

# Reinventing Nature: Environmental Stewardship in the Age of Earth System Models

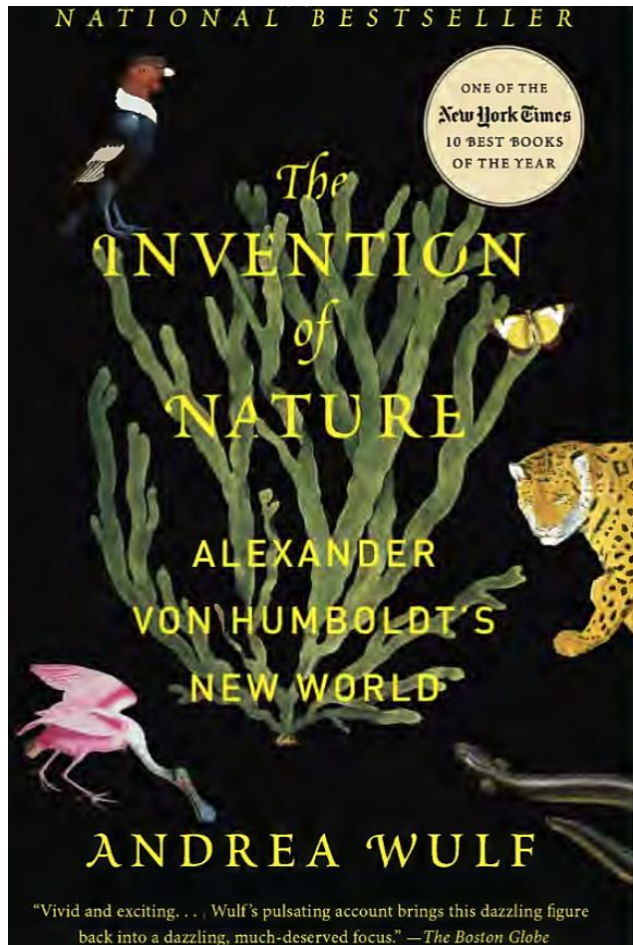
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CSDMS 2020 – Linking Ecosphere and Geosphere  
University of Colorado, Boulder, CO  
21 May 2020



# Reinventing nature

Alexander von Humboldt (1769-1859)  
Naturalist, geographer, explorer



- Created the way we understand nature today
- Presaged Earth system science by advocating for the study of the interconnectedness in nature

# Two views of climate

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## Blue marble



(Will Wieder, NCAR)

### Geophysical perspective

Atmospheric physics

Fluid dynamics

## Emerald planet



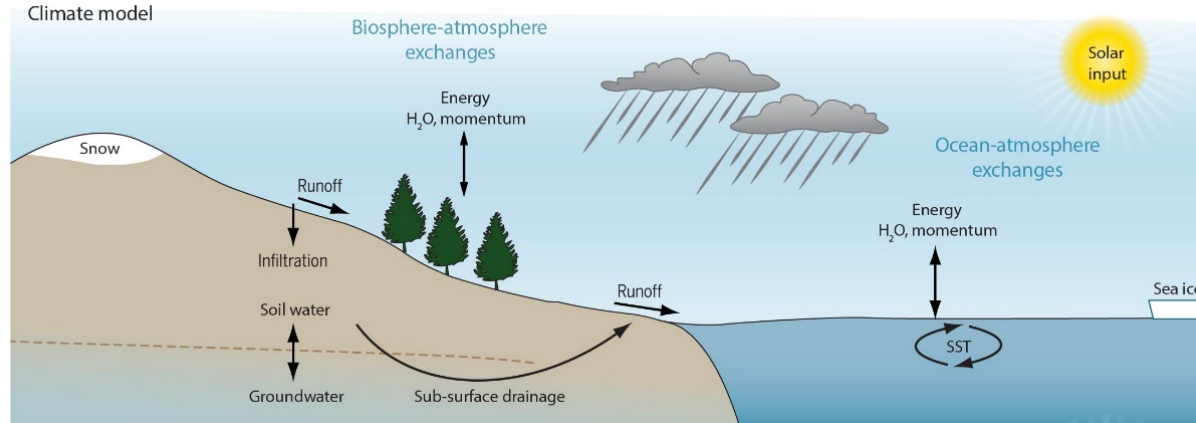
(Will Wieder, NCAR)

### Biogeoscience perspective

Effects of ecosystems on climate  
and atmospheric composition

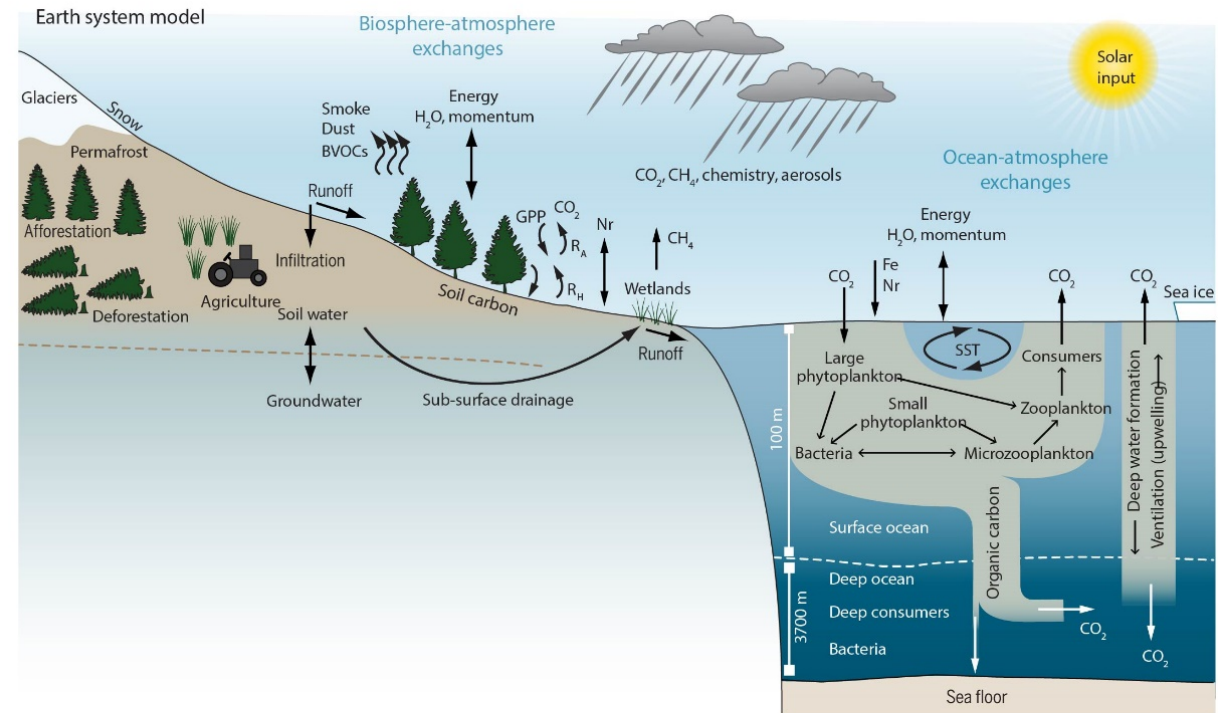
# From climate models to Earth system models

## Physical representation of climate (circa 1990s)

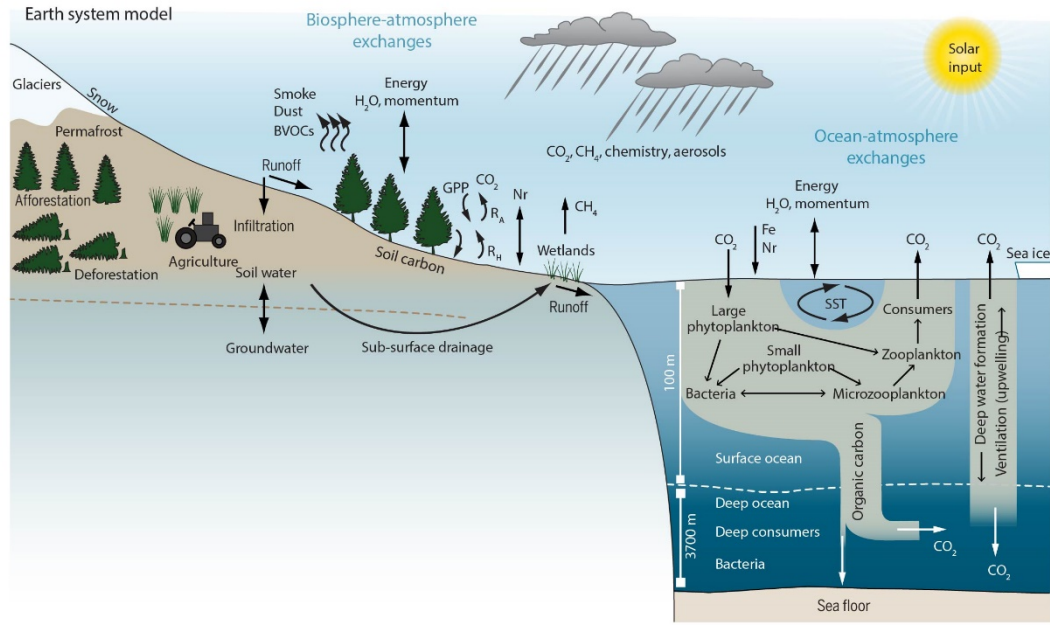


Bonan & Doney (2018) *Science*, 359, eaam8328, doi:10.1126/science.aam8328

## Earth system perspective with terrestrial and marine ecosystems and biogeochemical cycles (circa 2010s)



# Earth system models as a tool for ecological science



Bonan & Doney (2018) *Science*, 359,  
eaam8328, doi:10.1126/science.aam8328

## Earth system prediction

What are the consequences of alternative socioeconomic pathways?

## Scientific discovery

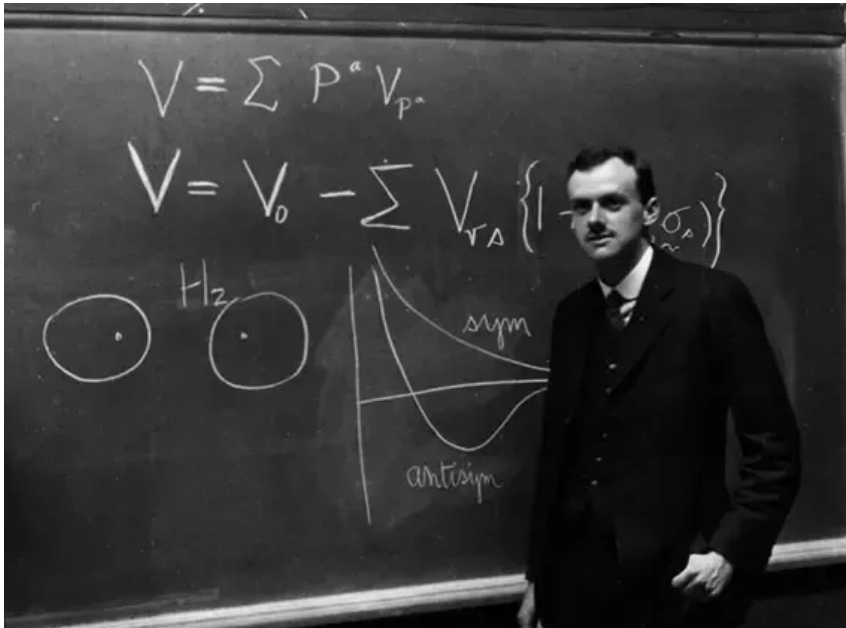
Identify ecological processes that determine climate

## Advance theory

Test generality of ecological theories at the macroscale

# A disciplinary perspective

Physicist



Paul Dirac

# A disciplinary perspective

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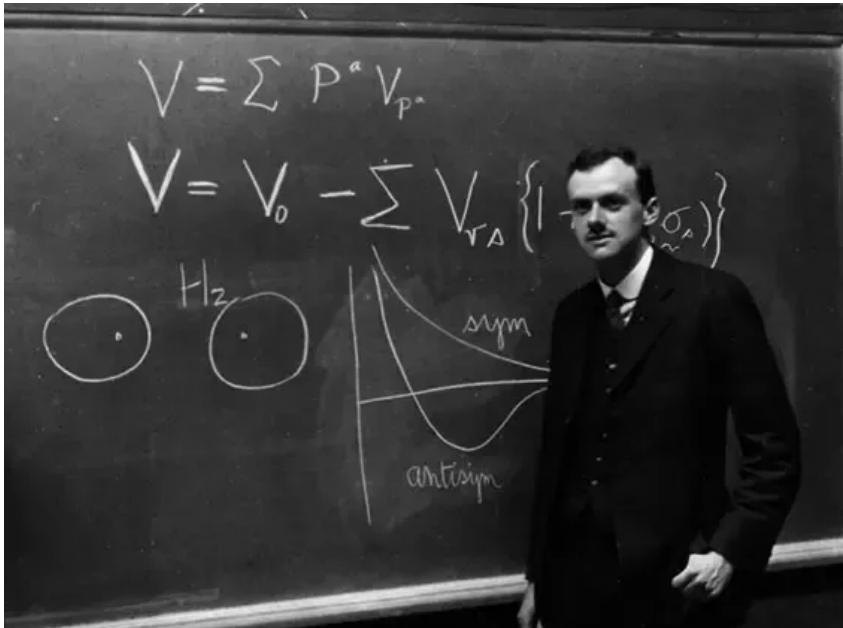
## Ecologist



Teal Potter conducting field sampling at Niwot Ridge LTER  
(photo credit: Bill Bowman)

# An interdisciplinary perspective

Physicist



Paul Dirac

Ecologist



Teal Potter conducting field sampling at Niwot Ridge LTER (photo credit: Bill Bowman)

Biosphere and climate



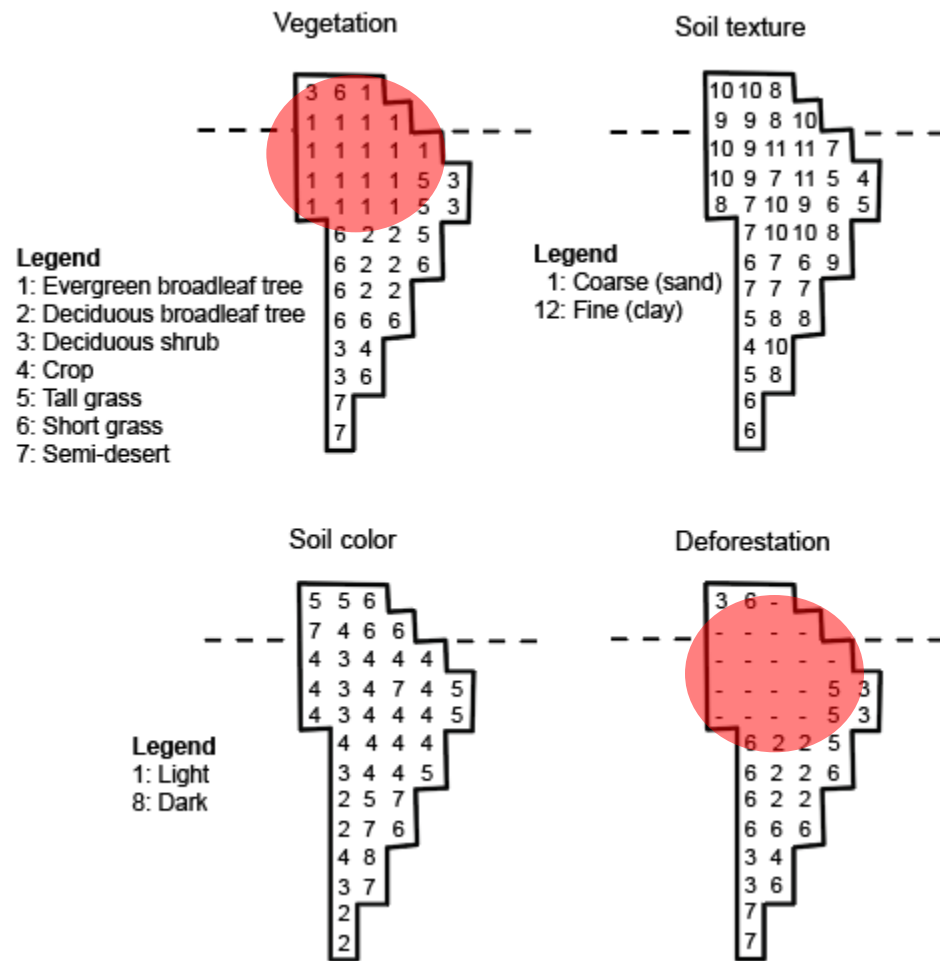
Quanta magazine / Gabriel Popkin



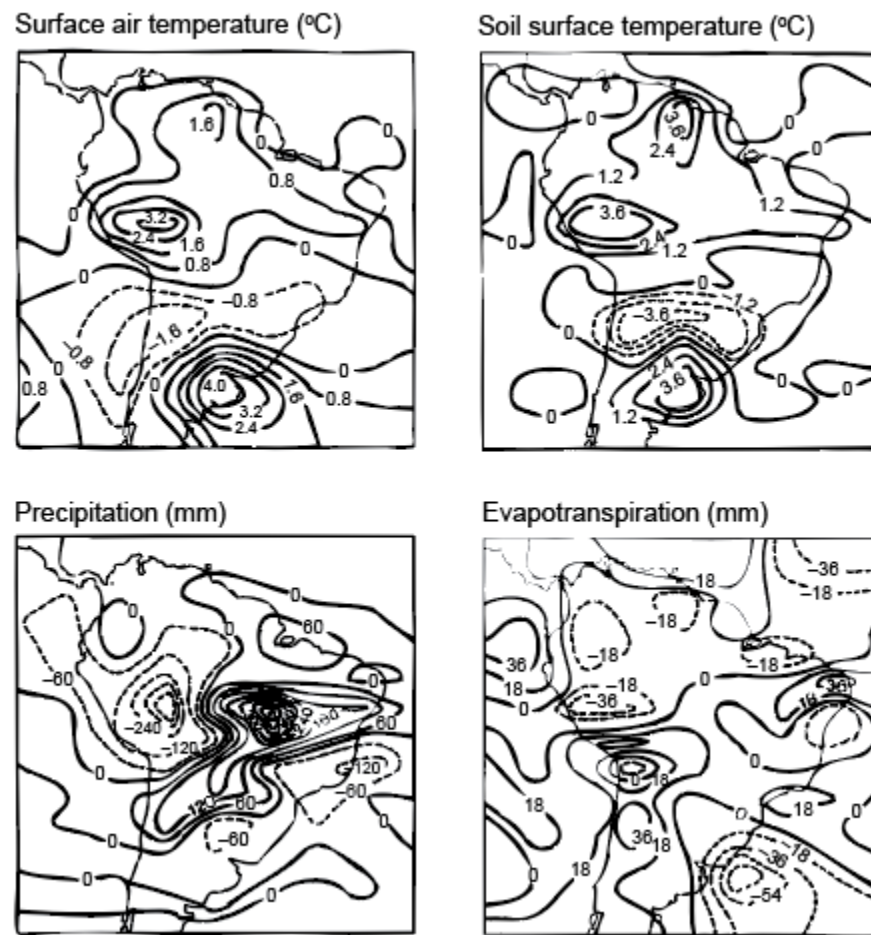


# Tropical deforestation

(a) Model surface datasets



(b) Model response



# Boreal forests and climate

## ENVIRONMENTAL FACTORS AND ECOLOGICAL PROCESSES IN BOREAL FORESTS

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Goddard Space Flight Center, Greenbelt, Maryland 20771

*Herman H. Shugart*

Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia 22903

Bonan & Shugart (1989) *Annu. Rev. Ecol. Syst.*, 20, 1-28

Google scholar: 886 citations



Photo credit: Wikipedia (Taiga)



Photo credit: Wikipedia (Taiga)

## Effects of boreal forest vegetation on global climate

**Gordon B. Bonan\***, David Pollard  
& Starley L. Thompson

National Center for Atmospheric Research, PO Box 3000, Boulder,  
Colorado 80307-3000, USA

Bonan et al. (1992) *Nature*, 359, 716-718

Google scholar: 1016 citations

# Centennial research

## Past

“rational climatology gives no basis for the much-talked of influence upon the climate of a country produced by the growth or destruction of forests ... and the cultivation of crops over a wide extent of prairie”

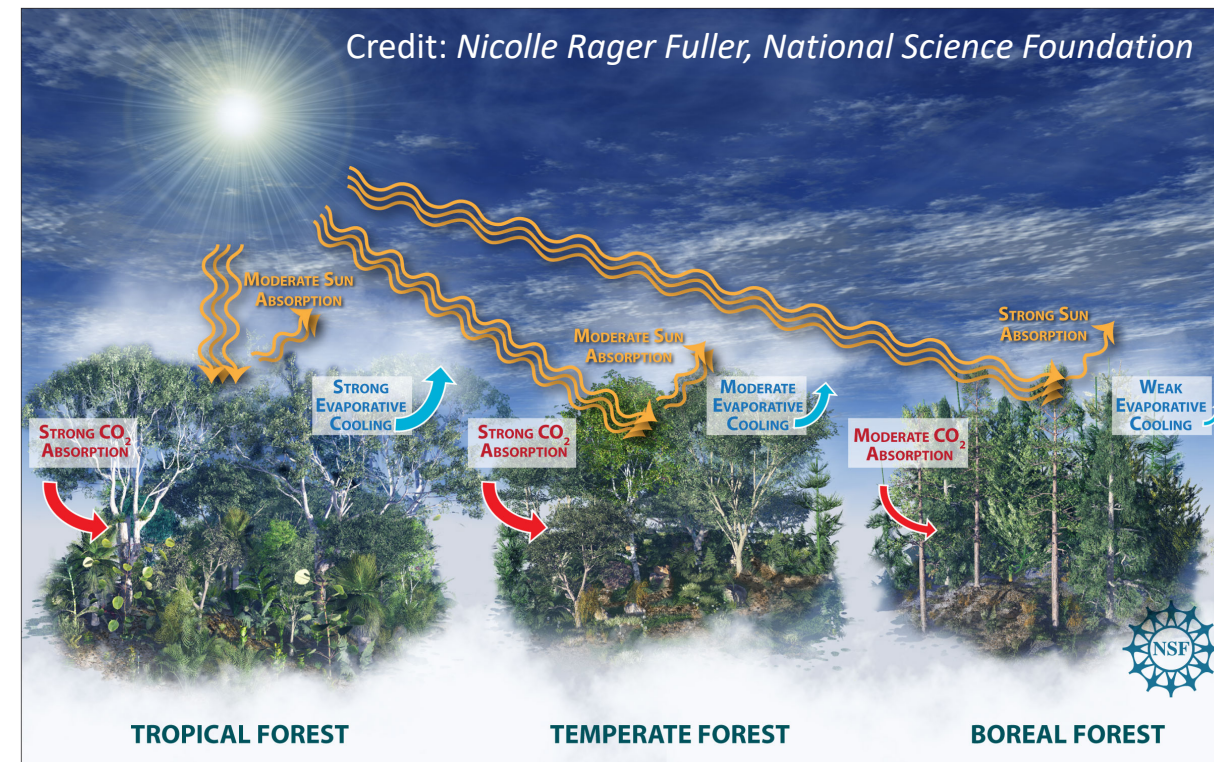
Abbe (1889) Is our climate changing? *Forum*, 6(Feb.), 678-688

(the AMS recognizes Abbe’s contributions with the Cleveland Abbe Award For Distinguished Service to Atmospheric Science)

For further details see:

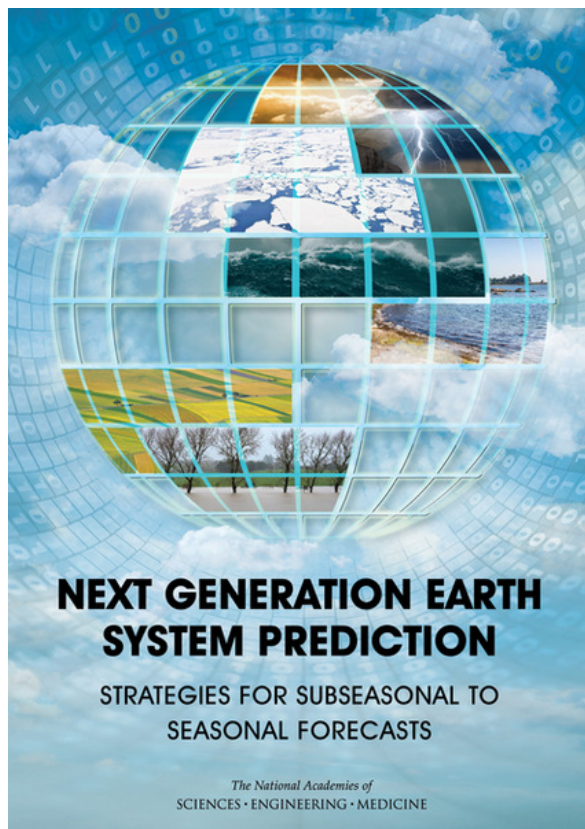
Bonan (2016) *Annu. Rev. Ecol. Evol. Syst.*, 47, 97-121

## Present: climate services of forests



Bonan (2008) *Science*, 320, 1444-49

# Earth system prediction

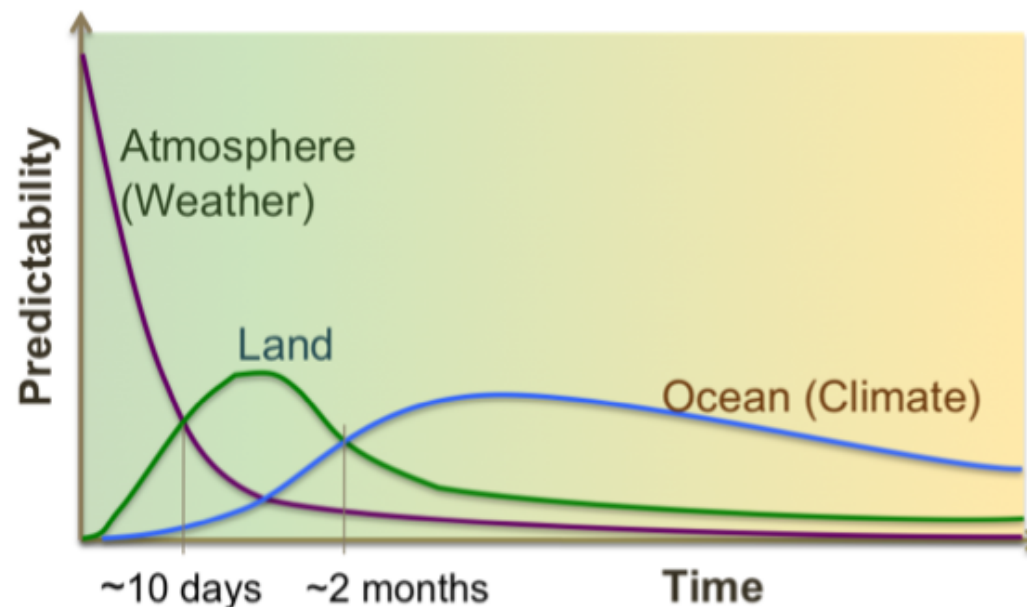


Land as a source of atmospheric predictability

- Soil moisture
- Snow
- Vegetation state (leaf area)

(NAS, 2016)

WMO (2015) *Seamless prediction of the earth system: from minutes to months*. WMO-No. 1156



# Earth system prediction: more than just climate

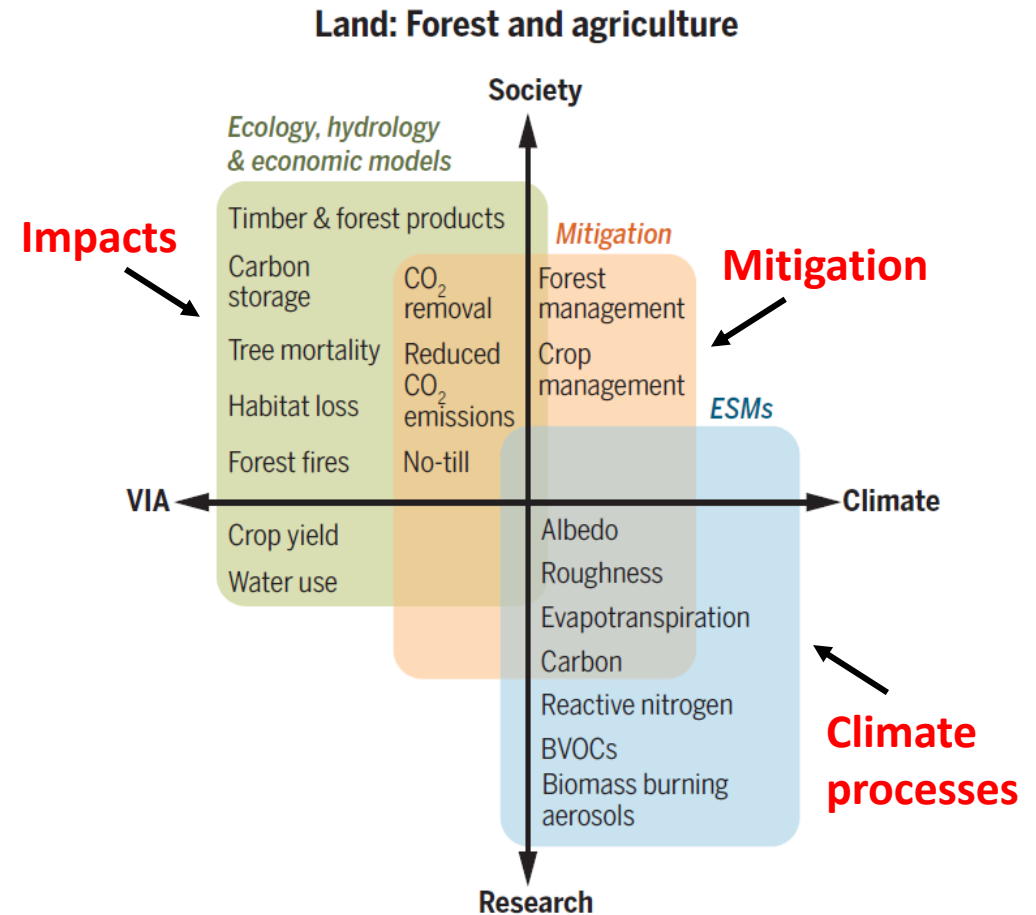
## REVIEW SUMMARY

### EARTH SYSTEMS

## Climate, ecosystems, and planetary futures: The challenge to predict life in Earth system models

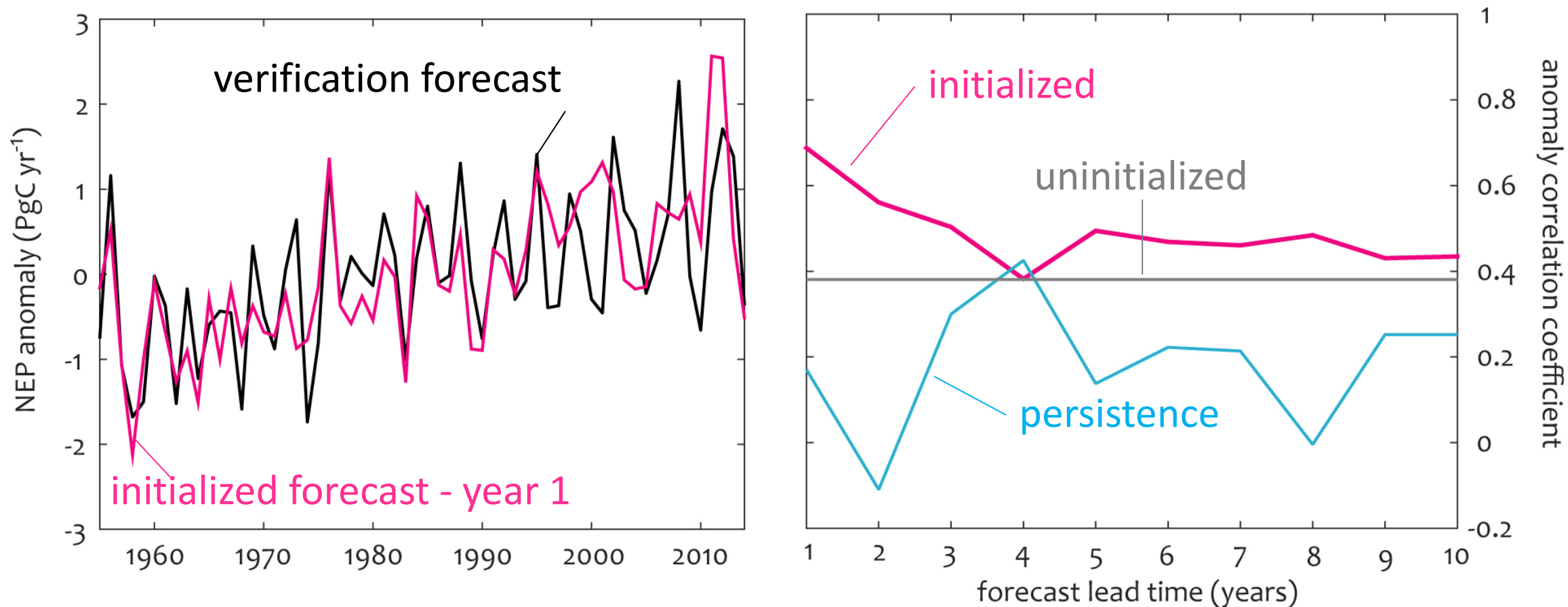
Gordon B. Bonan\* and Scott C. Doney\*

Bonan & Doney (2018) *Science*, 359, eaam8328, doi:10.1126/science.aam8328



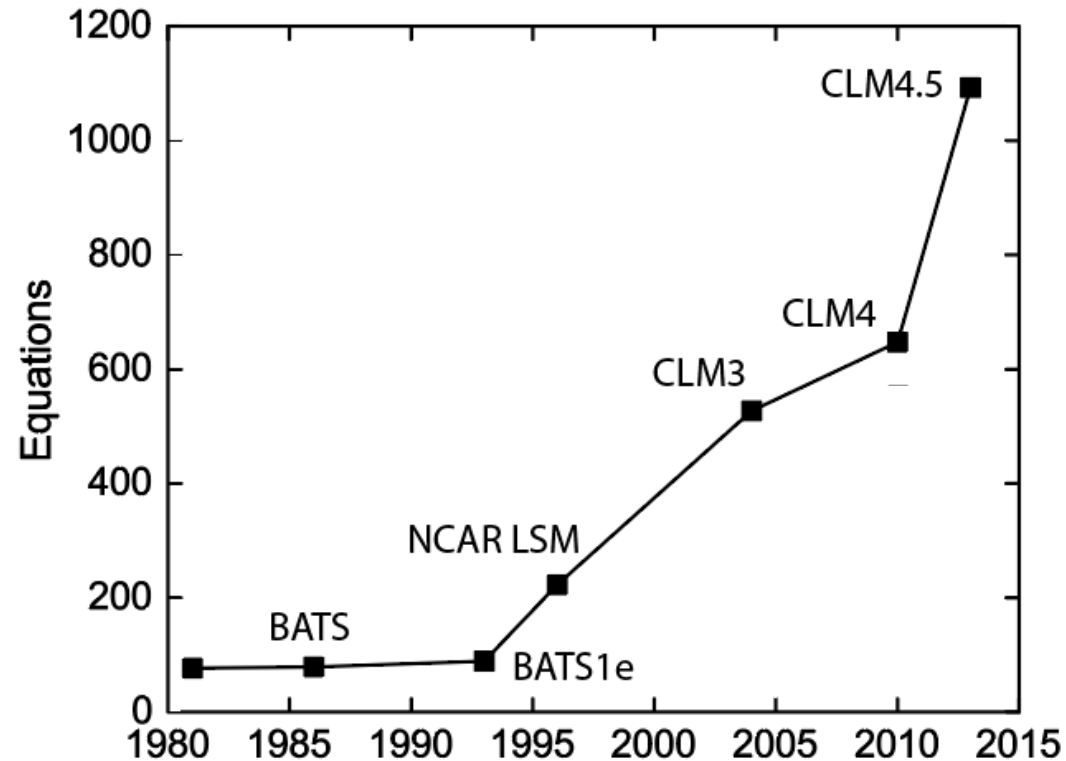
# Is net ecosystem production predictable?

Community Earth System Model (CESM1) Decadal Prediction Large Ensemble



# Increasing model complexity

Breadth and complexity of land surface models as documented by the number of equations included in NCAR technical notes



Bonan (2019) *Climate Change and Terrestrial Ecosystem Modeling* (Cambridge University Press)

Do more complexity and more authentic process parameterizations provide a better model?

# Deconstructing models

*deconstruct*: to take apart or examine (something) in order to reveal the basis or composition often with the intention of exposing biases, flaws, or inconsistencies

(Merriam-Webster)

Monin-Obukhov similarity theory  $\frac{k(z-d)}{u_*} \frac{\partial u}{\partial z} = \phi_m \left( \frac{z-d}{L_{MO}} \right)$

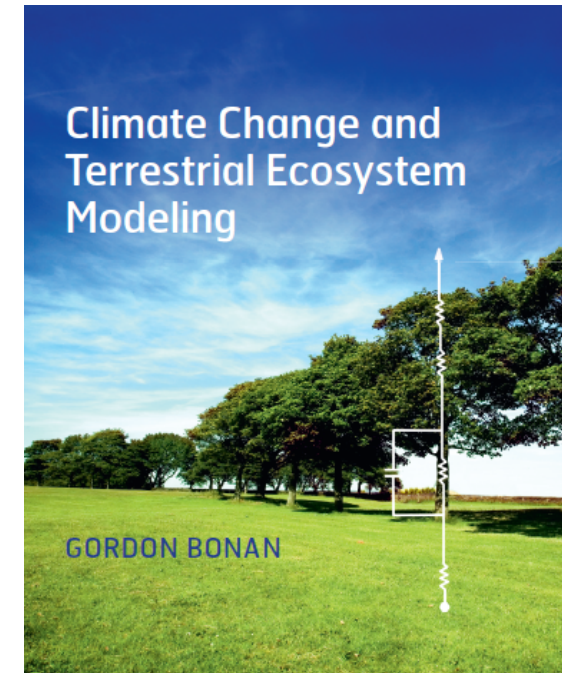
Richards equation  $\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K(\theta) \frac{\partial \psi}{\partial z} \right] + \frac{\partial K}{\partial z}$

Farquhar photosynthesis  $A_c = \frac{V_{c\max} (c_i - \Gamma_*)}{c_i + K_c (1 + o_i/K_o)} - R_d$

$$A_j = \frac{J}{4} \left( \frac{c_i - \Gamma_*}{c_i + 2\Gamma_*} \right) - R_d$$

Ball-Berry stomatal conductance  $g_{sw} = g_0 + g_1 \frac{A_n}{c_s} h_s$

Bonan (2019) *Climate Change and Terrestrial Ecosystem Modeling* (Cambridge University Press)





# Interdisciplinary perspective

## Ecological Interpretation

Forman & Godron (1986) *Landscape Ecology*

Defines ecological concept of a landscape

- heterogeneity of landscape elements
- spatial scale
- movement across the landscape

## Climate Interpretation

Hubert Lamb (Climatic Research Unit, Univ. East Anglia)

(1977) *Climate: Present, Past and Future. Vol. 2, Climatic History and the Future*

(1995) *Climate, History and the Modern World*

- Painted in the winter of 1565
- Mountains are incongruous with the Dutch landscape
- Records Bruegel's impression of severe winter
- Marked an extended period of colder than usual winters

Pieter Bruegel the Elder's "Hunters in the Snow" (1565)



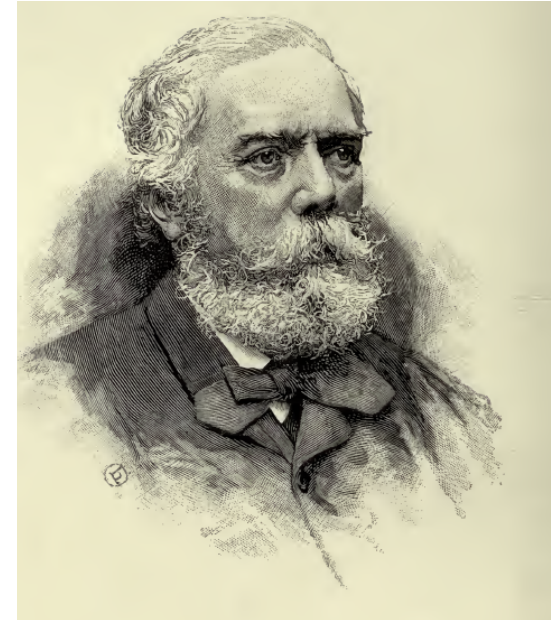
Bonan (2016) *Ecological Climatology*, 3rd ed. (Cambridge Univ. Press)

# Overcoming disciplinary biases

“... it has almost become a rule that each researcher progresses only along a single very narrow path. However, ***narrowness too often has hubris as its consequence.***”

Anton Kerner von Marilaun, *Pflanzenleben* (1888)

Deborah Coen (2018) *Climate in Motion* (University of Chicago Press)



Austrian botanist and  
plant geographer

