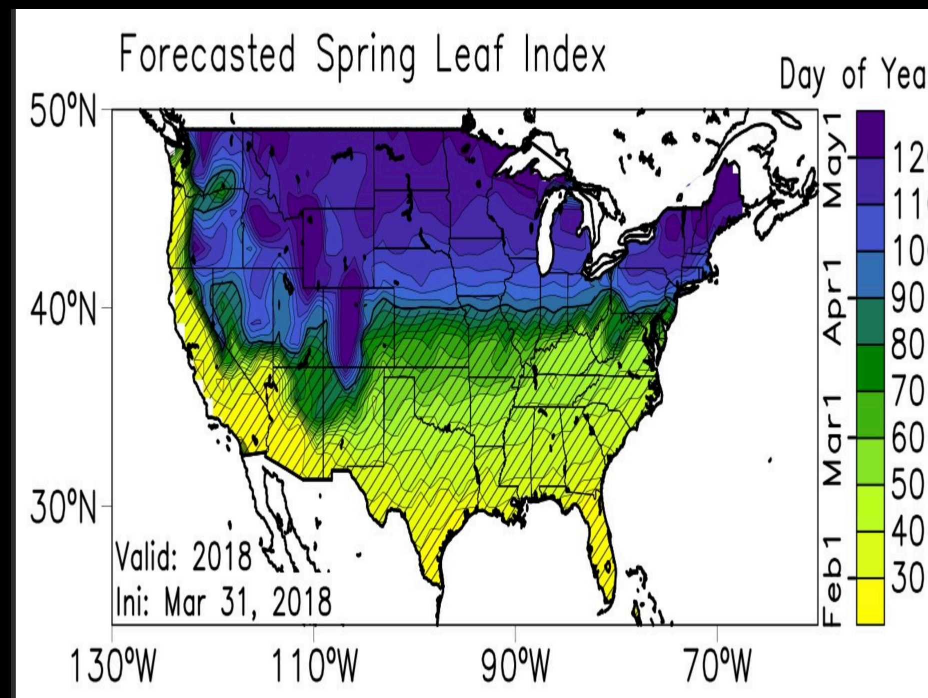
Move over weatherperson: Can we actually forecast ecology?

Ankur Desai, Dept of Atmospheric and Oceanic Sciences

UW-Madison Quantitative Biology Seminar, 11 April 2018

Columbia Pictures

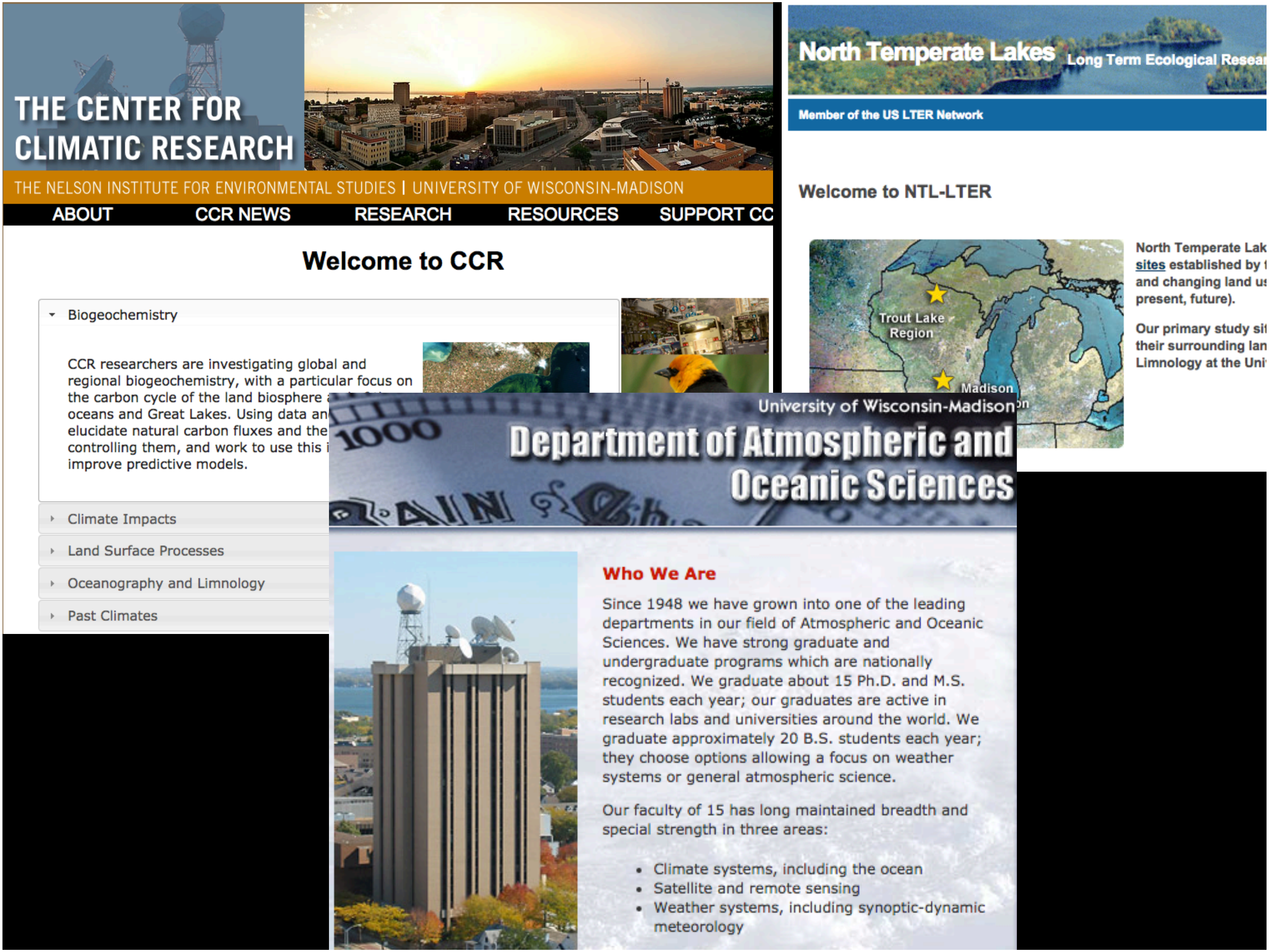


Toby Ault (Cornell)

http://flux.aos.wisc.edu desai@aos.wisc.edu @profdesai

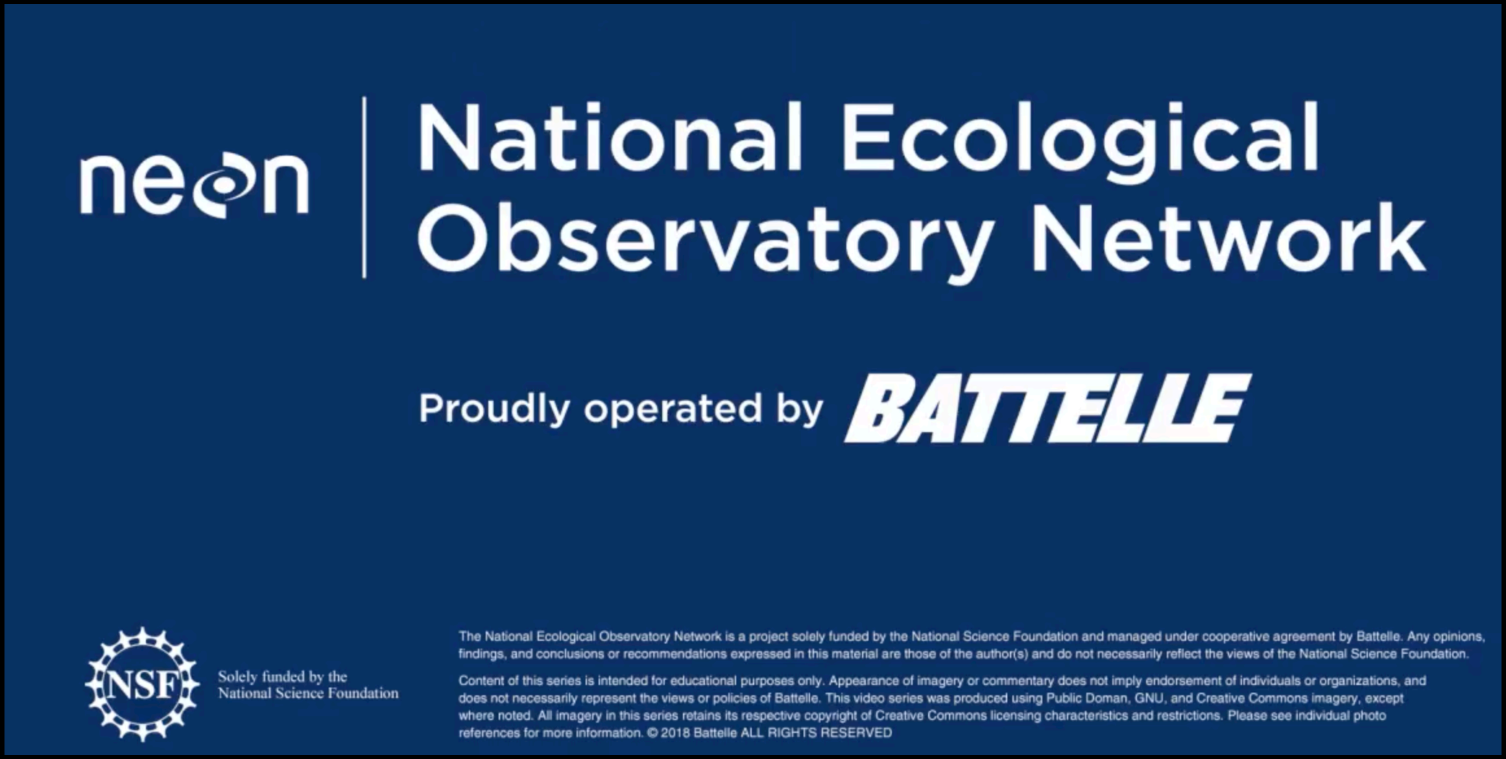
Acknowledgments

- Michael Dietze, Boston University
- Kathleen Weathers, Cary Institute
- Wendy Gram and Megan Jones, NEON/Battelle
- Aneesh Subramanian, UCSD
- And many contributors…
- + Support from NSF BIO (DEB, EF, ABI) and AGS, DOE TES Ameriflux, Battelle/NEON, NASA Carbon Cycle, NOAA, USGCRP


THE CENTER FOR CLIMATIC RESEARCH
THE NELSON INSTITUTE FOR ENVIRONMENTAL STUDIES | UNIVERSITY OF WISCONSIN-MADISON
ABOUT
CCR NEWS
RESEARCH
RESOURCES
SUPPORT CC
Welcome to CCR
Biogeochemistry
CCR researchers are investigating global and regional biogeochemistry, with a particular focus on the carbon cycle of the land biosphere a
oceans and Great Lakes. Using data an
elucidate natural carbon fluxes and the
controlling them, and work to use this i
improve predictive models.
Climate Impacts
Land Surface Processes
Oceanography and Limnology
Past Climates
North Temperate Lakes
Long Term Ecological Resea
Member of the US LTER Network
Welcome to NTL-LTER
Trout Lake Region
Madison
North Temperate Lak
sites established by t
and changing land us
present, future).
Our primary study sit
their surrounding lan
Limnology at the Uni
University of Wisconsin-Madison
Department of Atmospheric and Oceanic Sciences
Who We Are
Since 1948 we have grown into one of the leading departments in our field of Atmospheric and Oceanic Sciences. We have strong graduate and undergraduate programs which are nationally recognized. We graduate about 15 Ph.D. and M.S. students each year; our graduates are active in research labs and universities around the world. We graduate approximately 20 B.S. students each year; they choose options allowing a focus on weather systems or general atmospheric science.
Our faculty of 15 has long maintained breadth and special strength in three areas:
Climate systems, including the ocean
Satellite and remote sensing
Weather systems, including synoptic-dynamic meteorology


WISCONSIN

So What's The Deal With Forecasting Ecology?

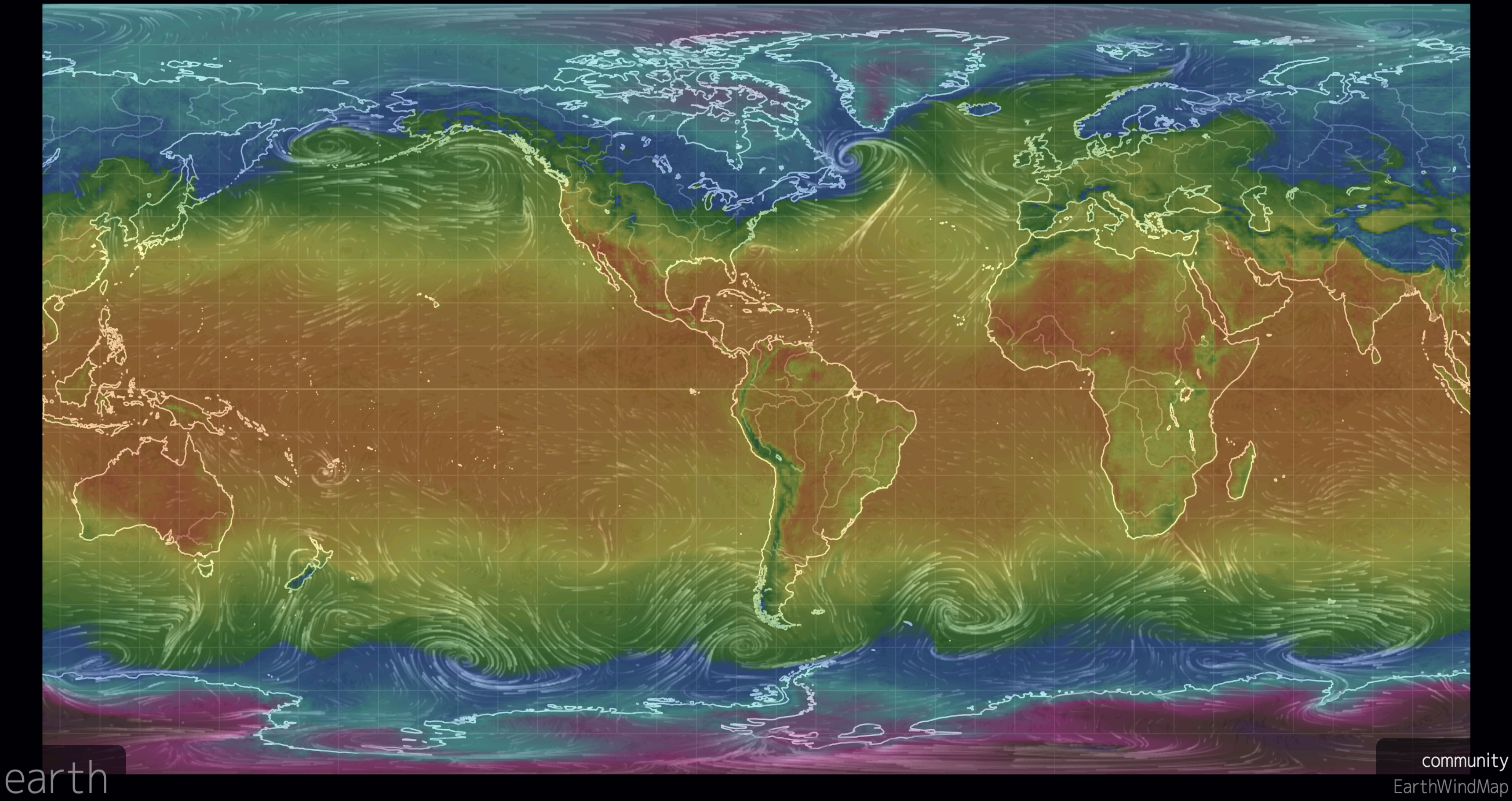


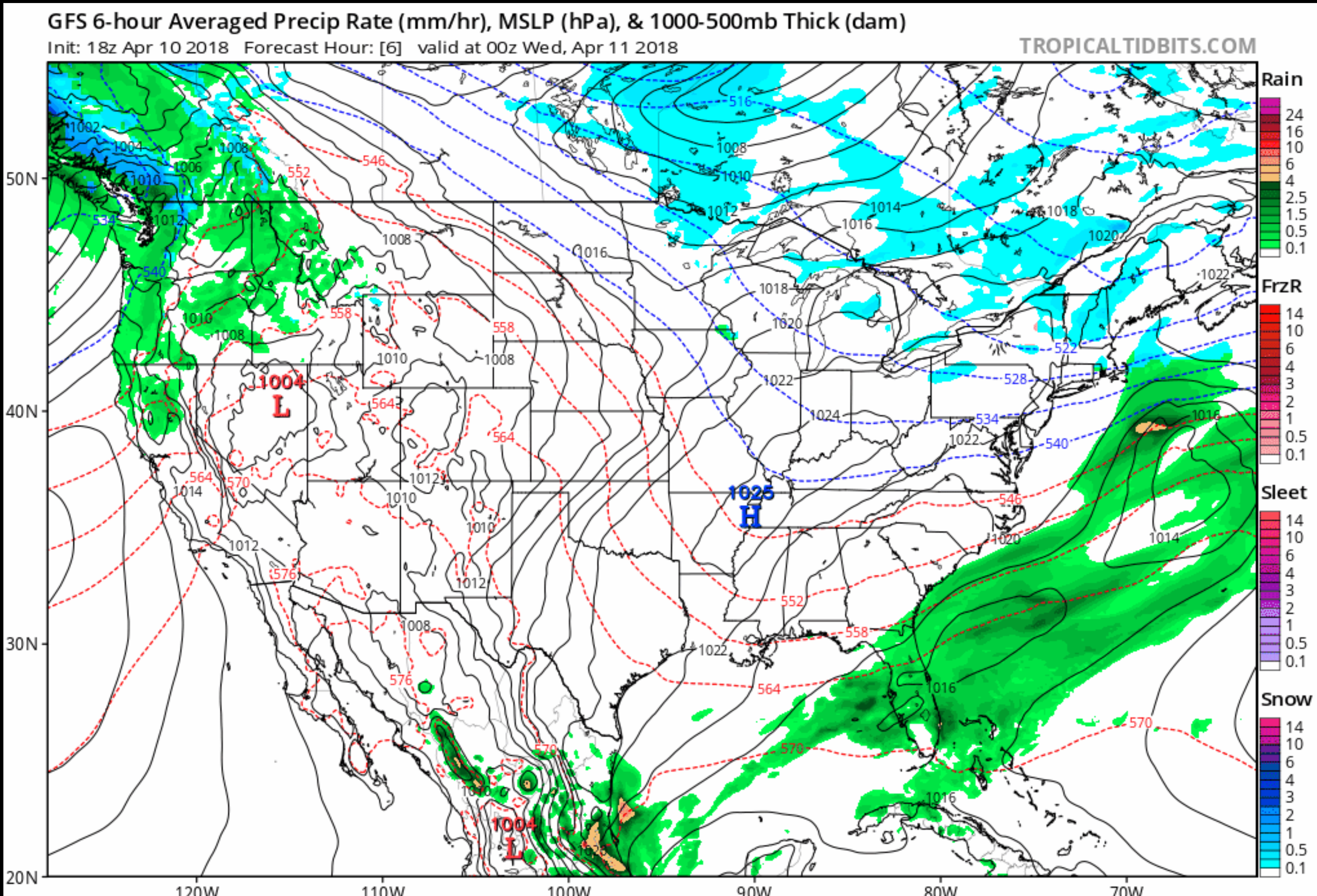
What should we talk about?

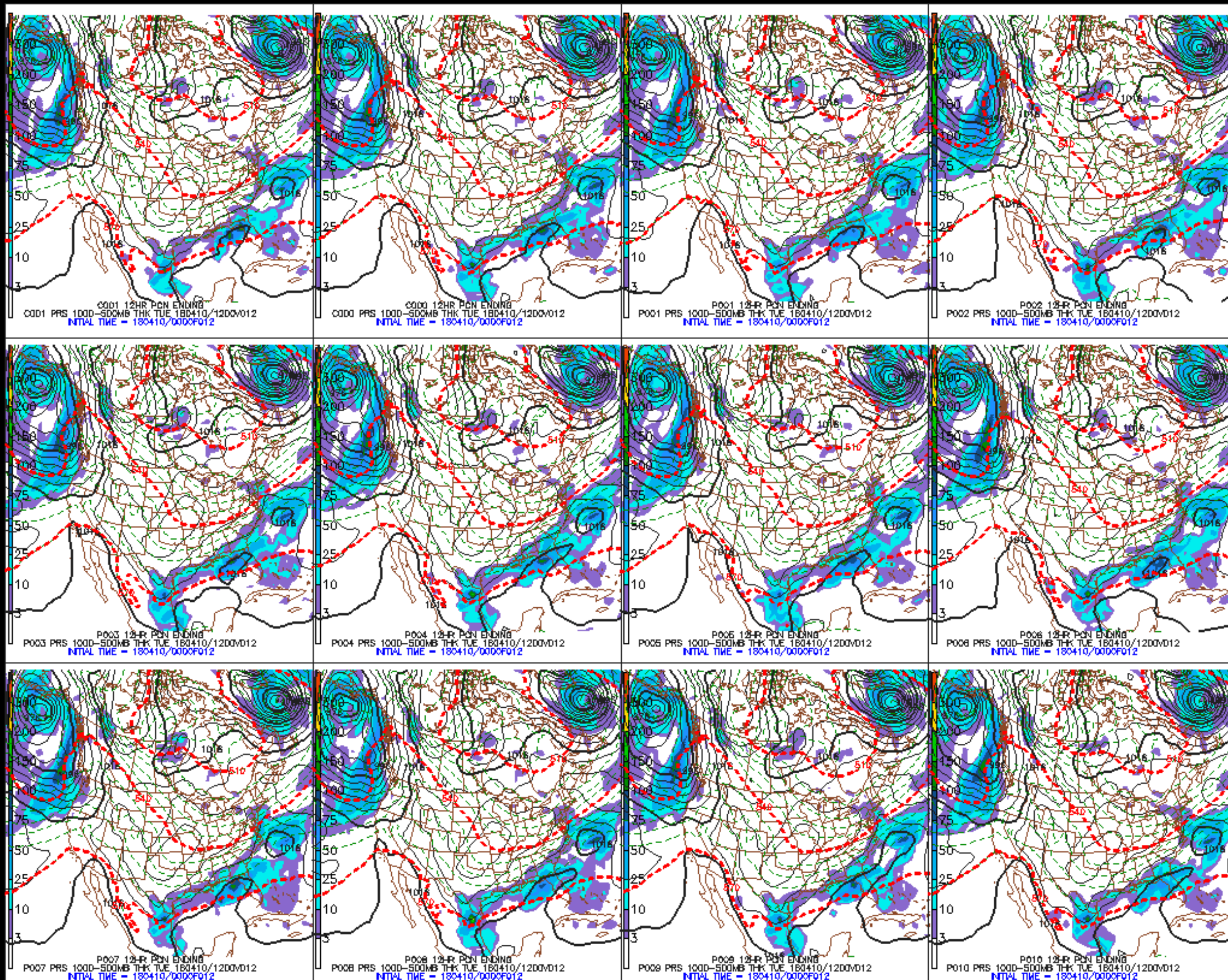
- The ecosystem of weather forecasting
- Symbiosis of models and data
- The current landscape of ecological forecasting
- Future evolution of the field in an era of global change

What should we talk about?

- *The ecosystem of weather forecasting* https://earth.nullschool.net/#current/wind/surface/level/overlay=temp/equirectangular



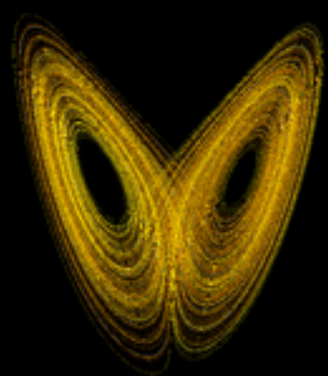

GFS 6-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)
Init: 18z Apr 10 2018   Forecast Hour: [6]   valid at 00z Wed, Apr 11 2018
TROPICALTIDBITS.COM
Rain
FrzR
Sleet
Snow
1004 L
1025 H
1004 L
50N
40N
30N
20N
120W
110W
100W
90W
80W
70W

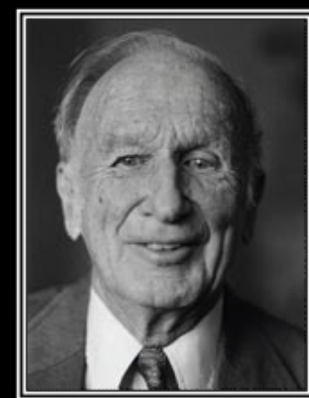


http://mp1.met.psu.edu/~fxg1/ENSPRS_12z/ensloop.html

Predictability in a deterministic nonperiodic flow

"Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?"
-(Lorenz 1972)





Deterministic Nonperiodic Flow[1]

EDWARD N. LORENZ

Massachusetts Institute of Technology

(Manuscript received 18 November 1962, in revised form 7 January 1963)

ABSTRACT

Finite systems of deterministic ordinary nonlinear differential equations may be designed to represent forced dissipative hydrodynamic flow. Solutions of these equations can be identified with trajectories in phase space. For those systems with bounded solutions, it is found that nonperiodic solutions are ordinarily unstable with respect to small modifications, so that slightly differing initial states can evolve into considerably different states. Systems with bounded solutions are shown to possess bounded numerical solutions.

A simple system representing cellular convection is solved numerically. All of the solutions are found to be unstable, and almost all of them are nonperiodic.

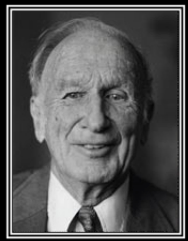
The feasibility of very-long-range weather prediction is examined in the light of these results.

Courtesy of A. Subramanian (Scipps)

Sensitive dependence to initial conditions

“Finite time for error in representation of small scales to affect accuracy of simulation of large scales, no matter how small in scale and hence amplitude this model error is”

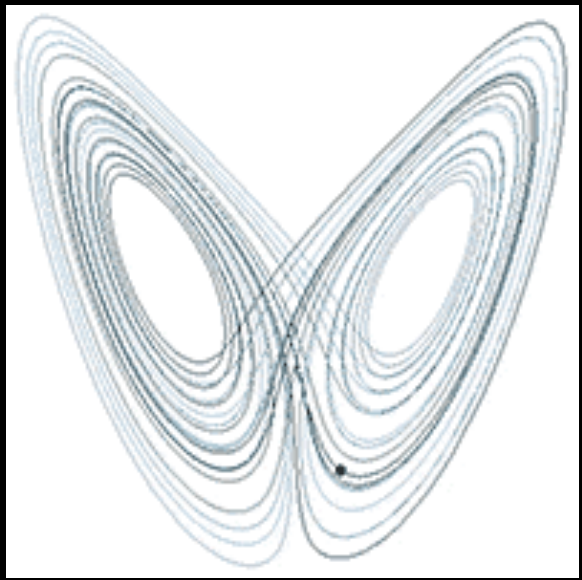
-(Lorenz 1969)



$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = rx - y - xz$$

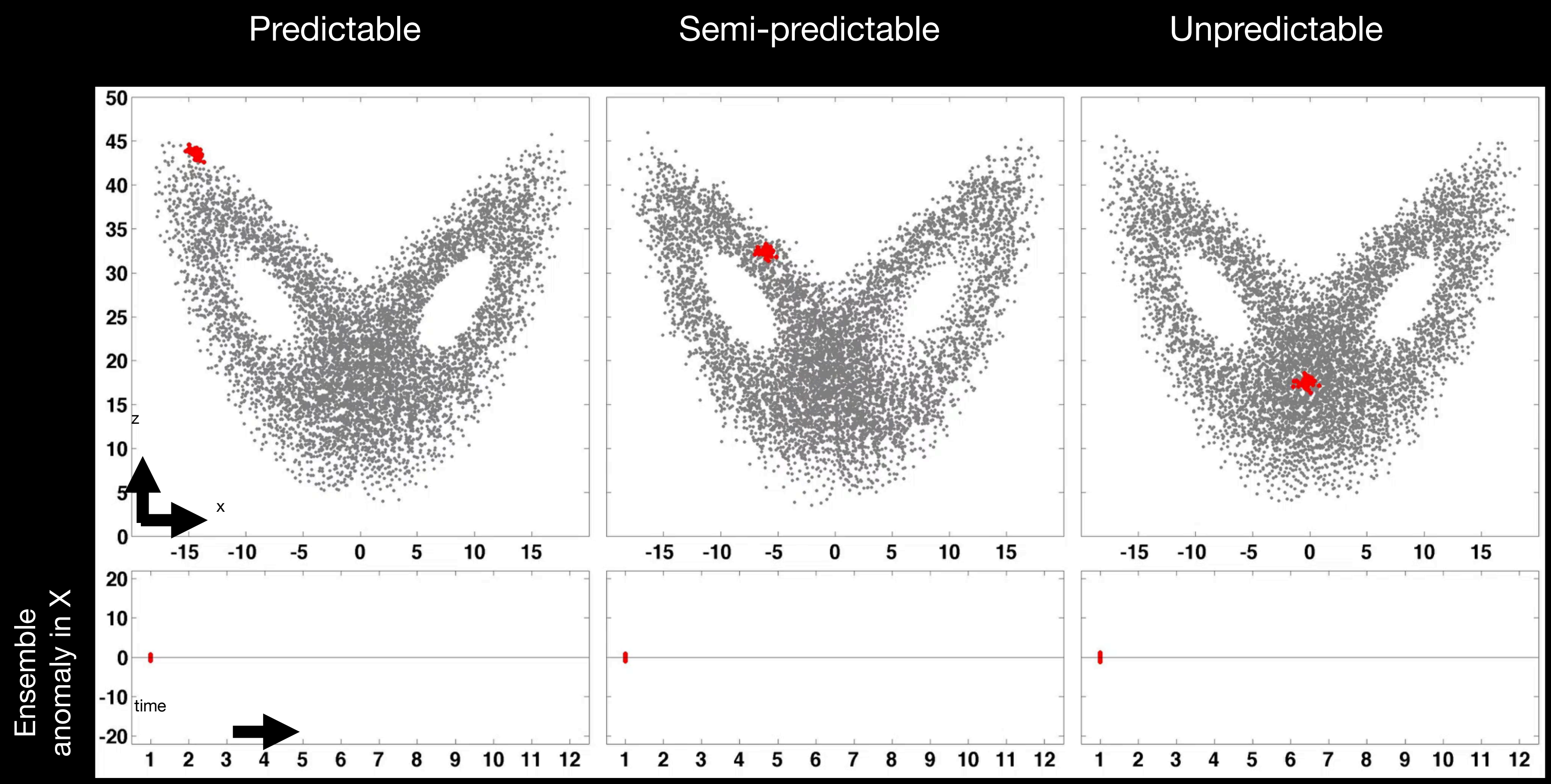
$$\frac{dz}{dt} = xy - bz$$

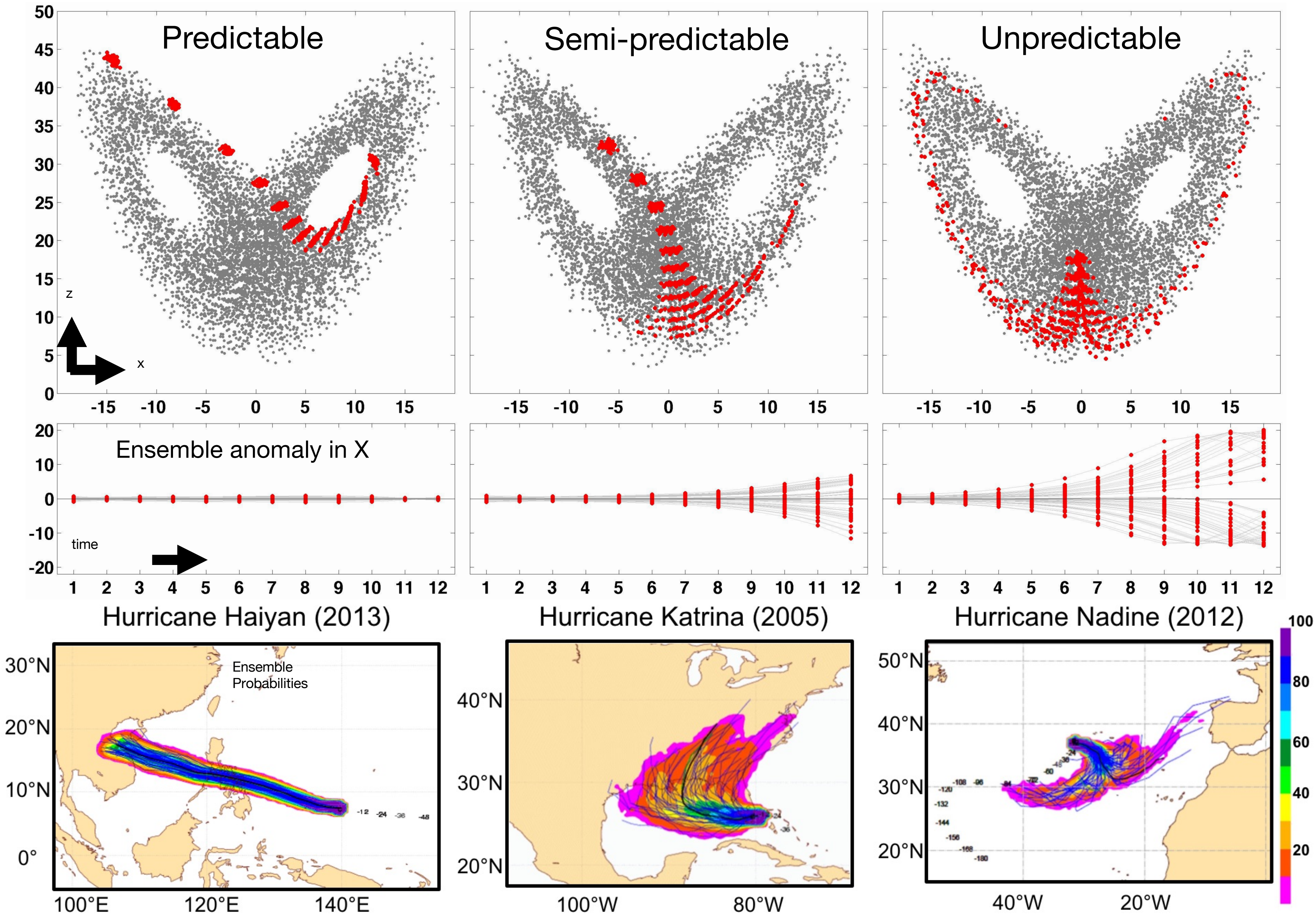


r = 28, σ = 10, and b = 8/3

source: wikipedia

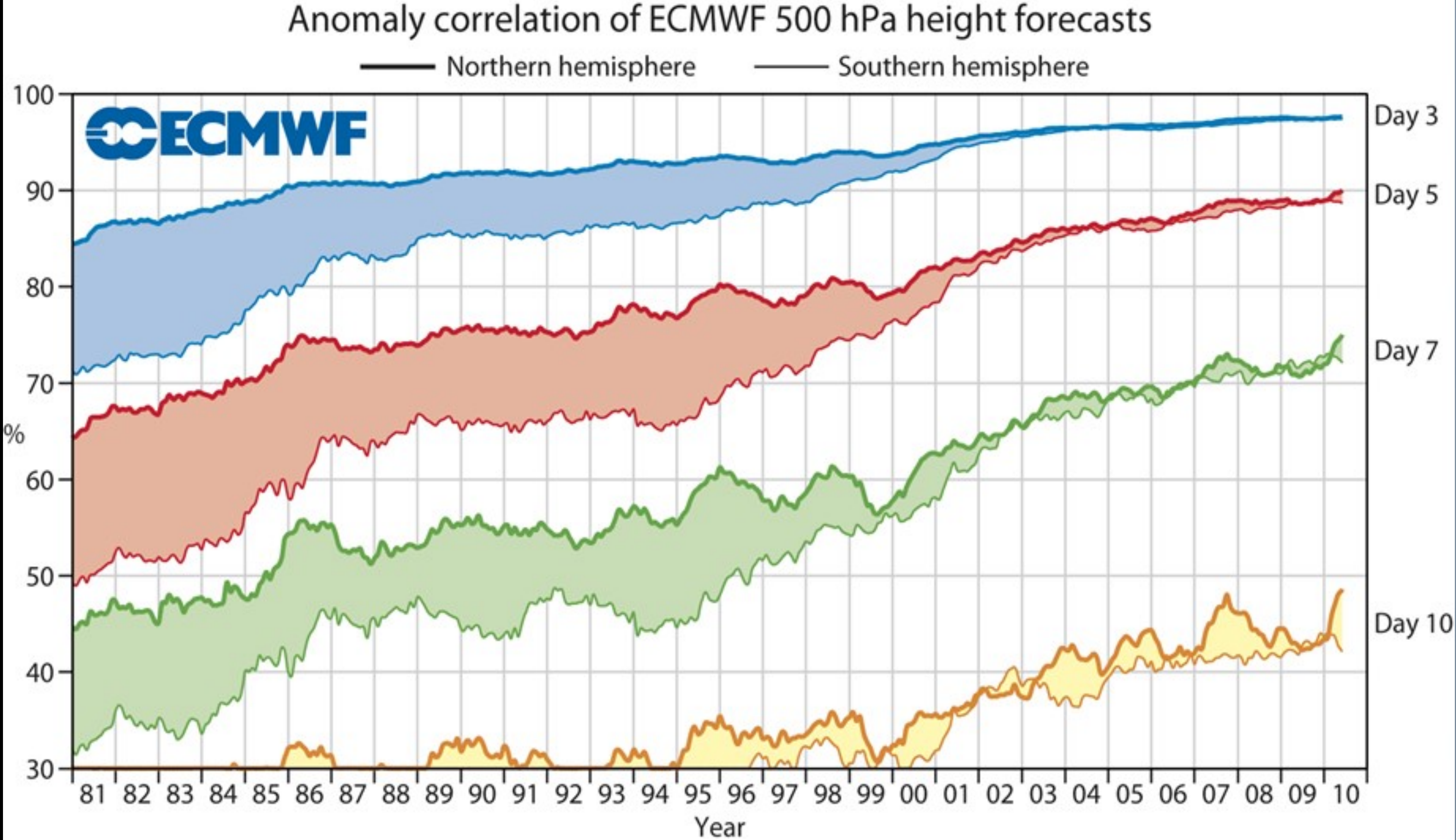
Ensemble Forecast with Initial Uncertainty



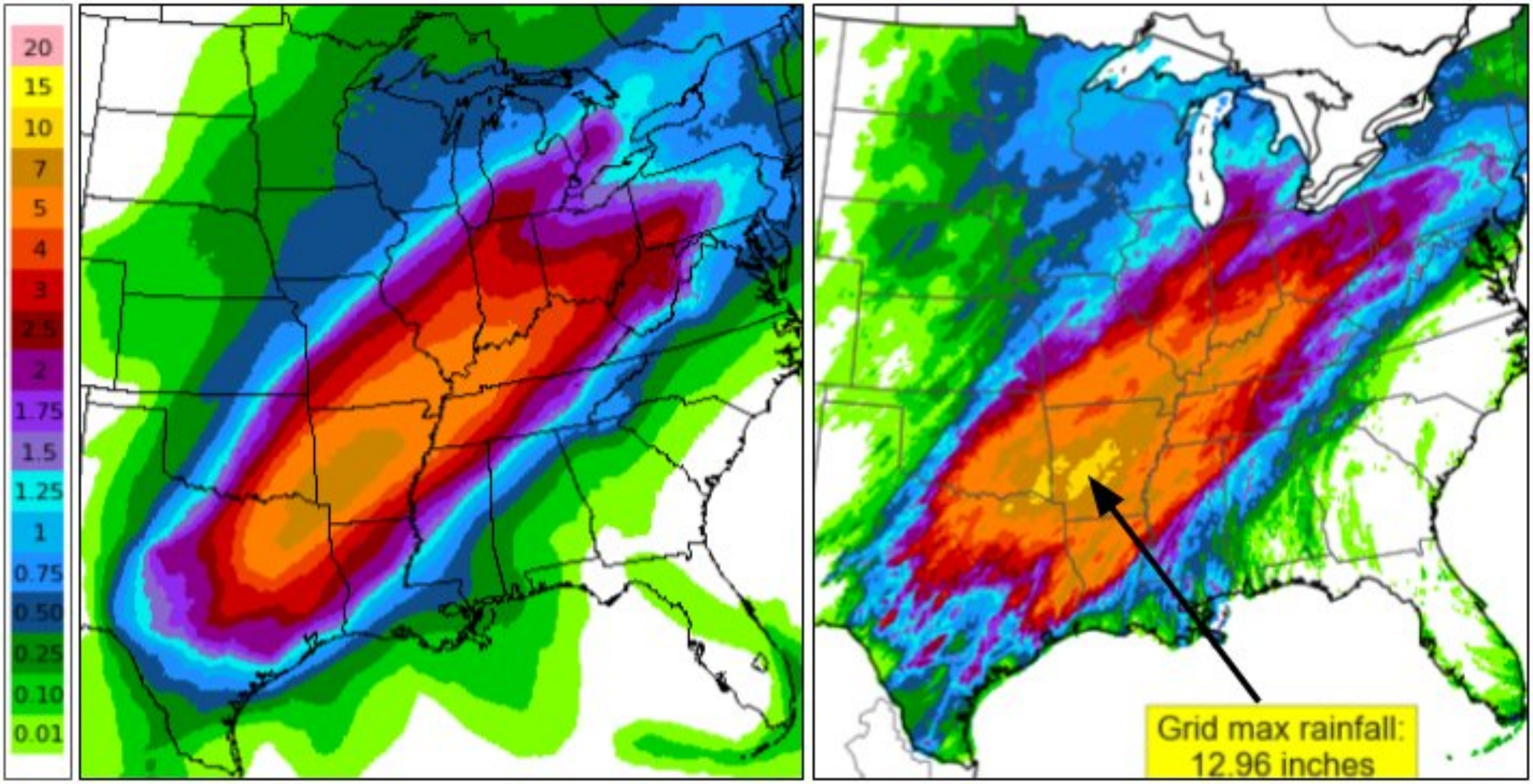


Predictable
Semi-predictable
Unpredictable
Ensemble anomaly in X
time
z
x
Hurricane Haiyan (2013)
Hurricane Katrina (2005)
Hurricane Nadine (2012)
Ensemble
Probabilities
30°N
20°N
10°N
0°
100°E
120°E
140°E
40°N
30°N
20°N
100°W
80°W
50°N
40°W
20°W
100
80
60
40
20

Advances in Global and Regional Weather Forecasts



WPC 120h (5-day) Precipitation Forecast (left) vs. Observed Precipitation (NWS/AHPS, right)



NWS/WPC 120h (5-day) forecast issued 0852 UTC Tue 2/20/18

NWS/AHPS 5-day total observed precipitation ending 12 UTC 2/25/18

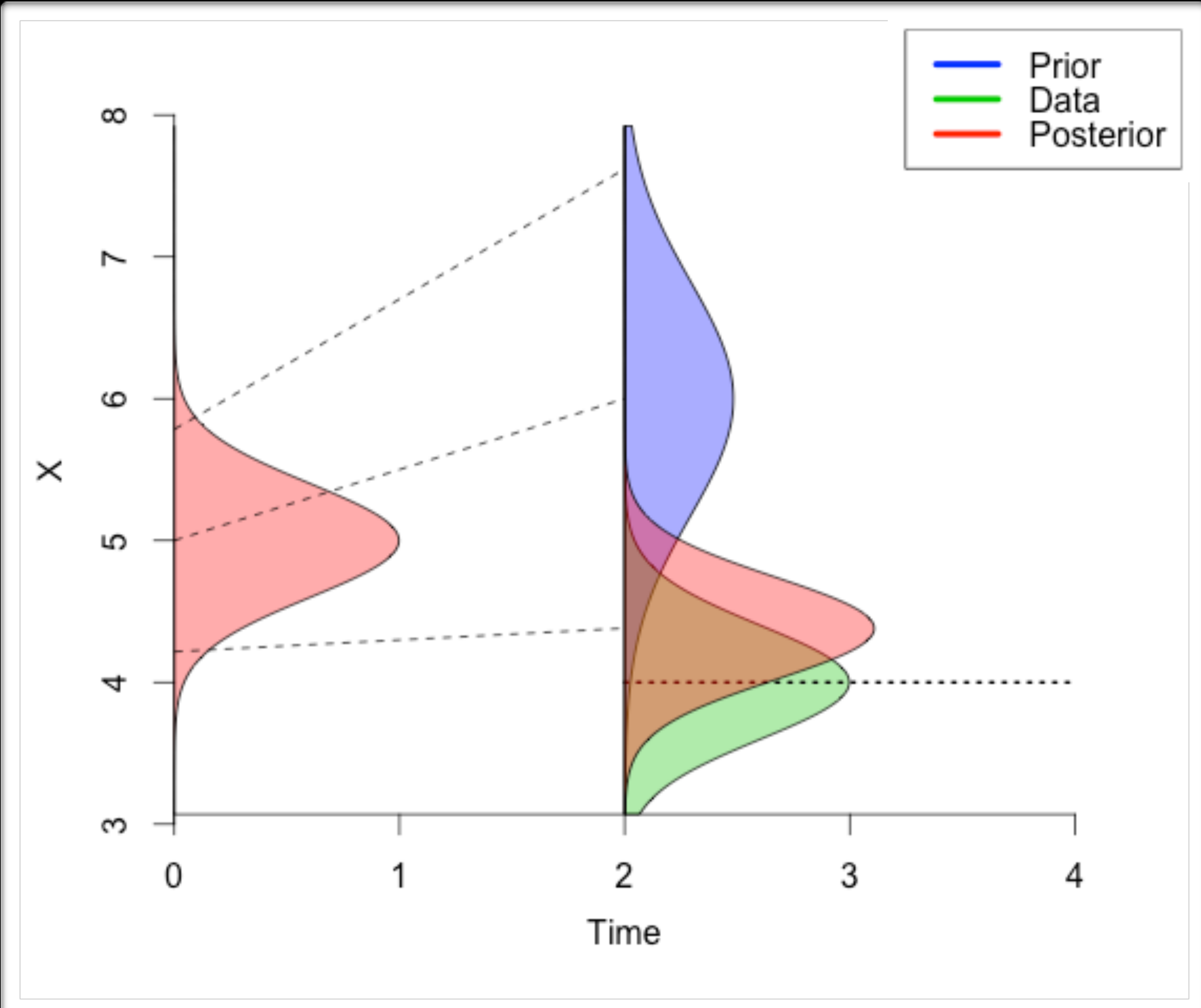
What should we talk about?

- The ecosystem of weather forecasting
- *Symbiosis of models and data*

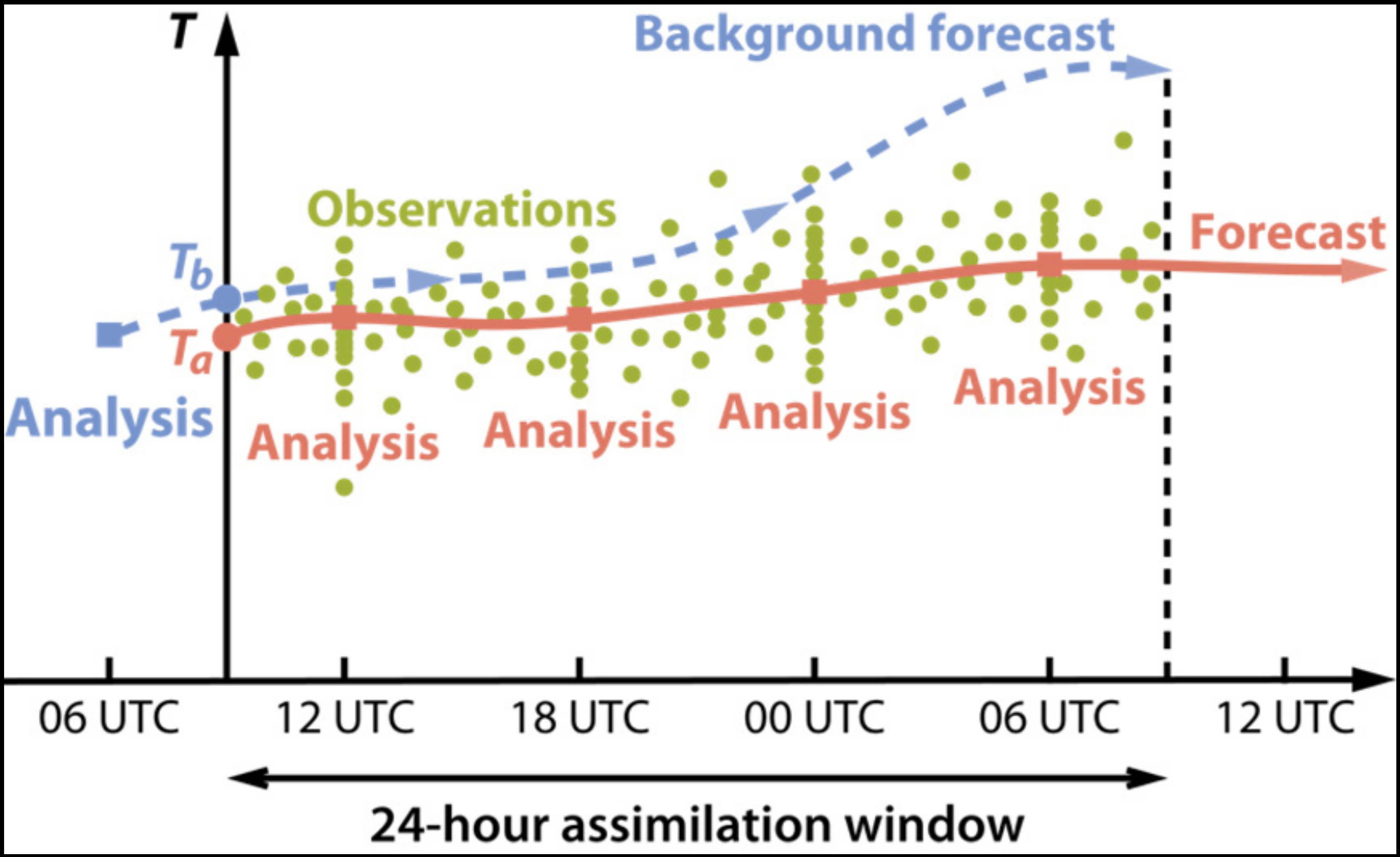
Navier-Stokes
a.k.a Newton’s Second Law
for a “Newtonian” Fluid

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + g_i \delta_{i3} - 2\varepsilon_{ijk}\Omega_j u_k + \frac{\mu}{\rho}\frac{\partial^2 u_i}{\partial x_j^2}$$

+ Conservations of Mass, Conservation of Energy (Electromagnetic radiation, Enthalpy, and Entropy), phase changes of water, equation of state, all on a rotating sphere, discretized and land, ocean, ice boundary conditions


Prior
Data
Posterior
X
Time
3
4
5
6
7
8
0
1
2
3
4

Model spread needs to be constrained by data



Applications of Bayes' Rule

Likelihood
How probable is the evidence given that our hypothesis is true?

Prior
How probable was our hypothesis *before* observing the evidence?

$$P(H \mid e) = \frac{P(e \mid H)\, P(H)}{P(e)}$$

Posterior
How probable is our hypothesis given the observed evidence?
(Not directly computable)

Marginal
How probable is the new evidence under all possible hypotheses?
$P(e) = \sum P(e \mid H_i)\, P(H_i)$

Lots of names, similar ideas

- Model-data fusion
- Data assimilation, dynamical state updating
- 4DVAR / 3DVAR variational adjoint method
- Maximum likelihood
- Bayesian hierarchical assimilation
- Parameter optimization
- Particle filters
- Markov Chain Monte Carlo (MCMC)
- Kalman Filter / Ensemble Kalman Filter

- *So Moving from Weather to Ecology…*

1st Problem: Putting ecology in Earth System Models

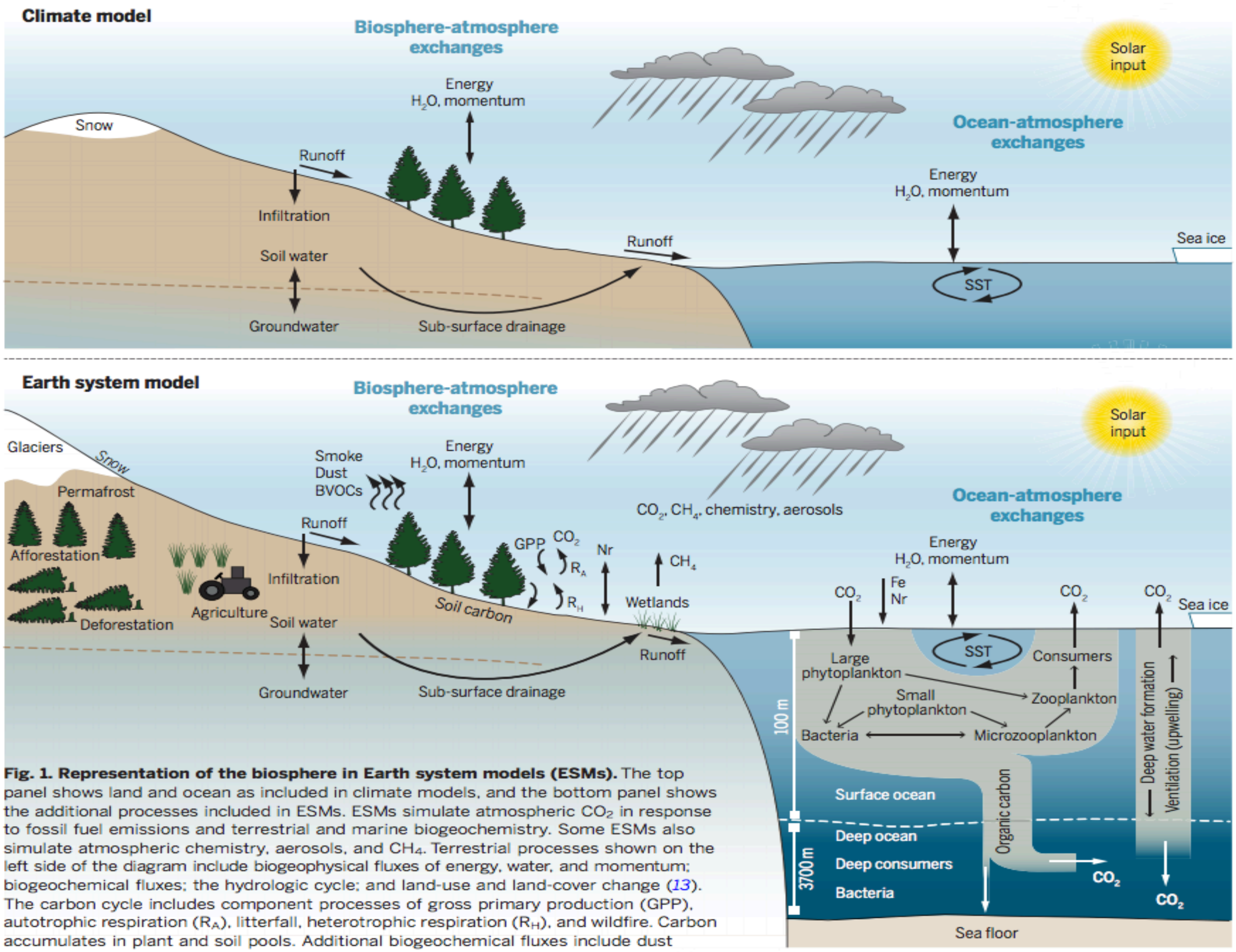
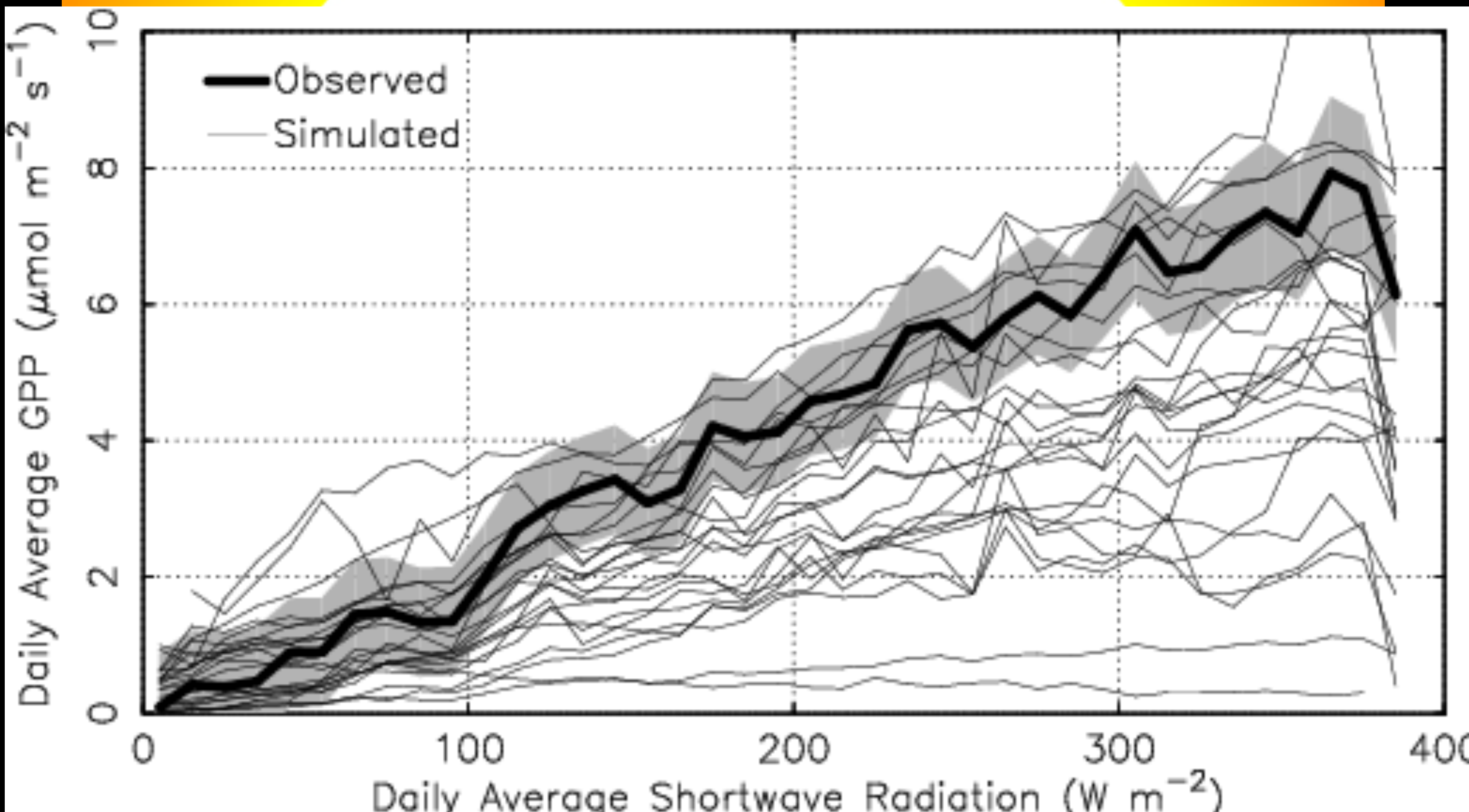


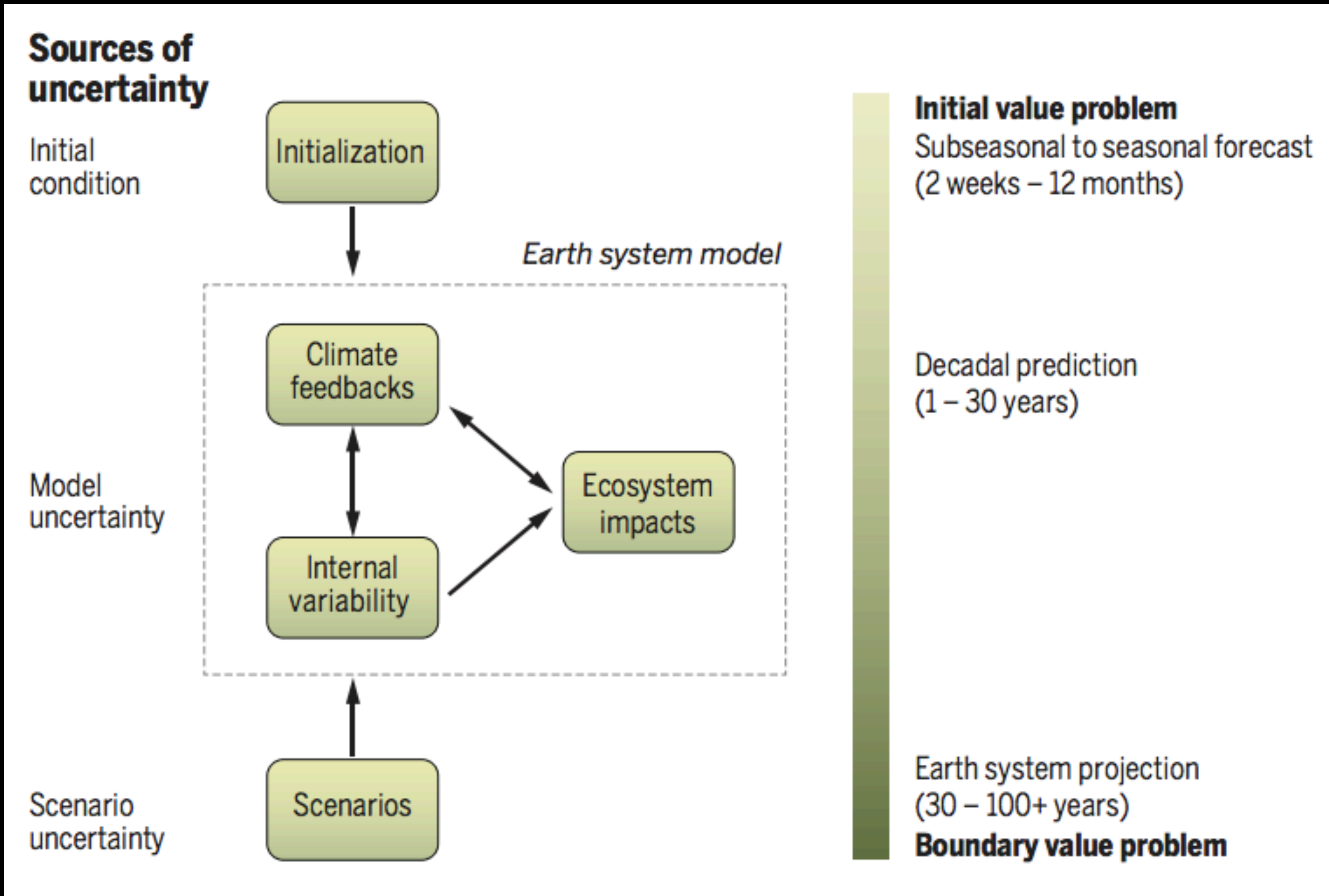
Fig. 1. Representation of the biosphere in Earth system models (ESMs). The top panel shows land and ocean as included in climate models, and the bottom panel shows the additional processes included in ESMs. ESMs simulate atmospheric CO_2 in response to fossil fuel emissions and terrestrial and marine biogeochemistry. Some ESMs also simulate atmospheric chemistry, aerosols, and CH_4. Terrestrial processes shown on the left side of the diagram include biogeophysical fluxes of energy, water, and momentum; biogeochemical fluxes; the hydrologic cycle; and land-use and land-cover change (13). The carbon cycle includes component processes of gross primary production (GPP), autotrophic respiration (R_A), litterfall, heterotrophic respiration (R_H), and wildfire. Carbon accumulates in plant and soil pools. Additional biogeochemical fluxes include dust entrainment, wildfire chemical emissions, biogenic volatile organic compounds (BVOCs),

Bonan *et al.*, *Science* **359**, eaam8328 (2018)   2 February 2018



Schaefer et al., 2012

2nd problem: Dominant uncertainty changes



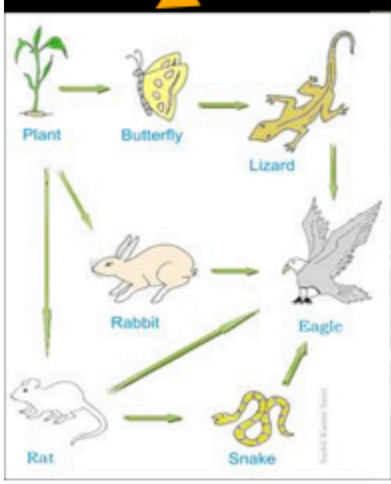
Bonan *et al.*, *Science* **359**, eaam8328 (2018)   2 February 2018

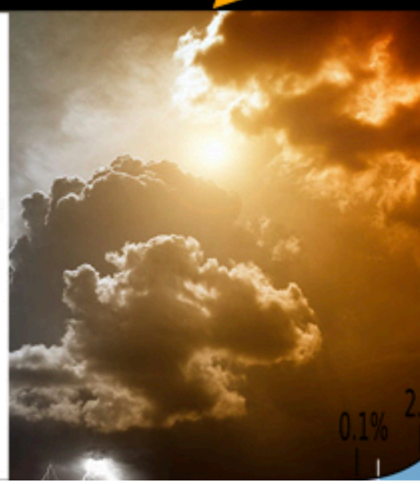
Dietze *2017 Ecological Applications*

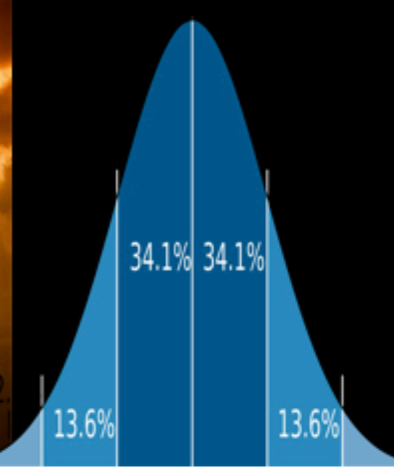
PREDICTABILITY IS KEY TO ECOLOGICAL THEORY AND PRACTICE

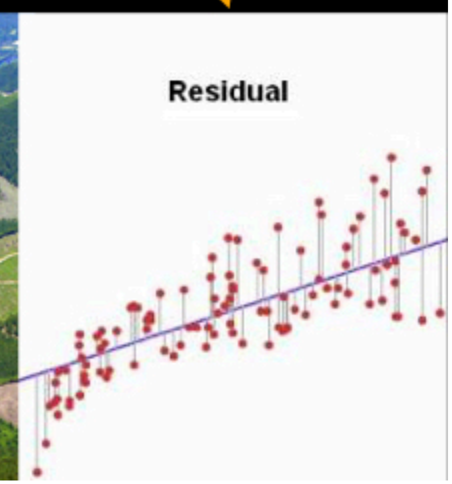
$$Var[Y_{t+1}] \approx \underbrace{\left(\frac{\partial f}{\partial Y}\right)^2}_{\text{stability}} \underbrace{Var[Y_t]}_{\text{IC uncert}} + \underbrace{\left(\frac{\partial f}{\partial X}\right)^2}_{\text{driver sens}} \underbrace{Var[X]}_{\text{driver uncert}} + \underbrace{\left(\frac{\partial f}{\partial \theta}\right)^2}_{\text{param sens}} \left(\underbrace{Var[\bar{\theta}]}_{\text{param uncert}} + \underbrace{Var[\alpha]}_{\text{param variability}} \right) + \underbrace{Var[\varepsilon]}_{\text{process error}}$$

$$= INTERNAL + EXTERNAL + PARAMETERS + \begin{matrix} RANDOM \\ EFFECTS \end{matrix} + \begin{matrix} PROCESS \\ ERROR \end{matrix}$$

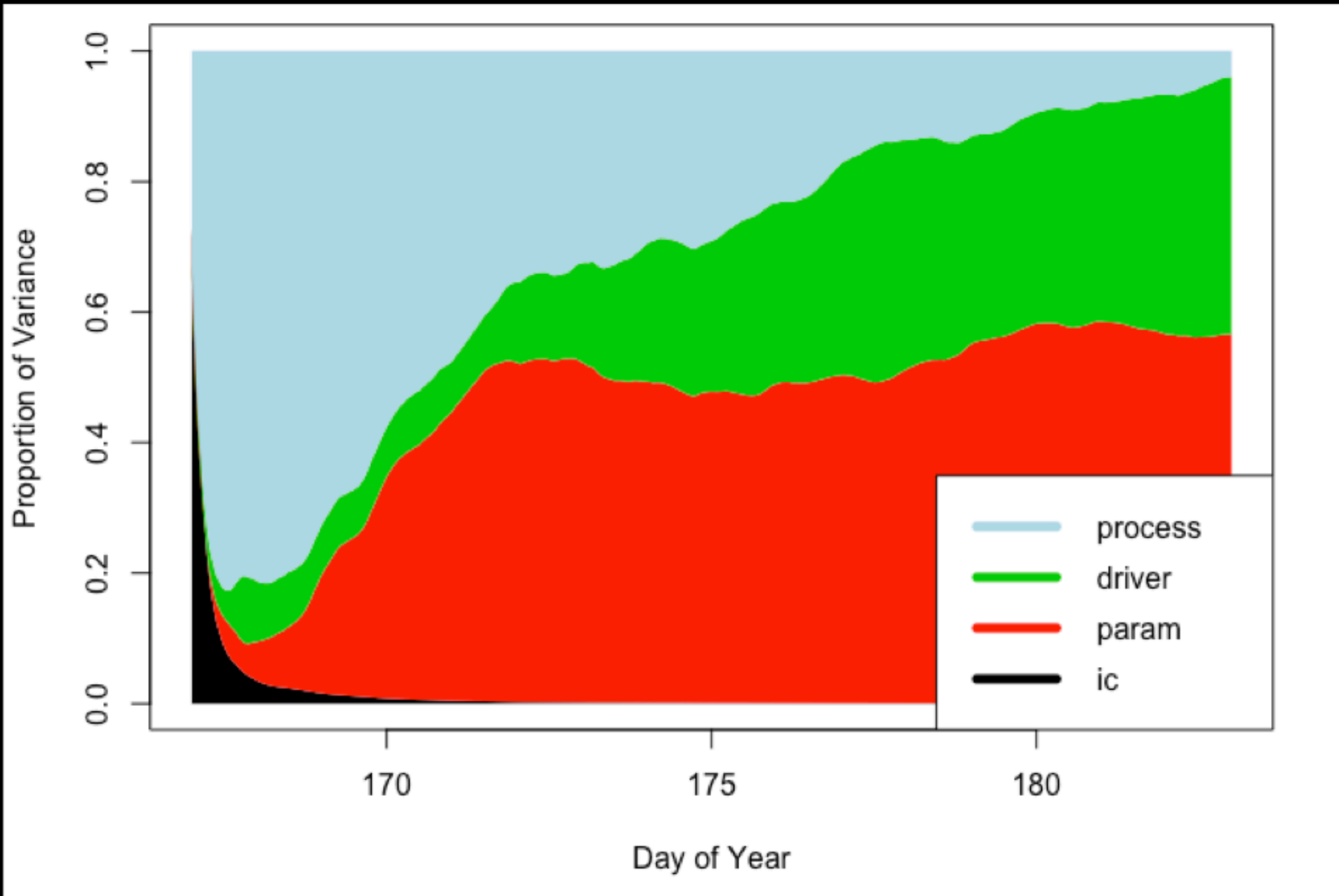






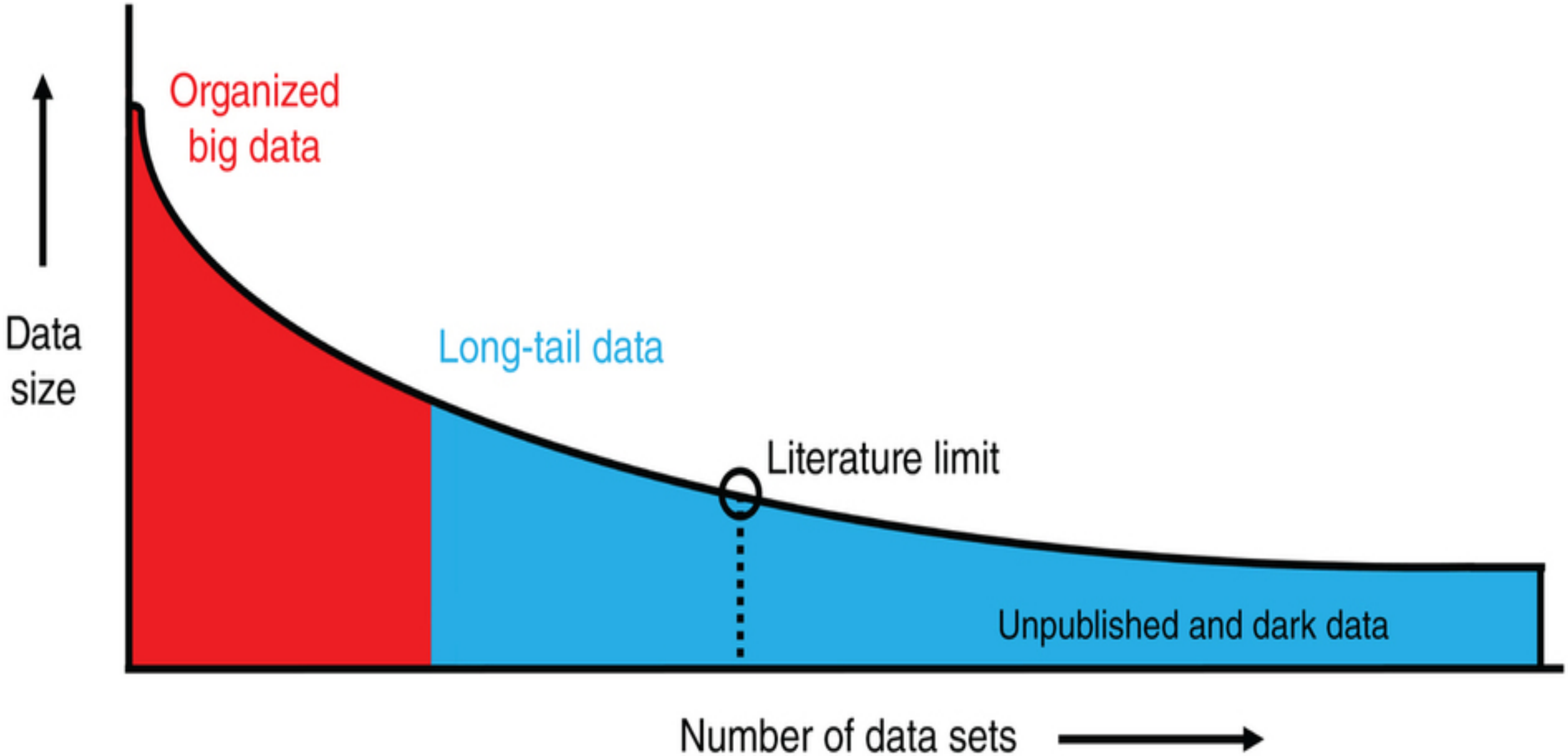


Willow Creek, Net Carbon Flux



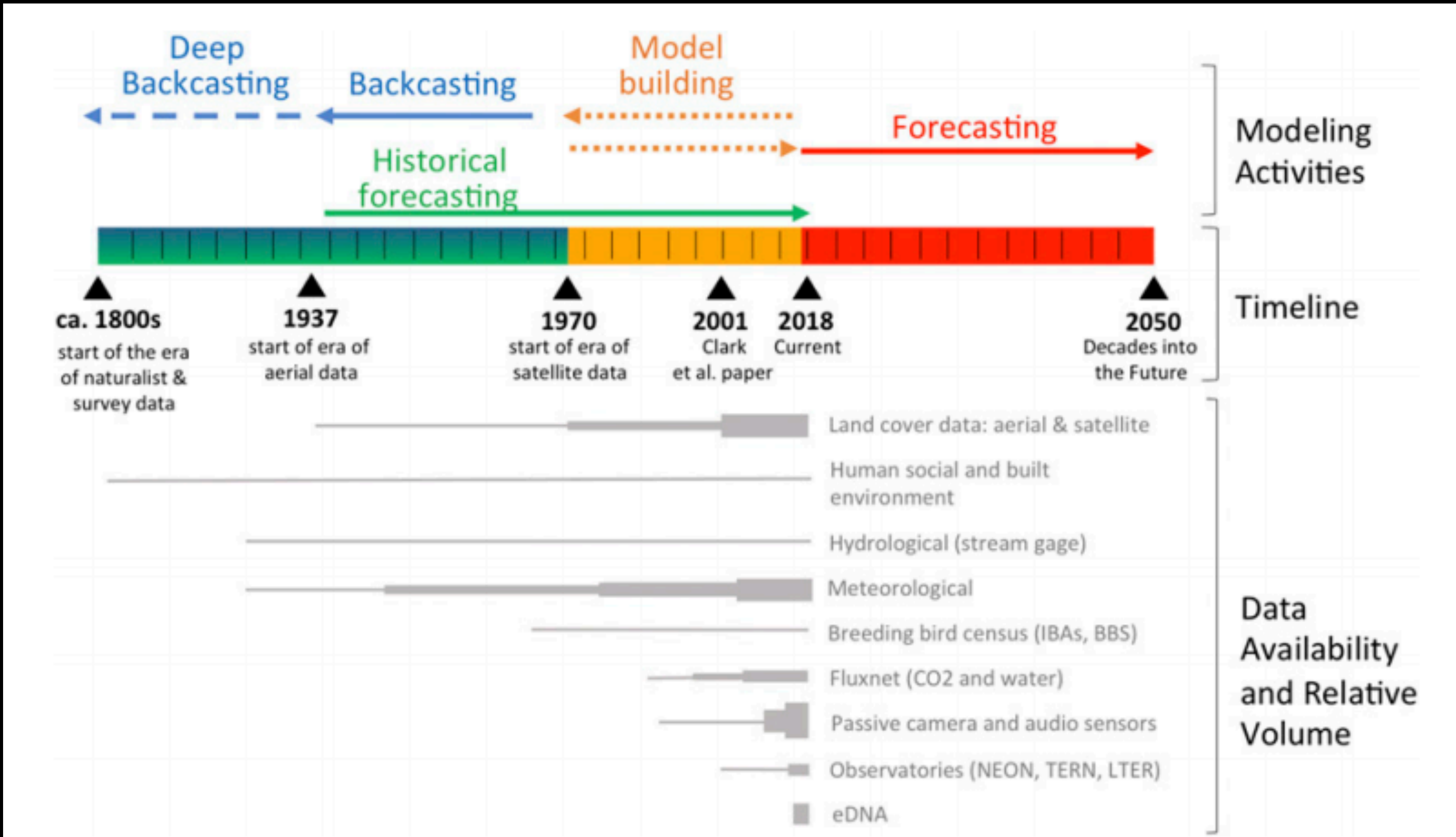
Dietze *2017 Ecological Applications*

3rd problem: Observations are big and long!

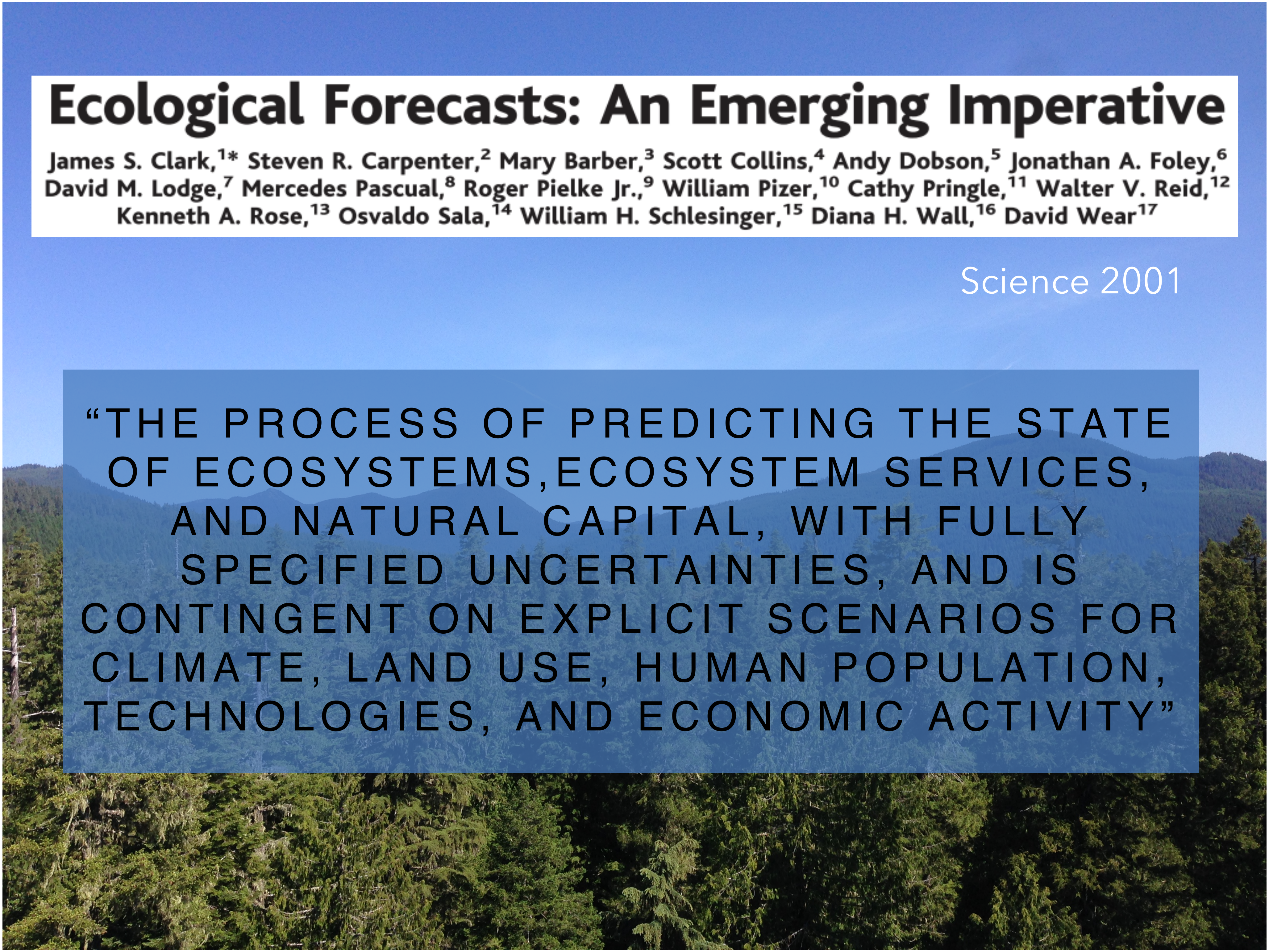


Ferguson et al., 2014
Nature Neuroscience

3rd problem: Observations are big and long!

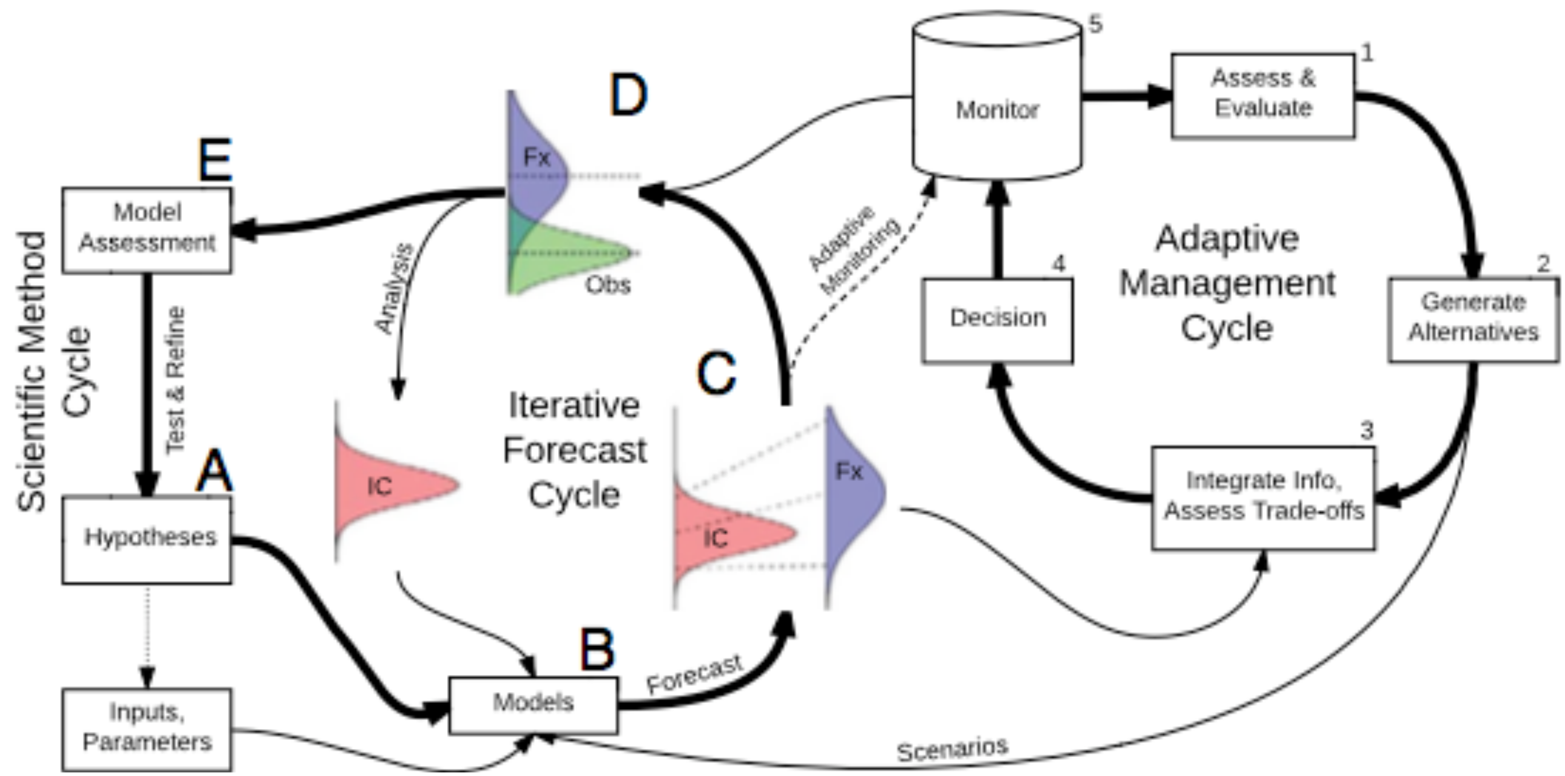


PNAS 2018; published ahead of print January 30, 2018, https://doi.org/10.1073/pnas.1710231115


Ecological Forecasts: An Emerging Imperative
James S. Clark,[1]* Steven R. Carpenter,[2] Mary Barber,[3] Scott Collins,[4] Andy Dobson,[5] Jonathan A. Foley,[6] David M. Lodge,[7] Mercedes Pascual,[8] Roger Pielke Jr.,[9] William Pizer,[10] Cathy Pringle,[11] Walter V. Reid,[12] Kenneth A. Rose,[13] Osvaldo Sala,[14] William H. Schlesinger,[15] Diana H. Wall,[16] David Wear[17]
Science 2001
“THE PROCESS OF PREDICTING THE STATE OF ECOSYSTEMS,ECOSYSTEM SERVICES, AND NATURAL CAPITAL, WITH FULLY SPECIFIED UNCERTAINTIES, AND IS CONTINGENT ON EXPLICIT SCENARIOS FOR CLIMATE, LAND USE, HUMAN POPULATION, TECHNOLOGIES, AND ECONOMIC ACTIVITY”

Iterative near-term ecological forecasting: Needs, opportunities, and challenges

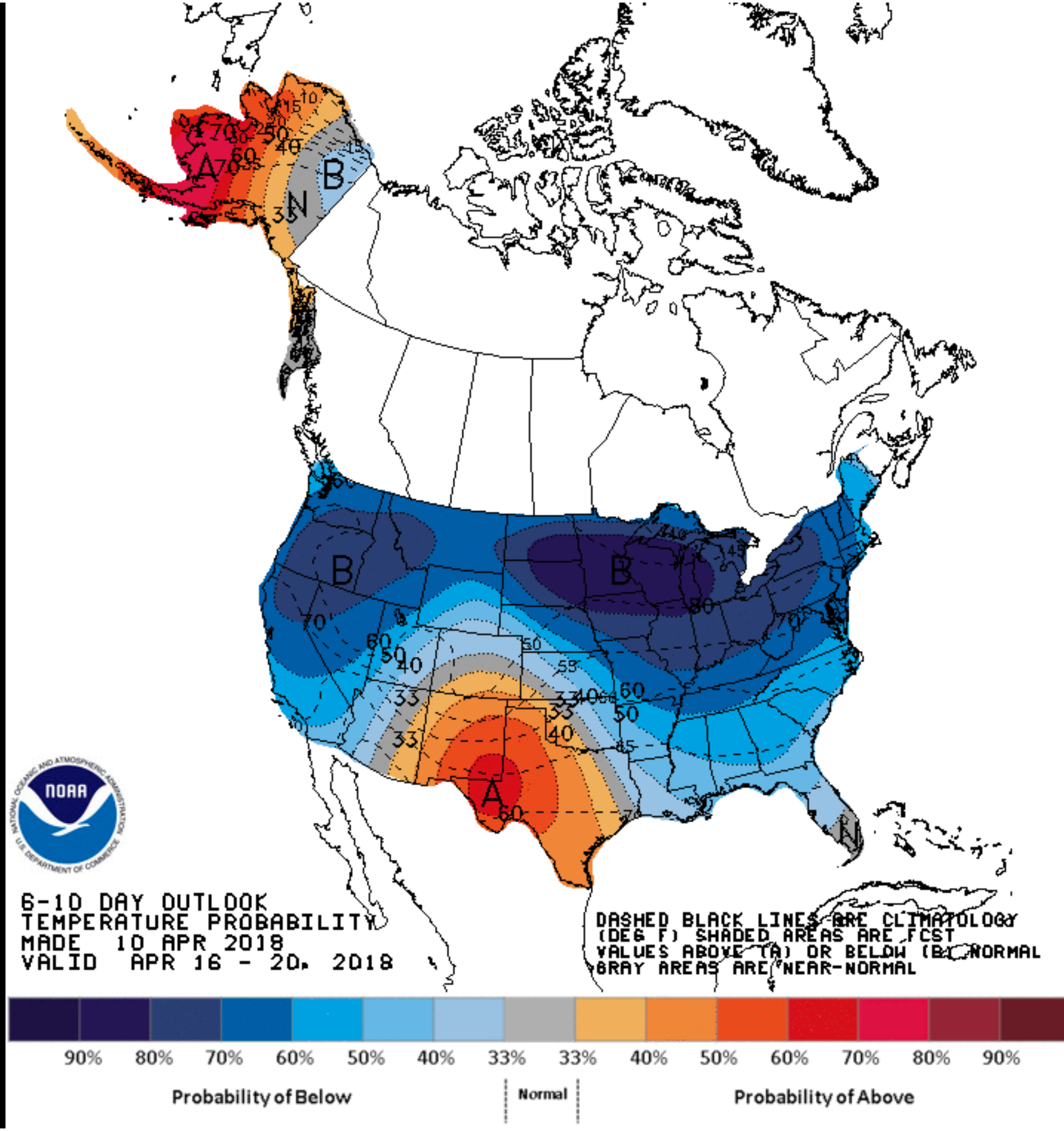
Michael C. Dietze[a,1], Andrew Fox[b], Lindsay M. Beck-Johnson[c], Julio L. Betancourt[d], Mevin B. Hooten[e,f,g], Catherine S. Jarnevich[h], Timothy H. Keitt[i], Melissa A. Kenney[j], Christine M. Laney[k], Laurel G. Larsen[l], Henry W. Loescher[k,m], Claire K. Lunch[k], Bryan C. Pijanowski[n], James T. Randerson[o], Emily K. Read[p], Andrew T. Tredennick[q,r], Rodrigo Vargas[s], Kathleen C. Weathers[t], and Ethan P. White[u,v,w]



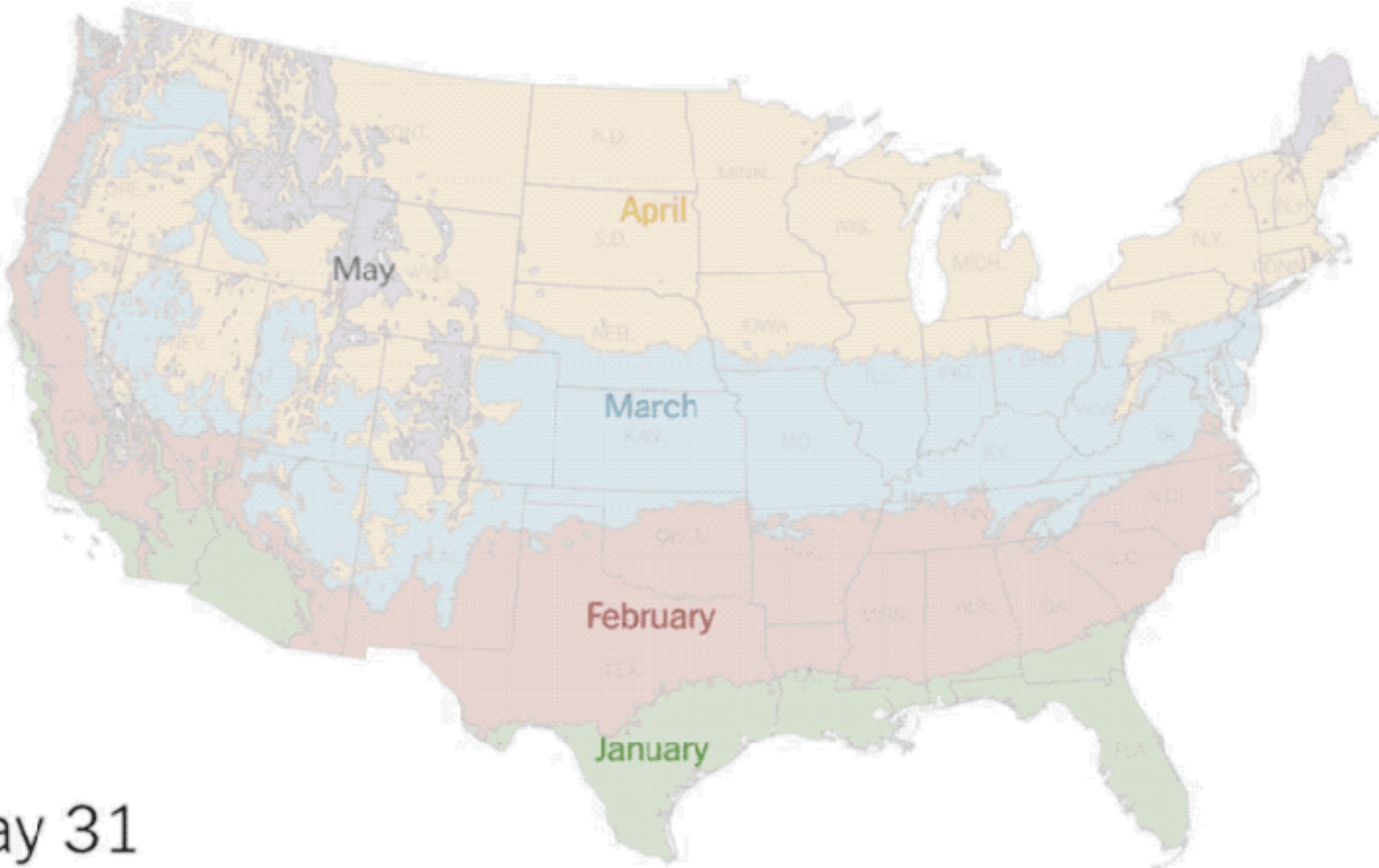
www.pnas.org/cgi/doi/10.1073/pnas.1710231115

What should we talk about?

- The ecosystem of weather forecasting
- Symbiosis of models and data
- *The current landscape of ecological forecasting*

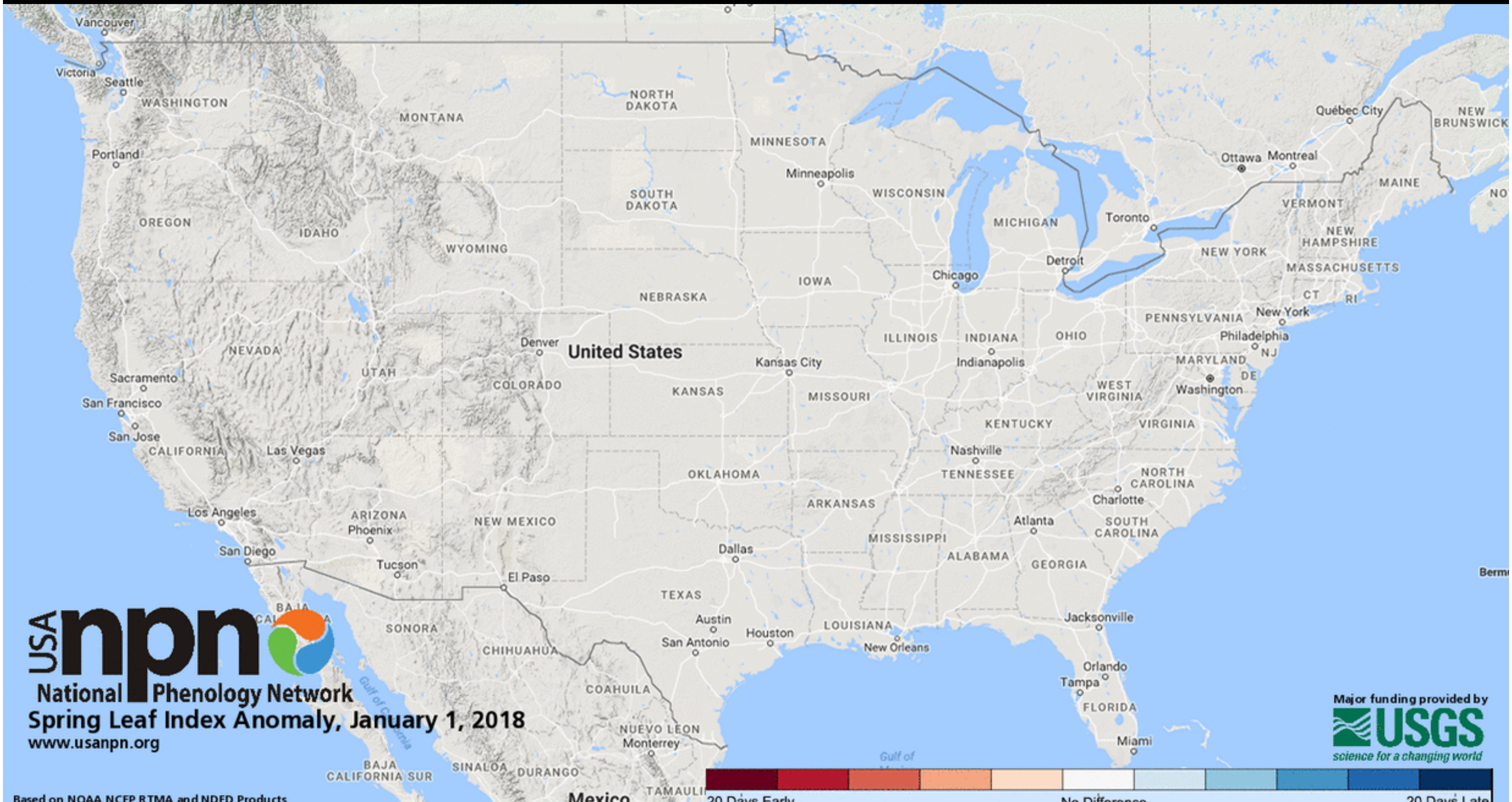

6-10 DAY OUTLOOK
TEMPERATURE PROBABILITY
MADE 10 APR 2018
VALID APR 16 - 20, 2018
DASHED BLACK LINES ARE CLIMATOLOGY
(DEG F) SHADED AREAS ARE FCST
VALUES ABOVE (A) OR BELOW (B) NORMAL
GRAY AREAS ARE NEAR-NORMAL
NOAA
90% 80% 70% 60% 50% 40% 33% 33% 40% 50% 60% 70% 80% 90%
Probability of Below
Normal
Probability of Above

Average 'First Leaf' Appearance



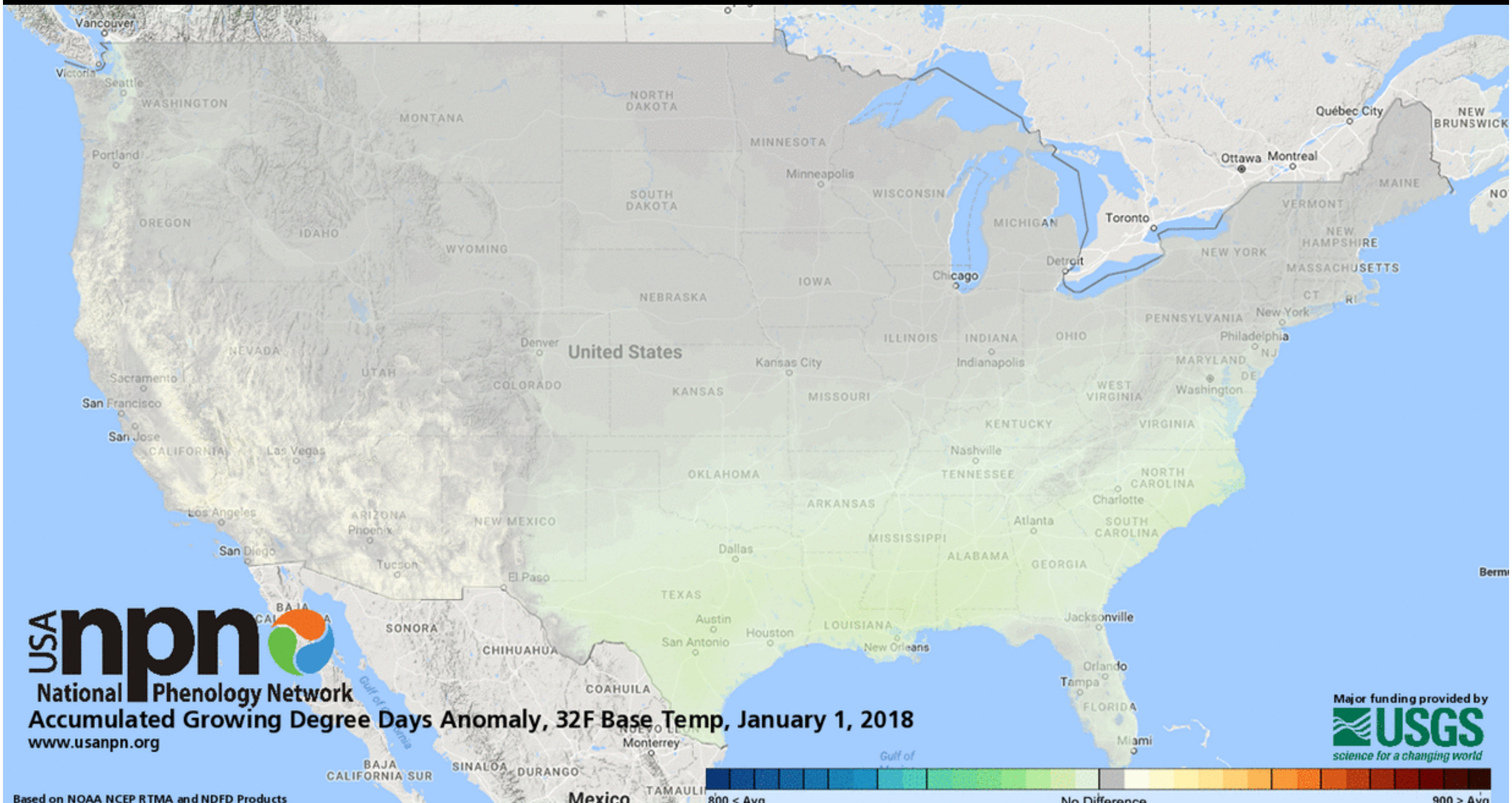
May 31

The New York Times | USA National Phenology Network



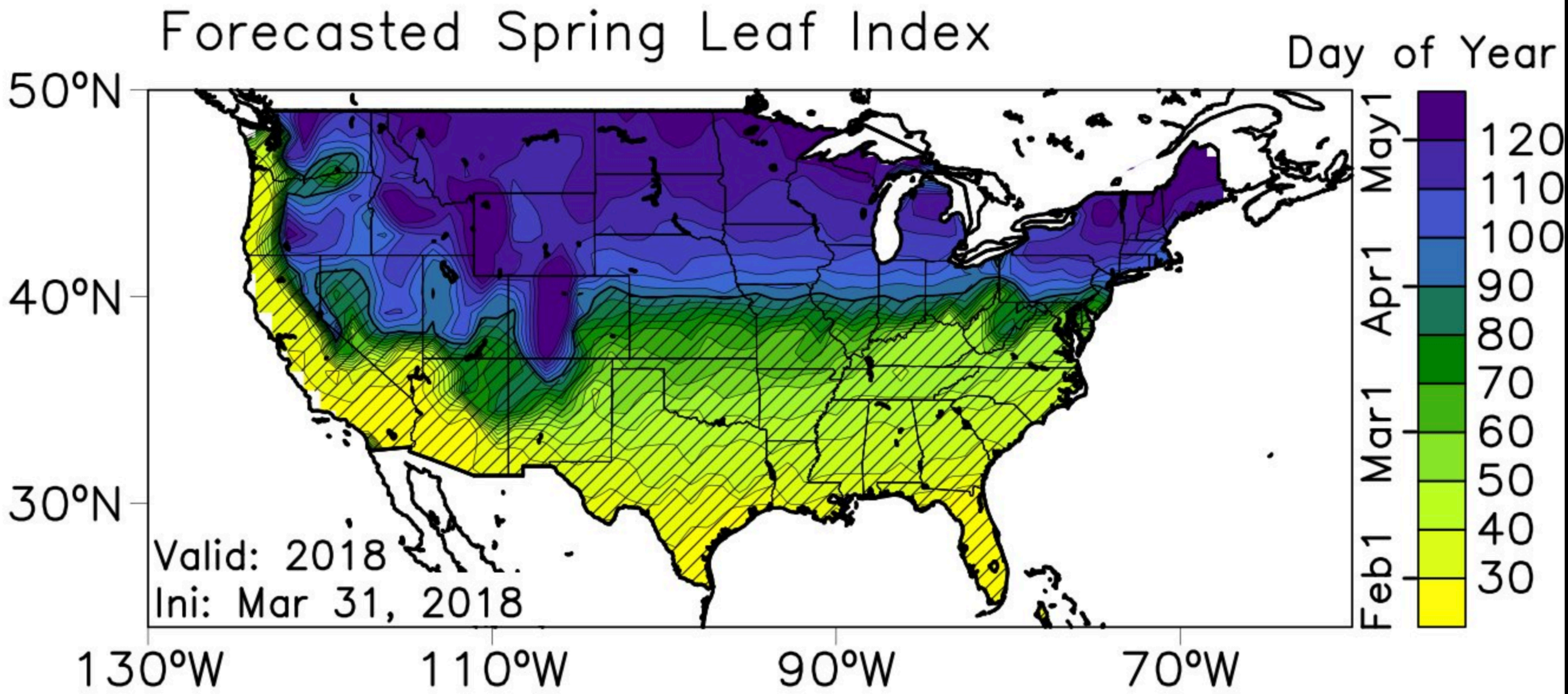
http://data.usanpn.org/npn-viz-tool/

Jake Weltzin , National Phonological Network

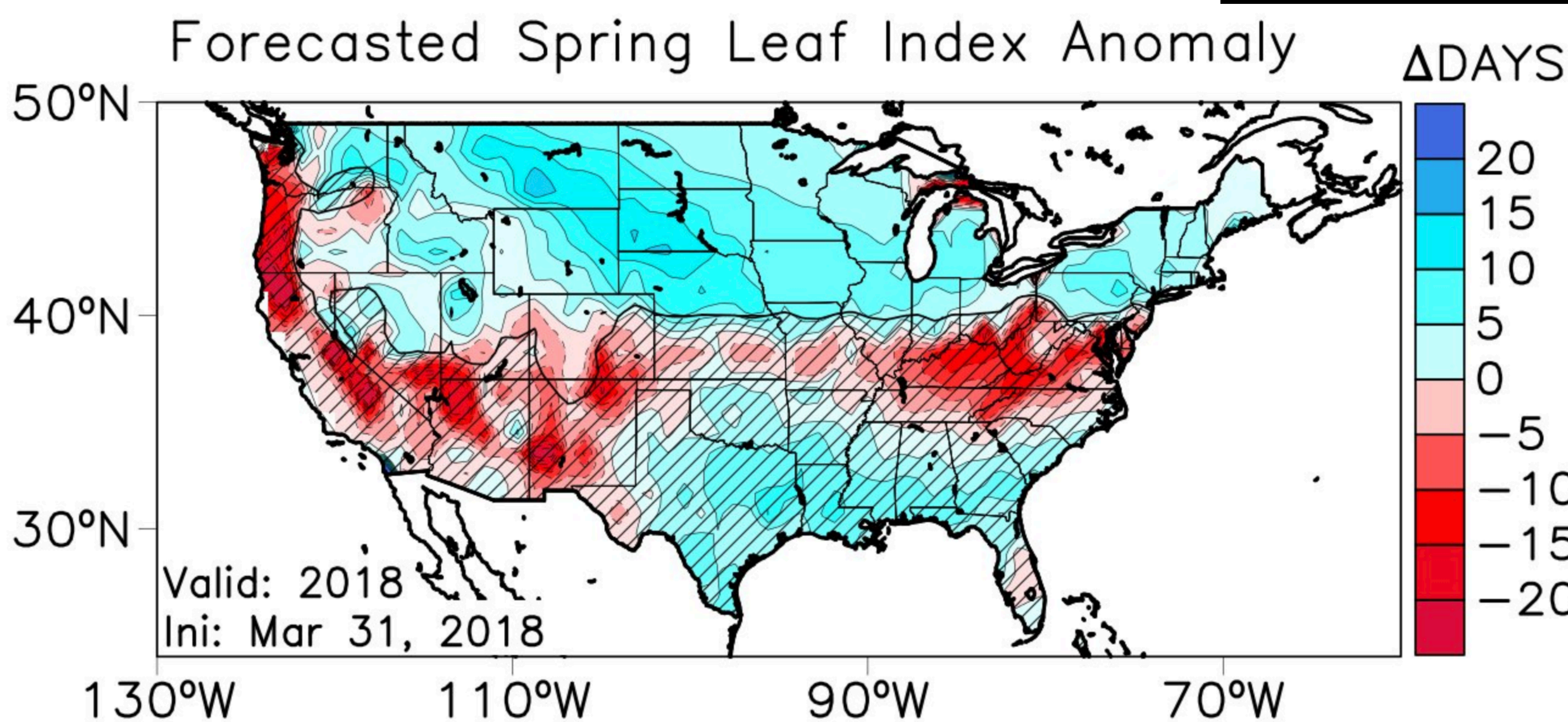


http://data.usanpn.org/npn-viz-tool/

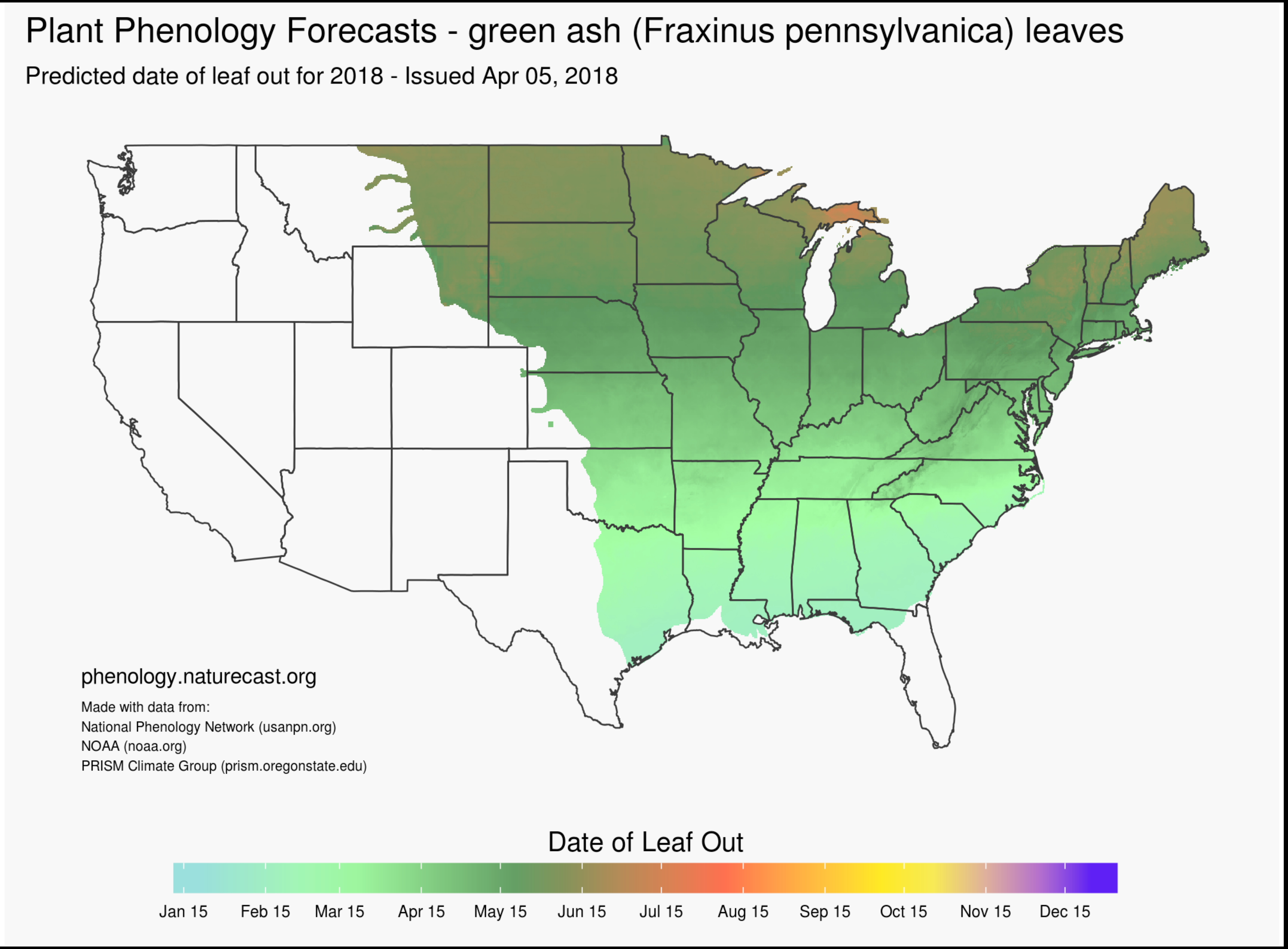
Jake Weltzin , National Phonological Network



Toby Ault
Cornell



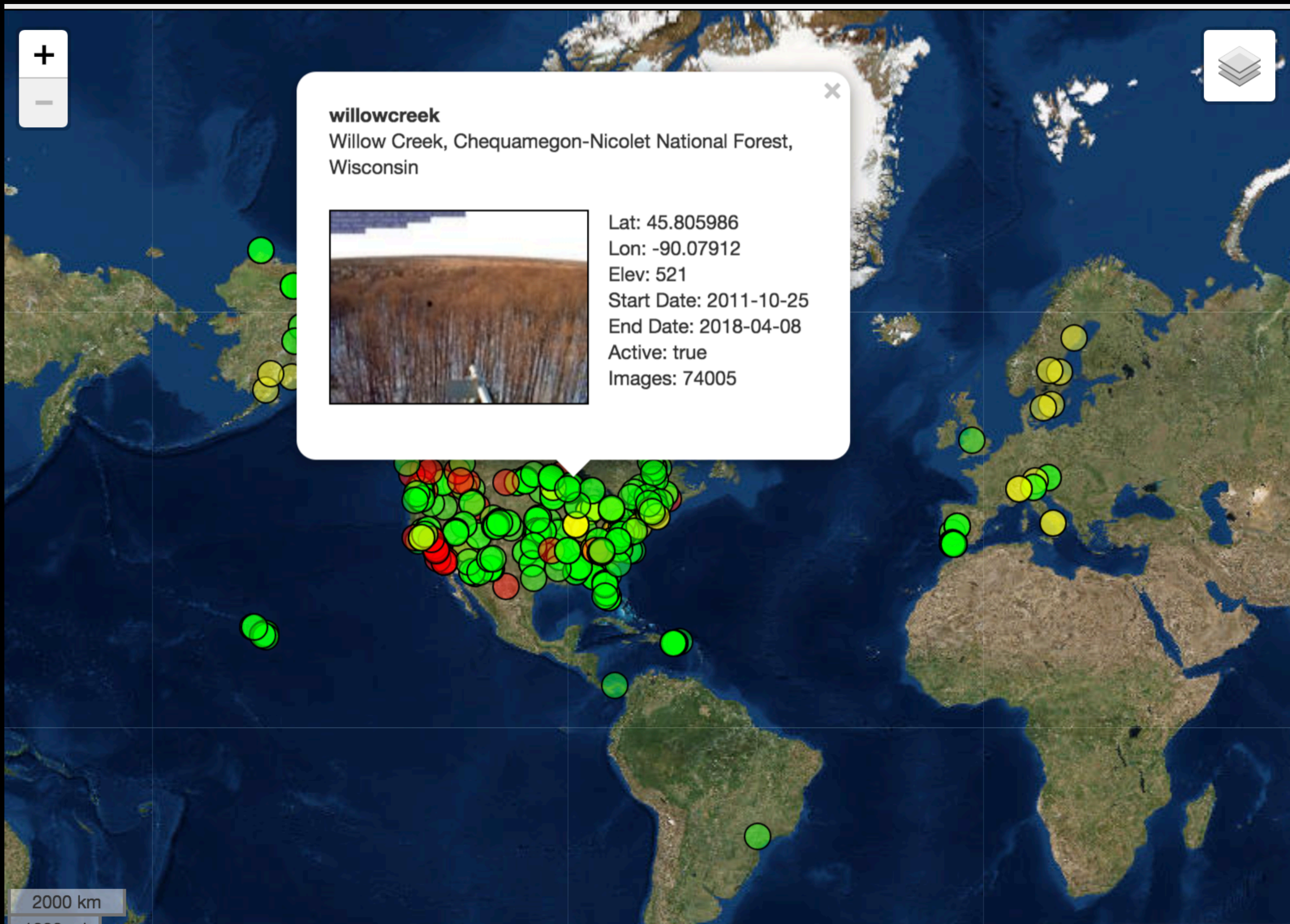
http://ecrl.eas.cornell.edu/node/60



Shawn Taylor, Ethan White, U Florida

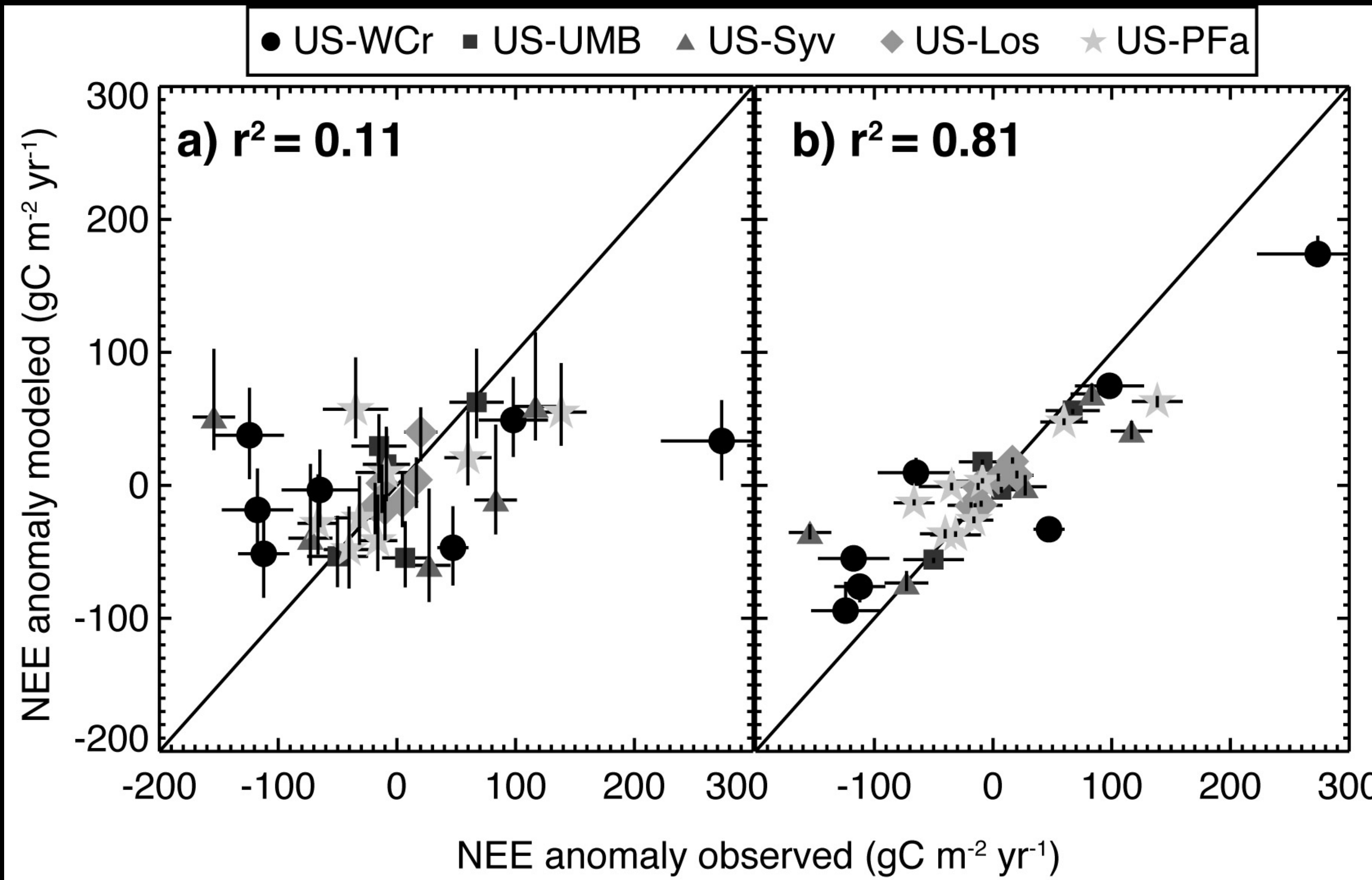
http://phenology.naturecast.org/

https://phenocam.sr.unh.edu/webcam/gallery/



Andrew Richardson, Northern Arizona U

Squeezing more information out of flux towers



Desai, 2010

Journal of Hazardous Materials 287 (2015) 356–363

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

ELSEVIER

CrossMark

Cyanobacterial bloom management through integrated monitoring and forecasting in large shallow eutrophic Lake Taihu (China)

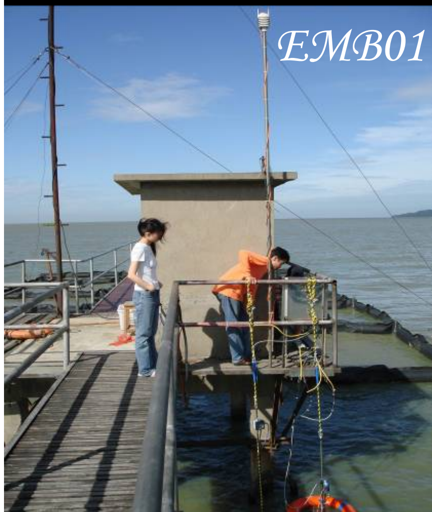
Boqiang Qin*, Wei Li, Guangwei Zhu, Yunlin Zhang, Tingfeng Wu, Guang Gao

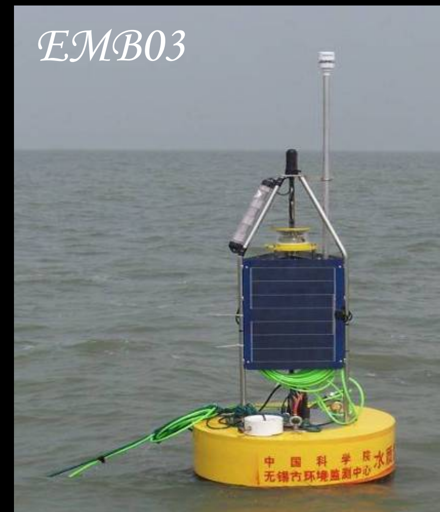
State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academic of Sciences, 73 East Beijing Road, Nanjing 210008, China

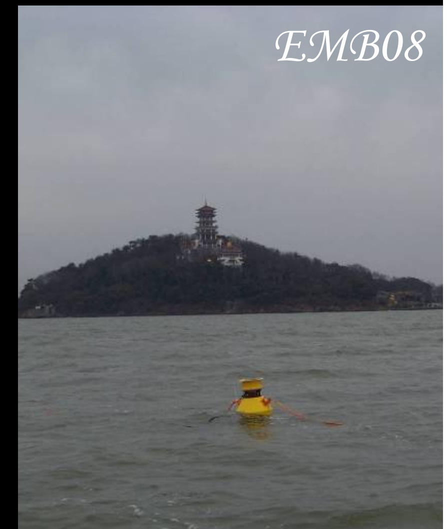
Algal Bloom in Taihu, 12 Jul, 2007, Guangwei Zhu

Slides courtesy of K.C. Weathers, Cary Institute and GLEON

Early-warning the harmful algal bloom







13 High frequency monitoring systems were built for basic data of the model (Guangwei Zhu)

The 3-days forecasting and early-warning **report** of harmful algal to public

太湖水污染及蓝藻监测预警半周报

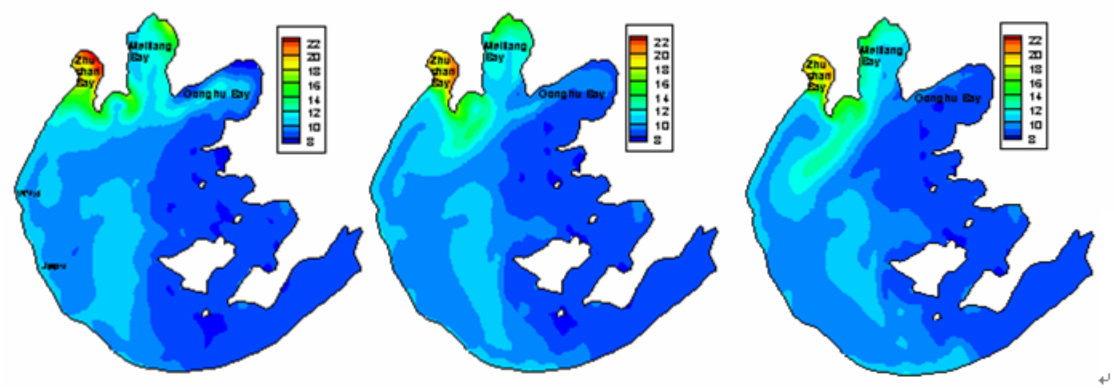
太湖水污染及蓝藻监测预警工作小组　　2010-07-29

中国科学院南京地理与湖泊研究所太湖蓝藻监测预警半周报

预测地点：太湖梅梁湾、贡湖湾　　日期：2010-07-29

	巡测点叶绿素 a 含量(微克/升)				三日温度（℃）			三日风向			三日气象		
	0	1	2	3	30	31	01	30	31	01	30	31	01
梅梁湾	10.5	6.3	3.3	4.1	28-35	28-36	28-36	SW	SW	SW	多云	多云	多云
贡湖湾	3.2	3.7	6.5	1.8									
预测概率	7 月 30 日至 8 月 1 日三天内 梅梁湾水面灾害性蓝藻水华发生概率 90 % 主要区域：牵龙口、东部沿岸带 贡湖湾水面灾害性蓝藻水华发生概率 90 % 主要区域：湾顶、北部沿岸带												

梅梁湾、贡湖湾随后三天叶绿素 a 浓度分布



7 月 30 日　　7 月 31 日　　8 月 1 日

今日太湖蓝藻水华现状描述：巡测时段西南风 3－4 级，风浪偏大，乌溪港以北至竺山湾次岸带水华密度很大，覆盖整个水面生物量也很高。夹浦以东，湖心藻颗粒密度不大，生物量也较少。梅梁湾东部湾口蓝藻水华密度中等，东北牵龙口水域，西部沿岸带南段有少量水华。贡湖湾口蓝藻密度较大，湾心至锡东水厂藻密度小于湾口，北部沿岸带蓝藻生物量中等。

未来三天内蓝藻水华发展趋势：未来三天天气炎热，风向为西南风。在西南风的影响下，竺山湾东部将出现较多蓝藻水华，而处于上风口的西太湖沿岸带与次沿岸带的水华情况可能稍有缓解，但仍需关注其变化。蓝藻将会向处于下风口的梅梁湾牵龙口水域、湾心以东的大部水域，贡湖湾湾心以西，尤其湾顶锡东水厂一带及南泉水厂附近的北部沿岸带漂移，容易形成水华堆积，应关注这一带的变化，并加强水源地的保护。

监测人：季江、薛静琛　　数据整理人：李未　　预报人：秦伯强、李未、孔繁翔

Courtesy of Guangwei Zhu

Experimental Lake Erie Harmful Algal Bloom Bulletin

7 November 2017, Bulletin 35, Seasonal Assessment

[redacted]

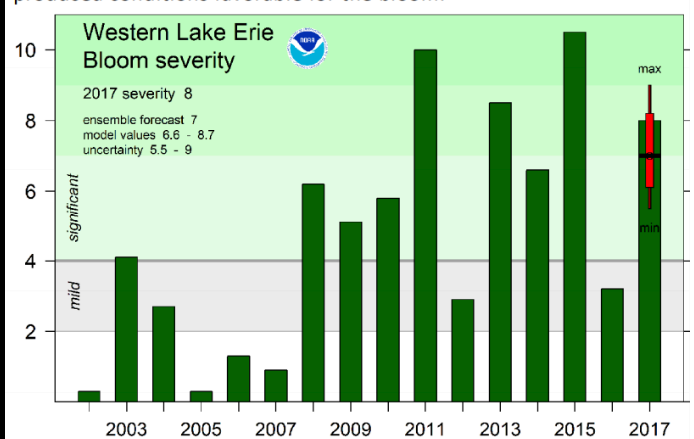


Figure 1. Bloom severity index for 2002-2017, and the forecast for 2017. The index is based on the amount of biomass over the peak 30-days. The 2017 bloom had a severity of 8, comparable to 2013 (8.5). 2011 had a severity of 10.

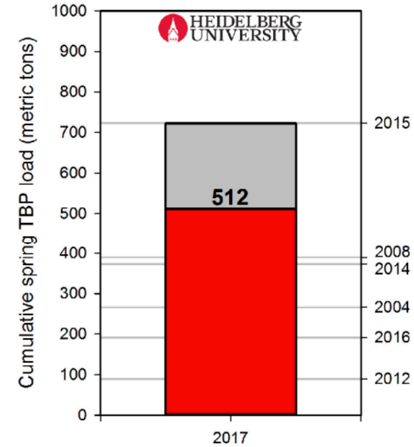
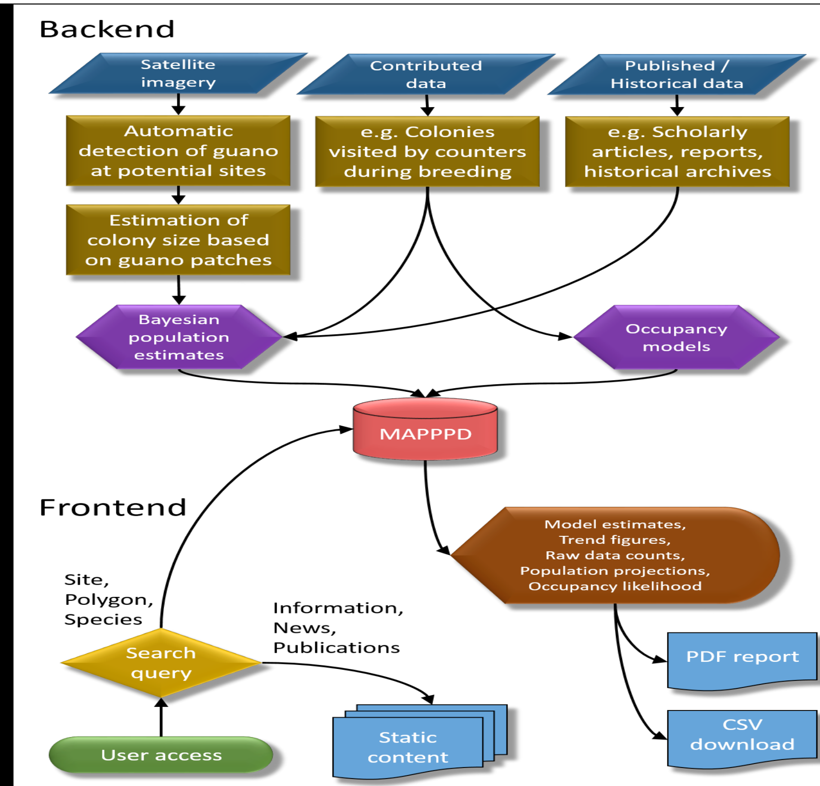
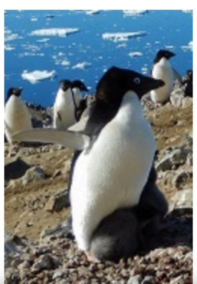


Figure 2. Total bioavailable phosphorus from the Maumee River for 2017 compared to some other years. Data collected by Heidelberg University, National Center for Water Quality Research.



The number of nests for each species of Antarctic penguin estimated by MAPPPD. **Results for chinstrap and gentoo penguins are preliminary and under review.**



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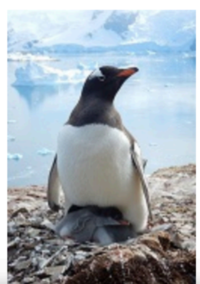

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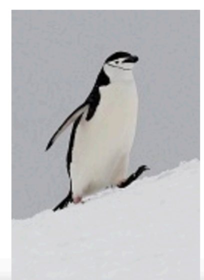

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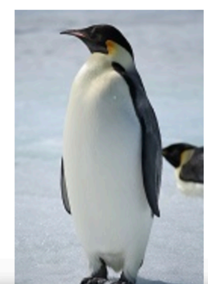

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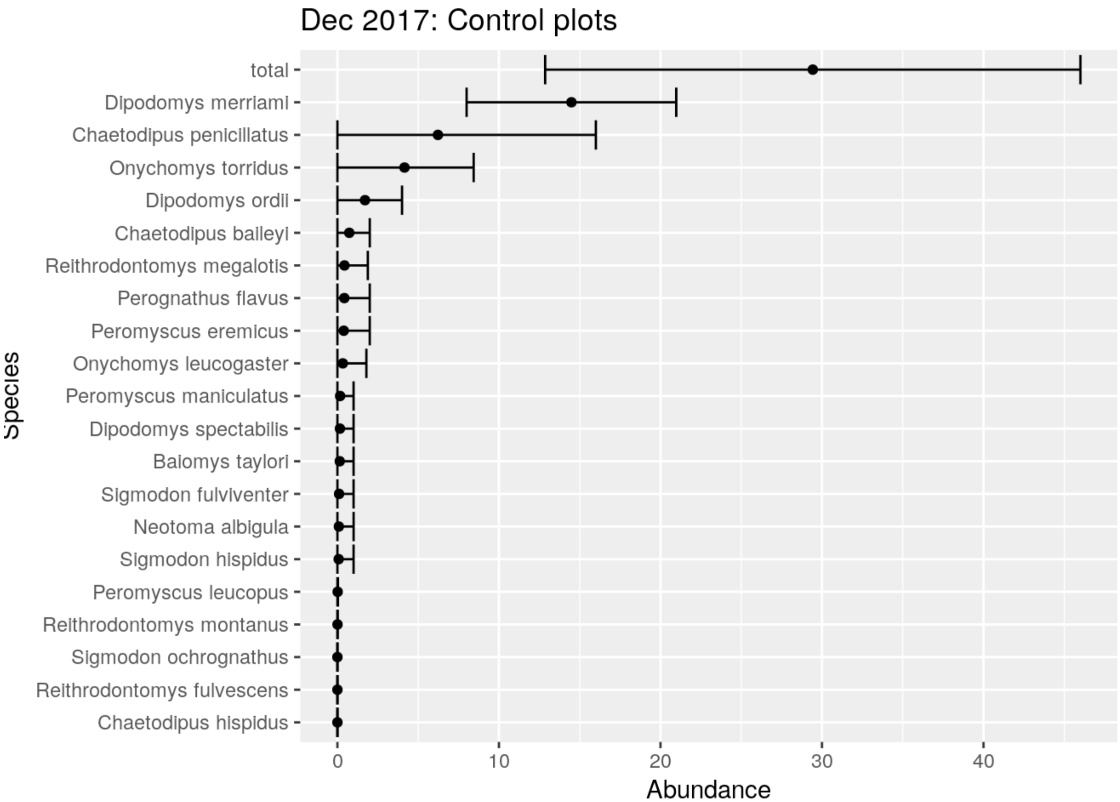
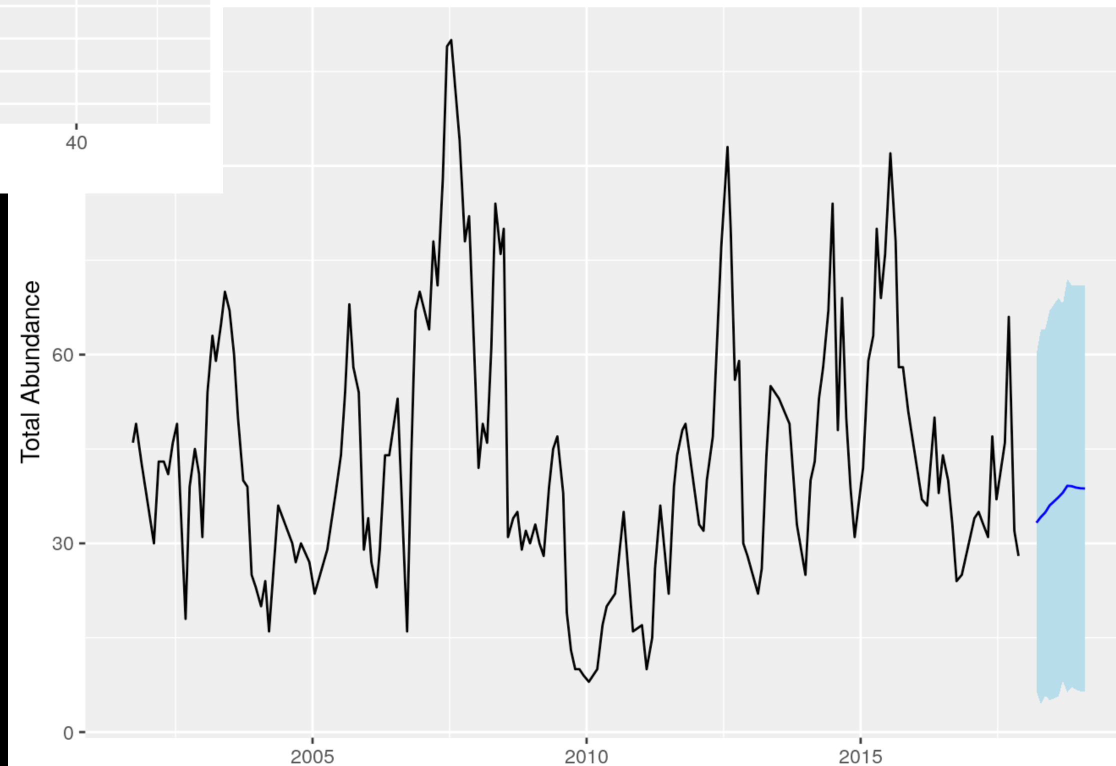
http://www.penguinmap.com/Dashboard/ (Heather Lynch, Stony Brook)

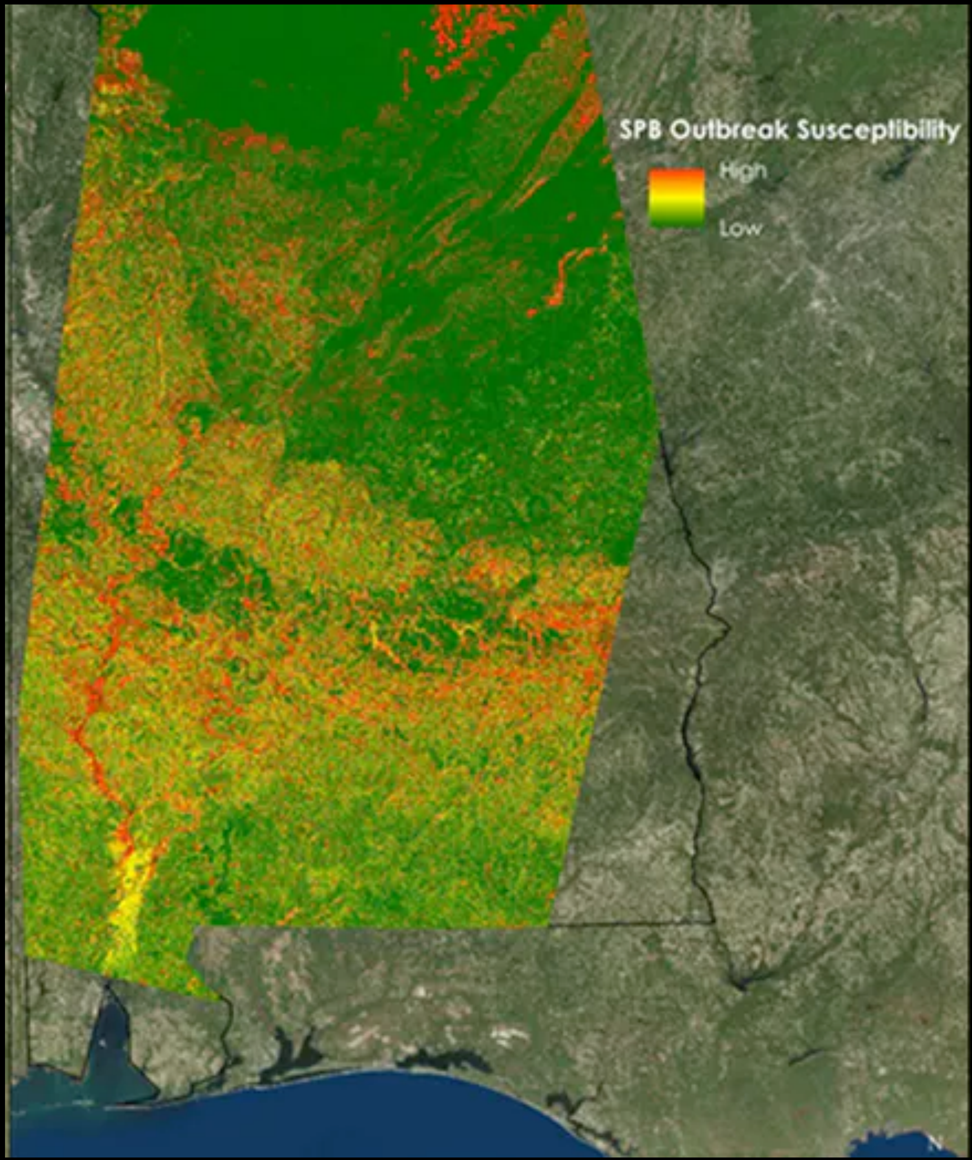




Ethan White's and Morgan Ernest's lab groups at the University of Florida

https://portal.naturecast.org /

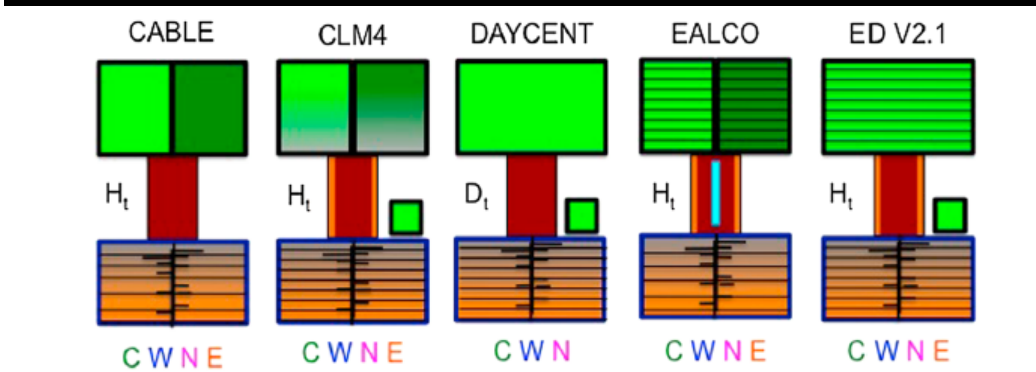
NASA with satellite data helped the U.S. Department of Agriculture analyze outbreak patterns for southern pine beetles in Alabama, in spring 2016

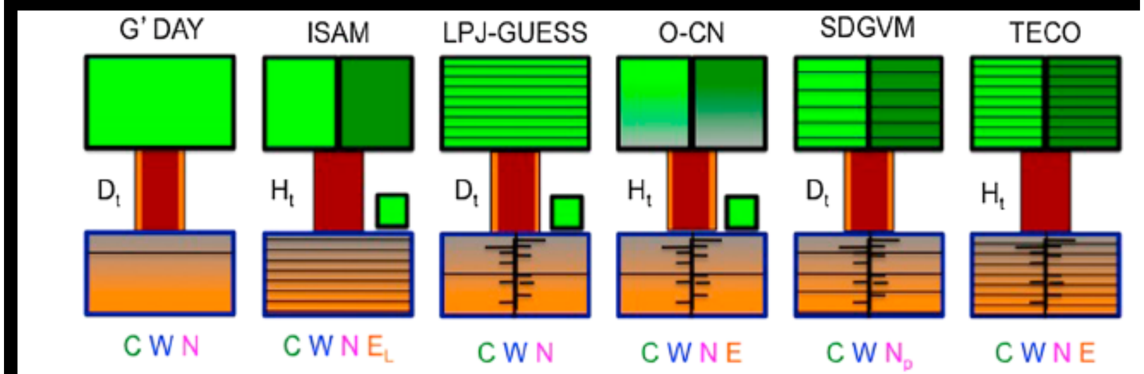


https://theconversation.com/can-scientists-learn-to-make-nature-forecasts-just-as-we-forecast-the-weather-90822

FACE Model-Data Synthesis Project

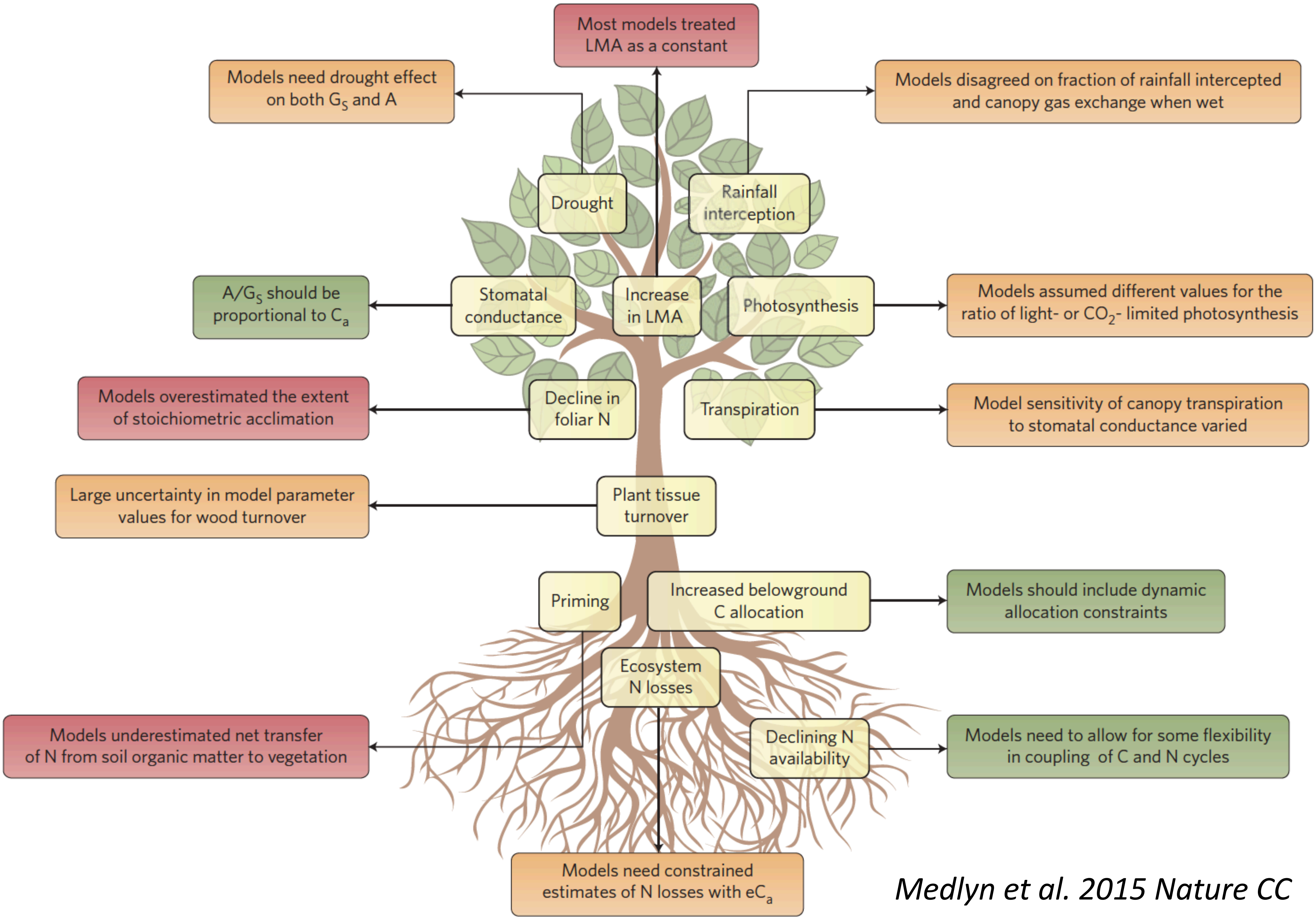
Belinda Medlyn,, Western Sydney University





Walker et al. 2014 J Geophys Res

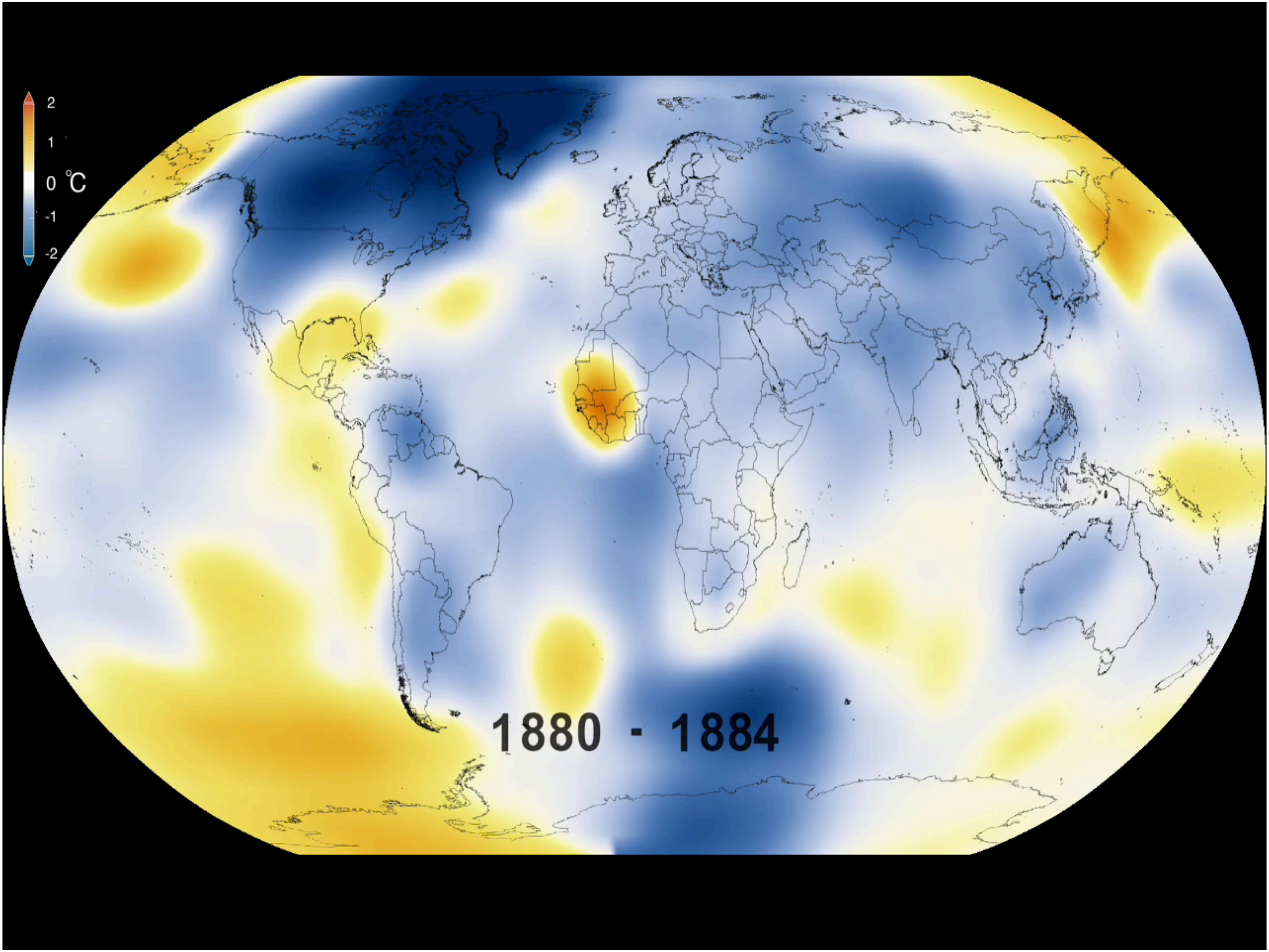
Also: De Kauwe et al. 2013 Global Change Biol; De Kauwe et al. 2014 New Phytol; Zaehle et al. 2014 New Phytol; Walker et al 2015 Global Biogeochem. Cycles; Medlyn et al. 2015 Nature CC; Medlyn et al. 2016 Global Change Biol; De Kauwe et al. 2017 Global Change Biol



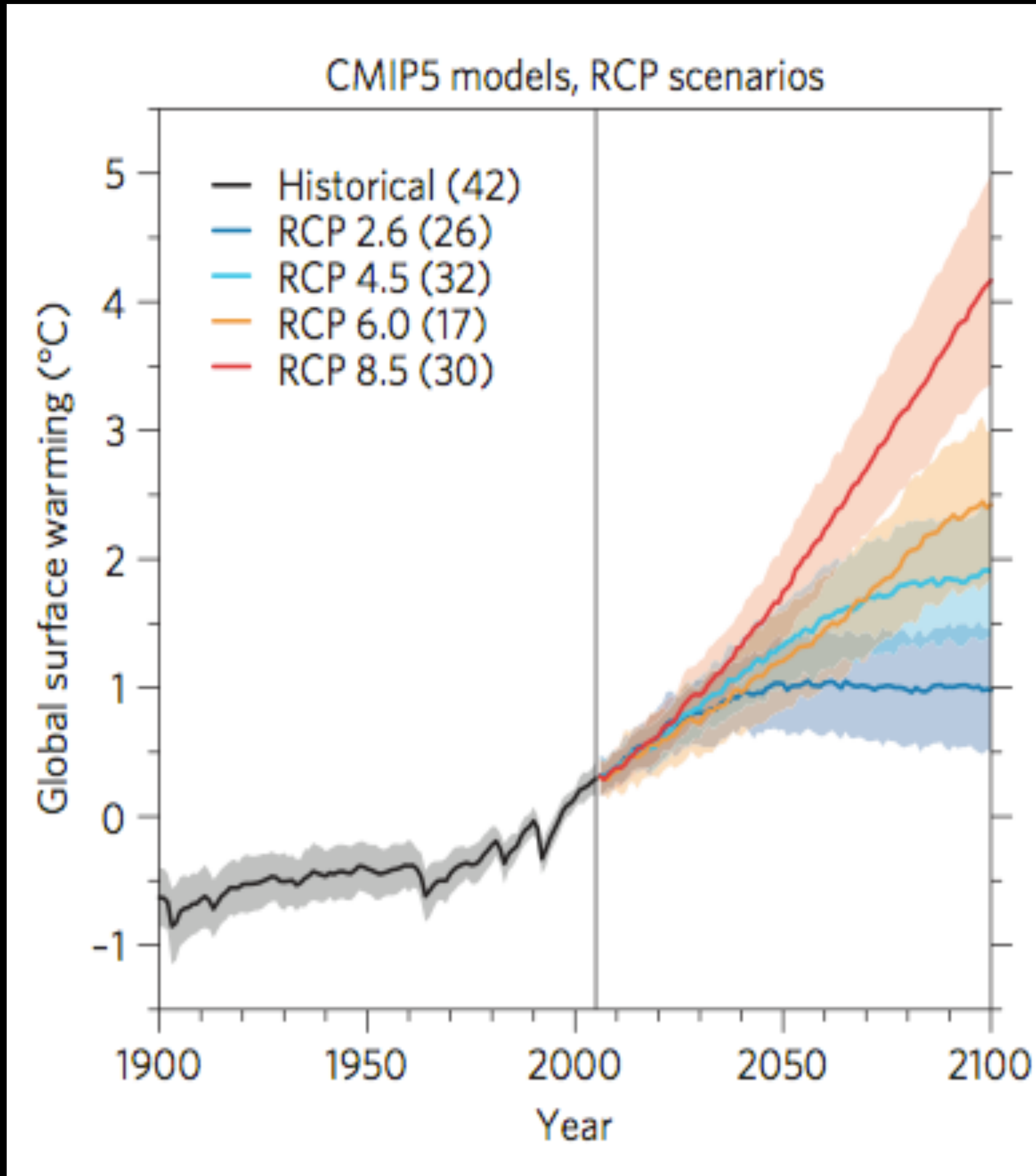
Medlyn et al. 2015 Nature CC

What should we talk about?

- The ecosystem of weather forecasting
- Symbiosis of models and data
- The current landscape of ecological forecasting
- *Future evolution of the field in an era of global change*

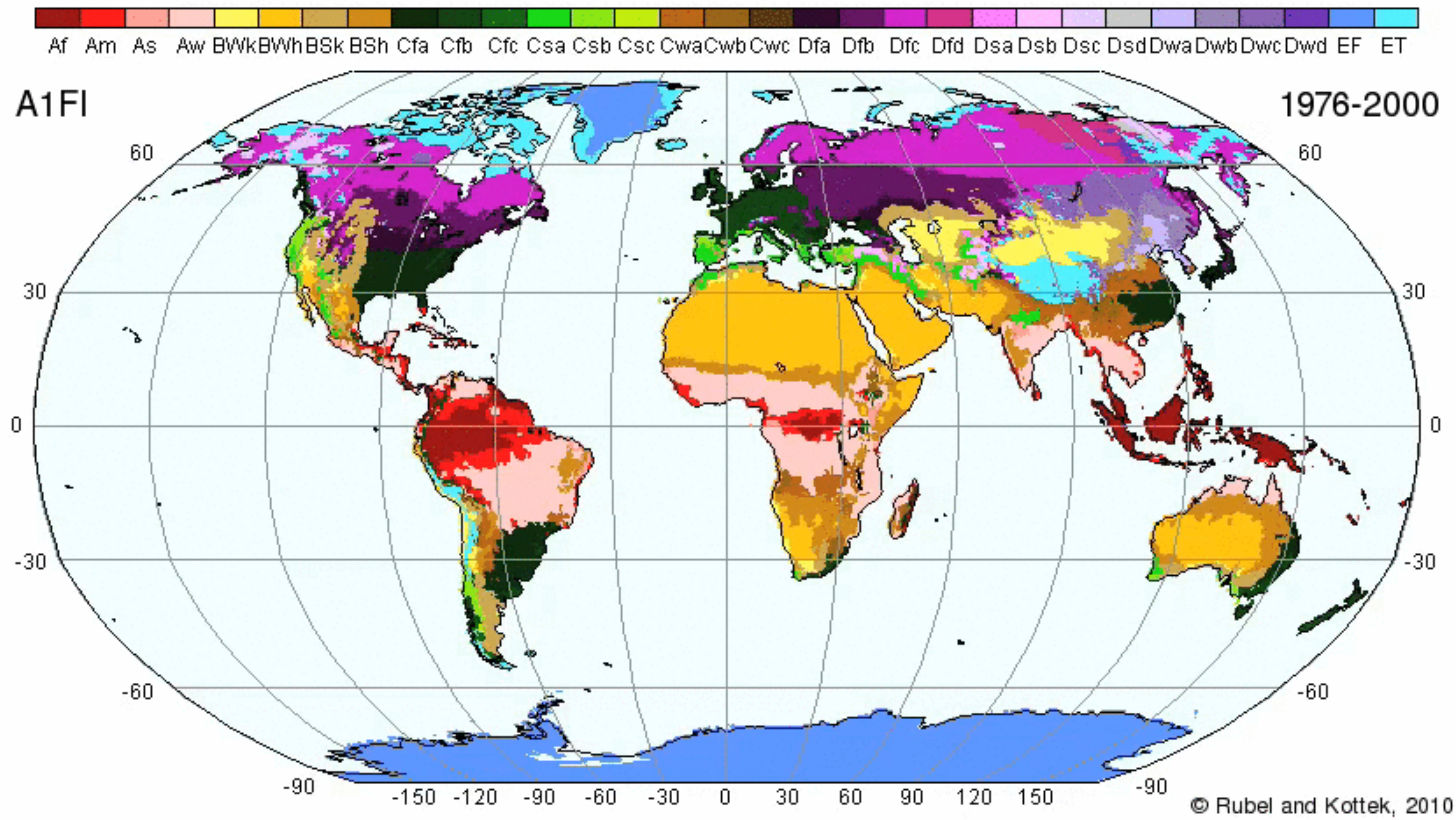


2
1
0 °C
-1
-2
1880 - 1884



Rogelj et al 2012

[redacted]



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1976-2000
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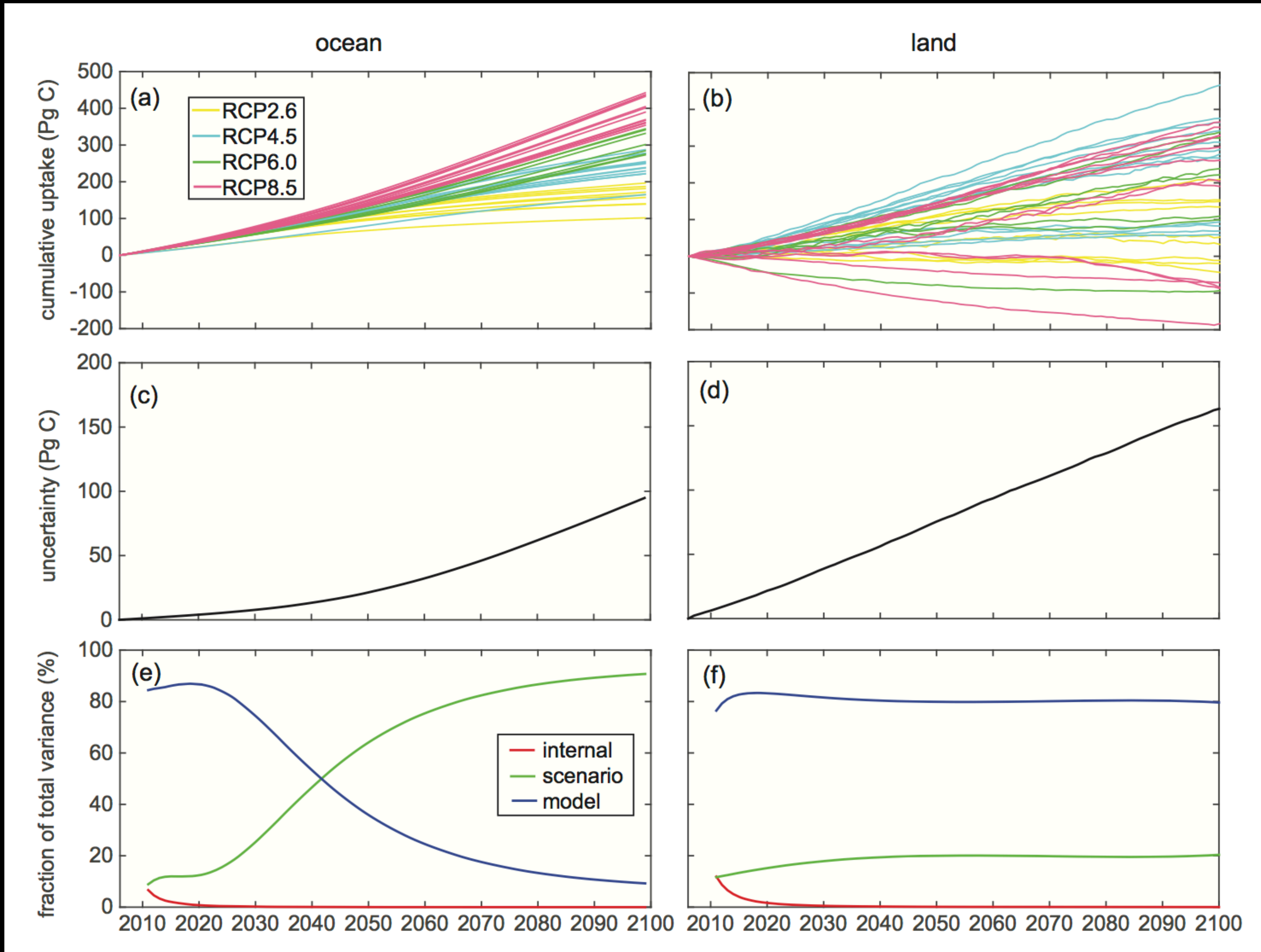
© Rubel and Kottek, 2010



Lovenduski et al., 2017

THE NEON PROJECT: ADDRESSING SCIENCE CHALLENGES

GRAND CHALLENGES → KEY QUESTIONS → NEON DATA PRODUCTS → DATA USERS

GRAND CHALLENGES

CAUSES OF CHANGE

- Climate Change
- Land Use
- Invasive Species

Interactions and Feedbacks

Productivity, functional diversity, soil moisture, habitat structure, etc.

RESPONSES TO CHANGE

- Biogeochemistry
- Biodiversity
- Ecohydrology
- Infectious Diseases

KEY QUESTIONS

1. What are the impacts of climate change on continental-scale ecology?
2. What are the impacts of land use change on continental-scale ecology?
3. What are the impacts of invasive species on continental scale ecology?
4. What are the interactive effects of climate, land use and invasives on continental-scale ecology?
5. How does transport and mobility of energy, matter and organisms affect continental-scale ecology?

NEON DATA PRODUCTS

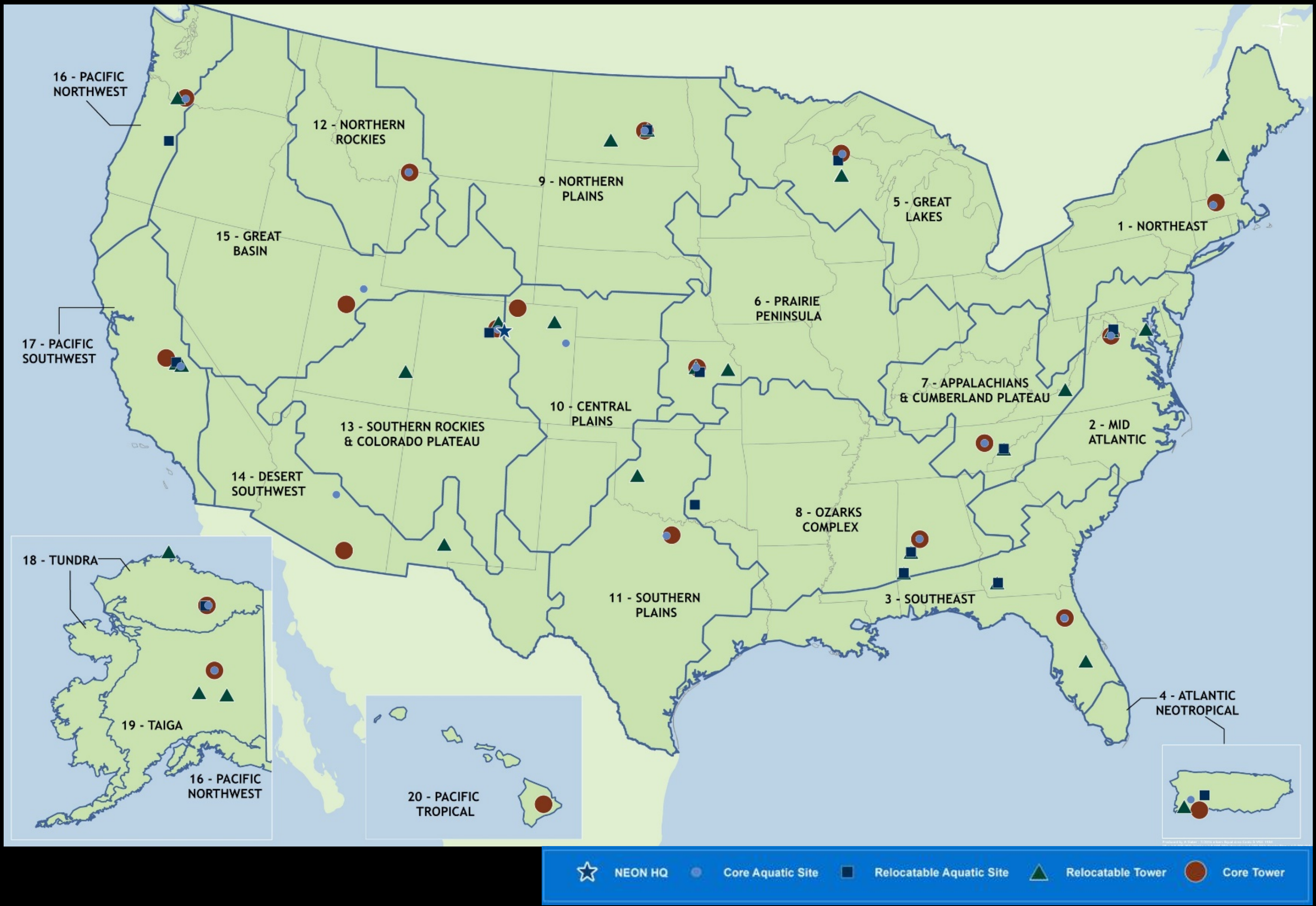
- Land Use and Land Cover
- Habitat, Landscape Structure
- Atmospheric, Air Quality
- Hydrology, Ecohydrology
- Bioclimate, Energy Balance
- Soil Structure, Physics
- Biomass, Productivity, Metabolism
- Biogeochemistry
- Infectious Diseases, Parasites
- Microbial Diversity, Function
- Population Dynamics, Demography
- Phenology
- Biodiversity, Invasives, Biogeography

DATA USERS

- SCIENTISTS
- EDUCATORS
- STUDENTS
- PUBLIC
- DECISION MAKERS

NEON provides a highly coordinated national system for monitoring a number of critical ecological and environmental properties at multiple spatial and temporal scales.

NEON's field sites and data products



81

FIELD SITES

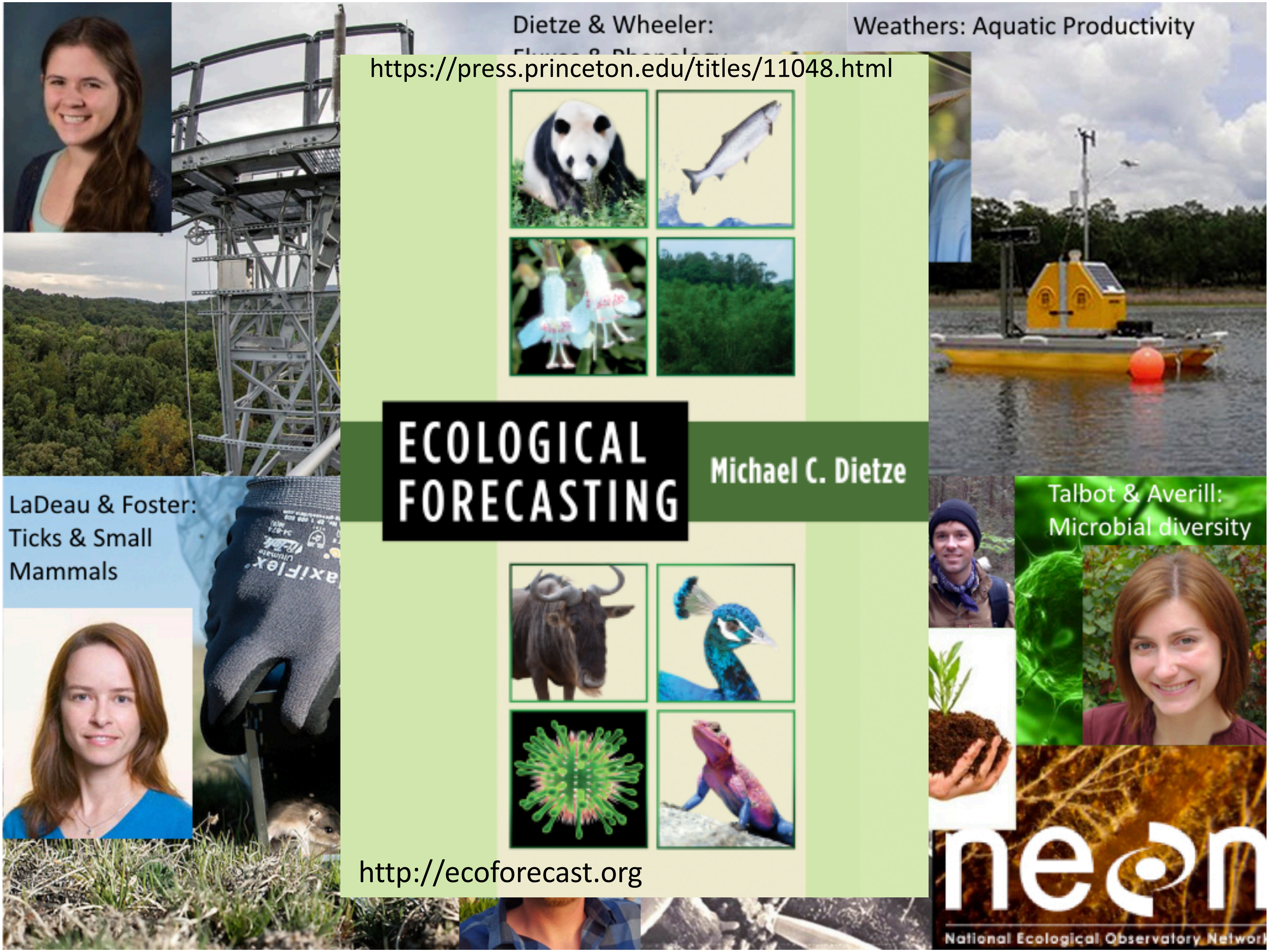
- 47 terrestrial
- 34 aquatic

Approximately

180

DATA PRODUCTS

HTTP://DATA.NEONSCIENCE.ORG/HOME


Dietze & Wheeler:
Weathers: Aquatic Productivity
https://press.princeton.edu/titles/11048.html
ECOLOGICAL FORECASTING
Michael C. Dietze
LaDeau & Foster: Ticks & Small Mammals
Talbot & Averill: Microbial diversity
http://ecoforecast.org
neon
National Ecological Observatory Network

Parting Thoughts

- Ecological forecasting draws on a rich history in data assimilation from fields such as weather forecasting
- Ecological observations are growing rapidly in abundance and diversity
- Rapid global change requires a forecasting approach to reduce uncertainty on the future of terrestrial and aquatic ecosystems
- Students should take advantage of growing number of books, databases, coding and statistical tools, tutorials, workshops, summer schools, and classes on this topic to stay at the forefront of the discipline

THANKS!

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+1-608-520-0305, http://flux.aos.wisc.edu