Reich. 2005. PnET Models: Carbon, Nitrogen, Water Dynamics in Forest Ecosystems (Vers. 4 and 5). ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/817



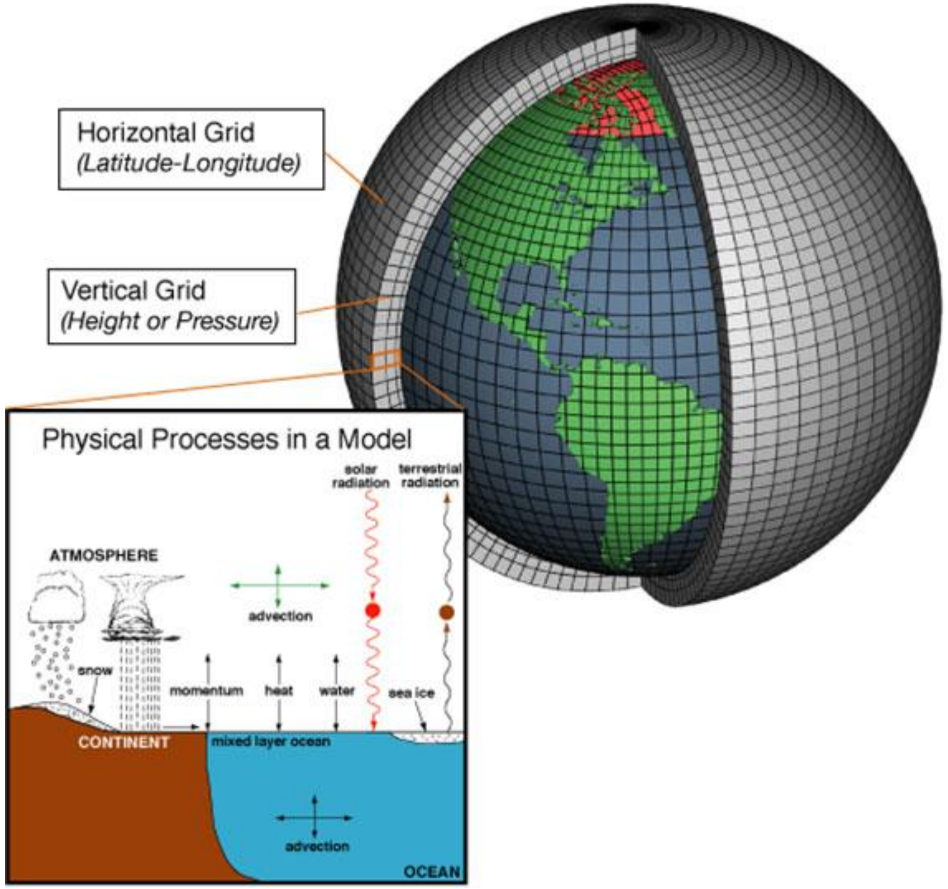
Processes depicted:

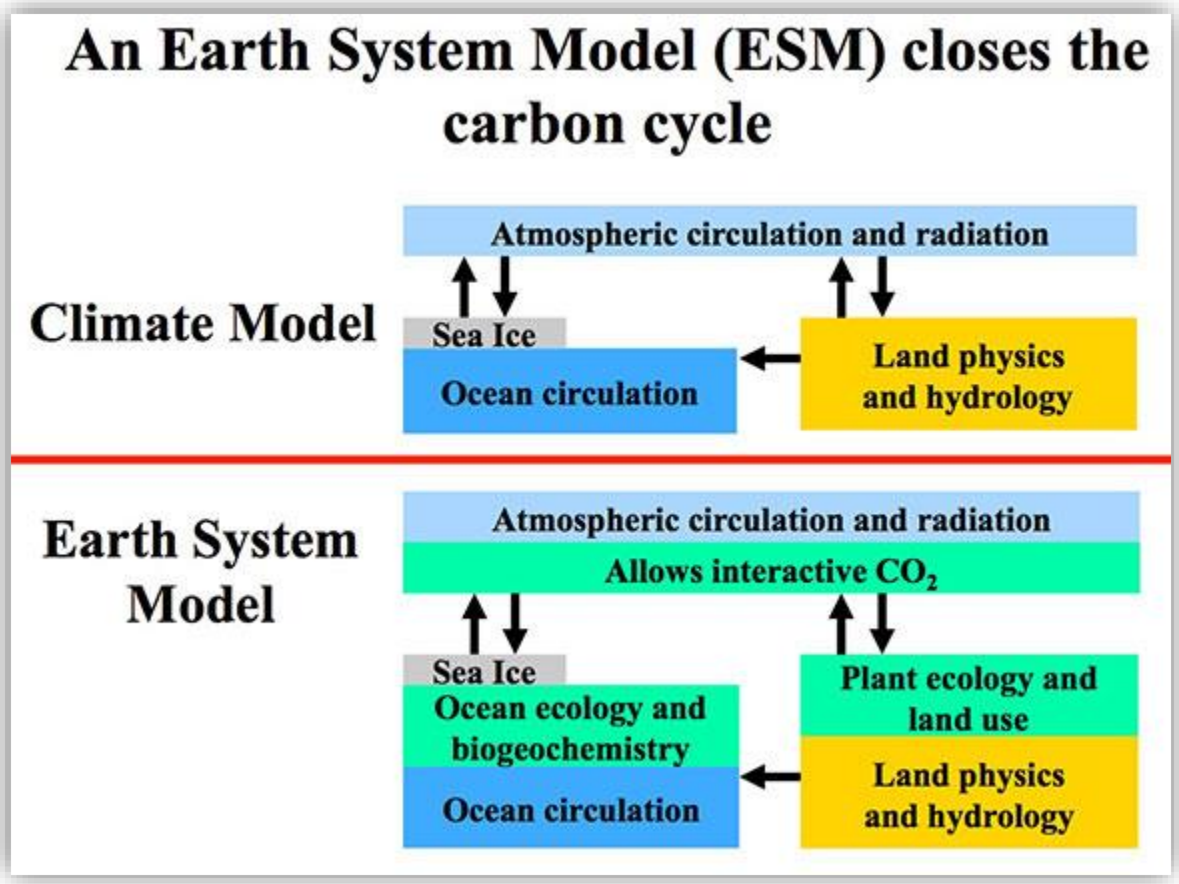
1. Gross photosynthesis
2. Foliar respiration
3. Transfer to mobile carbon
4. Growth and maintenance respiration
5. Allocation to buds
6. Allocation to fine roots
7. Allocation to wood
8. Foliar production
9. Wood production
10. Soil respiration
11. Weathering supply
12. Precipitation
13. Interception
14. Snow–rain partition
15. Snowmelt
16. Shallow flow
17. Water uptake
18. Transpiration
19. Deposition (wet and dry)
20. Foliar nutrient uptake
21. Foliar exudation
22. Throughfall and stemflow
23. Wood litter
24. Root litter
25. Foliar litter
26. Wood decay
27. Mineralization/immobilization
28. Nutrient uptake
29. Cation exchange reactions
30. Anion adsorption reactions
31. Drainage

https://www.researchgate.net/publication/232688300_Nor_Gloom_of_Night_A_New_Conceptual_Model_for_the_Hubbard_Brook_Ecosystem_Study/figures?lo=1

What is an Earth System Model (ESM)?

A coupled climate model is a computer code that estimates the solution to differential equations of fluid motion and thermodynamics to obtain time and space dependent values for temperature, winds and currents, moisture and/or salinity and pressure in the atmosphere and ocean. Components of a climate model simulate the atmosphere, the ocean, sea, ice, the land surface and the vegetation on land and the biogeochemistry of the ocean.
https://soccom.princeton.edu/content/what-earth-system-model-esm





An Earth System Model (ESM) closes the carbon cycle

Climate Model

Atmospheric circulation and radiation

Sea Ice

Ocean circulation

Land physics and hydrology

Earth System Model

Atmospheric circulation and radiation

Allows interactive CO_2

Sea Ice

Ocean ecology and biogeochemistry

Ocean circulation

Plant ecology and land use

Land physics and hydrology

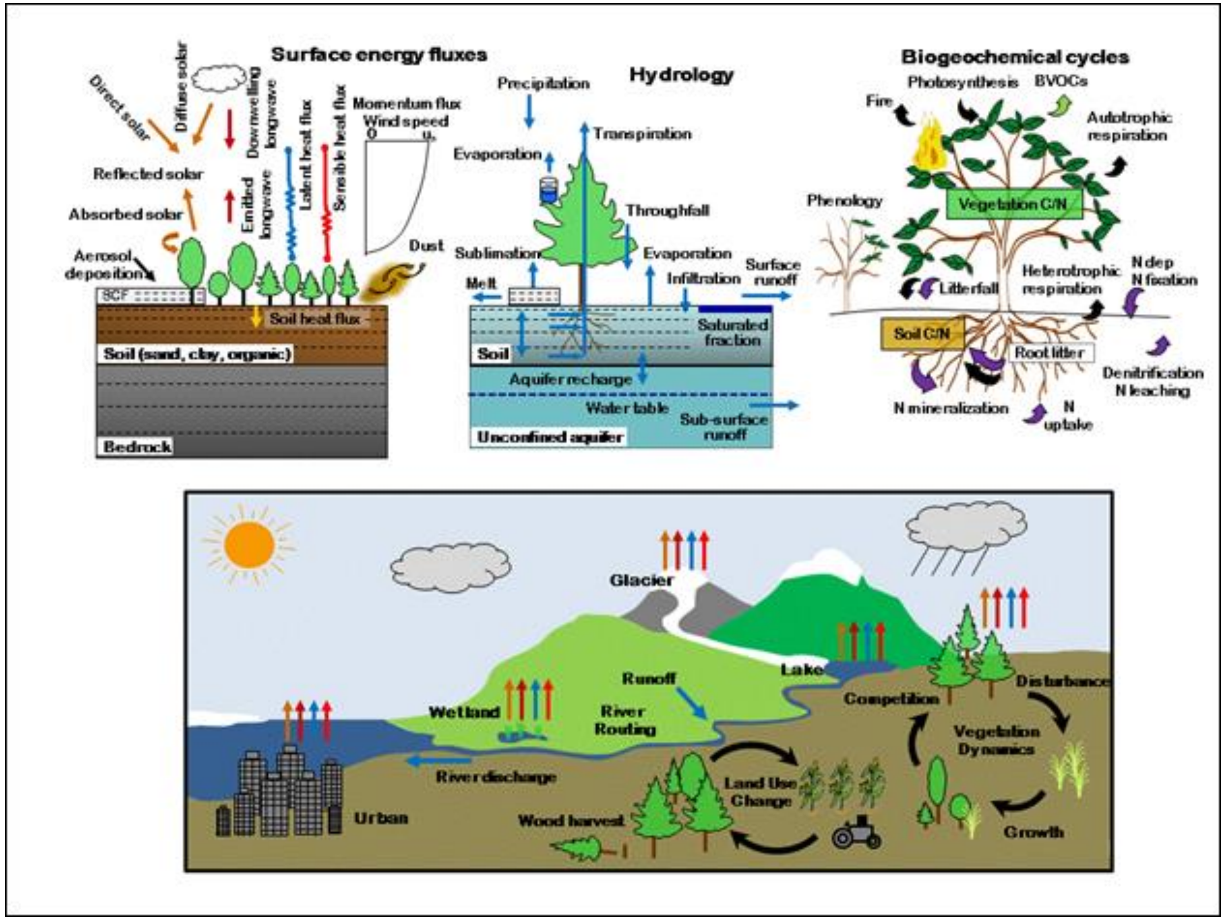
COMMUNITY LAND MODEL (CLM): the land model for the Community Earth System Model (CESM).

The model represents several aspects of the land surface including surface heterogeneity and consists of components or submodels related to land biogeophysics, the hydrologic cycle, biogeochemistry, human dimensions, and ecosystem dynamics. Specific processes that are represented include:

- Vegetation composition, structure, and phenology
- Absorption, reflection, and transmittance of solar radiation
- Absorption and emission of longwave radiation
- Momentum, sensible heat (ground and canopy), and latent heat (ground evaporation, canopy evaporation, transpiration) fluxes
- Heat transfer in soil and snow including phase change
- Canopy hydrology (interception, throughfall, and drip)
- Snow hydrology (snow accumulation and melt, compaction, water transfer between snow layers)
- Soil hydrology (surface runoff, infiltration, redistribution of water within the column, sub-surface drainage, groundwater)
- Plant hydrodynamics
- Stomatal physiology and photosynthesis
- Lake temperatures and fluxes
- Dust deposition and fluxes
- Routing of runoff from rivers to ocean
- Volatile organic compounds emissions
- Urban energy balance and climate
- Carbon-nitrogen cycling
- Dynamic landcover change
- Land management including crops and crop management and wood harvest
- Ecosystem Demography (FATES, optional)

Need a supercomputer to run!

http://www.cesm.ucar.edu/models/clm/



Schaefer, K., Schwalm, C. R., Williams, C., Arain, M. A., Barr, A., Chen, J. M., ... & Humphreys, E. (2012). A model-data comparison of gross primary productivity: Results from the North American Carbon Program site synthesis. *Journal of Geophysical Research: Biogeosciences*, *117*(G3).

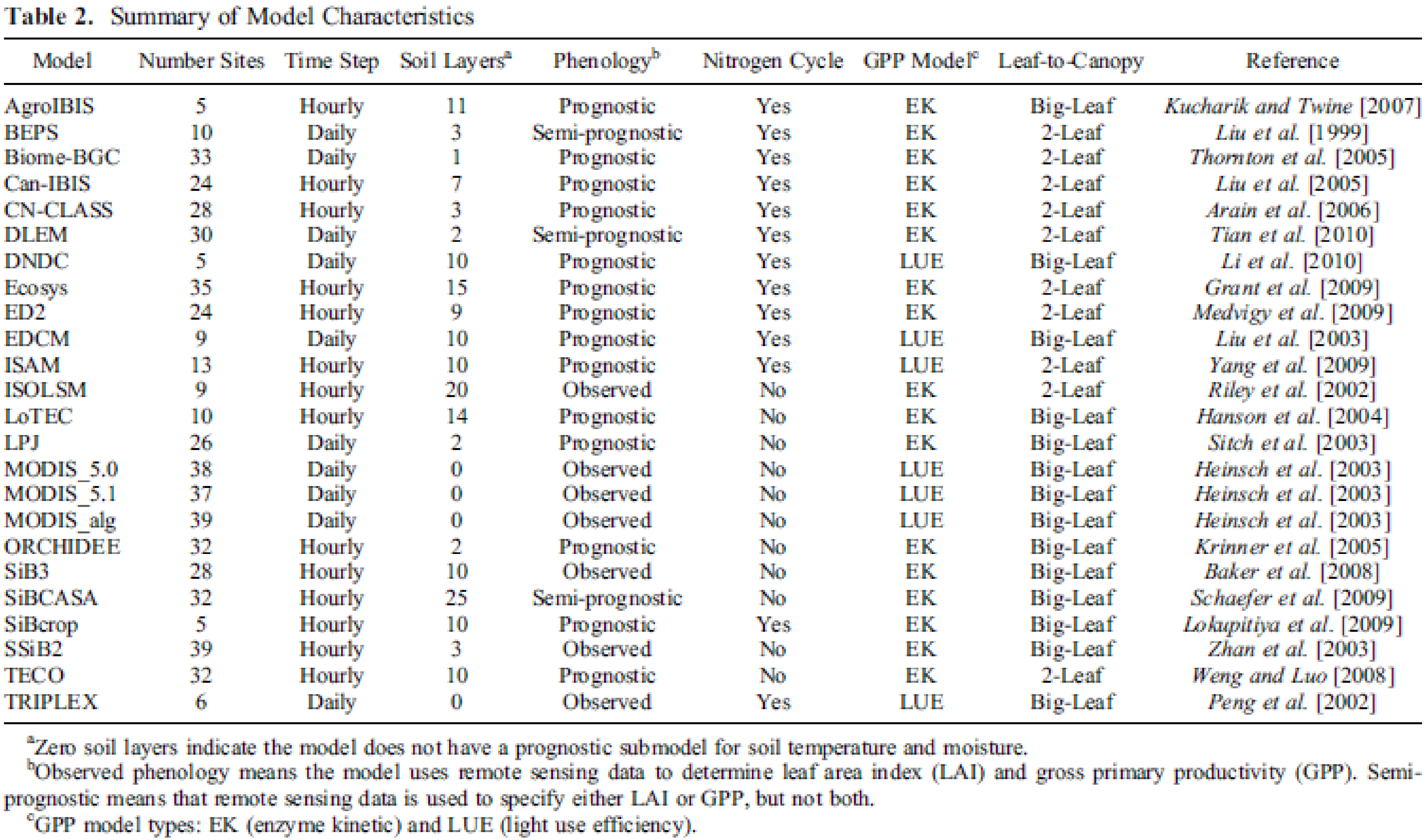


Table 2. Summary of Model Characteristics

Model	Number Sites	Time Step	Soil Layers[a]	Phenology[b]	Nitrogen Cycle	GPP Model[c]	Leaf-to-Canopy	Reference
AgroIBIS	5	Hourly	11	Prognostic	Yes	EK	Big-Leaf	*Kucharik and Twine* [2007]
BEPS	10	Daily	3	Semi-prognostic	Yes	EK	2-Leaf	*Liu et al.* [1999]
Biome-BGC	33	Daily	1	Prognostic	Yes	EK	2-Leaf	*Thornton et al.* [2005]
Can-IBIS	24	Hourly	7	Prognostic	Yes	EK	2-Leaf	*Liu et al.* [2005]
CN-CLASS	28	Hourly	3	Prognostic	Yes	EK	2-Leaf	*Arain et al.* [2006]
DLEM	30	Daily	2	Semi-prognostic	Yes	EK	2-Leaf	*Tian et al.* [2010]
DNDC	5	Daily	10	Prognostic	Yes	LUE	Big-Leaf	*Li et al.* [2010]
Ecosys	35	Hourly	15	Prognostic	Yes	EK	2-Leaf	*Grant et al.* [2009]
ED2	24	Hourly	9	Prognostic	Yes	EK	2-Leaf	*Medvigy et al.* [2009]
EDCM	9	Daily	10	Prognostic	Yes	LUE	Big-Leaf	*Liu et al.* [2003]
ISAM	13	Hourly	10	Prognostic	Yes	LUE	2-Leaf	*Yang et al.* [2009]
ISOLSM	9	Hourly	20	Observed	No	EK	2-Leaf	*Riley et al.* [2002]
LoTEC	10	Hourly	14	Prognostic	No	EK	Big-Leaf	*Hanson et al.* [2004]
LPJ	26	Daily	2	Prognostic	No	EK	Big-Leaf	*Sitch et al.* [2003]
MODIS_5.0	38	Daily	0	Observed	No	LUE	Big-Leaf	*Heinsch et al.* [2003]
MODIS_5.1	37	Daily	0	Observed	No	LUE	Big-Leaf	*Heinsch et al.* [2003]
MODIS_alg	39	Daily	0	Observed	No	LUE	Big-Leaf	*Heinsch et al.* [2003]
ORCHIDEE	32	Hourly	2	Prognostic	No	EK	Big-Leaf	*Krinner et al.* [2005]
SiB3	28	Hourly	10	Observed	No	EK	Big-Leaf	*Baker et al.* [2008]
SiBCASA	32	Hourly	25	Semi-prognostic	No	EK	Big-Leaf	*Schaefer et al.* [2009]
SiBcrop	5	Hourly	10	Prognostic	Yes	EK	Big-Leaf	*Lokupitiya et al.* [2009]
SSiB2	39	Hourly	3	Observed	No	EK	Big-Leaf	*Zhan et al.* [2003]
TECO	32	Hourly	10	Prognostic	No	EK	2-Leaf	*Weng and Luo* [2008]
TRIPLEX	6	Daily	0	Observed	Yes	LUE	Big-Leaf	*Peng et al.* [2002]

[a] Zero soil layers indicate the model does not have a prognostic submodel for soil temperature and moisture.

[b] Observed phenology means the model uses remote sensing data to determine leaf area index (LAI) and gross primary productivity (GPP). Semi-prognostic means that remote sensing data is used to specify either LAI or GPP, but not both.

[c] GPP model types: EK (enzyme kinetic) and LUE (light use efficiency).

4. Conclusions

[42] None of the models in this study match estimated GPP within the range of uncertainty of observed fluxes. On average, the models achieved good performance for only 12% of the simulations. Two models achieved overall marginal performance, matching estimated GPP within roughly two times the uncertainty. Our first hypothesis proved false: we found no statistically significant differences in performance due to model structure, mainly due to the large spread in performance among models and across sites. The models in our study reproduced the observed seasonal pattern with little or no GPP in winter and peak GPP in summer, but did not capture the observed GPP magnitude. We found, on average, that models overestimated GPP in spring and fall and underestimated GPP in summer. Our second hypothesis proved true: model performance depended on how models represented the GPP response to changing environmental conditions. We identified three areas of model improvement: simulated LUE, low temperature response function, and GPP response under dry conditions.

[43] The poor overall model performance resulted primarily from inadequate representation of observed LUE. Simulated LUE is controlled by the leaf-to-canopy scaling strategy and a small set of model parameters that define the maximum potential GPP, such as $\varepsilon_{\max}$ (light use efficiency), V_{cmax} (unstressed Rubisco catalytic capacity) or $J_{\max}$ (the maximum electron transport rate). The temperature, humidity, and drought scaling factors determined temporal variability in simulated GPP, but the LUE parameters determined the magnitude of simulated GPP. To improve simulated GPP, model developers should focus first on improving the leaf-to-canopy scaling and the values of those model parameters that control the LUE.

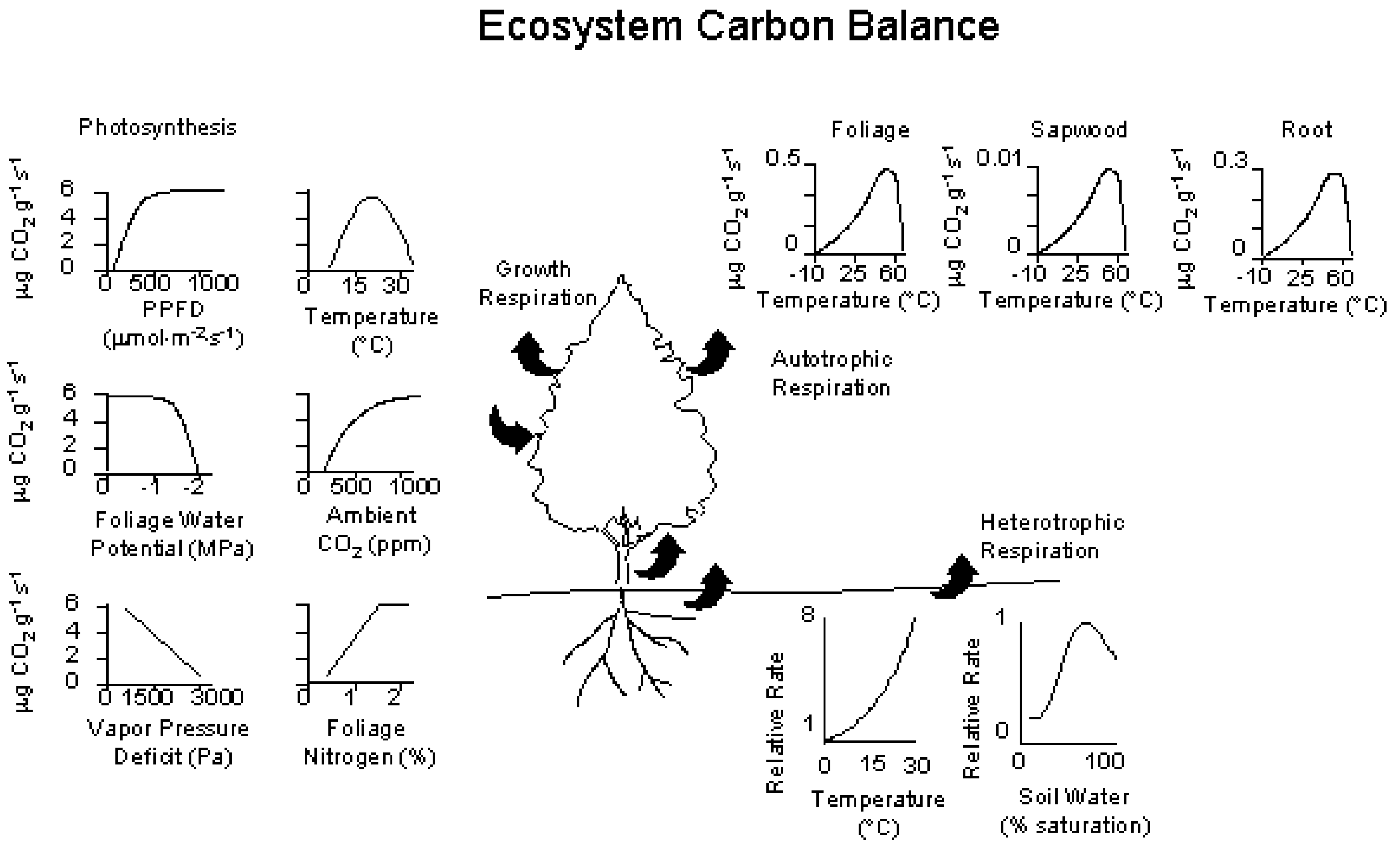
[44] Many models overpredicted GPP under dry conditions, explaining why, on average, models performed worse at grassland and savanna sites than at forest sites. The importance of this to model performance increases at sites where drier conditions occur more frequently. Since dry conditions occur more frequently at grassland and savanna sites than at forest sites, models tended to perform worse at grassland and savanna sites compared to forest sites. Improving how models simulate soil moisture, drought stress, or humidity stress can improve simulated GPP under dry conditions.

[45] Many models overpredicted GPP under cold conditions, partly explaining the positive bias in simulated GPP in winter, spring, and fall. The estimated GPP completely shut down for daily average temperatures less than -6°C, but the Q_{10} formulation used by many models did not shut down GPP under cold or frozen conditions. The simulated GPP started too early in spring and persisted too late in fall, resulting in a positive bias and phasing errors in phenology. Using an ensemble mean can cancel out errors in phenology, but does not cancel out bias. Improving or imposing a low temperature inhibition function in the GPP model will resolve the problem.

Good News

Now there are a variety of system models that predict the magnitudes and dynamics of ecosystem properties. Each of these models was carefully constructed with sound algorithms from meteorological, hydrological, ecological, biogeochemical, and/or statistical principles. As a result, they are complex in terms of the number of processes factored, as well as regarding the inter-connections among the processes. Understanding and applying these models are not easy due to their complexity. Fortunately, almost all ecosystem models were developed with a few common algorithms. For example, Farquhar's photosynthesis equation, the Ball–Berry stomatal conductance algorithm, Michaelis–Menten kinetics, temperature-dependent respiration in the form of Q10, and energy balance are widely used. This book is designed to describe and explain the major biophysical and empirical modules that have been used in ecosystem models. Understanding these fundamental algorithms will speed up the application of system models. For model developers, knowledge about each of the crucial modules, including their varieties, behaviors and parameterization, model performances, and their strengths and limitations, is essential to improving and advancing their work. For example, a simple Q10 algorithm based on exponential equation (Chapter 3) has been widely used in many ecosystem models for calculating respiration, yet there are many other forms that may provide more realistic predictions, albeit requiring different sets of parameters. (Chen 2020, Preface)

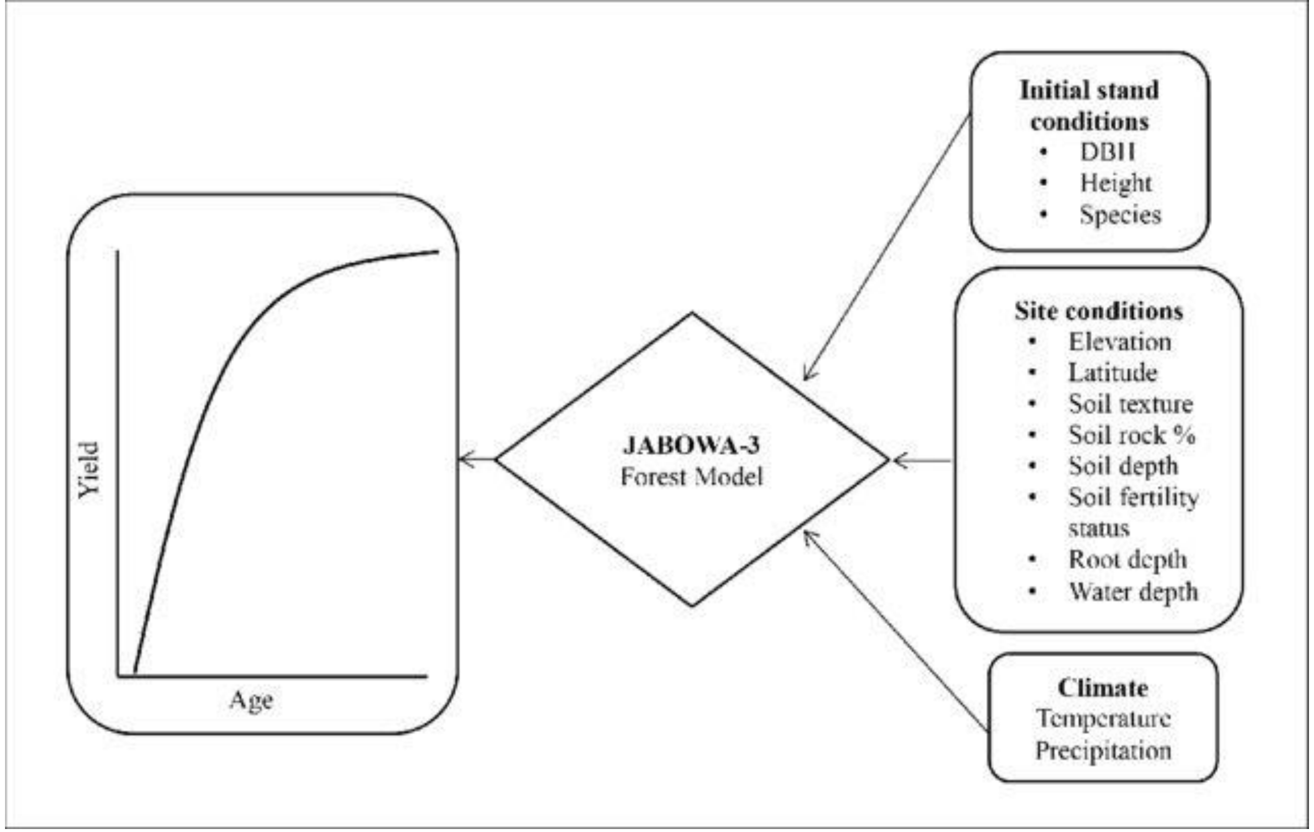
Community Land Model (CML)

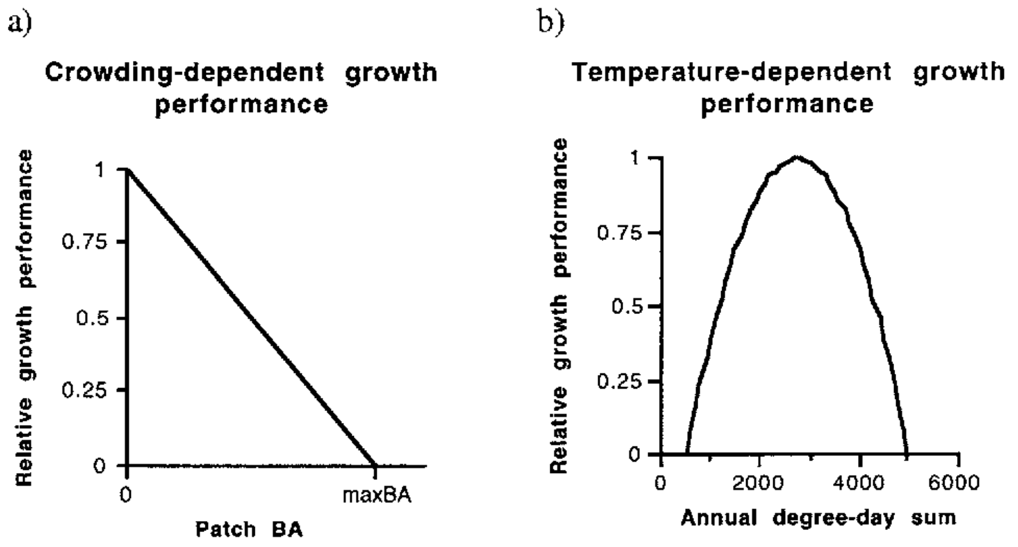


Copyright Bonan, G.B. (2002) Ecological Climatology: Concepts and Applications. Cambridge University Press, Cambridge

Computer Era models

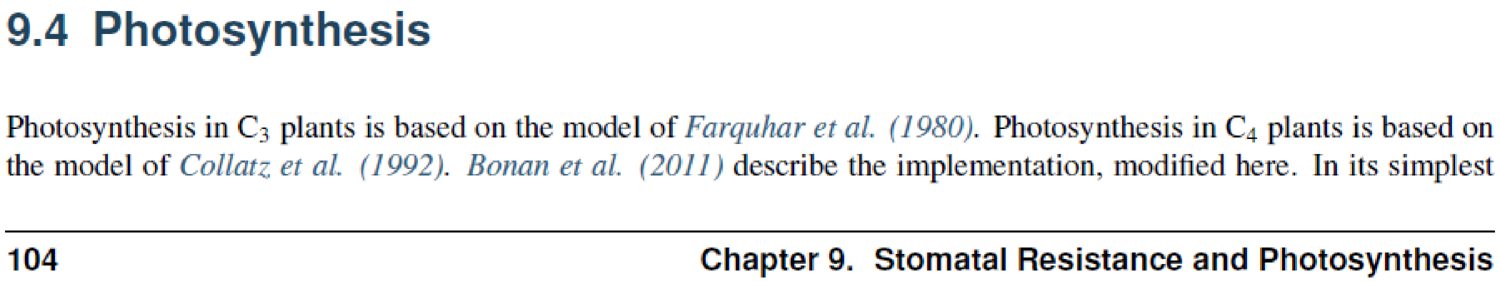
- Increasing number of variables
- Mostly empirical relationships
- Climatic, soil, disturbances, management as regulations included
- Interactions among components (e.g., species, soil-plants) are considered
- Example: JOBAWA, FORET models (a.k.a. GAP models)





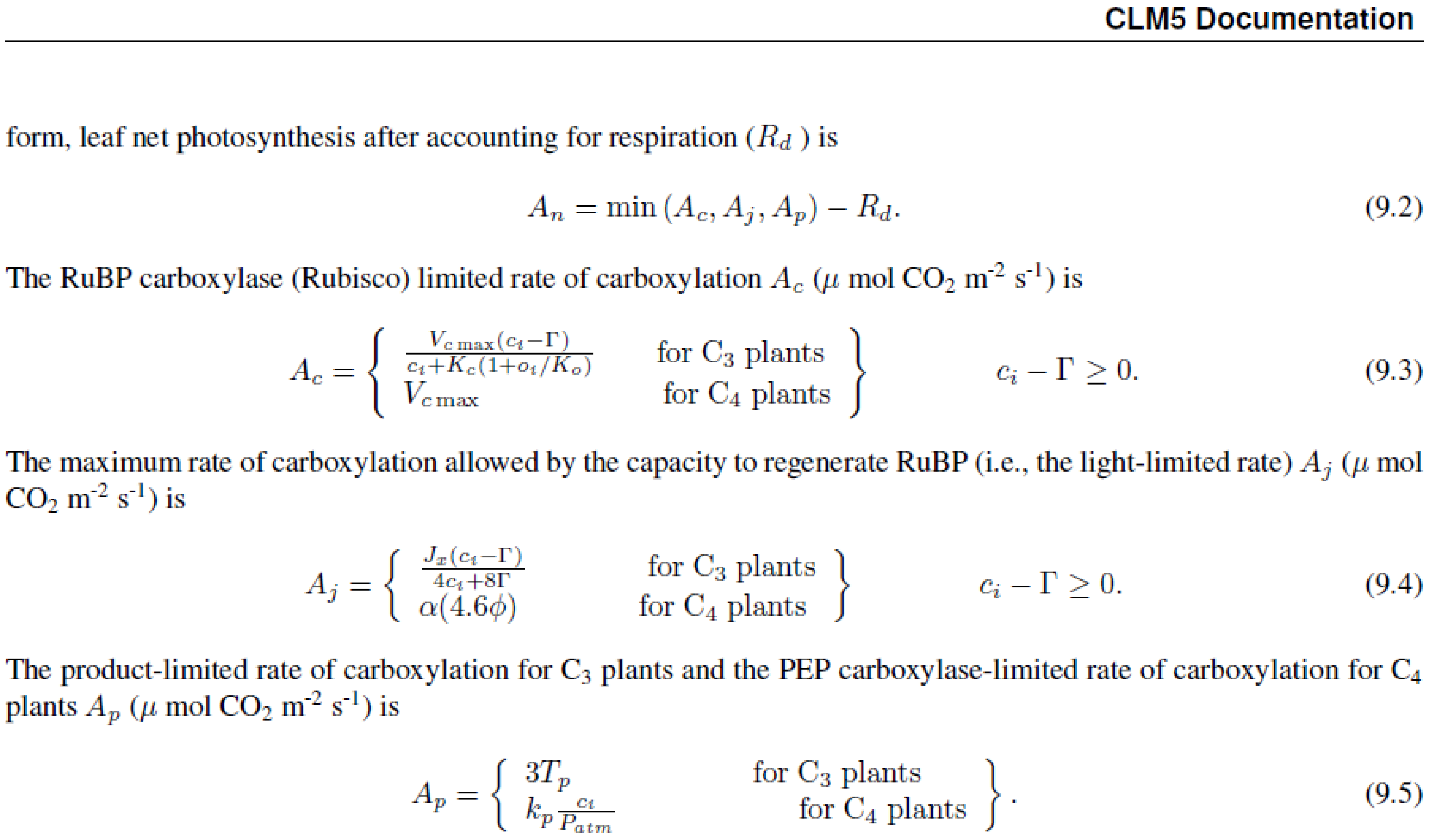
Ashraf, M. I., Bourque, C. P. A., MacLean, D. A., Erdle, T., & Meng, F. R. (2012). Using JABOWA-3 for forest growth and yield predictions under diverse forest conditions of Nova Scotia, Canada. *The Forestry Chronicle*, *88*(6), 708-721.

CLM5 Documentation
Feb 12, 2019



9.4 Photosynthesis

Photosynthesis in C_3 plants is based on the model of *Farquhar et al. (1980)*. Photosynthesis in C_4 plants is based on the model of *Collatz et al. (1992)*. *Bonan et al. (2011)* describe the implementation, modified here. In its simplest



form, leaf net photosynthesis after accounting for respiration (R_d) is

$$A_n = \min\left(A_c, A_j, A_p\right) - R_d. \tag{9.2}$$

The RuBP carboxylase (Rubisco) limited rate of carboxylation A_c (μ mol CO_2 m^{-2} s^{-1}) is

$$A_c = \left\{ \begin{array}{ll} \frac{V_{c\max}(c_i-\Gamma)}{c_i+K_c(1+o_i/K_o)} & \text{for } C_3 \text{ plants} \\ V_{c\max} & \text{for } C_4 \text{ plants} \end{array} \right\} \qquad c_i - \Gamma \geq 0. \tag{9.3}$$

The maximum rate of carboxylation allowed by the capacity to regenerate RuBP (i.e., the light-limited rate) A_j (μ mol CO_2 m^{-2} s^{-1}) is

$$A_j = \left\{ \begin{array}{ll} \frac{J_x(c_i-\Gamma)}{4c_i+8\Gamma} & \text{for } C_3 \text{ plants} \\ \alpha(4.6\phi) & \text{for } C_4 \text{ plants} \end{array} \right\} \qquad c_i - \Gamma \geq 0. \tag{9.4}$$

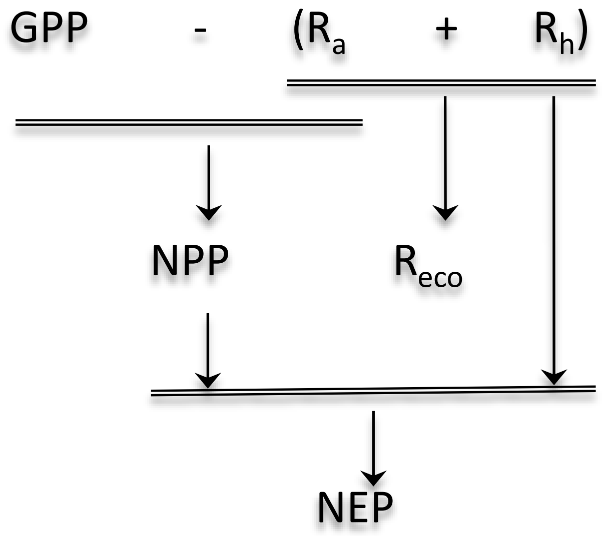
The product-limited rate of carboxylation for C_3 plants and the PEP carboxylase-limited rate of carboxylation for C_4 plants A_p (μ mol CO_2 m^{-2} s^{-1}) is

$$A_p = \left\{ \begin{array}{ll} 3T_p & \text{for } C_3 \text{ plants} \\ k_p \frac{c_i}{P_{atm}} & \text{for } C_4 \text{ plants} \end{array} \right\}. \tag{9.5}$$

For example

1) Michaelis-Menten kinetics for photosynthesis (GPP)

$$P_n = \frac{\alpha \cdot PAR \cdot P_m}{\alpha \cdot PAR + P_m} - R_d \qquad [2.2]$$



GPP - (R_a + R_h)

NPP

R_{eco}

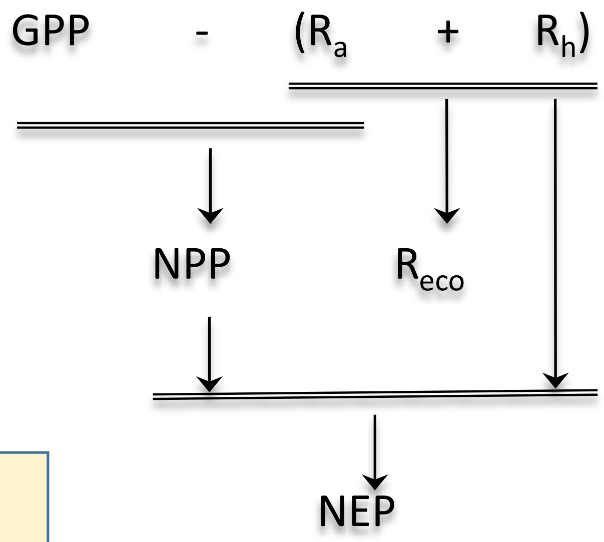
NEP

But with different varieties

$$P_n = \frac{1}{2 \cdot \beta}\left(\alpha \cdot PAR + P_m - \sqrt{(\alpha \cdot PAR + P_m)^2 - 4 \cdot \alpha \cdot PAR \cdot P_m \cdot \beta} \right) \qquad [2.4]$$

Chen, J. 2021. *Biophysical Models and Applications in Ecosystem Analysis*. East Lansing: Michigan State University Press. doi:10.14321/j.ctv1h1vc27

2) Q10 model for carbon loss (R_a, R_h, R_{eco}) in many models



The Q_{10} model (Van’t Hoff 1898):

$$Q_{10} = \left(\frac{R_2}{R_1}\right)^{\left(\frac{10}{T_2 - T_1}\right)}$$

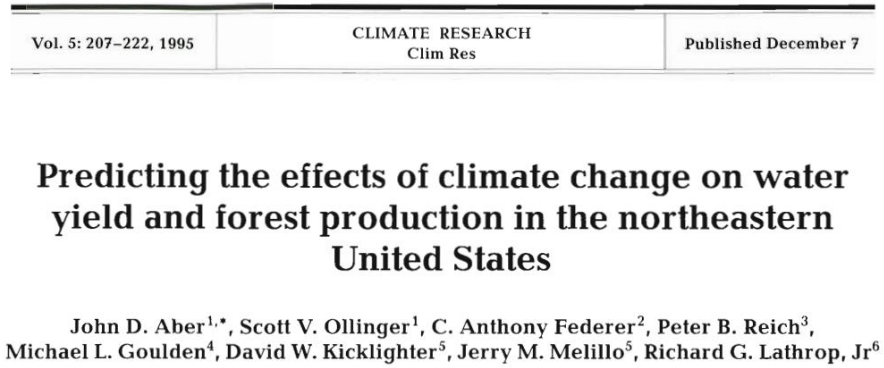
Brief history
Principles
Strengths/weakness
Model demonstrations
…

But also with different varieties

$$R = R_0 \cdot \; e^{\beta_0 \cdot T} \cdot \; e^{\beta_1 \cdot \theta} \cdot \beta_2 \cdot T \cdot \; \theta \qquad [3.17]$$

Chen, J. 2021. *Biophysical Models and Applications in Ecosystem Analysis*. East Lansing: Michigan State University Press. doi:10.14321/j.ctv1h1vc27

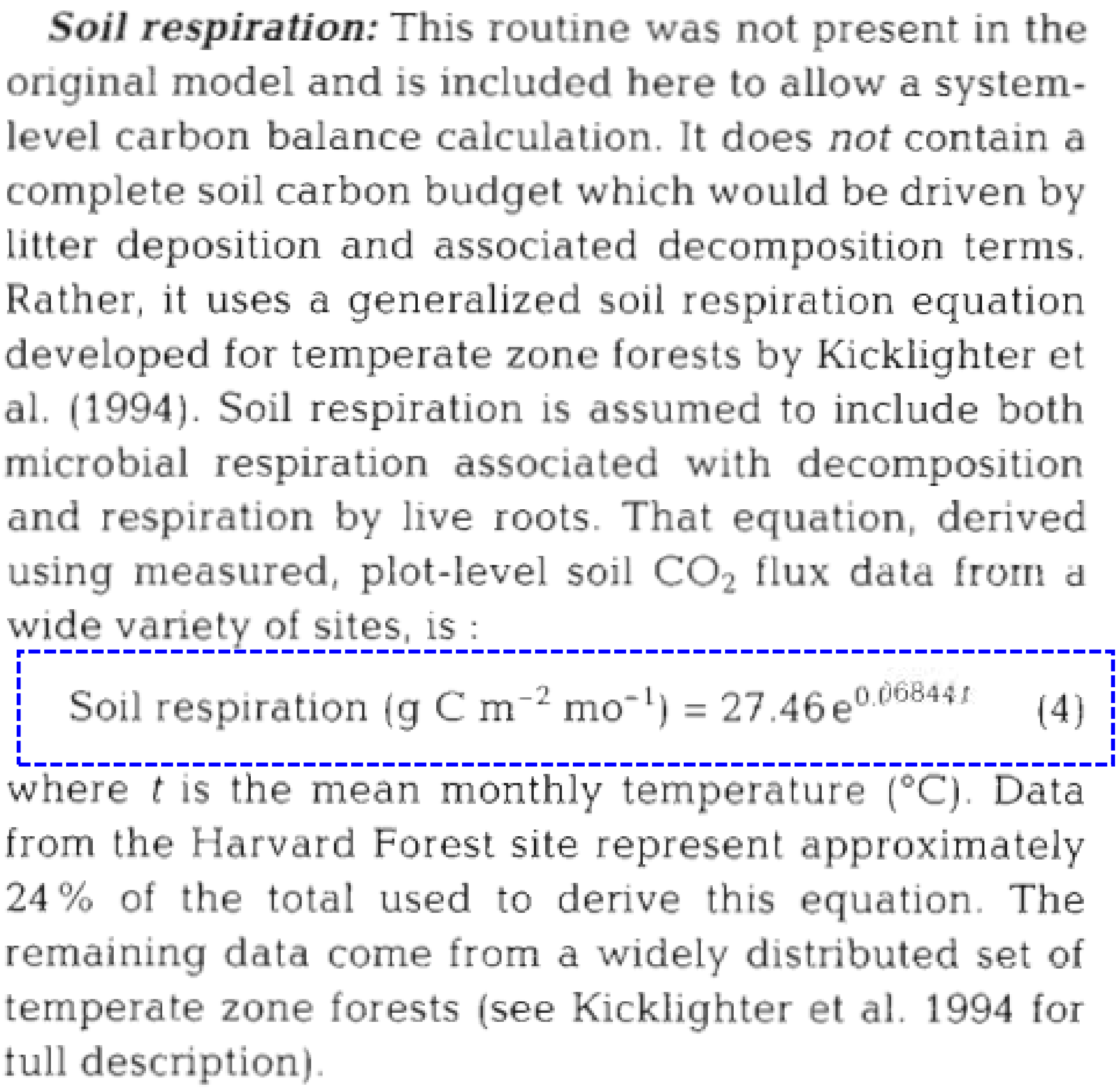
PnET-II model



Vol. 5: 207–222, 1995 | CLIMATE RESEARCH
Clim Res | Published December 7

Predicting the effects of climate change on water yield and forest production in the northeastern United States

John D. Aber[1,*], Scott V. Ollinger[1], C. Anthony Federer[2], Peter B. Reich[3], Michael L. Goulden[4], David W. Kicklighter[5], Jerry M. Melillo[5], Richard G. Lathrop, Jr[6]



Soil respiration: This routine was not present in the original model and is included here to allow a system-level carbon balance calculation. It does *not* contain a complete soil carbon budget which would be driven by litter deposition and associated decomposition terms. Rather, it uses a generalized soil respiration equation developed for temperate zone forests by Kicklighter et al. (1994). Soil respiration is assumed to include both microbial respiration associated with decomposition and respiration by live roots. That equation, derived using measured, plot-level soil CO_2 flux data from a wide variety of sites, is :

$$\text{Soil respiration } (\text{g C m}^{-2}\text{ mo}^{-1}) = 27.46\,e^{0.06844t} \qquad (4)$$

where *t* is the mean monthly temperature (°C). Data from the Harvard Forest site represent approximately 24% of the total used to derive this equation. The remaining data come from a widely distributed set of temperate zone forests (see Kicklighter et al. 1994 for full description).

AI technology and ESMs (Chen 2023)

- ChatGPT in November 2022
- AlphaGo won the first- ever game against a human professional Go player in 2015

Sun and colleagues recently looked into whether ML tools could be good alternatives of conventional ESMs for predicting the functions of terrestrial ecosystems (Sun et al., 2023). In their pioneering work, they applied the same input variables (27) to three versions of ORCHIDEE (i.e., a major ESM) and Baggin decision trees (i.e., a ML tool) for predicting terrestrial carbon, nitrogen, and phosphorous at global scale. They demonstrated that ML reduced the computing demand by 78– 80% while maintaining similar or even more accurate predictions than ORCHIDEEs. Such reductions are substantial, though computing power soon may no longer be a bottleneck hindering ESM runs due to rapid advancements in computing technology. An equally important finding in the Sun et al. study relates to the contributions of input variables for predicting carbon, nitrogen, and phosphorus production. It was especially interesting to see that ML only required a small number of input variables (20– 25) compared to a similar number of input variables to reach better accuracy in predictions using ORCHIDEE for different components of carbon, nitrogen, and phosphorus (figures 2– 4, respectively, in Sun et al., 2023).

Sun, Y., Goll, D. S., Huang, Y., Ciais, P., Wang, Y.- P., Bastrikov, V., & Wang, Y. (2023). Machine learning for accelerating process- based computation of land biogeochemical cycles. Global Change Biology, 1– 14. https://doi.org/10.1111/gcb.16623

Machine Learning in flux studies?

Speech Recognition

Human **expertise** does not exist

Personalized Medicine

Models must be **customized**

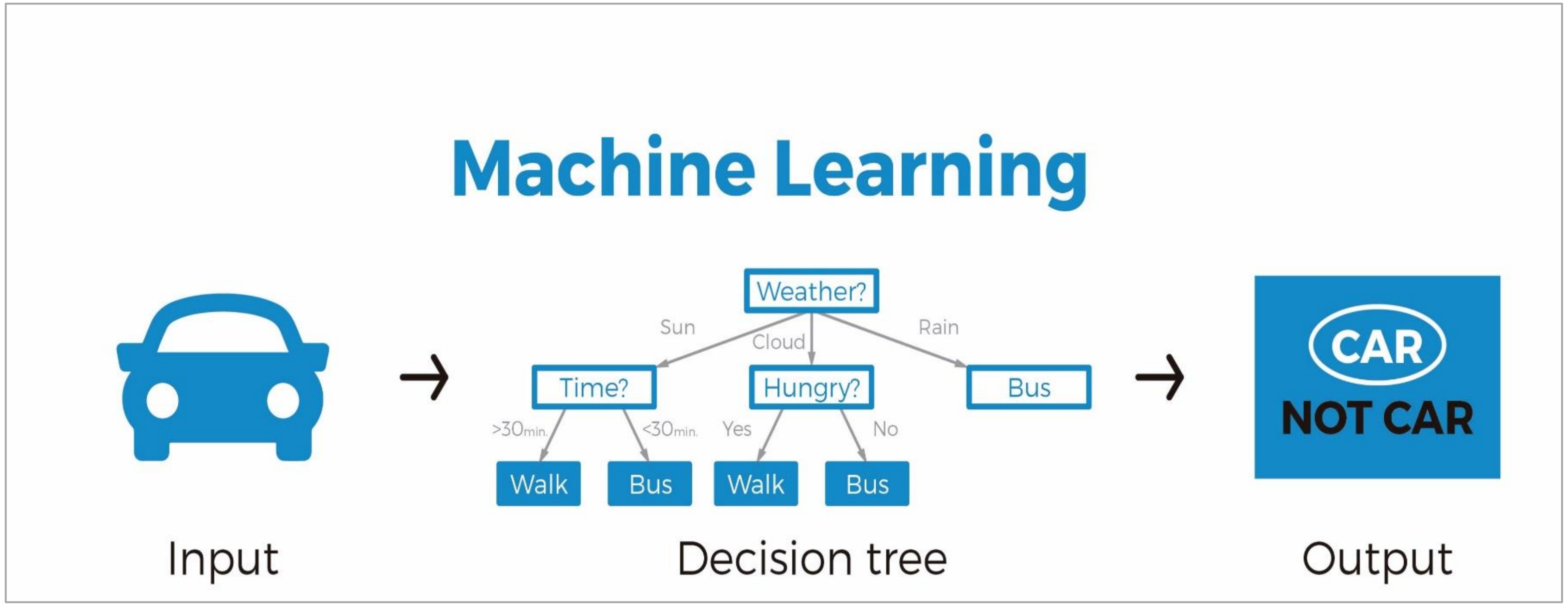
Genomics

Huge amounts of data

Credit: Dr. Jiliang Tang


ChatGPT
Crash Course
ME
How do I... as a beginne
Capabilities
Limitatio
"Expla
g in
im
Remembers what user said earlier in the conversation
May occa
in
"Got any creative ideas for a 10
Allows user to provide follow-up
May occasionally p

Deep Learning vs Traditional Machine Learning

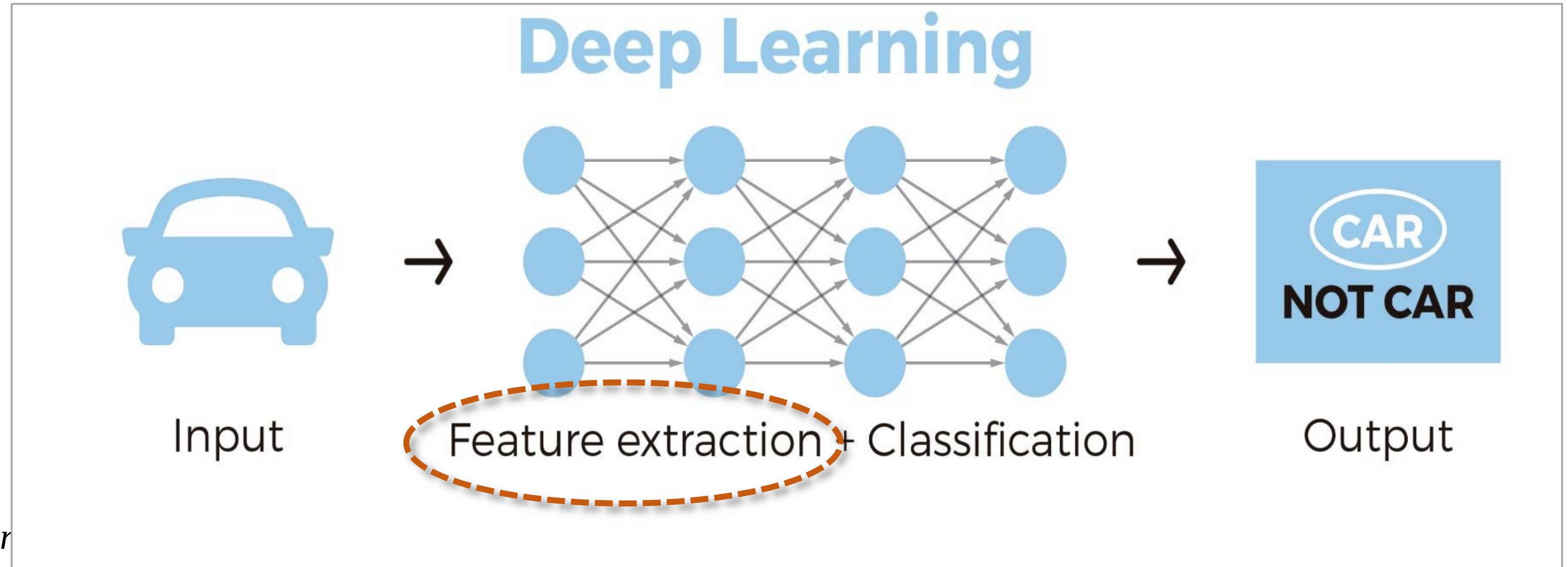


Common Knowledge

In flux studies

Ta, VPD, Ms, PAR, Rn, DOY, G, Ts, …

Fc



Partial knowns & unknowns

In flux studies

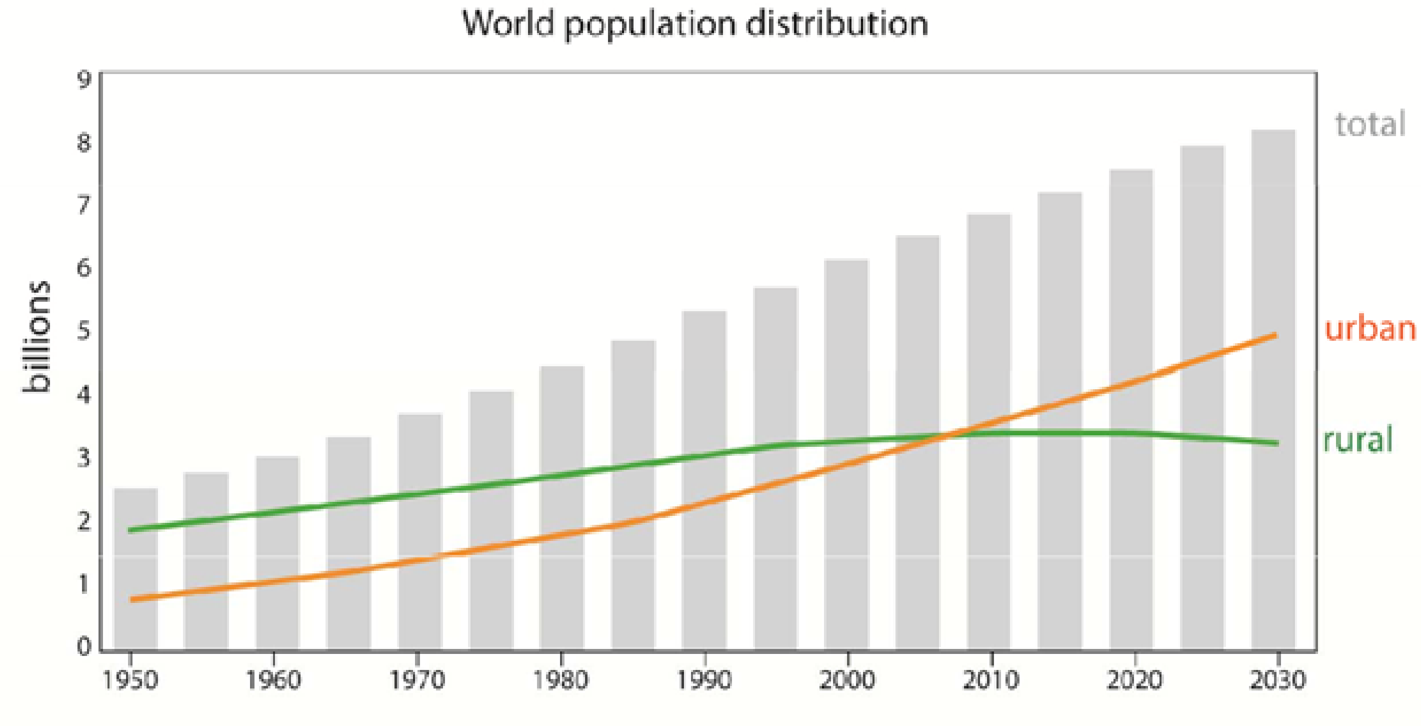
WD, WS, U*, CO_2, RH, …

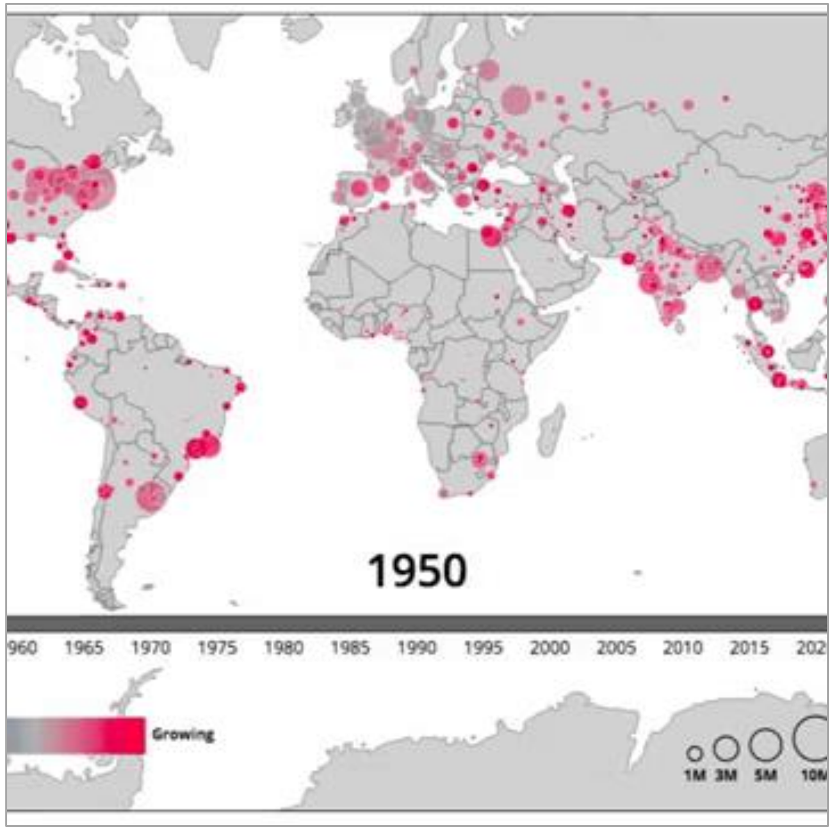
Fc

Cr

Complex Interconnections: Urbanization

By 2050, ~70% people will live in urban!



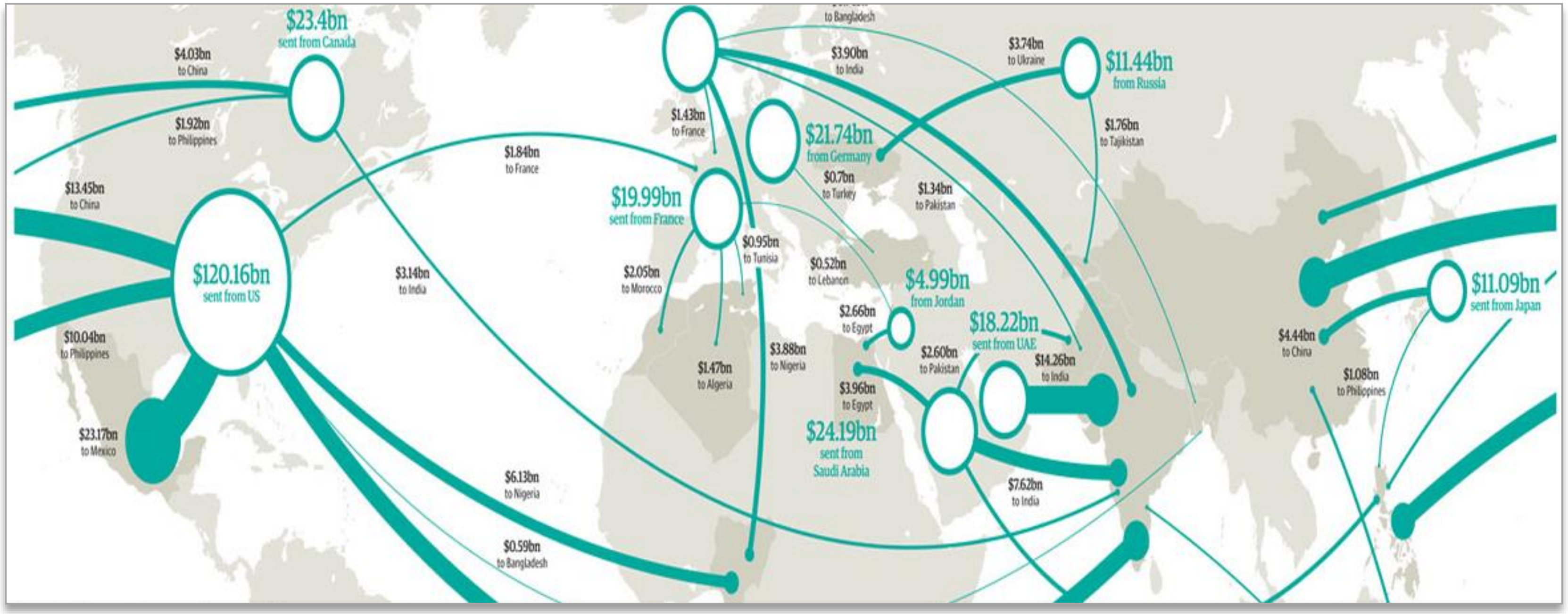


https://www.mathematica.org/commentary/global-urbanization

Sharemoney Blog

Global Remittances: another complexity

“The planet has undoubtedly ‘gotten smaller’, thanks to the amazing influence of the internet and a host of other technological advances. These changes leave us not only with more ways to communicate long distances, to send money remittance and to travel; they also give us more interest in foreign cultures and more opportunity to work remotely.”



https://blog.sharemoney.com/wheres-my-money-incredible-infographic-of-global-remittances/

Global Remittance: another complexity

- In many developing economies, workers migrate from rural to urbans in search of gainful employment.
- Labor migrants often remit a portion of their earnings to their families back home – global impacts.
- The top five recipients of remittances relative to GDP were Nepal, Liberia, Tajikistan, Kyrgyzstan, & Bermuda, comprising 32.2%, 31.2%, 28.8%, 25.7%, and 25.0% of their GDP.
- Global remittances in 2015 were >$210 billion; it reached $529 billion in 2018 and $550 billion in 2019. This is >3 times of Kaz GDP in 2019 ($170 billion)
- Global remittances are projected to decline sharply by 20% in 2020, due to the economic crisis induced by the **COVID-19** pandemic and shutdown.

https://migrationdataportal.org/themes/remittances

Complex Interconnections: Corona Virus

Free trial is for new customers only. Restrictions apply.

ENVIRONMENTAL JUSTICE

China's Air Pollution Is Now Worse Than Pre-Coronavirus Levels

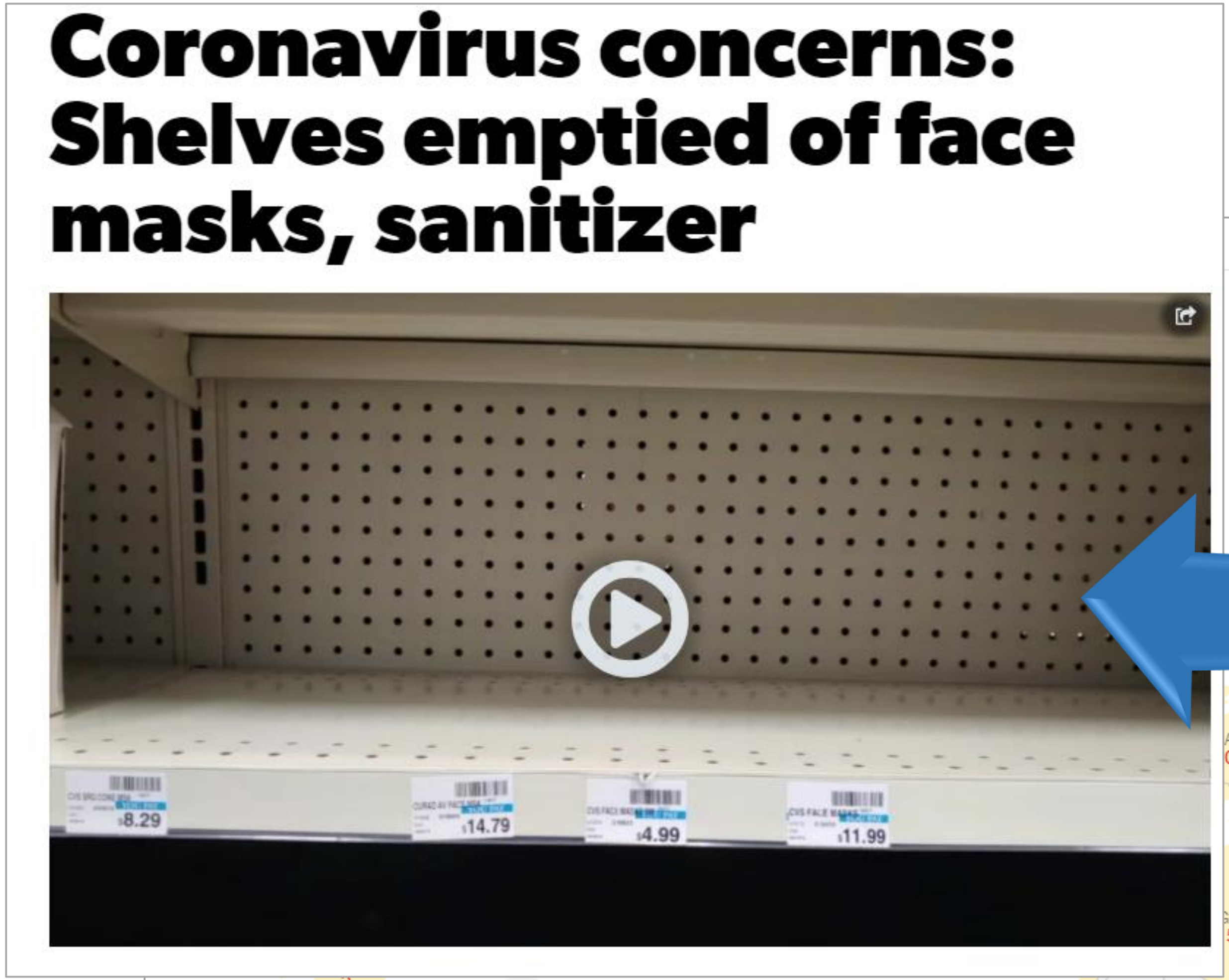
Yessenia Funes
5/18/20 11:30AM • Filed to: COVID-19

Photo: AP

Game of Thrones | HBO
Friends
Wonder Woman
WHERE HBO MEETS SO MUCH MORE
HBOmax
START FREE TRIAL ›
Free trial is for new customers only. Restrictions apply.

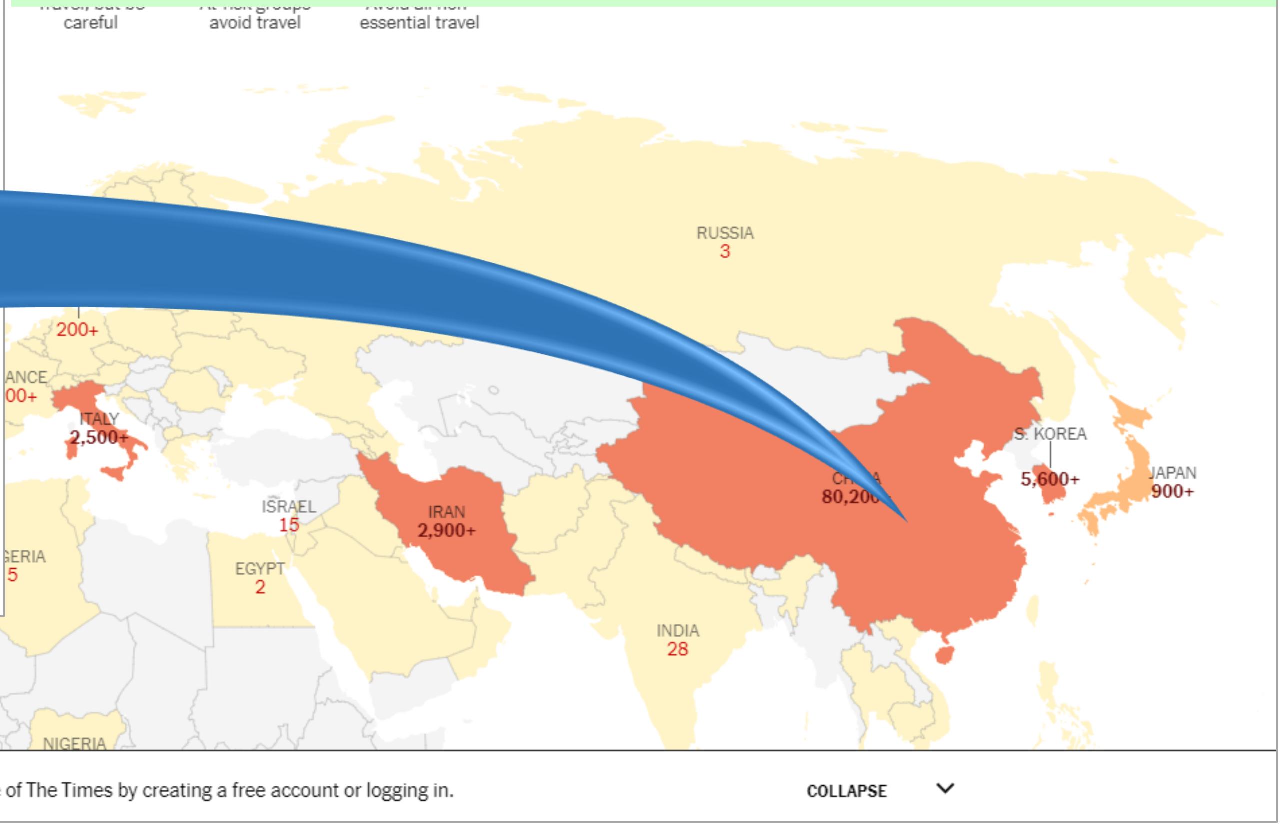
Recent Video

What happens in one place can affect elsewhere, globally.



Coronavirus concerns: Shelves emptied of face masks, sanitizer

- Not mentioning the tumbling stock market!
- Global health is our health!



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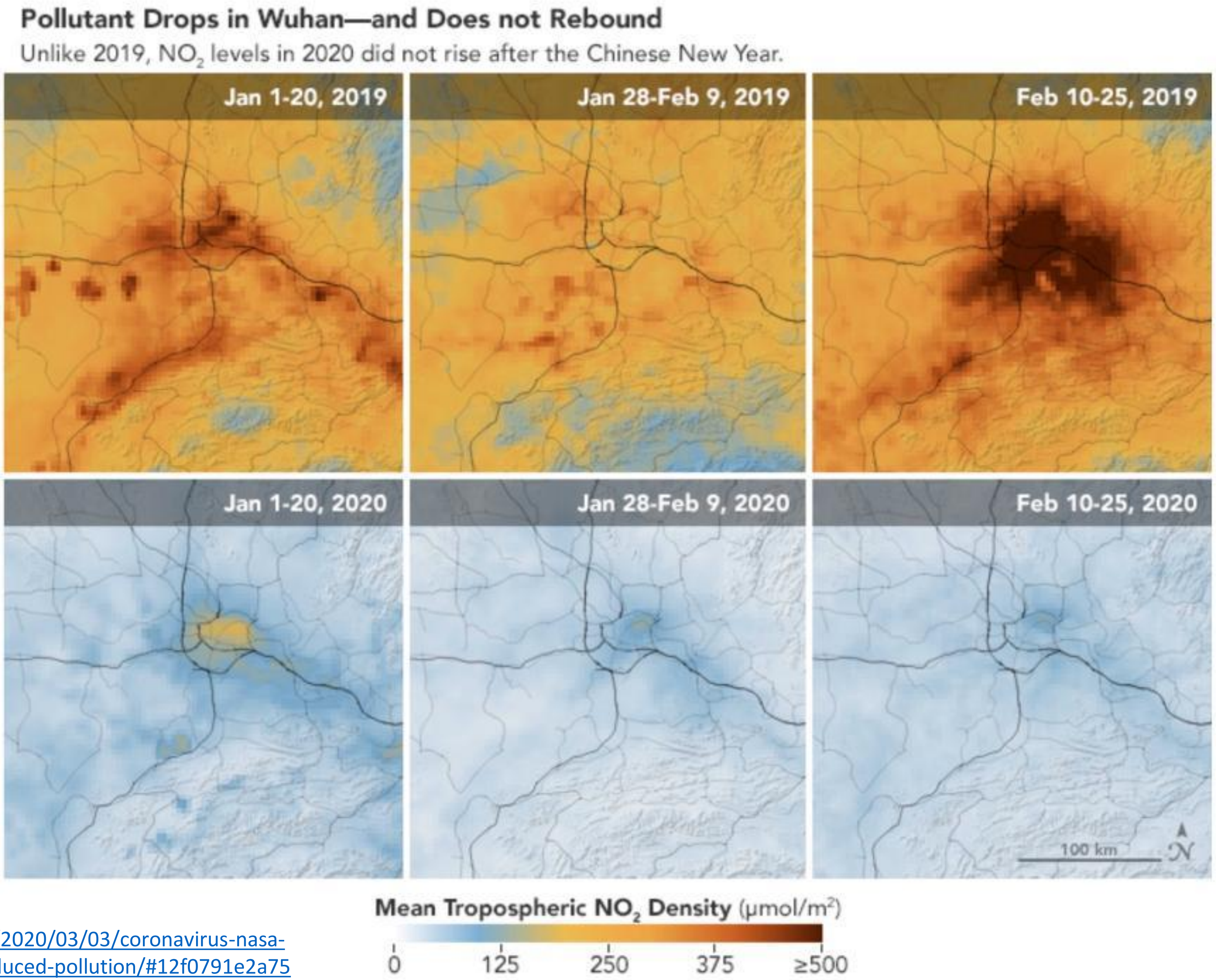
Complex Interconnections: Corona Virus



https://www.forbes.com/sites/trevornace/2020/03/03/coronavirus-nasa-reveals-how-cinas-lockdown-drastically-reduced-pollution/#12f0791e2a75

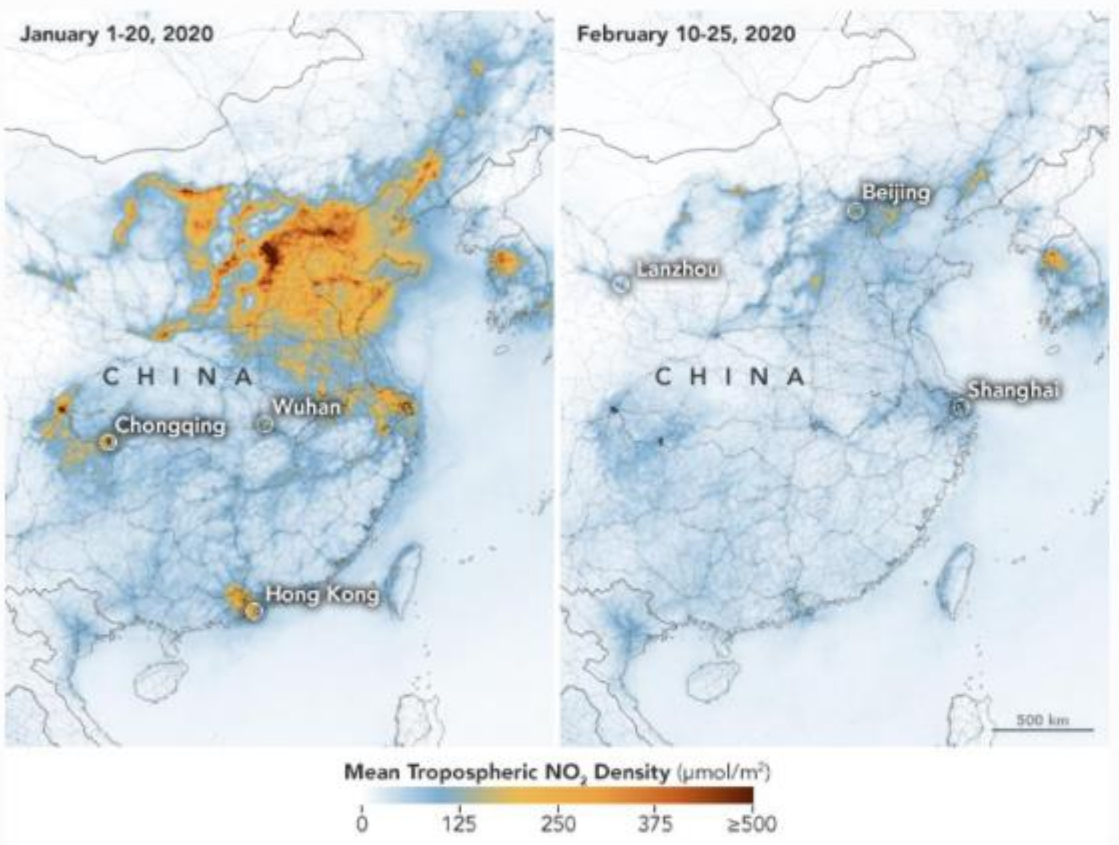
Complex Interconnections: Corona Virus

- The map below shows how NO_2 concentration changed from the period right before the Chinese government shut down transportation and factories compared to after the shutdown. The darker red areas show higher concentrations of NO_2, centered primarily around Beijing.
- The first reduction in NO_2 surrounded Wuhan and since then spread across the country. NASA scientists note that this is the most dramatic drop in pollution over a short time period across a county they have seen.

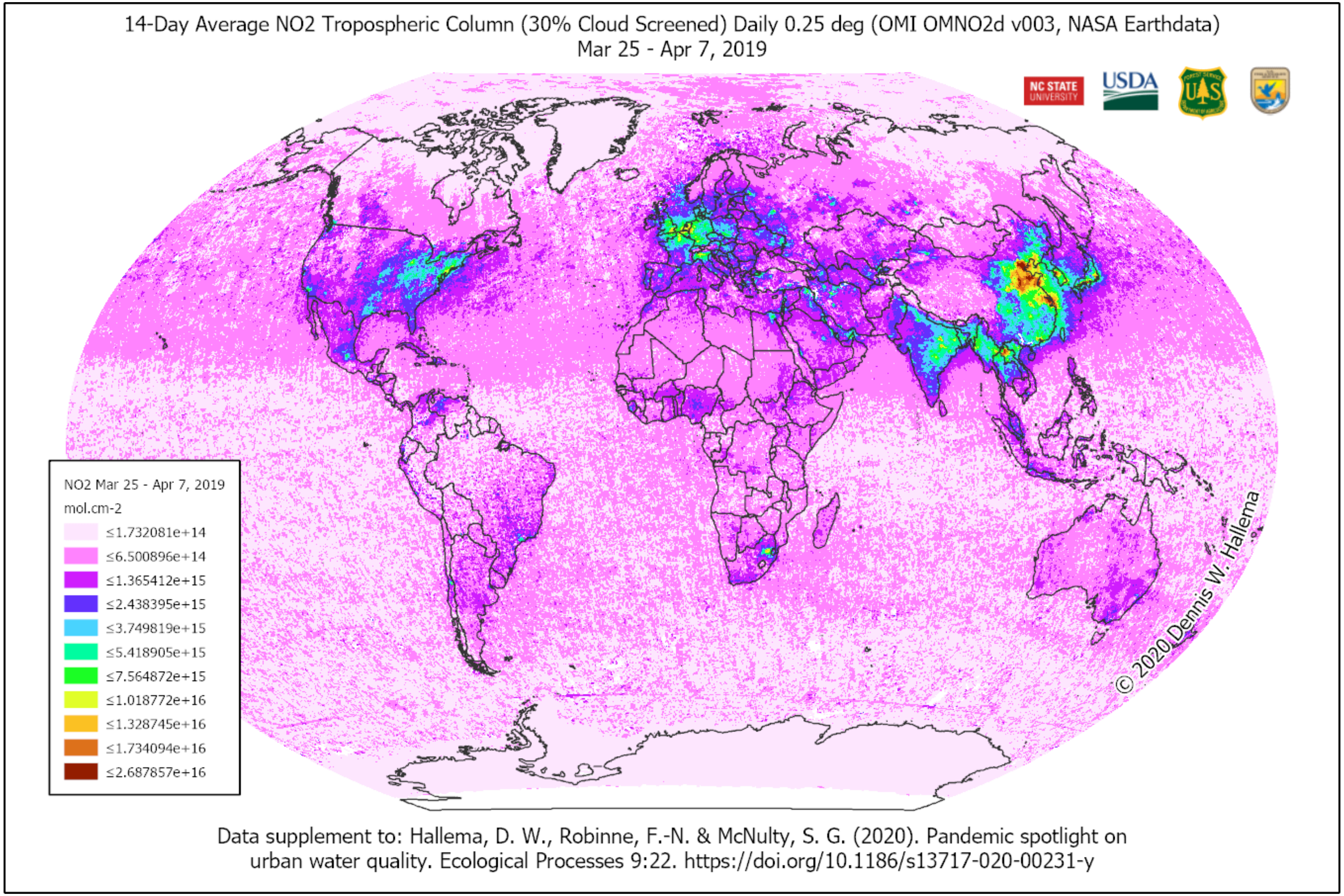
https://www.forbes.com/sites/trevornace/2020/03/03/coronavirus-nasa-reveals-how-cinas-lockdown-drastically-reduced-pollution/#12f0791e2a75

Coronavirus: NASA Reveals How China's Lockdown Drastically Reduced Pollution

Trevor Nace Senior Contributor ⓘ
Science
Explore More



Nitrogen dioxide before vs after Coronavirus. NASA

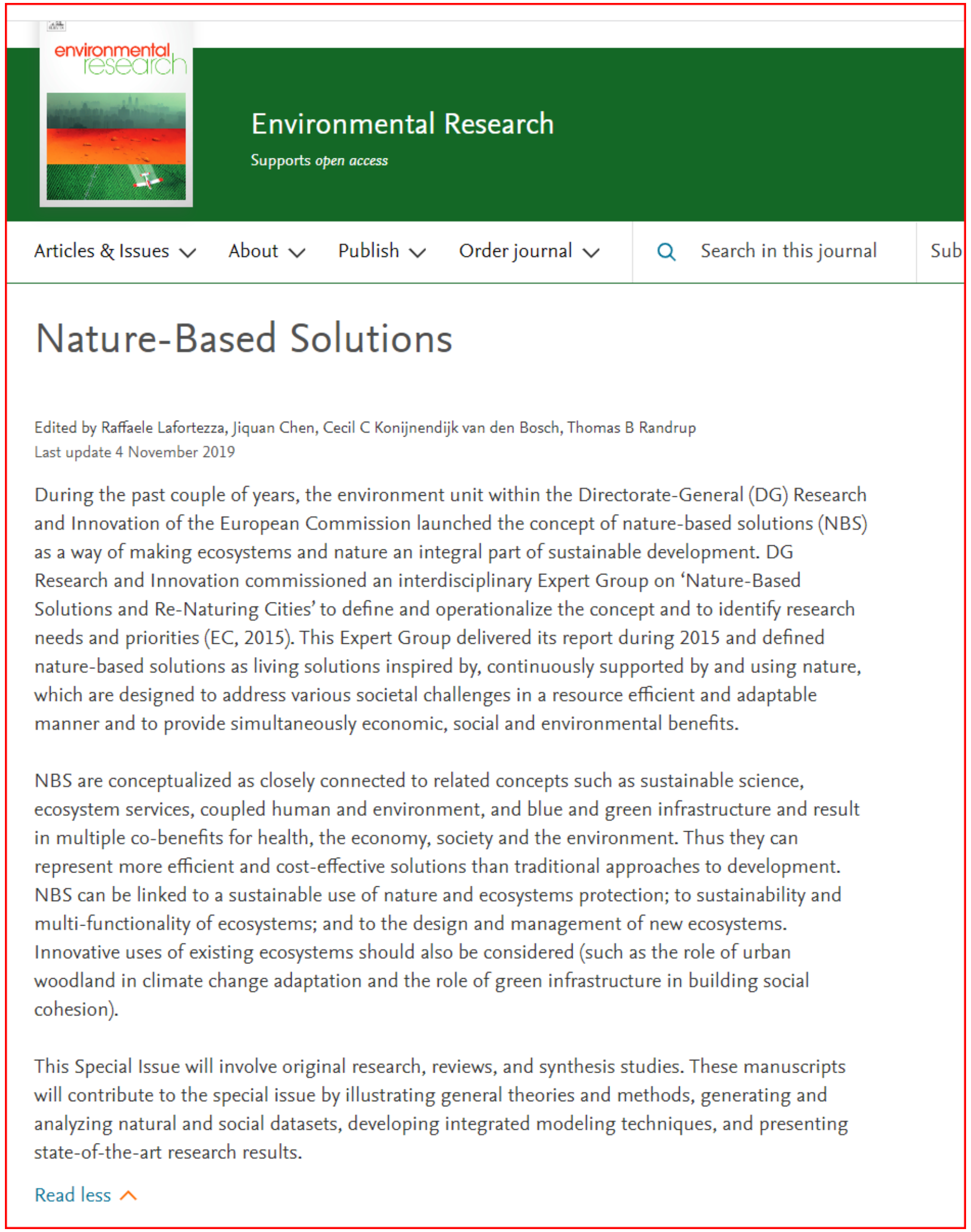


14-Day Average NO2 Tropospheric Column (30% Cloud Screened) Daily 0.25 deg (OMI OMNO2d v003, NASA Earthdata)
Mar 25 - Apr 7, 2019

Data supplement to: Hallema, D. W., Robinne, F.-N. & McNulty, S. G. (2020). Pandemic spotlight on urban water quality. Ecological Processes 9:22. https://doi.org/10.1186/s13717-020-00231-y

Hallema, D. W., Robinne, F. N., & McNulty, S. G. (2020). Pandemic spotlight on urban water quality. *Ecological Processes*, *9*, 1-3.

Solutions: Adaptation & Mitigation



Nature-Based Solutions

Edited by Raffaele Lafortezza, Jiquan Chen, Cecil C Konijnendijk van den Bosch, Thomas B Randrup
Last update 4 November 2019

During the past couple of years, the environment unit within the Directorate-General (DG) Research and Innovation of the European Commission launched the concept of nature-based solutions (NBS) as a way of making ecosystems and nature an integral part of sustainable development. DG Research and Innovation commissioned an interdisciplinary Expert Group on 'Nature-Based Solutions and Re-Naturing Cities' to define and operationalize the concept and to identify research needs and priorities (EC, 2015). This Expert Group delivered its report during 2015 and defined nature-based solutions as living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits.

NBS are conceptualized as closely connected to related concepts such as sustainable science, ecosystem services, coupled human and environment, and blue and green infrastructure and result in multiple co-benefits for health, the economy, society and the environment. Thus they can represent more efficient and cost-effective solutions than traditional approaches to development. NBS can be linked to a sustainable use of nature and ecosystems protection; to sustainability and multi-functionality of ecosystems; and to the design and management of new ecosystems. Innovative uses of existing ecosystems should also be considered (such as the role of urban woodland in climate change adaptation and the role of green infrastructure in building social cohesion).

This Special Issue will involve original research, reviews, and synthesis studies. These manuscripts will contribute to the special issue by illustrating general theories and methods, generating and analyzing natural and social datasets, developing integrated modeling techniques, and presenting state-of-the-art research results.

1) Nature-based solutions for resilient landscapes and cities
2) Innovative urban forestry governance in Melbourne?: Investigating "green placemaking" as a nature-based solution
3) Ecosystem services: Urban parks under a magnifying glass
4) Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks
5) Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges
6) Cultivating nature-based solutions: The governance of communal urban gardens in the European Union
7) Nature-based solutions to promote human resilience and wellbeing in cities during increasingly hot summers
8) Nature-based agricultural solutions: Scaling perennial grains across Africa
9) Public health risk of mercury in China through consumption of vegetables, a modelling study
10) The health benefits of nature-based solutions to urbanization challenges for children and the elderly – A systematic review
11) Grassland productivity and carbon sequestration in Mongolian grasslands: The underlying mechanisms and nomadic implications
12) Aerosol pollution and its potential impacts on outdoor human thermal sensation: East Asian perspectives
13) Natural Assurance Scheme: A level playing field framework for Green-Grey infrastructure development
14) Nature based solution for improving mental health and well-being in urban areas
15) A spatial framework for targeting urban planning for pollinators and people with local stakeholders: A route to healthy, blossoming communities?
16) Regulating urban surface runoff through nature-based solutions – An assessment at the micro-scale
17) Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements
18) Nature-based solutions for urban landscapes under post-industrialization and globalization: Barcelona versus Shanghai
19) The reduction of Chlorella vulgaris concentrations through UV-C radiation treatments: A nature-based solution (NBS)
20) Challenges for tree officers to enhance the provision of regulating ecosystem services from urban forests
21) Air contaminants and litter fall decomposition in urban forest areas: The case of São Paulo - SP, Brazil
22) Resilient landscapes in Mediterranean urban areas: Understanding factors influencing forest trends
23) Assessing allergenicity in urban parks: A nature-based solution to reduce the impact on public health
24) Hydro-dam – A nature-based solution or an ecological problem: The fate of the Tonlé Sap Lake
25) Comprehending the multiple 'values' of green infrastructure – Valuing nature-based solutions for urban water management from multiple perspectives
26) Re-defining the characteristics of environmental volunteering: Creating a typology of community-scale green infrastructure
27) Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews

Solutions: Adaptation & Mitigation

The Expert Group delivered its report in 2015 and defined NBS as

“living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits”

1) identifying obstacles (e.g., regulatory) and enabling factors (e.g., leverage of funding) to the delivery of NBS;
2) raising citizens’ awareness, engagement and empowerment;
3) integrating research, policy and the economic sector to provide the evidence base for NBS; (iv) scaling up NBS across Europe through a more comprehensive evidence base;
4) developing new business and investment models as well as legal and institutional frameworks for NBS; and
5) developing and deploying NBS that maximize cost-effectiveness and co-benefits.

Solutions: Adaptation & Mitigation

Overall, this Special Issue includes 26 contributions spanning more than 20 countries around the globe (Table 2). NBS applications range from the micro-scale (e.g., UV radiation as NBS to treat algae-polluted water; Chen and Bridgeman, 2017) to the macro-scale (e.g., grasslands as NBS supporting climate change adaptation on the Mongolian Plateau; Shao et al., 2017). The impacts are varied and include mitigation measures (e.g., Cariñanos et al., 2017), health benefits, as well as the ecological and economic value of NBS. We also present lessons learned from these sources to provide a more comprehensive evidence base for NBS applications (e.g., ‘NBS planning is used as a place-making tool to strengthen city image and attract global investment’; Fan et al., 2017).

Solutions: Adaptation & Mitigation

Remaining challenges:

- to understand the linkages between NBS and associated ecosystem services within the four main categories of provisioning, regulating, cultural and supporting across different scales (e.g., from the “core” urban area to the wider peri-urban landscape);
- to assess NBS using a multitude of sensors and data sources including remotely sensed images (i.e., high-resolution satellite sensors, field sensors, airborne LiDAR) and field data;
- to scale up NBS benefits to the global level and provide evidence metrics or indicators that managers and policy makers can easily access and use;
- to actually implement NBS in the future planning and management of green (blue) landscapes; and (v) to include institutional changes (e.g., policy, governance, and culture) for future refinements of the NBS concept and its applications in both rural and urban landscapes

Solutions: Adaptation & Mitigation – local applications

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OPINION

Land-based climate solutions for the United States

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Solutions: Adaptation & Mitigation – local applications

we now face an urgent need for negative emissions technologies (NETs) capable of removing GHGs from the atmosphere.

1) improved ecosystem stewardship or nature-based solutions, whereby more carbon is stored in ecosystems via practices like reforestation and afforestation, conservation agriculture, and wetland restoration

2) biological carbon capture with geologic storage as in bioenergy with carbon capture and storage (BECCS) and ocean fertilization

3) non-biological technologies such as enhanced rock weathering and direct air capture

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FIGURE 1 Mitigation potentials for U.S. land-based approaches totaling 110 Gt CO2e to 2100 (95% confidence interval: 57–178 Gt CO2e). Forest management includes afforestation and reforestation, and bioenergy is for light vehicle transportation. Bioenergy from 2050 includes carbon capture and storage with liquid fuel + internal combustion (ic) and then electricity production + electric vehicles (ev). Values in parentheses denote 95% confidence intervals. Values by emissions category and practice change appear in supplemental materials Table S1

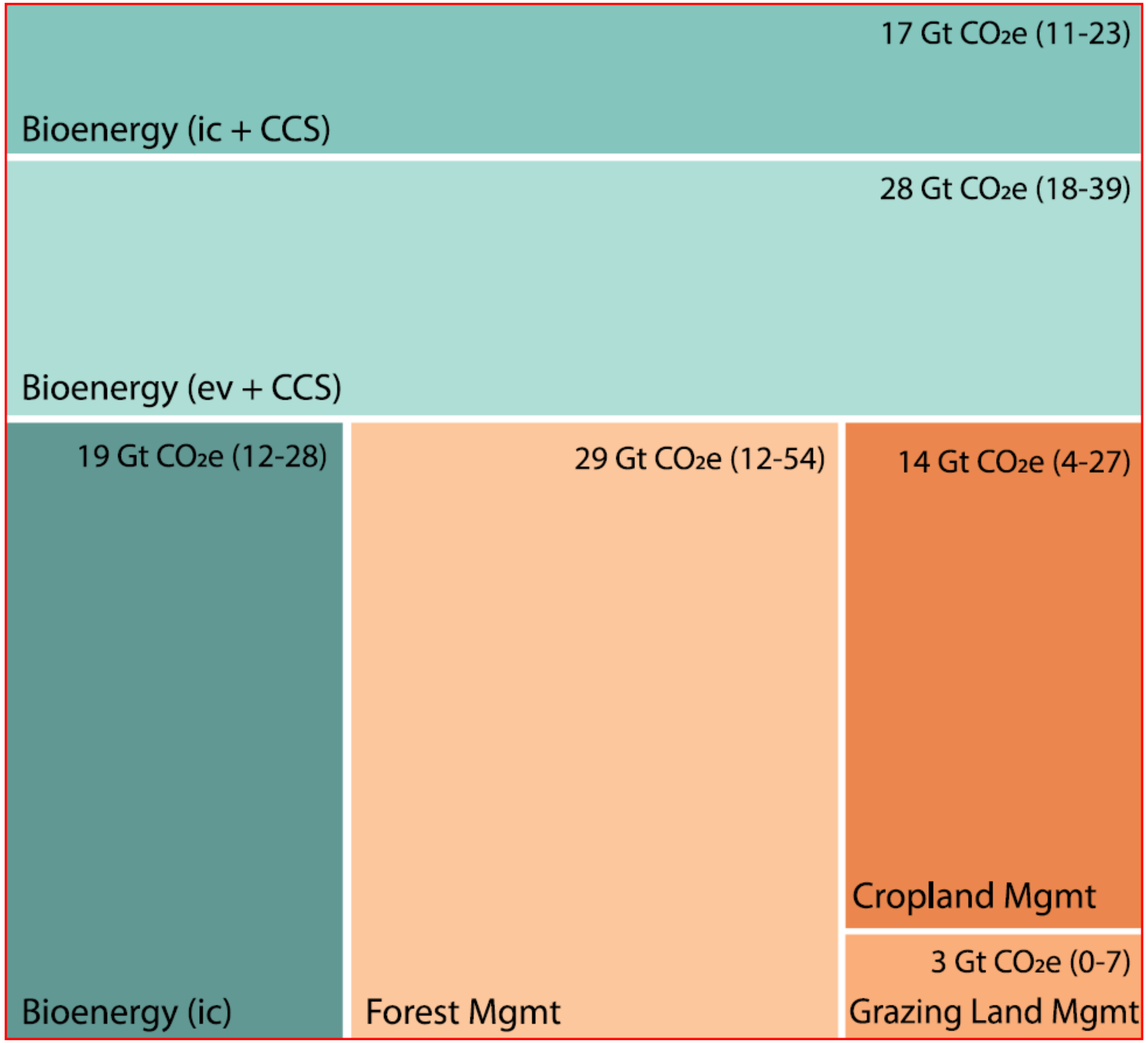

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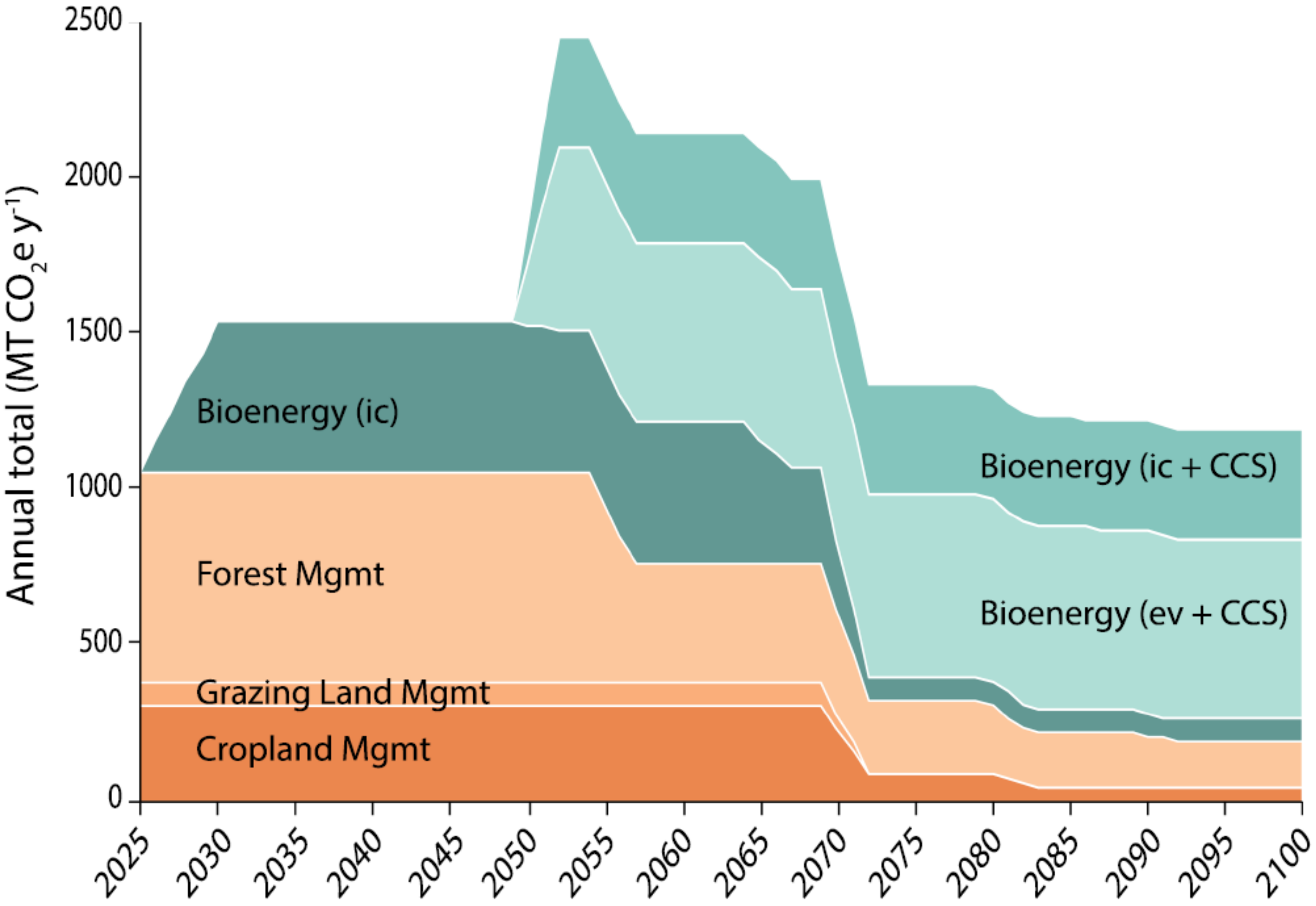
FIGURE 2 Annual mitigation potentials through 2100 for different emissions categories considering the strengths and durations of various sinks, and the presumed availability of geologic carbon capture and storage beginning ca. 2050. The steep declines in nature-based sinks (soil organic carbon and tree biomass) reflect the assumption in the calculations of an abrupt termination of their effectiveness, when in reality they would approach carbon saturation in a more gradual and asymptotic manner. The 2025 start date (2030 for bioenergy) is arbitrary but useful for comparison with other efforts; the entire timeline could be shifted to a later date with no change to the 75 years potential.



Next Week: new alternatives for agricultural managements in US's Midwest

Guest Lecture by Dr. Suraj Upadhaya, Iowa State University

Reading

1) Robertson, G. P., Hamilton, S. K., Paustian, K., & Smith, P. (2022). Land-based climate solutions for the United States. *Global Change Biology*, *28*(16), 4912-4919.

2) Lafortezza, R., Chen, J., Van Den Bosch, C. K., & Randrup, T. B. (2018). Nature-based solutions for resilient landscapes and cities. *Environmental research*, *165*, 431-441.