Global Warming

and

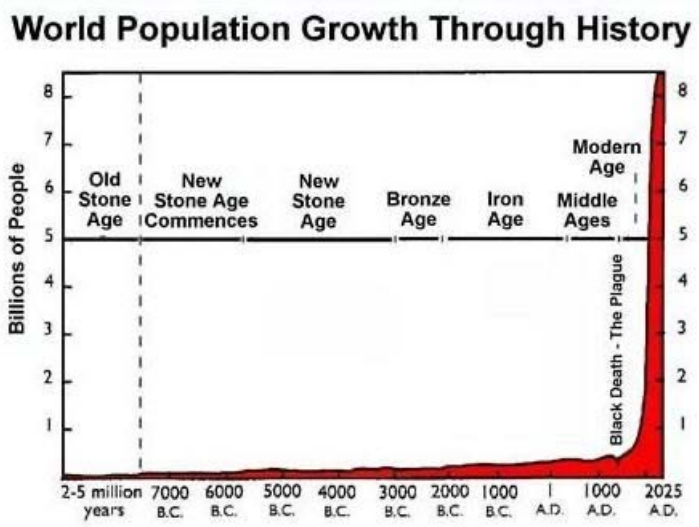
What To Do About It

Wolfgang Bauer

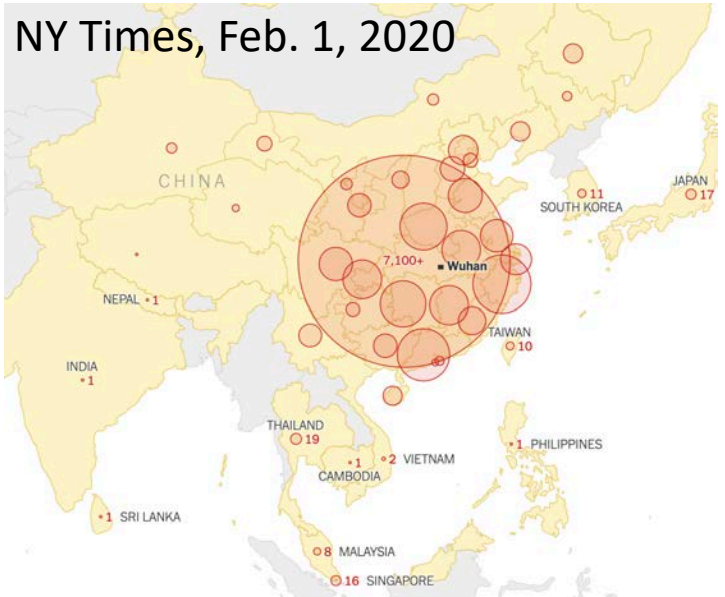
MSU & UUMC

Doomsday clock is closest to midnight it has ever been

- Nuclear War
- *Climate Apocalypse*
- Population Explosion
- Pollution
- Resource Depletion
- Artificial Intelligence
- Pandemics
- Meteor Strike
- …



Bulletin of the Atomic Scientists



Topics:

- Greenhouse Gases
- Temperature Record
- Climate Models
- What Could Happen?
- What Can We Do?
- What is MSU Doing?

Topics:

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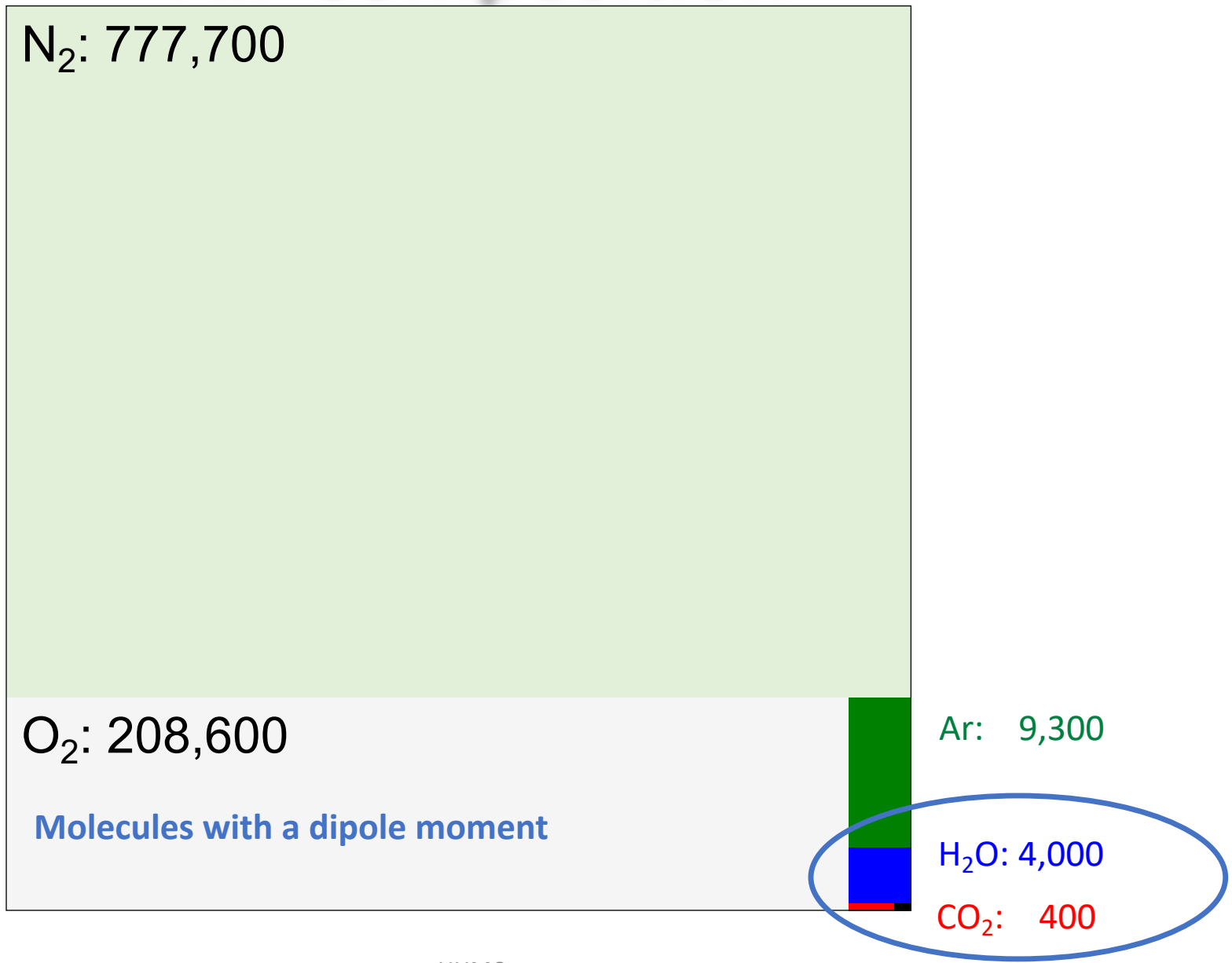
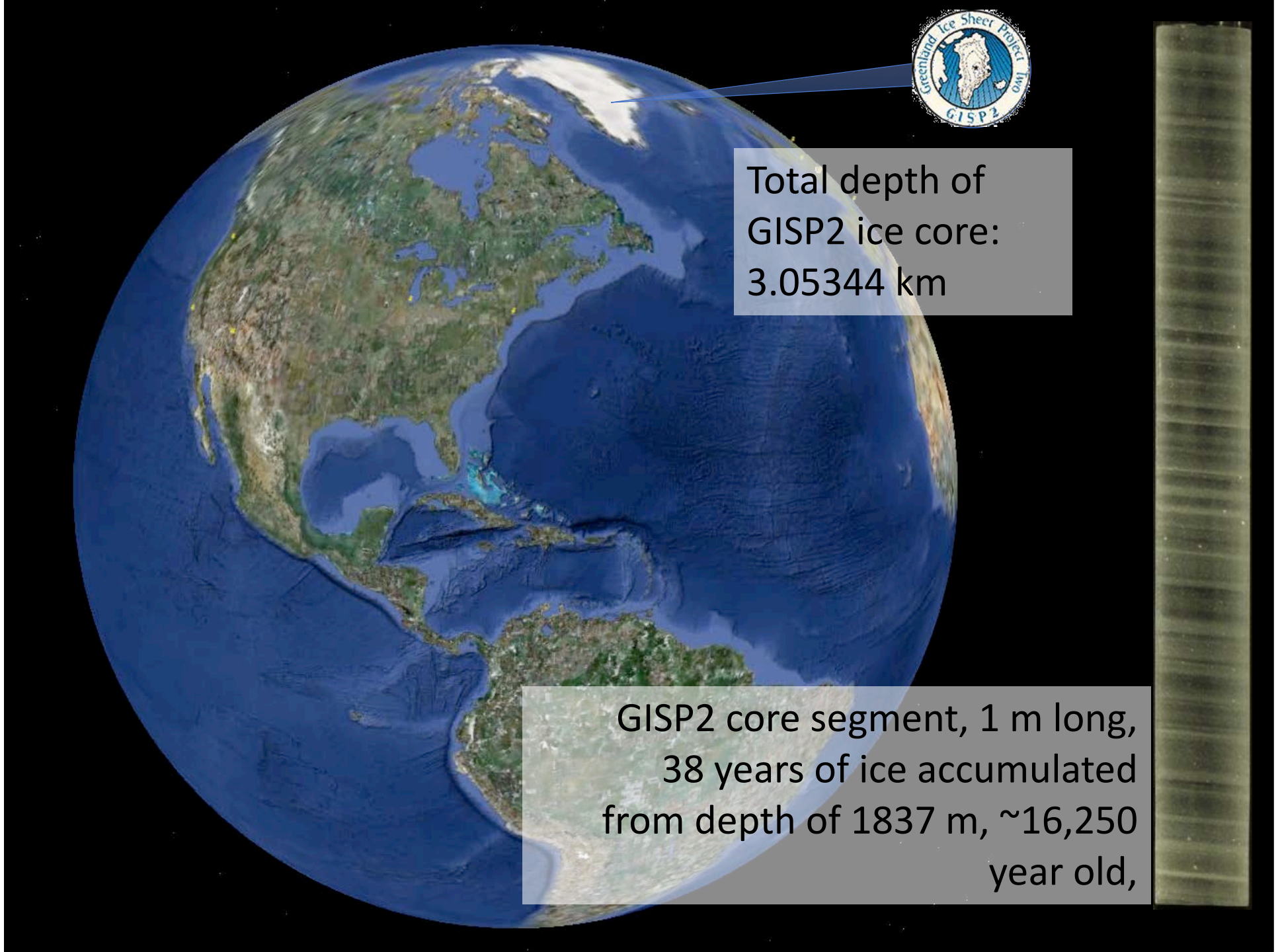
Air Composition

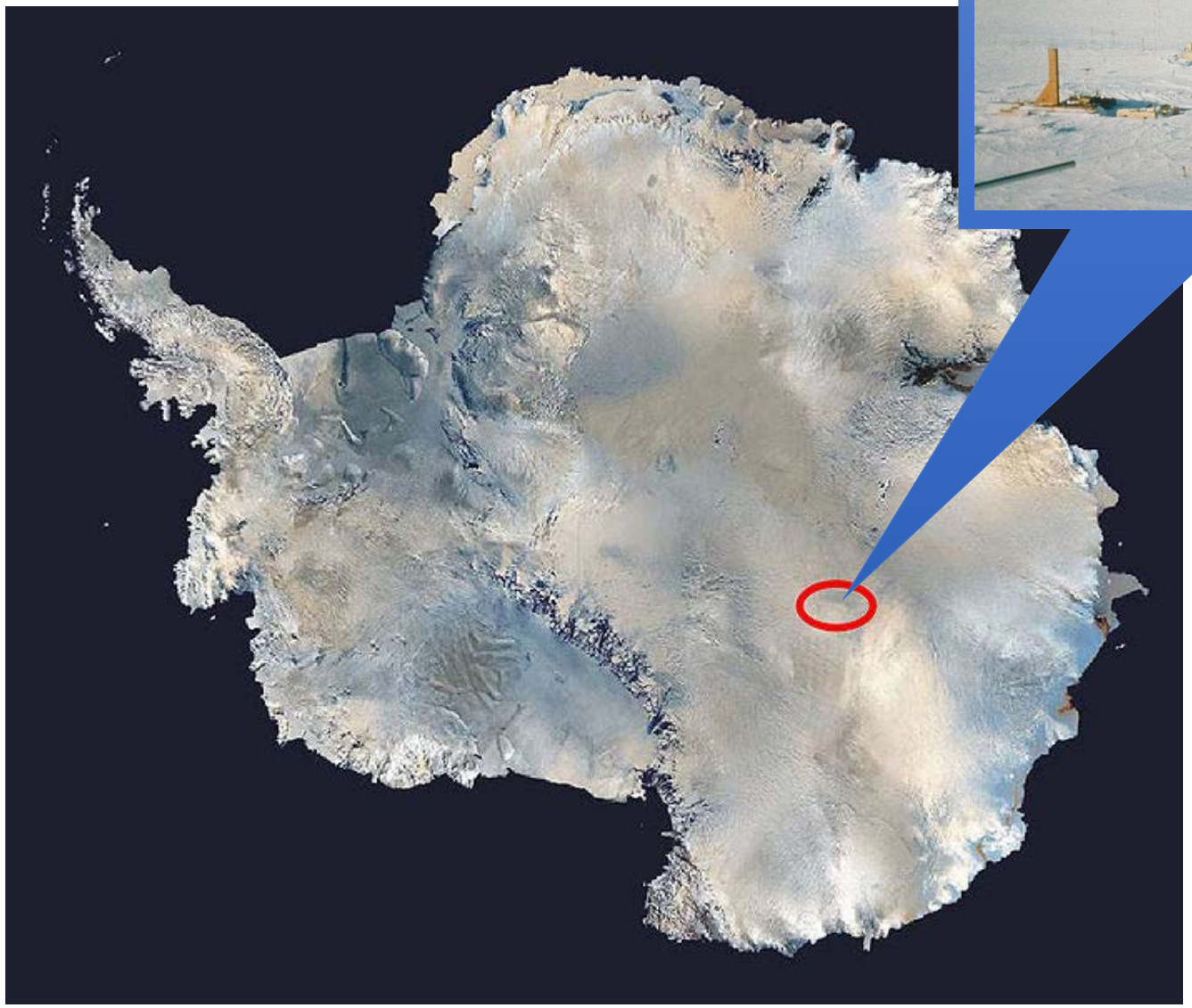


A History of CO_2

- Human activity measurably increased CO_2 in the atmosphere since the beginning of the industrial age, ~1750
- CO_2 concentration in atmosphere measured in air samples since 1867
  - Thorpe, T. E. (1867). On the Amount of Carbonic Acid Contained in Sea-Air, *J. Chem. Soc.* 20, pp. 189-199.
- Worries that increase in CO_2 may cause global warming since 1896
  - Arrhenius, S. (1896). On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground, *Philosophical Magazine* 41 (251), pp. 237-276.

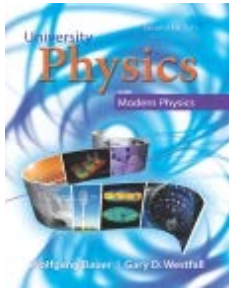

National Ice Core Laboratory
(NICL)
Denver Federal Center,
Lakewood, CO


Greenland Ice Sheet Project two
GISP2
Total depth of GISP2 ice core: 3.05344 km
GISP2 core segment, 1 m long, 38 years of ice accumulated from depth of 1837 m, ~16,250 year old,



Total ice core depth
3645 m

Atmospheric CO_2



- Concentration between 190 ppm and 290 ppm during the last half million years (ice core samples)
- Near exponential rise from burning fossil fuels since the beginning of the industrial revolution (hockey stick graph)
- 6-7 ppm seasonal oscillations from plant growth and decay
- Net addition of ~2 ppm/year from human activity

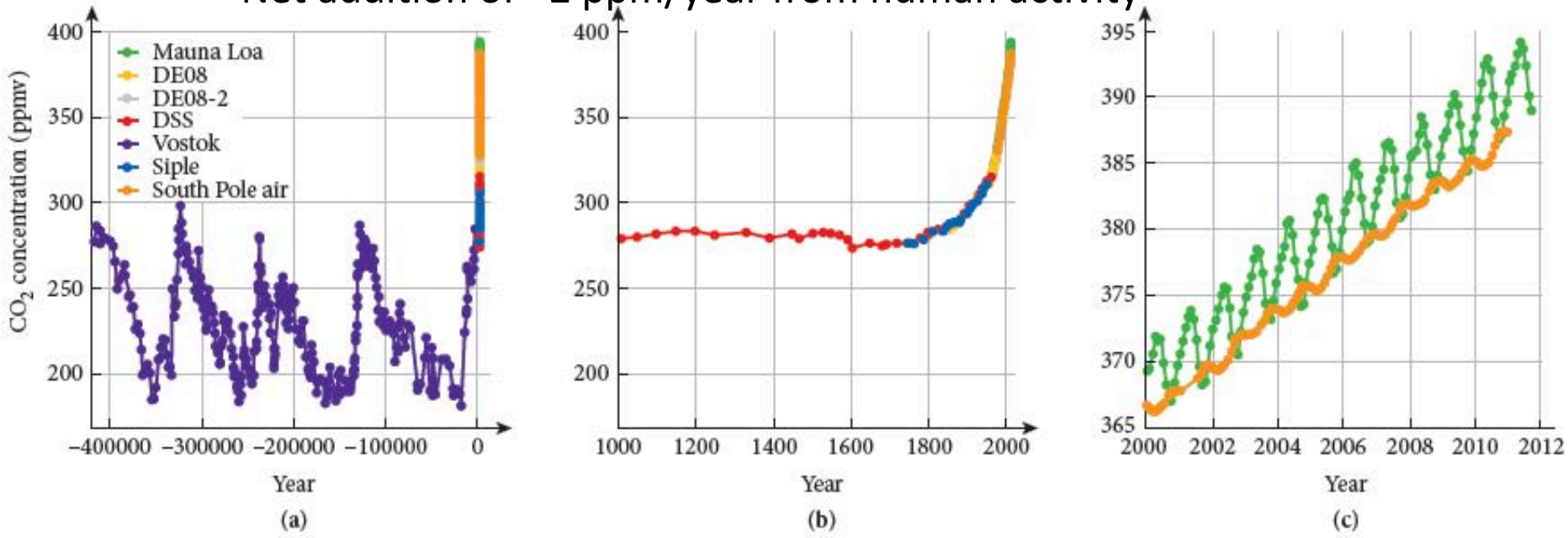
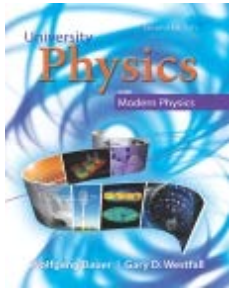
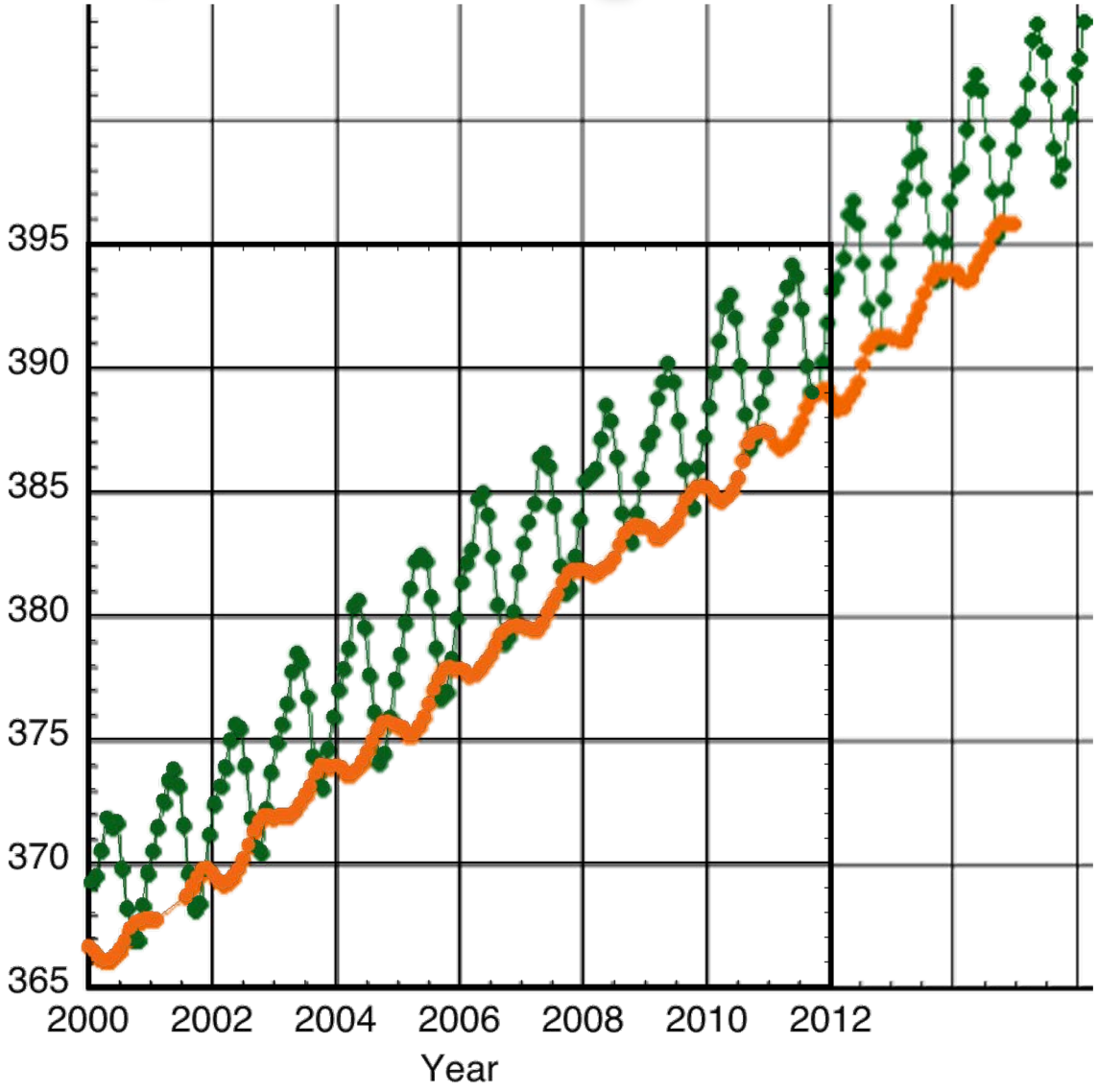


FIGURE 18.28 Concentration of carbon dioxide (CO_2) in the Earth's atmosphere in parts per million by volume (ppmv). (a) Concentration of carbon dioxide in the atmosphere during the last 420,000 years. The measurements shown are from air samples at Mauna Loa in Hawaii (green) and the South Pole (orange) and various ice core samples from Antarctica. (b) Display of the same data as in part (a), but only from 1000 AD to the present. (c) Display of the same data as in part (b), but only from 2000 to 2012.

Atmospheric CO_2

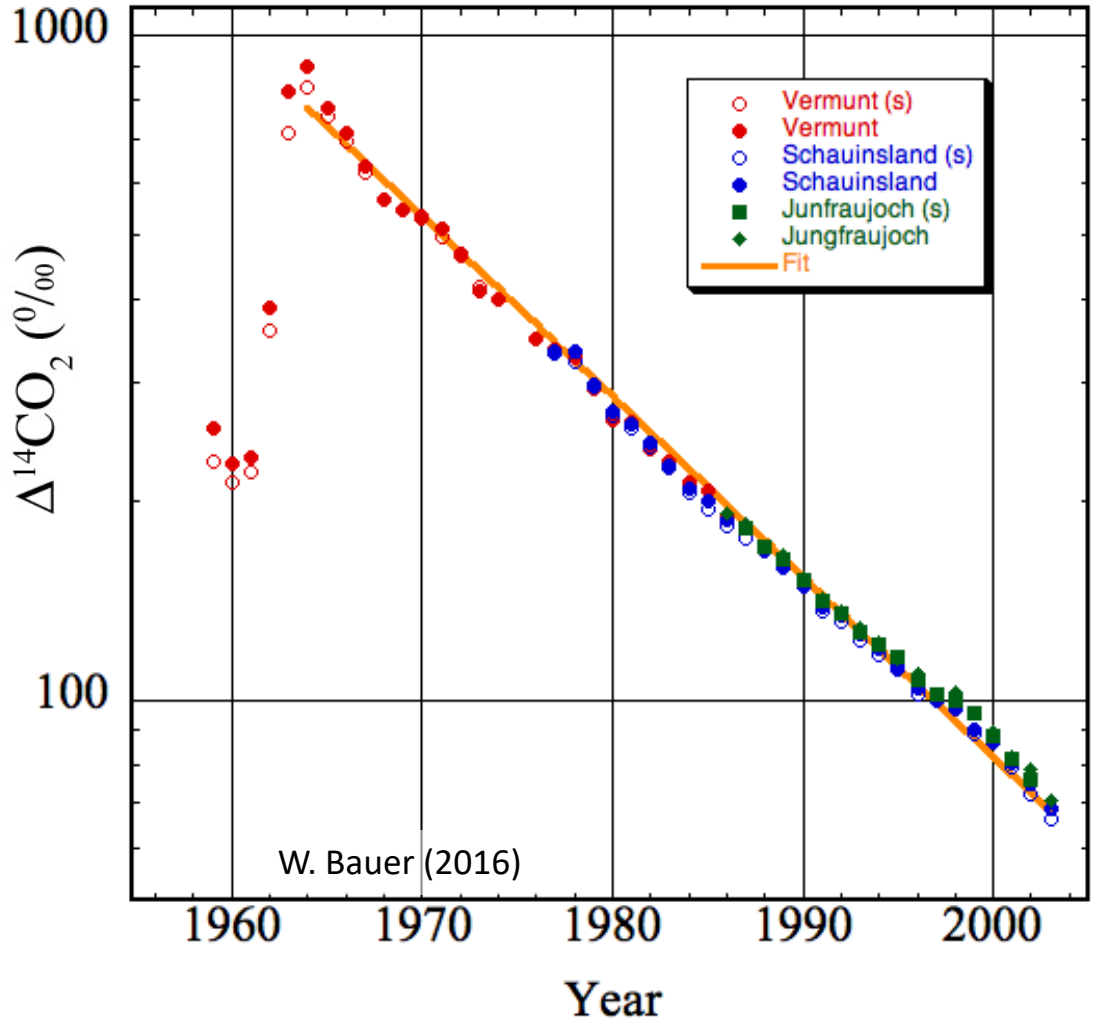


Net addition of 2 ppm/year of CO_2 to atmosphere
= 16 billion metric tons / year!
= 35 times the weight of all humans on the planet



CO_2 Lingers For Decades

- Atmospheric nuclear weapons tests in 1950s increased ^{14}C until test ban treaty in 1963
- Exponential decay since then
- Fit line: CO_2 half life of 16 years in atmosphere
- *Note*: $t_{1/2}(^{14}C) = 5730$ years



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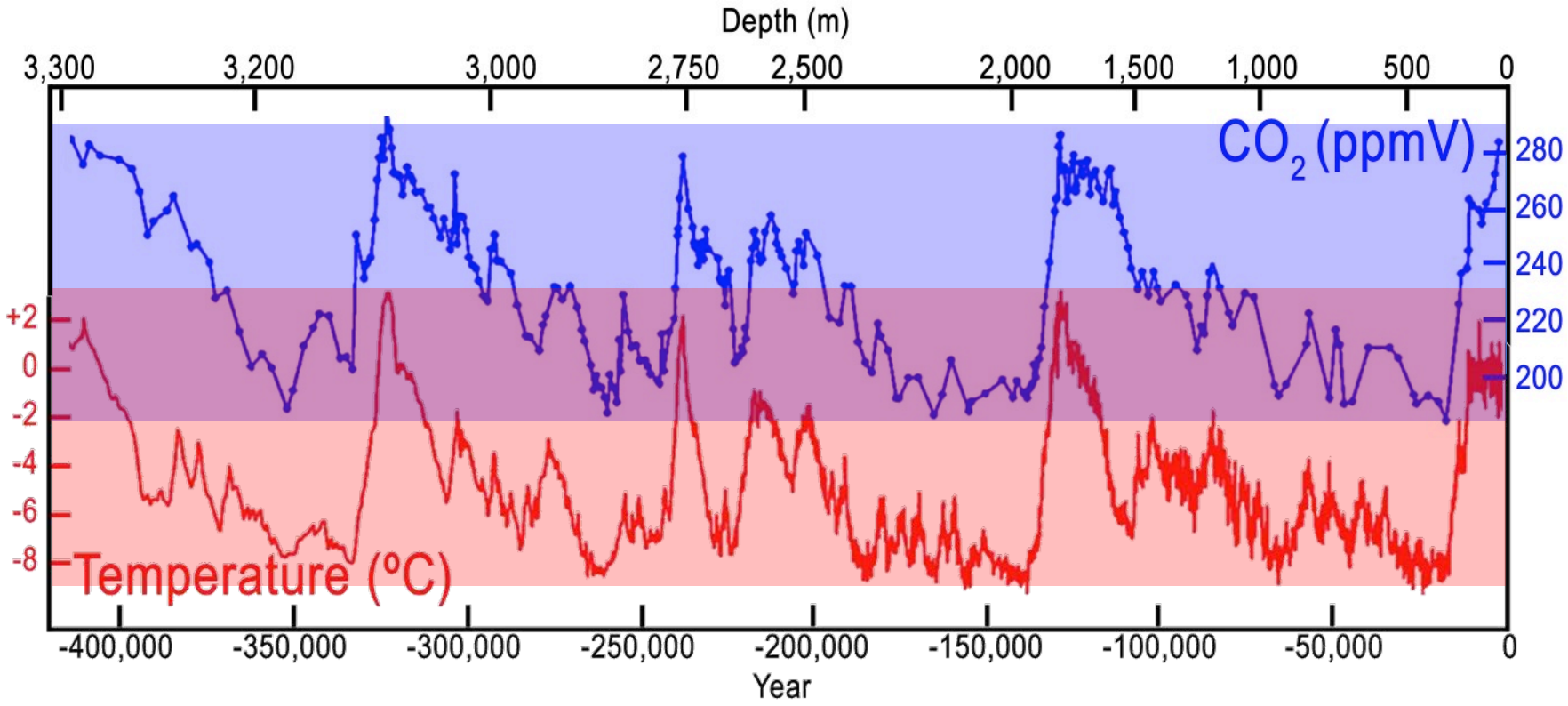
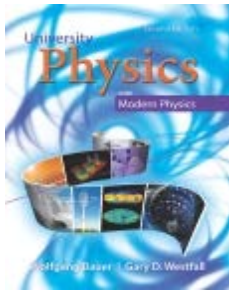
CO_2 and Air Temperature



CO_2 between 190 und 290 ppmV during the previous 0.5 million years

Temperature variations between +3 °C and -9 °C during this time

Strong correlations between time series: strongly coupled system



Global Average Temperature

- How hot is it?
- Not really hot, right here, right now …
- Careful averaging needed (over both, *space* and *time*)

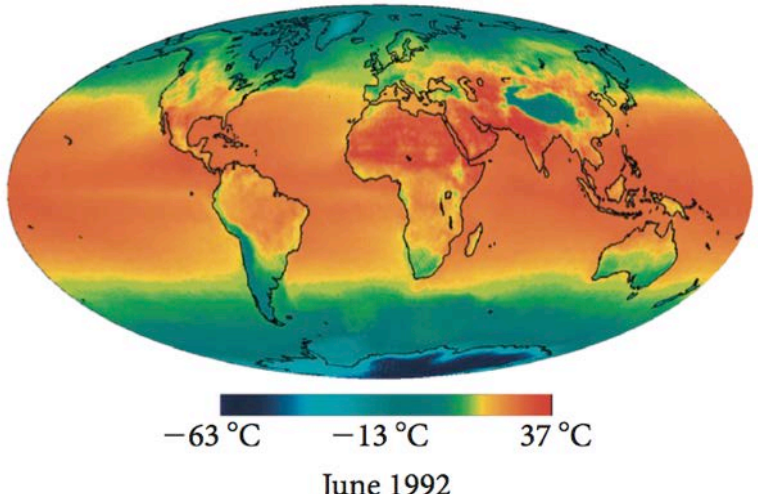


FIGURE 17.19 Time-averaged surface temperature of the Earth in June 1992. The colors represent a range of temperatures from −63 °C to +37 °C.

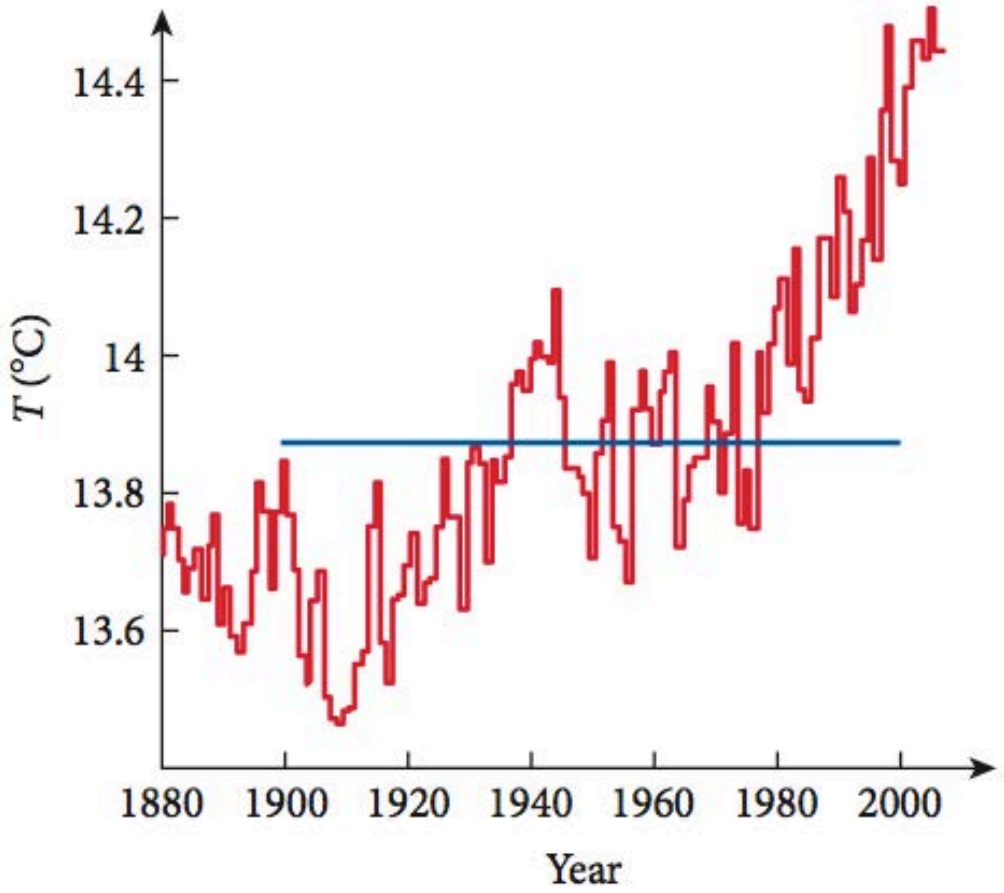
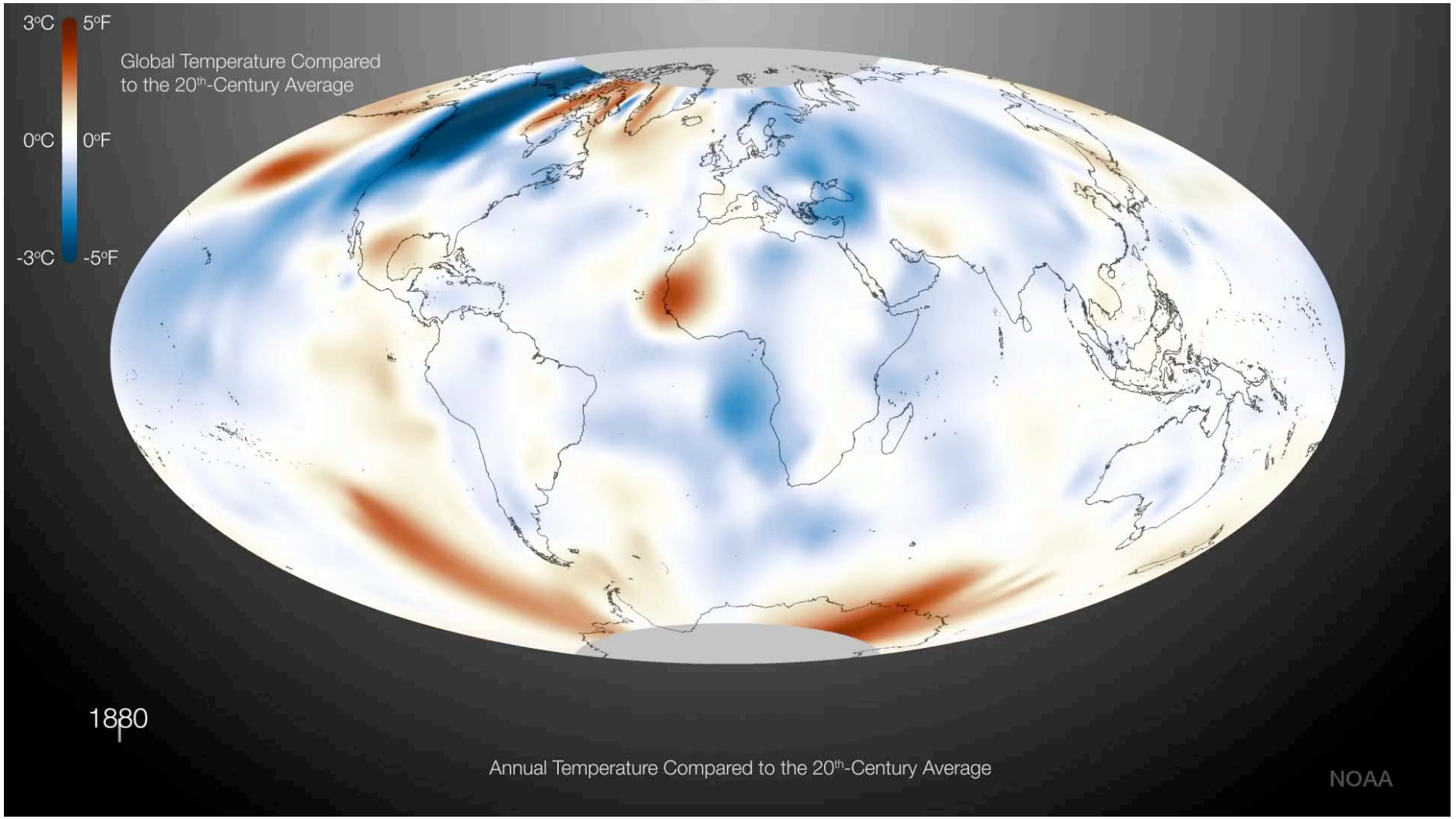


FIGURE 17.20 Annual average global surface temperature from 1880 to 2005 as measured by thermometers on land and in the ocean (red histogram). The blue horizontal line represents the average global temperature for the 20th century, 13.9 °C.

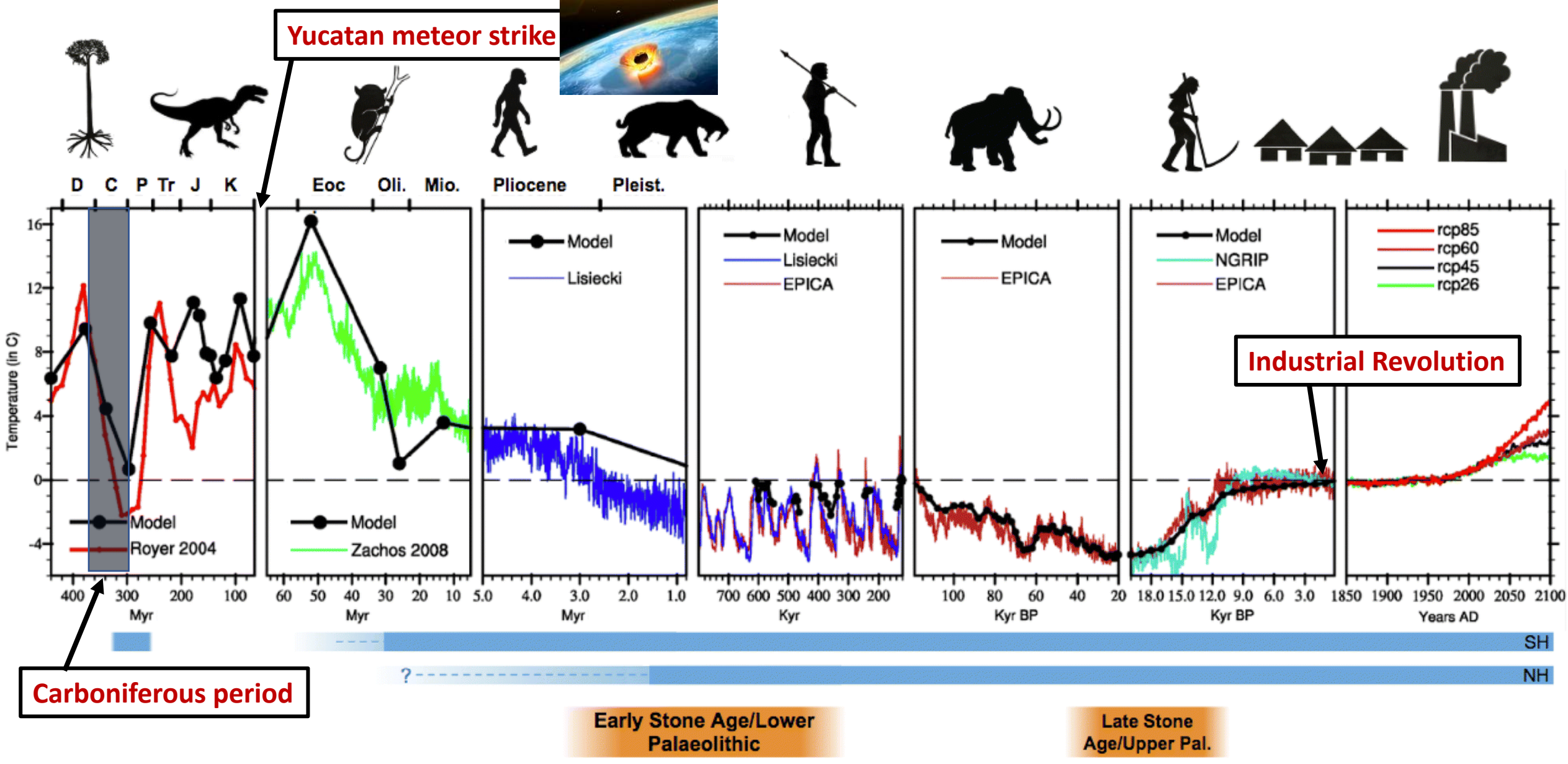
Global Average Temperature



https://www.climate.gov/news-features/videos/history-earths-temperature-1880

Consequences

- Higher temperatures
- (Partial) polar ice cap and glaciers melting
- Sea level rise
- More and stronger weather events
- Acidification of the oceans
- Species mass migrations and extinctions
- Food shortages / famines
- Human migration / wars



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https://link.springer.com/article/10.1007/s41748-019-00093-1?shared-article-renderer

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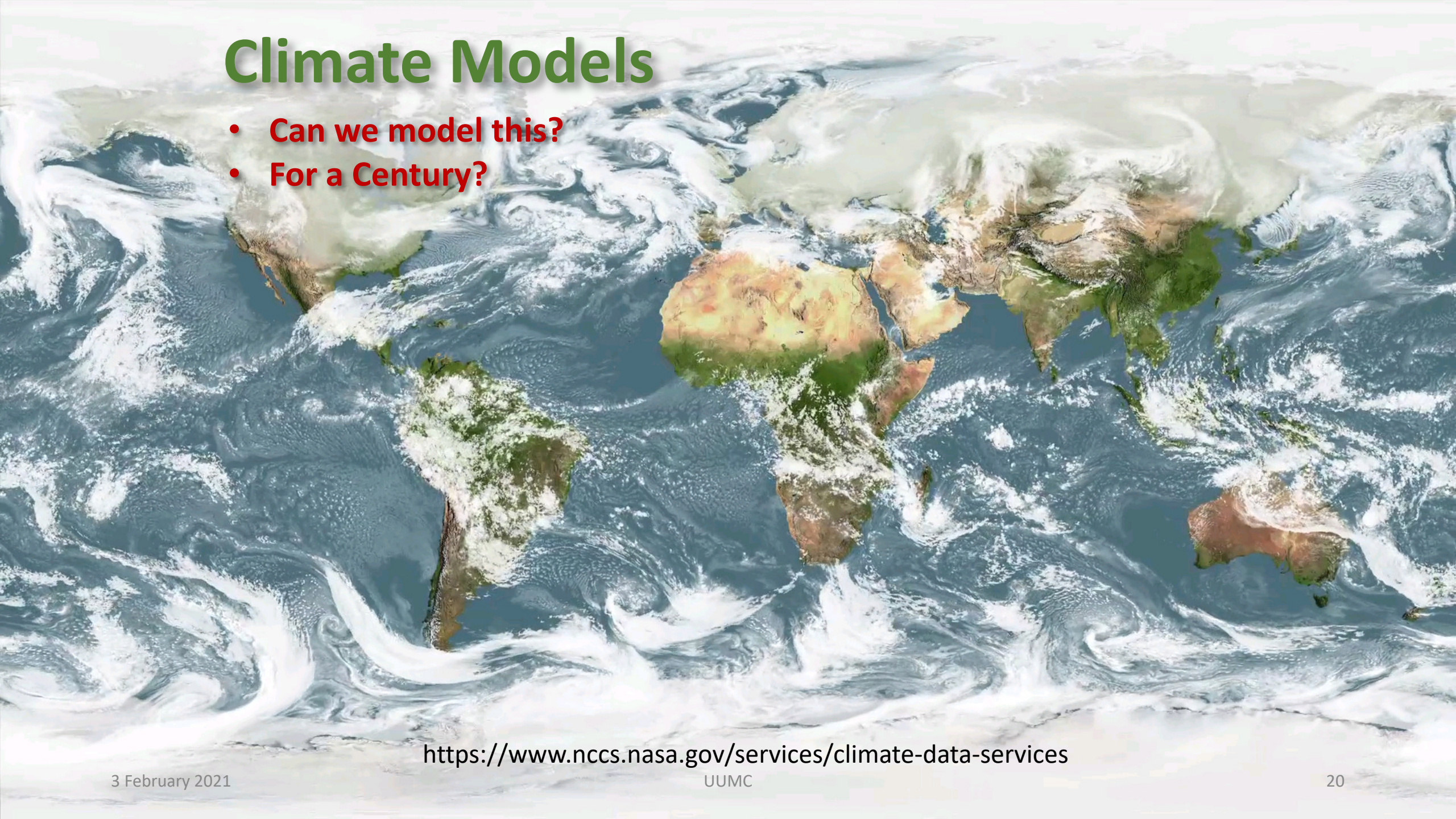
Climate Models

- **Can we model this?**
- **For a Century?**



https://www.nccs.nasa.gov/services/climate-data-services

Climate Models

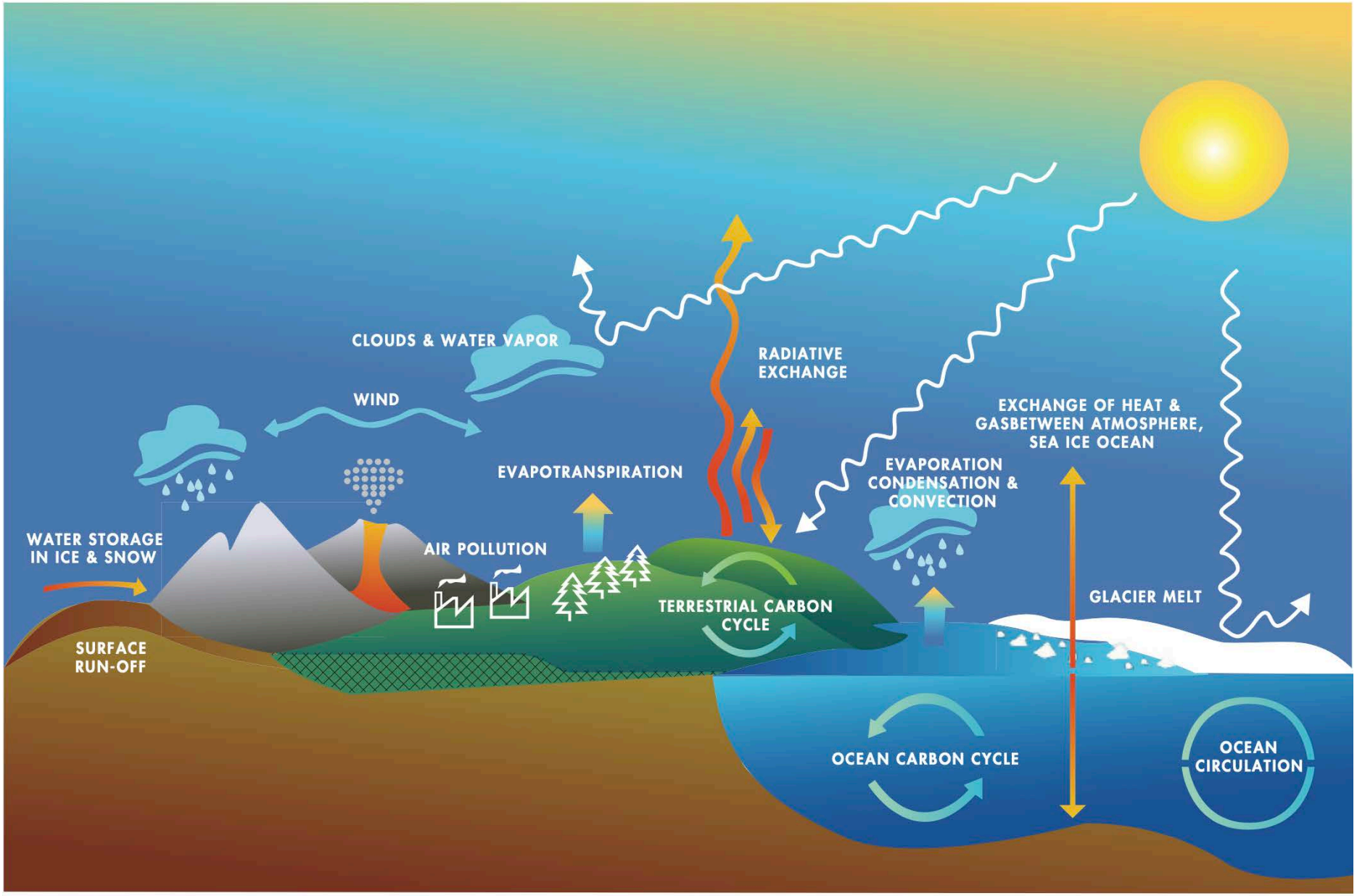
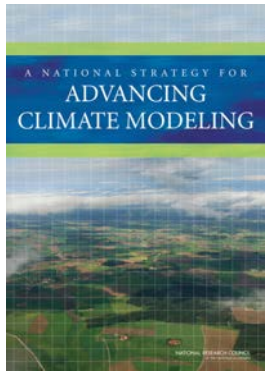


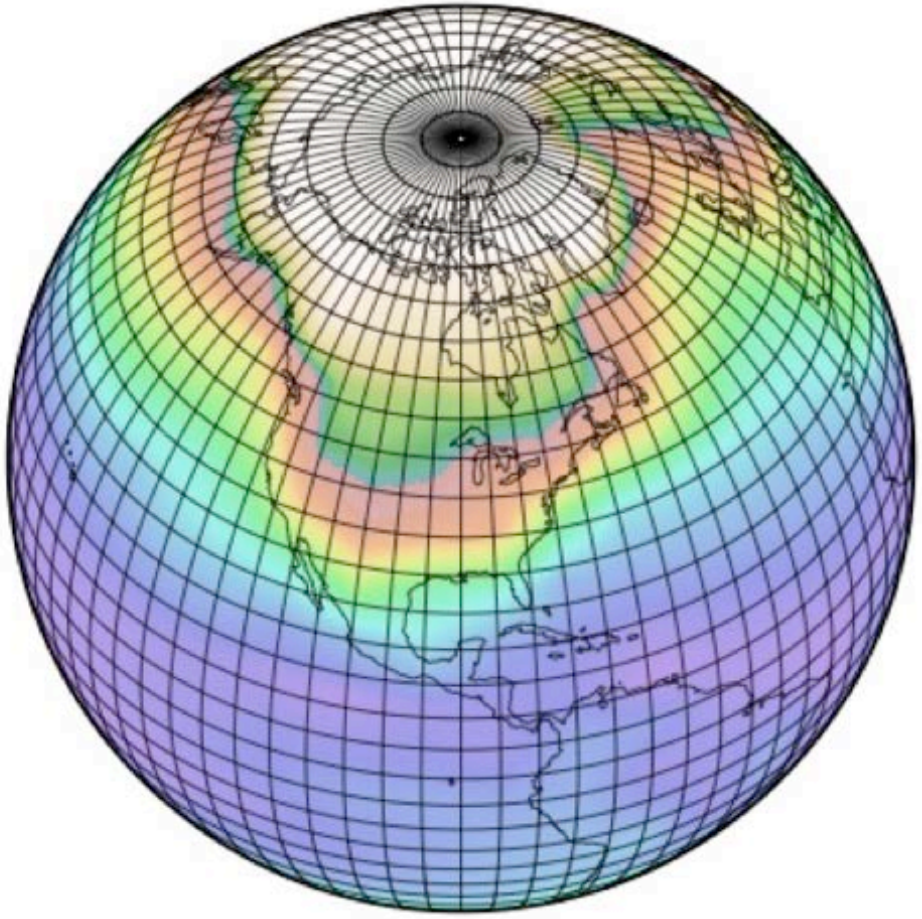
FIGURE 1.3 Climate models are mathematical representations of the physical, chemical, and biological processes in the Earth system. SOURCE: Marian Koshland Science Museum.

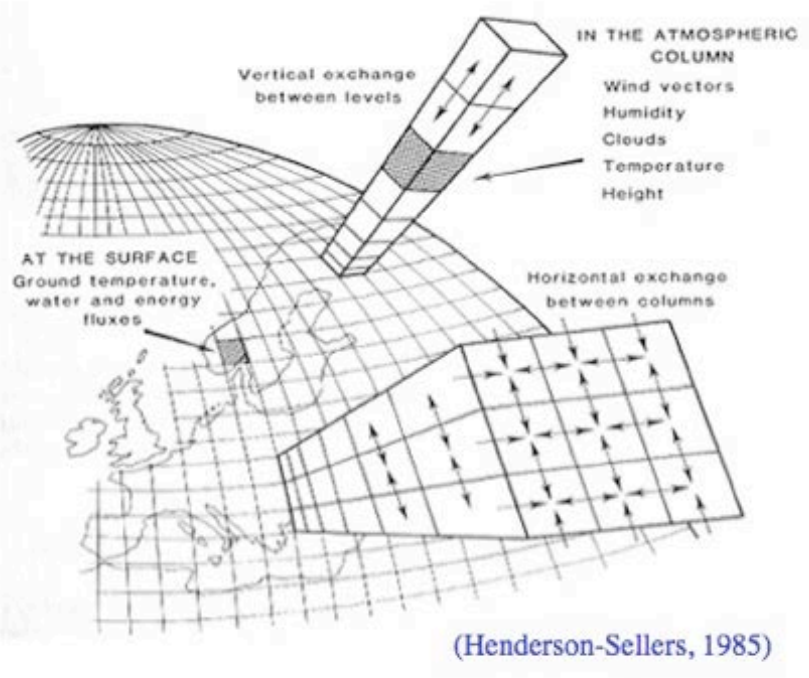


National Research Council 2012. *A National Strategy for Advancing Climate Modeling*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13430.

Climate Models

Grid Point Models





https://www.nccs.nasa.gov/services/climate-data-services

Climate Models

Fundamental Physical Quantities & Equations

At every grid cell GCMs calculate:

- Temperature (T)
- Pressure (P)
- Winds (U, V)
- Humidity (Q)

- Conservation of momentum

$$\frac{\partial \vec{V}}{\partial t} = -(\vec{V}\cdot\nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega}\times\vec{V} + \nabla\cdot(k_m\nabla\vec{V}) - \vec{F}_d$$

- Conservation of energy

$$\rho c_{\vec{v}}\frac{\partial T}{\partial t} = -\rho c_{\vec{v}}(\vec{V}\cdot\nabla)T - \nabla\cdot\vec{R} + \nabla\cdot(k_T\nabla T) + C + S$$

- Conservation of mass

$$\frac{\partial \rho}{\partial t} = -(\vec{V}\cdot\nabla)\rho - \rho(\nabla\cdot\vec{V})$$

- Conservation of H_2O (vapor, liquid, solid)

$$\frac{\partial q}{\partial t} = -(\vec{V}\cdot\nabla)q + \nabla\cdot(k_q\nabla q) + S_q + E$$

- Equation of state

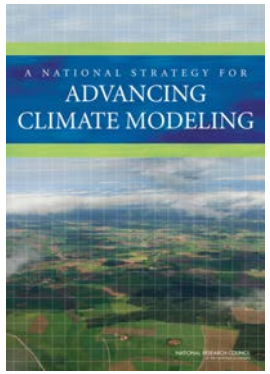
$$p = \rho R_d T$$

http://edgcm.columbia.edu

Climate Models

… are getting better

(AR = Assessment Report)



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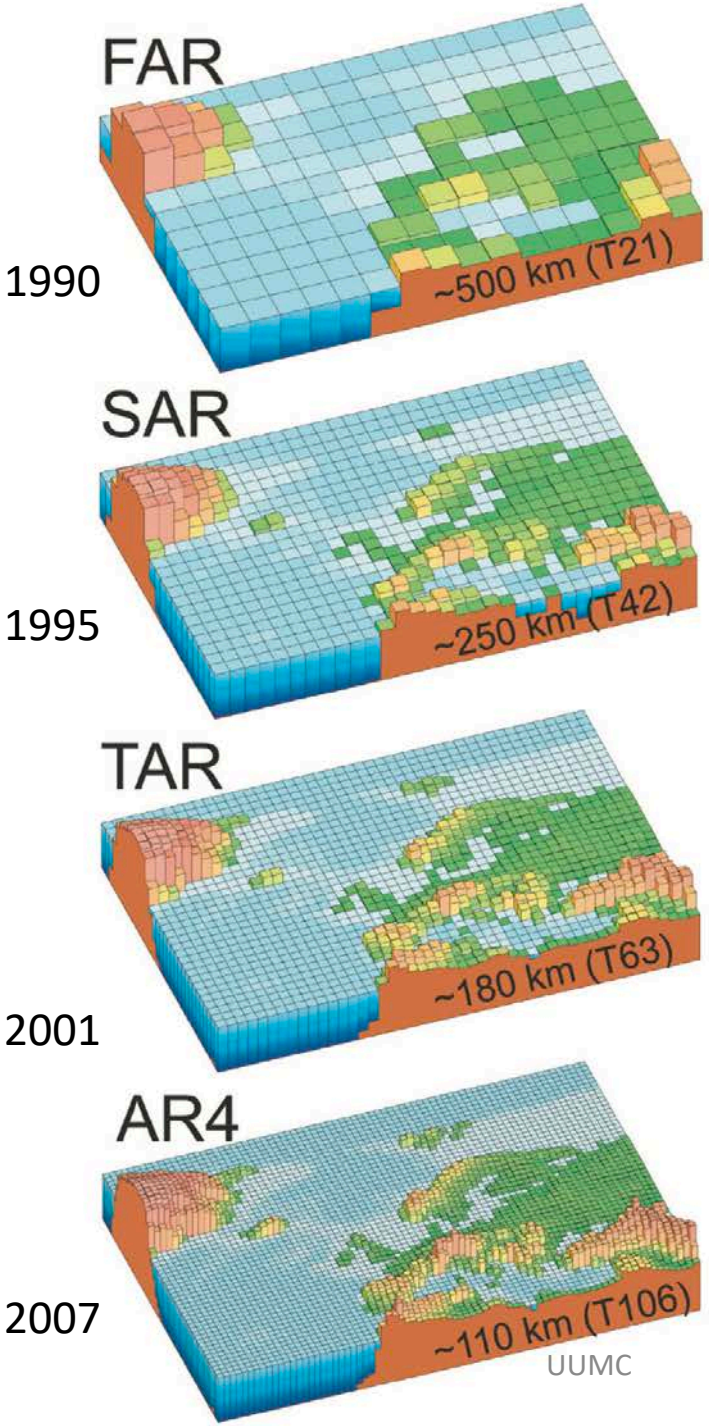
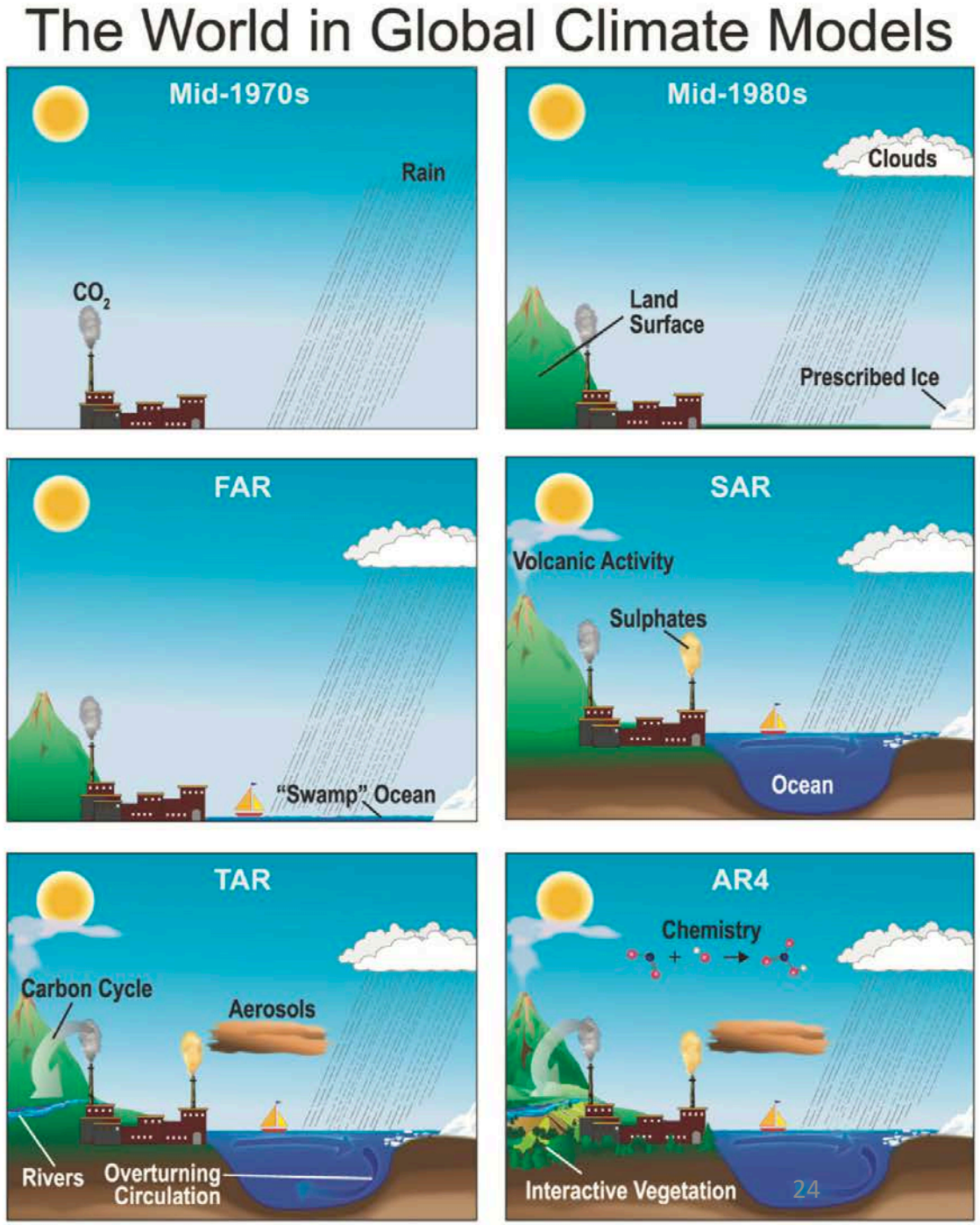
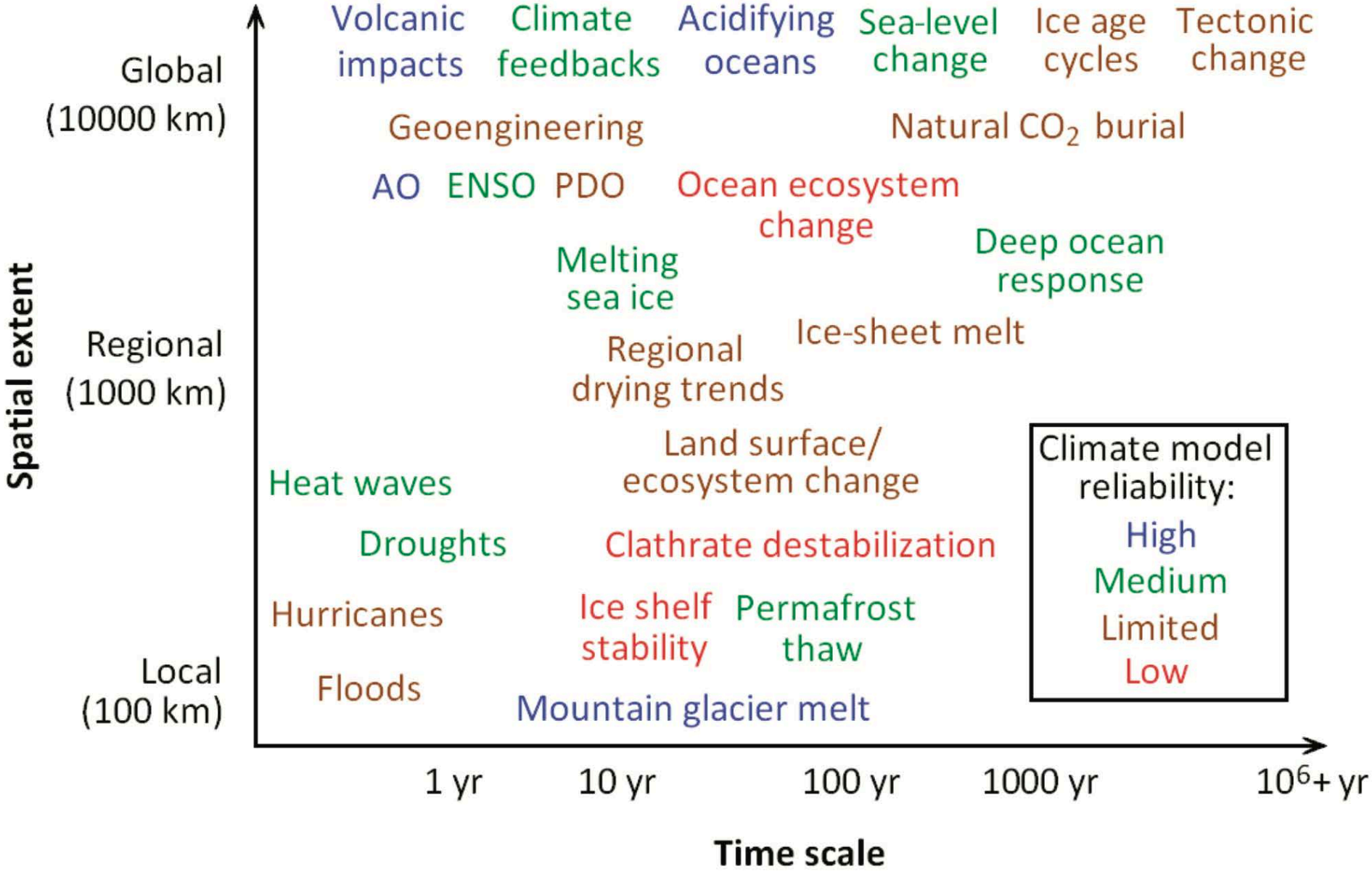
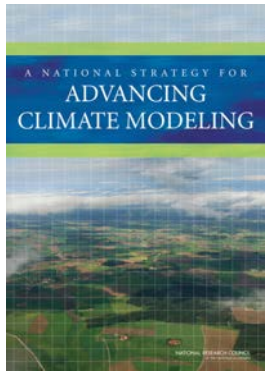




Climate Models





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Lansing, Mich.

Temperature Average: 48.1° ▼ **-0.3° below** normal

°F °C

https://www.nytimes.com/interactive/2020/world/year-in-weather.html#lan

120° 110° 100° 90° 80° 70° 60° 50° 40° 30° 20° 10° 0° -10° -20°

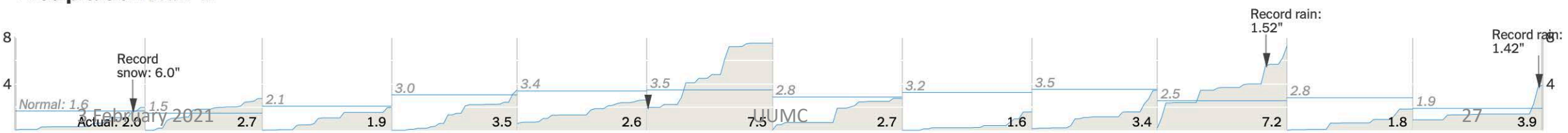
Record high: 59°

Bars represent range between the daily high and low.

Record High
Normal range
Record Low
Actual high
Actual low

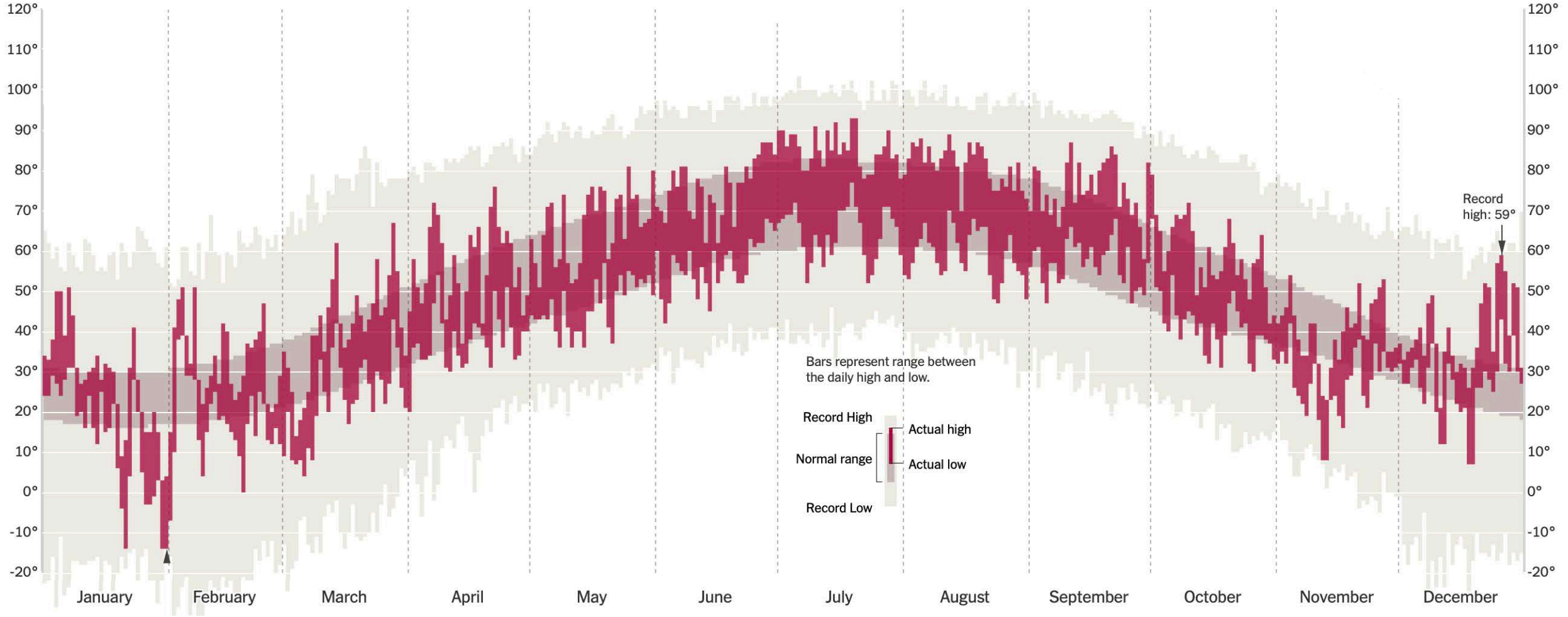
January February March April May June July August September October November December

Precipitation Total: 41"

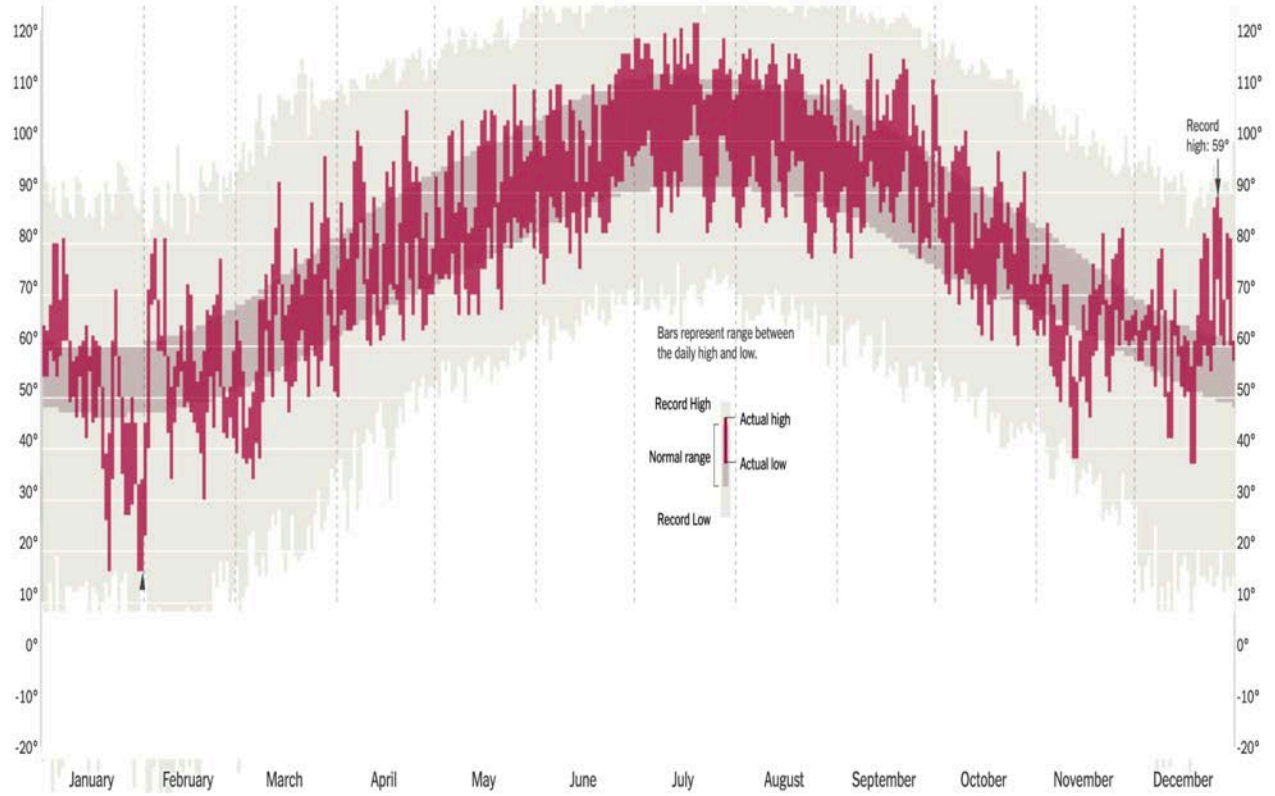


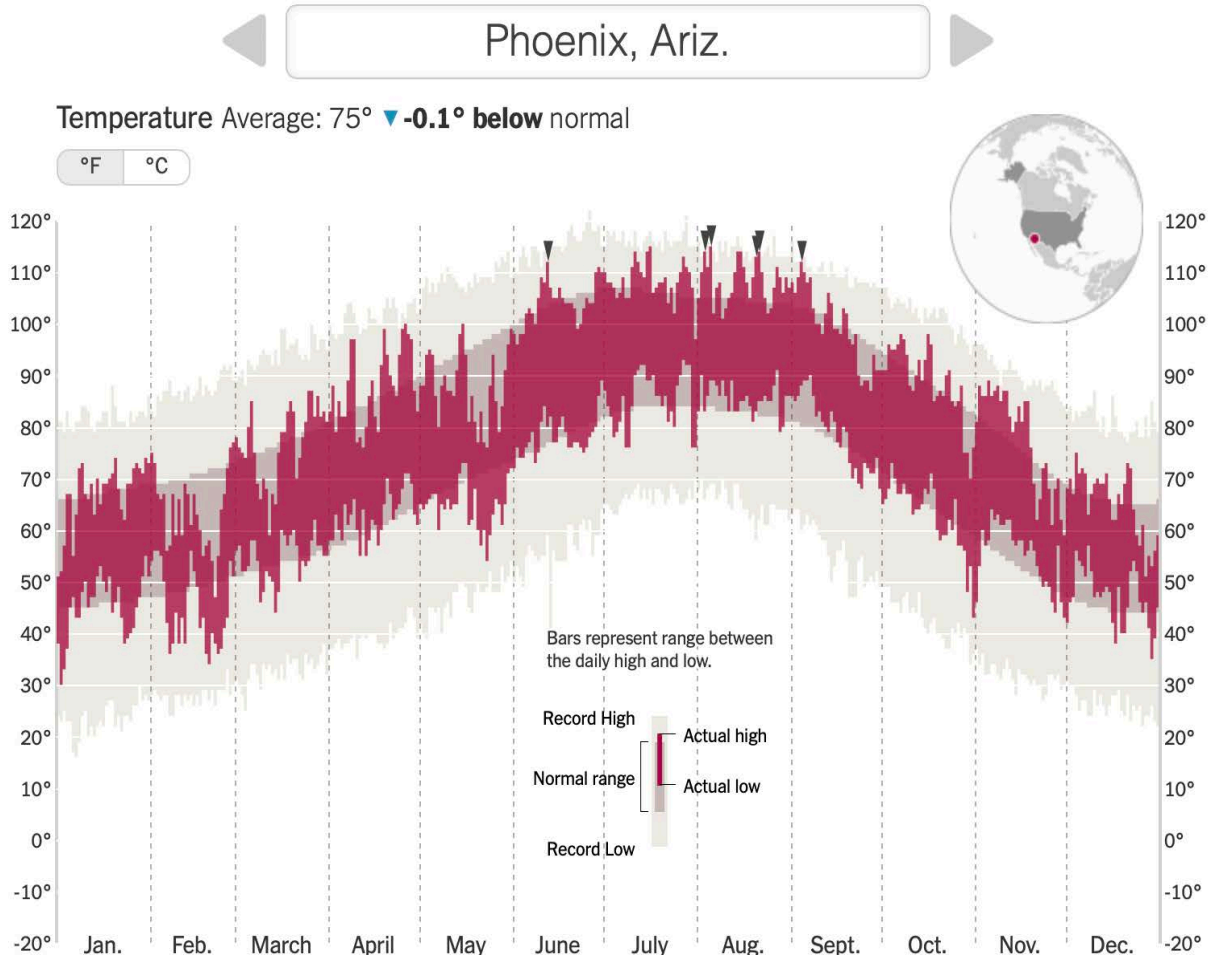
Cumulative monthly precipitation, in inches, compared with normal. Precipitation totals are rainfall plus the liquid equivalent of any frozen precipitation.

Pre-carboniferous Lansing (pure fiction): Let's raise the temperature by 30 F!



Hypothetical Lansing, T_{ave}=78 F





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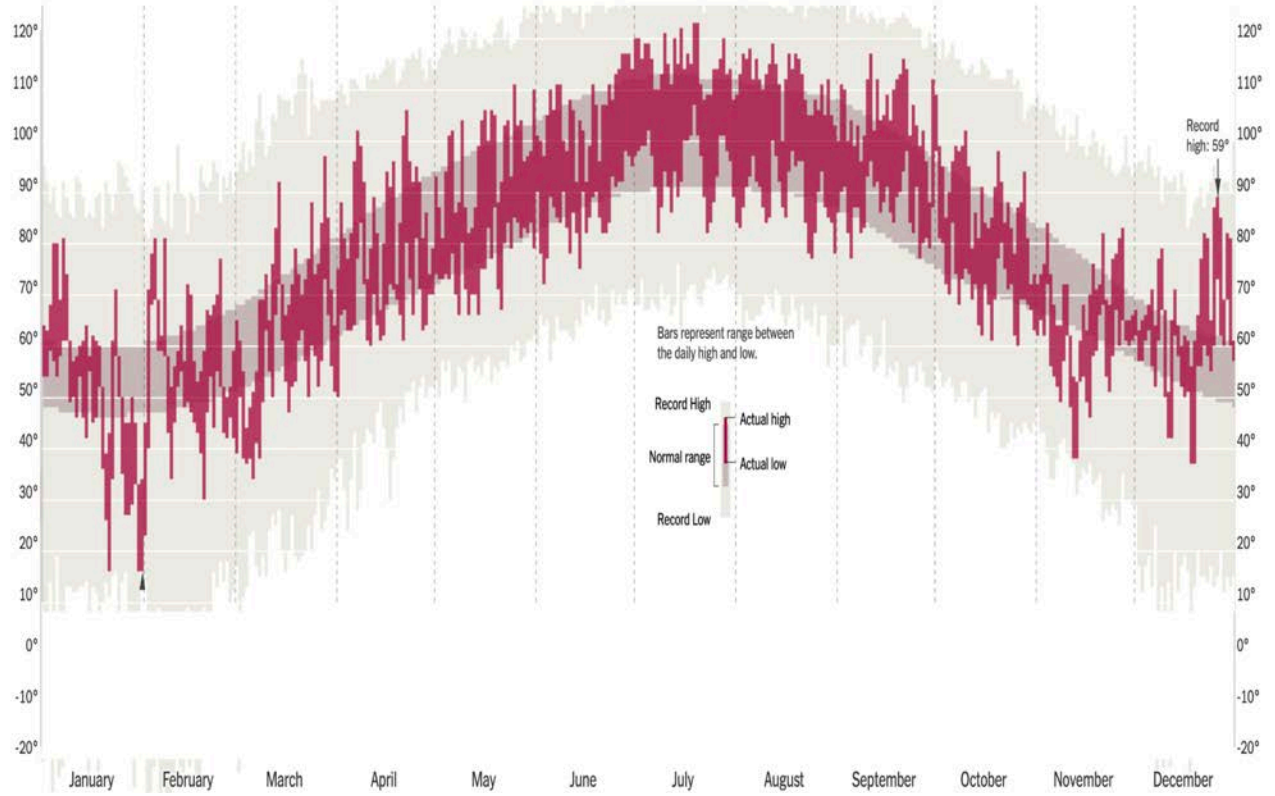
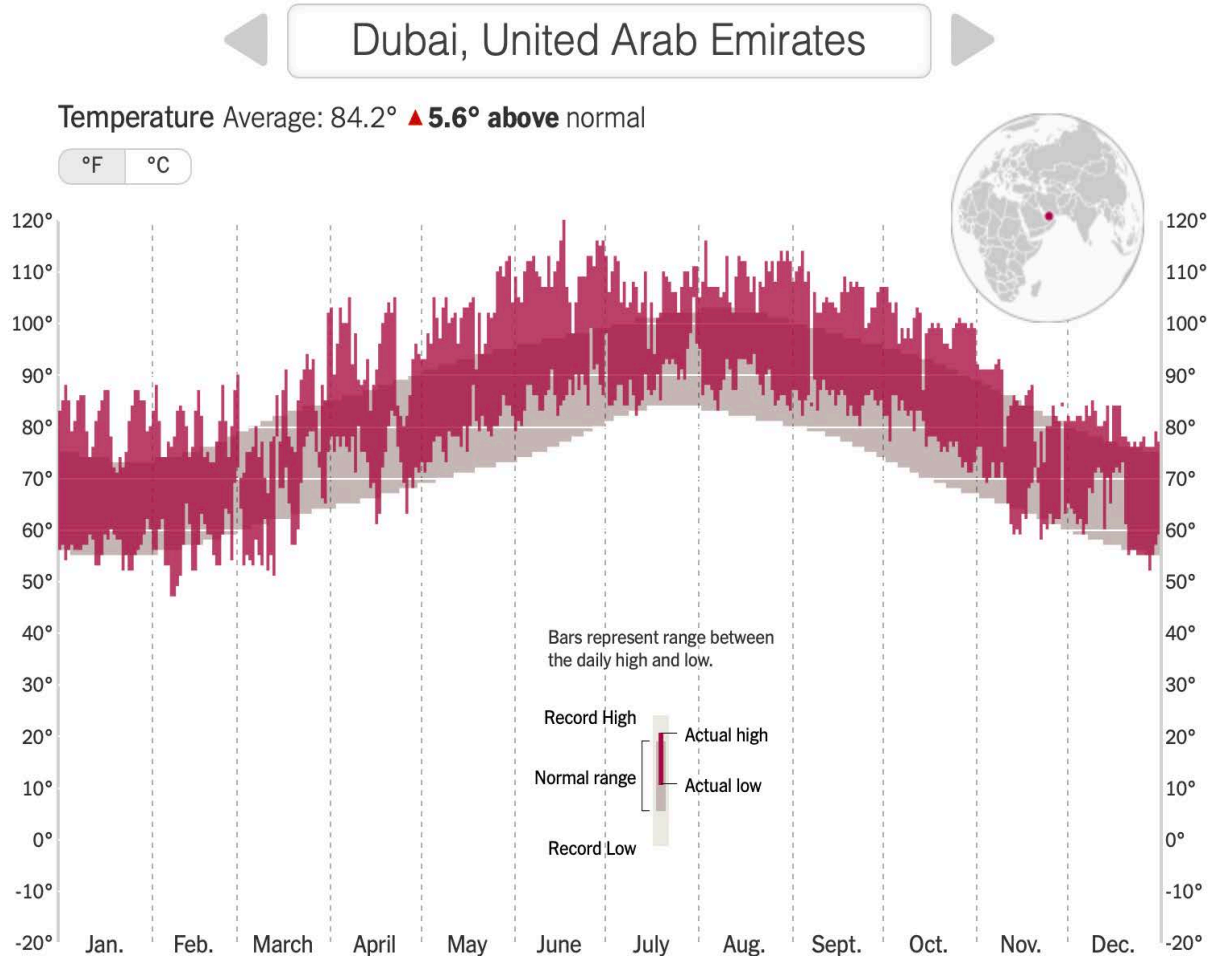
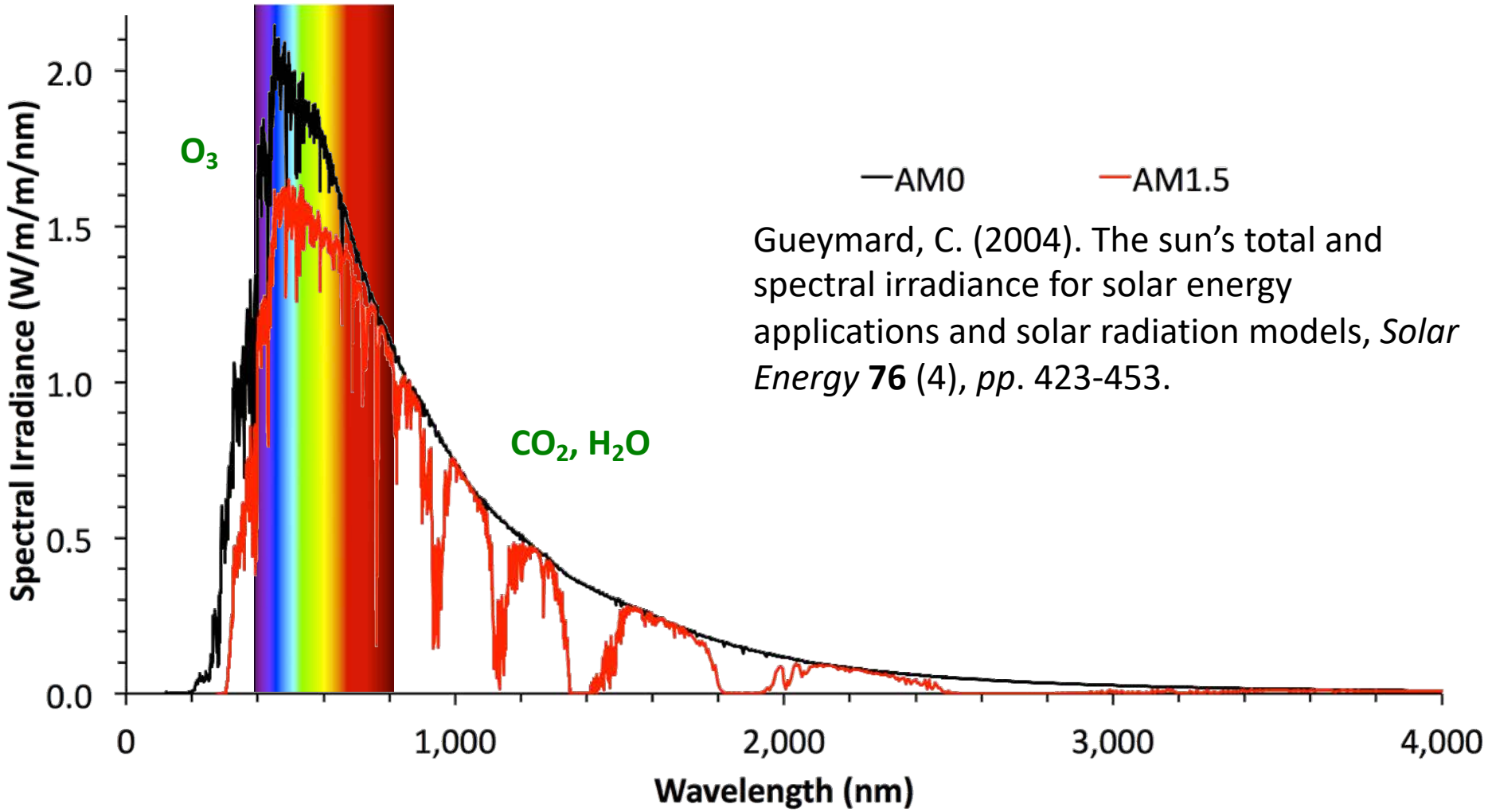


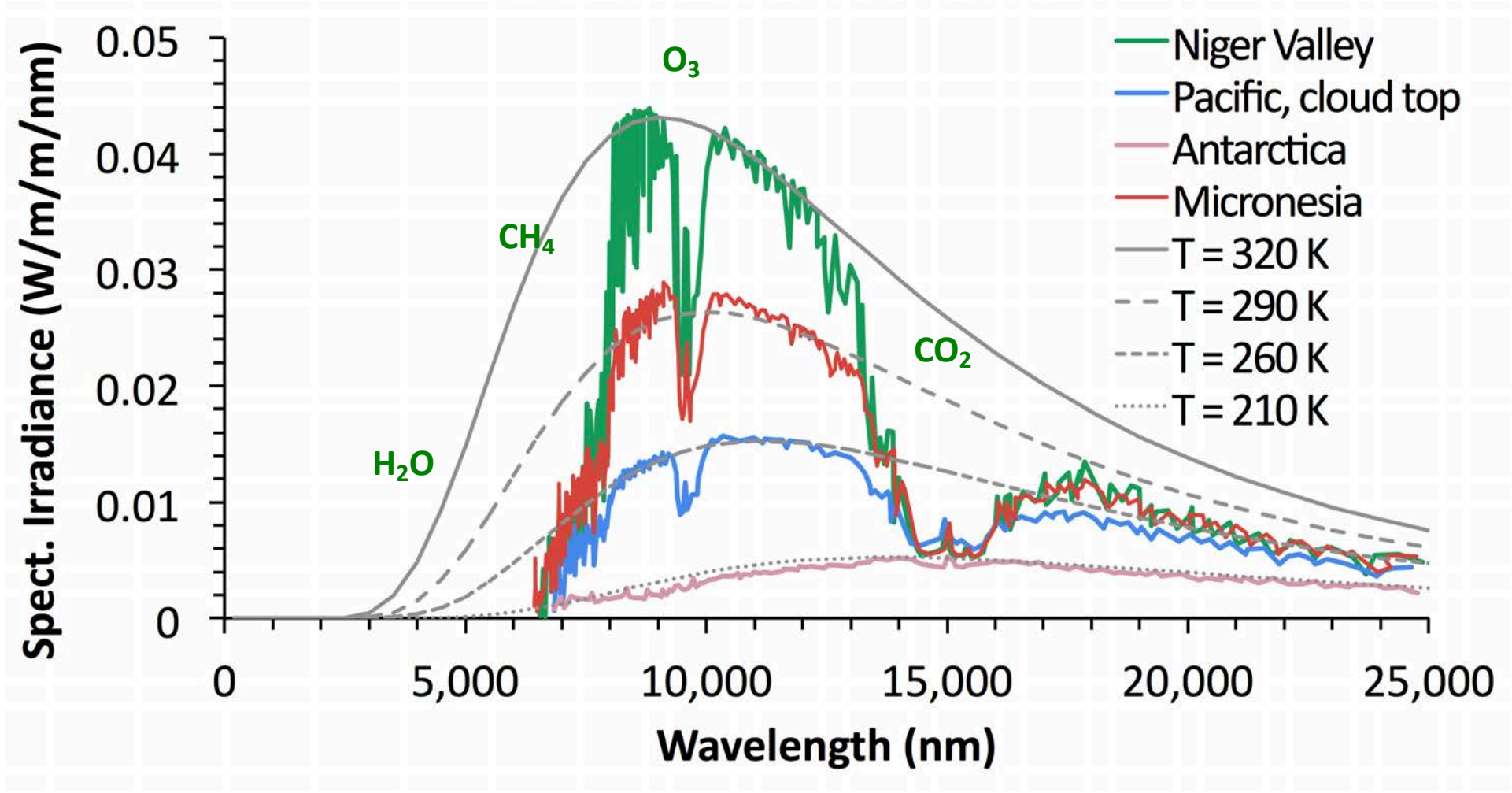


Solar radiation



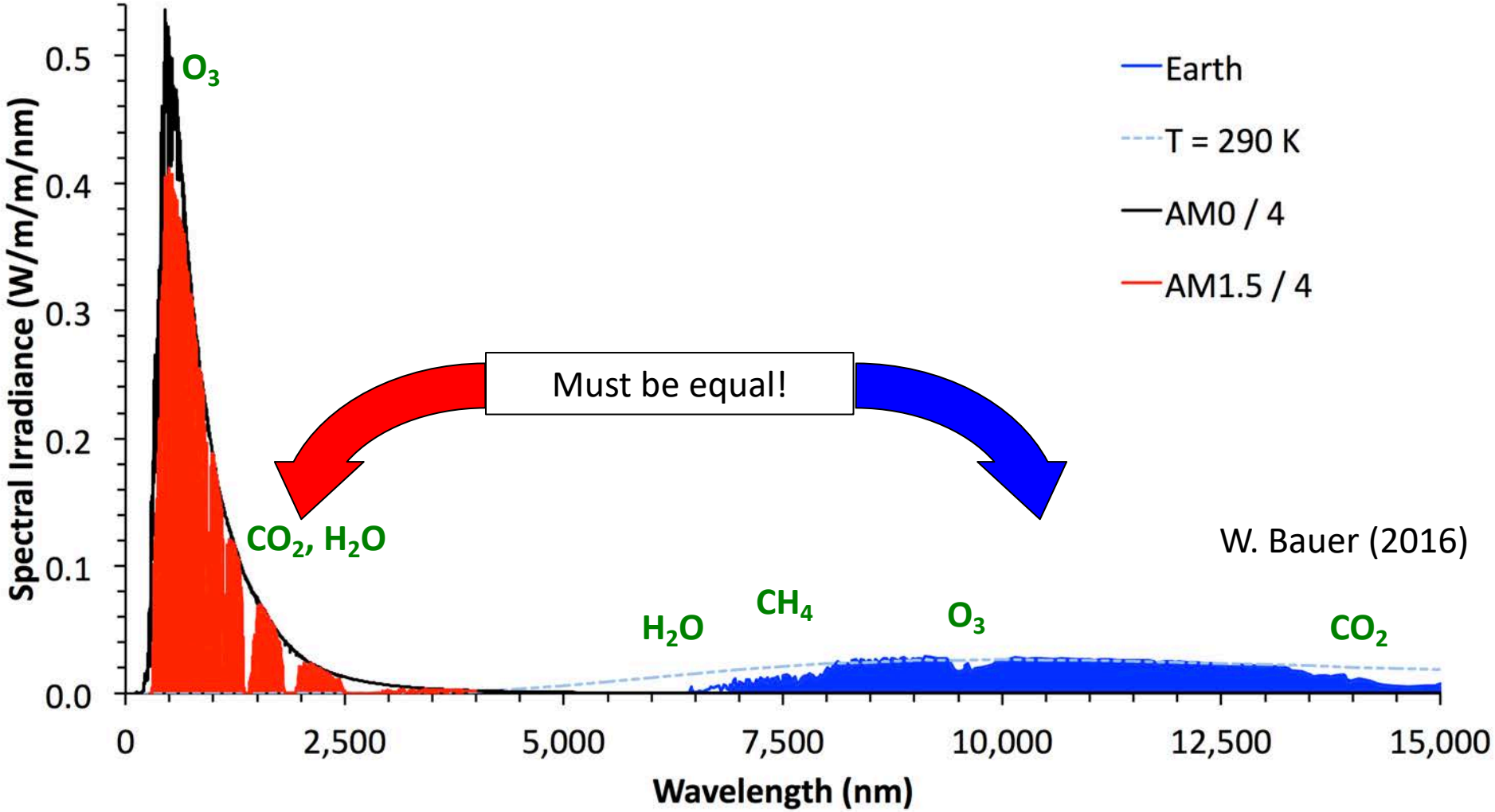
Gueymard, C. (2004). The sun's total and spectral irradiance for solar energy applications and solar radiation models, *Solar Energy* **76** (4), *pp*. 423-453.

Earth radiation

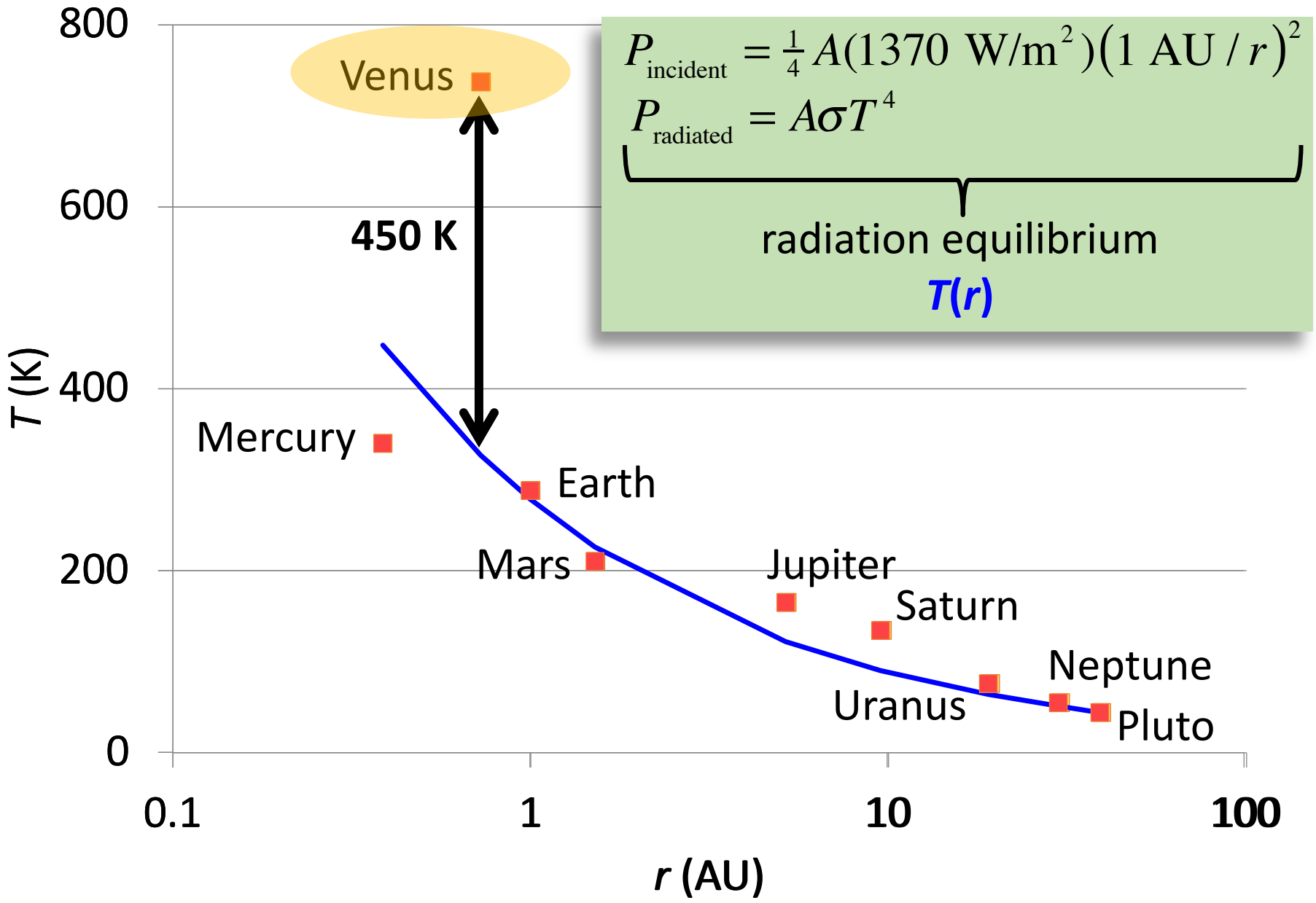


Data from: Hanel, R. A., Conrath, B. J., Kunde, V. G., Prabhakara, C., Revah, I., Solomonson, V. V., and Wolfrod, G. (1972). The Nimbus 4 Infrared Spectroscopy Experiment, 1. Calibrated Thermal Emission Spectra, *Journal of Geophysical Research* **77**, *pp*. 2629-2641.

Radiation balance



Planetary Surface Temperatures



Venus Runaway Greenhouse Effect

- Early Venus may have had liquid water oceans
- High greenhouse gas concentration led to warming of planet and subsequent boiling and evaporation of its oceans
- **Can Earth encounter the same fate?**

AGU PUBLICATIONS

Geophysical Research Letters

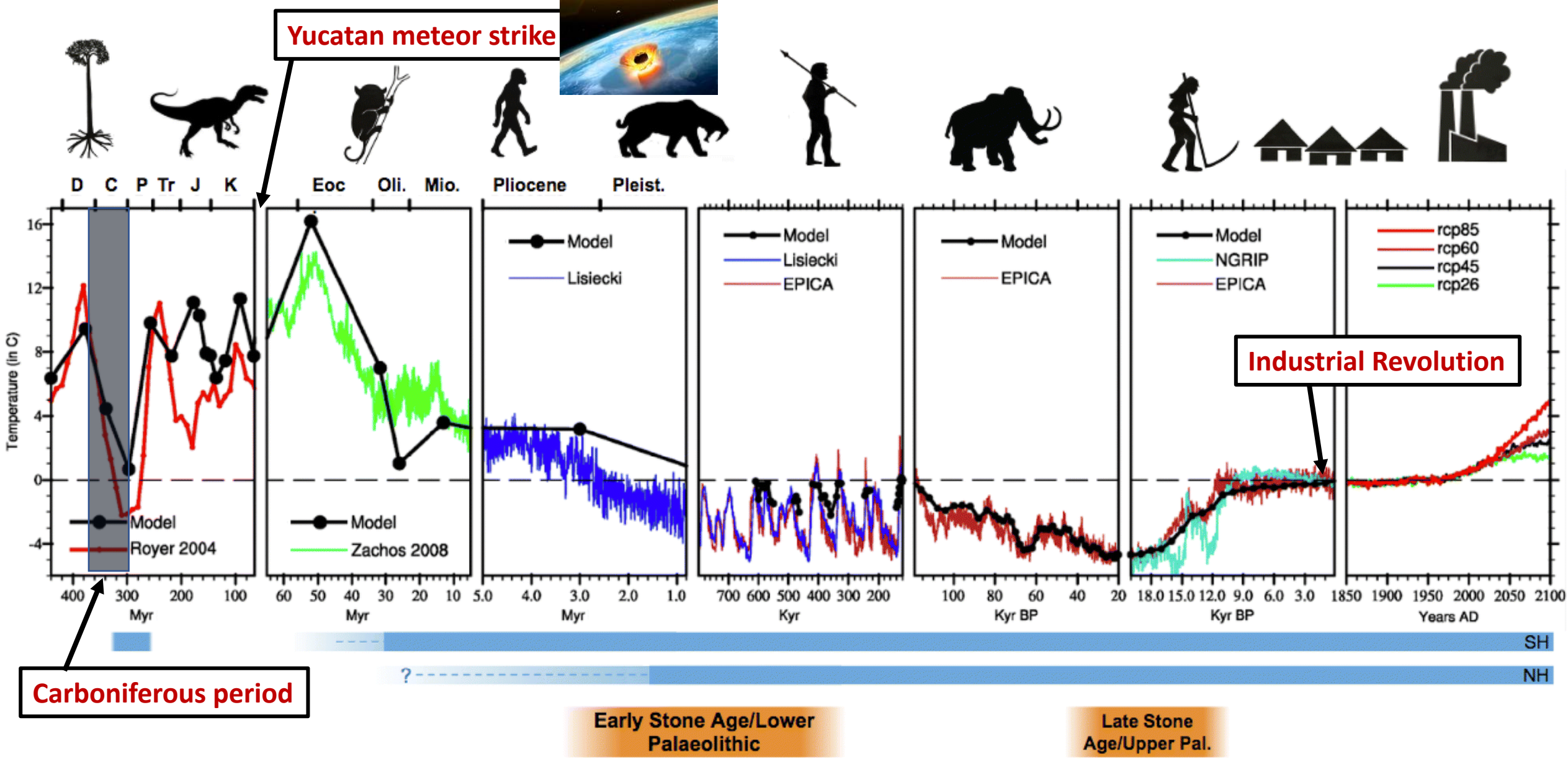
RESEARCH LETTER
10.1002/2016GL069790

Key Points:
- Venus may have had a climate with liquid water on its surface for approximately two billion years
- The rotation rate and topography of Venus play crucial roles in its surface temperature and moisture
- Young Venus-like exoplanets may be considered candidates for the search for life beyond Earth

Was Venus the first habitable world of our solar system?

M. J. Way[1,2], Anthony D. Del Genio[1], Nancy Y. Kiang[1], Linda E. Sohl[1,3], David H. Grinspoon[4], Igor Aleinov[1,3], Maxwell Kelley[1], and Thomas Clune[5]

[1]NASA Goddard Institute for Space Studies, New York, New York, USA, [2]Department of Astronomy and Space Physics, Uppsala University, Uppsala, Sweden, [3]Center for Climate Systems Research, Columbia University, New York, New York, USA, [4]Planetary Science Institute, Tucson, Arizona, USA, [5]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA



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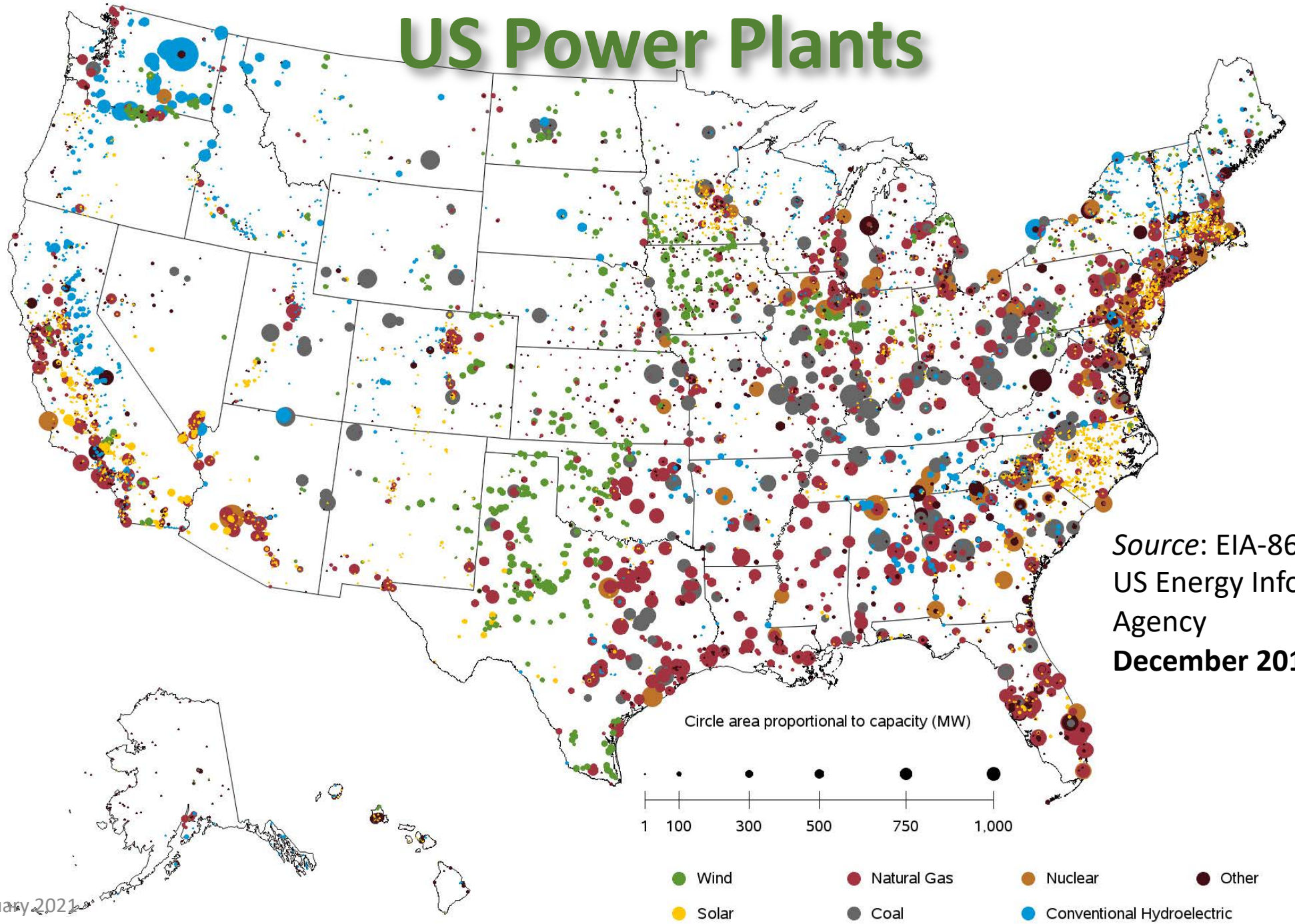
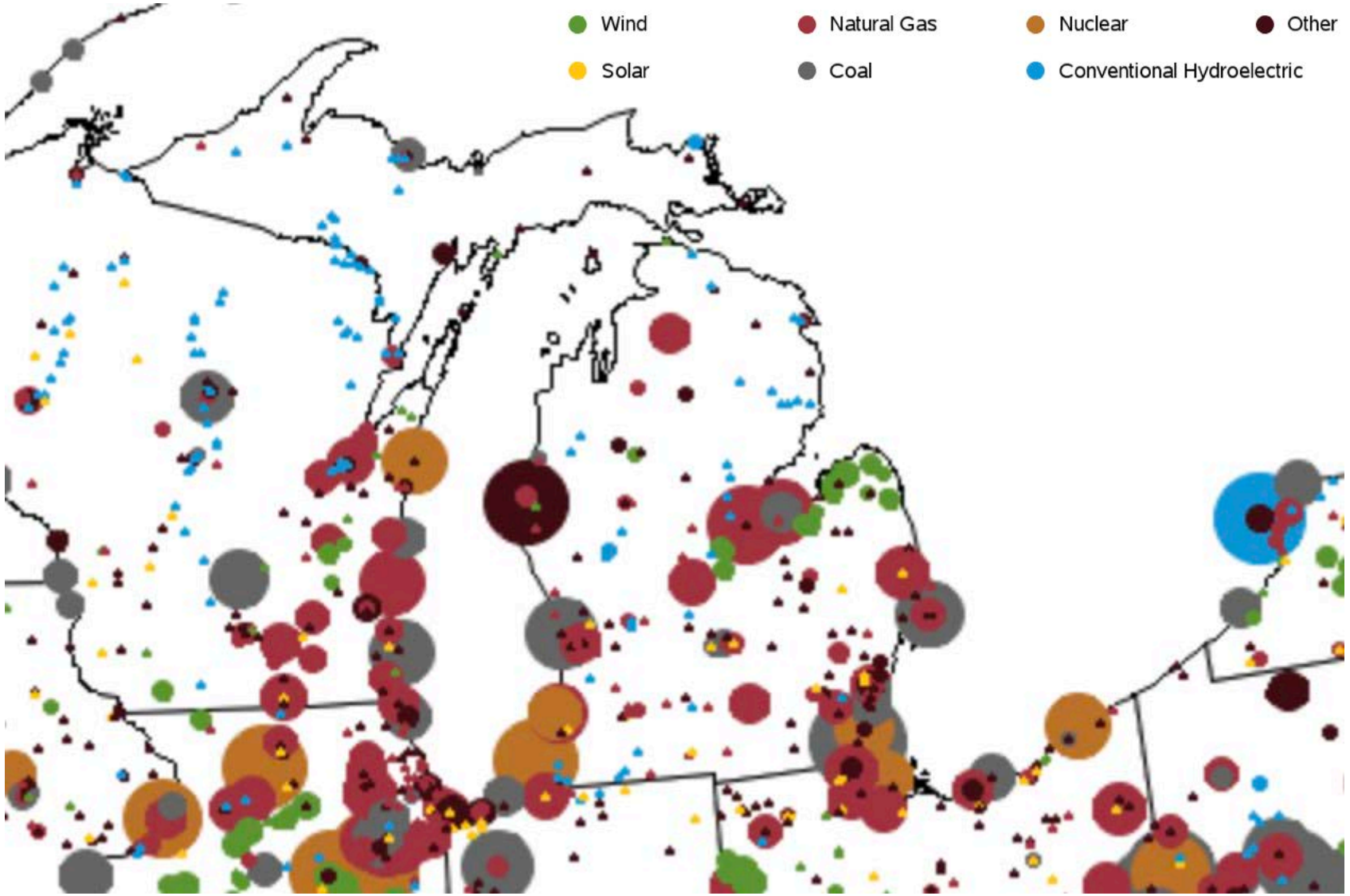
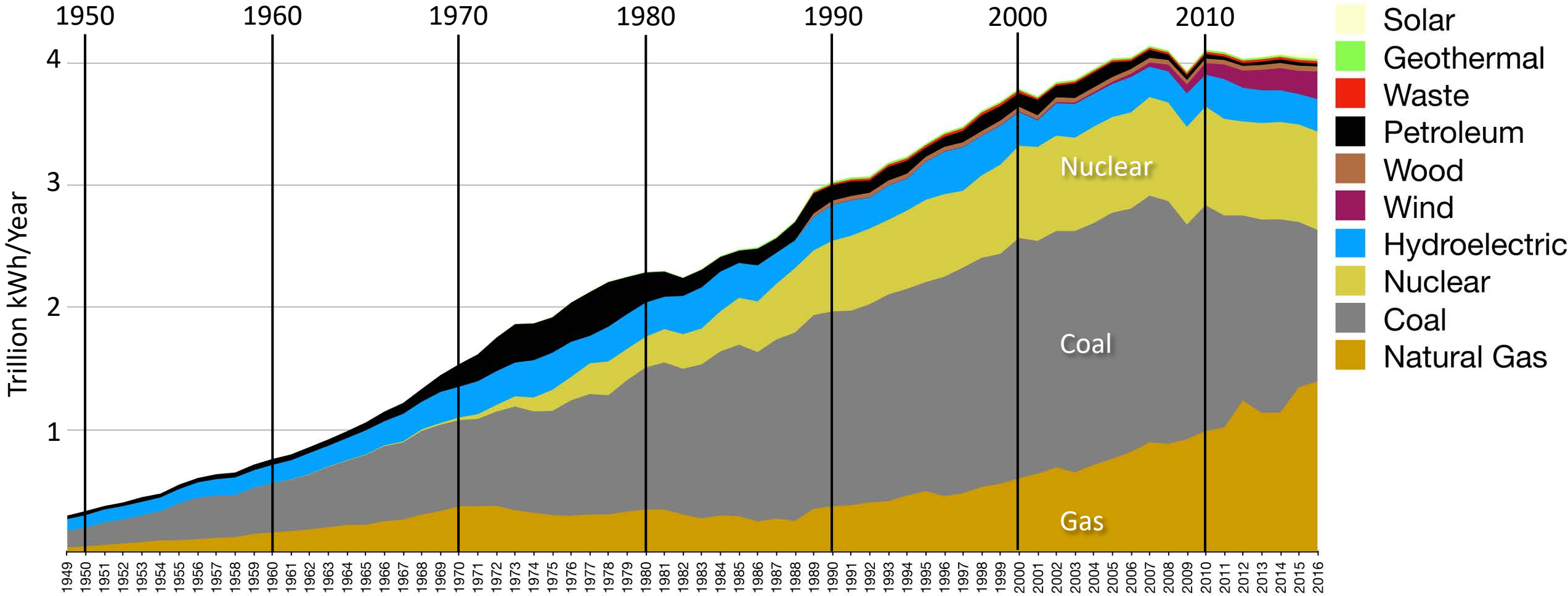
US Power Plants



Source: EIA-860, EIA-860M US Energy Information Agency
December 2018

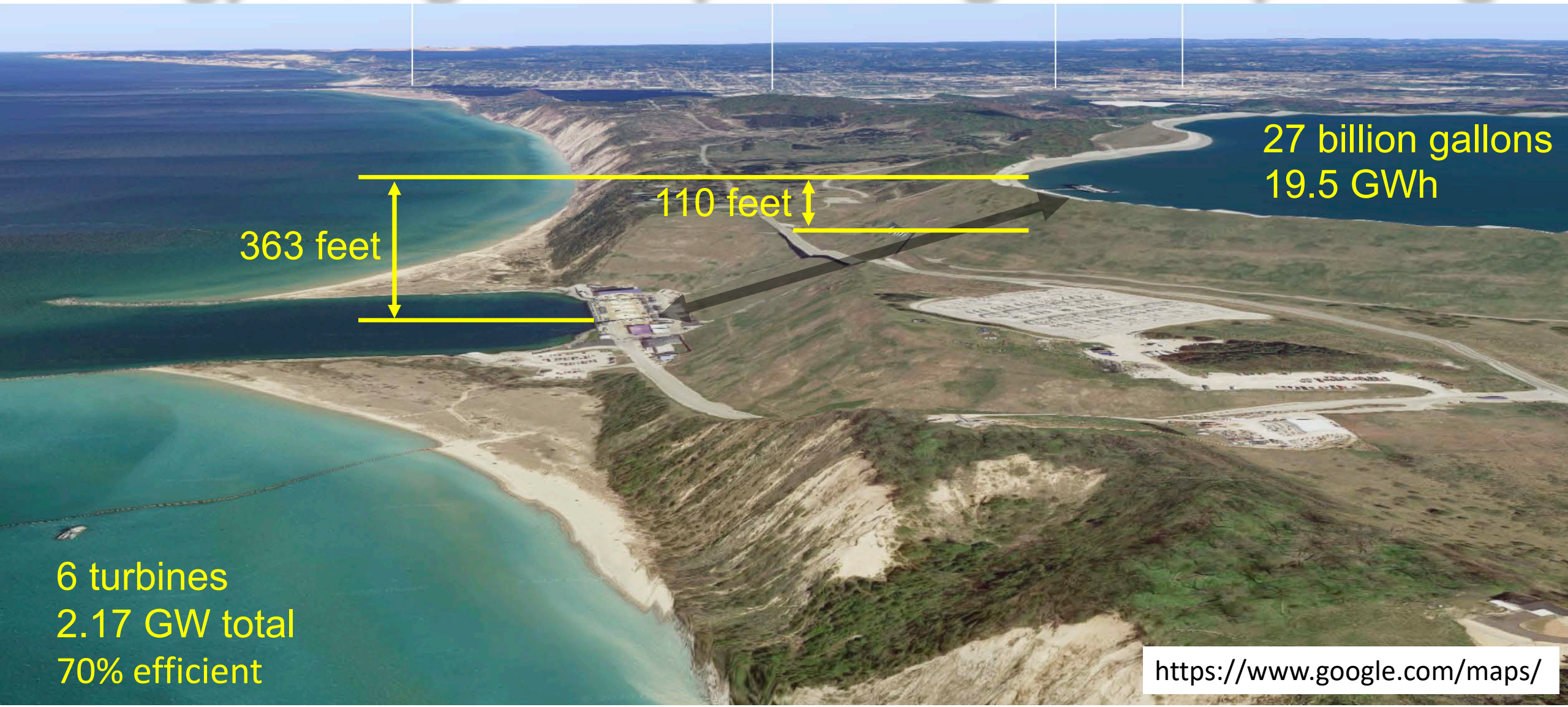

Wind
Natural Gas
Nuclear
Other
Solar
Coal
Conventional Hydroelectric

US Electricity Generation by Type



https://en.wikipedia.org/wiki/Electricity_sector_of_the_United_States#/media/File:US_Electricity_by_type.png

Energy Storage: Example Ludington Pump Storage



Green New Deal

Alexandria Ocasio-Cortez
14th District, New York

www.congress.gov/bill/116th-congress/house-resolution/109

Text: H.Res.109 — 116th Congress (2019-2020)

All Information (Except Text)

There is one version of the bill.

Text available as: XML/HTML | XML/HTML (new window) | TXT | PDF (PDF provides a complete and accurate display of this text.)

Shown Here:
Introduced in House (02/07/2019)

116TH CONGRESS
1ST SESSION

H. RES. 109

Recognizing the duty of the Federal Government to create a Green New Deal.

IN THE HOUSE OF REPRESENTATIVES

FEBRUARY 7, 2019

Ms. OCASIO-CORTEZ (for herself, Mr. HASTINGS, Ms. TLAIB, Mr. SERRANO, Mrs. CAROLYN B. MALONEY of New York, Mr. VARGAS, Mr. ESPAILLAT, Mr. LYNCH, Ms. VELÁZQUEZ, Mr. BLUMENAUER, Mr. BRENDAN F. BOYLE of Pennsylvania, Mr. CASTRO of Texas, Ms. CLARKE of New York, Ms. JAYAPAL, Mr. KHANNA, Mr. TED LIEU of California, Ms. PRESSLEY, Mr. WELCH, Mr. ENGEL, Mr. NEGUSE, Mr. NADLER, Mr. MCGOVERN, Mr. POCAN, Mr. TAKANO, Ms. NORTON, Mr. RASKIN, Mr. CONNOLLY, Mr. LOWENTHAL, Ms. MATSUI, Mr. THOMPSON of California, Mr. LEVIN of California, Ms. PINGREE, Mr. QUIGLEY, Mr. HUFFMAN, Mrs. WATSON COLEMAN, Mr. GARCÍA of Illinois, Mr. HIGGINS of New York, Ms. HAALAND, Ms. MENG, Mr. CARBAJAL, Mr. CICILLINE, Mr. COHEN, Ms. CLARK of Massachusetts, Ms. JUDY CHU of California, Ms. MUCARSEL-POWELL, Mr. MOULTON, Mr. GRIJALVA, Mr. MEEKS, Mr. SABLAN, Ms. LEE of California, Ms. BONAMICI, Mr. SEAN PATRICK MALONEY of New York, Ms. SCHAKOWSKY, Ms. DELAURO, Mr. LEVIN of Michigan, Ms. MCCOLLUM, Mr. DESAULNIER, Mr. COURTNEY, Mr. LARSON of Connecticut, Ms. ESCOBAR, Mr. SCHIFF, Mr. KEATING, Mr. DEFAZIO, Ms. ESHOO, Mrs. TRAHAN, Mr. GOMEZ, Mr. KENNEDY, and Ms. WATERS) submitted the following resolution; which was referred to the Committee on Energy and Commerce, and in addition to the Committees on Science, Space, and Technology, Education and Labor, Transportation and Infrastructure, Agriculture, Natural Resources, Foreign Affairs, Financial Services, the Judiciary, Ways and Means, and Oversight and Reform, for a period to be subsequently determined by the Speaker, in each case for consideration of such provisions as fall within the jurisdiction of the committee concerned

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RESOLUTION

Recognizing the duty of the Federal Government to create a Green New Deal.

Whereas the October 2018 report entitled "Special Report on Global Warming of 1.5 ºC" by the Intergovernmental Panel on Climate Change and the November 2018 Fourth National Climate Assessment report found that—

(1) human activity is the dominant cause of observed climate change over the past century;

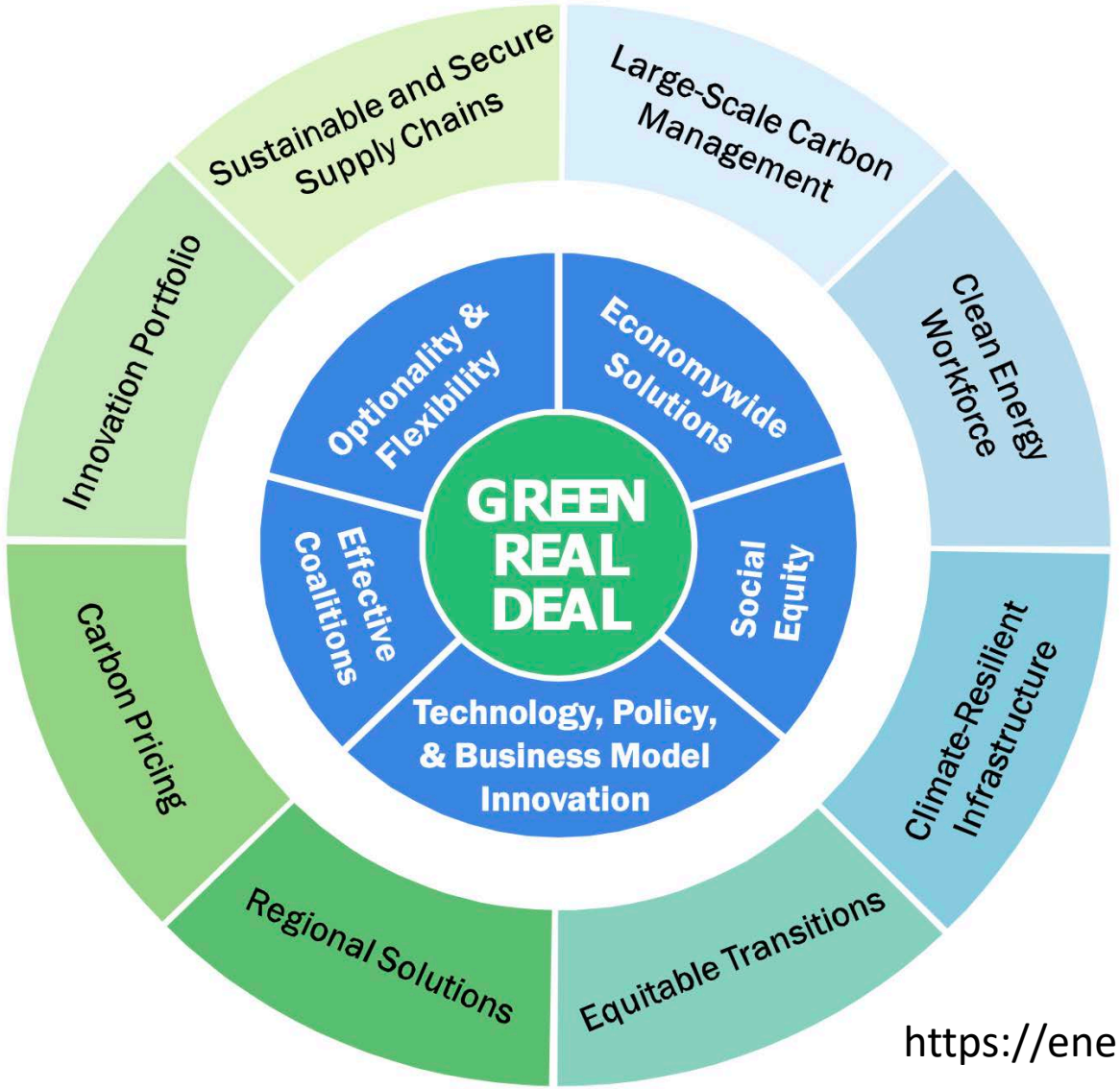
(2) a changing climate is causing sea levels to rise and an increase in wildfires, severe storms, droughts, and other extreme weather events that threaten human life, healthy communities, and critical infrastructure;

(3) global warming at or above 2 degrees Celsius beyond preindustrialized levels will cause—

Back to top

Figure 4

A Framework for Achieving a Deeply Decarbonized Economy



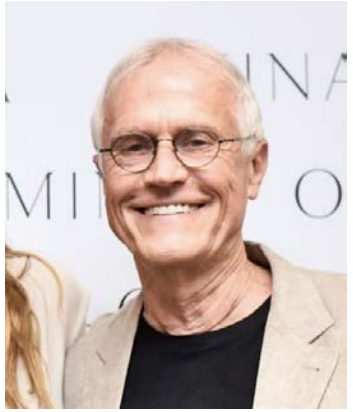
Ernest J. Moniz
President and CEO

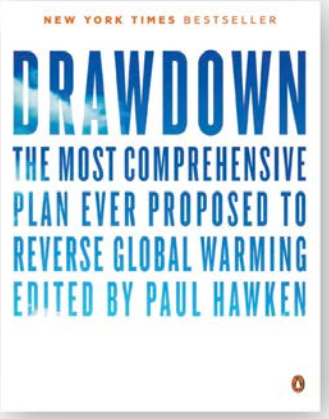
https://energyfuturesinitiative.org/grd-report

The Green Real Deal Principles are represented in the inner blue ring. Its Elements are represented by the outer ring. Source: EFI, 2019.

Drawdown

https://www.drawdown.org





Solutions by Rank

Rank	Solution	Sector	TOTAL ATMOSPHERIC CO2-EQ REDUCTION (GT)	NET COST (BILLIONS US $)	SAVINGS (BILLIONS US $)
1	Refrigerant Management	Materials	89.74	N/A	$-902.77
2	Wind Turbines (Onshore)	Electricity Generation	84.60	$1,225.37	$7,425.00
3	Reduced Food Waste	Food	70.53	N/A	N/A
4	Plant-Rich Diet	Food	66.11	N/A	N/A
5	Tropical Forests	Land Use	61.23	N/A	N/A
6	Educating Girls	Women and Girls	51.48	N/A	N/A
7	Family Planning	Women and Girls	51.48	N/A	N/A
8	Solar Farms	Electricity Generation	36.90	$-80.60	$5,023.84
9	Silvopasture	Food	31.19	$41.59	$699.37
10	Rooftop Solar	Electricity Generation	24.60	$453.14	$3,457.63

Topics:

- Greenhouse Gases
- Temperature Record
- Climate Models
- What Could Happen?
- What Can We Do?
- **What is MSU Doing?**

MSU Energy Infrastructure

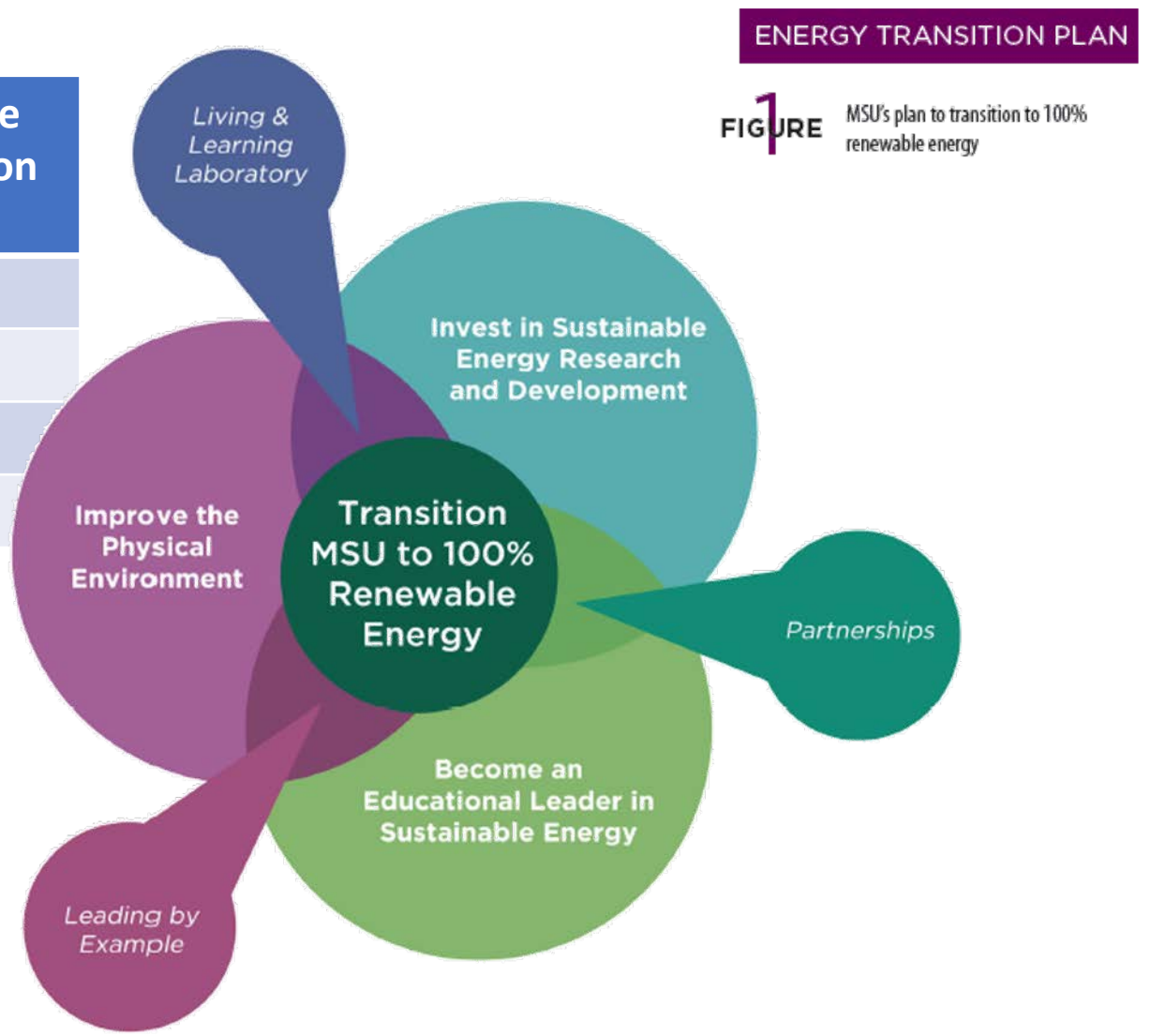
- MSU operates own micro-grid
  - Since 1894 (!)
  - Co-gen heat and electricity: T.B. Simon Plant
  - Significant cost savings vs. buying electricity
  - Historic record of reliability

- MSU consumes as much energy as 50,000 Michigan households, ~ 6 peta-Joule (6×10^{15} Joule) per year
- Carbon emissions need to be reduced
  - Man-made global warming is real
  - Fossil fuel burning has adverse health effects
- Funds are tight, and energy expenses need to be reduced

MSU Energy Transition Plan

- Timetable

Year	Campus Renewable Energy	Greenhouse Gas Emission Reduction
2015	15%	30%
2020	20%	45%
2025	25%	55%
2030	40%	65%



- Approved by MSU Board of Trustees, April 2012


March 24, 2016:
Last Coal at MSU

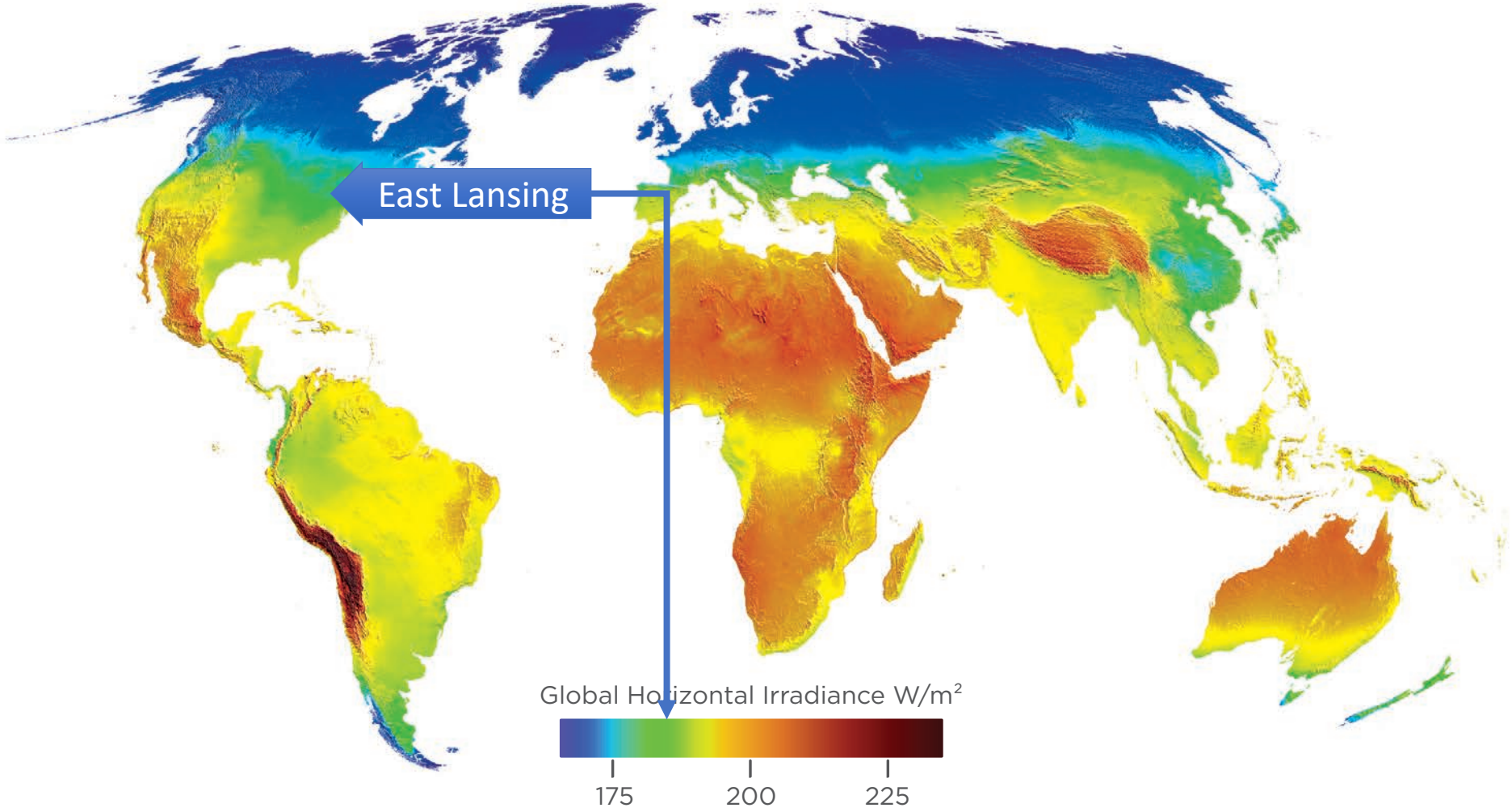
Sustainability / Renewables @ MSU

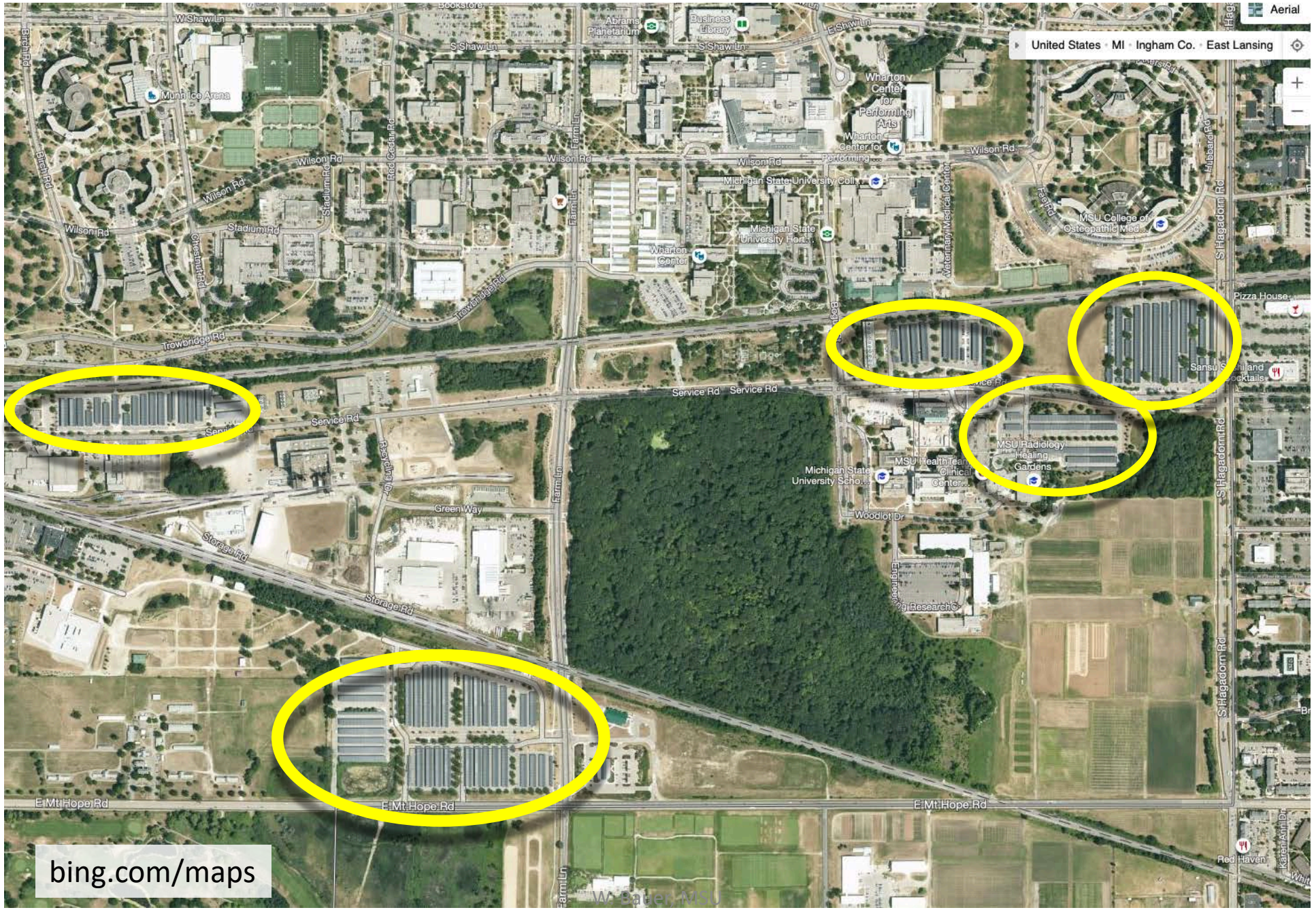
- Recycling center /surplus store
- Organic waste composting facility
- Geo-thermal array
  - Nursing building
- Anaerobic digester
  - Processing of food waste, reduction of artificial fertilizer use, electricity production
- Solar arrays
- Demand reduction
  - M$5-10/year energy conservation measures
  - Better building challenge
  - Data center challenge
  - Spartan treasure hunts

Usable Solar Radiation

VAISALA

Direct + Ambient



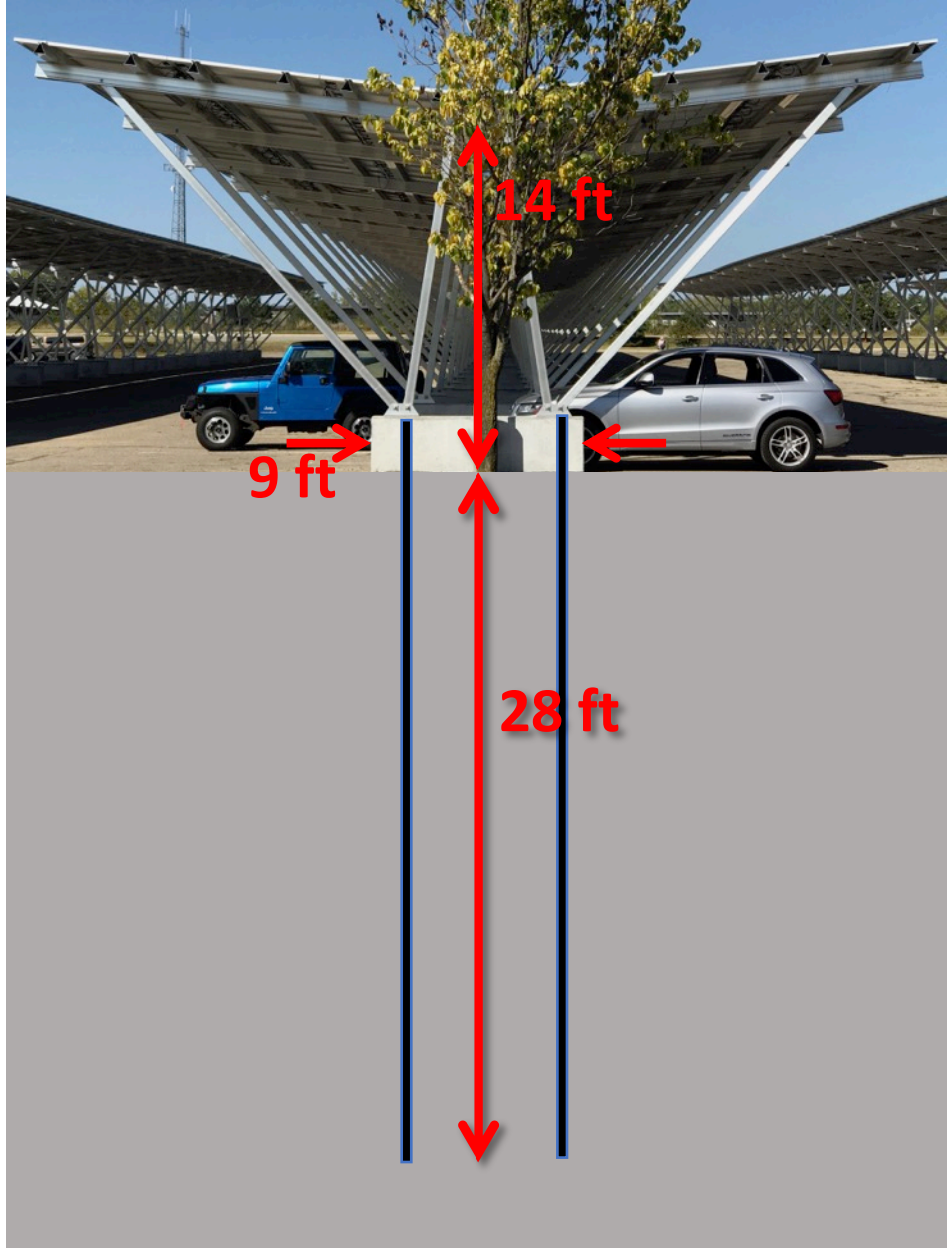

Aerial
United States · MI · Ingham Co. · East Lansing
W Shaw Ln
S Shaw Ln
E Shaw Ln
Munn Ice Arena
Abrams Planetarium
Business Library
Wharton Center for Performing Arts
Wilson Rd
Stadium Rd
Chestnut Rd
Birch Rd
Red Cedar Rd
Farm Ln
Trowbridge Rd
Michigan State University Coll...
Michigan State University Hort...
Wharton Center
Veterinary Medical Center
Pear Rd
MSU College of Osteopathic Med...
S Hagadorn Rd
Hubbard Rd
Pizza House
Service Rd
Green Way
Storage Rd
Woodlot Dr
MSU Radiology Healing Gardens
Michigan State University Scho...
MSU Health Care Clinical Center
Engineering Research C...
E Mt Hope Rd
Red Haven
Karen Ann Dr
bing.com/maps

Solar Panel

- 72 cells on each panel
  - Size: 6”x6”
  - Monocrystalline silicon
- Panel Size: 3’x6’
- Maximum power output: 335 W
- Power degradation < 0.7%/year
  - Year 25: no less than 80% of initial power

Dimensions

- 5,000 parking spots
- 45 acres
- 40,000 solar panels
- 13.4 MW dc peak power
- 10.5 MW ac peak power
- 15,000 MWh/year of solar energy
  - Enough electricity for 1,800 US households



Finished Product (2017)

18% of MSU peak power demand, 5% of MSU total annual energy

Finished Product (2017)

Largest solar carport array in the USA

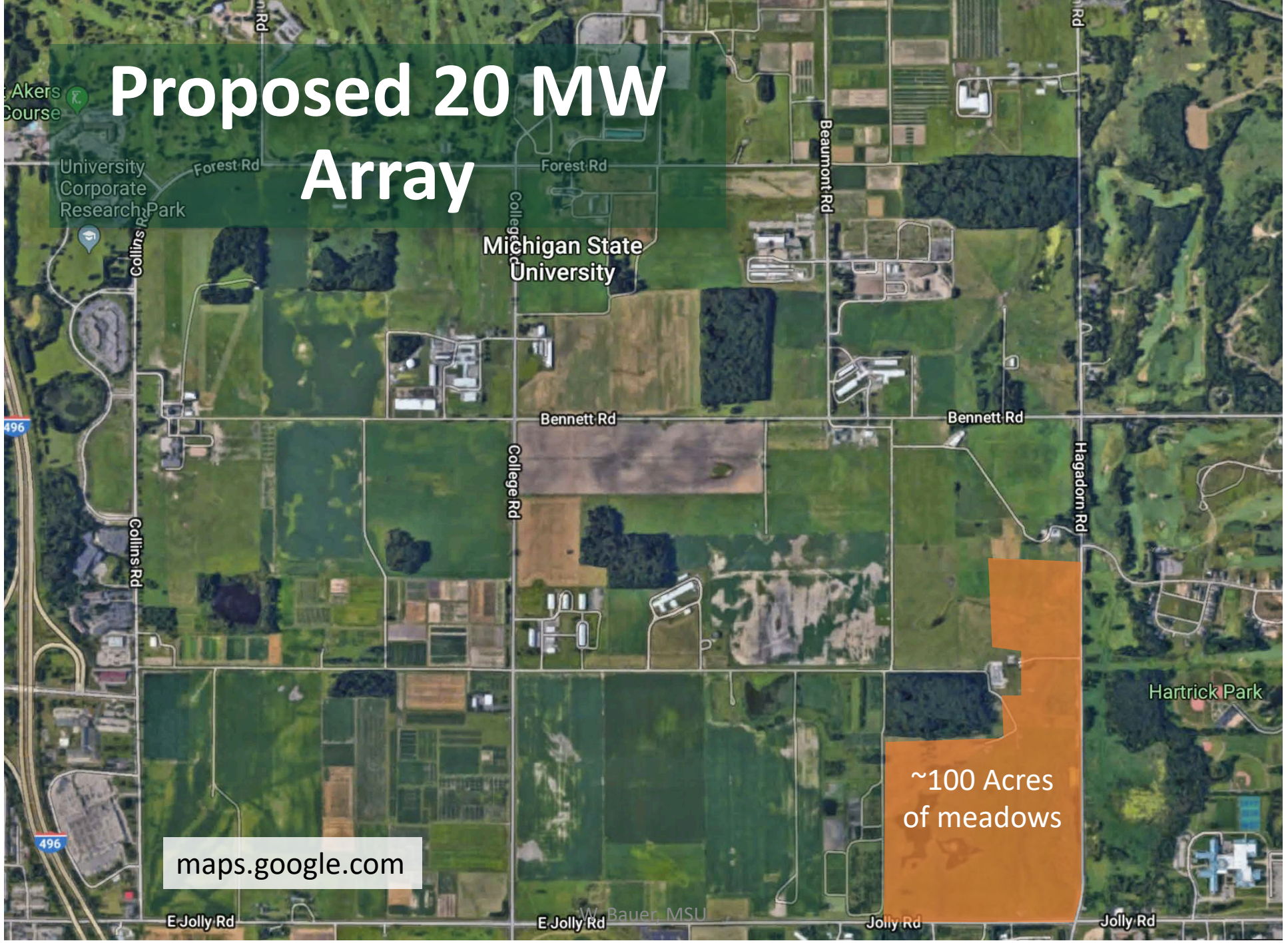
Recognition (March 2018)

2018 Smart Energy Decisions
Onsite Renewable Energy Award

Recognition (October 2018)

2018 US Environmental Protection Agency
Green Power Leadership Award
Direct Project Engagement

Recognition (November 2018)


Proposed 20 MW Array
University Corporate Research Park
Forest Rd
Michigan State University
Beaumont Rd
Bennett Rd
College Rd
Collins Rd
Hagadorn Rd
Hartrick Park
~100 Acres of meadows
maps.google.com
E Jolly Rd
Jolly Rd
496

Dual Use

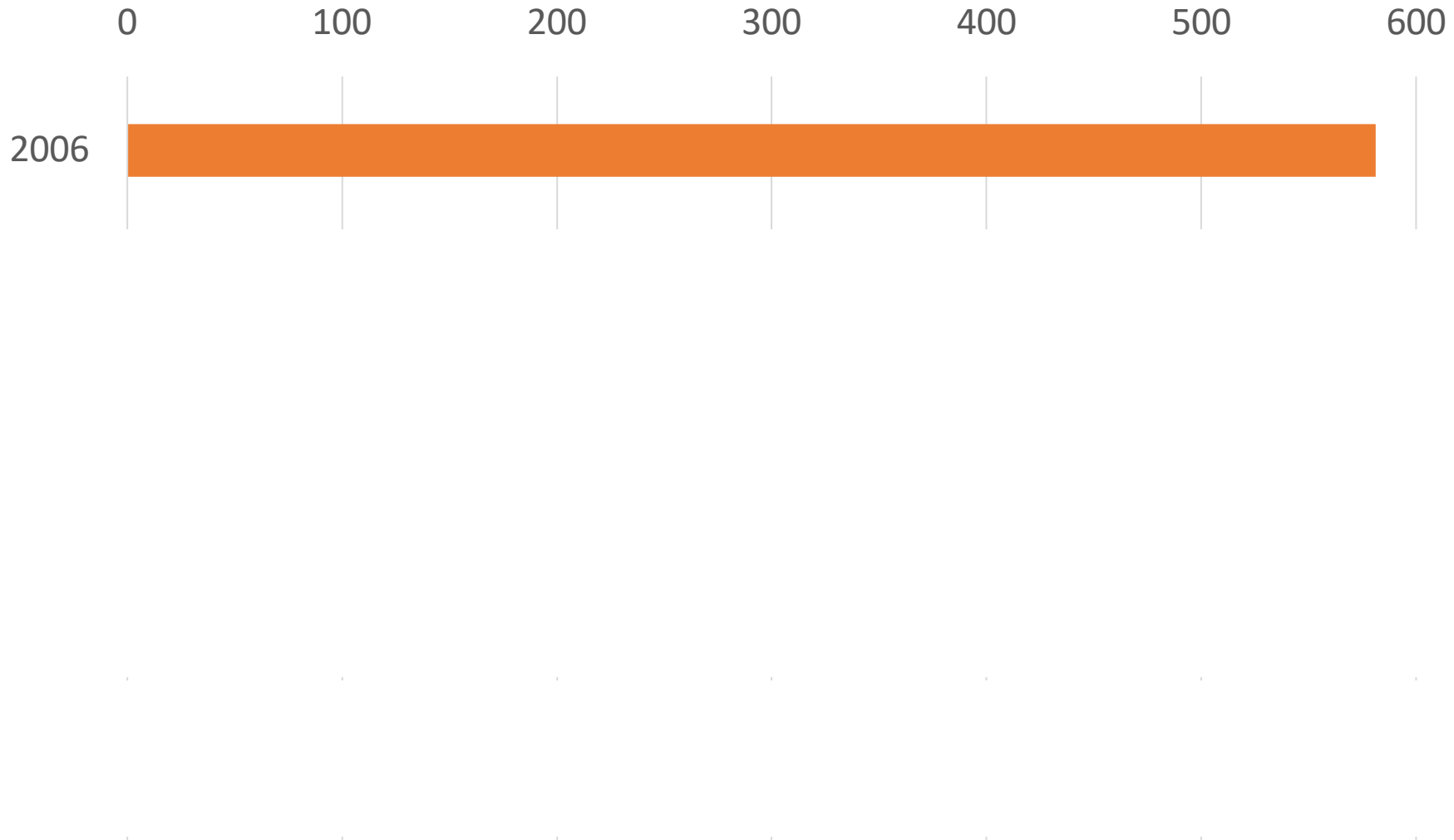
https://www.princeton.edu/news/2018/06/28/sheep-shear-maintenance-princetons-solar-field

Sheep Grazing Meadow

https://denison.edu/news-events/featured/131013

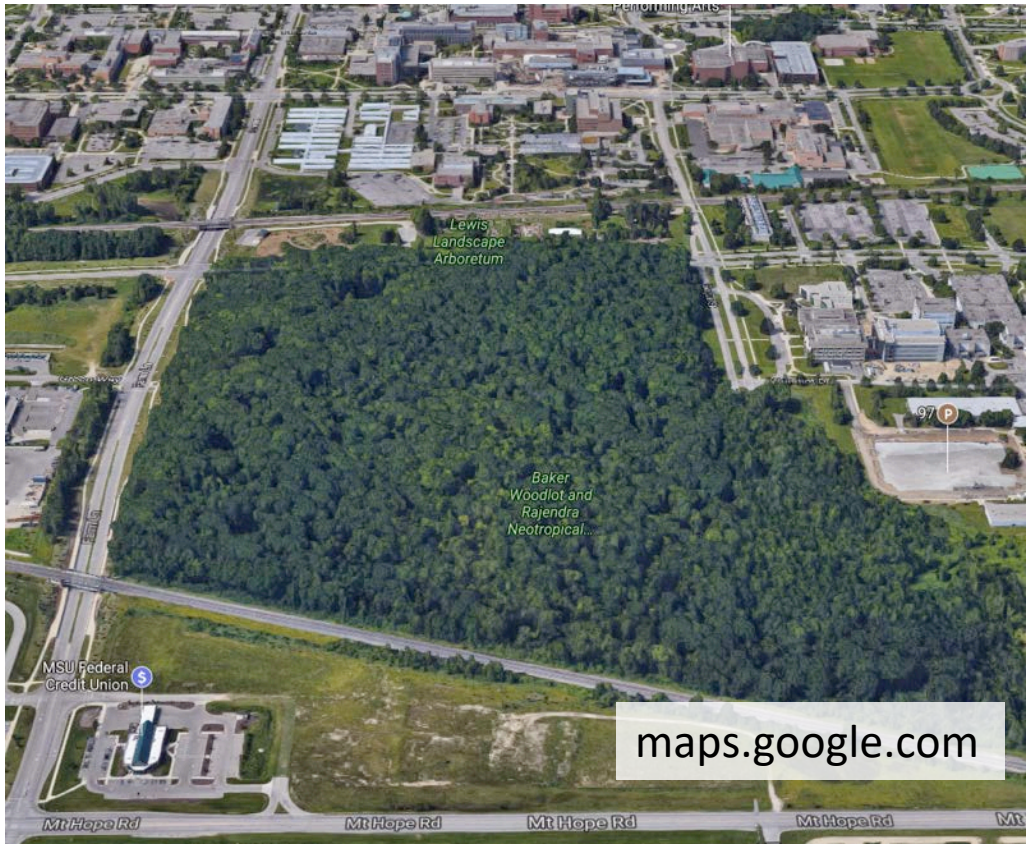
Wildflower/Pollinator Habitat

MSU Emissions: kiloTons of Carbon Dioxide / year



How many trees?

- 700 trees/acre
- 1000 pounds of CO_2 sequestered during life of a tree
- Total CO_2 emission reduction equivalent to planting 14 Baker Woodlots of trees (> 800,000 trees) *each year*.



Baker Woodlot, MSU:
78 acres (~ 320,000 m^2)
~55,000 trees

- *Contact Info*

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