Climate Change Projections for Western Forests

Dr. Dominique Bachelet, Dept of Biological and Ecological Engineering, OSU



Forest Health in Oregon – State of the State 2020

Corvallis, OR – February 26, 2020

The next IPCC Report (AR6) is coming!

AR = assessment report
CMIP = climate model intercomparison project

49 different modelling groups (CMIP5 had ~15)
21 CMIP6-Endorsed MIPs

JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2018MS001583

Special Section:
Community Earth System Model version 2 (CESM2) Special Collection

The Community Land Model Version 5: Description of New Features, Benchmarking, and Impact of Forcing Uncertainty

David M. Lawrence[1], Rosie A. Fisher[1], Charles D. Koven[2], Keith W. Oleson[1], Sean C. Swenson[1], Gordon Bonan[1], Nathan Collier[3], Bardan Ghimire[2], Leo van Kampenhout[4], Daniel Kennedy[5], Erik Kluzek[1], Peter J. Lawrence[1], Fang Li[6], Hongyi Li[7], Danica Lombardozzi[1], William J. Riley[2], William J. Sacks[1], Mingjie Shi[8,9], Mariana Vertenstein[1], William R. Wieder[1,18], Chonggang Xu[10], Ashehad A. Ali[11], Andrew M. Badger[12], Gautam Bisht[2], Michiel van den Broeke[4], Michael A. Brunke[13], Sean P. Burns[14,35], Jonathan Buzan[15], Martyn Clark[1], Anthony Craig[1], Kyla Dahlin[16], Beth Drewniak[17], Joshua B. Fisher[8,9], Mark Flanner[19], Andrew M. Fox[20], Pierre Gentine[5], Forrest Hoffman[3], Gretchen Keppel-Aleks[21], Ryan Knox[2], Sanjiv Kumar[22], Jan Lenaerts[23], L. Ruby Leung[24], William H. Lipscomb[1], Yaqiong Lu[25], Ashutosh Pandey[22], Jon D. Pelletier[26], Justin Perket[1,27], James T. Randerson[28], Daniel M. Ricciuto[29], Benjamin M. Sanderson[30], Andrew Slater[31], Zachary M. Subin[32], Jinyun Tang[2], R. Quinn Thomas[33], Maria Val Martin[34], and Xubin Zeng[13]

Key Points:
- Updated Community Land Model has more hydrological and ecological process fidelity and more comprehensive representation of land management.
- The model is systematically evaluated using International Land Model Benchmarking system and shows marked improvement over prior versions.

Supporting Information:
- Supporting Information S1

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Research Article | Open Access

Implementation of UK Earth system models for CMIP6

Alistair A. Sellar, Jeremy Walton, Colin G. Jones, Richard Wood, Nathan Luke Abraham, Miroslaw Andrejczuk, Martin B. Andrews, Timothy Andrews ... See all authors

First published: 07 February 2020 | https://doi.org/10.1029/2019MS001946

JAMES | Journal of Advances in Modeling Earth Systems

Research Article | Open Access

Evaluation of CNRM Earth System Model, CNRM-ESM2-1: Role of Earth System Processes in Present-Day and Future Climate

Roland Séférian, Pierre Nabat, Martine Michou, David Saint-Martin, Aurore Voldoire, Jeanne Colin, Bertrand Decharme, Christine Delire, Sarah Berthet ... See all authors

First published: 06 November 2019 | https://doi.org/10.1029/2019MS001791 | Citations: 2

Geosci. Model Dev., 12, 4823–4873, 2019
https://doi.org/10.5194/gmd-12-4823-2019

GMD | Articl

Article | Assets

Model description paper

The Canadian Earth System Model version 5 (CanESM5.0.3)

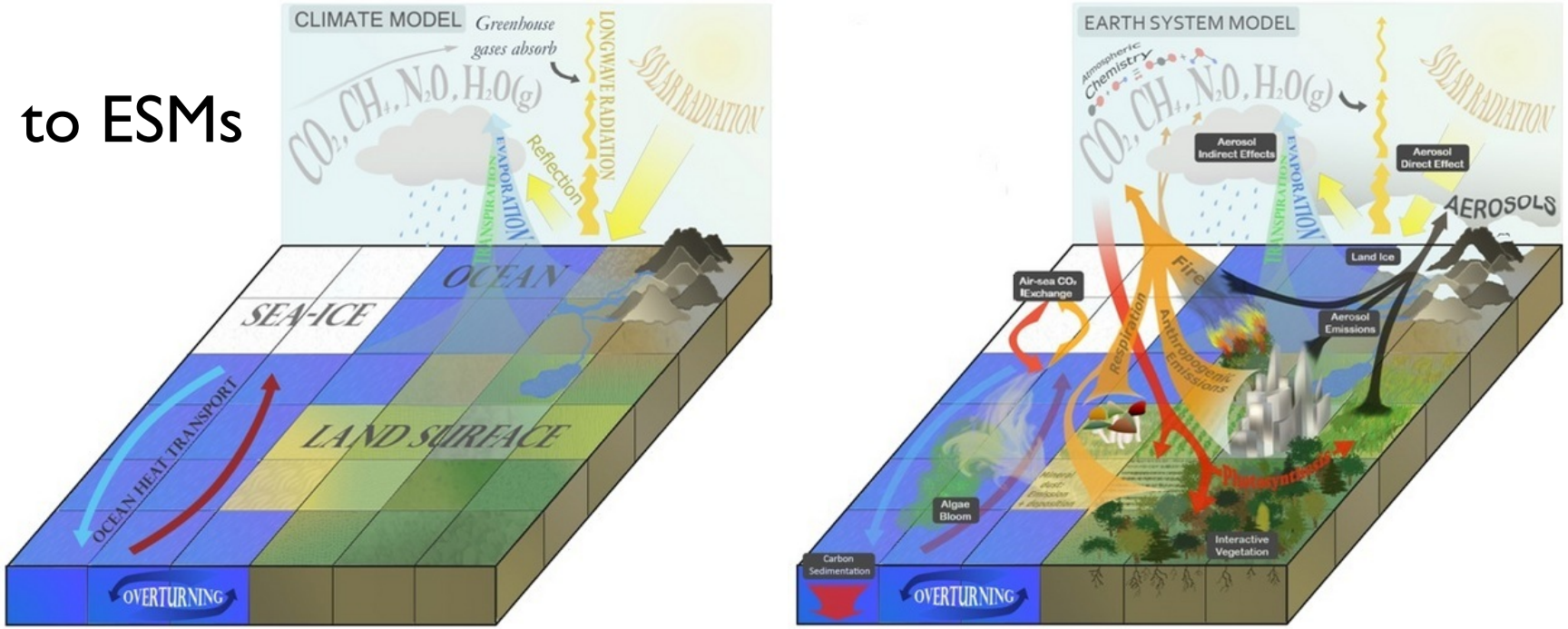
Neil C. Swart[1,3], Jason N. S. Cole[1], Viatcheslav V. Kharin[1], Mike Lazare[1], John F. Scinocca[1], Nathan P. Gillett[1], James Anstey[1], Vivek Arora[1], James R. Christian[1,2], Sarah Hanna[1], Yanjun Jiao[1], Warren G. Lee[1], Fouad Majaess[1], Oleg A. Saenko[1], Christian Seiler[4], Clint Seinen[1], Andrew Shao[3], Michael Sigmond[1], Larry Solheim[1], Knut von Salzen[1,3], Duo Yang[1], and Barbara Winter[1]
[1]Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Victoria, BC, V
[2]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canada
[3]University of Victoria, 3800 Finnerty Rd, Victoria, BC, V8P 5C2, Canada
[4]Climate Processes Section, Environment and Climate Change Canada, Victoria, BC, V8P 5C2, Canada

Credit: aerosol movement -NASA/Goddard Space Flight Center

Increased Complexity - Earth System Models

AR5 in 2014 – AR6 in 2021 (AR=assessment report)

GCMs to ESMs



Source: Heavens, N. G., Ward, D. S. & Natalie, M. M. (2013) Studying and Projecting Climate Change with Earth System Models. *Nature Education Knowledge* 4(5):4

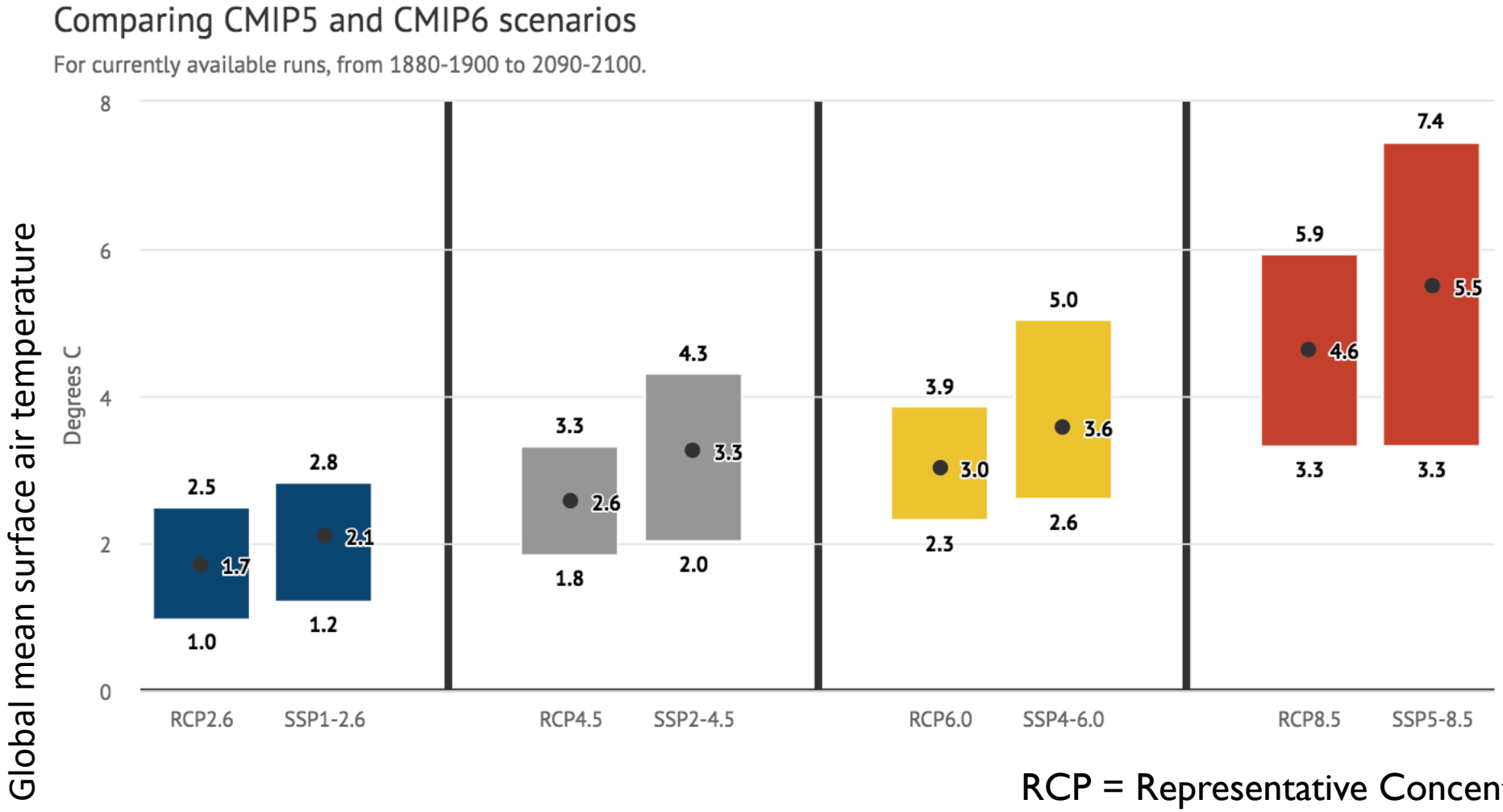
GRAND CHALLENGES

NEEDS MORE WORK!

Radiation
Wind patterns
Storms
Rainfall events

Land area
Salt Intrusion
Storm surges

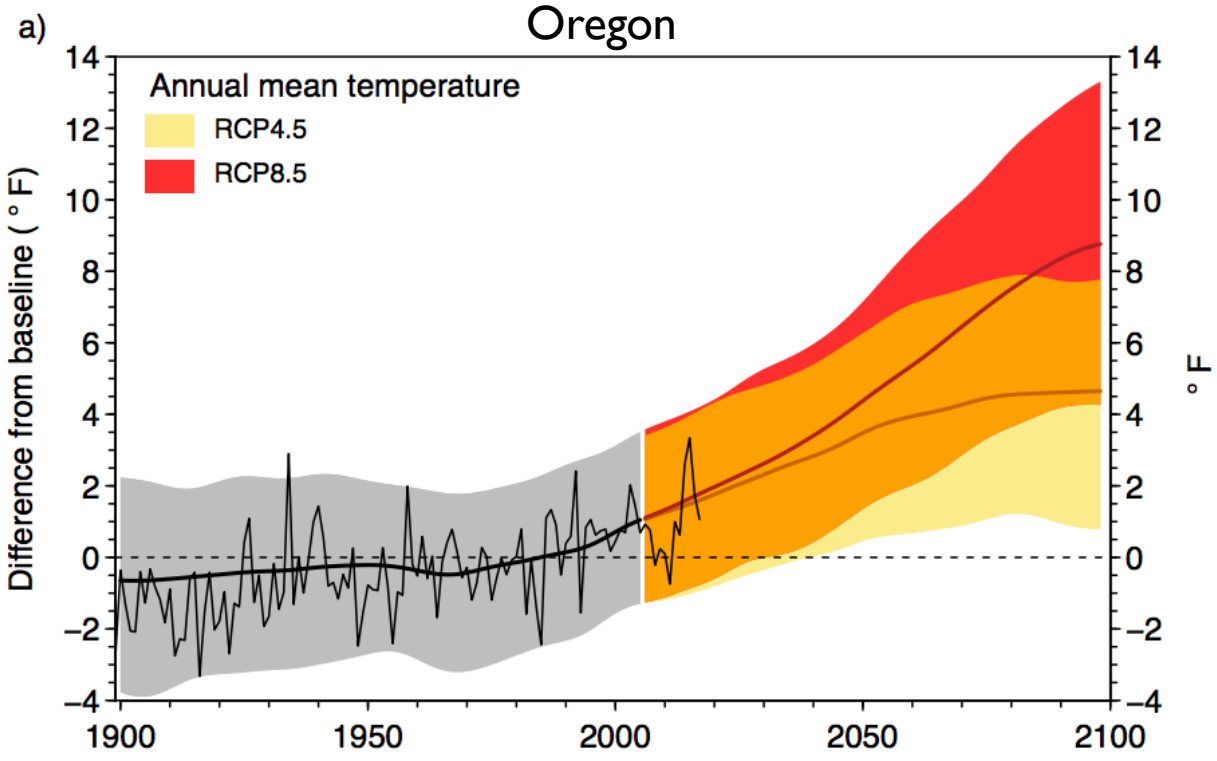
CMIP6 vs CMIP5 – greater warming



RCP = Representative Concentration Pathways
SSP = Shared Socioeconomic Pathways

https://www.carbonbrief.org/cmip6-the-next-generation-of-climate-models-explained

Warming is accelerating



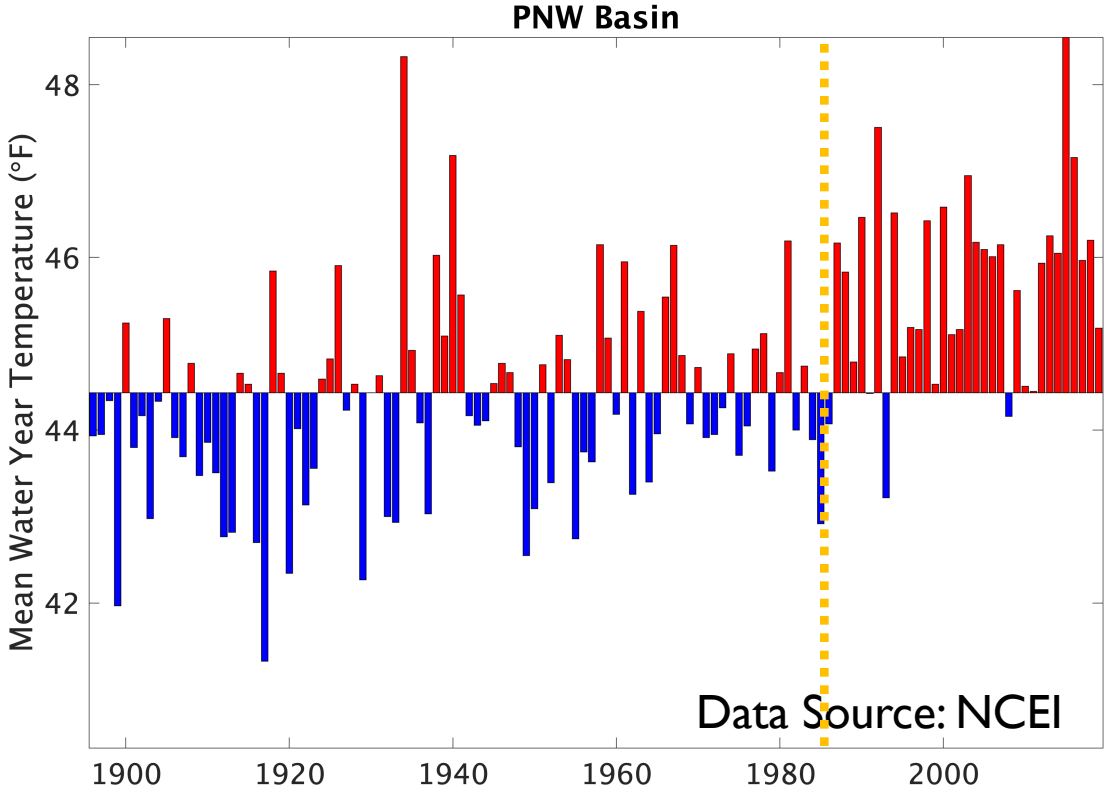
From: OR Clim. Ass. Report 4, 2019

Warming trend

1895-2019: +0.10°C

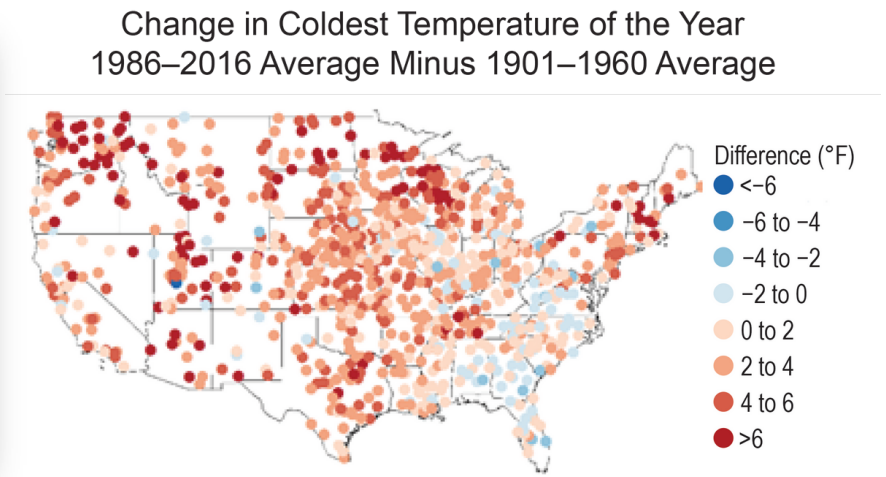
1950-2019: +0.17°C

1980-2019 : +0.23°C

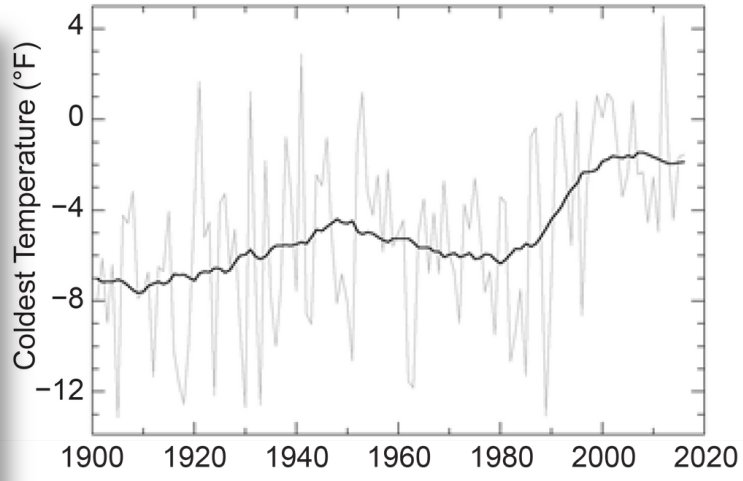


Seasonal Temperature change: Warmer Winters

e.g. Harrington and Gould 2015



Life cycle extended



Source: USGCRP, 2017: *Climate Science Special Report: Fourth National Climate Assessment, Volume I,* Wuebbles, D.J. et al. (eds.) U.S. Global Change Research Program, Washington, DC, USA.

Heat Waves

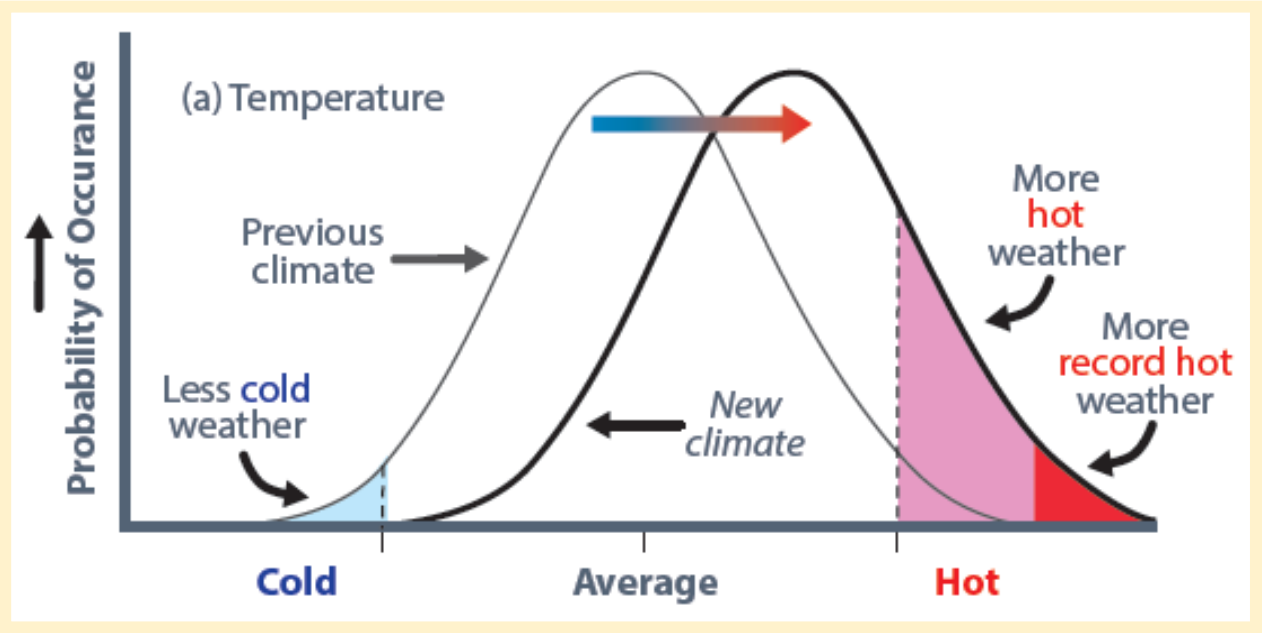
Antarctica logs hottest temperature on record with a reading of 18.3C

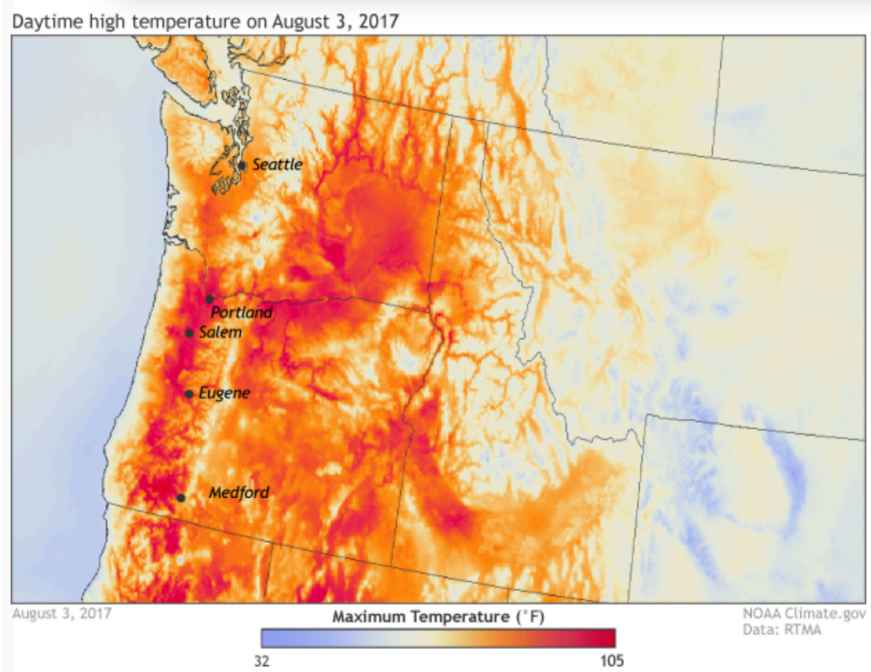
A new record set so soon after the previous record of 17.5C in March 2015 is a sign warming in Antarctica is happening much faster than global average

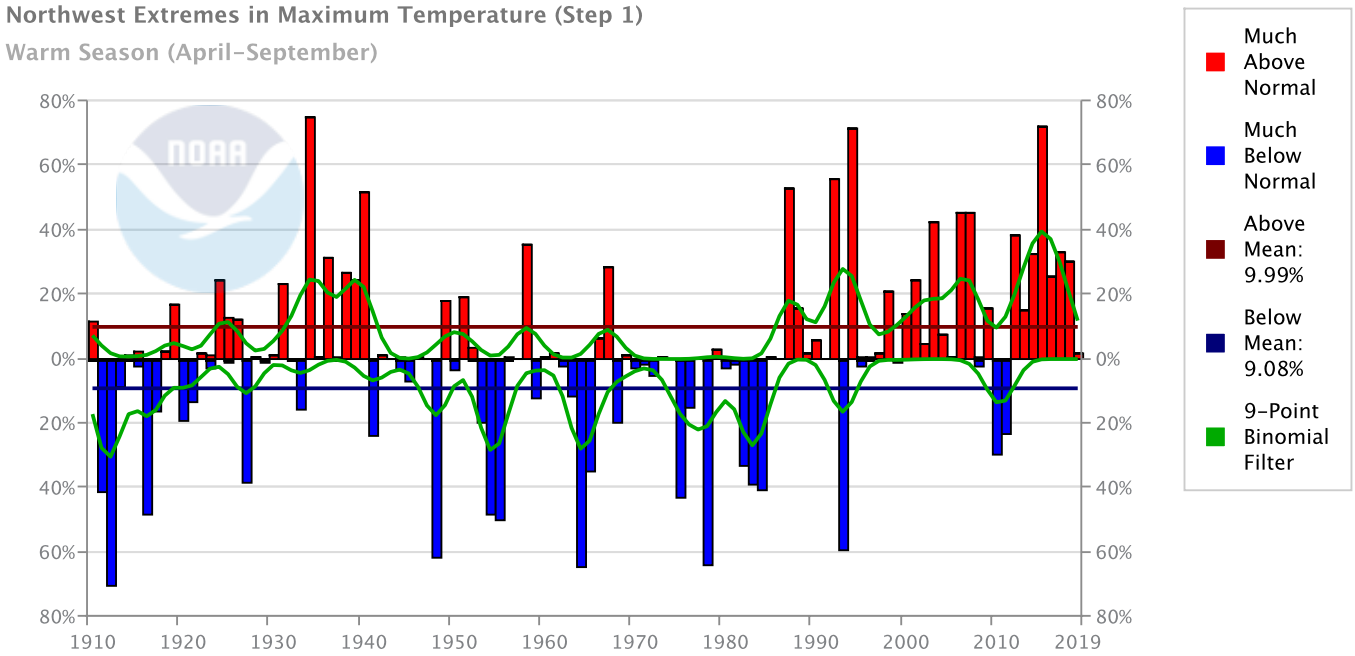
Anchorage was 90 degrees on July 4. That's not a typo

By Monica Garrett and Susan Scutti, CNN

Updated 3:40 AM ET, Sat July 6, 2019







https://www.ncdc.noaa.gov/extremes/cei/graph/nw/04-09/1

Physiological mechanisms of drought-induced tree die-off in relation to carbon, hydraulic and respiratory stress in a drought-tolerant woody plant

Shin-Taro Saiki[1], Atsushi Ishida[1], Kenichi Yoshimura[2] & Kenichi Yazaki[3]

Sc. Reports 2017

nature climate change LETTERS
PUBLISHED ONLINE: 5 SEPTEMBER 2016 | DOI: 10.1038/NCLIMATE3114

The increasing importance of atmospheric demand for ecosystem water and carbon fluxes

Kimberly A. Novick[1]*, Darren L. Ficklin[2], Paul C. Stoy[3], Christopher A. Williams[4], Gil Bohrer[5], A. Christopher Oishi[6], Shirley A. Papuga[7], Peter D. Blanken[8], Asko Noormets[9], Benjamin N. Sulman[10], Russell L. Scott[11], Lixin Wang[12] and Richard P. Phillips[13]

AUGUST 7, 2017

Drought-affected trees die from hydraulic failure and carbon starvation

by University of Sydney

Credit: Notneb82, Wikimedia Commons

PNAS

Increased water deficit decreases Douglas fir growth throughout western US forests

Christina M. Restaino[a,1], David L. Peterson[b], and Jeremy Littell[c]

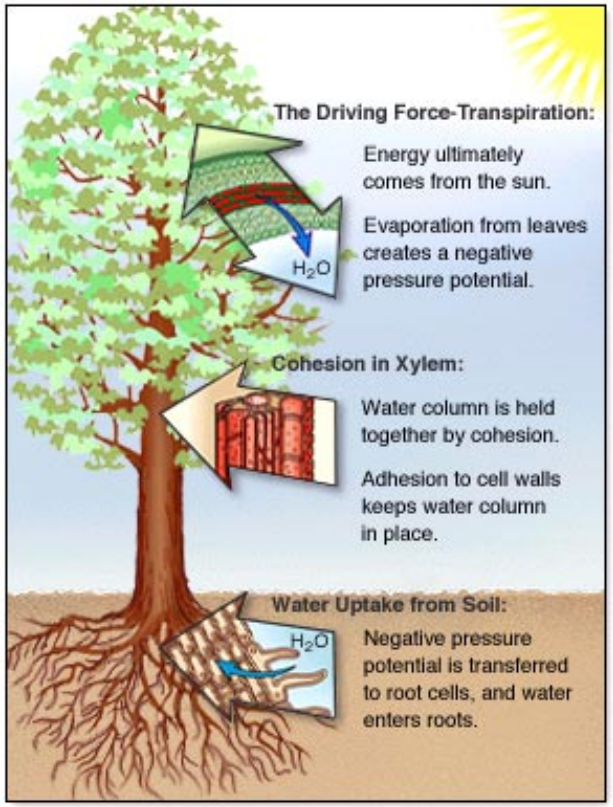
[a]Department of Environmental Science and Policy, University of California, Davis, CA 95616; [b]Pacific Northwest Research Station, US Forest Service, Seattle, WA 98103; and [c]Department of the Interior Alaska Climate Science Center, Anchorage, AK 99508

Edited by Monica G. Turner, University of Wisconsin-Madison, Madison, WI, and approved June 28, 2016 (received for review February 11, 2016)

Changes in tree growth rates can affect tree mortality and forest feedbacks to the global carbon cycle. As air temperature increases, evaporative demand also increases, increasing effective drought in forest ecosystems. Using a spatially comprehensive network of Douglas fir (*Pseudotsuga menziesii*) chronologies from 122 locations that represent distinct climate environments in the western United States, we show that increased temperature decreases growth via vapor pressure deficit (VPD) across all latitudes. Using an ensemble of global circulation models, we project an increase in both the mean VPD associated with the lowest growth extremes and the probability of exceeding these VPD values. As temperature continues to increase in future decades, we can expect deficit-related stress to increase and consequently Douglas fir growth to decrease throughout its US range.

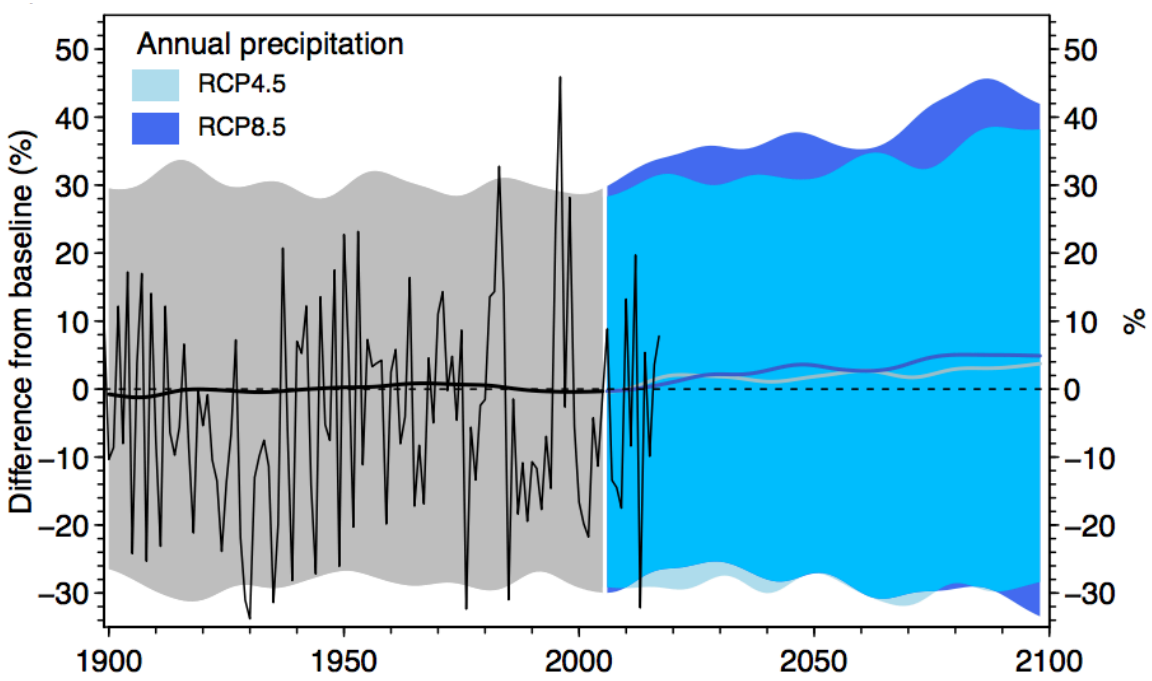
gradients or close stomata. DEF and VPD are variables that integrate water and energy and are sensitive to temperature increases (13).

We quantified the relationship between climate and Douglas fir growth in forests throughout the western United States. Douglas fir, which occupies diverse landscapes from sea level to 3,300 m and a broad range of climate regimes (Fig. S1 and Table S1), is one of the most ecologically and economically important coniferous species in western US forests. Our network of 122 tree-ring-width chronologies represents tree growth in a breadth of growing environments and climates (Fig. 1 and Fig. S1). This work builds on previous efforts to assess climate–growth relationships at regional scales (9, 13, 16) but expands to the realized climatic niche of the species rather than using data from the

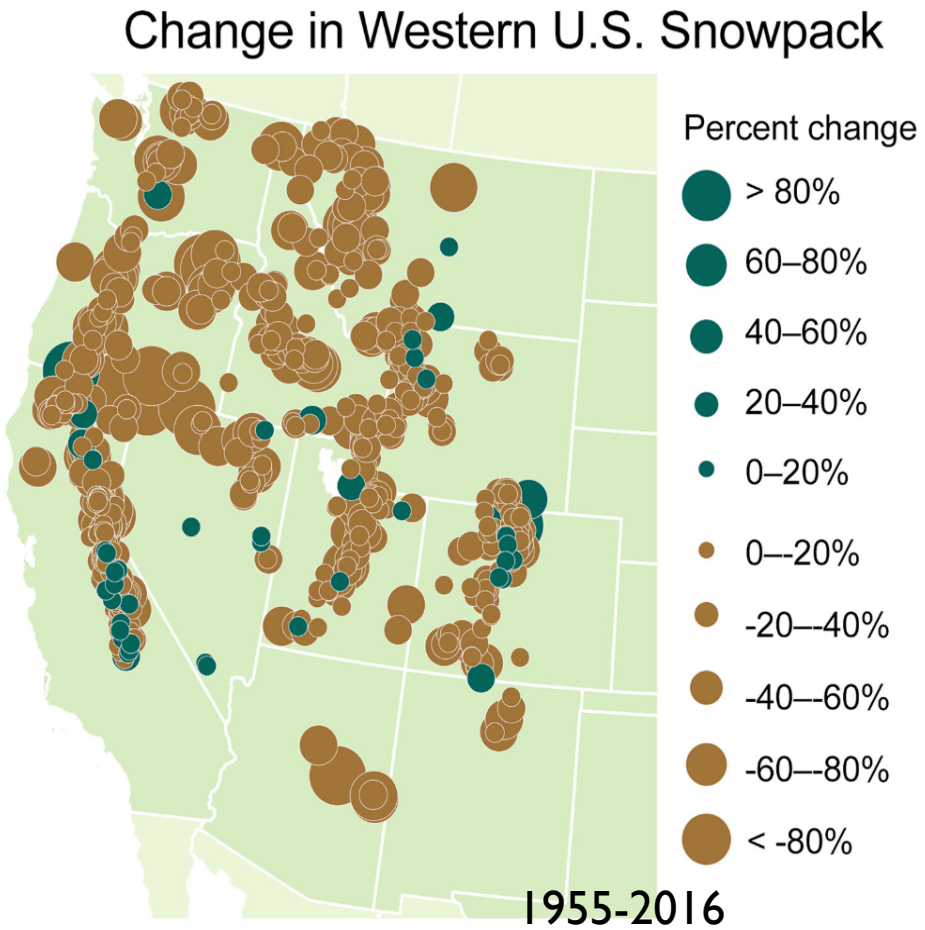


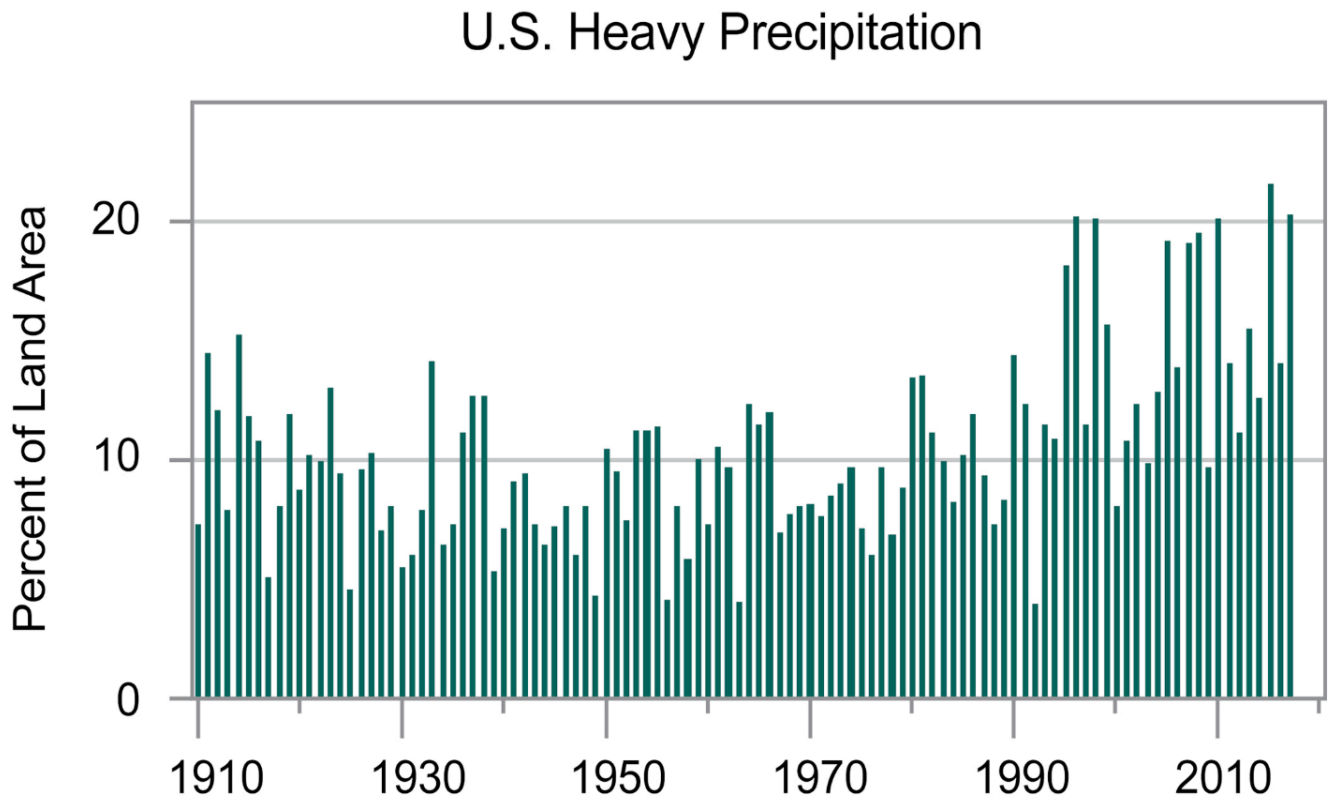
Heat Waves, Vapor Pressure Deficit, C starvation, Embolism, & Tall Tree Mortality

Natural Variability in Precipitation



From: OR Clim. Ass. Report 4, 2019





Source: NCA4 2017

The relative amount of annual rainfall that comes from large, single-day precipitation events has increased over the past century.

Floods and Droughts

Hermiston Herald

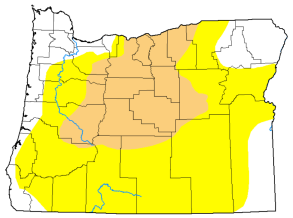
The Flood of 2020

By JADE MCDOWELL and JESSICA POLLARD Staff Writers Feb 11, 2020 0

2 of 7

Trucks sit in flood water covering Interstate 84 just west of milepost 188 at the Pilot truck stop at Stanfield.

Buy Now



Map released: Thurs. February 20, 2020

Data valid: February 18, 2020 at 7 a.m. EST

Intensity:

- None
- D0 (Abnormally Dry)
- D1 (Moderate Drought)
- D2 (Severe Drought)
- D3 (Extreme Drought)
- D4 (Exceptional Drought)
- No Data

Author(s):

David Miskus, NOAA/NWS/NCEP/CPC

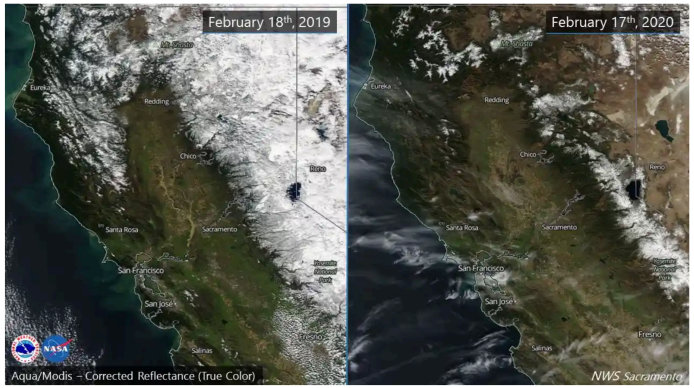
California

Susie Cagle

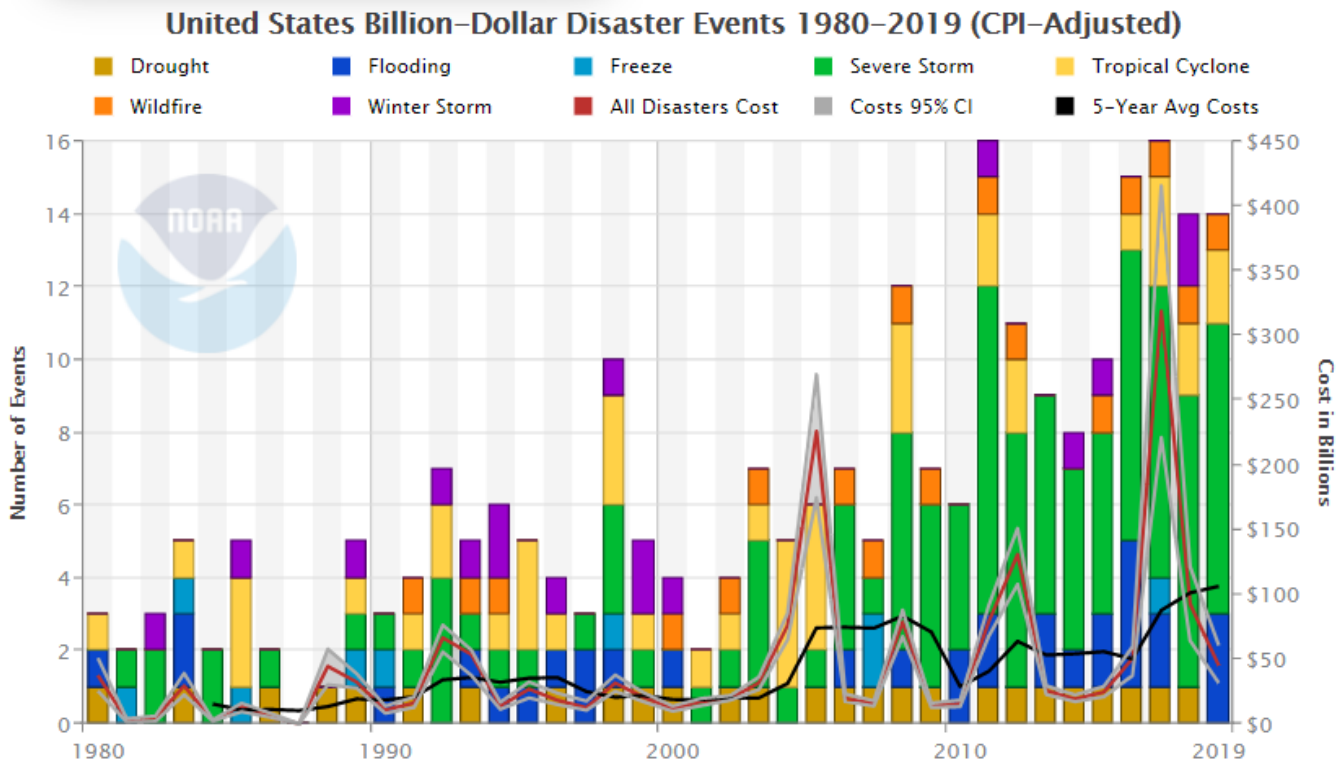
Fri 21 Feb 2020 06.00 EST

2,157

Dry February sends California back to drought: 'This hasn't happened in 150 years'



▲ Sierra snow pack is below normal for February. Photograph: NWS Sacramento



GRAND CHALLENGES for VEGETATION MODELLERS

Inputs

Processes

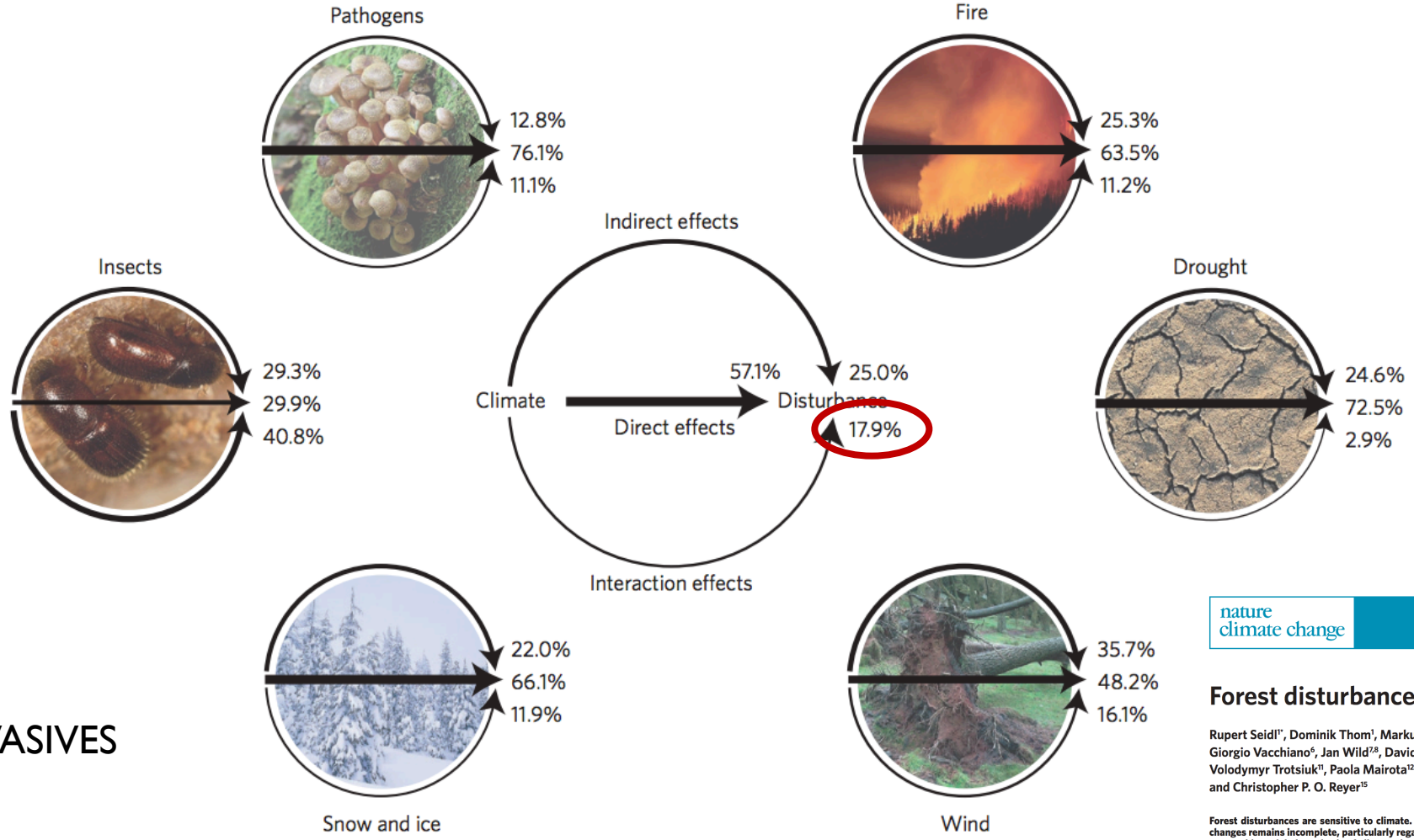
Thresholds

Feedbacks

Little is known about the **interactions** among climate, vegetation, and disturbance.

Interactions **among different disturbance regimes** could create novel landscape behaviors. *(Behrens et al. 2018).*

Published Direct, Indirect and Interaction Effects of CC on Forest Disturbance Agents



?

EXOTIC INVASIVES

nature climate change

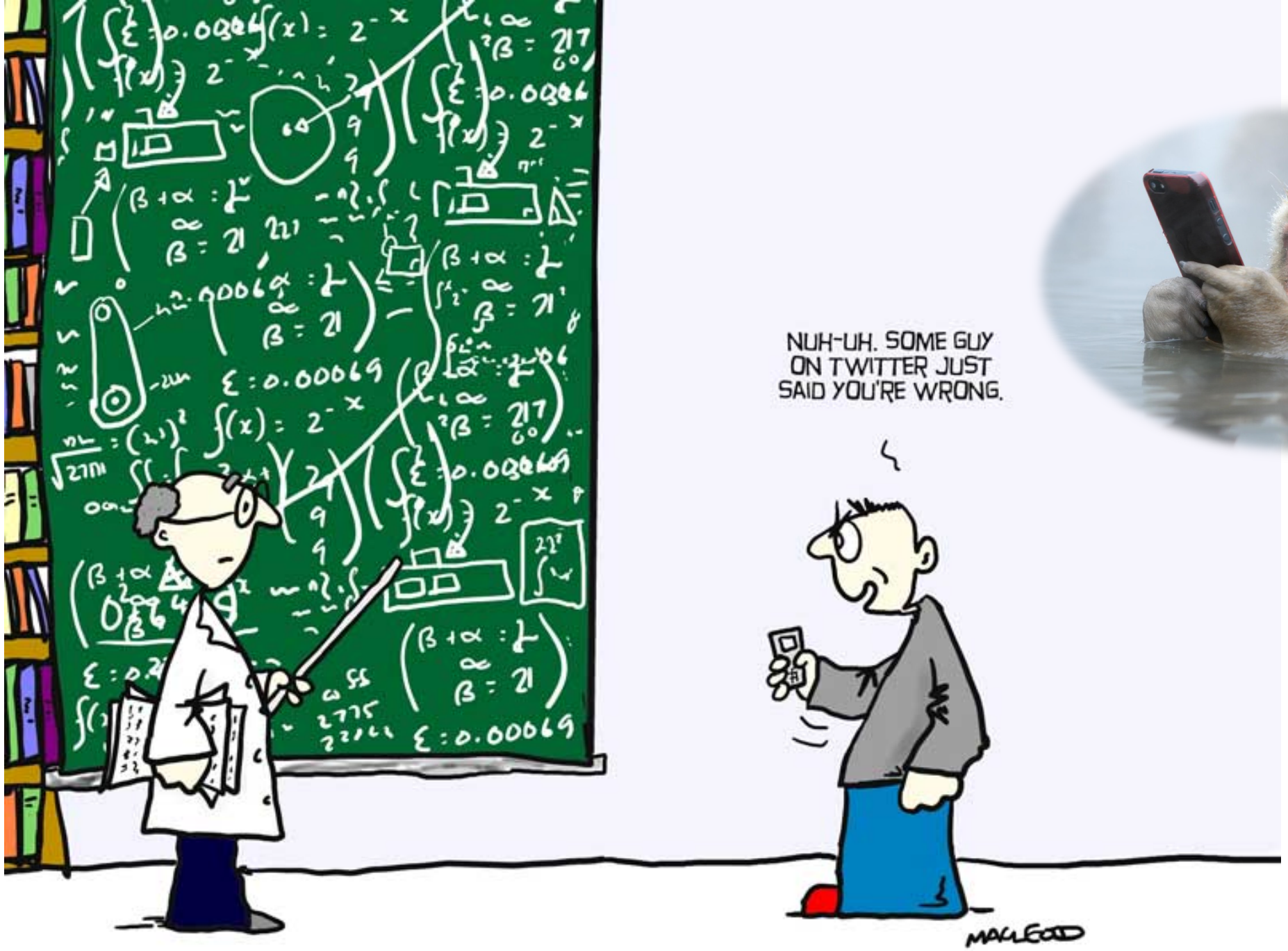
REVIEW ARTICLE

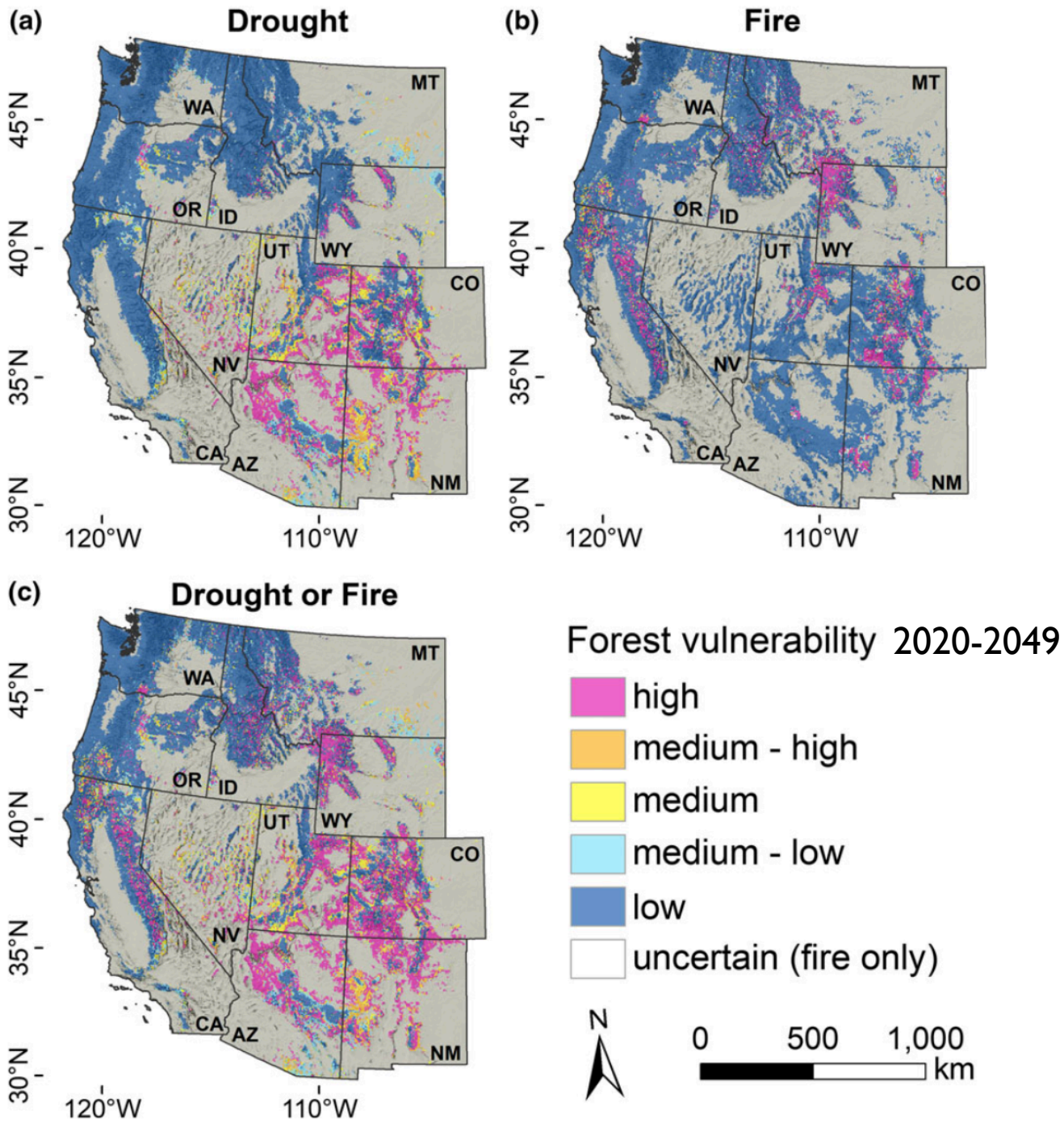
PUBLISHED ONLINE: 31 MAY 2017 | DOI: 10.1038/NCLIMATE3303

Forest disturbances under climate change

Rupert Seidl[1*], Dominik Thom[1], Markus Kautz[2], Dario Martin-Benito[3,4], Mikko Peltoniemi[5], Giorgio Vacchiano[6], Jan Wild[7,8], Davide Ascoli[9], Michal Petr[10], Juha Honkaniemi[5], Manfred J. Lexer[1], Volodymyr Trotsiuk[11], Paola Mairota[12], Miroslav Svoboda[11], Marek Fabrika[13], Thomas A. Nagel[11,14] and Christopher P. O. Reyer[15]

Forest disturbances are sensitive to climate. However, our understanding of disturbance dynamics in response to climatic changes remains incomplete, particularly regarding large-scale patterns, interaction effects and dampening feedbacks. Here we provide a global synthesis of climate change effects on important abiotic (fire, drought, wind, snow and ice) and biotic (insects and pathogens) disturbance agents. Warmer and drier conditions particularly facilitate fire, drought and insect disturbances, while warmer and wetter conditions increase disturbances from wind and pathogens. Widespread interactions between agents are likely to amplify disturbances, while indirect climate effects such as vegetation changes can dampen long-term disturbance sensitivities to climate. Future changes in disturbance are likely to be most pronounced in coniferous forests and the boreal biome. We conclude that both ecosystems and society should be prepared for an increasingly disturbed future of forests.


NUH-UH. SOME GUY ON TWITTER JUST SAID YOU'RE WRONG.
MACLEOD



Received: 28 July 2018 | Revised: 8 October 2018 | Accepted: 10 October 2018
DOI: 10.1111/gcb.14490
PRIMARY RESEARCH ARTICLE
WILEY Global Change Biology

Near-future forest vulnerability to drought and fire varies across the western United States

Polly C. Buotte[1] | Samuel Levis[2] | Beverly E. Law[1] | Tara W. Hudiburg[3] | David E. Rupp[4] | Jeffery J. Kent[3]

- high short-term drought vulnerability = 2+years with NPP = 0
- high vulnerability to prolonged drought = 4+years with low allocation to growth
- vulnerability to fire = weighted difference in simulated future (2020–2049) minus simulated past (1980–2009)

Model: CLM (Community Land Model)
Spatial Resolution: 4km x 4km

Future Climate: IPSL-CM5A-MR and MIROC5
Period: 1979–2049
Scenario: RCP 8.5

17

Simulating Vegetation Change, Carbon Cycling, and Fire Over the Western United States Using CMIP5 Climate Projections

D. Bachelet,[1,2] T. Sheehan,[1] K. Ferschweiler,[1] and J. Abatzoglou[3]

Natural Hazard Uncertainty Assessment: Modeling and Decision Support, Geophysical Monograph 223, First Edition.
Edited by Karin Riley, Peter Webley, and Matthew Thompson.

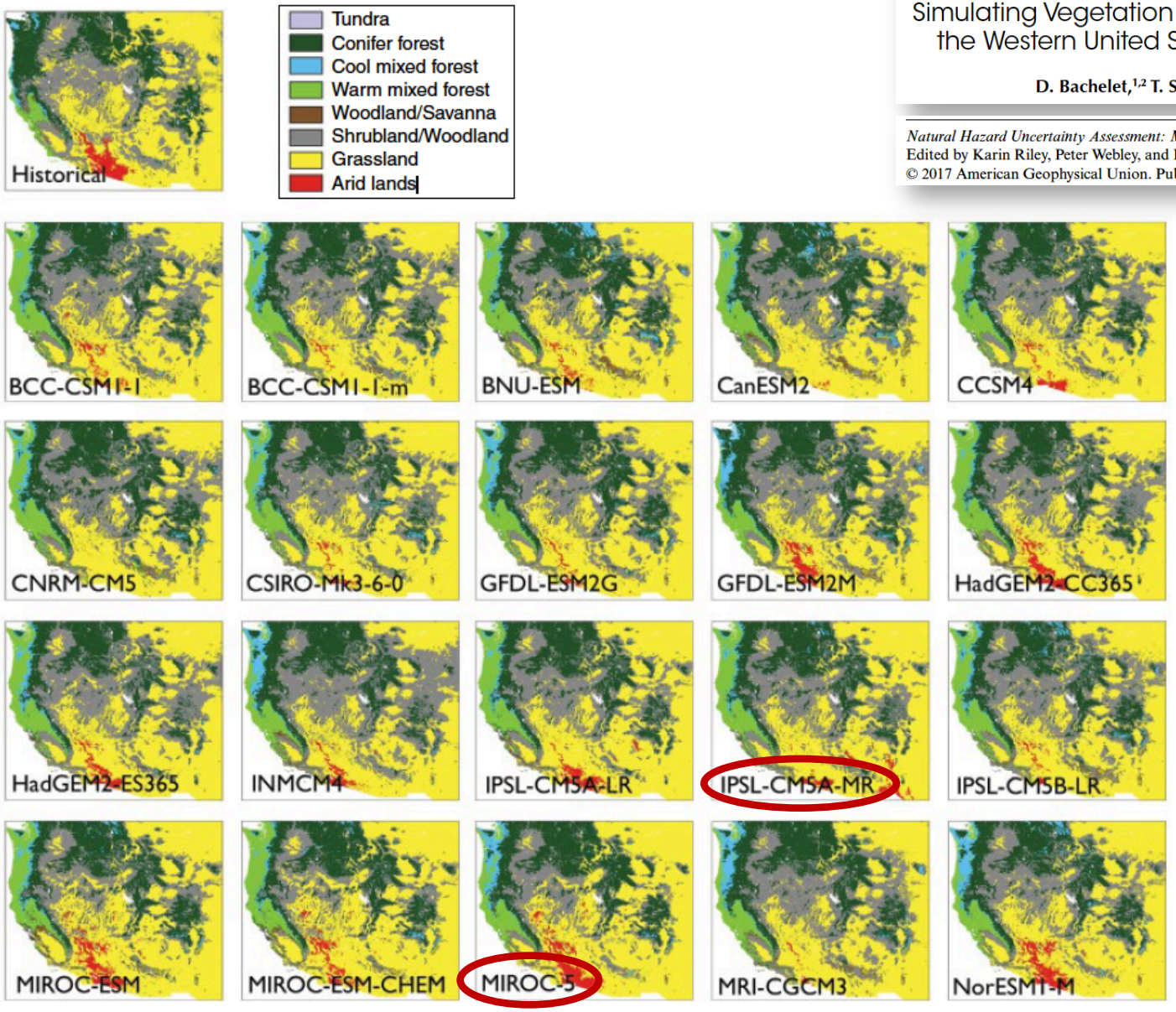
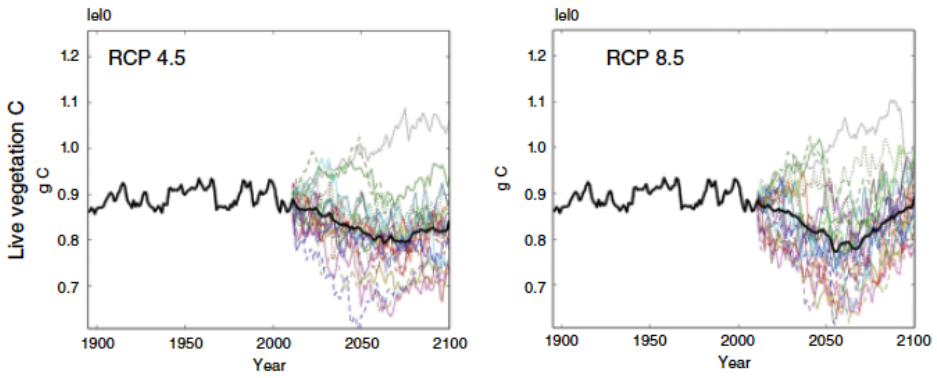


Figure 17.2 Simulated vegetation distribution (mode for 1971–2000) and projected vegetation distribution for the end of the 21st century (mode for 2071–2100) by 20 climate models from CMIP5 under RCP8.5.

Model: MC2
Spatial Resolution: 4km x 4km

Future Climate: 20 inc. IPSL-CM5A-MR and MIROC5
Period: 2010-2100
Scenario: RCP 8.5

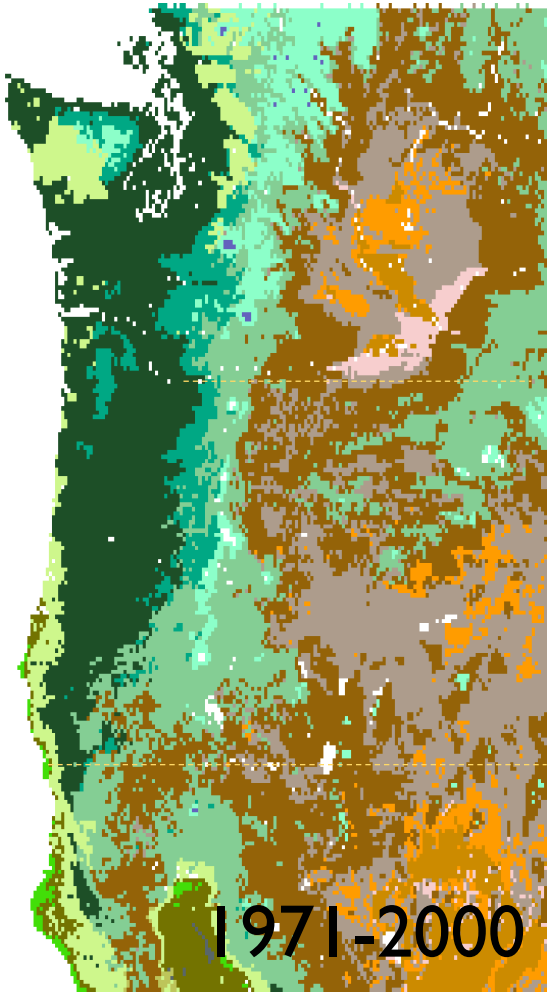


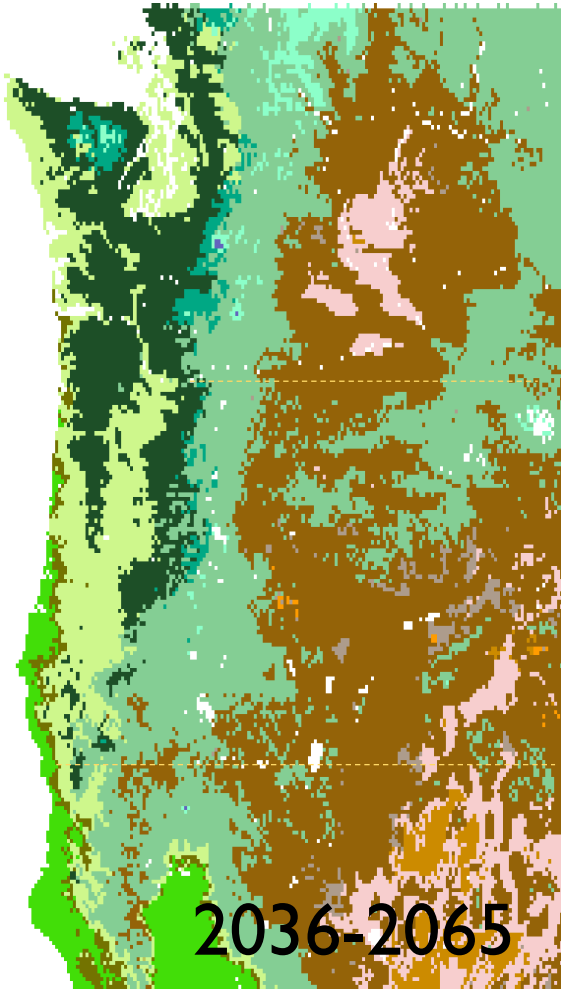
Simulating Vegetation Shifts by Mid-Century

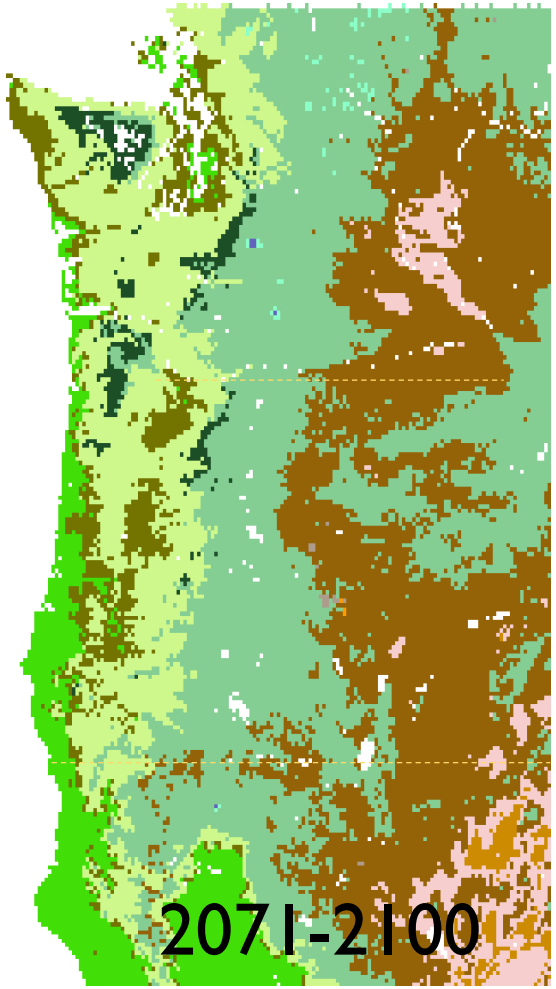
Pure evergreen forests

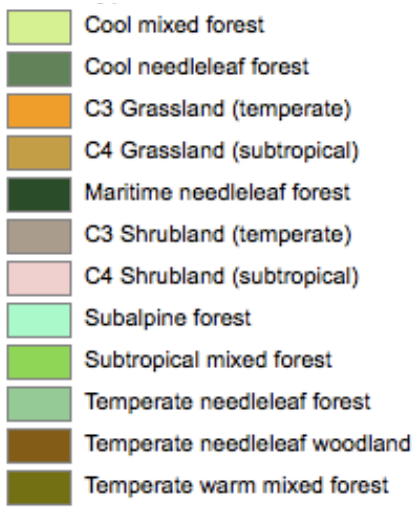
MIROC5 (Japan) RCP8.5

Mixed type forests - Decline of Grasslands









Loss of subalpine forests

Loss of temperate grasslands

Loss of temperate shrublands

Warmer mixed type forests

Expansion of shrublands and woodlands

Some changes mediated by fire

Simulation results - carbon implications

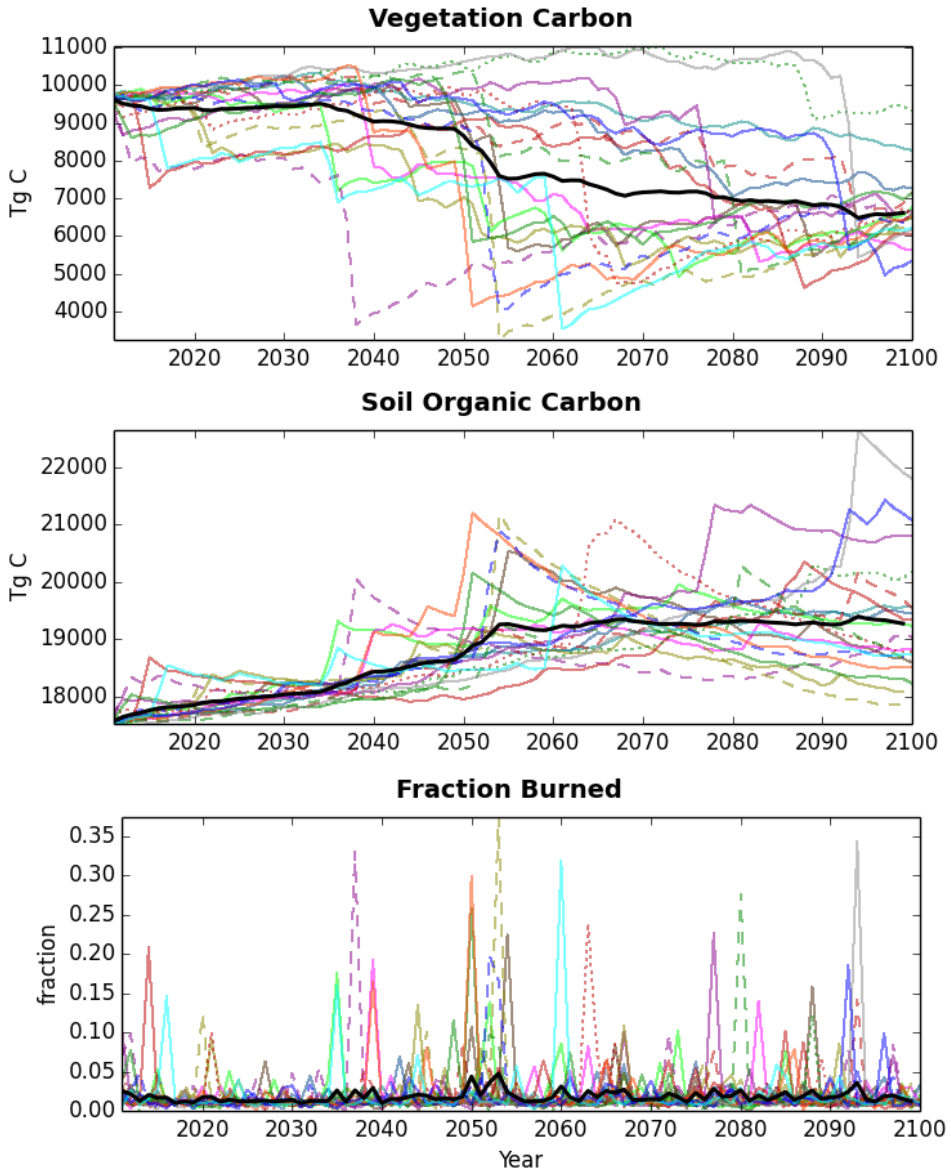
17

Simulating Vegetation Change, Carbon Cycling, and Fire Over the Western United States Using CMIP5 Climate Projections

D. Bachelet,[1,2] T. Sheehan,[1] K. Ferschweiler,[1] and J. Abatzoglou[3]

Natural Hazard Uncertainty Assessment: Modeling and Decision Support, Geophysical Monograph 223, First Edition.
Edited by Karin Riley, Peter Webley, and Matthew Thompson.

Cascades

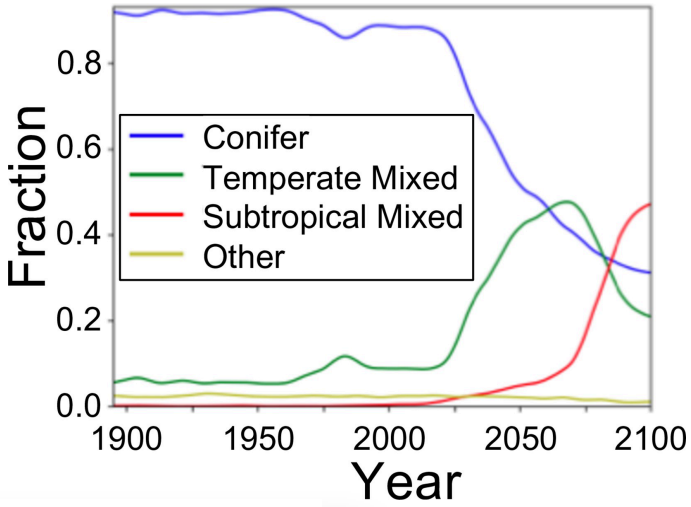


Some changes just happen

Transition to new climatic conditions

SYMPTOM of MALADAPTATION

" **Vegetation is projected to change** from predominantly conifer to predominantly mixed conifer and hardwood forests, **regardless of CO_2 fertilization and fire effects**. With climate, not fire, driving vegetation change, much of the current vegetation can be expected to experience **mortality**. It is reasonable to anticipate that climate stress will make forests more susceptible disease and pests"




PLOS | ONE

2019

RESEARCH ARTICLE

Fire, CO_2, and climate effects on modeled vegetation and carbon dynamics in western Oregon and Washington

Tim Sheehan[1,2]*, Dominique Bachelet[3], Ken Ferschweiler[1]

The purpose of models is not to fit the data but to sharpen the questions.

Samuel Karlin (1924-2007)

Photo credit: Janet Ohmann

Curse of knowledge &
Sins of omission

DELICATE
BALANCE
&
MULTIPLE
INTERACTIONS

TRAITS

PLANT RESPONSE

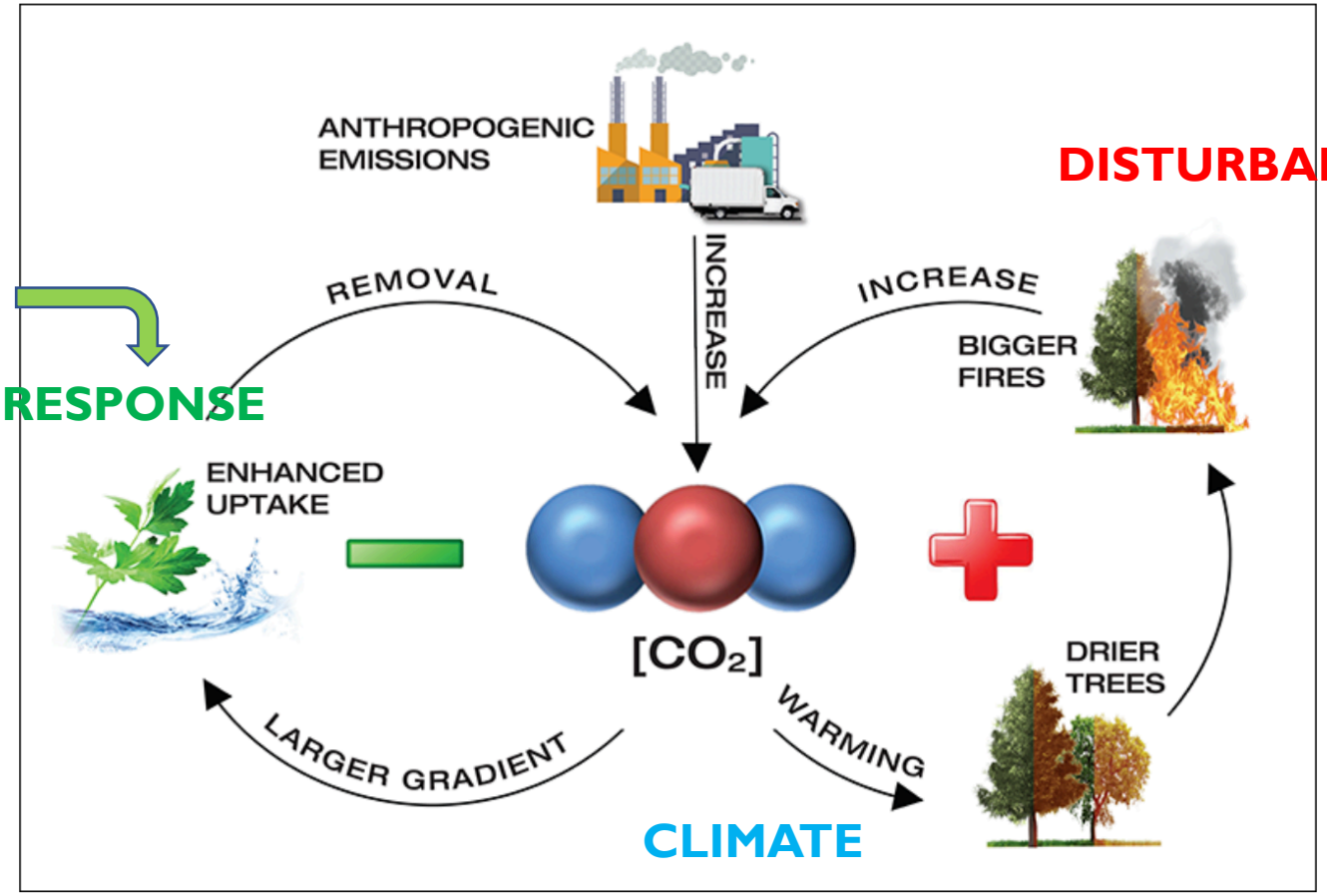
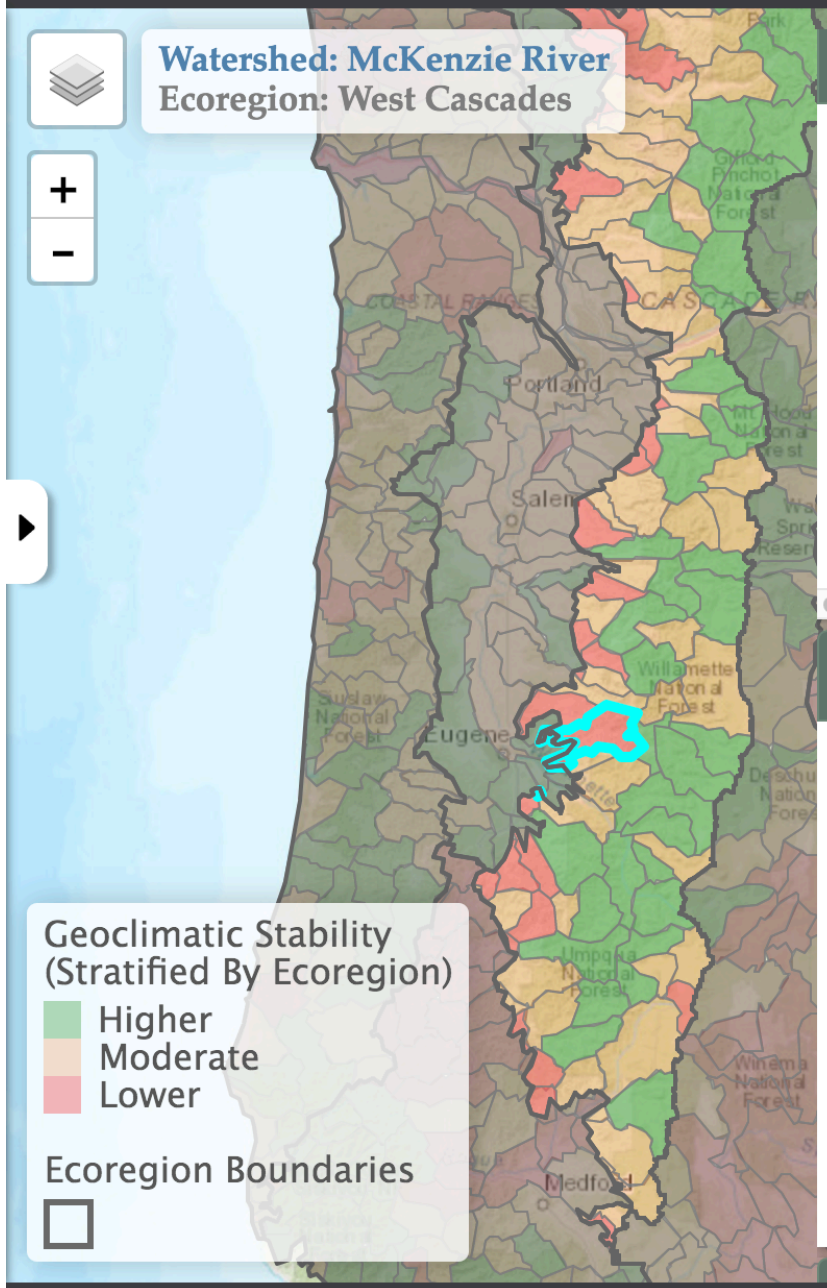


Fig. 2. In the negative carbon-climate feedback (left), increasing CO_2 concentrations stimulate plants to take up carbon from the atmosphere, which lowers the atmospheric concentration and causes a stabilizing effect. Conversely, in the positive feedback (right), higher temperatures from increasing atmospheric CO_2 concentrations cause drying of vegetation, leading to increased fire frequency and severity, which releases more carbon to the atmosphere, resulting in an amplifying effect. Credit: The authors and David Hinkle, NASA/JPL-Caltech

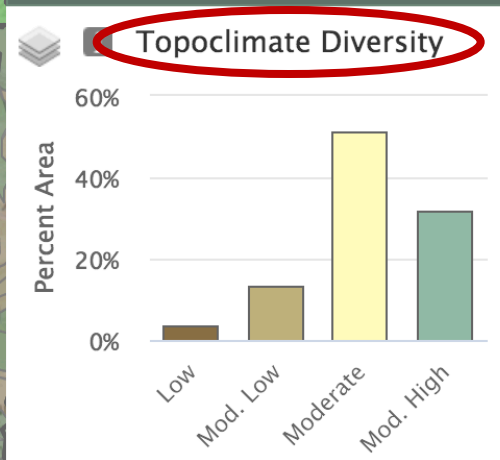
Source: Kaushik et al. EOS 2020

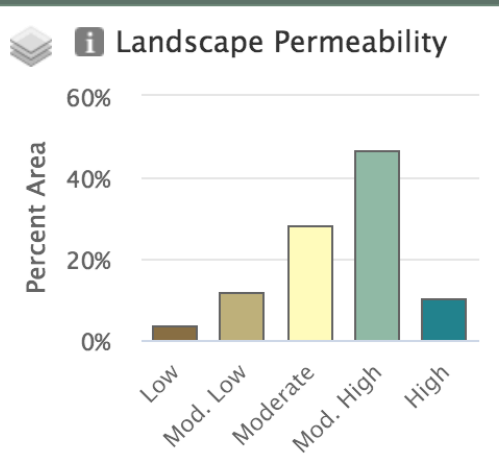
Nature's Stage Climate Mapper

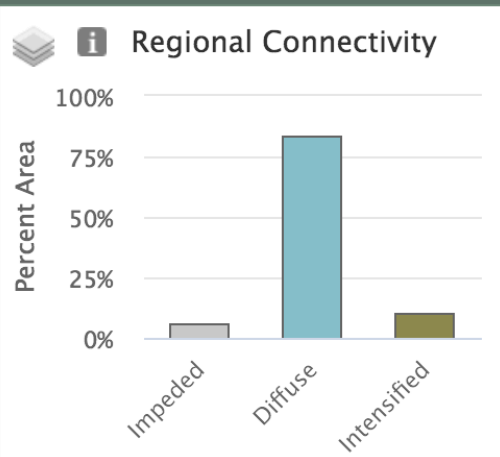
Map | About | Data & Links | Contact



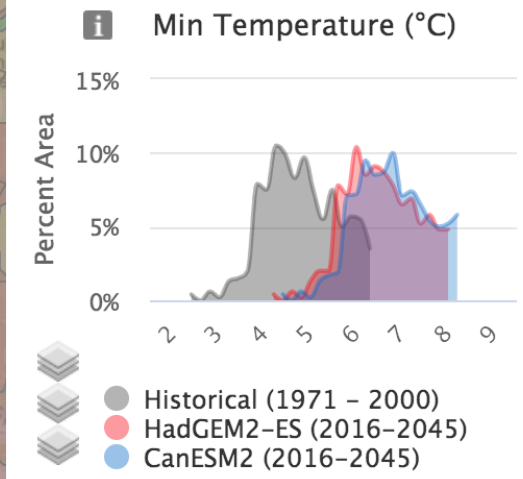
Climate Resilience Data (Conserving Nature's Stage)

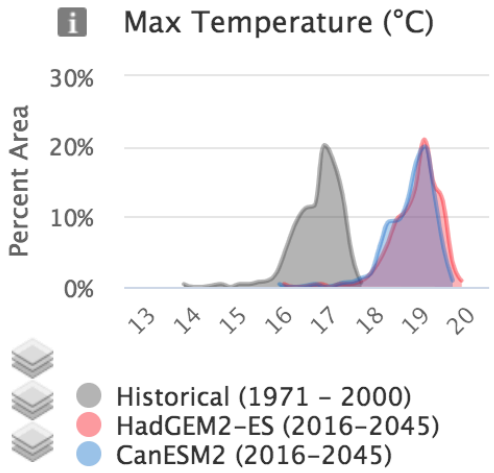


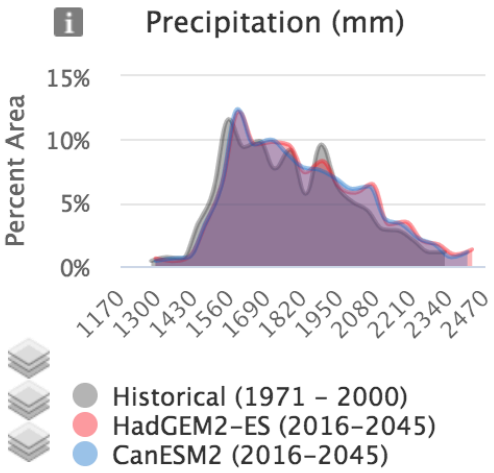


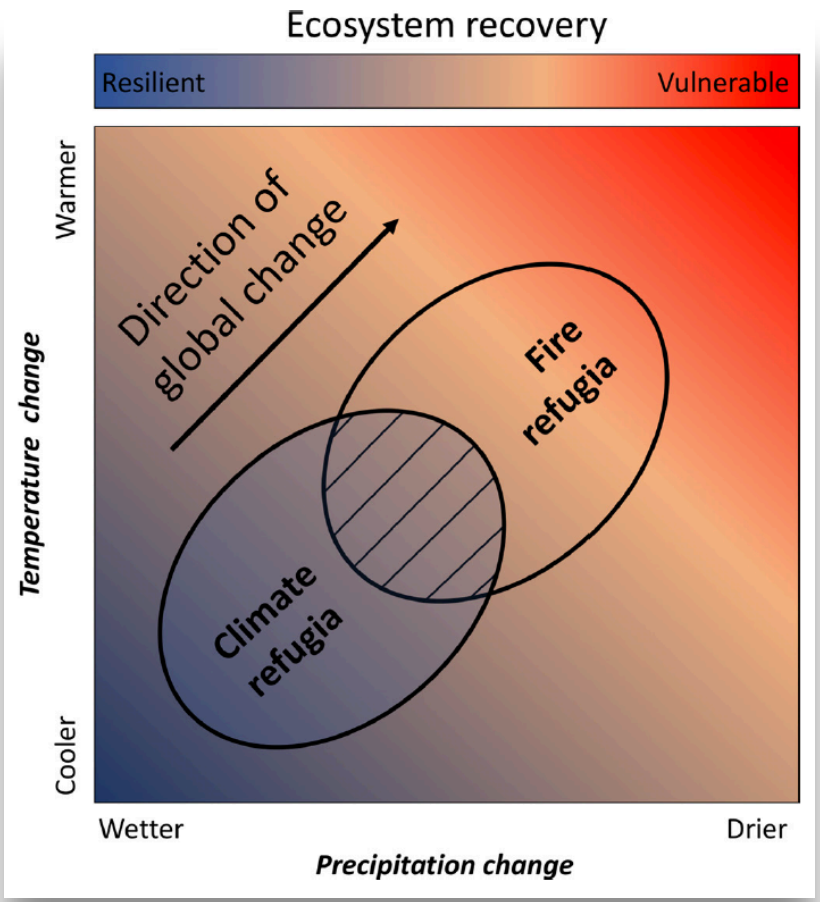


Climate Departure Data









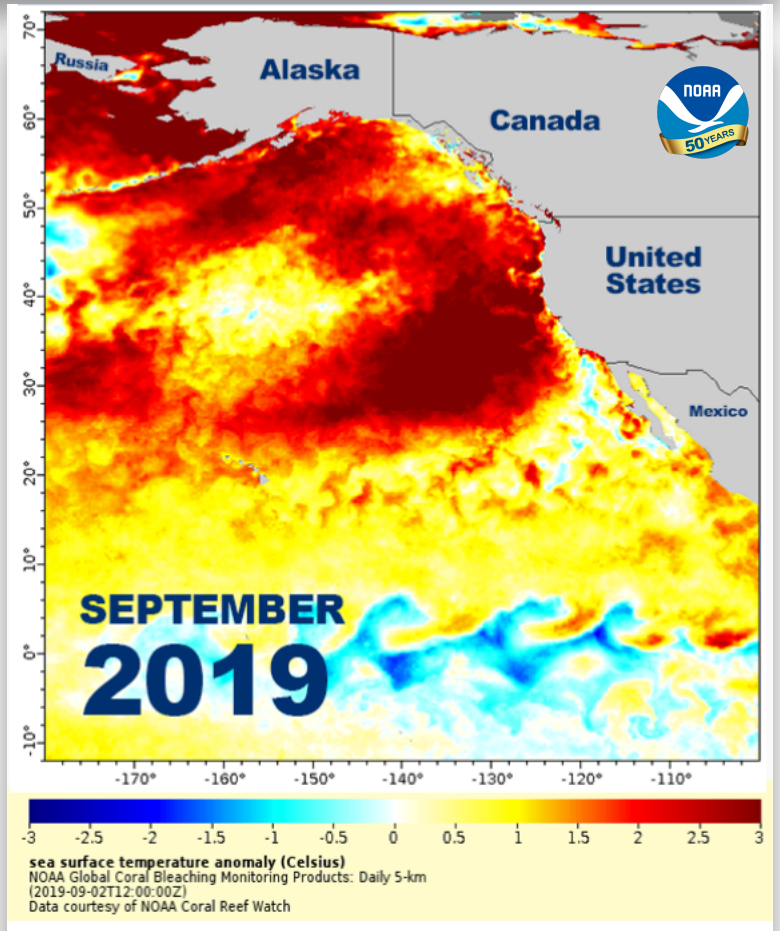
Meddens et al. 2018

The Missing Mountain Water: Slower Westerlies Decrease Orographic Enhancement in the Pacific Northwest USA

C. H. Luce,[1*] J. T. Abatzoglou,[2] Z. A. Holden[3]

2013

Local conditions are changing



Urbanization causes increased cloud base height and decreased fog in coastal Southern California

2015

A. Park Williams[1], Rachel E. Schwartz[2], Sam Iacobellis[2], Richard Seager[1], Benjamin I. Cook[1,3], Christopher J. Still[4], Gregory Husak[5], and Joel Michaelsen[5]

Vegetation Demography Models in Earth System Models

Model acronym	Name	Vegetation representation	Coupled to ESM?	Stochastic?	Canopy structure	Disturbance history patches?
SEIB	Spatially Explicit Individual-Based model	Individual	MIROC-ESM	Yes	Individuals	No
LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator	Individual or Cohort	EC-Earth, RCA-GUESS	Yes (optional for some processes)	Flat-top	Yes
LM3-PPA	Perfect Plasticity Approximation	Cohort	GFDL-ESM	No	PPA	No
ED	Ecosystem Demography model	Cohort	RAMS	No	Flat-top	Yes
ED2	Ecosystem Demography model v2	Cohort	RAMS	No	Flat-top	Yes
CLM(ED)	Community Land Model with Ecosystem Demography	Cohort	CESM	No	PPA	Yes

Fisher et al. 2017 Global Change Biology

IN SUMMARY

- Model projections have been conservative – rate of warming is increasing; weather records are broken; physiological thresholds exceeded.
- Validation of climate and vegetation models is still based on 20th century observations but "the future ain't what it used to be" so monitoring is critical.
- Disturbances (pest outbreaks, diseases, wildfire) are hastening shifts in vegetation cover – understanding interactions with climate is critical.
- Human actions are causing meddling changes (introduction of invasives/plants & diseases, fuel build up, fire ignition timing and location, landuse).
- Teams of modelers around the world are synthesizing current knowledge and building tools to simulate interactions and help inform management decisions.
- Ecological patience is required to record and understand the changes, protect climate/fire refugia, distinguish between climate refugees and exotic invasives.

Thank you for your attention

Contact: bacheled@oregonstate.edu