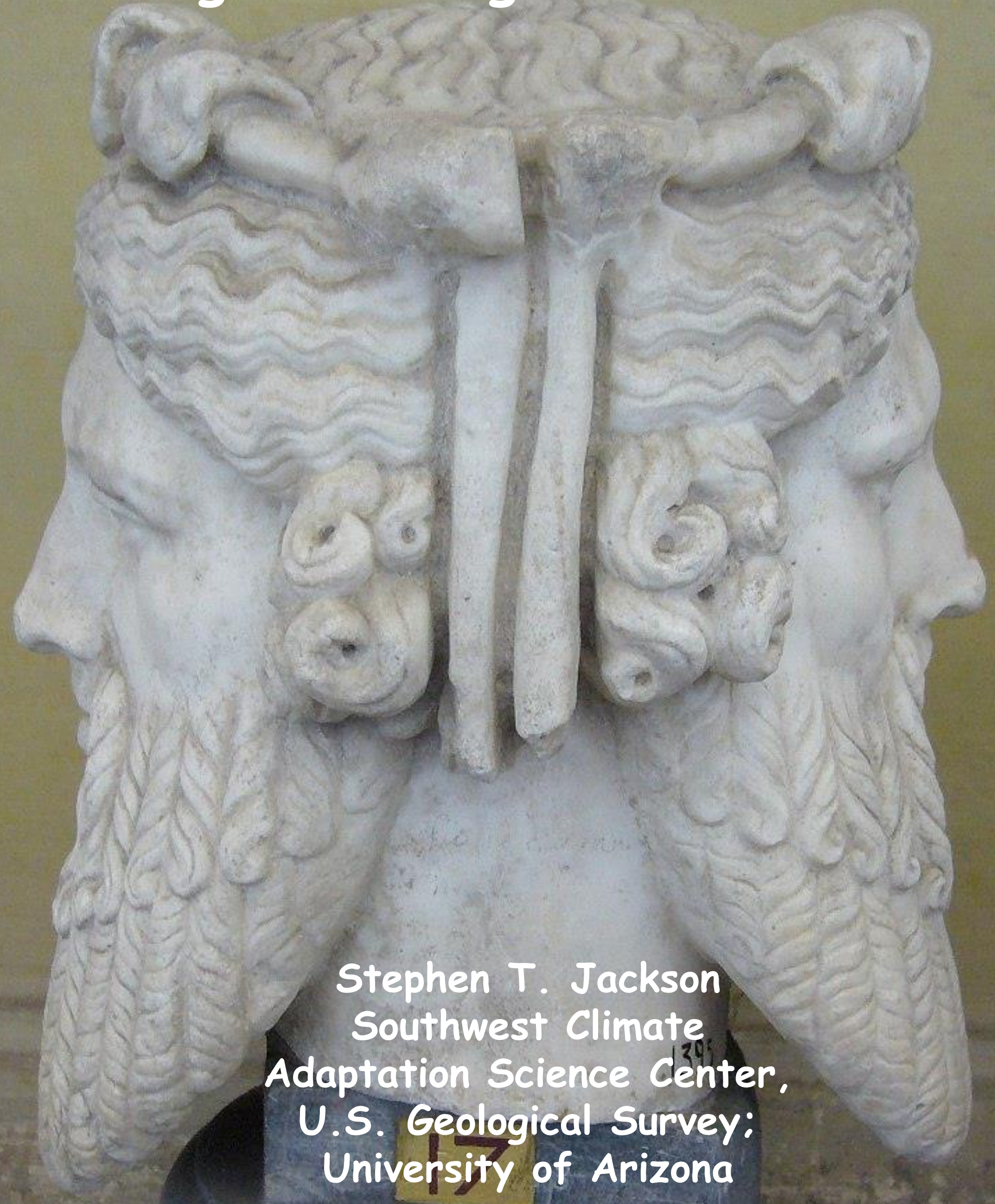
Climate Change: Looking Back and Looking Ahead



Stephen T. Jackson
Southwest Climate
Adaptation Science Center,
U.S. Geological Survey;
University of Arizona

Photo: Loudon Dodd

Janus, Vatican Museum, Rome

How will global climate change affect the Colorado River?

- **Highest vulnerability to warming-related discharge reduction in western North America**
- **Runoff low relative to precipitation (evaporative loss)**

Temperature increase —> ET increase —> reduced runoff —> reduced discharge

Scientists to the rescue!

Mid-21st Century Flow Projections from GCMs

- At least 12 major studies
- Divergent results:

  -6% (-40% to +18%)

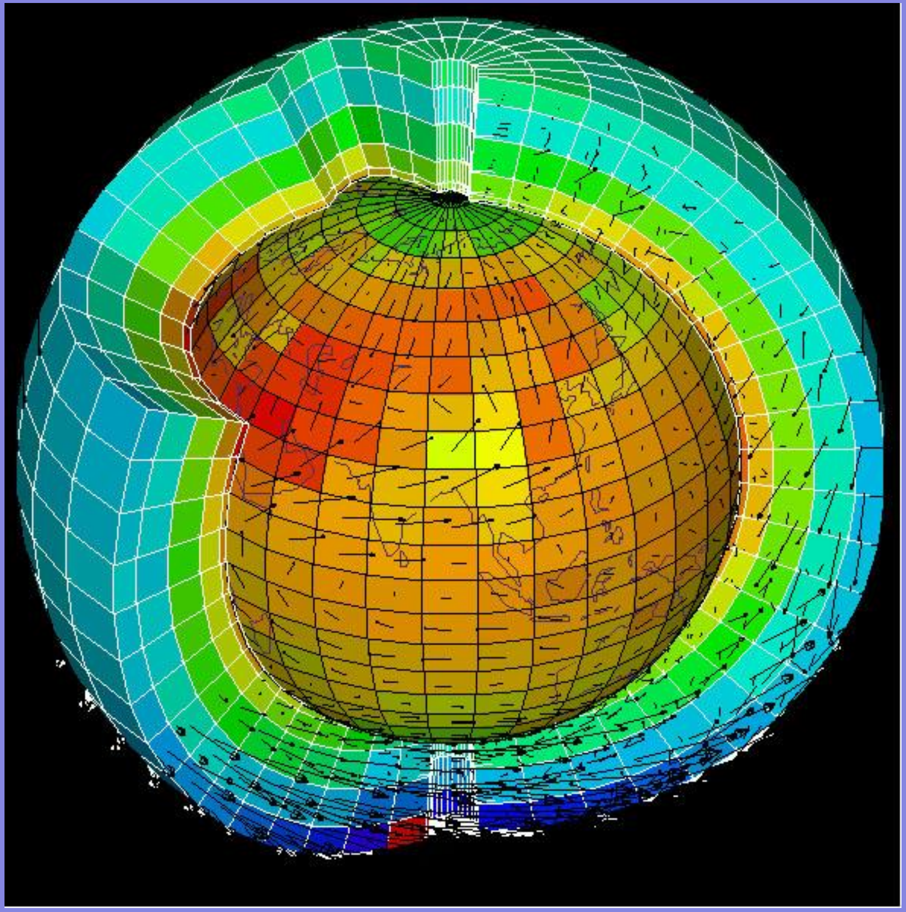
  -10% to -20%

  -16 % (-8% to -25%)

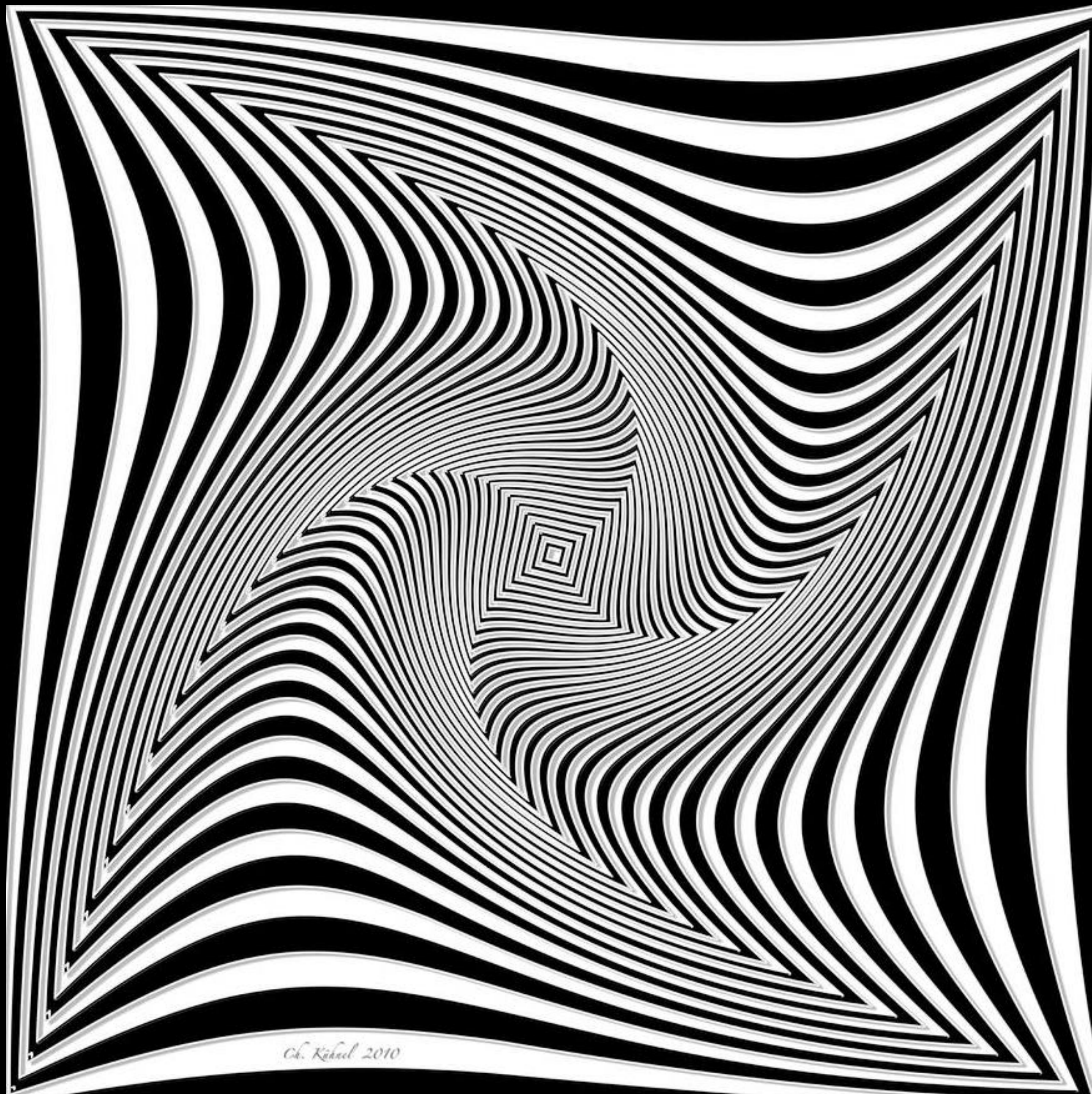
  -17%

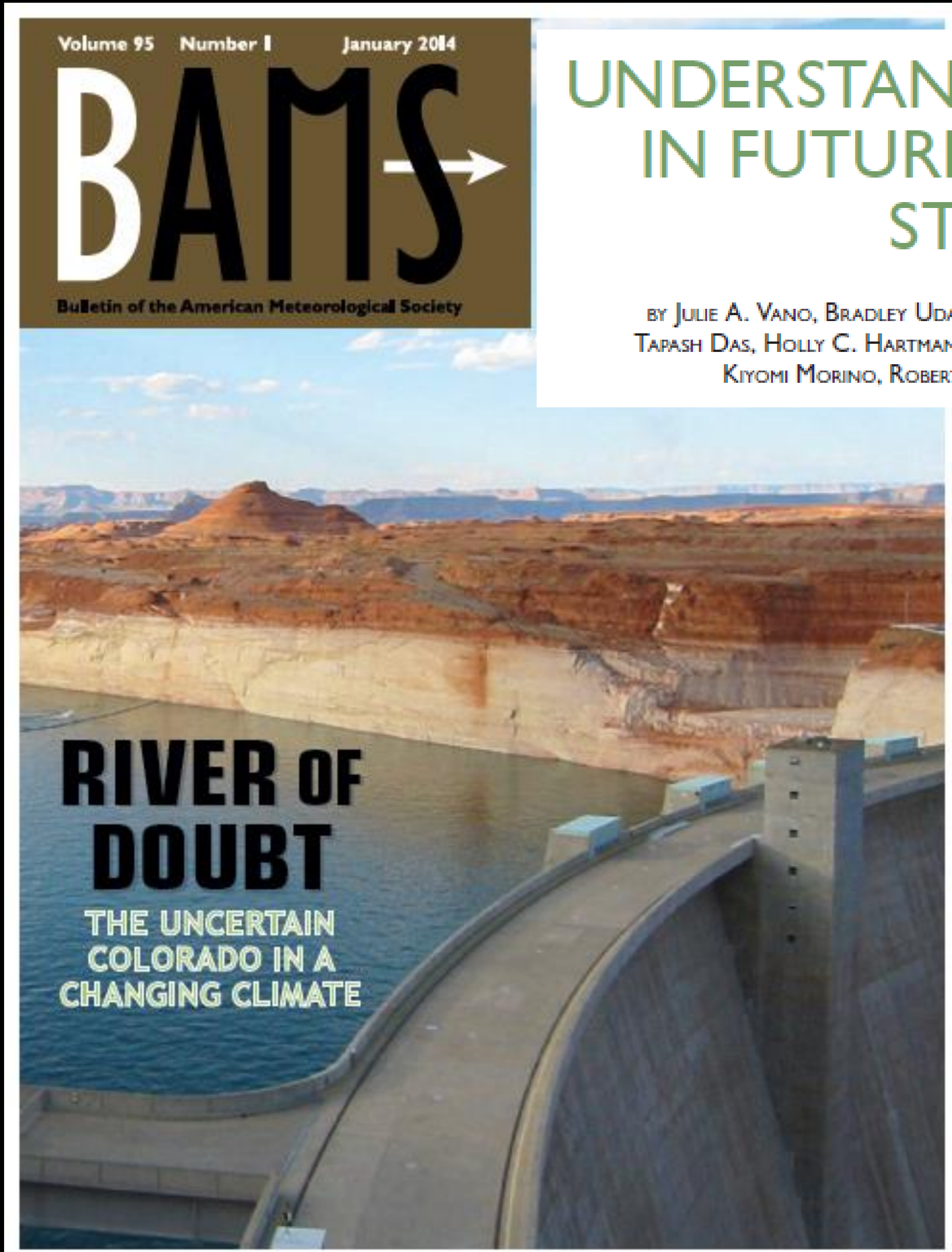
  -18%

  -45%



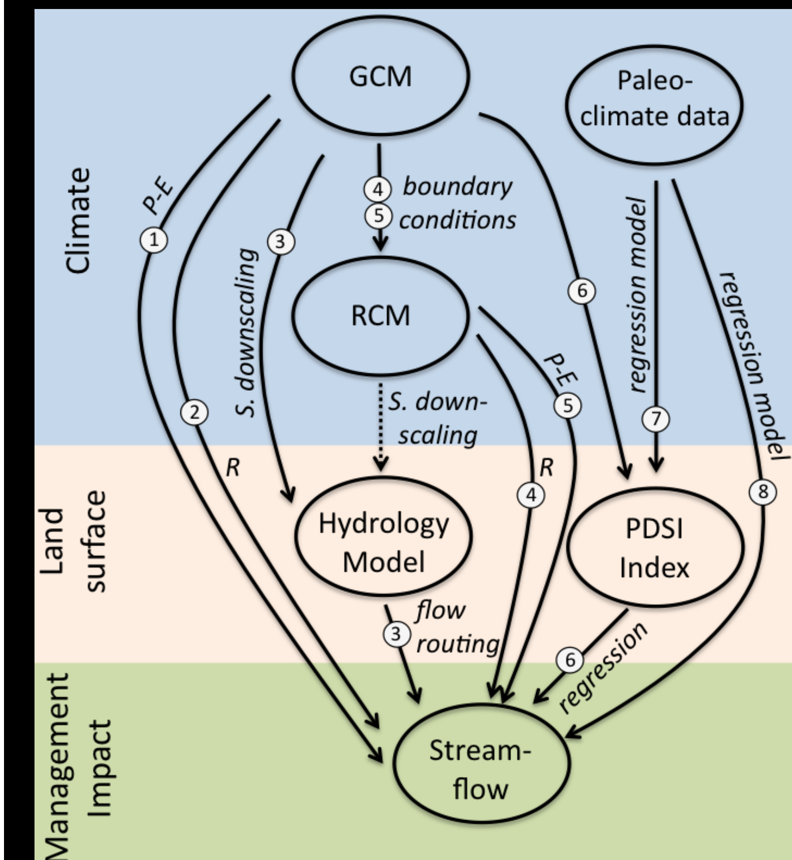
Stakeholder Confusion





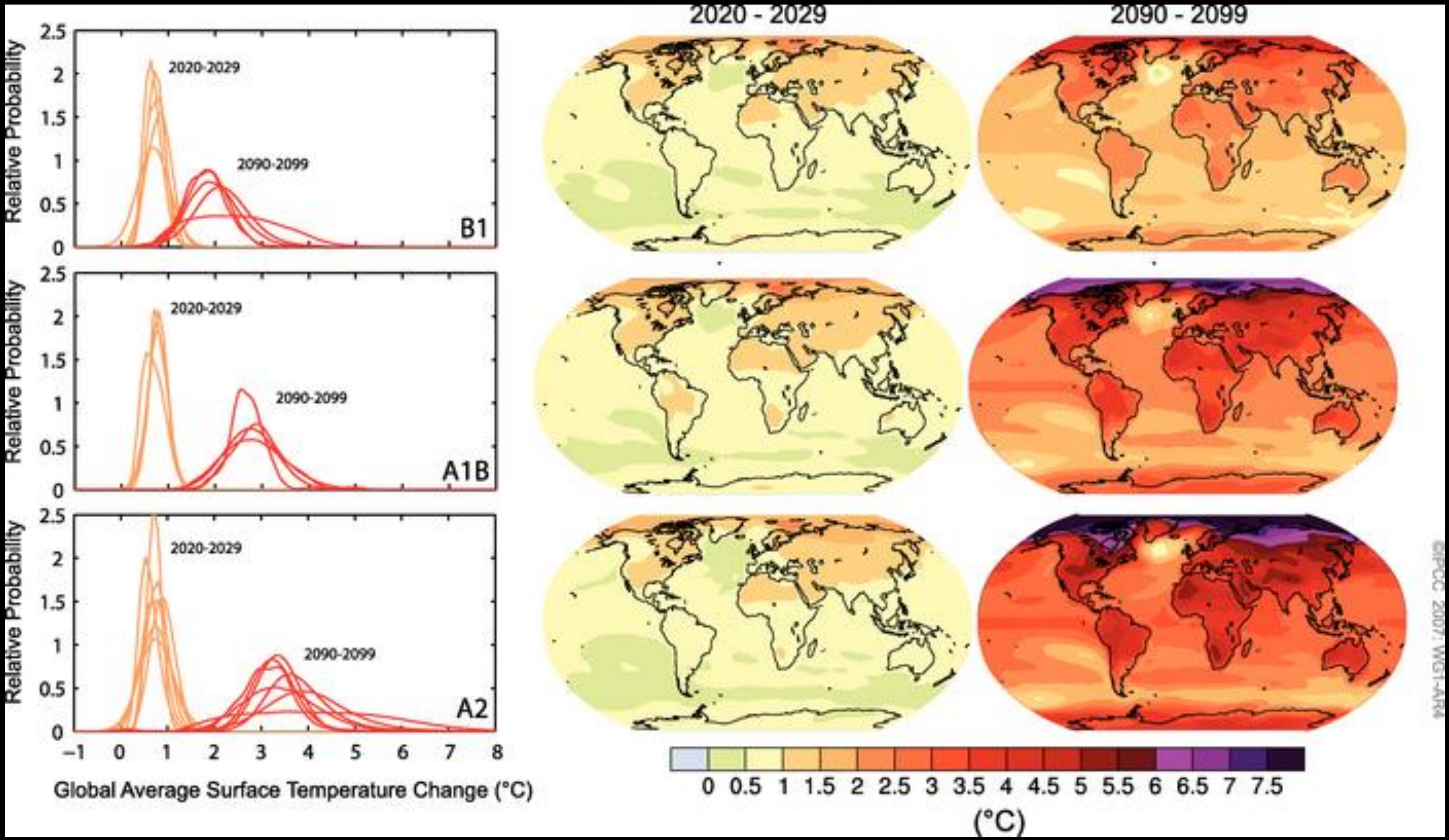
UNDERSTANDING UNCERTAINTIES IN FUTURE COLORADO RIVER STREAMFLOW

BY JULIE A. VANO, BRADLEY UDALL, DANIEL R. CAYAN, JONATHAN T. OVERPECK, LEVI D. BREKKE, TAPASH DAS, HOLLY C. HARTMANN, HUGO G. HIDALGO, MARTIN HOERLING, GREGORY J. MCCABE, KIYOMI MORINO, ROBERT S. WEBB, KEVIN WERNER, AND DENNIS P. LETTENMAIER

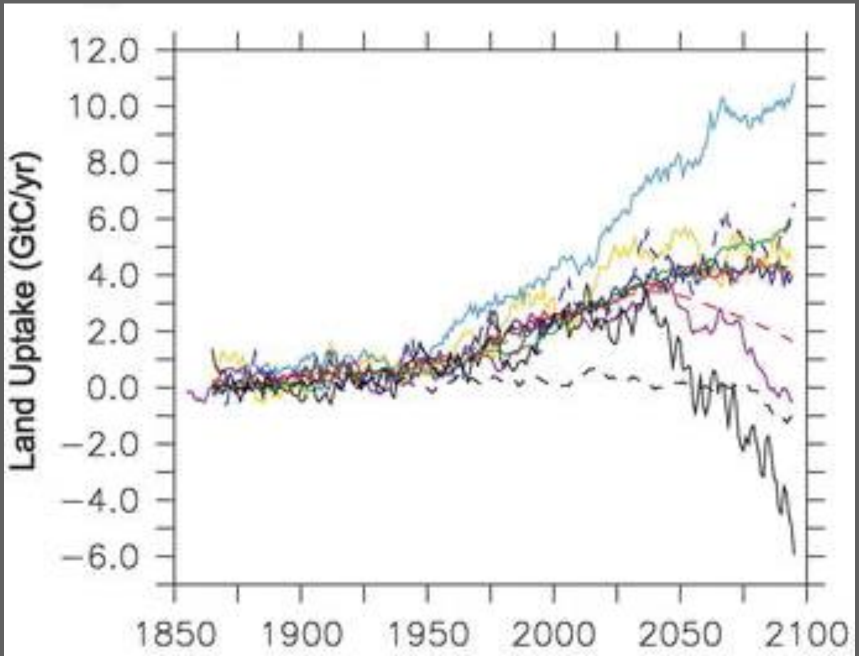


Is ecology any easier?

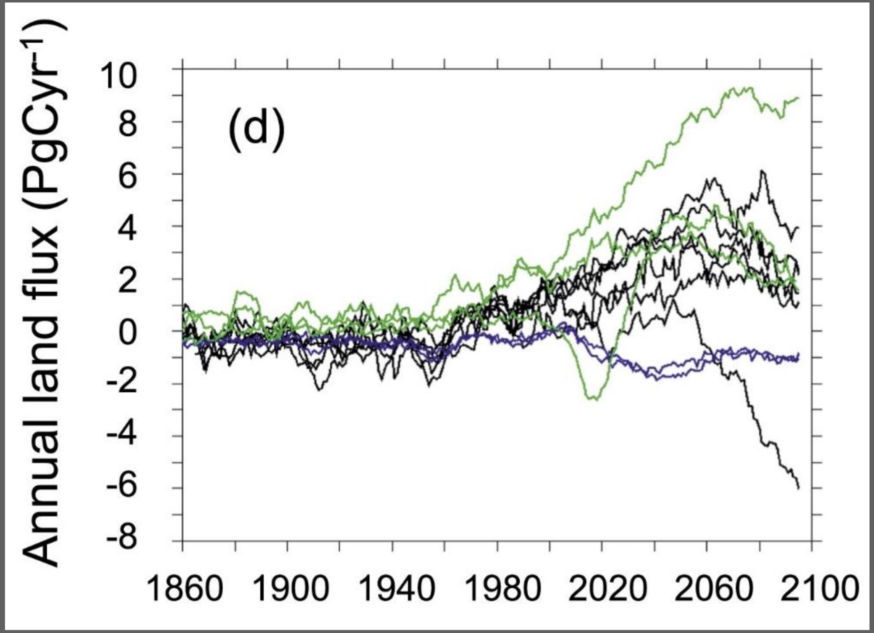
Long-term forecasts of simple climate variables from models are relatively straightforward…



…in contrast to forecasts of simple ecological variables.

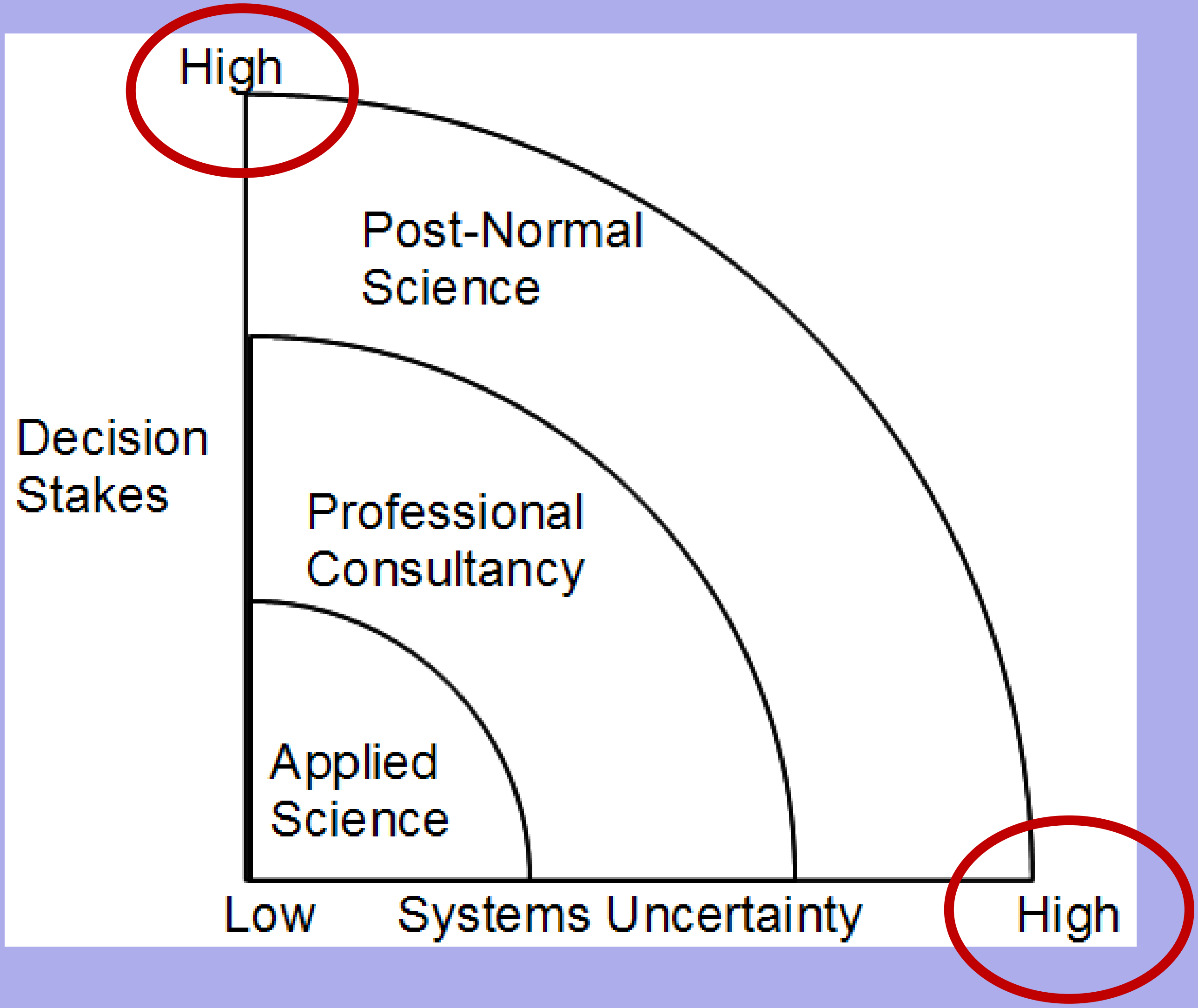


P. Friedlingstein *et al.* 2006. *Journal of Climate.*



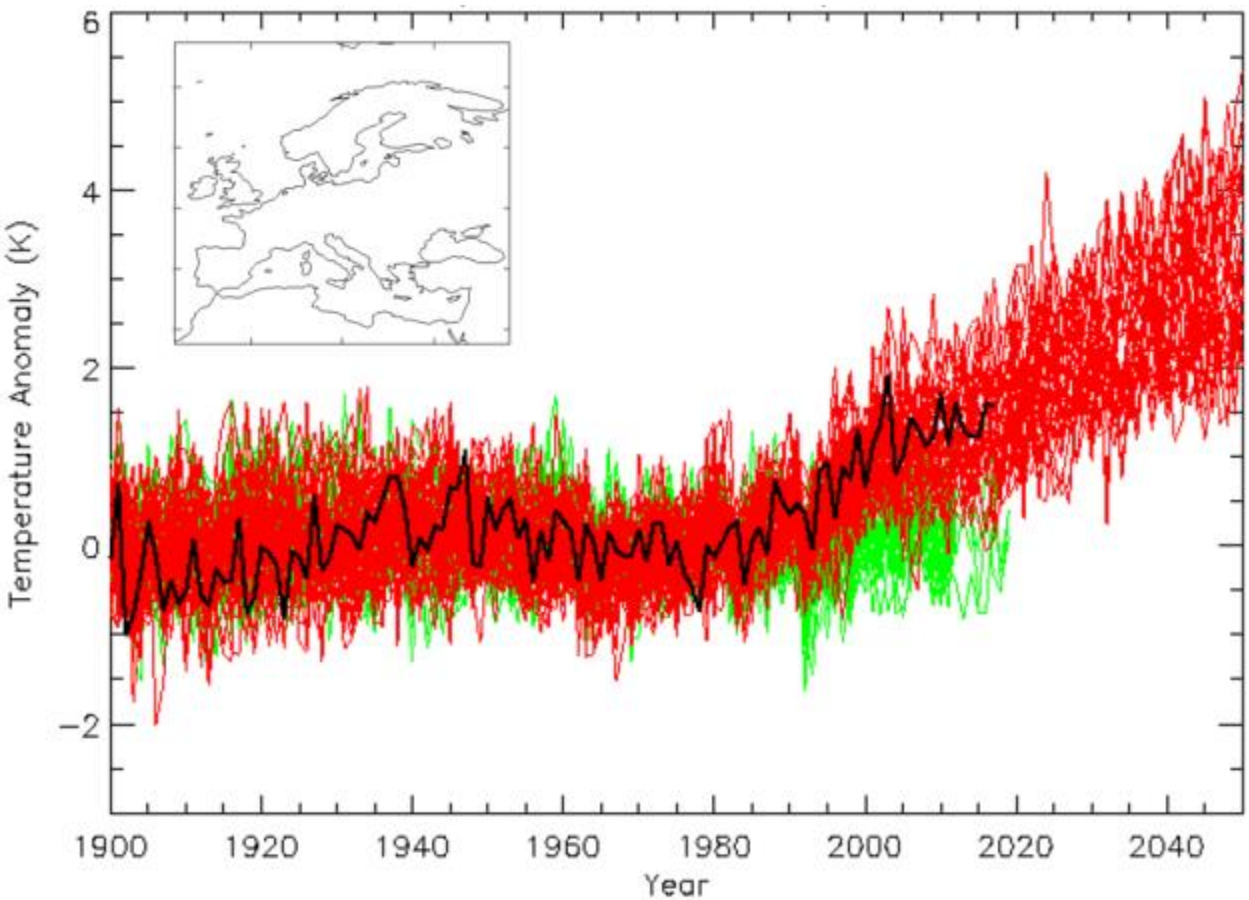
P. Friedlingstein *et al.* 2014. *Journal of Climate.*

Post-normal science



S. Funtowicz & J. Ravetz. 1993. Science for the post-normal age. *Futures* 25:739-755.

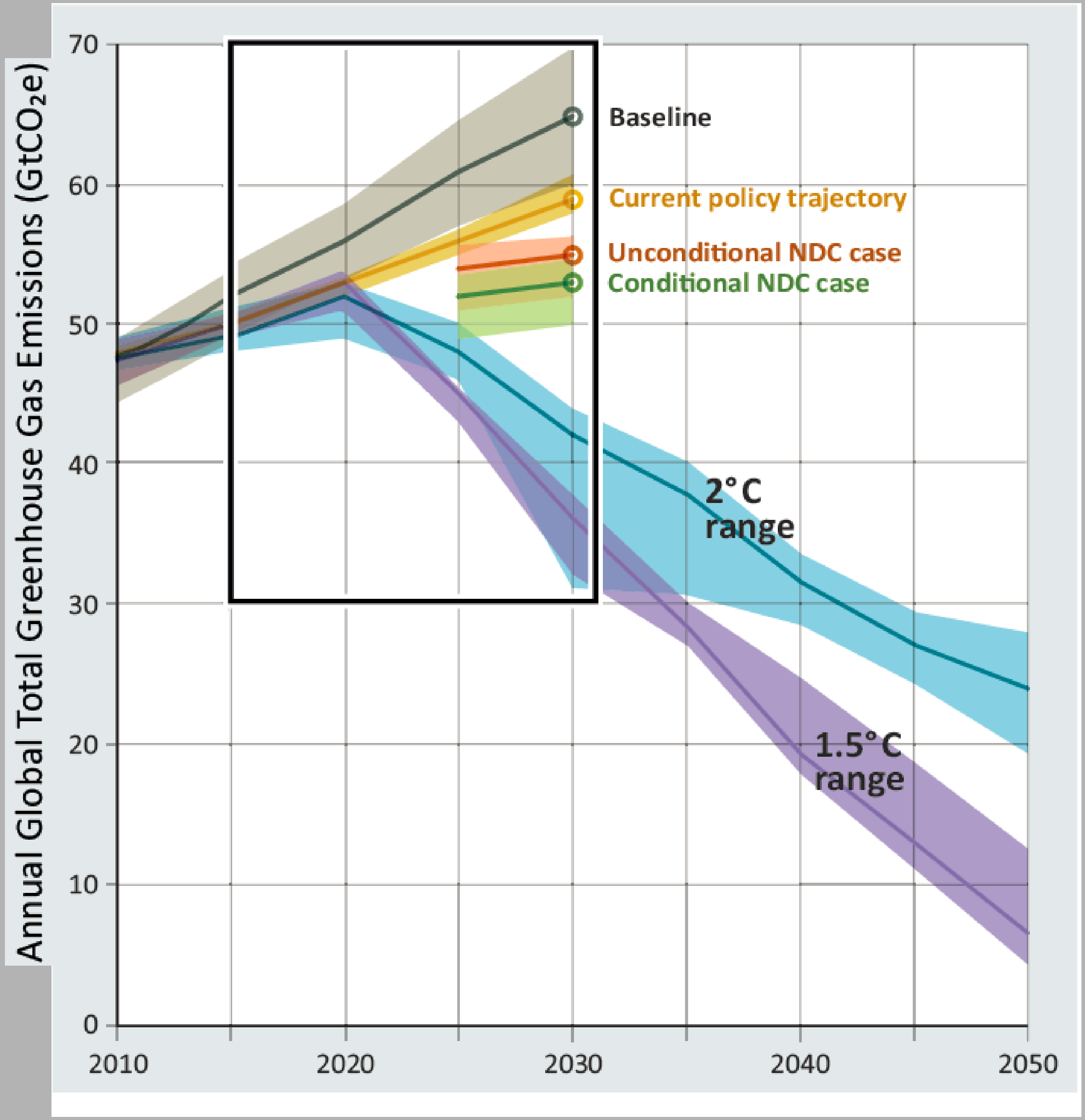
It's getting hotter out there.



Black: observed summer mean temperature anomalies over Europe
Red: RCP8.5 projections from CMIP5 simulations including GHG forcings
Green: RCP8.5 projections from CMIP5 simulations excluding GHG forcings

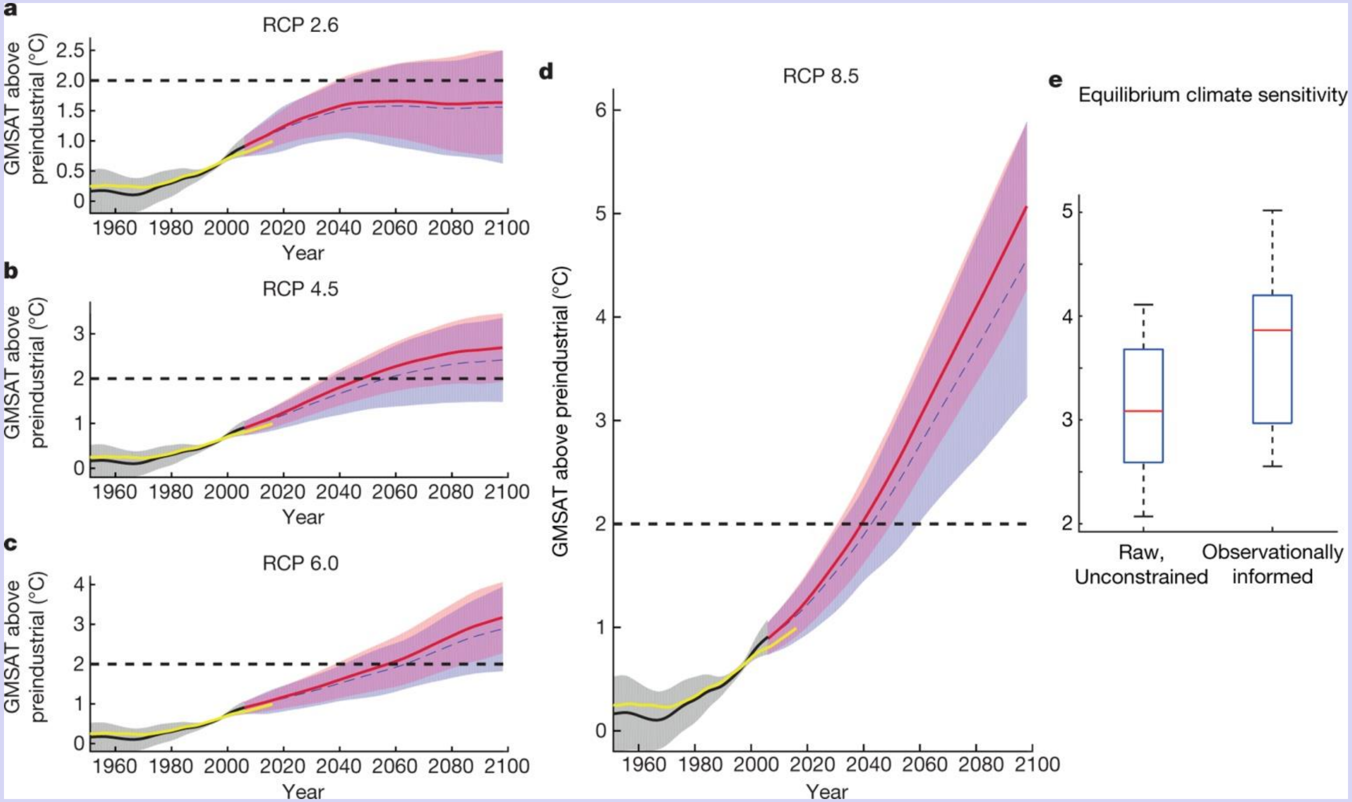
Grantham Institute, 27 July 2018

We're not doing well in meeting Paris temperature targets.



The Emissions Gap Report 2017. United Nations Environment Programme, Nov. 2017. Fig. 3.1

Climate models may underestimate climate sensitivity to greenhouse-gas forcing.

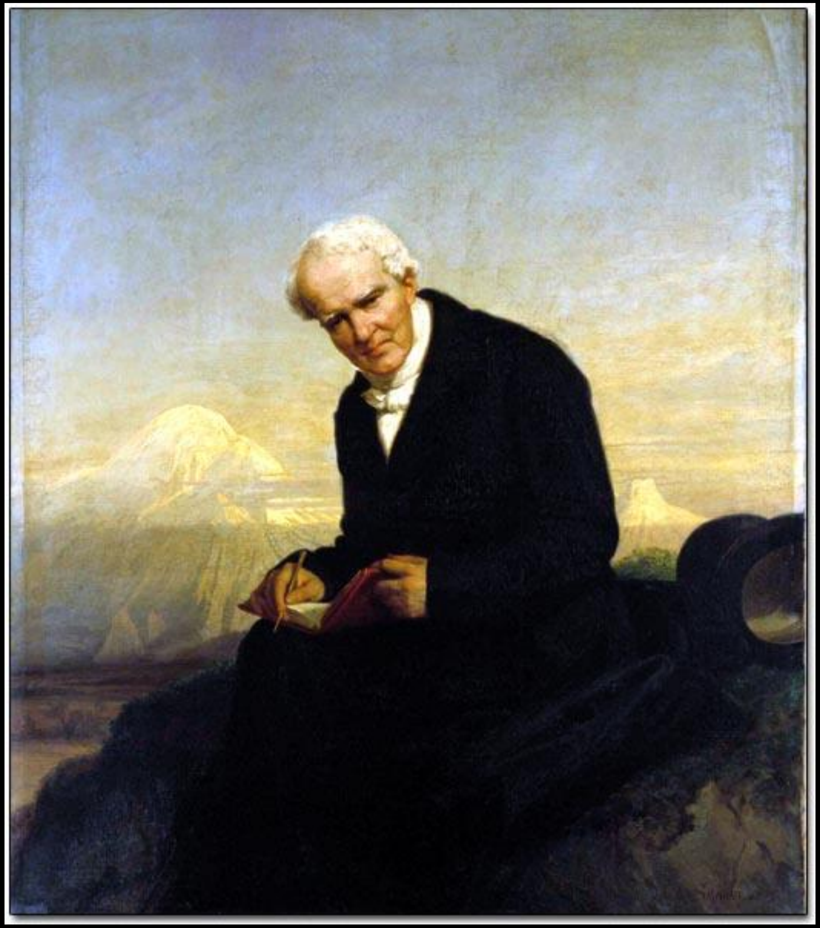


- RCP8.5 may be 15% warmer at 2100 than IPCC indicates.
- RCP4.5 is closer to RCP6.0 global temperature outcome.

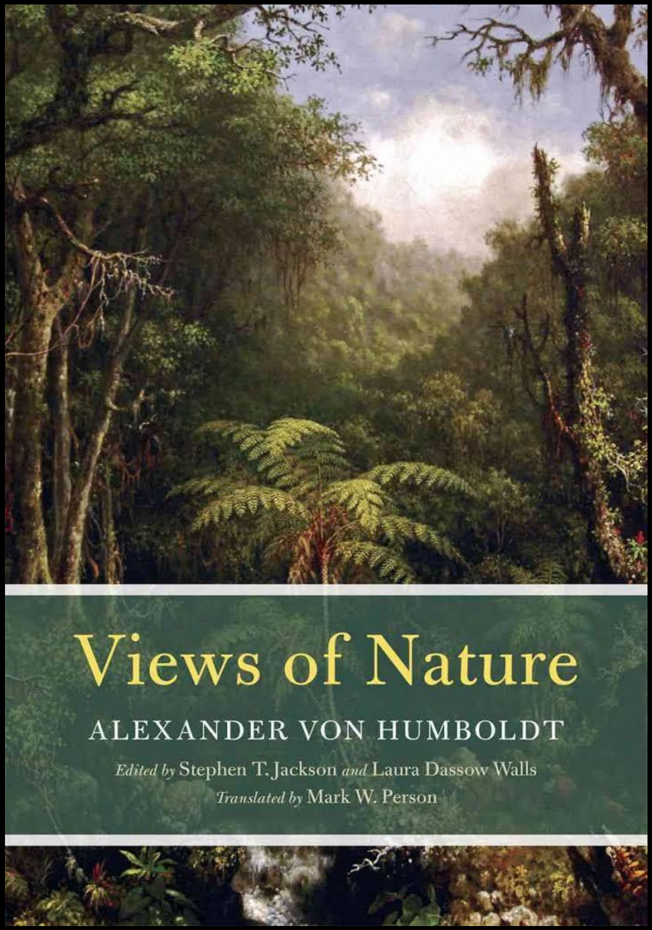
P.T. Brown & K. Caldeira. 2017. *Nature* 552:45-50.

"It is the privilege of the curious and active mind of humanity to occasionally drift out of the present and into the darkness of prehistory, to gain a sense of that which cannot yet be clearly discerned…"

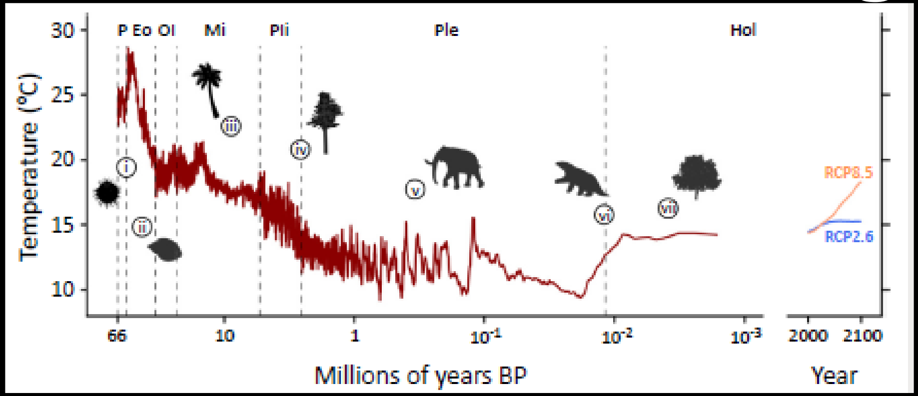
-Alexander von Humboldt, *Views of Nature*, 1849.



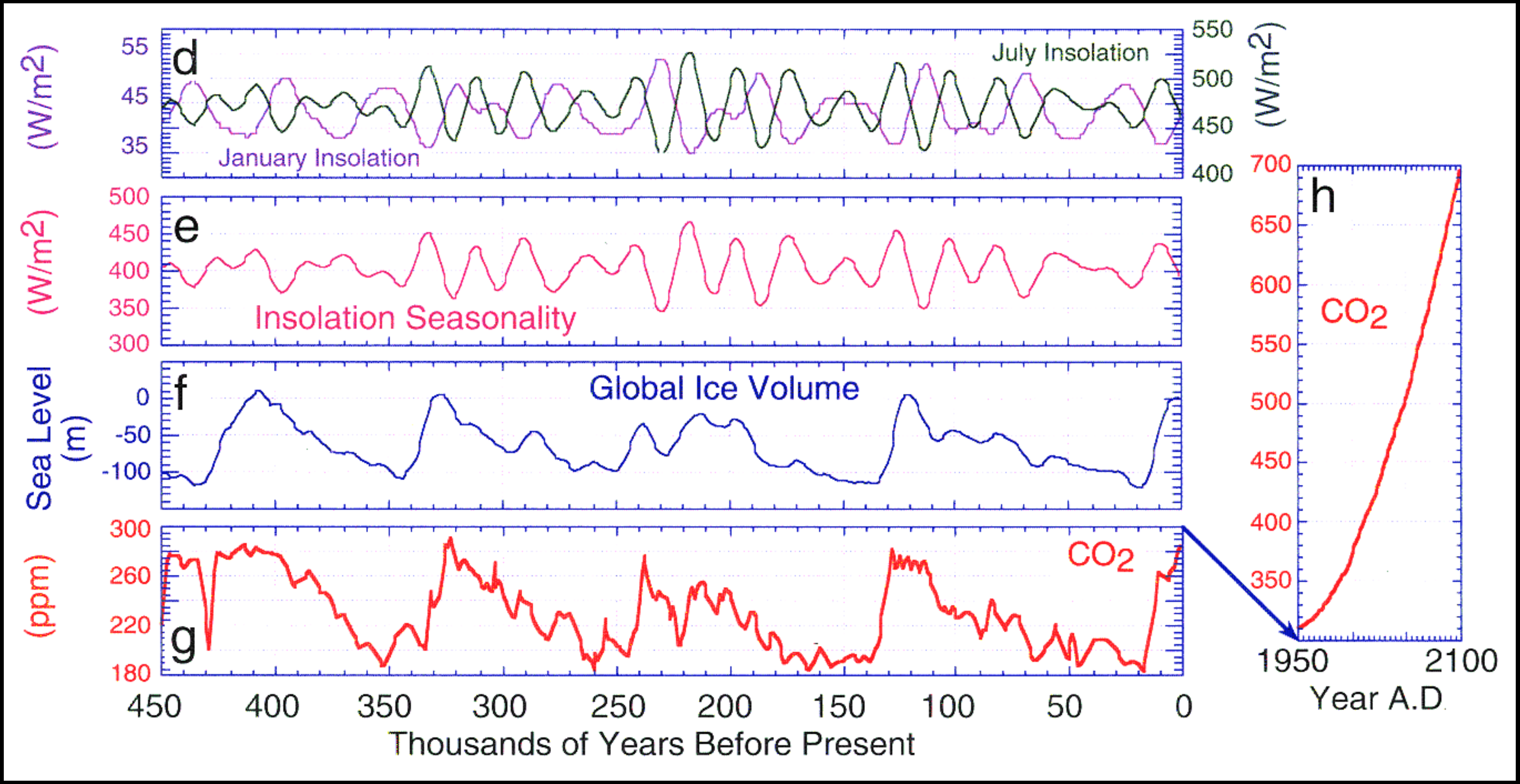
Julius Schrader, *Alexander von Humboldt* (1859)



We live in a world of change.

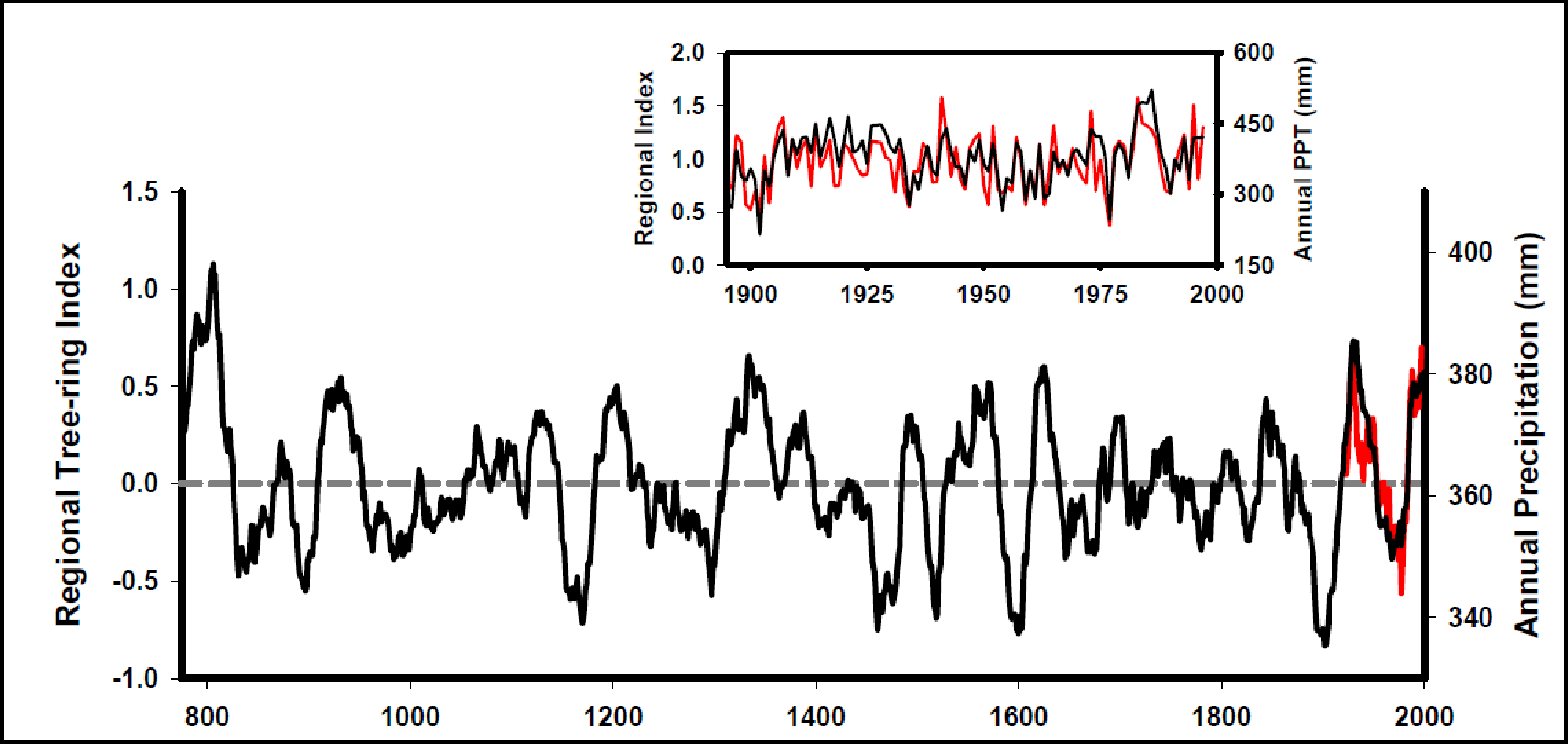


Past 66 million years: Global (Nogues-Bravo *et al*. 2018. *TREE*)



Past 450,000 years: Global (S.T Jackson & J.T. Overpeck. 2000. *Paleobiology (Suppl.)*

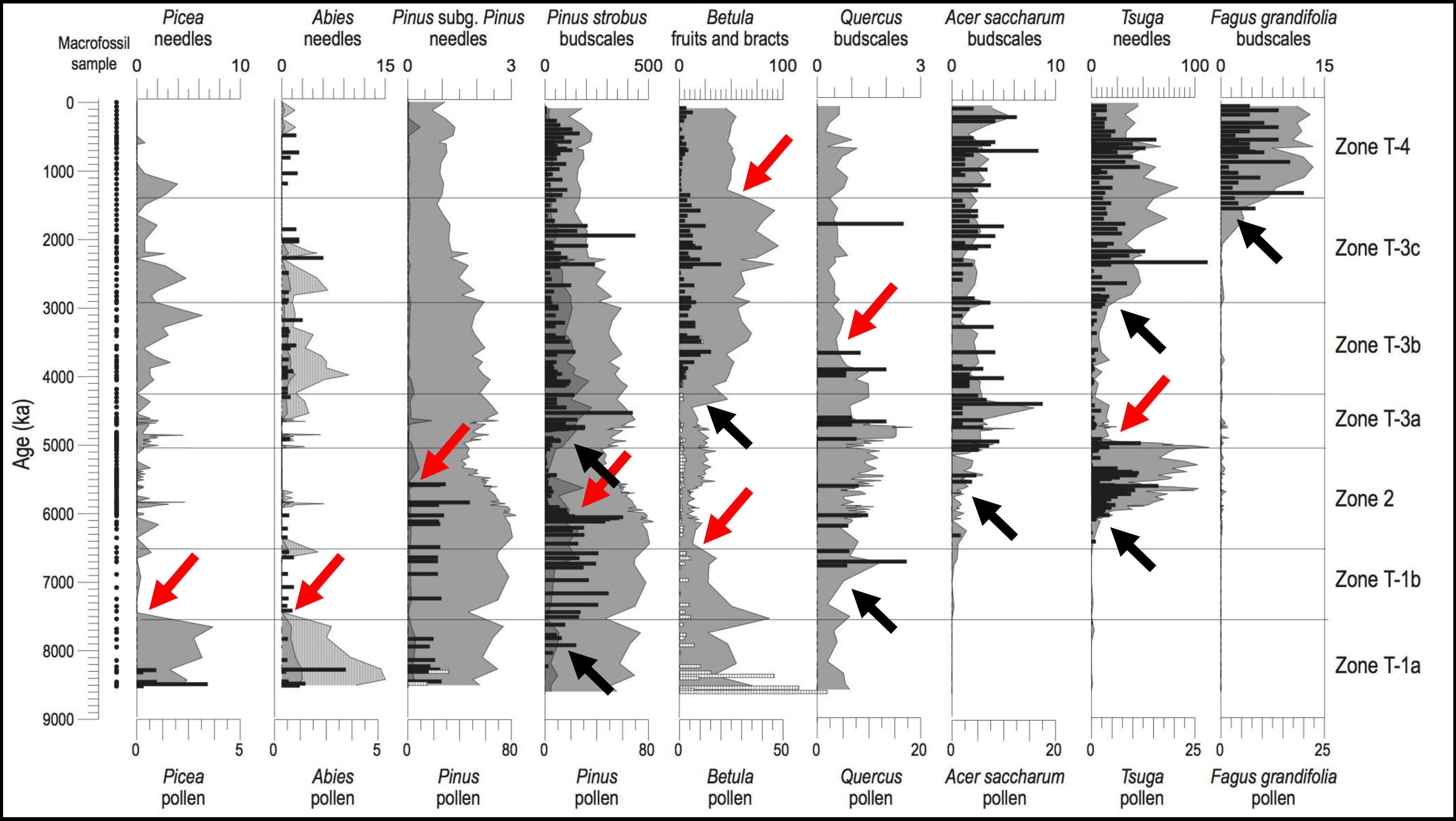
We live in a world of change.



Past 1200 years, Upper Colorado River Basin - modified from Meko *et al*. 2007

Ecological turnover and biodiversity dynamics: Hemlock/beech/sugar maple/yellow birch forest

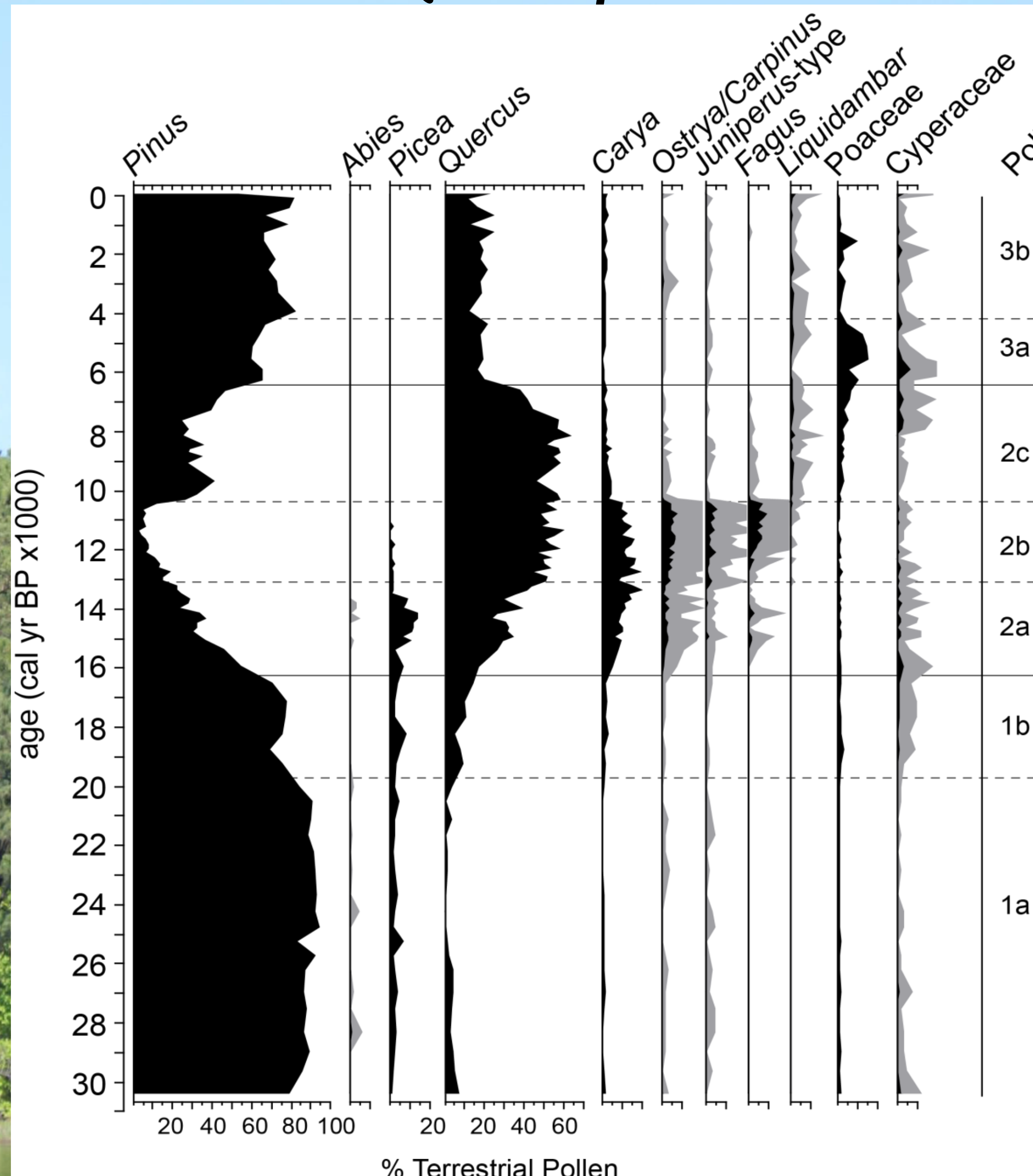
Tower Lake, Upper Michigan



S.T. Jackson, R.K. Booth, .J. Andersen, K. Reeves, T.A. Minckley & R.A. Jones. 2014. *Quaternary Science Reviews* (see discussion in S.T. Jackson & J.L. Blois. 2015. *PNAS*).

Coastal Plain of southeastern US (*Pinus palustris* forest)

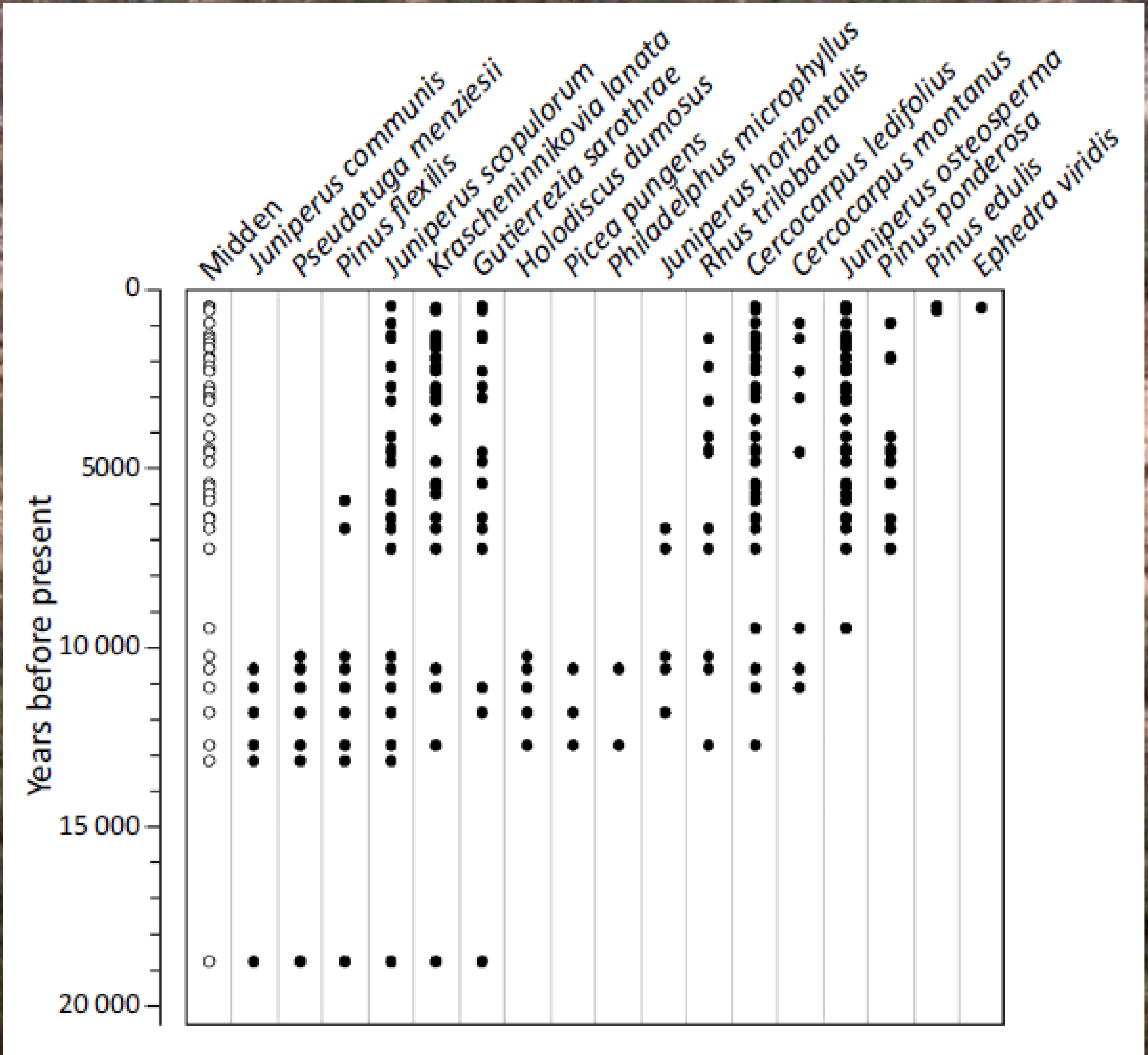
White Pond, South Carolina



T. Krause *et al.* *Quaternary Research*, in press

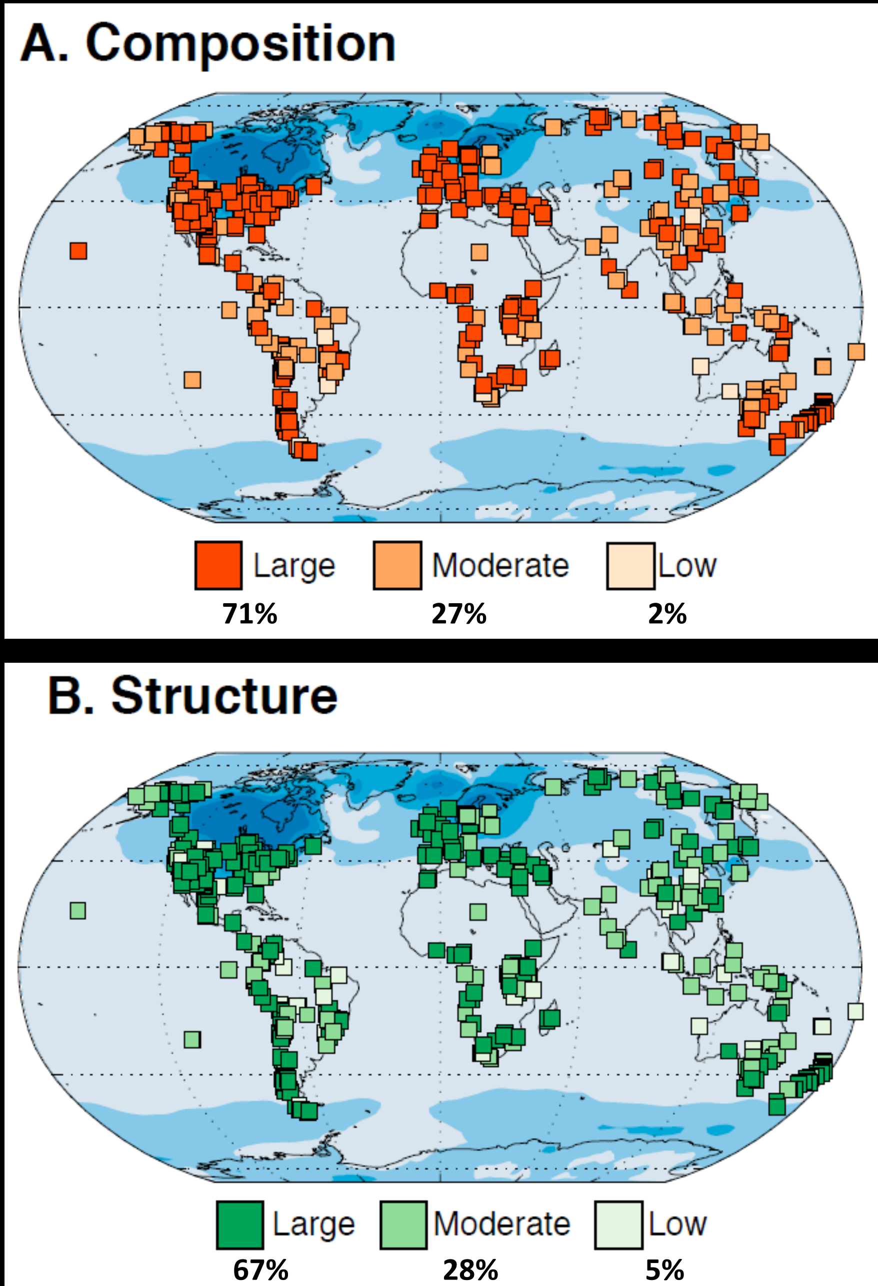
Dutch John Mountain, NE Utah

Pinyon-juniper woodland

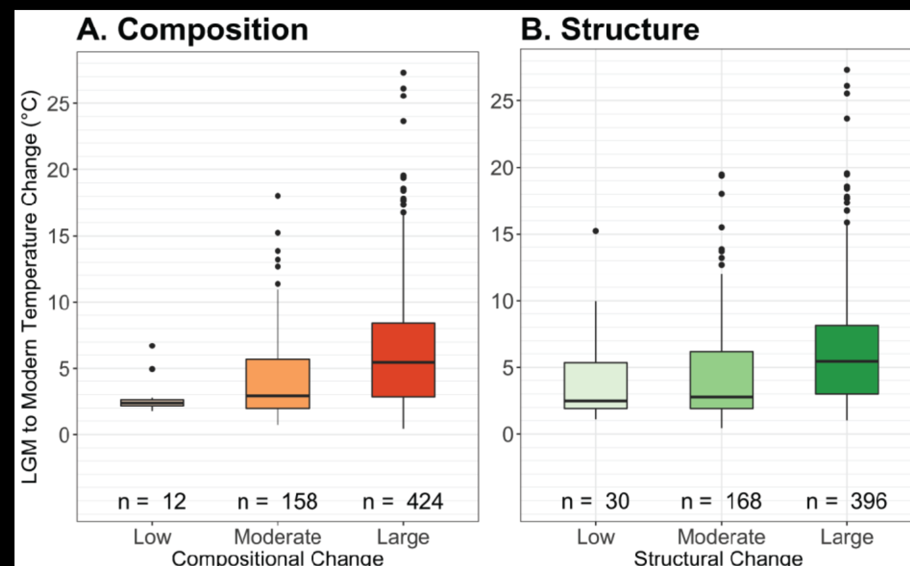


S.T. Jackson, J.L. Betancourt, M.E. Lyford, & S.T. Gray. 2005. Journal of Biogeography.

Exceptions to ecological turnover are rare



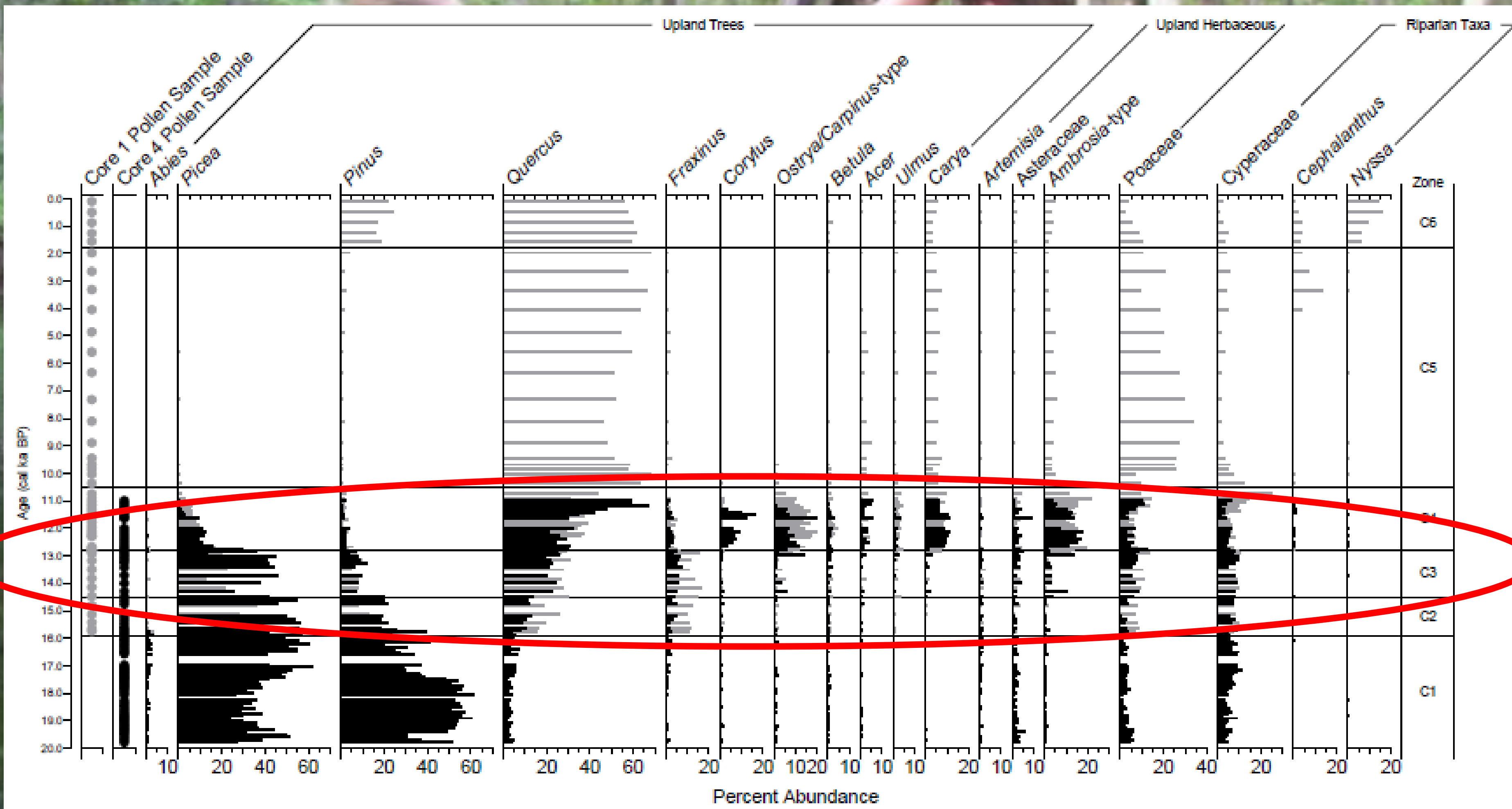
Estimated difference in vegetation between the last glacial maximum and the present (594 sites)



C. Nolan *et al.* 2018. Past and future global transformation of terrestrial ecosystems under climate change. *Science* 361:920-923.

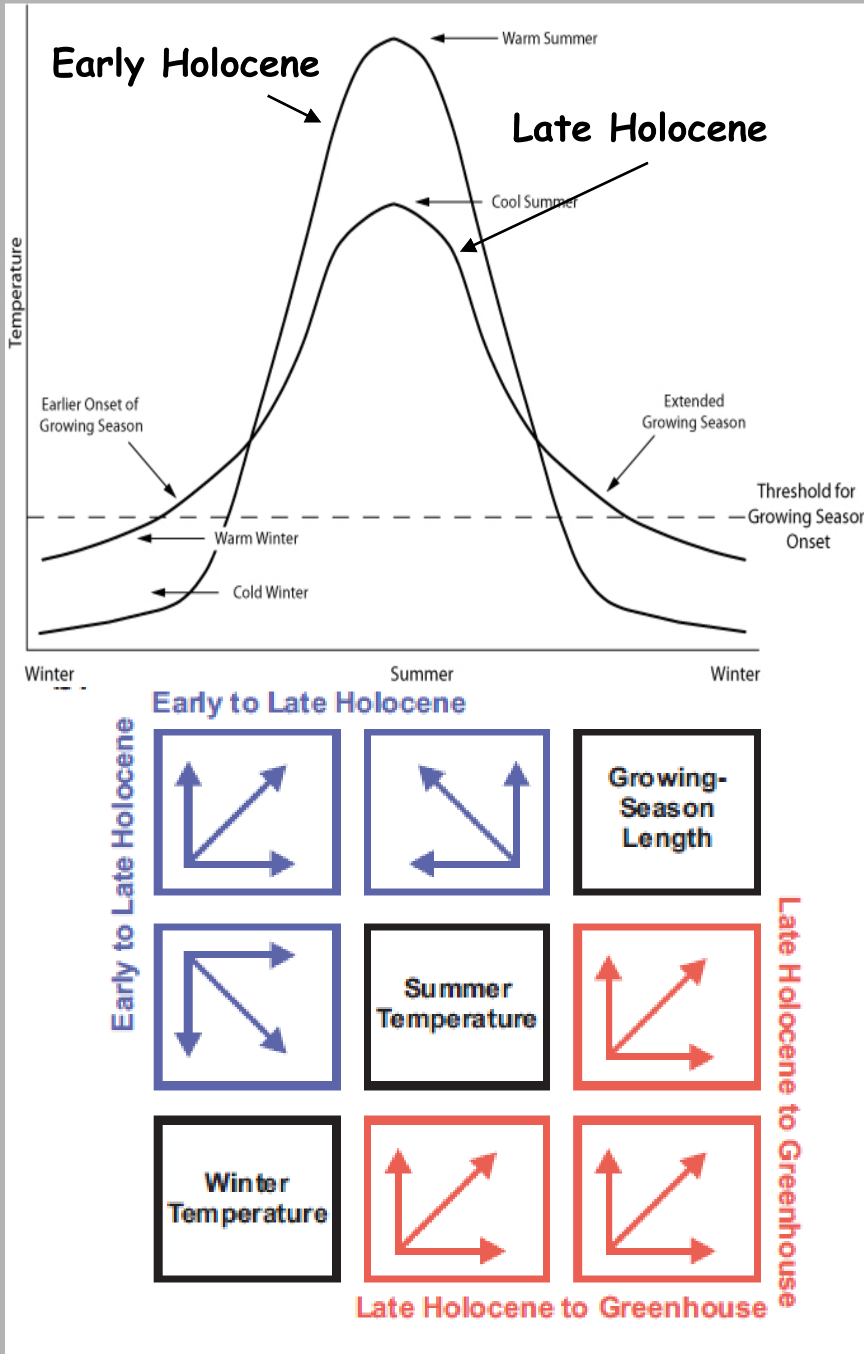
Ecological emergence and ecological novelty

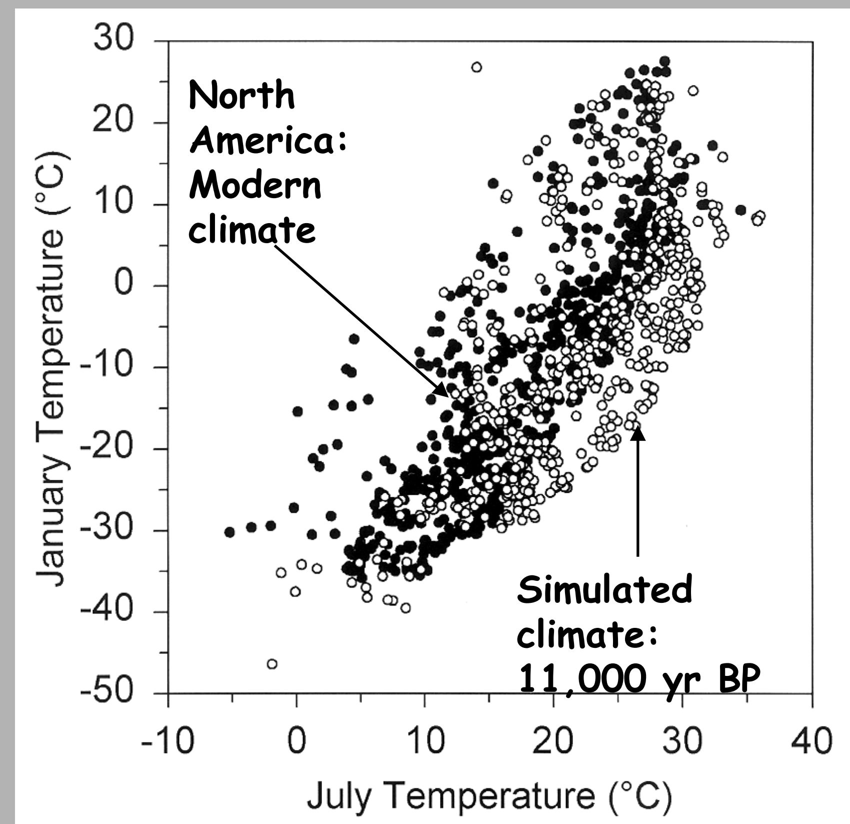
Cupola Pond, Ozark Mts. Missouri



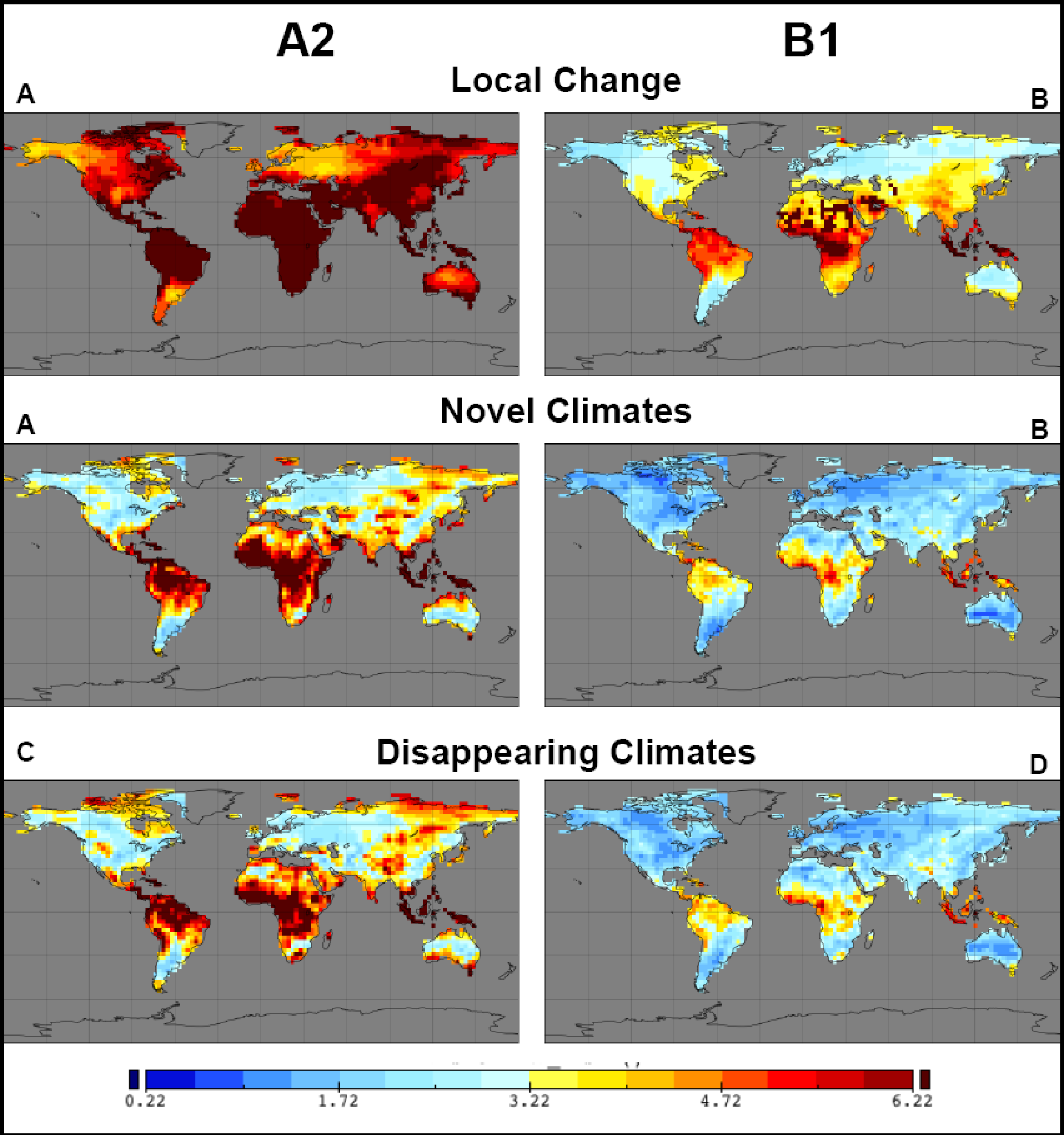
R.A. Jones, J.W. Williams, S.T. Jackson. 2017. *Quaternary Science Reviews.*

Correlations among climate variables may be conserved along spatial gradients, but not through time.





S.T. Jackson *et al.* 2009. *PNAS*. S.T. Jackson & J.T. Overpeck. 2000. *Paleobiology* (Suppl.).

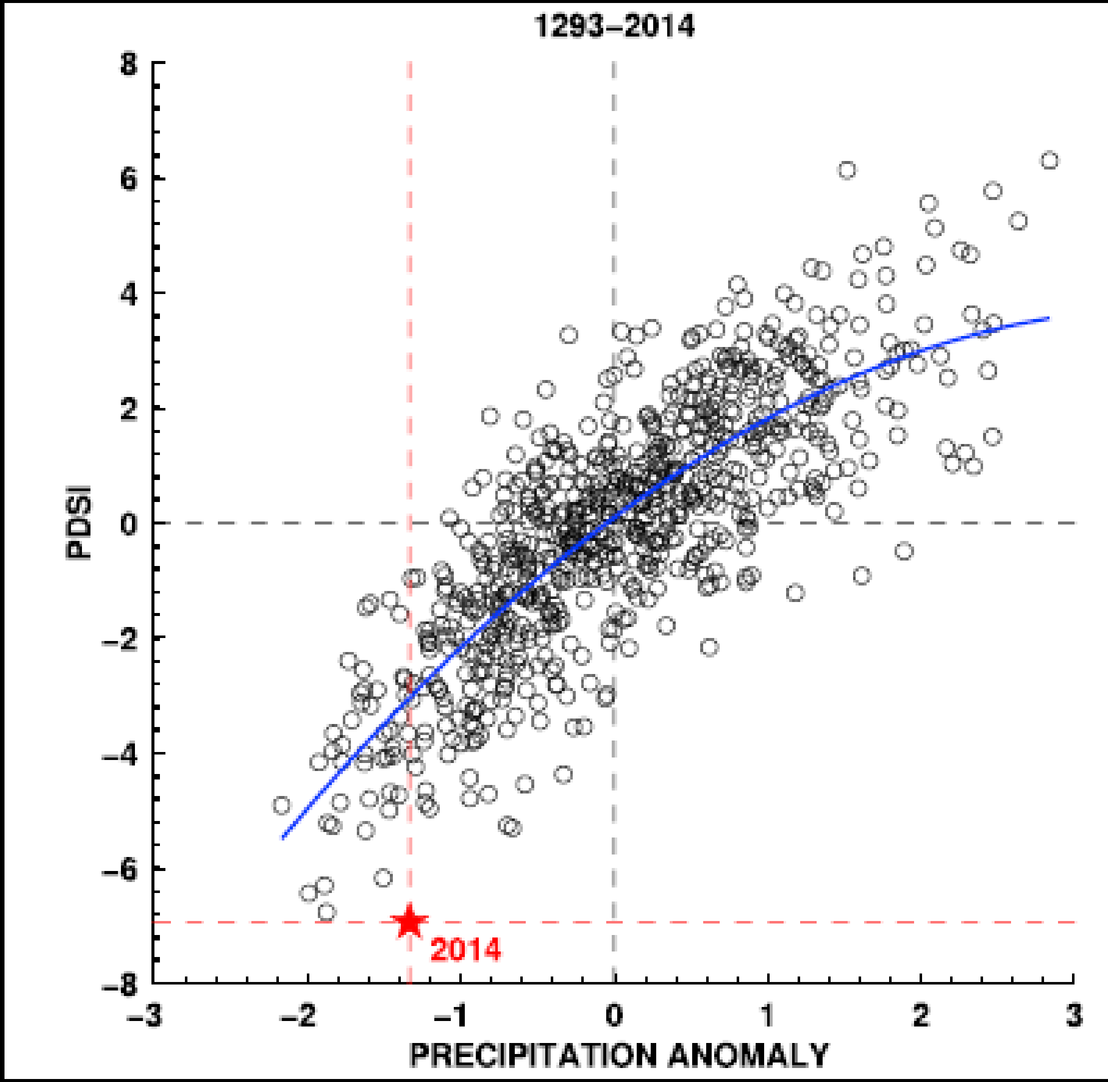


J.W. Williams, S.T. Jackson & J.E. Kutzbach. 2007. *PNAS*.

Novel climates will arise; some existing climates will vanish

Novel ecosystems will arise; some existing ecosystems will vanish

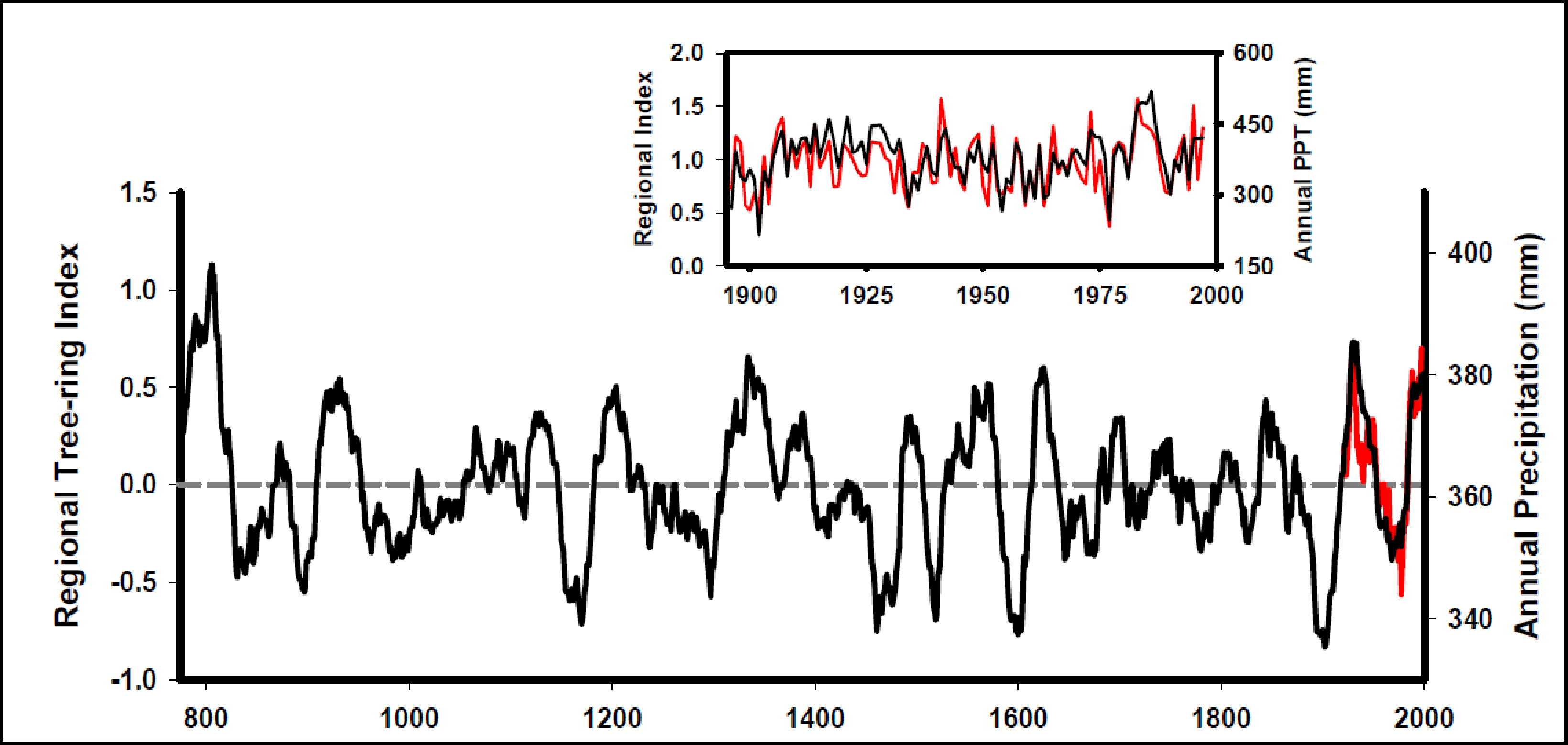
Novel drought in California: Unexceptionally dry, but exceptionally hot.



D. Griffin & K.J. Anchukaitis. 2014. *Geophysical Research Letters.*

See also: A.P. Williams *et al. 2015. Geophysical Research Letters;*
N.S. Diffenbaugh *et al.* 2015. *PNAS.*

Even though long-term climate trajectories can be forecast, the precise paths cannot.



Upper Colorado River Basin - modified from Meko *et al.* 2007

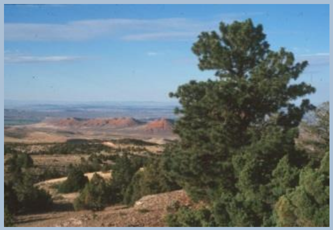
The climatic path from 2018 to 2028, 2058, 2118, etc. will NOT be a straight line.

Historically contingent ecological outcomes: inertias, legacies, and anachronisms

Climate variability, disturbance, recruitment

For details, see S.T Jackson, R.K. Booth, J.L. Betancourt & S.T. Gray. 2009. *PNAS.*

Many examples



***Pinus ponderosa* colonization, Bighorn Basin, Wyoming**
(M.R. Lesser & S.T. Jackson 2012 *Ecology;* M.R. Lesser & S.T. Jackson 2013 *Ecology Letters;* M.R. Lesser *et al.* 2013 *Molecular Ecology;* J.R. Norris *et al.* 2016 *J. Biogeography*)

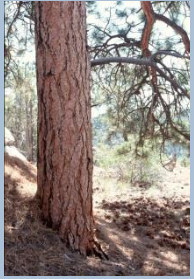
***Pinus edulis* colonization, Dutch John Mt., Utah**
(S.T. Gray *et al.* 2006 *Ecology*)

***Juniperus osteosperma* colonization, Bighorn Basin, WY/MT (M.E. Lyford *et al.* 2003 *Ecological Monographs*)**

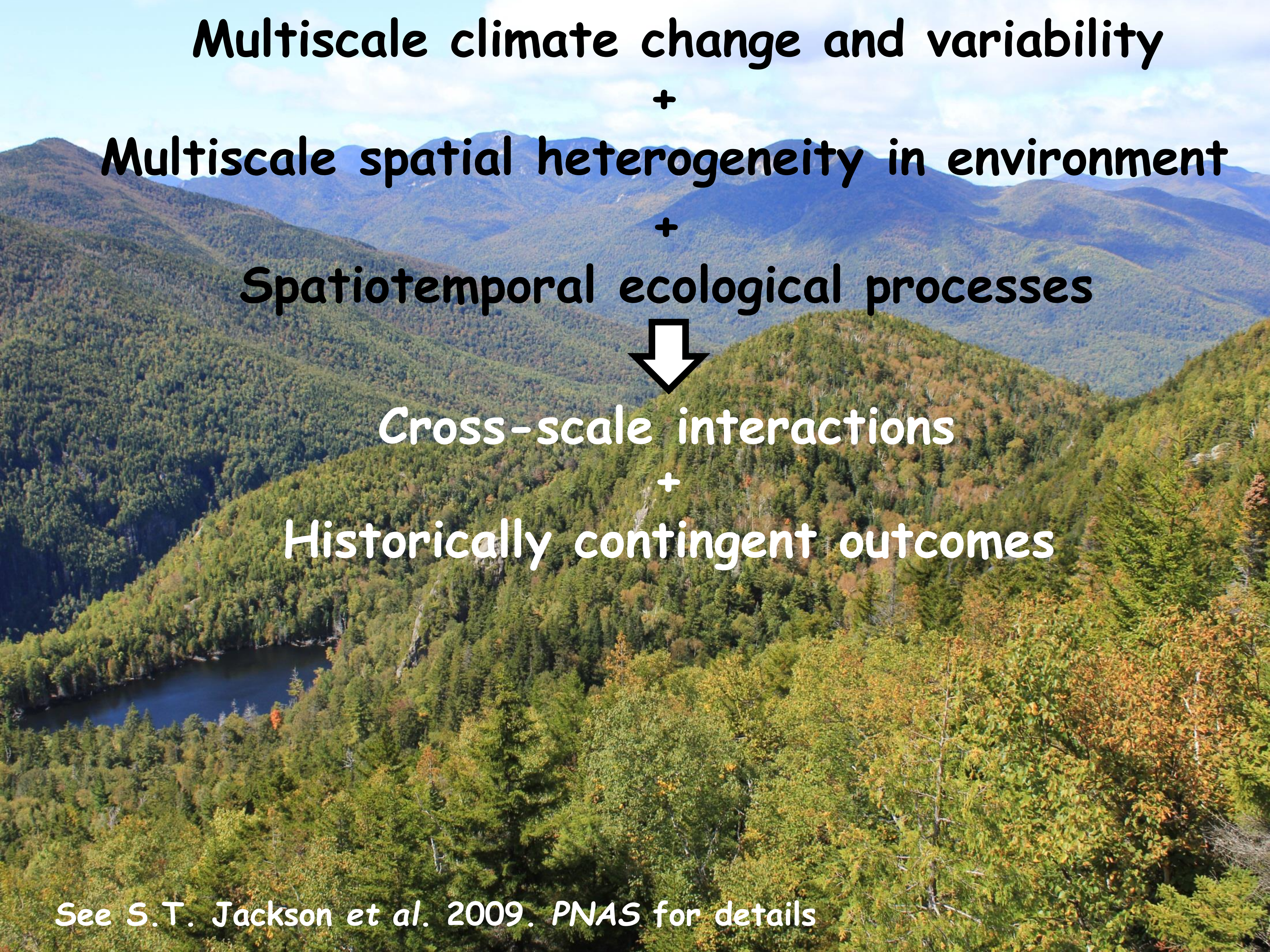
***Tsuga canadensis* rangewide decline, eastern North America**
(R.K. Booth *et al.* 2012a *Ecology*)

***Fagus grandifolia* regional decline, Michigan**
(R.K. Booth *et al.* 2012b *Ecology*)

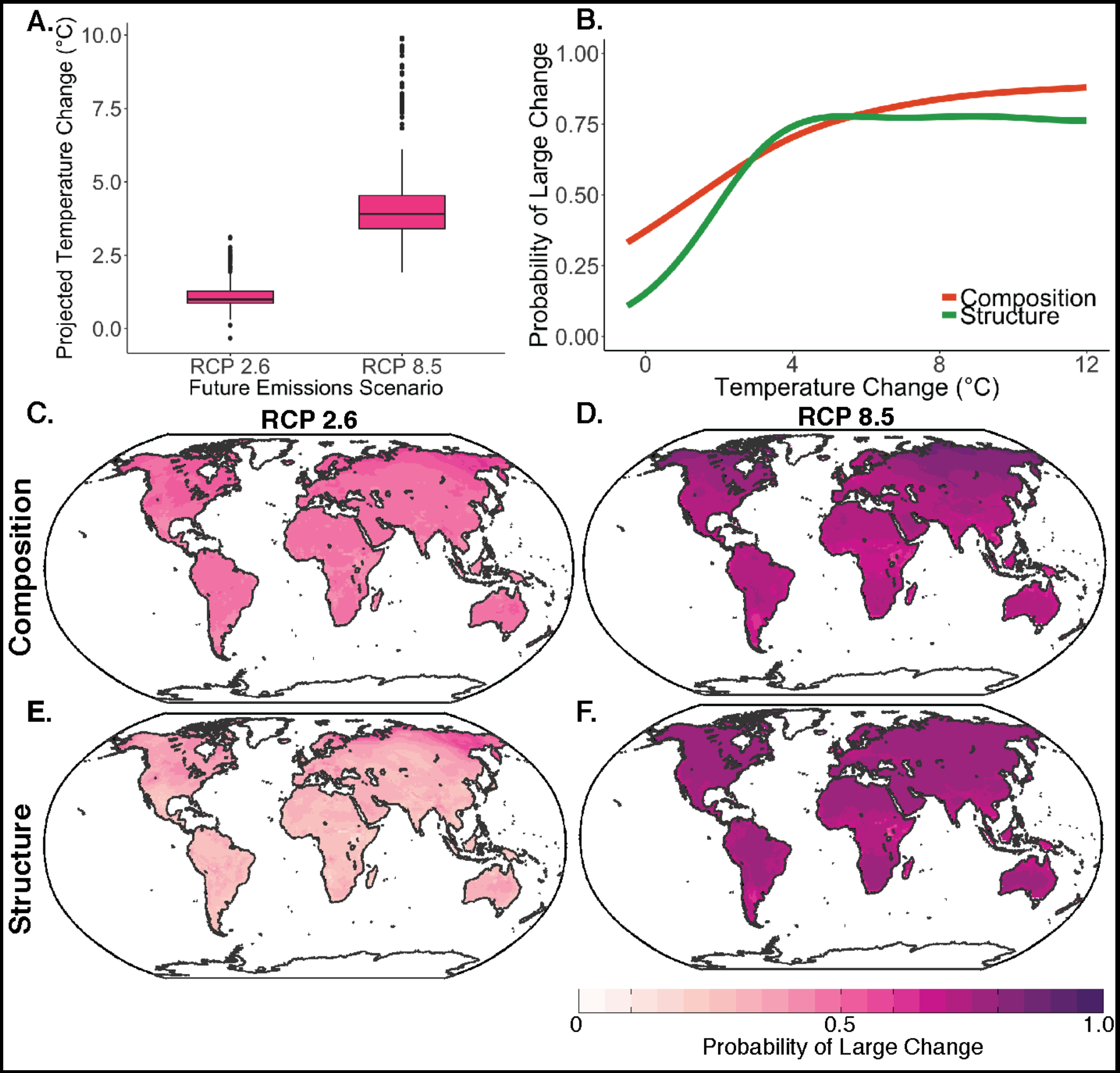
***Larix laricina* colonization, NW Québec (C. Peñalba & S. Payette 1997 *Quaternary Research*)**



***Pinus ponderosa* stand structure, Black Hills, WY/SD**
(P.M. Brown 2006 *Ecology*)


Multiscale climate change and variability
+
Multiscale spatial heterogeneity in environment
+
Spatiotemporal ecological processes
Cross-scale interactions
+
Historically contingent outcomes
See S.T. Jackson et al. 2009. PNAS for details

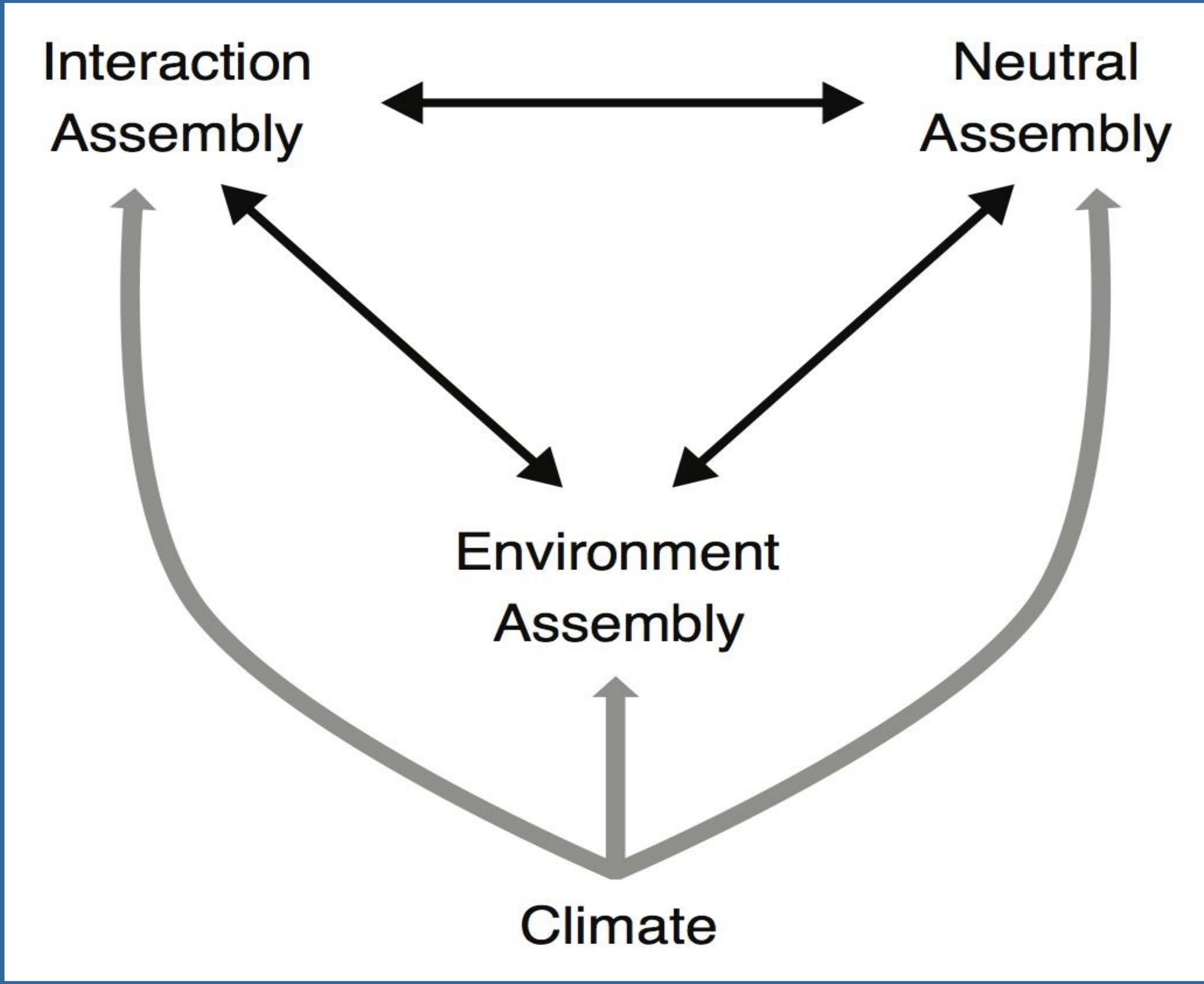
Climate change will drive transitions to new ecological states



C. Nolan *et al.* 2018. Past and future global transformation of terrestrial ecosystems under climate change. *Science* 361:920-923.

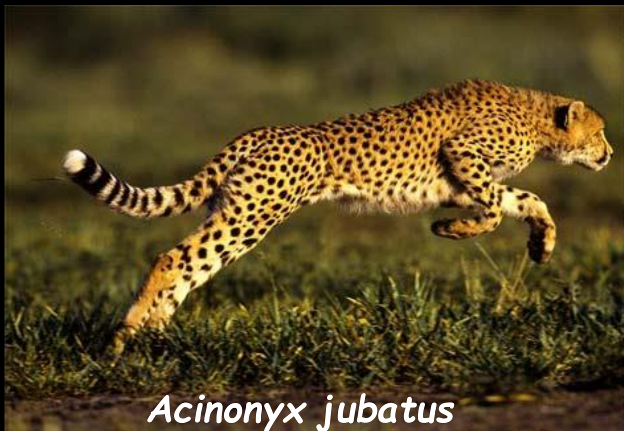
2016: Persistent Gambel-oak scrub replacing Ponderosa pine following Aspen Fire of 2003, Mt. Lemmon, Arizona.

Ecological Indeterminacies: arising from novel environments, biotic interactions, and chance (contingent dynamics)



S.T. Jackson & J.L. Blois. 2015. *PNAS.*

Climate change yields biodiversity casualties



Acinonyx jubatus

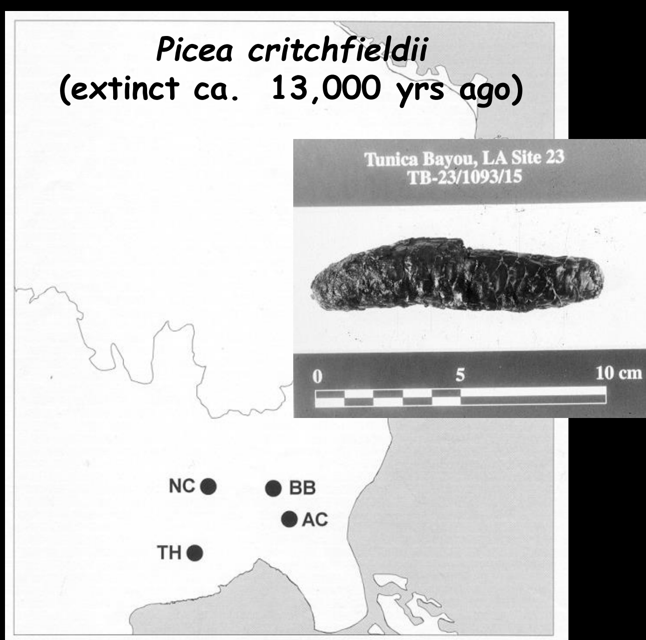
S.J. O'Brien & W.E Johnson. 2005. *Ann. Rev. Genomics & Hum. Gen.*

Megaloceros giganteus

A.D. Barnosky. 1986. *Quat. Res.*

Pinus torreyana

F.T. Ledig & M.T. Conkle. 1983. *Evolution*



Picea critchfieldii (extinct ca. 13,000 yrs ago)

S.T. Jackson & C. Weng, 1999. *PNAS*

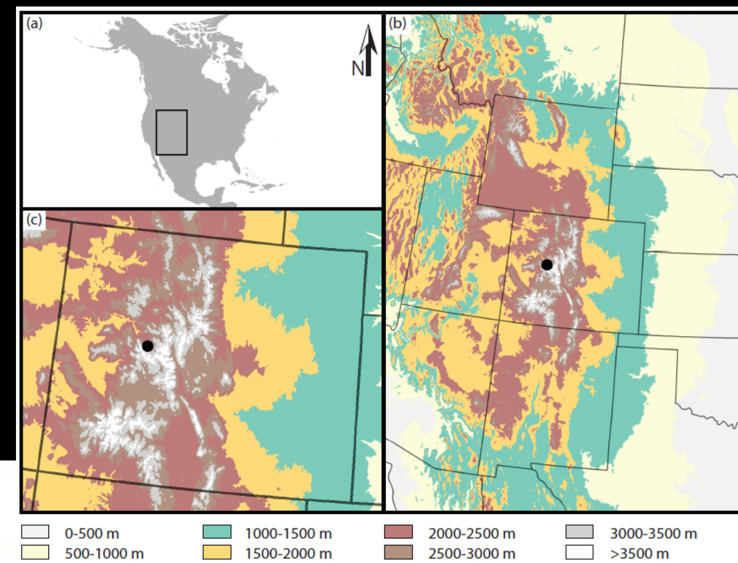
Pinus resinosa

J. Boys *et al.* 2005. *Amer. J. Bot.*

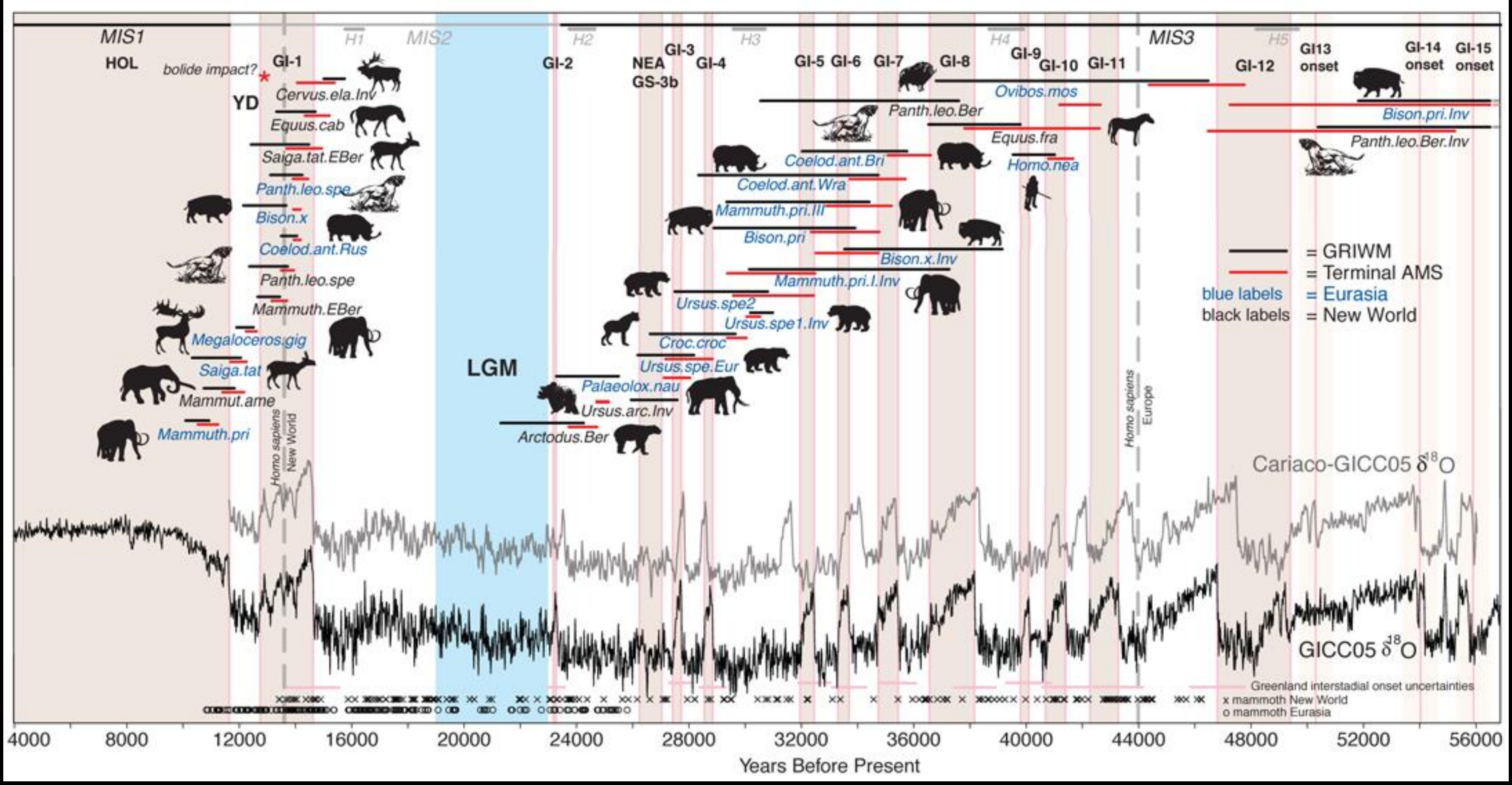
Alces alces

K.J. Hundtermark *et al.* 2002. *Mol. Phylogen. Evol.*

Picea sp. nov., Zeigler Reservoir Site, Colorado (140,000 – 80,000 yr BP)

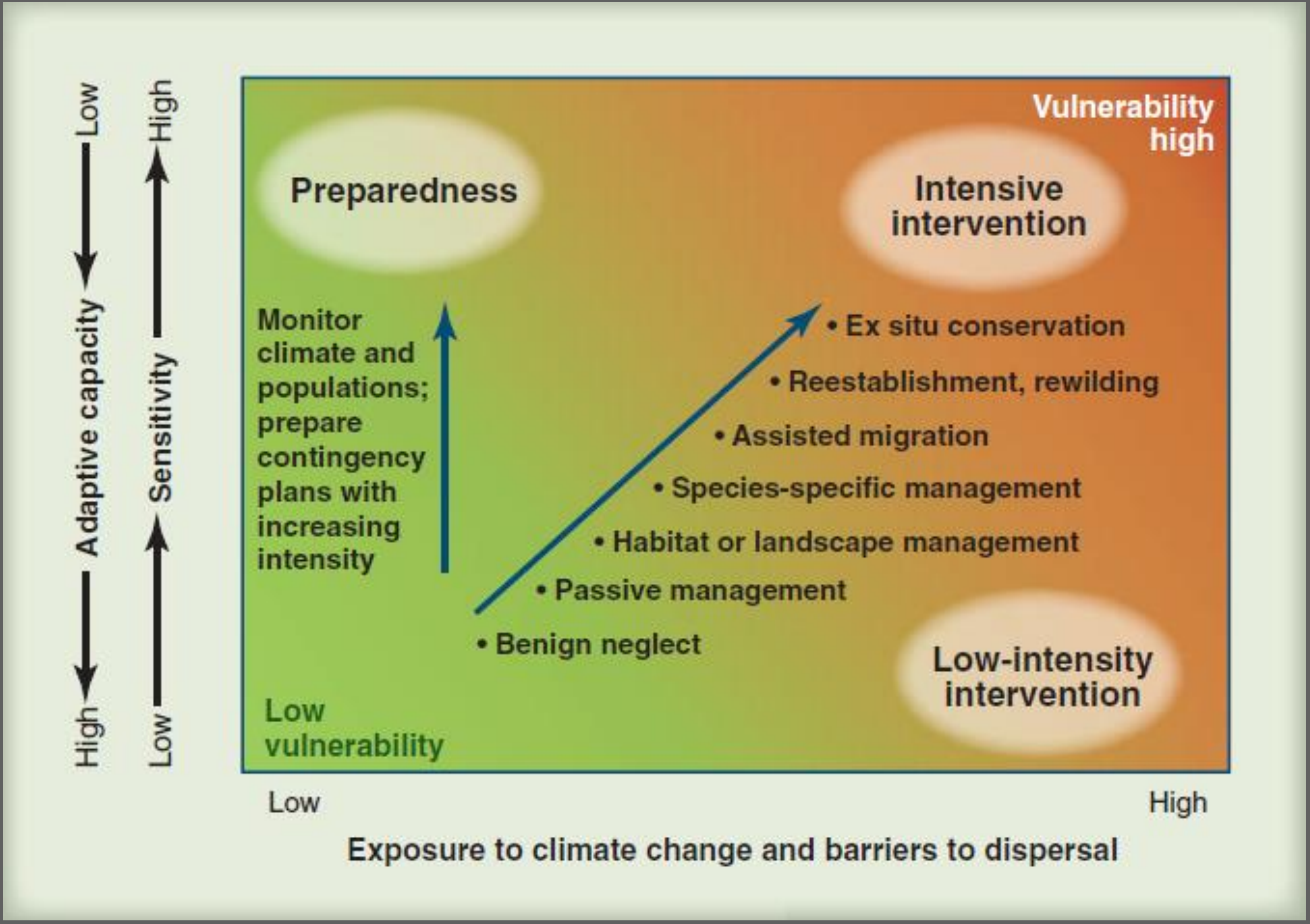


D.M. Miller, I.M. Miller & S.T. Jackson. 2014. *Quat. Res.*



A. Cooper, C. Turney, K.A. Hughen, B.W. Brook, H.G. McDonald & C.J.A. Bradshaw. 2015. Abrupt warming events drove Late Pleistocene Holarctic megafaunal turnover. *Science*.

Despite the biodiversity losses and disruptions, many species abide.



T.P. Dawson, S.T. Jackson, J.I. House, I.C. Prentice & G.M. Mace. 2011. *Science* 332:53-58.

Learn how to leverage natural adaptation capacity:

- Phenotypic adjustment
- Habitat shift
- Migration
- Evolutionary adaptation

Long-term Population Persistence

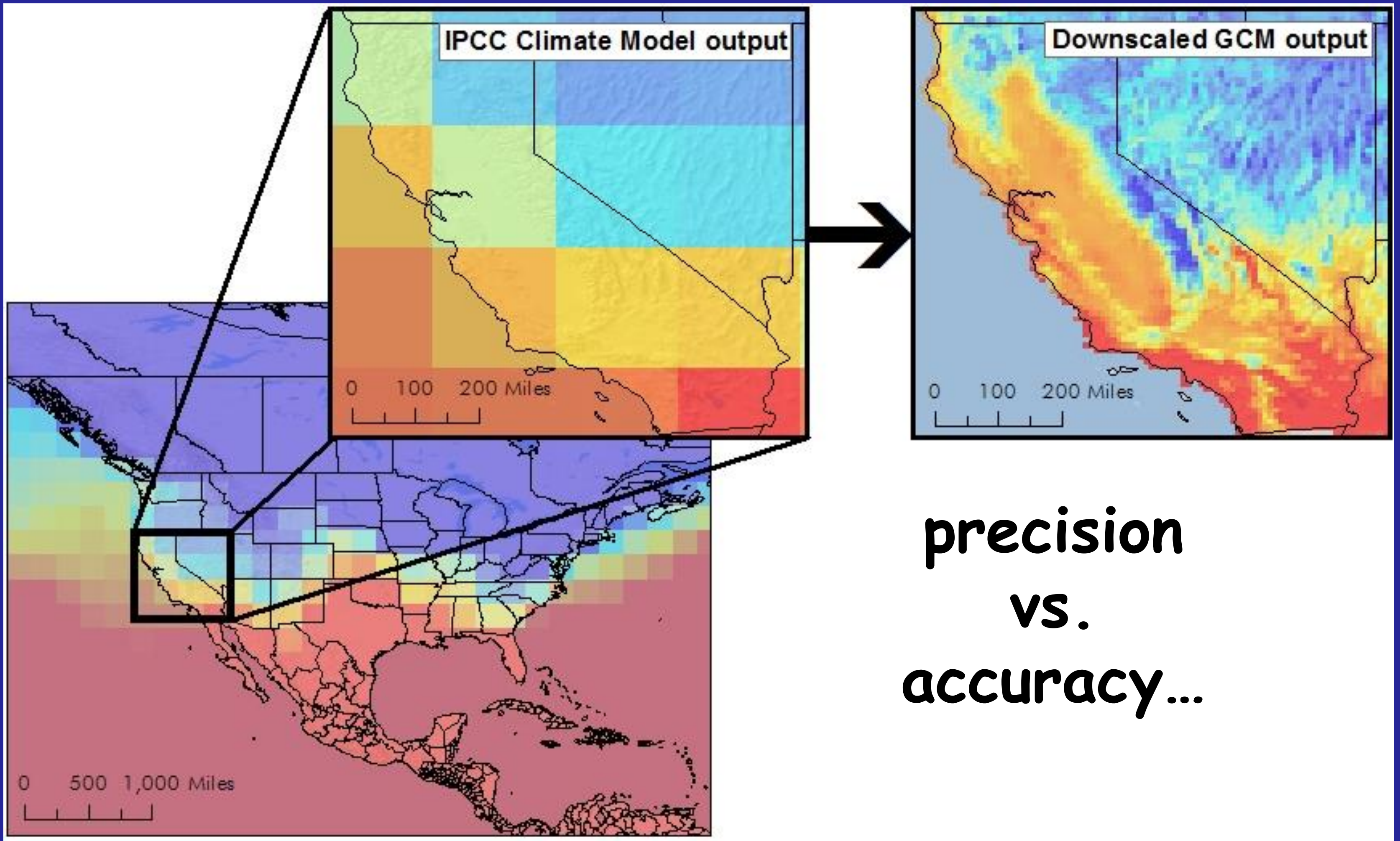
Species	Site	Duration (yr)
Juniperus osteosperma	Painted Hills, NV	34,000
Juglans nigra	Tunica Hills, LA	22,500
Carpinus caroliniana	Tunica Hills, MS	22,500
Choisya dumosa	Otero Mesa, NM	21,000
Juglans nigra	Nonconnah Ck, TN	20,500
Liriodendron tulipifera	Nonconnah Ck, TN	20,500
Fagus grandifolia	Nonconnah Ck, TN	20,500
Juniperus scopulorum	Dutch John Mt., UT	18,800
Cercocarpus ledifolius	Dutch John Mt., UT	13,150
Pinus ponderosa	Kaibab Plateau, AZ	12,000
Abies lasiocarpa	Kaibab Plateau, AZ	12,000
Abies balsamea	Adirondack Mts., NY	11,000
Pinus contorta	Yellowstone Plateau, WY	10,900

Challenges and Uncertainties

What are the appropriate climate variables?
Example: What do we mean by temperature?

- Mean annual temperature
- Mean growing-season temperature
- Growing-season length
- Growing degree days
- Maximum summer temperature
- Minimum winter temperature
- Number of consecutive days (or hours) above a temperature threshold
- Number of consecutive days (or hours) below a temperature threshold
  (11^{o}, or 0^{o}, or -10^{o}, or -40^{o} C)
- Date of inception of growing season
- Frequency of years with springtime temperatures between *x* and *y*
- Probability of temperatures below a threshold following bud break
- Frequency of years with temperatures above or below a threshold relative to mean generation time
- Frequency of days with early-morning growing-season temperatures below a low-temperature photoinhibition threshold

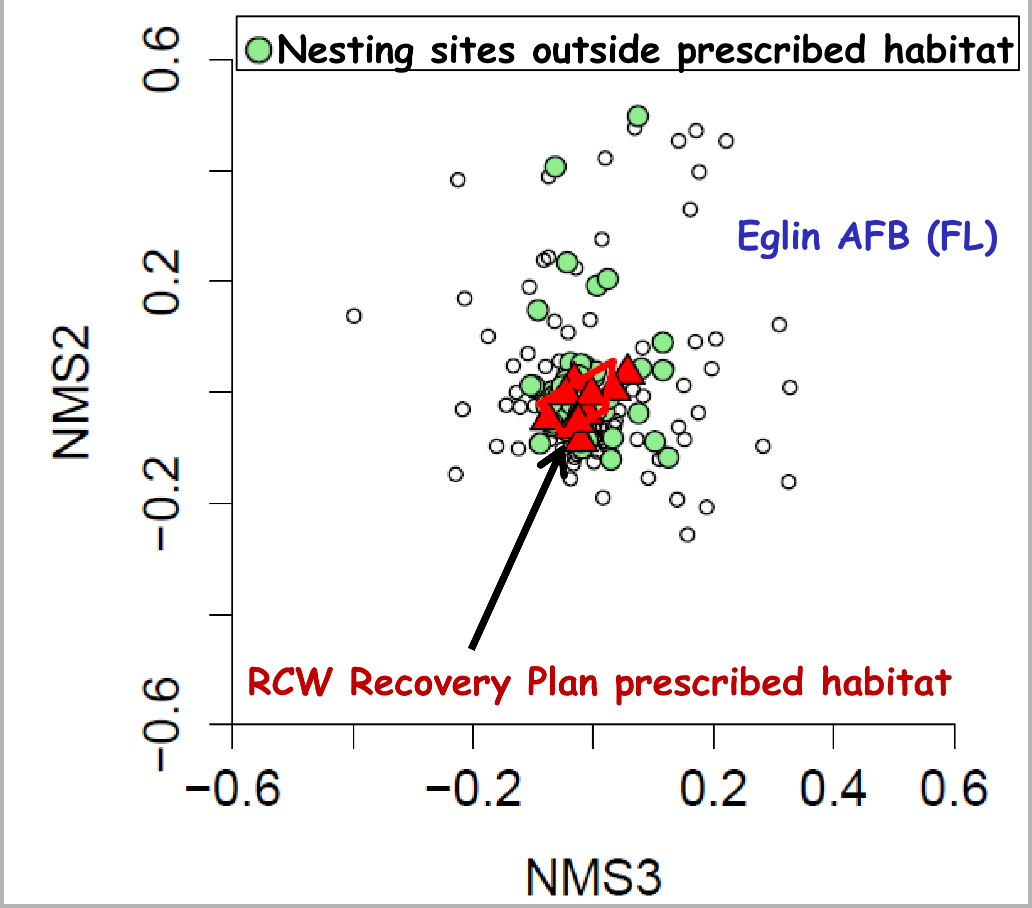
Can we downscale the right predictor variables to ecologically relevant spatial scales with accuracy in the right places?



precision
vs.
accuracy...

Cal-adapt.org

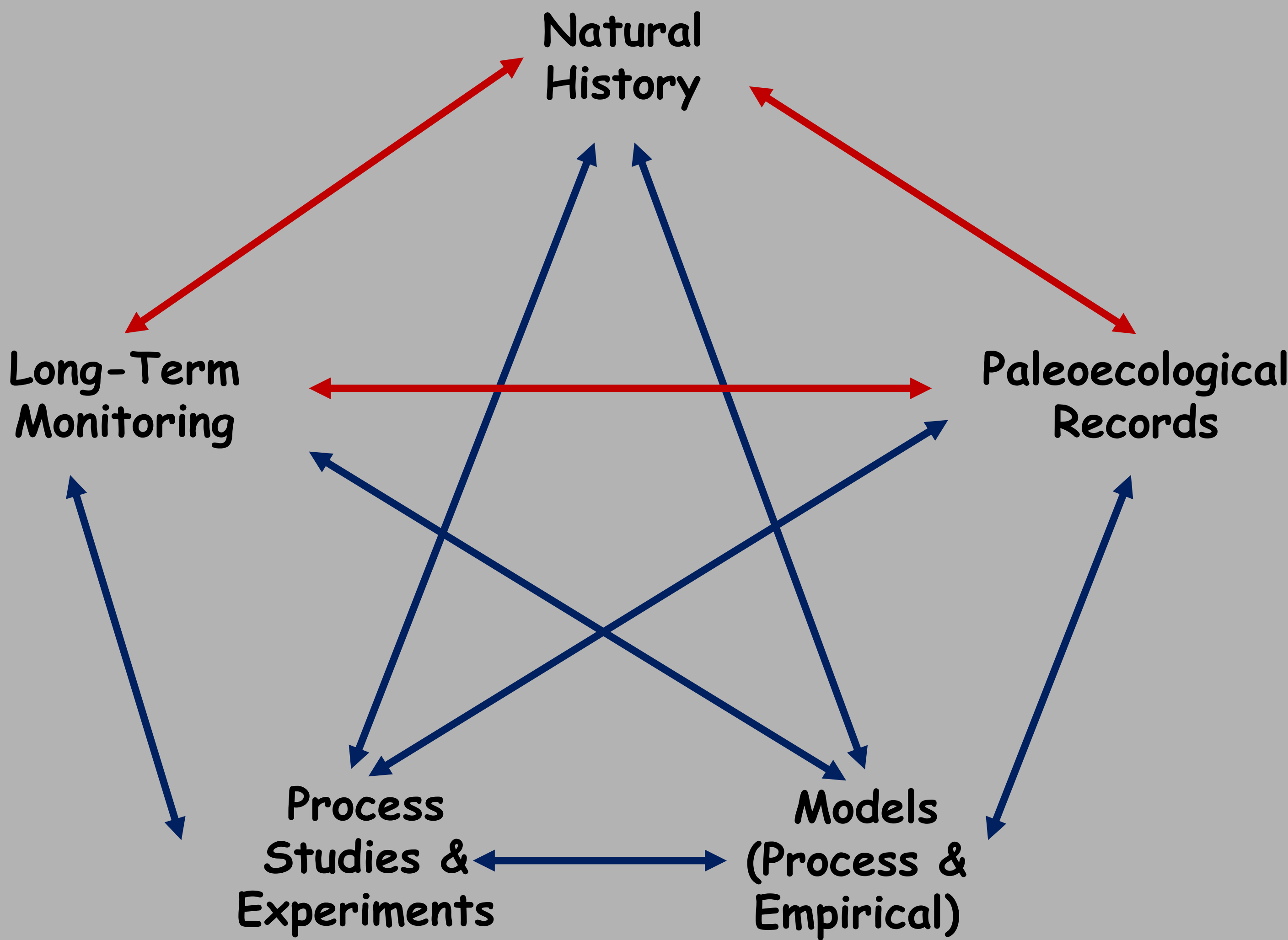
Real-world complexity: critters don't read the scientific literature



John James Audubon
Red-cockaded woodpecker

J.K. Hiers, S.T. Jackson, R.J. Hobbs, E.S. Bernhardt, L. Valentine. 2016. *Trends in Ecology and Evolution.*

Use ALL the information we have at hand



Southwest Climate Science Center

USGS
science for a changing world

The University of Arizona

Scripps Institution of Oceanography

UCLA

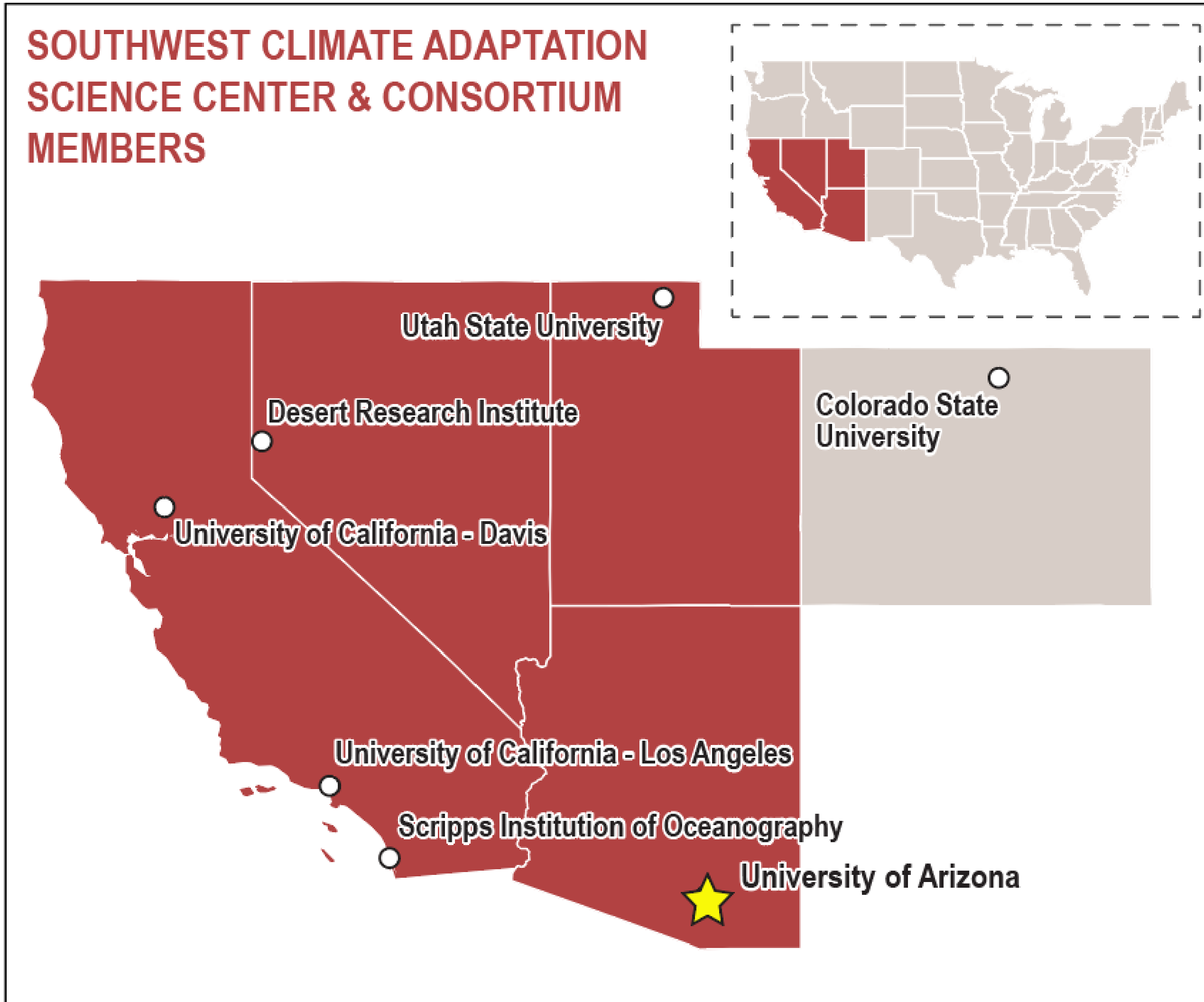
UC Davis
University of California

DRI
Desert Research Institute

Utah State University

Colorado State University

- 16% of U.S. population
- 25% of federal lands
- 25% of Dept. of Interior lands
- 25% of tribal lands (151 tribes)
- 22% of National Forest lands



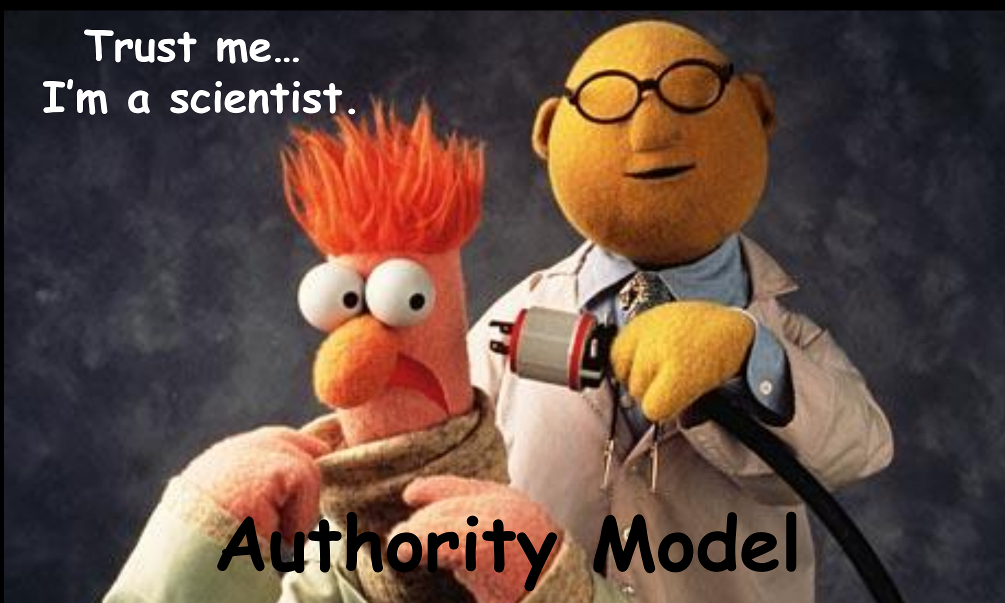
The 'great gap'

- communities of research
- communities of decision

National Archives


31
29
Loading Dock Model

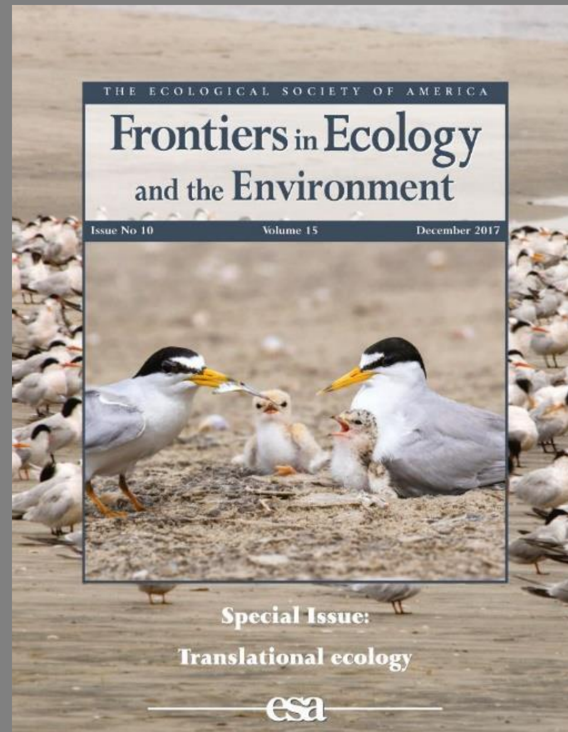

Megaphone Model


Trust me…
I'm a scientist.
Authority Model


Packaging Model

Engage with decision-makers and practitioners

NCEAS Translational Ecology
Working Group, November 2015



December 2017

"Translational ecology is an intentional process by which ecologists, stakeholders, and decision-makers work collaboratively to develop scientific research that … results in improved decision-making."

Climate-change ecology isn't rocket science!

Werner von Braun &
John F. Kennedy,
Cape Canaveral, 1963

It's <u>much</u> more difficult…