

References

Below is a list of references to the second edition of *The Thinking Person's Guide to Climate Change*. The list is structured by chapter, subchapter, and opening words of the relevant sentence. The book's Selected Bibliography, which is included in the print and online editions, is primarily drawn from the list below and is arranged alphabetically by chapter.

The most comprehensive summaries of research into climate change can be found in the assessments published by the Intergovernmental Panel on Climate Change (IPCC). Most of the chapters in this book draw on the IPCC's Fifth Assessment Report (AR5), prepared by three working groups (WGI, WGII, and WGIII):

IPCC AR5 WGI

IPCC, 2013: *Climate Change 2013: The Physical Science Basis*. T. F. Stocker et al., Eds., Cambridge University Press, 1535 pp., <https://doi.org/10.1017/CB09781107415324>.

IPCC AR5 WGII Part 1

IPCC, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. C. B. Field et al., Eds., Cambridge University Press, 1132 pp., <https://doi.org/10.1017/CB09781107415379>.

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For U.S. climate change, the most comprehensive analyses are the series of national assessments issued by the U.S. Global Change Research Program. Several chapters in this book draw on the most recent assessment as of this writing:

Fourth NCA, Vol. 1

USGCRP, 2017: *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. D. J. Wuebbles et al., Eds., U.S. Global Change Research Program, 470 pp., <https://doi.org/10.7930/J0J964J6>.

Fourth NCA, Vol. 2

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. D.R. Reidmiller et al., Eds., U.S. Global Change Research Program, 1515 pp., <https://doi.org/10.7930/NCA4.2018>.

For attribution studies of extreme events, including heat waves and heavy precipitation, see these resources:

The American Meteorological Society's "Explaining Extreme Events from a Climate Perspective" reports (each year's report going back to 2011 is linked from main page): <https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/explaining-extreme-events-from-a-climate-perspective>.

The international, multi-institutional World Weather Attribution program: <https://www.worldweatherattribution.org>.

CHAPTER 1

Climate Change: A Primer

The big picture

Is the planet really warming up?

These analyses all point...

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Samenow, J., 2018: Debunking the claim 'they' changed 'global warming' to 'climate change' because warming stopped. *Washington Post* (29 January), accessed 10 September 2018, <https://www.washingtonpost.com/news/capital-weather-gang/wp/2018/01/29/debunking-the-claim-they-changed-global-warming-to-climate-change-because-its-cooling>.

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...the eruption of a single major volcano...

Scott, M., and R. Lindsey, 2016: Which emits more carbon dioxide: volcanoes or human activities? Climate.gov, NOAA, accessed 20 September 2018, <https://www.climate.gov/news-features/climate-qa/which-emits-more-carbon-dioxide-volcanoes-or-human-activities>.

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IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 17,
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How do rainforests fit into the picture?

Though deforestation has eased significantly over the last few years...
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Are hurricanes getting worse because of global warming?

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Skeptical Science, 2016: ENSO Temperature Trends, accessed 20 September 2018, <https://www.skepticalscience.com/graphics.php?g=67>.

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Nutticelli, D., 2018: ENSO Temps 2017, accessed 20 September 2018, <https://www.youtube.com/watch?v=GorWMLSPC6I>.

The outlook

How hot will it get?

According to the 2013 IPCC Working Group I report...

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Pathways to our future climate

With this in mind, a new set of tools...

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How many people might be hurt or killed?

The World Health Organization estimated that in the year 2000...

WHO, 2003: Climate Change and Human Health – Risks and Responses: Summary. World Health Organization, 36 pp., <http://www.who.int/globalchange/environment/en/ccSCREEN.pdf>.

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Costello, A., and Coauthors, 2009: Managing the health effects of climate change. *Lancet*, **373**, 1693–1733, [https://doi.org/10.1016/S0140-6736\(09\)60935-1](https://doi.org/10.1016/S0140-6736(09)60935-1).

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Thomas, C., and Coauthors, 2004: Extinction risk from climate change. *Nature*, **427**, 145–148, <https://doi.org/10.1038/nature02121>.

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[Will rising seas really put cities such as New York and London under water?](#)

Depending on how much greenhouse gas is emitted this century...

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[Will the Gulf Stream stop, freezing the United Kingdom and northern Europe?](#)

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Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1033, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf.

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Another approach is to set a stabilization level...

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What can we do about it?

What would it take to stop climate change?

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CHAPTER 2

The Greenhouse Effect

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Carbon dioxide (CO₂), the chief offender...

Global Greenhouse Gas Monitoring Network, 2018: Trends in Atmospheric Carbon Dioxide. NOAA Earth System Research Laboratory/Global Monitoring Division, accessed 20 September 2018, <https://www.esrl.noaa.gov/gmd/ccgg/trends>.

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Greenhouse pioneers

In the mid-1890s, the Swedish chemist...

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Schlesinger, M. E., 1986: Equilibrium and transient climatic warming induced by increased atmospheric CO₂. *Climate Dynamics*, **1**, 35–51, <https://doi.org/10.1007/BF01277045>.

Guy Stewart Callendar, a British engineer...

Fleming, J. R., 2009: *The Callendar Effect: The Life and Work of Guy Stewart Callendar*. American Meteorological Society, 176 pp.

The tale told by a curve

If there's one set of data...

Scripps CO₂ Program, 2018: The early Keeling curve, accessed 20 September 2018, http://scrippsco2.ucsd.edu/history_legacy/early_keeling_curve.

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Manabe, S., and R. T. Wetherald, 1967: Thermal equilibrium of the atmosphere with a given distribution of relative humidity. *Journal of the Atmospheric Sciences*, **24**, 241–259, [https://doi.org/10.1175/1520-0469\(1967\)024<0241:TEOTAW>2.0.CO;2](https://doi.org/10.1175/1520-0469(1967)024<0241:TEOTAW>2.0.CO;2).

CHAPTER 3

Who's Responsible?

How much greenhouse gas is in the air right now?

The global atmosphere currently carries...

U.S. Carbon Dioxide Information Analysis Center: <http://cdiac.ess-dive.lbl.gov>. In 2018, the archive was in the process of being transferred to the U.S. Department of Energy's (DOE) Environmental System Science Data Infrastructure for a Virtual Ecosystem (ESS-DIVE) archive: <http://ess-dive.lbl.gov>.

As of 2016, according to the Netherlands Environmental Assessment Agency...

PBL Netherlands Environmental Assessment Agency, 2017: Trends in global CO₂ emissions. Updated annually, accessed 21 September 2018, <http://www.pbl.nl/en/trends-in-global-co2-emissions>.

Comparing greenhouse gases

Because greenhouse gases vary so widely...

Greenhouse Gas Protocol, 2018: Global warming potential values. 4 pp., accessed 21 September 2018, <https://ghgprotocol.org/calculation-tools>.

Will Earth's land-based carbon sink get stopped up?

Many parts of eastern North America...

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Schimel, D., B. B. Stephens, and J. B. Fisher, 2015: Effect of increasing CO₂ on the terrestrial carbon cycle. *PNAS*, **112**, 436–441, <https://doi.org/10.1073/pnas.1407302112>.

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Walsh, B., P. Ciais, I. A. Janssens, J. Peñuelas, K. Riahi, F. Rydzak, D. P. van Vuuren, and M. Obersteiner, 2017: Pathways for balancing CO₂ emissions and sinks. *Nature Communications*, **8**, 14856, <https://doi.org/10.1038/ncomms14856>.

What happens to the greenhouse gas we put into the air?

Over the last few years, the balance has played out ...

Global Carbon Project, 2018: Global Carbon Budget 2017. Updated annually, accessed 27 September 2018, <http://www.globalcarbonproject.org/carbonbudget>.

The chart opposite shows two different ways...

Ecofys, 2016: World GHG Emissions Flow Chart. Published 3 May 2016, https://www.ecofys.com/files/files/world-ghg-emission-flow-chart-2012_v9-c-asn-ecofys-2016_02.pdf

Aviation: Taking emissions to new heights

After years of international wrangling...

International Civil Aviation Organization, 2018: What is CORSIA and how does it work? Accessed 9 September 2018, https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ2.aspx.

Even though “green landings” ...

Chen, H., and S. Solak, 2014: Lower cost arrivals for airlines: optimal policies for managing runway operations under optimized profile descent. *Production and Operations Management*, **24**, 402–420, <https://doi.org/10.1111/poms.12244>.

Carbon intensity: An easy way out?

This is a measure of how much fossil fuel...

Pretis, F., and M. Roser, 2017: Carbon dioxide emission-intensity in climate projections: Comparing the observational record to socio-economic scenarios. *Energy*, **135**, 718–725, <https://doi.org/10.1016/j.energy.2017.06.119>.

Outsourcing emissions

A 2010 study by Steven Davis and Ken Caldeira...

Davis, S. J., and K. Caldeira, 2010: Consumption-based accounting of CO₂ emissions. *Proceedings of the National Academy of Sciences U.S.A.*, **107**, 5687–5692, <https://doi.org/10.1073/pnas.0906974107>.

A 2013 study led by Kuishuang Feng...

Feng, K., S. J. Davis, L. Sun, X. Li, D. Guan, W. Liu, Z. Liu, and K. Hubacek, 2013: Outsourcing CO₂ within China. *Proceedings of the National Academy of Sciences of the United States*, **110**, <https://doi.org/10.1073/pnas.1219918110>.

Which countries are most responsible?

Above is a list of the world's top 20...

Carbon Dioxide Information Analysis Center, 2014: Global, regional, and national fossil-fuel CO₂ emissions (top 20), accessed 9 September 2018, <http://cdiac.ess-dive.lbl.gov/trends/emis/top2014.tot>.

CHAPTER 4

Extreme Heat

As of 2018, many central U.S. states...

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In 2016 alone, 22 nations...

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In the contiguous United States, the summer of 2018...

NOAA National Centers for Environmental Information, 2018: National Climate Report - August 2018. <https://www.ncdc.noaa.gov/sotc/national/201808>

Off the charts

In the contiguous United States, daily record highs...

Meehl, G. A., C. Tebaldi, and D. Adams-Smith, 2016: US daily temperature records past, present, and future. *Proceedings of the National Academy of Sciences U.S.A.*, **113**, 13977–13982, <https://doi.org/10.1073/pnas.1606117113>.

Looking ahead on the global scale...

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For the contiguous United States, the last 50 years...

Walton, G., personal communication, 4 January 2018.

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Alexander, L., and S. Perkins, 2013: Debate heating up over changes in climate variability. *Environmental Research Letters*, **8**, 041001, <https://doi.org/10.1088/1748-9326/8/4/041001>.

Pollution: Heat’s hidden partner in crime

The World Health Organization estimates...

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CHAPTER 5

Floods and Droughts

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CHAPTER 6

The Big Melt

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CHAPTER 7

Oceans

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Climate change and El Niño

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High-tide flooding: More than a nuisance

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The NAM, the NAO, and other climate cycles

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Zheng, F., J. Li, R. T. Clark, and H. C. Nnamchi, 2013: Simulation and projection of the Southern Hemisphere annular mode in CMIP5 Models. *Journal of Climate*, **26**, 9860–9879, <https://journals.ametsoc.org/doi/full/10.1175/JCLI-D-13-00204.1>.

Most climate models have projected a tendency...

Kirtman, B., S.B. Power, J.A. Adedoyin, G.J. Boer, R. Bojariu, I. Camilloni, F.J. Doblas-Reyes, A.M. Fiore, M. Kimoto, G.A. Meehl, M. Prather, A. Sarr, C. Schär, R. Sutton, G.J. van Oldenborgh, G. Vecchi and H.J. Wang, 2013: Near-term Climate Change: Projections and Predictability. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, <https://www.ipcc.ch/report/ar5/wg1>.

During the winter of 2009–2010...

Osborn, T. J., 2010: Winter 2009/2010 temperatures and a record-breaking North Atlantic

Oscillation index. *Weather*, **66**, 19–21, <https://doi.org/10.1002/wea.660>.

But many scientists are intrigued by...

Di Liberto, T., 2016: Going out for ice cream: a first date with the Pacific decadal oscillation. Climate.gov (25 August 2016), accessed 11 February 2019, <https://www.climate.gov/news-features/blogs/enso/going-out-ice-cream-first-date-pacific-decadal-oscillation>

A positive mode of the IOD...

Ashok, K., Z. Guan, and T. Yamagata, 2001: Impact of the Indian Ocean dipole on the relationship between the Indian monsoon rainfall and ENSO. *GRL*, **28**, 4499–4502, <https://doi.org/10.1029/2001GL013294>

... and in Australia, a strongly negative IOD...

Giles, B. D., 2012: The Australian Summer 2010/2011. *Weather*, **67**, 9–12, <https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/wea.860>.

Some research suggests that a chain of atmospheric events...

Smith, K. L., P. J. Kushner, and J. Cohen, 2011: The role of linear interference in northern annular mode variability associated with Eurasian snow cover extent. *Journal of Climate*, **24**, 6185–6202, <https://doi.org/10.1175/JCLI-D-11-00055.1>.

Other scientists have found apparent links...

Francis, J., and N. Skific, 2015: Evidence linking rapid Arctic warming to mid-latitude weather patterns. *Philosophical Transactions of the Royal Society A*, **373**, <https://doi.org/10.1098/rsta.2014.0170>.

Will the Atlantic turn cold on Britain?

We're now in the midst of a century-plus AMOC slowdown...

Thornalley, D. J. R., and Coauthors, 2018: Anomalously weak Labrador Sea convection and Atlantic overturning during the past 150 years. *Nature*, **556**, 227–230, <https://doi.org/10.1038/s41586-018-0007-4>.

Likewise, in a 2018 analysis published in *Nature*...

Caesar, L., S. Rahmstorf, A. Robinson, G. Feulner, and V. Saba, 2018: Observed fingerprint of a weakening Atlantic Ocean overturning circulation. *Nature*, **556**, 191–196, <https://doi.org/10.1038/s41586-018-0006-5>.

In response to this concern...

NERC, 2019: RAPID-AMOC: Monitoring the Atlantic meridional overturning circulation. U.K. Natural Environment Research Council, accessed 11 February 2019, <https://www.rapid.ac.uk/background.php>.

Nearly all of the modeling generated for the 2013 IPCC assessment...

Kirtman, B., S.B. Power, J.A. Adedoyin, G.J. Boer, R. Bojariu, I. Camilloni, F.J. Doblas-Reyes, A.M. Fiore, M. Kimoto, G.A. Meehl, M. Prather, A. Sarr, C. Schär, R. Sutton, G.J. van Oldenborgh, G. Vecchi and H.J. Wang, 2013: Near-term Climate Change: Projections and Predictability. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, <https://www.ipcc.ch/report/ar5/wg1>.

Living in a changing sea

Looming over this entire scene is the gargantuan threat...

Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas, 2009: Ocean acidification: The other CO₂ problem. *Annual Review of Marine Science*, **1**, 169–192, <https://doi.org/10.1146/annurev.marine.010908.163834>.

A 2006 study using NASA satellite data...

Doney, S. C., 2006: Plankton in a warmer world. *Nature*, **444**, 695–696, <https://doi.org/10.1038/444695a>.

This topic broke wide open in 2010...

Boyce, D. G., M. R. Lewis, and B. Worm, 2010: Global phytoplankton decline over the past century. *Nature*, **466**, 591–596, <https://doi.org/10.1038/nature09268>.

... and several critics have argued that Boyce's blending...

McQuatters-Gollop, A., and Coauthors, 2011: Is there a decline in marine phytoplankton? *Nature*, **472**, E6–E7, <https://doi.org/10.1038/nature09950>.

One of the world's largest and oldest phytoplankton surveys...

Raitsos, D. E., A. Walne, S. L. Lavender, P. Licandro, P. C. Reid, and M. Edwards, 2012: A 60-year ocean colour data set from the continuous plankton recorder. *Journal of Plankton Research*, **5**, 158–164, <https://doi.org/10.1093/plankt/fbs079>.

Rousseaux, C. S, and W. W. Gregg, 2015: Recent decadal trends in global phytoplankton composition. *Global Biogeochemical Cycles*, **29**, 1674–1688, <https://doi.org/10.1002/2015GB005139>.

A 2010 report by the U.S. National Research Council...

National Research Council, 2010: Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. Washington, DC: The National Academies Press, <https://doi.org/10.17226/12904>.

Coral reefs at risk

More than half of a global sample of reefs...

Hughes, T. P., and Coauthors, 2018: Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science*, **359**, 80–83, <https://doi.org/10.1126/science.aan8048>.

One study by Drew Harvell of Cornell University...

Harvell, D., E. Jordán-Dahlgren, S. Merkel, E. Rosenberg, Laurie Raymundo, Garriet Smith, Ernesto Weil, and Bette Willis, 2007: Coral disease, environmental drivers, and the balance between coral and microbial associates. *Oceanography*, **20**, 172–195, <https://doi.org/10.5670/oceanog.2007.91>.

CHAPTER 8

Hurricanes and Other Storms

This shift remains difficult to nail down...

L., A. M. G. Klein Tank, M. Rusticucci, L. V. Alexander, S. Brönnimann, Y. Charabi, F. J. Dentener, E. J. Dlugokencky, D. R. Easterling, A. Kaplan, B. J. Soden, P. W. Thorne, M. Wild and P. M. Zhai, 2013: Observations: Atmosphere and Surface. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., p. 216, <https://www.ipcc.ch/report/ar5/wg1>.

A hurricane rolls down towards Rio

All the attention has fed a growing awareness...

Evans, J. L., and A. Braun, 2012: A Climatology of Subtropical Cyclones in the South Atlantic. *Journal of Climate*, **25**, 7328–7340, <https://doi.org/10.1175/JCLI-D-11-00212.1>.

Heat content in the topmost 160 m...

Trenberth, K. E., L. Cheng, P. Jacobs, Y. Zhang, and J. Fasullo, 2018: Hurricane Harvey links to ocean heat content and climate change adaptation. *Earth's Future*, **6**, 730–744, <https://doi.org/10.1029/2018EF000825>.

Katrina, Sandy, and climate change

One analysis led by NASA's Timothy Hall...

Hall, T. M., and A. H. Sobel, 2013: On the impact angle of Hurricane Sandy's New Jersey landfall. *GRL*, **40**, 2312–2315, <https://doi.org/10.1002/grl.50395>.

In a paper published only a few months...

Francis, J. A., and S. J. Vavrus, 2012: Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters*, **39**, L06801, <https://doi.org/10.1029/2012GL051000>.

Keeping count: Will there be more cyclones in the future?

An early sign of progress came in 2006...

Oouchi, K., J. Yoshimura, H. Yoshimura, R. Mizuta, S. Kusunoki, and A. Noda, 2006: Tropical cyclone climatology in a global-warming climate as simulated in a 20 km-mesh global atmospheric model: Frequency and wind intensity analyses. *Journal of the Meteorological Society of Japan, Ser. II*, **84**, 259–276, <https://doi.org/10.2151/jmsj.84.259>.

The results from these varied approaches...

Knutson, T. R., and Coauthors, 2010: Tropical cyclones and climate change. *Nature Geoscience*, **3**, 157–163, <https://doi.org/10.1038/ngeo779>.

Some work with high-resolution modeling...

Emanuel, K. A., 2013: Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. *Proceedings of the National Academy of Sciences U.S.A.*, **110**, 12,219–12,224, <https://doi.org/10.1073/pnas.1301293110>.

By examining 18 model simulations...

Vecchi, G. A., and B. J. Soden, 2007: Effect of remote sea surface temperature change on

tropical cyclone potential intensity. *Nature*, **450**, 1066–1070, <https://doi.org/10.1038/nature06423>.

Triple whammy: Harvey, Irma, and Maria

A 2018 *Nature* paper by James Kossin...

Kossin, J. P., 2018: A global slowdown of tropical-cyclone translation speed. *Nature*, 558, 104–107, <https://doi.org/10.1038/s41586-018-0158-3>.

A 2017 analysis in *Earth's Future*...

Trenberth, K. E., L. Cheng, P. Jacobs, Y. Zhang, and J. Fasullo, 2018: Hurricane Harvey links to ocean heat content and climate change adaptation. *Earth's Future*, **6**, 730–744, <https://doi.org/10.1029/2018EF000825>.

Another study, led by Michael Mann*...

*Note: The study was actually led by Kerry Emanuel (Massachusetts Institute of Technology). Emanuel, K., 2017: Assessing the present and future probability of Hurricane Harvey's rainfall. *Proceedings of the National Academy of Sciences U.S.A.*, **114**, 12,681–12,684, <https://doi.org/10.1073/pnas.1716222114>.

... multiple studies and anecdotal reports suggested...

Kishore, N., and Coauthors, 2018: Mortality in Puerto Rico after Hurricane Maria. *New England Journal of Medicine*, **379**, 162–170, <https://doi.org/10.1056/NEJMsa1803972>.

A revised official death toll came from a study...

The George Washington University, 2018: Ascertainment of the estimated excess mortality from Hurricane Maria in Puerto Rico. Project Report, 69 pp., <https://prstudy.publichealth.gwu.edu>.

Packing more power

MIT's Kerry Emanuel examined tropical cyclones...

Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, **436**, 686–688, <https://doi.org/10.1038/nature03906>.

A team led by Peter Webster...

Webster, P. J., G. J. Holland, J. A. Curry, and H.-R. Chang, 2005: Changes in tropical cyclone

number, duration, and intensity in a warming environment. *Science*, **309**, 1844–1846, <https://doi.org/10.1126/science.1116448>.

In his 2007 book *Storm World...*

Mooney, C., 2007: *Storm World: Hurricanes, Politics, and the Battle over Global Warming*. Harcourt Trade, 392 pp.

Even by restricting one's view...

Elsner, J. B., J. P. Kossin, and T. H. Jagger, 2008: The increasing intensity of the strongest tropical cyclones. *Nature*, **455**, 92–95, <https://doi.org/10.1038/nature07234>.

For example, a 2006 study by Kevin Trenberth...

Trenberth, K. E., and D. J. Shea, 2006: Atlantic hurricanes and natural variability in 2005. *GRL*, **33**, L12704, <https://doi.org/10.1029/2006GL026894>.

The IPCC's special 2012 report on climate extremes noted...

Seneviratne, S. I., N. Nicholls, D. Easterling, C. M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, p. 162, <https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation>.

One analysis found no significant change...

Knaff, J. A., 2014: An Objective Satellite-Based Tropical Cyclone Size Climatology. *Journal of Climate*, **27**, 455–476, <https://doi.org/10.1175/JCLI-D-13-00096.1>.

Surges and downpours

In a 2018 *Journal of Climate* study...

Gutmann, E. D., R. M. Rasmussen, C. Liu, and K. Ikeda, 2018: Changes in hurricanes from a 13-yr convection-permitting pseudo-global warming simulation. *Journal of Climate*, **31**, 3643–3657, <https://doi.org/10.1175/JCLI-D-17-0391.1>.

In 2006, hurricane researchers from across the spectrum...

Emanuel, K., R. Anthes, J. Curry, J. Elsner, G. Holland, P. Klotzbach, T. Knutson, C. Landsea,

and M. Mayfield, “Statement on the U.S. Hurricane Problem” (25 July 2006), accessed 20 January 2019, <https://emanuel.mit.edu/statement-us-hurricane-problem>.

Coastal concerns beyond the tropics

A multimodel review published in 2013...

Chang, E. K. M., 2013: CMIP5 Projection of significant reduction in extratropical cyclone activity over North America. *Journal of Climate*, **26**, 9903–9922, <https://doi.org/10.1175/JCLI-D-13-00209.1>.

A group of scientists that includes Judah Cohen...

Cohen, J., K. Pfeiffer, and J. A. Francis, 2018: Warm Arctic episodes linked with increased frequency of extreme winter weather in the United States. *Nature Communications*, **9**, 869, <https://doi.org/10.1038/s41467-018-02992-9>.

Coastal-storm flooding: A deepening problem

However, the Thames Estuary 2100 plan...

UK Environment Agency, 2017: Policy Paper, Thames Estuary 2100 (TE2100), <https://www.gov.uk/government/publications/thames-estuary-2100-te2100/thames-estuary-2100-te2100>

Tornadoes: An overblown connection?

That number ballooned with the advent...

Groenemeijer, P., and T. Kühne, 2014: A climatology of tornadoes in Europe: results from the European Severe Weather Database. *Monthly Weather Review*, **142**, 4775–4790, <https://doi.org/10.1175/MWR-D-14-00107.1>.

Both types of storms could qualify...

Trapp, R. J., and K. A. Hoogewind, 2016: The realization of extreme tornadic storm events under future anthropogenic climate change. *Journal of Climate*, **29**, 5251–5265, <https://doi.org/10.1175/JCLI-D-15-0623.1>

Del Genio, A. D., M. Yao, and J. Jonas, 2007: Will moist convection be stronger in a warmer climate? *GRL*, **34**, L16703, <https://doi.org/10.1029/2007GL030525>.

This possibility was reinforced...

Diffenbaugh, N. S., M. Scherer, and R. J. Trapp, 2013: Robust increases in severe thunderstorm environments in response to greenhouse forcing. *Proceedings of the National Academy of Sciences U.S.A.*, **110**, 16,361–16,366, <https://doi.org/10.1073/pnas.1307758110>.

Along with an increase in such year-to-year volatility...

Brooks, H. E., G. W. Carbin, and P. T. Marsh, 2014: Increased variability of tornado occurrence in the United States. *Science*, **346**, 349–352, <https://doi.org/10.1126/science.1257460>.

CHAPTER 9

Ecosystems and Agriculture

This concept was put in stark terms...

Mora, C., and Coauthors, 2013: The projected timing of climate departure from recent variability. *Nature*, **502**, 183–187, <https://doi.org/10.1038/nature12540>.

Along these lines, a 2009 study...

Wright, S. J., H. C. Muller-Landau, and J. Schipper, 2009: The future of tropical species on a warmer planet. *Conservation Biology*, **23**, 1418–1426, <https://doi.org/10.1111/j.1523-1739.2009.01337.x>.

In a 2013 survey of more than 500 birds, mammals, amphibians, and reptiles...

Quintero, I., and J. J. Wiens, 2013: Rates of projected climate change dramatically exceed past rates of climatic niche evolution among vertebrate species. *Ecology Letters*, **16**, 1095–1103, <https://doi.org/10.1111/ele.12144>.

In a 2016 study in *PLOS Biology*,

Wiens, J. J., 2016: Climate-related local extinctions are already widespread among plant and animal species. *PLOS Biology*, **14**, e2001104, <https://doi.org/10.1371/journal.pbio.2001104>.

One landmark study of the extinction risks...

Thomas, C. D., and Coauthors, 2004: Extinction risk from climate change. *Nature*, **427**, 145–148, <https://doi.org/10.1038/nature02121>.

The canaries of climate change

More than 30% of amphibian species were found to be vulnerable...

Global Wildlife Conservation, 2017: The global amphibian assessment, accessed 26 August 2018, <https://www.globalwildlife.org/our-work/regions/global/global-amphibian-assessment>.

The most recent update, in 2008, reiterated that diagnosis...

International Union for Conservation of Nature and Natural Resources, 2008: The IUCN Red List of Threatened Species/Amphibians on the IUNC Red List, accessed 26 August 2018, <http://www.iucnredlist.org/initiatives/amphibians/process>.

A broader look at these relationships...

Rohr, J., and T. Raffel, 2010: Linking global climate and temperature variability to widespread amphibian declines putatively caused by disease. *PNAS*, 107, 8269–8274, <https://www.pnas.org/content/107/18/8269.short>

In 2018, genomic analysis showed...

O’Hanlon, S. J., and Coauthors, 2018: Recent Asian origin of chytrid fungi causing global amphibian declines. *Science*, **360**, 621–627, <https://doi.org/10.1126/science.aar1965>.

A major survey of European butterflies...

Settele, J., and Coauthors, 2008: Climatic Risk Atlas of European butterflies. *BioRisk* 1, 1–712, <https://doi.org/10.3897/biorisk.1>.

At the Netherlands Institute for Ecology...

Schaper, S. V., A. Dawson, P. J. Sharp, P. Gienapp, S. P. Caro, and M. E. Visser, 2011: Increasing temperature, not mean temperature, is a cue for avian timing of reproduction. *The American Naturalist*, **179**, E55–E69, <https://doi.org/10.1086/663675>.

Similarly, in California, a Stanford University team...

McLaughlin, J. F., J. J. Hellmann, C. L. Boggs, and P. R. Ehrlich, 2002: Climate change hastens population extinctions. *PNAS*, **99**, 6070–6074. <https://doi.org/10.1073/pnas.052131199>.

NASA is working to relate the amount of nectar...

Volland, A., “Honey bees turned data collectors help scientists understand climate change,” (25 August 2009), <https://www.nasa.gov/topics/earth/features/beekeepers.html>

Eric Post (Pennsylvania State University) has found...

Post, E., and Coauthors, 2009: Ecological dynamics across the Arctic associated with recent climate change. *Science*, **325**, 1355–1358, <https://doi.org/10.1126/science.1173113>.

In a 2013 paper in *Proceedings of the National Academy of Sciences*...

Mills, L. S., M. Zimova, J. Oyler, S. Running, J. T. Abatzoglou, and P. M. Lukacs, 2013: Camouflage mismatch in seasonal coat color due to decreased snow duration. *PNAS*, **110**, 7360–7365, <https://doi.org/10.1073/pnas.1222724110>.

In an extensive survey published in *Nature* in 2003,

Parmesan, C., and G. Yohe, 2003: A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, **421**, 37–42, <https://doi.org/10.1038/nature01286>.

Further evidence came with an exhaustive global survey...

Rosenzweig, C., and Coauthors, 2008: Attributing physical and biological impacts to anthropogenic climate change. *Nature*, **453**, 353–357, <https://doi.org/10.1038/nature06937>.

In an 2016 meta-study published in *Science*...

Scheffers, B., and Coauthors, 2016: The broad footprint of climate change from genes to biomes to people. *Science*, **354**, aaf7671, <https://doi.org/10.1126/science.aaf7671>.

A 2011 survey in *Nature* led by Jennifer Sheridan...

Sheridan, J. A., and D. Bickford, 2011: Shrinking body size as an ecological response to climate change. *Nature Climate Change*, **1**, 401–406, <https://doi.org/10.1038/nclimate1259>.

Up, up, and away?

On the plus side, a wide-ranging 2018 survey...

Millar, C. I., D. L. Delany, K. A. Hersey, M. R. Jeffress, A. T. Smith, K. J. Van Gunst, and R. D. Westfall, 2018: Distribution, climatic relationships, and status of American pikas (*Ochotona princeps*) in the Great Basin, USA. *Arctic, Antarctic, and Alpine Research*, **50**, e1436296, <https://doi.org/10.1080/15230430.2018.1436296>.

A 2018 *Nature* paper led by Manuel Steinbauer...

Steinbauer, M., and Coauthors, 2018: Accelerated increase in plant species richness on mountain summits is linked to warming. *Nature*, **556**, 231–234, <https://doi.org/10.1038/s41586-018-0005-6>.

The big squeeze

Elsewhere around the planet, ecologists...

Conservation International, 2018: Hotspots, accessed 26 August 2018, <https://www.conservation.org/How/Pages/Hotspots.aspx>.

The tropics themselves—as demarcated by high-level jet streams...

Fu, Q., and P. Lin, 2011: Poleward shift of subtropical jets inferred from satellite-observed lower-stratospheric temperatures. *Journal of Climate*, **24**, 5597–5603, <https://doi.org/10.1175/JCLI-D-11-00027.1>.

Implied in this expansion is a poleward push...

Schmidt, D.F., and K. M. Grise, 2017: The response of local precipitation and sea level pressure to Hadley cell expansion. *GRL*, **44**, 10,573–10,582, <https://doi.org/10.1002/2017GL075380>.

March of the fire ants

One projection shows that if atmospheric carbon dioxide...

Morrison, L. W., M. D. Korzukhin, and S. D. Porter, 2005: Predicted range expansion of the invasive fire ant, *Solenopsis invicta*, in the eastern United States based on the VEMAP global warming scenario. *Diversity and Distributions*, **11**, 199–204, <https://doi.org/10.1111/j.1366-9516.2005.00142.x>.

Bugged by a changing climate

In fact, the first comprehensive analysis of parasites...

Carlson, C., and Coauthors, 2017: Parasite biodiversity faces extinction and redistribution in a changing climate. *Science Advances*, **3**, e1602422, <https://doi.org/10.1126/sciadv.1602422>.

Happily, protective measures such as insecticidal bed nets...

World Health Organization, 2018: Global Health Observatory (GHO) data, accessed 26 August 2018, <http://www.who.int/gho/en>.

A 2013 modeling study headed by Volker Ermert...

Ermert, V., A. H. Fink, and H. Paeth, 2013: The potential effects of climate change on malaria transmission in Africa using bias-corrected regionalised climate projections and a simple

malaria seasonality model. *Climatic Change*, **120**, 741–754,
<https://doi.org/10.1007/s10584-013-0851-z>.

Unlike malaria, dengue fever is on the upswing...

Ebi, K. L., and J. Nealon, 2016: Dengue in a changing climate. *Environmental Research*, **151**, 115–123, <https://doi.org/10.1016/j.envres.2016.07.026>.

One study estimates that a 1°C (1.8°F) rise...

Patz, J. A., W. J. M. Martens, D. A. Focks, and T. H. Jetten, 1998: Dengue fever epidemic potential as projected by general circulation models of global climate change. *Environmental Health Perspectives*, **106**, 147–153, <https://doi.org/10.1289/ehp.98106147>.

A separate study found that increased economic development...

Åström, C., J., Rocklöv, S. Hales, A. Béguin, V. Louis, and R. Sauerborn, 2012: Potential distribution of dengue fever under scenarios of climate change and economic development. *Ecohealth*, **9**, 448–454, <https://doi.org/10.1007/s10393-012-0808-0>.

Researchers have been investigating whether climate change...

Lozano-Fuentes, S., and Coauthors, 2012: The dengue virus mosquito vector *Aedes aegypti* at high elevation in México. *American Journal of Tropical Medicine and Hygiene*, **87**, 902–909, <https://doi.org/10.4269/ajtmh.2012.12-0244>.

Shrinking forests

Russian scientists Anastassia Makarieva and Victor Gorshkov theorize...

Makarieva, A. and V. Gorshkov, 2007: Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. *Hydrology and Earth System Sciences*, **11**, 1013–1033, <https://doi.org/10.5194/hess-11-1013-2007>.

It has invaded whitebark pine in Utah...

van de Gevel, S. L., E. R. Larson, and H. D. Grissino-Mayer, 2017: Separating trends in whitebark pine radial growth related to climate and mountain pine beetle outbreaks in the northern Rocky Mountains, USA. *Forests*, **8**, 195, <https://doi.org/10.3390/f8060195>.

As the coldest nights of each winter gradually warm up...

Lesk, C., E. Coffel, A. W. D'Amato, K. Dodds, and R. Horton, 2017: Threats to North American forests from southern pine beetle with warming winters. *Nature Climate Change*, **7**, 713–717, <https://doi.org/10.1038/nclimate3375>.

A drought in the 1950s had already taken...

Breshears, D. D., and Colleagues, 2005: Regional vegetation die-off in response to global-change-type drought. *Proceedings of the National Academy of Sciences U.S.A.*, **102**, 15,144–15,148, <https://doi.org/10.1073/pnas.0505734102>.

Recent research suggests that piñon could manage to hang on...

Redmond, M. D., P. J. Weisberg, N. S. Cobb, and M. J. Clifford, 2017: Woodland resilience to regional drought: Dominant controls on tree regeneration following overstorey mortality. *Journal of Ecology*, **106**, 625–639, <https://doi.org/10.1111/1365-2745.12880>.

For example, some studies project an increase...

Wotton, B. M., M. D. Flannigan, and G. A. Marshall, 2017: Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. *Environmental Research Letters*, 12, 095003, <https://doi.org/10.1088/1748-9326/aa7e6e/pdf>.

It's also not out of the question that a decades-long megadrought...

Seager, R., and Coauthors, 2007: Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, **316**, 1181–1184, <https://doi.org/10.1126/science.1139601>.

The northward flow of maple syrup

This piece of Americana appears to be in jeopardy...

Dupigny-Giroux, L.A., E.L. Mearns, M.D. Lemcke-Stampone, G.A. Hodgkins, E.E. Lentz, K.E. Mills, E.D. Lane, R. Miller, D.Y. Hollinger, W.D. Solecki, G.A. Wellenius, P.E. Sheffield, A.B. MacDonald, and C. Caldwell, 2018: Northeast. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 669–742. <https://doi.org/10.7930/NCA4.2018.CH18>.

But since the 1980s, winters across New England...

Kahn, B., 2016: Climate change is coming for your maple syrup. Climate Central (28 March 2016), accessed 16 February 2019, <https://www.climatecentral.org/news/climate-change-maple-syrup-20178>.

Crops and climate: A growing concern

To cite just one prominent study...

McMahon, S. M., G. G. Parker, and D. R. Miller, 2010: Evidence for a recent increase in forest growth. *PNAS*, **107**, 3611–3615, <https://doi.org/10.1073/pnas.0912376107>.

A 2013 analysis headed by David Keenan (Harvard University)...

Keenan, T. F., D. Y. Hollinger, G. Bohrer, D. Dragoni, J. W. Munger, H. P. Schmid, and A. D. Richardson, 2013: Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. *Nature*, **499**, 324–327, <https://doi.org/10.1038/nature12291>.

A 2018 study of sugar maples in Michigan...

Ibáñez, I., D. R. Zak, A. J. Burton, and K. S. Pregitzer, 2018: Anthropogenic nitrogen deposition ameliorates the decline in tree growth caused by a drier climate. *Ecology*, **99**, 411–420, <https://doi.org/10.1002/ecy.2095>.

A 2006 study at Duke University...

Mohan, J., E., L. H. Ziska, W. H. Schlesinger, R. B. Thomas, R. C. Sicher, K. George, and J. S. Clark, 2006: Biomass and toxicity responses of poison ivy (*Toxicodendron radicans*) to elevated atmospheric CO₂. *PNAS*, **103**, 9086–9089, <https://doi.org/10.1073/pnas.0602392103>.

One of the open-air studies carried out...

Morgan, P. B., C. J. Bernacchi, D. R. Ort, and S. P. Long, 2004: An in vivo analysis of the effect of season-long open-air elevation of ozone to anticipated 2050 levels on photosynthesis in soybean. *Plant Physiology*, **135**, 2348–2357, <http://doi.org/10.1104/pp.104.043968>.

Another open-air study, this one in Wisconsin...

Talhelm, A. F., and Coauthors, 2014: Elevated carbon dioxide and ozone alter productivity and ecosystem carbon content in northern temperate forests. *Global Change Biology*, **20**, 2492–2504, <https://doi.org/10.1111/gcb.12564>.

Already, plant hardiness zones across the contiguous United States...

Daly, C., M. P. Widrlechner, M. D. Halbleib, J. I. Smith, and W. P. Gibson, 2012: Development of a new USDA Plant Hardiness Zone Map for the United States. *Journal of Applied Meteorology and Climatology*, **51**, 242–264, <https://doi.org/10.1175/2010JAMC2536.1>.

Will greenhouse gases boost plant growth?

In a 2005 review of more than a hundred FACE studies...

Ainsworth, E. A., and S. P. Long, 2005: What have we learned from 15 years of free-air CO₂ enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy

properties and plant production to rising CO₂. *New Phytologist*, **165**, 351–372, <https://doi.org/10.1111/j.1469-8137.2004.01224.x>.

Winners and losers in farming

A battle royal is setting up for the coming decades...

Lobell, D. B., and S. M. Gourdj, 2012: The influence of climate change on global crop productivity. *Plant Physiology*, **160**, 1686–1697, <https://doi.org/10.1104/pp.112.208298>.

From 1960 to 2015, world population...

Our World In Data, 2019: World population growth, 1750–2100, accessed 16 February 2019, <https://ourworldindata.org/uploads/2013/05/updated-World-Population-Growth-1750-2100.png>.

... yet global harvests more than tripled...

World Bank, 2019: Crop production index (2004-2006 = 100), accessed 16 February 2019, <https://data.worldbank.org/indicator/AG.PRD.CROP.XD?view=chart>.

The UN's Food and Agriculture Organization estimates...

Alexandratos, N. and J. Bruinsma. 2012: World agriculture towards 2030/2050: the 2012 revision. ESA Working Paper No. 12-03. Rome, FAO.

The 2014 IPCC report on impacts, adaptation, and vulnerability...

IPCC, 2014: Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T.E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 17–18, <https://www.ipcc.ch/report/ar5/wg2>.

The expanding set of global and regional efforts...

Rosenzweig, C., and Coauthors, 2013: The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. *Agricultural and Forest Meteorology*, **170**, 166–182, <https://doi.org/10.1016/j.agrformet.2012.09.011>.

Another critical step in formulating crops for a warming world...

Zhu, C., and Coauthors, 2018: Carbon dioxide (CO₂) levels this century will alter the protein, micronutrients, and vitamin content of rice grains with potential health consequences for

the poorest rice-dependent countries. *Science Advances*, **4**, eaaq1012, <http://doi.org/10.1126/sciadv.aaq1012>.

CHAPTER 10

Keeping Track

The discussion in this chapter benefitted from the insights of Spencer Weart:
Weart, S., 2018: The Discovery of Global Warming, accessed 26 August 2018, <https://history.aip.org/climate/index.htm#contents>.

We know it was a relatively mild 22.5°C (72.5°F)...

Moore, T., 2018: Here's what the weather was like when the U.S. declared independence on July 4, 1776, accessed 26 August 2018, <https://weather.com/holiday/july-fourth/news/weather-holiday-philadelphia-temperature-4th-of-july>.

A few regional networks were set up in Europe...

Cassidy, D. C., 1985: Meteorology in Mannheim: The Palatine Meteorological Society, 1780–1795. *Sudhoffs Archiv*, **69**, 8–25, <https://www.jstor.org/stable/20776952>.

One of the products of the postwar drive for global unity...

World Meteorological Organization, 2018: History of WMO, accessed 26 August 2018, <https://public.wmo.int/en/about-us/who-we-are/history-of-wmo>.

What about the temperature of the planet as a whole?...

Weart, S., 2018: The modern temperature trend. The Discovery of Global Warming, accessed 26 August 2018, <https://history.aip.org/climate/20ctrend.htm#S1>.

The Climatic Research Unit of the University of East Anglia (UEA)...

Climatic Research Unit, 2016: Answers to frequently-asked questions. University of East Anglia, accessed 26 August 2018, <https://crudata.uea.ac.uk/cru/data/temperature/#faq>.

A group at NASA originally led by James Hansen...

NASA, 2018: GISS Surface Temperature Analysis (GISTEMP) frequently asked questions (FAQ), accessed 26 August 2018, <https://data.giss.nasa.gov/gistemp/faq>.

NOAA uses a “pairwise” method that automatically identifies...

NOAA, 2018: Monitoring Global and U.S. temperatures at NOAA's National Centers for Environmental Information, accessed 26 August 2018, <https://www.ncdc.noaa.gov/monitoring-references/faq/temperature-monitoring.php>.

In a series of peer-reviewed papers in 2012 and 2013...

Rhode, R., and Coauthors, 2013: A new estimate of the average Earth surface land temperature spanning 1753 to 2011. *Geoinformatics and Geostatistics: An Overview*, **1**, <https://doi.org/10.4172/2327-4581.1000101>.

Although the Berkeley group focused on land-based readings...

Hausfather, Z., 2017: Explainer: How data adjustments affect global temperature records. Carbon Brief, accessed 26 August 2018, <https://www.carbonbrief.org/explainer-how-data-adjustments-affect-global-temperature-records>.

A photo-studded report...

Watts, A., 2009: *Is the U.S. Surface Temperature Record Reliable?* Heartland Institute, 29 pp.

A 2011 inquiry by the U.S. General Accounting Office...

U.S. Government Accountability Office, 2011: Climate Monitoring: NOAA Can Improve Management of the U.S. Historical Climatology Network, accessed 26 August 2018, <https://www.gao.gov/new.items/d11800.pdf>.

In a 2010 paper, a NOAA team headed by Matthew Menne...

Menne, M. J., C. N. Williams Jr., and M. A. Palecki, 2010: On the reliability of the U.S. surface temperature record. *Journal of Geophysical Research*, **115**, D11108, <https://doi.org/10.1029/2009JD013094>.

Berkeley's Richard Muller, who has also voiced support...

Muller, R. A., and Coauthors, 2013: Earth atmospheric land surface temperature and station quality in the contiguous United States. *Geoinformatics and Geostatistics: An Overview*, **1**, <https://doi.org/10.4172/2327-4581.1000107>.

So what is Earth's temperature, anyway?

Each of these cities has an annual mean air temperature...

Lindsey, R. and L. Dahlman, 2018: Climate change: Global temperature. NOAA, accessed 26 August 2018, <https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature>.

Bright lights, big cities, bogus data?

Almost half of that rise can be attributed to urban effects...

Yang, X., Y. Hou, and B. Chen, 2011: Observed surface warming induced by urbanization in east China. *JGR*, **116**, D14113, <https://doi.org/10.1029/2010JD015452>.

James Hansen's group at NASA started out...

Hansen, J., R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl, 2001: A closer look at United States and global surface temperature change. *J. Geophys. Res.*, **106**, 23,947–23,964, <https://doi.org/10.1029/2001JD000354>.

Thomas Peterson of the U.S. National Climatic Data Center...

Peterson, T. C., and T. W. Owen, 2005: Urban Heat Island Assessment: Metadata Are Important. *Journal of Climate*, **18**, 2637–2646, <https://doi.org/10.1175/JCLI3431.1>.

This inspired David Parker (Met Office Hadley Centre)...

Parker, D. E., 2004: Large-scale warming is not urban. *Nature*, **432**, 290, <https://doi.org/10.1038/432290a>.

The great pseudo-halt in global warmings

At least 90% of the solar energy trapped...

Scott, M., and R. Lindsey, 2017 State of the Climate: Ocean Heat Content. Climate.gov, NOAA (1 August 2018), <https://www.climate.gov/news-features/featured-images/2017-state-climate-ocean-heat-content>.

Globally, it was only a matter of time...

C. D. Roberts, M. D. Palmer, D. McNeall & M. Collins, 2015: Quantifying the likelihood of a continued hiatus in global warming. *Nature Climate Change*, **5**, 337–342, <https://doi.org/10.1038/nclimate2531>.

Perhaps conditioned by headlines...

Knutson, T. R., R. Zhang, and L. W. Horowitz, 2016: Prospects for a prolonged slowdown in global warming in the early 21st century. *Nature Communications*, **7**, 13676, <https://doi.org/10.1038/ncomms13676>.

However, there's always a chance...

Santer, B. D., and Coauthors, 2011: Separating signal and noise in atmospheric temperature changes: The importance of timescale. *Journal of Geophysical Research*, **116**, D22105, <https://doi.org/10.1029/2011JD016263>.

Research papers at the time—which drew on an array...

Lewandowsky, S., J. S. Risbey, and N. Oreskes, 2015: On the definition and identifiability of the alleged “hiatus” in global warming. *Scientific Reports*, **5**, 16784, <https://doi.org/10.1038/srep16784>.

How the greenhouse turns

This picture reverses in the stratosphere, where—oddly enough...

Randel, W. J., L. Polvani, F. Wu, D. E. Kinnison, C.-Z. Zou, and C. Mears, 2017: Troposphere-stratosphere temperature trends derived from satellite data compared with ensemble simulations from WACCM. *Journal of Geophysical Research: Atmospheres*, **122**, 9651–9667, <https://doi.org/10.1002/2017JD027158>.

Heat at a height

The fireworks began with the first Spencer–Christy paper...

Spencer, R. W., and J. R. Christy, 1990: Precise monitoring of global temperature trends from satellites. *Science*, **247**, 1558–1562, <https://doi.org/10.1126/science.247.4950.1558>.

In 1998, two scientists in California, Frank Wentz and Matthias Schabel...

Wentz, F. J., and M. Schabel, 1998: Effects of orbital decay on satellite-derived lower-tropospheric temperature trends. *Nature*, **394**, 661–664, <https://doi.org/10.1038/29267>.

In 2000, the U.S. National Academies weighed in...

National Research Council, 2000: *Reconciling Observations of Global Temperature Change*. The National Academies Press, <https://doi.org/10.17226/9755>.

Global dimming?

A 2003 paper in *Science* gave the phenomenon of global dimming...

Anderson, T. L., R. J. Charlson, S. E. Schwartz, R. Knutti, O. Boucher, H. Rodhe, and J. Heintzenberg, 2003: Climate forcing by aerosols—a hazy picture. *Science*, **300**, 1103–1104, <https://doi.org/10.1126/science.1084777>.

In fact, the timing of global dimming’s rise to fame was a bit paradoxical...

Wild, M., B. Trüssel, A. Ohmura, C. N. Long, G. König-Langlo, E. G. Dutton, and A. Tsvetkov, 2009: Global dimming and brightening: An update beyond 2000. *JGR: Atmospheres*, **114**, D00D13, <https://doi.org/10.1029/2008JD011382>.

Using a set of long-term readings from the highest-quality instruments...

Stanhill, G., and S. Cohen, 2001: Global dimming: a review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences. *Agricultural and Forest Meteorology*, **107**, 255--278, [https://doi.org/10.1016/S0168-1923\(00\)00241-0](https://doi.org/10.1016/S0168-1923(00)00241-0).

Even these studies failed to jolt the climate research community...

Roderick, M. L., and G. D. Farquhar, 2002: The cause of decreased pan evaporation over the past 50 years. *Science*, **298**, 1410–1411, <https://doi.org/10.1126/science.1075390-a>.

The plane truth about contrails

One of the first analyses to combine a high-end climate model...

Chen, C., and A. Gettelman, 2013: Simulated radiative forcing from contrails and contrail cirrus. *Atmospheric Chemistry and Physics*, **13**, 12525–12536, <https://doi.org/10.5194/acp-13-12525-2013>.

CHAPTER 11

The Long View

The really big picture: From Earth's origins to the expansion of life

In 2010, Danish scientist Minik Rosing...

Rosing, M. T., D. K. Bird, N. H. Sleep, C. J. Bjerrum, 2010: No climate paradox under the faint early Sun. *Nature*, **464**, 744–747, <https://doi.org/10.1038/nature08955>.

In a 2013 study published in *Astrobiology*...

Wolf, E. T., and O. B. Toon, 2014: Controls on the Archean climate system investigated with a global climate model. *Astrobiology*, **14**, 241–253, <https://doi.org/10.1089/ast.2013.1112>.

What trees tell us about climate

In Germany, the University of Hohenheim...

Friedrich, M., S. Remmele, B. Kromer, J. Hofmann, M. Spurk, K. F. Kaiser, C. Orcel, and M. Küppers, 2004: The 12,460-Year Hohenheim oak and pine tree-ring chronology from

central Europe—a unique annual record for radiocarbon calibration and paleoenvironment reconstructions. *Radiocarbon*, **46**, 1111–1122, <https://doi.org/10.1017/S003382220003304X>.

Connie Woodhouse of NOAA went to the Arizona lab...

Cook, E. R., R. Seager, R. R. Heim Jr., R. S. Vose, C. Herweijer, and C. Woodhouse, 2009: Megadroughts in North America: placing IPCC projections of hydroclimatic change in a long-term palaeoclimate context. *Journal of Quaternary Science*, **25**, 48–61, <https://doi.org/10.1002/jqs.1303>.

Earth's age: 4.5 billion years or 6000 years?

National Science Board, 2018: Science and Engineering Indicators 2018, Table 7–1, accessed 31 August 2018, <https://www.nsf.gov/statistics/2018/nsb20181/report>.

Gaia and global warming

His 2009 book *The Vanishing Face of Gaia*...

Lovelock, J., 2009: *The Vanishing Face of Gaia: A Final Warning*. Basic Books, 304 pp.

Lovelock later pulled back a bit...

Parry, W., 2012: 'Gaia' scientist takes back climate change predictions. Live Science, accessed 31 August 2018, <https://www.livescience.com/19875-gaia-lovelock-climate-change.html>.

Lovelock told the United Kingdom's The Guardian newspaper...

Hickman, J., 2012: James Lovelock: The UK should be going mad for fracking. *Guardian*, accessed 31 August 2018, <https://www.theguardian.com/environment/2012/jun/15/james-lovelock-interview-gaia-theory>.

Partial vindication came in 2001...

Pronk, J., 2002: The Amsterdam declaration on global change. *Challenges of a Changing Earth*, W. Steffen et al., Eds., Springer, 207–208.

Among them are earth scientist Toby Tyrrell...

Tyrrell, T., 2013: *On Gaia: A Critical Investigation of the Relationship between Life and Earth*. Princeton University Press, 320 pp.

Close calls for life on Earth

The other is a distinct blip early in the already toasty Eocene epoch...

Kiehl, J. T., and C. A. Shields, 2013: Sensitivity of the Palaeocene–Eocene thermal maximum climate to cloud properties. *Philosophical Transactions of the Royal Society A*, **371**, 20130093, <https://doi.org/10.1098/rsta.2013.0093>.

Hot in here: Earth's warm periods

A 2006 study of sediments beneath the Arctic Ocean...

Sluijs, A., and Coauthors, 2006: Subtropical Arctic Ocean temperatures during the Palaeocene/Eocene thermal maximum. *Nature*, **441**, 610–613, <https://doi.org/10.1038/nature04668>.

...some intriguing evidence of readings at or above 33°C (91°F)...

Frieling, J., 2017: Extreme warmth and heat-stressed plankton in the tropics during the Paleocene-Eocene Thermal Maximum. *Science Advances*, **3**, e1600891, <https://doi.org/10.1126/sciadv.1600891>.

Core value: Getting information out of ice

In 2010 a new coring project...

Rasmussen, S. O., and Coauthors, 2013: A first chronology for the North Greenland Eemian Ice Drilling (NEEM) ice core. *Climate of the Past*, **9**, 2713–2730, <https://doi.org/10.5194/cp-9-2713-2013>.

The total Vostok record...

Petit, J. R., and Coauthors, 1999: Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature*, **399**, 429–436, <https://doi.org/10.1038/20859>.

For more than a decade, the oldest core on Earth...

Oerter, H., and EPICA Team, 2008: Two EPICA ice cores revealing 800,000 years of climate history: An overview. Internationale Polartagung der Deutschen für Polarforschung, Münster, Germany, Deutschen Gesellschaft für Polarforschung, <http://epic.awi.de/18400>.

In 2017, the group announced...

Voosen, P., 2018: 2.7-million-year-old ice opens window on past. *Science*, **357**, 630–631, <https://doi.org/10.1126/science.357.6352.630>.

From greenhouse to icehouse: The planet cools down

In the late 1980s, Maureen Raymo...

Raymo, M. E., and W. F. Ruddiman, 1992: Tectonic forcing of late Cenozoic climate *Nature*, **359**, 117–122, <https://doi.org/10.1038/359117a0>.

In the absence of enough data...

Norton, K. P., and F. Schlunegger, 2017: Lack of a weathering signal with increased Cenozoic erosion? *Terra Nova*, **29**, 265–272, <https://doi.org/10.1111/ter.12278>.

Another intriguing idea, advanced by Peter Huybers...

Huybers, P., 2011: Combined obliquity and precession pacing of late Pleistocene deglaciations. *Nature*, **480**, 229–232, <https://doi.org/10.1038/nature10626>.

And a 2013 study in *Nature* led by Ayako Abe-Ouchi...

Abe-Ouchi, A., F. Saito, K. Kawamura, M. E. Raymo, J. Okuno, K. Takahashi, and H. Blatter, 2013: Insolation-driven 100,000-year glacial cycles and hysteresis of ice-sheet volume. *Nature*, **500**, 190–193, <https://doi.org/10.1038/nature12374>.

Computer modeling by Jonathan Overpeck (University of Arizona)...

Overpeck, J. T., B. L. Otto-Bliesner, G. H. Miller, D. R. Muhs, R. B. Alley, and J. T. Kiehl, 2006: Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. *Science*, **311**, 1747–1750, <https://doi.org/10.1126/science.1115159>.

Emerging from the ice

Instead, the cores revealed that Earth swung through...

Bond, G., W. J. Showers, M. Cheseby, and G. Bonani, 1998: A pervasive millennial-scale cycle in the North Atlantic Holocene and glacial climates. *Science*, **278**, 1257–1266, <https://doi.org/10.1126/science.278.5341.1257>.

However, most paleoclimatologists point to the massive draining...

Leydet, D. J., and Coauthors, 2018: Opening of glacial Lake Agassiz's eastern outlets by the start of the Younger Dryas cold period. *Geology*, **46**, 155–158, <https://doi.org/10.1130/G39501.1>.

From AD 1000 to today (and beyond)

The Mayan collapse in eastern Mexico apparently coincided...

Marx, W., R. Haunschild, and L. Bornmann, 2017: The role of climate in the collapse of the Maya civilization: a bibliometric analysis of the scientific discourse. *Climate*, **5**, 88–109, <https://doi.org/10.3390/cli5040088>

...pointing to signs of other factors such as migration...

Bocinsky, R. K., J. Rush, K. W. Kintigh, and T. A. Kohler, 2016: Exploration and exploitation in the macrohistory of the pre-Hispanic Pueblo Southwest. *Science Advances*, **2**, e1501532, <https://doi.org/10.1126/sciadv.1501532>.

As historian Brian Fagan notes, the Little Ice Age...

Fagan, B., 2001: *The Little Ice Age: How Climate Made History 1300–1850*. Basic Books, 272 pp.

However, recent studies have brought down the relative importance...

Owens, M. J., M. Lockwood, E. Hawkins, I. Usoskin, G. S. Jones, L. Barnard, A. Schurer, and J. Fasullo, 2017: The Maunder minimum and the Little Ice Age: An update from recent reconstructions and climate simulations. *Journal of Space Weather and Space Climate*, **7**, A33, <https://doi.org/10.1051/swsc/2017034>.

Sowing a savory climate

He's since elaborated it for a broader audience...

Ruddiman, W., 2010: *Plows, Plagues, and Petroleum: How Humans Took Control of Climate*. Princeton University Press, 240 pp.

A comparison of ice cores from both Northern and Southern Hemispheres...

Mitchell, L., E. Brook, J. E. Lee, C. Buizert, and T. Sowers, 2013: Constraints on the late Holocene anthropogenic contribution to the atmospheric methane budget. *Science*, **342**, 964–966, <https://doi.org/10.1126/science.1238920>.

Ruddiman's theory has met with enthusiastic agreement and stout resistance...

SAGE Journals, 2011: Holocene Special Issue: The early-Anthropocene hypothesis, accessed 31 August 2018, <http://journals.sagepub.com/toc/hola/21/5>

...according to a study in *Environmental Research Letters* led by Laura Wilcox...

Wilcox, L. J., E. J. Highwood, and N. J. Dunstone, 2013: The influence of anthropogenic

aerosol on multi-decadal variations of historical global climate. *Environmental Research Letters*, **8**, 024033, <https://doi.org/10.1088/1748-9326/8/2/024033>.

In an alternate view, much of the midcentury hemispheric cooling...

Thompson, D. W. J., J. M. Wallace, J. J. Kennedy, and P. D. Jones, 2010: An abrupt drop in Northern Hemisphere sea surface temperature around 1970. *Nature*, **467**, 444–447, <https://doi.org/10.1038/nature09394>.

Painting the Little Ice Age

Hans Neuberger quantified the treatment of clouds...

Neuberger, N., 1970: Climate in Art. *Weather*, **25**, 46–56, <https://doi.org/10.1002/j.1477-8696.1970.tb03232.x>.

According to astronomer Donald Olson of Texas State University...

Olson, D. W., R. L. Doescher, and M. S. Olson, 2004: When the sky ran red: the story behind the "scream". *Sky & Telescope*, **107**, 29–35.

Initial results were published in a 1998 *Nature* paper...

Mann, M. E., R. S. Bradley, and M. K. Hughes, 1998: Global-scale temperature patterns and climate forcing over the past six centuries *Nature*, **392**, 779–787, <https://doi.org/10.1038/33859>.

...and in a 1999 follow-up...

Mann, M. E., R. S. Bradley, and M. K. Hughes, 1999: Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. *GRL*, **26**, 759–762, <https://doi.org/10.1029/1999GL900070>.

The debate broke open in early 2005...

McIntyre, S., and R. McKittrick, 2005: Hockey sticks, principal components, and spurious significance. *GRL*, **32**, L03710, <https://doi.org/10.1029/2004GL021750>.

The panel's 2006 report supported the type of multiproxy research...

National Research Council, 2006: *Surface Temperature Reconstructions for the Last 2,000 Years*. The National Academies Press, 206 pp., <https://doi.org/10.17226/11676>.

In the wake of the report, MBH and several colleagues extended their reconstruction...

Mann, M. E., Z. Zhang, M. K. Hughes, R. S. Bradley, S. K. Miller, S. Rutherford, and F. Ni, 2008: Proxy-based reconstructions of hemispheric and global surface temperature variations

over the past two millennia. *Proceedings of the National Academy of Sciences U.S.A.*, **205**, 13,252–13,257, <https://doi.org/10.1073/pnas.0805721105>.

CHAPTER 12

Circuits of Change

Paul Edwards' overview of the history and architecture of global climate modeling is highly recommended:

Edwards, P. N., 2010: *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. MIT Press, 552 pp.

In 1957, Roger Revelle and Hans Seuss...

Revelle, R., and H. E. Seuss, 1957: Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO₂ during the past decades. *Tellus*, **9**, 18–27, <https://doi.org/10.3402/tellusa.v9i1.9075>.

Climate, weather, and chaos theory

Small disturbances missed in the data can influence larger weather events...

Lorenz, E. N., 1963: Deterministic nonperiodic flow. *Journal of the Atmospheric Sciences*, **20**, 130–141, [https://doi.org/10.1175/1520-0469\(1963\)020<0130:DNF>2.0.CO;2](https://doi.org/10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2).

From great ideas to global views

The computer modelers now helping the world decide...

Richardson, L. F., 1922: *Numerical Prediction by Numerical Process*, 2nd edition (2007). Cambridge Univ. Press. 250 pp.

The computer took almost a week...

Lynch, P., 2008: The ENIAC Forecasts: a re-creation. *Bulletin of the American Meteorological Society*, **89**, 45–56, <https://doi.org/10.1175/BAMS-89-1-45>.

In the mid-1960s, NCAR's Warren Washington and Akira Kasahara...

Kasahara, A., and W. M. Washington, 1967: NCAR global general circulation model of the atmosphere. *Monthly Weather Review*, **95**, 389–402, [https://doi.org/10.1175/1520-0493\(1967\)095<0389:NGGCMO>2.3.CO;2](https://doi.org/10.1175/1520-0493(1967)095<0389:NGGCMO>2.3.CO;2).

How computer modeling got started

Modelers rely on two major types of simulations...

Schlesinger, M. E., 1986: Equilibrium and transient climatic warming induced by increased atmospheric CO₂. *Climate Dynamics*, **1**, 35–51, <https://doi.org/10.1007/BF01277045>.

The Met Office began issuing 5- and 10-year forecasts...

Knight, J. R., and Coauthors, 2014: Predictions of climate several years ahead using an improved decadal prediction system. *Journal of Climate*, **27**, 7550–7657, <https://doi.org/10.1175/JCLI-D-14-00069.1>.

The 2013 IPCC report draws on the suite of modeling runs...

Taylor, K. E., R. J. Stouffer, and G. A. Meehl, 2012: An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, **93**, 485–498, <https://doi.org/10.1175/BAMS-D-11-00094.1>.

Researchers embarked in the late 2010s...

Eyring, V., S. Bony, G. A. Meehl, C. A. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor, 2016: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geoscientific Model Development*, **9**, 1937–1958, <https://doi.org/10.5194/gmd-9-1937-2016>.

Modeling for the masses: ClimatePrediction.net

That all changed with ClimatePrediction.net...

Frame, D. J., and Coauthors, 2009: The climateprediction.net BBC climate change experiment: design of the coupled model ensemble. *Philosophical Transactions of the Royal Society: Series A, Mathematical, Physical and Engineering Sciences*, **367**, 855–870, <https://doi.org/10.1098/rsta.2008.0240>.

In 2010 it launched its first experiments with regional climate models...

Massey, N., and Coauthors, 2015: weather@home—Development and validation of a very

large ensemble modelling system for probabilistic event attribution. *Quarterly Journal of the Royal Meteorological Society*, **141**, 1528–1545, <https://doi.org/10.1002/qj.2455>.

This range—something of a best guess at the time—was first cited...

National Research Council, 1979: *Carbon Dioxide and Climate: A Scientific Assessment*. The National Academies Press, 34 pp., <https://doi.org/10.17226/12181>.

One recent piece of evidence is a 2017 analysis...

Cox, P. M., C. Huntingford, and M. S. Williamson, 2018: Emergent constraint on equilibrium climate sensitivity from global temperature variability. *Nature*, **553**, 319–322, <https://doi.org/10.1038/nature25450>.

In a 2007 *Science* paper, Peter Cox and David Stephenson...

Cox, P., and D. Stephenson, 2007: A changing climate for prediction. *Science*, **317**, 207–208, <https://doi.org/10.1126/science.1145956>.

CHAPTER 13

A Heated Debate

The early days

The Saturday Evening Post, then one of the biggest U.S. magazines...

Abarbanel A., and T. McCluskey, 1950: Is the world getting warmer? *Saturday Evening Post* (1 July), 22–23 and 57–63.

In a 1972 *Nature* paper entitled...

Sawyer, J. S., 1972: Man-made carbon dioxide and the “greenhouse” effect. *Nature*, **239**, 23–26, <https://doi.org/10.1038/239023a0>.

A British documentary in 1974 called *The Weather Machine*...

Calder, N., 1975: *The Weather Machine*. Viking, 143 pp.

A landmark 1975 paper in *Science*...

Broecker, W. S., 1975: Climatic Change: Are We on the Brink of a Pronounced Global Warming? *Science*, **189**, 460–463, <https://doi.org/10.1126/science.189.4201.460>.

Two studies late in the 1970s...

National Research Council, 1979: *Carbon Dioxide and Climate: A Scientific Assessment*. The National Academies Press, 34 pp., <https://doi.org/10.17226/12181>.

On a record-hot June day in Washington...

Hansen, J. E., 1988: The Greenhouse Effect: Impacts on Current Global Temperature and Regional Heat Waves. Testimony to U.S. Senate, Committee on Energy and Natural Resources, June 23, 1988.

Time magazine named “Endangered Earth” Planet of the Year...

Sancton, T. A., 1989: Planet of the year: what on Earth are we doing? *TIME* (2 January), <http://content.time.com/time/subscriber/article/0,33009,956627-1,00.html>

In August, U.S. presidential candidate George H. W. Bush declared...

Editorial, 1989: The White House and the greenhouse. *New York Times* (9 May), A30, <https://www.nytimes.com/1989/05/09/opinion/the-white-house-and-the-greenhouse.html>.

Together, *The New York Times* and *Washington Post*...

McComas, K., and J. Shanahan, 1999: Telling stories about global climate change: measuring the impact of narratives on issue cycles. *Communication Research*, **26**, 30–57, <https://doi.org/10.1177/009365099026001003>.

In September, British Prime Minister Margaret Thatcher...

Thatcher, M., 1988: Speech to the Royal Society. Margaret Thatcher Foundation (27 September), accessed 1 September 2018, <https://www.margaretthatcher.org/document/107346>.

Even some spokespeople for the U.S. fossil fuel industry...

Rich, N., 2018: Losing Earth: The decade we almost stopped climate change. *New York Times*, 1 August, <https://www.nytimes.com/interactive/2018/08/01/magazine/climate-change-losing-earth.html>.

In her 1962 book *Silent Spring*...

Carson, R., 1962: *Silent Spring*. Houghton Mifflin, 368 pp.

In her footsteps came a series of similarly dire scenarios...

Erhlich, P., 1968: *The Population Bomb*. Ballantine Books, 223 pp.

Some researchers have found that fear-based rhetoric...

Moser, S. C., and L. Dilling, 2004: Making climate hot: communicating the urgency and challenge of global climate Change. *Environment*, **56**, 32–46, <https://doi.org/10.1080/00139150409605820>.

Debates among the activists

...and some influential authors, such as Naomi Klein...

Klein, N., 2014: *This Changes Everything: Capitalism vs. The Climate*. Simon and Schuster, 576 pp.

However, many of the most influential environmental groups...

Greenpeace International, 2017: 23 countries and states to phase out coal as US\$432 billion of capital leaves the industry. Press release (18 October), accessed 1 September 2018, <https://www.greenpeace.org/archive-international/en/press/releases/2017/23-countries-and-states-to-phase-out-coal-as-US432-billion-of-capital-leaves-the-industry>.

Pushing against climate change action

One highly visible group throughout the 1990s...

DeSmog, 2018: Global Climate Coalition (GCC), accessed 1 September 2018, <https://www.desmogblog.com/global-climate-coalition>.

A 2001 memo written to ExxonMobil...

Vidal, J., 2005: Revealed: how oil giant influenced Bush. *Guardian* (June 8), accessed 1 September 2018, <http://www.webcitation.org/6gjDL8wj3>.

Ironically, Exxon's own scientists had participated in climate change research...

Banerjee, N., L. Song, and D. Hasemyer, 2015: Exxon: The road not taken. *InsideClimate News*, 16 September, accessed 1 September 2018, <https://insideclimatenews.org/content/Exxon-The-Road-Not-Taken>.

However, a 2014 analysis in *Climatic Change* by Robert Brulle (Drexel University)...

Brulle, R. J., 2014: Institutionalizing delay: Foundation funding and the creation of U.S. climate change counter-movement organizations. *Climatic Change*, **122**, 681–694, <https://doi.org/10.1007/s10584-013-1018-7>.

On the 2006 release of the Al Gore documentary...

Sutherland, J. J., 2006: They call it pollution. We call it life. National Public Radio (23 May), accessed 1 September 2018, <https://www.npr.org/templates/story/story.php?storyId=5425355>.

In 2018, the institute's website declared...

CEI, Issues: Energy and Environment. Competitive Enterprise Institute, accessed 1 September 2018, <https://cei.org/issues/energy-and-environment>.

Even among like-minded organizations...

Geman, B., 2012: Heartland Institute yanks Unabomber climate billboard. The Hill (4 May), accessed 1 September 2018, <http://thehill.com/policy/energy-environment/225559-heartland-institute-yanks-unabomber-climate-billboard>.

Yet emails released in 2018 showed top staff at Heartland...

Knickmeyer, E., 2018: Emails show collaboration among EPA, climate-change deniers. Associated Press (25 May), accessed 1 September 2018, <https://apnews.com/64cd37b0503440c0b92e6ca075f87dd4/Emails-show-cooperation-among-EPA-climate-change-deniers>

That same year, an article at Heartland's website...

Wrightstone, G., The science that Al Gore doesn't want you to hear. Heartland Institute (7 May), <https://www.heartland.org/multimedia/podcasts/the-science-that-al-gore-doesnt-want-you-to-know-guest-gregory-wrightstone>.

The rise of climate-change denial

It had been used to delay tobacco regulation for decades...

Oreskes, N., and E. M. Conway, 2010: *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*. Bloomsbury Press, 343 pp.

"I am convinced that in fifteen to twenty years...

U.S. Senate Committee on Environment and Public Works, 2005: The Role of Science in Environmental Policy Making. Senate Hearing 109-1003 (28 September), accessed 1 September 2018, <https://www.gpo.gov/fdsys/pkg/CHRG-109shrg38918/html/CHRG-109shrg38918.htm>.

In the 1970s, the late Stephen Schneider...

Schneider, S., 1976: *The Genesis Strategy*. Springer, 419 pp.

In 1988 Schneider wrote *Global Warming...*

Schneider, S., 1989: *Global Warming: Are We Entering the Greenhouse Century?* Sierra Club Books, 317 pp.

The release of the IPCC's second assessment...

IPCC SAR SYR, 1996: *Climate Change 1995: A report of the Intergovernmental Panel on Climate Change*, Second Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, p. iii, <https://www.ipcc.ch/site/assets/uploads/2018/05/2nd-assessment-en-1.pdf>.

Bjørn Lomborg's skeptical environmentalism

In his influential 2001 book *The Skeptical Environmentalist...*

Lomborg, B., 2001: *The Skeptical Environmentalist*. Cambridge University press, 540 pp.

In his 2007 follow-up *Cool It...*

Lomborg, B., 2007: *Cool It: The Skeptical Environmentalist's Guide to Global Warming*. Cyan Communications / Marshall Cavendish, 368 pp.

In a 2017 *Wall Street Journal* op-ed...

Lomborg, B., 2017: The Charade of the Paris Treaty. *Wall Street Journal* (16 June), accessed 1 September 2018, <https://www.wsj.com/articles/the-charade-of-the-paris-treaty-1497623798>.

But the climate change denials and the lobbying groups...

Phillips, M., 2009: The great global warming scam. *Daily Mail* (October 3).

Even when climate change did appear in the news...

Brüggemann, M., and S. Engesser, 2017: Beyond false balance: How interpretive journalism shapes media coverage of climate change. *Global Environmental Change*, **42**, 58–67, <https://doi.org/10.1016/j.gloenvcha.2016.11.004>.

When global warming meets TV weather

As consultant Matthew Felling told the website *Salon*...

Baker, L., 2006: Just say it's sunny. *Salon* (4 April), accessed 1 September 2018, https://www.salon.com/2006/04/04/weather_4.

A survey of more than 500 weathercasters in 2010...

Maibach, E. K., K. Wilson, and J. Witte, 2010: A national survey of television meteorologists about climate change: Preliminary findings. George Mason University Center for Climate Change Communication, 24 pp. Available online at [www.webpages.uidaho.edu/envs501/downloads/TV_Meteorologists_Survey_Findings_\(March_2010\).pdf](http://www.webpages.uidaho.edu/envs501/downloads/TV_Meteorologists_Survey_Findings_(March_2010).pdf).

In 2017, a research group at George Mason University...

Maibach, E., and Coauthors, 2017: TV weathercasters' views of climate change appear to be rapidly evolving. *Bulletin of the American Meteorological Society*, **98**, 2061–2064, <https://doi.org/10.1175/BAMS-D-15-00206.1>.

The Weather Channel's position statement on climate change...

The Weather Channel, 2017: Global warming and climate change: The Weather Company Stand. Weather.com (9 March), accessed 1 September 2018, <https://weather.com/science/environment/news/global-warming-weather-channel-position-statement-20141029>.

In a later study for the journal *Global Environmental Change*...

Boykoff, M. T., and J. M. Boykoff, 2004: Balance as bias: global warming and the US prestige press. *Global Environmental Change*, **14**, 125–136, <https://doi.org/10.1016/j.gloenvcha.2003.10.001>.

In June 2005, *The New York Times* reported...

Revkin, A. C., 2005: Bush aide softened greenhouse gas links to global warming. *New York Times* (8 June), accessed 1 September 2018, <https://www.nytimes.com/2005/06/08/politics/bush-aide-softened-greenhouse-gas-links-to-global-warming.html>.

NASA's James Hansen told *The New York Times* and the BBC in 2006...

Editorial, 2006: Censoring Truth. *New York Times* (9 February), accessed 1 September 2018, <https://www.nytimes.com/2006/02/09/opinion/censoring-truth.html>.

...and the U.S. National Science Board called for uniform federal guidelines...

NSB, 2006: Memorandum to Members and Consultants of the National Science Board. NSB-

06-61 (12 June), accessed 1 September 2018,
<https://www.nsf.gov/nsb/meetings/2006/0509/summary.pdf>.

Climate change and the world of faith

They made the news in 2006...

Goodstein, L., 2006: Evangelical leaders join global warming initiative. *New York Times* (2 September), accessed 1 September 2018,
<https://www.nytimes.com/2006/02/08/us/evangelical-leaders-joining-global-warming-initiative.html>

It was the first salvo in the Evangelical Climate Initiative...

The Evangelical Climate Initiative, 2006: Climate Change: An Evangelical Call to Action, accessed 1 September 2018, <http://www.christiansandclimate.org/statement>,

More recently, Pope Francis drew worldwide notice...

Pope Francis, 2015: Laudato Si. The Vatican (24 May), accessed 1 September 2018,
http://w2.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html.

In their 2016 book *Caring for Creation*...

Hescox, M., and P. Douglas, 2016: *Caring for Creation: The Evangelical's Guide to Climate Change and a Healthy Environment*. Bethany House Publishers, 192 pp.

A paper by one of their founders...

Beisner, E. C., 2005: Biblical Principles for Environmental Stewardship. In *An Examination of the Scientific, Ethical and Theological Implications of Climate Change Policy*. Interfaith Stewardship Alliance, 19 pp.

The group later morphed into the Cornwall Alliance...

Cornwall Alliance, 2015: An Open Letter on Climate Change to the People, their Local Representatives, the State Legislatures and Governors, the Congress, and the President of the United States of America, accessed 1 September 2018,
<https://cornwallalliance.org/landmark-documents/an-open-letter-on-climate-change-to-the-people-their-local-representatives-the-state-legislatures-and-governors-the-congress-and-the-president-of-the-united-states-of-america>.

Hayhoe and her husband Andrew Farley...

Hayhoe, K., and A. Farley, 2009: *A Climate for Change: Global Warming Facts for Faith-Based Decisions*. FaithWords, 224 pp.

In her study of three U.K. newspapers...

Carvalho, A., and J. Burgess, 2005: Cultural circuits of climate change in U.K. broadsheet newspapers, 1985–2003. *Risk Analysis*, **25**, 1457–1469, <https://doi.org/10.1111/j.1539-6924.2005.00692.x>.

One of the first concrete signs...

Vergano, D., 2005: The debate's over: Globe is warming. *USA TODAY* (13 June).

Copenhagen and beyond

In a 2006 survey by the Pew Research Center...

Pew Research Center, 2009: Fewer Americans see solid evidence of global warming. Pew Research Center (22 October), accessed 1 September 2018, <http://www.pewresearch.org/2009/10/22/fewer-americans-see-solid-evidence-of-global-warming>.

The media quickly dubbed the event Climategate...

Pearce, F., 2010: 'Climategate' was 'a game-changer' in science reporting, say climatologists. *Guardian* (4 July), accessed 1 September 2018, <https://www.theguardian.com/environment/2010/jul/04/climatechange-hacked-emails-muir-russell>.

A series of investigations from 2010 onward exonerated the researchers...

Russell, Sir Muir, KCB DL FRSE, 2010: The Independent Climate Change Email Review. University of East Anglia (7 July), accessed 1 September 2018, <http://www.cce-review.org>.

A series of investigations from 2010 onward exonerated the researchers...

NSF Office of Inspector General, Closeout Memorandum, Case #A09120086. National Science Foundation, accessed 1 September 2018, <http://www.science20.com/uploads/1770191916-429173860.pdf>.

Finally, the IPCC itself commented on the brouhaha...

IPCC Chair and Vice Chairs and Co-Chairs of IPCC Working Groups, 2010: IPCC statement on the melting of Himalayan glaciers. Intergovernmental Panel on Climate Change (20 January), accessed 1 September 2018, <https://www.ipcc.ch/pdf/presentations/himalaya-statement-20january2010.pdf>.

A blue-ribbon group assembled in 2010 by the world's national science academies...

Committee to Review the Intergovernmental Panel on Climate Change, 2010: Climate

change assessments: Review of the processes and procedures of the IPCC. InterAcademy Council, 103 pp., https://www.ipcc.ch/organization/organization_review.shtml.

In February 2010, the family of U.S. senator James Inhofe...

Johnson, B., 2010: Inhofe's grandchildren build igloo to mock killer snow storm: 'Al Gore's New Home'. ThinkProgress (9 February), accessed 1 September 2018, <https://thinkprogress.org/inhofes-grandchildren-build-igloo-to-mock-killer-snow-storm-al-gore-s-new-home-ee8c076aa707>.

When David Cameron became U.K. prime minister...

Perkins, A., 2015: Coalition Britain: has the 'greenest ever' government lived up to its promise? *Guardian* (12 March), accessed 1 September 2018, <https://www.theguardian.com/environment/2015/mar/12/did-coalition-live-up-to-greenest-government-pledge>.

Likewise, an Australian carbon tax...

Taylor, L., 2014: Carbon tax repealed: a short timeline of Australia's long debate about emissions trading. *Guardian* (16 July), accessed 1 September 2018, <https://www.theguardian.com/world/2014/jul/17/carbon-tax-repealed-a-short-timeline-of-australias-long-debate-about-emissions-trading>.

"As bad as Sandy was...

Bloomberg, M., 2013: Full Text: Bloomberg's Speech on Climate Plan. Adapt NY (11 June), accessed 1 September 2018, <https://www.adaptny.org/2013/06/13/full-text-bloombergs-speech-on-climate-plan>.

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Friedman, L., 2013: Philippines diplomat opens climate talks with plea to end 'madness' of rising emissions. E&E News (12 November), accessed 1 September 2018, <https://www.eenews.net/stories/1059990296/print>.

Even more encouragement came from a surprising trend...

IEA, 2017: IEA finds CO₂ emissions flat for third straight year even as global economy grew in 2016. International Energy Agency (17 March), accessed 1 September 2018, <https://www.iea.org/newsroom/news/2017/march/iea-finds-co2-emissions-flat-for-third-straight-year-even-as-global-economy-grew.html>.

The science of climate change communication

The 2010s were a fertile decade for such research...

Moser, S. C., 2016: Reflections on climate change communication research and practice in the second decade of the 21st century: What more is there to say? *Wiley Interdisciplinary Reviews: Climate Change*, **7**, 345–369, <https://doi.org/10.1002/wcc.403>.

One early landmark was the influential “Six Americas” concept...

Maibach, E. W., A. Leiserowitz, C. Roser-Renouf, and C. K. Mertz, 2011: Identifying like-minded audiences for global warming public engagement campaigns: an audience segmentation analysis and tool development. *PLoS One*, **6**, e17571, <https://doi.org/10.1371/journal.pone.0017571>.

These concepts are exemplified in Texas...

Leiserowitz, A., G. Feinberg, P. Howe, and S. Rosenthal, 2013: Climate change in the Texan mind. Yale Project on Climate Change Communication, accessed 2 September 2018, http://climatecommunication.yale.edu/wp-content/uploads/2016/02/2013_09_Climate-Change-in-the-Texan-Mind.pdf.

In fact, multiple studies have shown...

Kahan, D., 2013: Ideology, motivated reasoning, and cognitive reflection: an experimental study. *Judgment and Decision Making*, **8**, 407–424, <https://doi.org/10.2139/ssrn.2182588>.

One linchpin of this strategy...

Cook, J., and Coauthors, 2013: Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environmental Research Letters*, **8**, 024024, <https://doi.org/10.1088/1748-9326/8/2/024024>.

Stressing the consensus doesn’t convince everyone...

Pearce, W., R. Grundmann, M. Hulme, S. Raman, E. H. Kershaw, and J. Tsouvalis, 2017: Beyond counting climate consensus. *Environmental Communication*, **11**, 723–730, <https://doi.org/10.1080/17524032.2017.1333965>.

However, “inoculating” people...

van der Linden, S., A. Leiserowitz, S. Rosenthal, and E. Maibach, 2017: Inoculating the public against misinformation about climate change. *Global Challenges*, **1**, 1600008, <https://doi.org/10.1002/gch2.201600008>.

The battle lines harden

Vox’s Dylan Matthews compiled more than 100 tweets...

Matthew, D., 2017: Donald Trump has tweeted climate change skepticism 115 times. Here's all of it. *Vox* (1 June), accessed 1 September 2018, <https://www.vox.com/policy-and-politics/2017/6/1/15726472/trump-tweets-global-warming-paris-climate-agreement>

By mid-2017, he'd stocked his administration with climate change dismissers...
Davenport, C., and E. Lipton, 2017: How G.O.P. leaders came to view climate change as fake science. *New York Times* (3 June),
<https://www.nytimes.com/2017/06/03/us/politics/republican-leaders-climate-change.html>.

A 2017 report from the U.K. House of Lords noted...
UK Parliament, 2017: Summary: Brexit: environment and climate change.
www.parliament.uk, accessed 1 September 2018,
<https://publications.parliament.uk/pa/ld201617/ldselect/lddeucom/109/10903.htm>.

Suing for climate justice

As of 2017, more than 800 lawsuits...
Sabin Center for Climate Change Law at Columbia University, 2019: Climate Change Litigation Databases: About, accessed 15 October 2018,
<http://climatecasechart.com/about>.

Such a suit resulted in a Dutch court...
Sabin Center for Climate Change Law at Columbia University, 2019: Urgenda Foundation v. Kingdom of the Netherlands, accessed 15 October 2018, <http://climatecasechart.com/non-us-case/urgenda-foundation-v-kingdom-of-the-netherlands>.

Likewise, a Pakistani farmer won a lawsuit...
Sabin Center for Climate Change Law at Columbia University, 2019: Leghari v. Federation of Pakistan, accessed 15 October 2018, <http://climatecasechart.com/non-us-case/ashgar-leghari-v-federation-of-pakistan>.

In a 2018 paper in the journal *Transnational Environmental Law*...
Peel, J., and H. M. Osofsky, 2018: A rights turn in climate change litigation? *Transnational Environmental Law*, 7, 37–67, <https://doi.org/10.1017/S2047102517000292>.

... one against the utility American Electric Power...
Sabin Center for Climate Change Law at Columbia University, 2019: American Electric Power Co., v. Connecticut, accessed 15 October 2018,

<http://climatecasechart.com/case/american-electric-power-co-v-connecticut/>

...and the other against ExxonMobil...

Sabin Center for Climate Change Law at Columbia University, 2019: Native Village of Kivalina v. ExxonMobil Corp., accessed 15 October 2018,

<http://climatecasechart.com/case/native-village-of-kivalina-v-exxonmobil-corp.>

State-level common law has been invoked...

Sabin Center for Climate Change Law at Columbia University, 2019: City of Oakland v. BP p.l.c., accessed 15 October 2018, <http://climatecasechart.com/case/people-state-california-v-bp-plc-oakland.>

In 2018, Judge William Alsup dismissed that suit...

Greene, R., 2018: A judge's ruling puts climate change in limbo. *Fort Worth Star-Telegram* (6 July 2018), accessed 15 October 2018, <https://www.star-telegram.com/opinion/opn-columns-blogs/richard-greene/article214451019.html>.

Working with the trust and with Earth Guardians...

Sabin Center for Climate Change Law at Columbia University, 2019: Juliana v. United States, accessed 15 October 2018, <http://climatecasechart.com/case/juliana-v-united-states.>

One of the plaintiffs was Sophie Kivlehan...

Our Children's Trust, 2019: Sophie Kivlehan. Accessed 15 October 2018, <https://www.ourchildrenstrust.org/sophie.>

CHAPTER 14

The Predicament

The schematic at right shows how these three quantities evolve...

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Fig. 12.44, p. 1104, <https://www.ipcc.ch/report/ar5/wg1.>

In its 2013 assessment, the IPCC considered...

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1113, <https://www.ipcc.ch/report/ar5/wg1>.

Selecting a target

This value, the “do not exceed” goal...

Gao, Y., X. Gao, and X. Zhang, 2017: The 2 °C global temperature target and the evolution of the long-term goal of addressing climate change—From the United Nations Framework Convention on Climate Change to the Paris Agreement. *Engineering*, **3**, 272–278, <https://doi.org/10.1016/J.ENG.2017.01.022>.

As German analyst Oliver Geden noted in 2013...

Geden, O., 2013: Modifying the 2°C target: climate policy objectives in the contested terrain of scientific policy advice, political preferences, and rising emissions. SWP Research Paper, German Institute for International and Security Affairs, <https://www.swp-berlin.org/en/publication/climate-modifying-the-2-c-target>.

2°C—or beyond?

The implications of going past 1.5°C to 2.0°C...

IPCC, 2018: Special Report: Global Warming of 1.5°C. Intergovernmental Panel on Climate Change, <http://www.ipcc.ch/report/sr15>.

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McKibben, B., 2012: Global warming’s terrifying new math. *Rolling Stone*, 19 July, accessed 2 September 2018, <https://www.rollingstone.com/politics/politics-news/global-warmings-terrifying-new-math-188550>.

The wedge strategy

The two Princeton University scientists brought the wedge concept...

Pacala, S., and R. Socolow, 2004: Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. *Science*, **305**, 968–972, <https://doi.org/10.1126/science.1100103>.

In 2011, seven years after the breakthrough paper...

Socolow, R., 2011: Wedges reaffirmed. *Bulletin of the Atomic Scientists*, 27 September, accessed 2 September 2018, <https://thebulletin.org/2011/09/wedges-reaffirmed>.

Taking into account the stark realities of our current path...

Davis, S. J., L. Cao, K. Caldeira, and M. I. Hoffert, 2013: Rethinking wedges. *Environmental Research Letters*, **8**, 011001, <https://doi.org/10.1088/1748-9326/8/1/011001>.

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Romm, J., 2008: Cleaning up on carbon. *Nature Reports Climate Change*, **2**, 85–87, <https://doi.org/10.1038/climate.2008.59>.

CHAPTER 15

Political Solutions

Before Paris, there was Kyoto

A year earlier the UN had forged the Montreal Protocol...

UN Treaty Collection, 1987: Montreal Protocol on Substances that Deplete the Ozone Layer, accessed 2 September 2018, https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-2-a&chapter=27&clang=_en.

The protocol even had a happy side effect...

Morgenstern, O., P. Braesicke, M. M. Hurwitz, F. M. O'Connor, A. C. Bushell, C. E. Johnson, and J. A. Pyle, 2008: The world avoided by the Montreal Protocol. *GRL*, **35**, L16811, <https://doi.org/10.1029/2008GL034590>.

Had nations not acted to cut CFCs...

Molina, M., D. Zaelke, K. M. Sarma, S. O. Andersen, V. Ramanathan, and D. Kaniaru, 2009: Reducing abrupt climate change risk using the Montreal Protocol and other regulatory

actions to complement cuts in CO₂ emissions. *PNAS*, **106**, 20616–20621, <https://doi.org/10.1073/pnas.0902568106>.

Through this amendment, adopted in 2016...

UN Treaty Collection, 2016: Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, accessed 2 September 2018, https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-2-f&chapter=27&clang=_en.

In response, the World Meteorological Organization...

UNFCCC, 2018: UNFCCC — 20 Years of Afford and Achievement, accessed 2 September 2018, <http://unfccc.int/timeline>.

The UN Framework Convention on Climate Change...

United Nations, 2012: United Nations Framework Convention on Climate Change. UN Document FCCC/INFORMAL/84, 24 pp., accessed 2 September 2018, <https://unfccc.int/sites/default/files/conveng.pdf>.

But in 1997 the U.S. Congress voted 95–0...

U.S. Senate, 1997: S.Res.98 - A resolution expressing the sense of the Senate regarding the conditions for the United States becoming a signatory to any international agreement on greenhouse gas emissions under the United Nations Framework Convention on Climate Change. Congress.gov, accessed 2 September 2018, <https://www.congress.gov/bill/105th-congress/senate-resolution/98>.

Australia belatedly joined the treaty in December 2007...

Rootes, C., The first climate change election? The Australian general election of 24 November 2007. *Environmental Politics*, **17**, 473–480, <https://doi.org/10.1080/09644010802065815>.

The only major country to withdraw from Kyoto...

Staff and agencies, 2011: Canada pulls out of Kyoto Protocol. *Guardian* (12 December), accessed 2 September 2018, <https://www.theguardian.com/environment/2011/dec/13/canada-pulls-out-kyoto-protocol>.

How Kyoto worked

The meat of the Kyoto Protocol...

POLIMP, 2018: Overview of Climate Targets in Europe. Climate Policy Info Hub, accessed 2 September 2018, <https://climatepolicyinfohub.eu/overview-climate-targets-europe>.

About 2.5% of the total emission cuts...

Shishlov, I., R. Morel, and V. Bellassen, 2016: Compliance of the parties to the Kyoto Protocol in the first commitment period. *Climate Policy*, **16**, 768–782, <https://doi.org/10.1080/14693062.2016.1164658>.

The emissions market

Emissions trading is just what its name implies...

UN Climate Change, 2019: Emissions trading. Accessed 17 February 2019, <https://unfccc.int/process/the-kyoto-protocol/mechanisms/emissions-trading>.

The Clean Development Mechanism (CDM), first proposed by Brazil...

UN Climate Change, 2019: The Clean Development Mechanism. Accessed 17 February 2019, <https://unfccc.int/process-and-meetings/the-kyoto-protocol/mechanisms-under-the-kyoto-protocol/the-clean-development-mechanism>.

UN Climate Change, 2019: Joint implementation. Accessed 17 February 2019, <https://unfccc.int/process/the-kyoto-protocol/mechanisms/joint-implementation>.

For example, more than a dozen large factories...

Schapiro, M., 2012: 'Perverse' carbon payments send flood of money to China. Yale Environment360 (13 December 2010), accessed 17 February 2019, [perverse_co2_payments_send_flood_of_money_to_china](https://www.yale.edu/en360/perverse_co2_payments_send_flood_of_money_to_china)

Although the UN banned new factories in 2007...

Rosenthal, E., and A. W. Lehren, 2012: Profits on carbon credits drive output of a harmful gas. New York Times (8 August 2012), <https://www.nytimes.com/2012/08/09/world/asia/incentive-to-slow-climate-change-drives-output-of-harmful-gases.html>.

Such credits were banned from Europe's emissions trading system...

Carbon Market Watch, 2012: Industrial Gases (HFC-23 & N₂O). Carbon Market Watch (30 May 2012), accessed 17 February 2019, <https://carbonmarketwatch.org/2012/05/30/industrial-gases-hfc-23-n2o>.

This comfortable margin was derisively termed “hot air” ...

Böhringer, C., 2000: Cooling down hot air: a global CGD analysis of post-Kyoto carbon abatement strategies. *Energy Policy*, **28**, 779–789, [https://doi.org/10.1016/S0301-4215\(00\)00060-4](https://doi.org/10.1016/S0301-4215(00)00060-4).

From Copenhagen to Paris

A number of Kyoto participants opted not to join...

European Commission, 2013: Questions & Answers on EU ratification of the second commitment period of the Kyoto Protocol. European Union (6 November 2013), accessed 17 February 2019, http://europa.eu/rapid/press-release_MEMO-13-956_en.htm.

The resulting Copenhagen Agreement...

UN Climate Change, 2019: Information provided by Parties to the Convention relating to the Copenhagen Accord. Accessed 17 February 2019, <https://unfccc.int/process/conferences/pastconferences/copenhagen-climate-change-conference-december-2009/statements-and-resources/information-provided-by-parties-to-the-convention-relating-to-the-copenhagen-accord>

...was merely “noted” by participants...

Reuters, 2009: FACTBOX-Main points of the Copenhagen Accord (22 December 2009), accessed 17 February 2019, <https://www.reuters.com/article/us-copenhagen-climate-accord-idUSTRE5BL2M920091222>

...it did manage to codify unprecedented pledges from China...

Climate Action Tracker, 2019: Pledges and targets: China. Accessed 17 February 2019, <https://climateactiontracker.org/countries/china/pledges-and-targets/>

...and the United States...

Climate Action Tracker, 2019: Pledges and targets: United States. Accessed 17 February 2019, <https://climateactiontracker.org/countries/usa/pledges-and-targets/>

...and to establish a Green Climate Fund...

Green Climate Fund, 2019: Who We Are: About the Fund. Accessed 17 February 2019, <https://www.greenclimate.fund/who-we-are/about-the-fund>

...there was fresh debate over how and whether...

Harvey, F., 2012: Doha climate change deal clears way for 'damage aid' to poor nations. *The Guardian* (8 December 2012), accessed 17 February 2019,

<https://www.theguardian.com/environment/2012/dec/08/doha-climate-change-deal-nations>

The push for a new global accord by 2015...

The White House, 2015: U.S.-China Joint Presidential Statement on Climate Change, accessed 2 September 2018, <https://obamawhitehouse.archives.gov/the-press-office/2015/09/25/us-china-joint-presidential-statement-climate-change>.

The traumatic aftermath threatened to cast a pall...

The White House, 2015: Remarks by President Obama at the First Session of COP21, accessed 2 September 2018, <https://obamawhitehouse.archives.gov/the-press-office/2015/11/30/remarks-president-obama-first-session-cop21>.

"The delegates were clapping, cheering...

2015: Paris climate change agreement: the world's greatest diplomatic success. *Guardian* (14 December), accessed 2 September 2018, <https://www.theguardian.com/environment/2015/dec/13/paris-climate-deal-cop-diplomacy-developing-united-nations>.

"The world finally has a framework...

Davenport, C., 2015: Nations approve landmark climate accord in Paris. *New York Times* (12 December), accessed 2 September 2018, <https://www.nytimes.com/2015/12/13/world/europe/climate-change-accord-paris.html>.

UN climate chief Christiana Figueres tweeted...

Twitter, 2015: @CFigueres: "I used to say we must, we can, we will, today we can say we did!" #ParisAgreement #COP21 #GoCOP21. @COP21en, accessed 2 September 2018, <https://twitter.com/COP21en/status/675774496129814532>

If the Paris Agreement is to make a real difference...

Rogelj, J., O. Fricko, M. Meinshausen, V. Krey, J. J. Zilliacus, and K. Riahi, 2017: Understanding the origin of Paris Agreement emission uncertainties. *Nature Communications*, **8**, 15748, <https://doi.org/10.1038/ncomms15748>.

This interpretation boomeranged in June 2017...

Zhang, H., H. Dai, H. Lai, and W. Wang, 2017: U.S. withdrawal from the Paris Agreement: Reasons, impacts, and China's response. *Advances in Climate Change Research*, **8**, 220–225, <https://doi.org/10.1016/j.accre.2017.09.002>

The pros and cons of clean development

Yet not everyone likes the CDM...

Sandbag, 2019: What is the Clean Development Mechanism (CDM)? The Guardian (26 July 2011), accessed 17 January 2019, <https://www.theguardian.com/environment/2011/jul/26/clean-development-mechanism>.

Some activist groups, including the WWF...

Morgan, J., 2000: Make-or-break for the Kyoto Protocol. World Wildlife Fund press release (10 November 2000), accessed 17 January 2019, <https://www.worldwildlife.org/press-releases/make-or-break-for-the-kyoto-protocol>.

...the Plantar project in southeastern Brazil...

De Gouvello, C., C. Diwald, and F. N. de Valera Marques, 2018: From Project to Global Public Good: The story of the Plantar Group – World Bank Partnership. World Bank, Washington, D.C., 22 pp., <http://documents.worldbank.org/curated/en/181531530091352113/From-Project-to-Global-Public-Good-The-story-of-the-Plantar-Group-World-Bank-Partnership>.

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Buzzo, A., 2016: The new investment model in development and its limits. Pitt Panoramas (5 October 2016), accessed 17 January 2019, <https://www.panoramas.pitt.edu/economy-and-development/new-investment-model-development-and-its-limits>.

The neighboring Ngäbe-Buglé peoples...

Giraldo, C. M., 2017: Panama's Barro Blanco dam to begin operation, indigenous pleas refused. Mongabay (24 March 2017), accessed 17 January 2019, <https://news.mongabay.com/2017/03/panamas-barro-blanco-dam-to-begin-operation-indigenous-pleas-refused>.

In a more distributed approach...

Shahan, Z., 2014: The solar energy revolution everyone's ignoring...is in Bangladesh. Clean Technica (25 October 2014), accessed 17 January 2019, <https://cleantechnica.com/2014/10/25/solar-energy-revolution-everyones-ignoring-bangladesh/>

Other microfinance programs for decentralized solar power...

Merchant, E. F., 2018: Off grid electric secures \$55 million in financing. Green Tech Media (24 January 2018), accessed 17 January 2019, <https://www.greentechmedia.com/articles/read/55-million-investment-sets-new-record-for-off-grid-service-companies#gs.IdYMWcL5>

What makes for a useful climate agreement?

In 2005, the United States teamed up with...

McGee, J. and R. Taplin, 2014: The Asia-Pacific partnership and market-liberal discourse in global climate governance. *International Journal of Law in Context*, **10**, 338–356, <https://doi.org/10.1017/S1744552314000159>.

Among the most intriguing and influential plans...

Meyer, A. 2000: *Contraction & Convergence: The Global Solution to Climate Change*. UIT Cambridge, 100 pp.

Putting a price on carbon

The main question has been which of two competing approaches...

Hovi, J., and B. Holtsmark, 2006: Cap-and-trade or carbon taxes? The feasibility of enforcement and the effects of non-compliance. *International Environmental Agreements: Politics, Law and Economics*, **6**, 137–155, <https://doi.org/10.1007/s10784-006-9002-6>.

However, he warned in his 2013 book...

Nordhaus, W. B., 2013: *The Climate Casino: Risk, Uncertainty, and Economics for a Warming World*. Yale University Press, 392 pp.

Scientist and activist James Hansen believes a global carbon tax...

Hansen, J., 2016: Carbon pricing: a useful cautionary tale. Earth Institute/Columbia University (28 October), accessed 3 September 2018, <http://csas.ei.columbia.edu/2016/10/28/carbon-pricing-a-useful-cautionary-tale>.

...he calls for a fairly large one...

van der Zee, B., 2010: James Hansen rails against cap-and-trade plan in open letter. *Guardian* (12 January), accessed 3 September 2018, <https://www.theguardian.com/environment/2010/jan/12/james-hansen-carbon-emissions>.

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Baker, J. A. III, M. Feldstein, T. Halstead, N. G. Mankiw, H. M. Paulson Jr, G. P. Schultz, T. Stephenson, and R. Walton, 2017: The Conservative Case for Carbon Dividends. Climate Leadership Council, accessed 3 September 2018, <https://www.clcouncil.org/wp-content/uploads/2017/02/TheConservativeCaseforCarbonDividends.pdf>

Leading the charge were California Governor Jerry Brown...

Bloomberg Philanthropies Support, 2018: About America's Pledge, accessed 3 September, 2018, <https://www.americaspledgeonclimate.com/about>.

National, regional, and local schemes

A big part of the EU's strategy for climate protection...

Ellerman, A. D., C. Marcantonini, and A. Zaklan, 2016: The European Union emissions trading system: Ten years and counting. *Review of Environmental Economics and Policy*, **10**, 89–107, <https://doi.org/10.1093/reep/rev014>.

After peaking in 2005, the nation's CO₂ emissions...

U.S. Energy Information Administration, 2017: U.S. Energy-Related Carbon Dioxide Emissions, 2016, accessed 3 September 2018, <https://www.eia.gov/environment/emissions/carbon>

The plan was promptly rescinded by Donald Trump...

Lisa Friedman and Brad Plumer, 2017: E.P.A. announces repeal of major Obama-era carbon emissions rule. *New York Times* (9 October), accessed 3 September 2018, <https://www.nytimes.com/2017/10/09/climate/clean-power-plan.html>.

The EPA's 2018 Green Power Partnership Top 100 list...

U.S. Environmental Protection Agency, 2018: Green Power Partnership National Top 100. Updated 23 July 2018, accessed 3 September 2018, <https://www.epa.gov/greenpower/green-power-partnership-national-top-100>.

One of the leaders in this movement was Masdar City...

Goldenberg, S., 2016: Masdar's zero-carbon dream could become world's first green ghost town. *Guardian* (16 February), accessed 3 September 2018, <https://www.theguardian.com/environment/2016/feb/16/masdars-zero-carbon-dream-could-become-worlds-first-green-ghost-town>.

It's no coincidence that grand eco-developments tend to spring up...

Sze, J., 2015: *Fantasy Islands: Chinese Dreams and Ecological Fears in an Age of Climate Crisis*. University of California Press, 248 pp.

Pulling money out of fossil fuels

Some 350 institutions and local governments...

350.org, 350 Campaign Update: Divestment. Accessed 17 February 2019, <https://350.org/350-campaign-update-divestment>.

Desmond Tutu, the South African archbishop...

Tutu, D., 2014: We need an apartheid-style boycott to save the planet. *The Guardian* (10 April 2014), accessed 17 February 2019, <https://www.theguardian.com/commentisfree/2014/apr/10/divest-fossil-fuels-climate-change-keystone-xl>.

The lion's share of greenhouse gas...

Griffin, P., 2017: The Carbon Majors Database: CDP Carbon Majors Report. Carbon Accountability Institute, accessed 17 February 2019, <http://climateaccountability.org/pdf/CarbonMajorsRpt2017%20Jul17.pdf>.

Divestment jumped to a new level in 2018...

Chestney, N., 2018: Ireland commits to divesting public funds from fossil fuel companies. Reuters (12 July 2018), accessed 17 February 2019, <https://www.reuters.com/article/us-ireland-fossilfuels-divestment/ireland-commits-to-divesting-public-funds-from-fossil-fuel-companies-idUSKBN1K22AA>.

As 350.org's Bill McKibben told InsideClimate News...

McKenna, P., 2018: Ireland set to divest from fossil fuels, first country in global climate campaign. InsideClimate News (13 July 2018), <https://insideclimatenews.org/news/13072018/ireland-fossil-fuel-divestment-bill-climate-change-investors-350-campaign-coal-oil-gas>.

How much will it cost?

The terms of the debate shifted sharply in 2006...

HM Treasury, 2006: *Stern Review on the Economics of Climate Change*. UK National Archives, accessed 3 September 2018, http://webarchive.nationalarchives.gov.uk/+tf/http://www.hm-treasury.gov.uk/sternreview_index.htm

While he praised the Stern report for its attempt...

Nordhaus, W. D., 2007: A review of the *Stern Review on the Economics of Climate Change*. *Journal of Economic Literature*, **45**, 686–702, <https://doi.org/10.1257/jel.45.3.686>.

In the journal *Global Environment Change*, for example...

Pielke, R. Jr., 2007: Mistreatment of the economic impacts of extreme events in the Stern Review Report on the Economics of Climate Change. *Global Environmental Change*, **17**, 302–310, <https://doi.org/10.1016/j.gloenvcha.2007.05.004>.

A 2017 study in *Science*, led by Solomon Hsiang...

Hsiang, S., and Coauthors, 2017: Estimating economic damage from climate change in the United States. *Science*, **356**, 1362–1369, <https://doi.org/10.1126/science.aal4369>.

Who owns the Arctic?

Via submarine, Russia planted a flag...

Falcounbridge, G., 2007: Russian sub plants flag under North Pole. Reuters (August 7), accessed 3 September 2018, <https://www.reuters.com/article/idINIndia-28784420070802>.

These and other disputes are addressed through the Law of the Sea...

Fishman, J., 2015: Russian territorial claim collides with Convention on the Law of the Sea. *North Carolina Journal of International Law* (18 September), accessed 3 September 2018, <http://blogs.law.unc.edu/ncilj/2015/09/18/russian-territorial-claim-collides-with-convention-on-the-law-of-the-sea>.

For example, the Denver-based firm Omnitrax...

Henson, B., 2018: Hanging on. Weather.com (24 August), accessed 3 September 2018, <https://features.weather.com/exodus/chapter/churchill-canada-exodus>.

Russia appears to have the strongest long-term designs...

Daiss, T., 2016: Russia kicks up Arctic oil drilling as polar ice caps melt. *Forbes* (22 August), accessed 3 September 2018, <https://www.forbes.com/sites/timdaiss/2016/08/22/a-deal-with-the-devil-russia-kicks-up-arctic-oil-drilling/#53f940e8381e>

In his book *The World in 2050*...

Smith, L. C., 2010: *The World in 2050: Four Forces Shaping Civilization's Northern Future*. Dutton, 336 pp.

The risk of international conflict

Such research has played out in the American military sphere...

National Defense University, 1978: *Climate Change to the Year 2000*. U.S. Government Printing Office, 137 pp., accessed 3 September 2018, <https://eric.ed.gov/?id=ED160394>.

One landmark defense-oriented assessment of climate change...

Schwartz, P., and D. Randall, 2003: *An Abrupt Climate Change Scenario and Its Implications for United States National Security*, accessed 3 September 2018, <https://www.iatp.org/documents/an-abrupt-climate-change-scenario-and-its-implications-for-unitedstates-national-security>.

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Sullivan, Gen. G. R., and Coauthors, 2007: *National Security and the Threat of Climate Change*. CNA Corporation, 63 pp., accessed 3 September 2018, <http://ossfoundation.us/projects/environment/global-warming/summary-docs/security-reports/National%20Security%20and%20the%20Threat%20of%20Climate%20Change.pdf/view>.

Although the Trump administration yanked all mention...

U.S. House Armed Services Committee, 2018: H.R.2810 - National Defense Authorization Act for Fiscal Year 2018, accessed 3 September 2018, <https://www.congress.gov/bill/115th-congress/house-bill/2810/text>.

A group led by Colin Kelley (University of California, Santa Barbara)...

Kelley, C. P., S. Mohtadi, M. A. Cane, R. Seager, and Y. Kushnir, 2015: Climate change in the Fertile Crescent and implications of the recent Syrian drought. *Proceedings of the National Academy of Sciences U.S.A.*, **112**, 3241–3246, <https://doi.org/10.1073/pnas.1421533112>.

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Selby, J., O. S. Dahi, C. Fröhlich, and M. Hulme, 2017: Climate change and the Syrian civil war revisited. *Political Geography*, **60**, 232–244, <https://doi.org/10.1016/j.polgeo.2017.05.007>.

CHAPTER 16

Technological Solutions

The future of fossil fuels

In 2015, according to the International Energy Agency...

International Energy Agency, 2019: Statistics Data Browser; Share of electricity generation by fuel | World 2016. Accessed 17 February 2019, <https://www.iea.org/statistics/?country=WORLD&year=2016&category=Electricity&indicator=undefined&mode=chart&dataTable=ELECTRICITYANDHEAT>.

This includes China, India, and the United States...*

U.S. Energy Information Administration, 2019: Coal explained: How much coal is left. Accessed 17 February 2019, https://www.eia.gov/energyexplained/index.php?page=coal_reserves.

*The top five coal-coal emitting nations as of 2015 also include Russia and Australia.

Global consumption of coal dropped by more than 4%...

Ritchie, H., and Roser, M., 2019: Fossil Fuels: Coal: Coal production by region. Our World in Data, accessed 17 February 2019, <https://ourworldindata.org/fossil-fuels#coal>.

Donald Trump's vocal support for what he's called "beautiful, clean coal"...

Irfan, U., 2018: Trump's perennial "war on coal" claim, fact-checked. *Vox* (31 January), accessed 4 September 2018, <https://www.vox.com/2018/1/30/16953292/trump-war-on-coal-claim-fact-checked>.

As early as 2007, a state agency in Kansas denied permits...

Wald, M. L., 2007: Citing global warming, Kansas denies plant permit. *New York Times* (20 October), accessed 4 September 2018, <https://www.nytimes.com/2007/10/20/business/20plant.html>.

U.S. Environmental Protection Agency, 2015: Carbon Pollution Standards Final Rule August 2015, accessed 4 September 2018, <https://archive.epa.gov/epa/cleanpowerplan/carbon-pollution-standards-final-rule-august-2015.html>.

Similarly, a 2009 ruling mandated that any new coal-fired power plants...

Carrington, D., 2009: No new coal without carbon capture, UK government rules. *Guardian* (23 April), accessed 4 September 2018, <https://www.theguardian.com/environment/2009/apr/23/carbon-capture-plans>.

...and in 2013 the nation announced...

U.K. Department of Energy & Climate Change and The Rt. Hon. Edward Davey, 2013: Written statement to Parliament: UK position on public financing of coal plants overseas.

UK.gov, accessed 4 September 2018, <https://www.gov.uk/government/speeches/uk-position-on-public-financing-of-coal-plants-overseas>.

Yet as of 2013, only about a third...

World Coal Association, 2014: A Global Platform for Accelerating Coal Efficiency, accessed 4 September 2018,

https://www.worldcoal.org/sites/default/files/resources_files/pace_concept_paper%2809_01_2015%29.pdf.

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U.S. Department of Energy, 2018: Gasification Systems. Energy.gov, accessed 4 September 2018, <https://www.energy.gov/fe/science-innovation/clean-coal-research/gasification>.

When will the oil (and gas) run out?

In 1956, M. King Hubbert, a geologist at Shell...

Donev, J., 2015: Energy education: Hubbert's peak. University of Calgary, accessed 4 September 2018, https://energyeducation.ca/encyclopedia/Hubbert's_peak.

In its 2017 World Energy Outlook...

International Energy Agency, 2017: World Energy Outlook 2017, accessed 4 September 2018, <https://www.iea.org/weo2017>.

Carbon capture and storage

This process is known as carbon capture and storage...

Haszeldine, R. S., S. Flude, G. Johnson, and V. Scott, 2018: Negative emissions technologies and carbon capture and storage to achieve the Paris Agreement commitments.

Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 376, 20160447, <https://doi.org/10.1098/rsta.2016.0447>.

There are two big pieces to the CCS puzzle...

CCP, 2018: Key large-scale CO₂ capture and storage (CCS) projects, accessed 4 September 2018, https://www.co2captureproject.org/ccs_in_action.html.

The first was the Boundary Dam project in Saskatchewan...

SaskPower, 2018: BD3 Status Update, August 2018, accessed 4 September 2018,

<https://www.saskpower.com/about-us/our-company/blog/bd3-status-update-august-2018>.

The other full-scale CSS facility...

NRG.com, Petra Nova: Carbon capture and the future of coal power, accessed 4 September 2018, <https://www.nrg.com/case-studies/petra-nova.html>.

Meanwhile, the United Kingdom revamped its slow spin-up...

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