

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/CBO9781107415324>.

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/CBO9781107415379>.

IPCC AR5 WGII Part 2

IPCC, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects*. V. R. Barros et al., Eds., Cambridge University Press, 688 pp., <https://doi.org/10.1017/CBO9781107415386>.

IPCC AR5 WGIII

IPCC, 2014: *Climate Change 2014: Mitigation of Climate Change*. O. Edenhofer et al., Eds., Cambridge University Press, 1465 pp., <https://doi.org/10.1017/CBO9781107415416>.

IPCC AR5 Synthesis

IPCC, 2014: *Climate Change 2014: Synthesis Report*. R. K. Pachauri et al., Eds., IPCC, 151 pp., <http://www.ipcc.ch/report/ar5/syr/>.

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...

NOAA National Centers for Environmental Information, 2018: Global Climate Report – Annual 2017, accessed 7 September 2018, <https://www.ncdc.noaa.gov/sotc/global/201713>.

The first decade of the twenty-first century...

Columbia University, 2010: 2000-2009: The warmest decade. The Earth Institute (22

January), accessed 7 September 2018,
<http://www.earth.columbia.edu/articles/view/2620>.

The major glaciers remaining...

Milman, O., 2017: US Glacier national park losing its glaciers with just 26 of 150 left. *Guardian* (11 May), accessed 7 September 2018,
<https://www.theguardian.com/environment/2017/may/11/us-glacier-national-park-is-losing-its-glaciers-with-just-26-of-150-left>.

The average blooming date of Japan's famous sakura...

Primack, R., H. Higuchi, and A. Miller-Rushing, 2009: The impact of climate change on cherry trees and other species in Japan. *Biological Conservation*, 142, 1943–1949,
<https://doi.org/10.1016/j.biocon.2009.03.016>.

In the region around Massachusetts' Walden Pond...

Primack, R., 2014: *Walden Warming: Climate Change Comes to Thoreau's Woods*. University of Chicago Press, 264 pp.

Southern flying squirrels are meeting and mating...

Loten, A., 2013: Southern flying squirrels land in Canada. *Wall Street Journal* (11 October), accessed 10 September 2018, <https://www.wsj.com/articles/southern-flying-squirrels-land-in-canada-1381543272>

Armadillos—once confined to Texas and Florida...

Handwerk, B., 2011: Armadillo invasion: Warm-weather critters expanding east. *National Geographic News* (8 October), accessed 10 September 2018,
<https://news.nationalgeographic.com/news/2011/10/111007-armadillos-united-states-invasive-species-animals-environment>.

Inuit in the Canadian Arctic...

Ashford, G., and J. Castleden, 2011: *Inuit Observations on Climate Change: Final Report*. International Institute for Sustainable Development, 36 pp.,
https://www.iisd.org/pdf/inuit_final_report.pdf

Many forms of marine life...

Pecl, G. T., and Coauthors, 2017: Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being, *Science*, 355, eaai9214,
<https://doi.org/10.1126/science.aai9214>.

Climate change or global warming?

In 1975, Wallace Broecker...

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>.

Politicians hoping to downplay...

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>.

How could humans change the whole world's climate?

...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>.

Couldn't the changes have natural causes?

1995: "The balance of evidence..."

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>.

2001: "There is new and stronger evidence..."

IPCC TAR WG1, 2001: Albritton, D. L., et al, *Climate Change 2001: The Scientific Basis*, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Summary for Policymakers, p. 10, https://www.ipcc.ch/site/assets/uploads/2018/07/WG1_TAR_SPM.pdf.

2007: "Human-induced warming of the climate system..."

Hegerl, G.C., and Coauthors, 2007: Understanding and Attributing Climate Change. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the

Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 665, <https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter9-1.pdf>.

2013: “It is extremely likely that human influence... 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, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf.

One such study, conducted at the National Center for Atmospheric Research (NCAR)... Meehl, G. A., W. M. Washington, C. M. Ammann, J. M. Arblaster, T. M. L. Wigley, and C. Tebaldi, 2004: Combinations of natural and anthropogenic forcings in twentieth-century climate. *Journal of Climate*, **17**, 3721–3727, [https://doi.org/10.1175/1520-0442\(2004\)017<3721:CONAAF>2.0.CO;2](https://doi.org/10.1175/1520-0442(2004)017<3721:CONAAF>2.0.CO;2).

How do rainforests fit into the picture?

Though deforestation has eased significantly over the last few years... Gibbs, D., N. Harris and F. Seymour, By the numbers: The value of tropical forests in the climate change equation. World Resources Institute, accessed 28 January 2019, <https://www.wri.org/blog/2018/10/numbers-value-tropical-forests-climate-change-equation>

Are hurricanes getting worse because of global warming?

A number of studies since 2005... Knutson, T. R., and Coauthors, 2010: Tropical cyclones and climate change. *Nature Geoscience*, **3**, 157–163, <https://doi.org/10.1038/ngeo779>.

Didn't we have “global cooling” a while back?

After temperatures reached a new global high in 1998... Focus: Recent slowdown in global warming (special collection). *Nature Climate Change*, **7**, <https://www.nature.com/collections/sthnxgntvp>.

During El Niño (see chapter 7)...

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

The twenty-first century so far has seen an outsized number...

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...

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. 23, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf.

Pathways to our future climate

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

van Vuuer, D. P., and Coauthors, 2011: The representative concentration pathways: An overview. *Climatic Change*, **109**, 5–31, <https://doi.org/10.1007/s10584-011-0148-z>.

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>.

In subsequent work, they noted...

WHO, 2018: *Climate change and health*. World Health Organization, accessed 20 September 2018, <http://www.who.int/news-room/fact-sheets/detail/climate-change-and-health>.

The medical journal *Lancet*, building on IPCC findings...

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).

Will agriculture suffer?

Once global temperatures rise beyond a certain point...

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. 18, https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf.

How will the changes impact wildlife?

A report in the journal *Ecology Letters*...

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>.

According to a 2004 study in *Nature*...

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

The 2014 report from the IPCC's Working Group II concluded...

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. 14, https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf.

How will the economy be affected?

The most prominent research into this question...

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.

A 2018 review of nearly two dozen studies...

Tol, R. S. J., 2018: The economic impacts of climate change. *Review of Environmental Economics and Policy*, **12**, 4–25, <https://doi.org/10.1093/reep/rex027>.

The IPCC's Working Group III noted this in its 2014 report...

IPCC, 2014: Summary for Policymakers. In: *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 5, https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_summary-for-policymakers.pdf.

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

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

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. 23, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf.

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

The Atlantic meridional overturning circulation...

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.

Will we reach a “tipping point”?

Another approach is to set a stabilization level...

National Research Council, 2011: *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. The National Academies Press, 298 pp., <https://doi.org/10.17226/12877>.

What can we do about it?

What would it take to stop climate change?

Even if we turned off every fuel-burning machine...

Meehl, G. A., W. M. Washington, W. D. Collins, J. M. Arblaster, A. Hu, L. E. Buja, W. G. Strand, and H. Teng, 2005: How much more global warming and sea level rise? *Science*, **307**, 1769–1772, <https://doi.org/10.1126/science.1106663>.

CHAPTER 2

The Greenhouse Effect

The discussion in this chapter was heavily guided by the work of Spencer Weart:

Weart, S., 2018: The Discovery of Global Warming, accessed 26 August 2018, <https://history.aip.org/climate/index.htm#contents>.

In the 1850s, an amateur U.S. scientist...

Jackson, R., 2018: The saga of Eunice Foote and John Tyndall, accessed 20 September 2018, <https://www.rolandjackson.co.uk/single-post/2018/05/19/The-saga-of-Eunice-Foote-and-John-Tyndall>.

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>.

Methane emerges from a wide array of sources...

Global Greenhouse Gas Monitoring Network, 2018: Trends in Atmospheric Methane. NOAA

Earth System Research Laboratory/Global Monitoring Division, accessed 20 September 2018, https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4.

As for the renewed rise in emissions...

Worden, J.R., A. A. Bloom, S. Pandey, Z. Jiang, H. M. Worden, T. W. Walker, S. Houweling, and T. Röckmann, 2018: Reduced biomass burning emissions reconcile conflicting estimates of the post-2006 atmospheric methane budget. *Nature Communications*, **8**, 2227, <https://doi.org/10.1038/s41467-017-02246-0>.

Ozone, like a versatile actor...

Schultz, M. G., and Coauthors, 2018: Tropospheric Ozone Assessment Report: Database and metrics data of global surface ozone observations. *Elementa—Science of the Anthropocene*, **5**, 58, <https://doi.org/10.1525/elementa.244>.

Is the ozone hole linked to global warming?

Shortly thereafter, scientists identified the three factors...

Solomon, S., R. R. Garcia, F. S. Rowland, and D. J. Wuebbles, 1986: On the depletion of Antarctic ozone. *Nature*, **321**, 755–758, <https://doi.org/10.1038/321755a0>.

The 1987 Montreal Protocol...

UNEP Ozone Secretariat, 2018: The Montreal Protocol on Substances that Deplete the Ozone Layer. United Nations Environment Programme, accessed 20 September 2018, <http://ozone.unep.org/montreal-protocol-substances-deplete-ozone-layer/32506>.

Greenhouse pioneers

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

Arrhenius, S., 1896: On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine and Journal of Science*, **5**, 237–276, accessed 20 September 2018, http://www.rsc.org/images/Arrhenius1896_tcm18-173546.pdf.

Scientists now use a doubling of CO₂...

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.

One model created by Syukuro Manabe...

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...

Thompson, J., D. N. Carpenter, C. V. Cogbill, and D. R. Foster, 2013: Four centuries of change in northeastern United States forests. *PLOS ONE*, **8**, e72540, <https://doi.org/10.1371/journal.pone.0072540>.

...although it now appears the tropics...

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>.

One key area of inquiry is the evolving balance...

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...

NOAA/NCEI, 2018: State Climate Extremes Committee, list of state records, accessed 21 September 2018, <https://www.ncdc.noaa.gov/extremes/scec/records>.

In 2016 alone, 22 nations...

Masters, J., 2017: Confirmed: 2016 the warmest year in history of global recordkeeping. Weather Underground (18 January 2017),

<https://www.wunderground.com/blog/JeffMasters/confirmed-2016-the-warmest-year-in-history-of-global-recordkeeping.html>

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...

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. 20, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf.

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

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

“While we may want to sort out...”

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...

World Health Organization, 2014: Ambient (outdoor) air quality and health. Fact sheet 313, updated March 2014. <http://www.who.int/mediacentre/factsheets/fs313/en/>

The comprehensive Global Burden of Disease project...

GBD 2016 Risk Factor Collaborators, 2017: Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. *Lancet*, **390**, 1345–1422, [https://doi.org/10.1016/S0140-6736\(17\)32366-8](https://doi.org/10.1016/S0140-6736(17)32366-8).

One analysis led by U.S. scientists Mario and Luisa Molina...

Molina, M., and L. Molina, 2000: Integrated strategy for air quality management in the Mexico City metropolitan area. Massachusetts Institute of Technology Integrated Program on Urban, Regional and Global Air Pollution: Mexico City Case Study, Report No. 7 (October 2000),

<https://pdfs.semanticscholar.org/9fd8/05f29af1a67194c8b520abb66041a71ef34f.pdf>

When a fever hits

Alexander Frolov, the head of Russia's...

BBC, 2012: Death rate doubles in Moscow as heatwave continues. BBC (6 March 2012), <https://www.bbc.com/news/world-europe-10912658>.

All told, the months of July and August...

Gutterman, S., 2010: Heat, smoke sent Russia deaths soaring in 2010. Reuters (25 October 2010), <https://www.reuters.com/article/us-russia-heat-deaths/heat-smoke-sent-russia-deaths-soaring-in-2010-govt-idUSTRE6904LB20101025>.

Early in 2010, President Dmitry Medvedev...

Shuster, S., 2010: Will Russia's Heat Wave End Its Global-Warming Doubts? TIME (2 August 2010), <http://content.time.com/time/world/article/0,8599,2008081,00.html>.

At least three U.S. locations experienced evening lows...

Masters, M., 2012: Summer in March, 2012, draws to a close. Weather Underground (23 March 2012), <https://www.wunderground.com/blog/JeffMasters/summer-in-march-2012-draws-to-a-close.html>.

July 2012 ended up...

NOAA National Centers for Environmental Information, 2012: National Climate Report – July 2012. <https://www.ncdc.noaa.gov/sotc/national/201207>

The human cost of heat

Later estimates brought the toll...

Robine, J.-M., S. L. K. Cheung, S. Le Roy, H. Van Oyen, C. O. Griffiths, J.-P. Michel, and F. Herrmann, 2008: Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes Rendus Biologies*, **331**, 171–178, <https://doi.org/10.1016/j.crvi.2007.12.001>.

In Rome, more than half...

P. Michelozzi, F. de' Donato, G. Accetta, F. Forastiere, M. D'Ovidio, and C. Perucci, 2004: Impact of heat waves on mortality — Rome, Italy, June-August 2003. *Morbidity and Mortality Weekly Report*, **53**, 369–371, <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5317a5.htm>.

That same year, Laurence Kalkstein...

Sheridan, S. K., and L. S. Kalkstein, 2004: Progress in heat watch-warning system technology. *BAMS*, **85**, 1931–1942, <https://doi.org/10.1175/BAMS-85-12-1931>.

It's been estimated that Philadelphia's heat plan...

Ebi, K., L., T. J. Teisberg, L. S. Kalkstein, L. Robinson, and R. F. Weiher, 2004: Heat watch/warning systems save lives: estimated costs and benefits for Philadelphia 1995–98. *Bull. Amer. Meteor. Soc.*, **85**, <https://doi.org/10.1175/BAMS-85-8-1067>.

The nights Chicago fried

Then things really heated up...

Klinenberg, E., 2015: *Heat Wave: A Social Autopsy of Disaster in Chicago*. 2nd ed., University of Chicago Press, 328 pp.

“They were often interpreted...

Klinenberg, E., personal communication, 10 October 2003.

A 2014 study in *Environmental Health Perspectives*...

Bobb, J. F., R. D. Peng, M. L. Bell, and F. Dominici, 2014: Heat-related mortality and adaptation to heat in the United States. *Environmental Health Perspectives*, **122**, 811–816, <http://doi.org/10.1289/ehp.1307392>.

Hundreds of Californians died in...

Joe, L., H. Sumi, D. Dobraca, R. Jackson, S. Smorodinsky, D. Smith, and M. Harnly, 2016: Mortality during a large-scale heat wave by place, demographic group, internal and external causes of death, and building climate zone. *International Journal of Environmental Research and Public Health*, **13**, 299, <https://doi.org/10.3390/ijerph13030299>.

Attributing the heat

The resulting study, published in Nature in 2004...

Stott, P. A., D. A. Stone, and M. R. Allen, 2004: Human contribution to the European heatwave of 2003. *Nature*, **432**, <https://doi.org/10.1038/nature03089>.

For example, Randall Dole...

R. Dole, M. Hoerling, J. Perlwitz, J. Eischeid, P. Pegion, T. Zhang, X.-W. Quan, T. Xu, and D. Murray, 2011: Was there a basis for anticipating the 2010 Russian heat wave? *GRL*, **38**, <https://doi.org/10.1029/2010GL046582>.

However, using a different technique...

Rahmstorf, S., and D. Coumou, 2011: Increase of extreme events in a warming world. *PNAS*, **108**, <https://doi.org/10.1073/pnas.1101766108>.

Out of 16 heat-related attribution studies...

AMS, 2017 and 2016: Explaining Extreme Events from a Climate Perspective. Titles linked from main page for each year's report, available from <https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/explaining-extreme-events-from-a-climate-perspective>

The future of summer sizzle

Drawing on these core indices...

Donat, M. G., and Coauthors, 2013: Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *Journal of Geophysical Research: Atmospheres*, **118**, 2098–2118, <https://doi.org/10.1002/jgrd.50150>.

Jana Sillmann (Canadian Centre for Climate Modelling and Analysis)...

Sillmann, J., V. V. Kharin, F. W. Zwiers, X. Zhang, and D. Bronaugh, 2013: Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections. *Journal of Geophysical Research: Atmospheres*, **118**, 2473–2493, <https://doi.org/10.1002/jgrd.50188>.

When they sifted through the 2013 IPCC modeling...

Donat, M. G., A. J. Pitman, and S. I. Seneviratne, 2017: Regional warming of hot extremes accelerated by surface energy fluxes. *Geophysical Research Letters*, **44**, 7011–7019, <https://doi.org/10.1002/2017GL073733>.

A wild card in the Atlantic

The Atlantic meridional overturning circulation...

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. 1094, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf.

Handling the heat

Because diabetes inhibits sweating...

Nassar, A. A., R. D. Childs, M. E. Boyle, K. A. Jameson, M. Fowke, K. R. Waters, M. J. Hovan, and C. B. Cook, 2010: Diabetes in the desert: what do patients know about the heat? *Journal of Diabetes Science and Technology*, **4**, 1156–1163, <https://doi.org/10.1177/193229681000400514>.

High temperatures may also be related...

Ordunez, P., C. Saenz, R. Martinez, E. Chapman, L. Reveiz, and F. Becerra, 2014: The epidemic of chronic kidney disease in Central America. *Lancet Global Health*, **2**, e440–441, [http://doi.org/10.1016/S2214-109X\(14\)70217-7](http://doi.org/10.1016/S2214-109X(14)70217-7).

CHAPTER 5

Floods and Droughts

However, some regional patterns have emerged...

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. 5, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf.

(In the United States, average precipitation has increased...

NOAA National Centers for Environmental Information, 2018: National Climate Report - Annual 2017, accessed 29 January 2019, <https://www.ncdc.noaa.gov/sotc/national/201713>.

A more potent monsoon for India?

Consistent with this picture, most of the global models...

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. 1078, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf.

Since the 1950s, India's average monsoon rainfall...

Saha, A., S. Ghosh, A. S. Sahana, and E. P. Rao, 2014: Failure of CMIP5 climate models in simulating post-1950 decreasing trend of Indian monsoon. *GRL*, **41**, 7323–7330, <https://doi.org/10.1002/2014GL061573>.

... and the tepid 2012 season...

Romero, J. J., 2012: Blackouts illuminate India's power problems. *IEEE Spectrum* (28 September 2012), <https://spectrum.ieee.org/energy/the-smarter-grid/blackouts-illuminate-indias-power-problems>.

Yet the 2013 monsoon...

TNN, 2013: 2013 monsoon longest in years. *Times of India* (11 October 2013), <http://timesofindia.indiatimes.com/articleshow/23930343.cms>.

At least some of India's recent drying...

Chung, C. E., and V. Ramanathan, 2006: Weakening of north Indian SST gradients and the monsoon rainfall in India and the Sahel. *Journal of Climate*, **19**, 2036–2045, <https://doi.org/10.1175/JCLI3820.1>.

A 2010 study led by Purdue's Dev Niyogi...

Niyogi, D., C. Kishtawal, S. Tripathi, and R. S. Govindaraju, 2010: Observational evidence that agricultural intensification and land use change may be reducing the Indian summer monsoon rainfall. *Water Resources Research*, **3**, W03533, <https://doi.org/10.1029/2008WR007082>.

Despite the overall trend toward weaker monsoons...

Roxy, M. K., S. Ghosh, A. Pathak, R. Athulya, M. Mujumdar, R. Murtugudde, P. Terray, and M. Rajeevan, 2017: A threefold rise in widespread extreme rain events over central India, *Nature Communications*, **8**, 708, <https://doi.org/10.1038/s41467-017-00744-9>.

A wetter world (but not everywhere)

A 2015 United Nations report...

UNISDR/CRED, 2015: The Human Cost of Weather Related Disasters, 1995–2015. United Nations Office for Disaster Risk Reduction/Centre for Research on the Epidemiology of Disasters, 28 pp., <https://news.un.org/en/story/2015/11/516232-un-report-finds-90-cent-disasters-are-weather-related>.

Drought-related famines led to...

Davis, M., 2001: *Late Victorian Holocausts: El Niño Famines and the Making of the Third World*. Verso, 464 pp.

...and an estimated 15 million across China...

Edgerton-Tarpley, K., 2017: Famine in Imperial and Modern China. Oxford Research Encyclopedias: Asian History. Published online March 2017, <https://doi.org/10.1093/acrefore/9780190277727.013.133>.

The World Meteorological Organization estimates...

WMO, 2014: Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2012). World Meteorological Organization, 44 pp., https://library.wmo.int/index.php?lvl=notice_display&id=16279#.W6cU1VJRcvp.

England and the rains of autumn

You'd have to have been...

Gov.uk, 2000: Lessons Learned Autumn 2000 Floods. UK Environment Agency, 68 pp., <https://www.gov.uk/government/publications/autumn-2000-floods-review>

Only a few years later...

UK Met Office, 2014: Winter 2013/14, accessed 21 September 2018, <https://www.metoffice.gov.uk/climate/uk/summaries/2014/winter>.

And on December 5, 2015,...

McCarthy, M., S. Spillane, S. Walsh, and M. Kendon, 2016: The meteorology of the exceptional winter of 2015/2016 across the UK and Ireland. *Weather*, **71**, 305–313, <https://doi.org/10.1002/wea.2823>.

As part of a European Commission–funded project...

Ekström, M., H.J. Fowler, C.G. Kilsby, and P.D. Jones, 2005: New estimates of future changes in extreme rainfall across the UK using regional climate model integrations. 2. Future estimates and use in impact studies. *Journal of Hydrology*, **300**, 234–251, <https://doi.org/10.1016/j.jhydrol.2004.06.019>.

Subsequent work by Fowler and colleagues...

Jones, M. R., H. J. Fowler, C. G. Kilsby, and S. Blenkinsop, 2012: An assessment of changes in seasonal and annual extreme rainfall in the UK between 1961 and 2009. *International Journal of Climatology*, **33**, 1178–1194, <https://doi.org/10.1002/joc.3503>.

In 2002, Povel Frich...

Frich, P., L. V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. M. G. Klein Tank, and T. Peterson, 2002: Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research*, **19**, 193–212, <https://doi.org/10.3354/cr019193>.

A 2013 overview led by Markus Donat...

Donat, M., and Coauthors, 2013: Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *Journal of Geophysical Research: Atmospheres*, **118**, 2098–2118, <https://doi.org/10.1002/jgrd.50150>.

Are floods increasing?

Putting aside any potential contribution...

Jongman, B., and Coauthors, 2014: Increasing stress on disaster-risk finance due to large floods. *Nature Climate Change*, **4**, 264–268, <https://doi.org/10.1038/nclimate2124>.

One of the first attempts at a global flood census...

Milly, P. C. D., R. T. Wetherald, K. A. Dunne, and T. L. Delworth, 2002: Increasing risk of great floods in a changing climate. *Nature*, **415**, 514–517, <https://doi.org/10.1038/415514a>.

A 2009 study from the National Center for Atmospheric Research...

Dai, A., T. Qian, K. E. Trenberth, and J. D. Milliman, 2009: Changes in Continental Freshwater Discharge from 1948 to 2004. *Journal of Climate*, **22**, 2773–2792, <https://doi.org/10.1175/2008JCLI2592.1>.

In its special 2012 report...

Seneviratne, S. I., and Coauthors, 2012: Changes in climate extremes and their impacts on the natural physical environment. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, C. B. Field et al., Eds., Cambridge University Press, 109–230, <http://www.ipcc.ch/report/srex>.

A comprehensive 2017 study...

Alfieri, L., B. Bisselink, F. Dottori, G. Naumann, A. de Roo, P. Salamon, K. Wyser, and L. Feyen, 2016: Global projections of river flood risk in a warmer world. *Earth's Future*, **5**, 171–182, <https://doi.org/10.1002/2016EF000485>.

Which way will the Sahel go?

Dai, A., P. J. Lamb, K. E. Trenberth, M. Hulme, P. D. Jones, and P. Xie, 2004: The recent Sahel drought is real. *International Journal of Climatology*, **24**, 1323–1331, <https://doi.org/10.1002/joc.1083>.

It appears that the North Atlantic...

Hoerling, M., J. Hurrell, J. Eischeid, and A. Phillips, 2006: Detection and attribution of twentieth-century northern and southern African rainfall change. *Journal of Climate*, **19**, 3989–4008, <https://doi.org/10.1175/JCLI3842.1>.

Subsequent work by Giannini and colleagues...

Giannini, A., S. Salack, T. Lodoun, A. Ali, A. T. Gaye, and O. Ndiaye, 2013: A unifying view of climate change in the Sahel linking intra-seasonal, interannual and longer time scales.

Environmental Research Letters, **8**, 024010, <https://doi.org/10.1088/1748-9326/8/2/024010>.

Michela Biasutti (Lamont-Doherty Earth Observatory)...

M. Biasutti, 2013: Forced Sahel rainfall trends in the CMIP5 archive. *JGR Atmospheres*, **118**, 1613–1623, <https://doi.org/10.1002/jgrd.50206>.

Right now, the region...

Potts, M., E. Zulu, M. Wehner, F. Castillo, and C. Henderson, 2013: *Crisis in the Sahel: Possible Solutions and the Consequences of Inaction*. University of California, Berkeley, 66 pp., <http://sph.berkeley.edu/perfect-storm-climate-change-and-population-growth-brewing-african-sahel-experts-warn>

The story of Lake Chad...

UN Environment Programme, 2018: The tale of a disappearing lake. ReliefWeb (28 February 2018), <https://reliefweb.int/report/chad/tale-disappearing-lake>.

From that angle, says NCAR's Hurrell...

Hurrell, J., personal communication, 1 September 2013.

Defining drought

Diffenbaugh, N. S., D. L. Swain, and D. Touma, 2015: Anthropogenic warming has increased drought risk in California. *Proceedings of the National Academy of Sciences U.S.A.*, **112**, 3931–3936, <https://doi.org/10.1073/pnas.1422385112>.

The drying of southern Australia

As a severe dry spell raged...

Lawson, H., 1888: Beaten Back. The Poetry of Henry Lawson, accessed 21 September 2018, <http://www.ironbarkresources.com/henrylawson/BeatenBack.html>.

A 1920 book called *Australian Meteorology*...

Taylor, T. G., 1920: *Australian Meteorology: A Text-Book Including Sections on Aviation and Climatology*. Clarendon Press, 312 pp.

Since the mid-1970s...

BOM, 2017: Greater Perth in 2017: Rain and temperatures near average. Australian Government, Bureau of Meteorology. Previous years of data available from this website, accessed 21 September 2018, <http://www.bom.gov.au/climate/current/annual/wa/perth.shtml>

Australia's Bureau of Meteorology...
Australian Government, 2007: Climate Change in Australia (2007), accessed 21 September 2018, <http://ccia2007.climatechangeinaustralia.gov.au>

... followed by an even more comprehensive analysis...
Australian Government, 2016: Climate Change in Australia (2015), accessed 21 September 2018, <https://www.climatechangeinaustralia.gov.au/en/>

The pattern switched dramatically...
Boening, C., J. K. Willis, F. W. Landerer, R. S. Nerem, and J. Fasullo, 2012: The 2011 La Niña: So strong, the oceans fell. *GRL*, **39**, L19602, <https://doi.org/10.1029/2012GL053055>.

Desalination—the conversion of ocean water...
Australian Water Association, 2018: Desalination (fact sheet), accessed 21 September 2018, http://www.awa.asn.au/AWA_MBRR/Publications/Fact_Sheets/Desalination_Fact_Sheet.a_spx

What do oceans have to do with drought?

Scientists such as Richard Seager...
R. Seager 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>.

...and Toby Ault...
Ault, T. R., J. E. Cole, J. T. Overpeck, G. T. Pederson, and D. M. Meko, 2014: Assessing the risk of persistent drought using climate model simulations and paleoclimate data. *Journal of Climate*, **27**, 7529–7549, <https://doi.org/10.1175/JCLI-D-12-00282.1>.

After three years of major drought...
Conradie, W. S., The “Day Zero” Drought: When and Where? CSAG Blog (23 July 2018), accessed 20 September 2018, <http://www.csag.uct.ac.za/2018/07/23/drought-when-and-where>.

Tedford, D., 2017: Over the last 40 years, there is a surprising trend with California wildfires. Orange County Register (17 September 2017), accessed 20 September 2018, <https://www.ocregister.com/2017/09/14/you-may-not-believe-it-but-the-number-of-california-wildfires-has-been-going-down>.

A team led by LeRoy Westerling...

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam, 2006: Warming and earlier spring increase western U.S. forest wildfire activity. *Science*, **313**, 940–943, <https://doi.org/10.1126/science.1128834>.

Interestingly, the state's long-term average rainfall...

NOAA/NCEI, Climate at a Glance: Statewide Time Series (California, temperature and precipitation, 1895–2017), accessed 20 September 2018, <https://www.ncdc.noaa.gov/cag/statewide/time-series>.

...including Noah Diffenbaugh...

Diffenbaugh, N. S., D. L. Swain, and D. Touma, 2015: Anthropogenic warming has increased drought risk in California. *PNAS*, **112**, 3931–3936, <https://doi.org/10.1073/pnas.1422385112>.

...Daniel Swain...

Swain, D. L., B. Langenbrunner, J. D. Neelin, and A. Hall, 2018: Increasing precipitation volatility in twenty-first-century California. *Nature Climate Change*, **8**, 427–433, <https://doi.org/10.1038/s41558-018-0140-y>.

...and Michael Mann...

Mann, M. E., and P. H. Gleick, 2015: Climate change and California drought in the 21st century. *Proceedings of the National Academy of Sciences U.S.A.*, **112**, 3858–3859, <https://doi.org/10.1073/pnas.1503667112>.

The plow and its followers: Farming and rainfall

The flip side of this faith...

Glantz, M. H. (ed.), 1994: *Drought Follows the Plow: Cultivating Marginal Areas*. Cambridge University Press, 216 pp.

Now it seems that researchers...

Behnke, R. H., and M. Mortimore (eds.), 2016: *The End of Desertification?: Disputing Environmental Change in the Drylands*. Springer, 560 pp.

CHAPTER 6

The Big Melt

... sending frozen and melted water to the ocean at accelerating rates...

Rignot, E., I. Velicogna, M. R. van den Broeke, A. Monaghan, and J. T. M. Lenaerts, 2011: Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *GRL*, **38**, L05503, <https://doi.org/10.1029/2011GL046583>.

On thin ice

As of 2017, the average coverage in September...

NSIDC, 2017: Arctic sea ice 2017: Tapping the brakes in September. National Snow and Ice Data Center (5 October 2017), accessed 29 January 2019, <http://nsidc.org/arcticseaicenews/2017/10>.

Even the wintertime ice extent is shrinking...

NSIDC, 2018: Arctic sea ice maximum at second lowest in the satellite record. National Snow and Ice Data Center (23 March 2018), accessed 29 January 2019, <http://nsidc.org/arcticseaicenews/2018/3>.

The summer of 2007 smashed all prior records...

NASA, 2007: Record Arctic sea ice loss in 2007. NASA Earth Observatory (26 September 2007), accessed 29 January 2019, <https://earthobservatory.nasa.gov/images/8074/record-arctic-sea-ice-loss-in-2007>.

A team led by Xiangdong Zhang...

Zhang, X., A. Sorteberg, J. Zhang, R. Gerdes, and J. C. Comiso, 2008: Recent radical shifts of atmospheric circulations and rapid changes in Arctic climate system. *GRL*, **35**, L22701, doi:10.1029/2008GL035607.

In almost every year since 2007...

Cressey, D., Arctic melt opens Northwest Passage. *Nature*, **449**, 267, <https://doi.org/10.1038/449267b>.

Meanwhile, the Northern Sea Route...

Hodges, J., A. Shiryayevskaya, and D. Khrennikova, 2018: As Arctic ice melts, new energy

shipping trade route opens. *Insurance Journal* (30 August 2018), accessed 29 January 2019, <https://www.insurancejournal.com/news/international/2018/08/30/499650.htm>.

In 2010, two yachts—*Northern Passage* and *Peter 1*...
ExplorersWeb, 2010: Best of ExplorersWeb 2010 Awards: North Pole circumnavigation (24 December 2010), accessed 29 January 2019, <https://www.explorersweb.com/polar/news.php?id=19834>.

Data on ice thickness collected by U.S. nuclear submarines...
Rothrock, D. A., D. B. Percival, and M. Wensnahan, 2008: The decline in arctic sea-ice thickness: Separating the spatial, annual, and interannual variability in a quarter century of submarine data. *JGR Oceans*, **113**, C05003, <https://doi.org/10.1029/2007JC004252>.

At the University of Washington, a model called...
Neven, 2017: PIOMAS May 2017. Arctic Sea Ice Blog (4 May 2017), accessed 29 January 2019, <https://neven1.typepad.com/blog/2017/05/piomas-may-2017.html>.

...and the September minimum had plunged...
Neven, 2017: PIOMAS October 2017. Arctic Sea Ice Blog (9 October 2017), accessed 29 January 2019, <https://neven1.typepad.com/blog/2017/10/piomas-october-2017.html>.

A team led by David Barber (University of Manitoba)...
Barber, D. G., R. Galley, M. G. Asplin, R. De Abreu, K.-A. Warner, M. Pućko, M. Gupta, S. Prinsenberg, and S. Julien, 2009: Perennial pack ice in the southern Beaufort Sea was not as it appeared in the summer of 2009, *GRL*, **36**, L24501, <https://doi.org/10.1029/2009GL041434>.

The tenuous state of today's Arctic ice . . .
Zhang, J., R. Lindsay, A. Schweiger, and M. Steele, 2013: The impact of an intense summer cyclone on 2012 Arctic sea ice retreat, *GRL*, **40**, 720–726, <https://doi.org/10.1002/grl.50190>.

As pointed out by James Overland and Muyin Wang...
Overland, J. E., and M. Wang, 2013: When will the summer Arctic be nearly sea ice free? *GRL*, **40**, 2097–2101, <https://doi.org/10.1002/grl.50316>.

... it looks as if the storm mainly hastened the destruction...
Zhang, J., R. Lindsay, A. Schweiger, and M. Steele, 2013: The impact of an intense summer cyclone on 2012 Arctic sea ice retreat. *GRL*, **40**, 1–7, <https://doi.org/10.1002/grl.50190>.

What makes the Arctic so vulnerable?

As a team of scientists noted...

Overpeck, J. T., and Coauthors, 2005: Arctic system on trajectory to new, seasonally ice-free state. *Eos*, **86**, 309–313, <https://doi.org/10.1029/2005EO340001>.

In a definitive 2005 study,

ACIA Secretariat and Cooperative Institute for Arctic Research 2005: Arctic Climate Impact Assessment. Cambridge University Press, 1042 pp., <http://www.acia.uaf.edu/pages/scientific.html>.

One analysis found that distinctive low-lying clouds...

Bennartz, R., and Coauthors, 2013: July 2012 Greenland melt extent enhanced by low-level liquid clouds. *Nature*, **496**, 83–86, <https://doi.org/10.1038/nature12002>.

People, animals, and ice

At Hudson Bay, near the southern end...

Obbard, M. E., M. R. L. Cattet, E. J. Howe, K. R. Middel, E. J. Newton, G. B. Kolenosky, K. F. Abraham, and C. J. Greenwood, 2016: Trends in body condition in polar bears (*Ursus maritimus*) from the Southern Hudson Bay subpopulation in relation to changes in sea ice. *Arctic Science*, **2**, 15–32, <https://doi.org/10.1139/as-2015-0027>.

Natural variations alone may make it impossible...

Jahn, A., J. E. Kay, M. M. Holland, and D. M. Hall, 2016: How predictable is the timing of a summer ice-free Arctic? *GRL*, **43**, 9113–9120, <https://doi.org/10.1002/2016GL070067>.

One bear shot in 2006 in northern Canada...

Jex, C., 2016: Grizzly-polar bear hybrids spotted in Canadian Arctic. *ScienceNordic* (6 June 2016), <http://sciencenordic.com/grizzly-polar-bear-hybrids-spotted-canadian-arctic>.

A 2016 study in *Biology Letters* led by Eric Regehr...

Regehr, E. V., and Coauthors, 2016: Conservation status of polar bears (*Ursus maritimus*) in relation to projected sea-ice declines. *Biology Letters*, **12**, 20160556, <http://doi.org/10.1098/rsbl.2016.0556>.

One survey of ringed seal populations...

Chambellant, M., I. Stirling, W. A. Gough, and S. H. Ferguson, 2012: Temporal variations in Hudson Bay ringed seal (*Phoca hispida*) life-history parameters in relation to environment. *Journal of Mammalogy*, **93**, 267–281, <https://doi.org/10.1644/10-MAMM-A-253.1>.

In 2012 the U.S. government...

U.S. Federal Register, 2012: Endangered and Threatened Species; Threatened Status for the Arctic, Okhotsk, and Baltic Subspecies of the Ringed Seal and Endangered Status for the Ladoga Subspecies of the Ringed Sea. Rule issued on 28 December 2012.

<https://www.federalregister.gov/documents/2012/12/28/2012-31066/endangered-and-threatened-species-threatened-status-for-the-arctic-okhotsk-and-baltic-subspecies-of>

...and two populations of bearded seals...

U.S. Federal Register, 2012: Endangered and Threatened Species; Threatened Status for the Beringia and Okhotsk Distinct Population Segments of the *Erignathus barbatus nauticus* Subspecies of the Bearded Seal. Rule issued on 28 December 2012.

<https://www.federalregister.gov/documents/2012/12/28/2012-31068/endangered-and-threatened-species-threatened-status-for-the-beringia-and-okhotsk-distinct-population>

Move or drown: One town's tough choice

Residents have long counted on the freeze-up...

Milman, O., 2016: Alaska indigenous people see culture slipping away as sea ice vanishes. *The Guardian* (19 December 2016), accessed 29 January 2019,

<https://www.theguardian.com/environment/2016/dec/19/alaska-sea-ice-vanishing-climate-change-indigenous-people>

Recent October and November storms...

Thompson, A., 2017: Alaska's coast is vanishing, 1 storm at a time. *Scientific American* (30 November 2017), accessed 29 January 2019,

<https://www.scientificamerican.com/article/alaskas-coast-is-vanishing-1-storm-at-a-time>.

Cliff-bolstering structures and a seawall...

State of Alaska, 2019: Alaska Climate Change Impact Mitigation Program, Community Planning Grants: Shishmaref. Alaska Department of Commerce, Community, and Economic Development, accessed 29 January 2019,

<https://www.commerce.alaska.gov/web/dkra/PlanningLandManagement/ACCIMP/CommunityPlanningGrants/ShishmarefCPG.aspx>.

In 2002 the townspeople voted...

Serhan, Y., 2016: The vote on the future of a Native Alaskan community. *The Atlantic* (18 August 2016), accessed 29 January 2019, <https://www.theatlantic.com/news/archive/2016/08/alaskas-eroding-island/496421>.

Four mainland sites within a few miles...

Aecom, 2016: Relocation Site Selection Feasibility Study. City of Shishmaref, accessed 29 January 2019, https://www.commerce.alaska.gov/web/Portals/4/pub/Shishmaref_Site_Selection_Feasibility_Study_FINAL_022316.pdf

Wherever they end up, the move will be a costly process...

Wachs, A., 2016: One remote Alaska city is seeking \$200 million to flee the rising sea. *The Architects Newspaper* (18 October 2016), accessed 29 January 2019, <https://archpaper.com/2016/10/shishmaref-alaska-flee-rising-sea/>

A softening landscape

In Yakutsk, the major city . . .

GRID-Arendal, "Permafrost May Accelerate Global Warming, UNEP Scientists Warn," 7 February 2001, <http://www.grida.no/polar/news/2442.aspx>

Even so, future warming is bound to make things worse...

Shiklomanov, N. I., D. A. Streletskiy, T. B. Swales, and V. A. Kokorev, 2016: Climate change and stability of urban infrastructure in Russian permafrost regions: prognostic assessment based on GCM climate projections. *Geographical Review*, **107**, 125–142, <https://doi.org/10.1111/gere.12214>.

One of the first major analyses of permafrost–climate feedback...

Schaefer, K., T. Zhang, L. Bruhwiler, and A. P. Barrett, 2011: Amount and timing of permafrost carbon release in response to climate warming. *Tellus B*, **63**, 165–180, <https://doi.org/10.1111/j.1600-0889.2011.00527.x>.

Methane lurking in the muck

...more recent studies have lent further support...

Ruppel, C. D., and J. D. Kessler, 2017: The interaction of climate change and methane hydrates. *Reviews of Geophysics*, **55**, 126–168, <https://doi.org/10.1002/2016RG000534>.

How will Greenland's fate affect ours?

A major ice-core analysis released in 2012 ...

NEEM community members, 2013: Eemian interglacial reconstructed from a Greenland folded ice core. *Nature*, **493**, 489–494, <https://doi.org/10.1038/nature11789>.

The 2013 IPCC report notes that if global temperatures were sustained...

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. 29, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf.

On July 12, satellites detected wet snow...

NSIDC, 2012: What caused last summer's Greenland surface melt? National Snow and Ice Data Center (3 December 2012), accessed 10 February 2019, <https://nsidc.org/cryosphere/icelights/2012/12/what-caused-last-summer's-greenland-surface-melt>.

According to an exhaustive 2012 analysis...

Shepherd, A., and Coauthors, 2012: A reconciled estimate of ice-sheet mass balance. *Science*, **338**, 1183–1189, <https://doi.org/10.1126/science.1228102>.

Thanks in large part to the remnants of Hurricane Nicole...

Mottram, R., P. Langen, and M. Stendel, 2017: Guest post: How the Greenland ice sheet fared in 2017. CarbonBrief (1 September 2017), accessed 10 February 2019, <https://www.carbonbrief.org/guest-post-greenland-ice-sheet-2017>.

...the winter of 2016–17 was the first since 2002...

NSIDC, 2018: 2017 review and 2018 season kick-off. National Snow and Ice Data Center (9 April 2018), accessed 10 February 2019, <http://nsidc.org/greenland-today/2018/04/2017-review-and-2018-season-kick-off>.

...a dissenting view appeared in a modeling study...

Shannon, S. R., and Coauthors, 2013: Enhanced basal lubrication and the contribution of the Greenland ice sheet to future sea-level rise. *Proceedings of the National Academy of Sciences U.S.A.*, **110**, 14,156–14,161, <https://doi.org/10.1073/pnas.1212647110>.

This glacier moved seaward...

Jonathan Amos, 2005: Greenland glacier races to ocean. BBC News (8 December 2005), <http://news.bbc.co.uk/2/hi/science/nature/4508964.stm>.

...surged to a new record speed in 2013...

Joughin, I., B. E. Smith, D. E. Shean, and D. Floricioiu, 2014: Brief Communication: Further summer speedup of Jakobshavn Isbræ. *The Cryosphere*, **8**, 209–214, <https://doi.org/10.5194/tc-8-209-2014>.

Calving from Jakobshavn hit a dramatic point...

ESA, 2015: Chasing Ice (21 August 2015), https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1/Chasing_ice.

In the summer of 2010, Greenland's north coast...

NASA, 2010: Ice island calves off Petermann Glacier. NASA Earth Observatory (9 August 2010), <https://www.nasa.gov/topics/earth/features/petermann-calve.html>.

What about Antarctica?

... followed by even higher values in 2013 and 2014...

Scott, M., 2014: Antarctic winter sea ice extent sets new record in 2014. Climate.gov (7 October 2014), <https://www.climate.gov/news-features/featured-images/antarctic-winter-sea-ice-extent-sets-new-record-2014>.

A spectacular shift occurred in 2017 and 2018...

NSIDC, 2018: A warm approach to the equinox. National Snow and Ice Data Center (6 March 2018), <http://nsidc.org/arcticseaicenews/2018/03/a-warm-approach-to-the-equinox>.

A team at the British Antarctic Survey...

Turner, J., and Coauthors, 2016: Absence of 21st century warming on Antarctic Peninsula consistent with natural variability. *Nature*, **535**, 411–415, <https://doi.org/10.1038/nature18645>.

During the second half of the 20th century...

Turner, J., T. A. Lachlan-Cope, S. Colwell, G. J. Marshall, and W. M. Connolley, Significant warming of the Antarctic winter troposphere. *Science*, **311**, 1914–1917, <https://doi.org/10.1126/science.1121652>.

In a special 2018 issue of *Nature*...

The IMBIE Team, 2018: Mass balance of the Antarctic Ice Sheet from 1992 to 2017. *Nature*, **558**, 219–222, <https://doi.org/10.1038/s41586-018-0179-y>.

Trouble toward the equator

Not far away from Kilimanjaro, Mount Kenya lost 7 of its 18 glaciers...*

Prinz, R., A. Heller, M. Ladner, L. I. Nicholson, and G. Kaser, 2018: Mapping the loss of Mt. Kenya's glaciers: an example of the challenges of satellite monitoring of very small glaciers. *Geosciences*, **8**, 174, <https://doi.org/10.3390/geosciences8050174>

*This paper notes the loss of an additional glacier, or 8 out of 18, by 2004.

...its long-studied Lewis Glacier...

Prinz, R., L. Nicholson, and G. Kaser, 2012: Variations of the Lewis Glacier, Mount Kenya, 2004–2012. *Erdkunde*, **66**, 255–262, <https://doi.org/10.3112/erdkunde.2012.03.05>.

On the Indonesian island of Irian Jaya...

NASA, 2012: Ice loss on Puncak Jaya. NASA Earth Observatory (1 September 2012), accessed 10 February 2019, <https://earthobservatory.nasa.gov/images/79084/ice-loss-on-puncak-jaya>.

... and by 2009 the glacier had vanished...

Stacey Feldman, 2009: Bolivia's Chacaltaya Glacier melts to nothing 6 years early. InsideClimate News (6 May 2009), accessed 10 February 2019, <https://insideclimatenews.org/news/20090506/bolivias-chacaltaya-glacier-melts-nothing-6-years-early>.

The fast-disappearing ice of Kilimanjaro

Cullen, N. J., P. Sirguey, T. Mölg, G. Kaser, M. Winkler, and S. J. Fitzsimons, 2013: A century of ice retreat on Kilimanjaro: The mapping reloaded. *The Cryosphere*, **7**, 419–431, <https://doi.org/10.5194/tc-7-419-2013>.

Georg Kaser of the University of Innsbruck argues...

Kaser, G., D. R. Hardy, T. Mölg, R. S., Bradley, and T. M. Hyera, 2004: Modern glacier retreat on Kilimanjaro as evidence of climate change: observations and facts. *International Journal of Climatology*, **24**, 329–339, <https://doi.org/10.1002/joc.1008>.

One possible solution to the mystery...

Mölg, T., G. Kaser, and N. J. Cullen, 2010: Glacier loss on Kilimanjaro is an exceptional case *PNAS*, **107**, E68, <https://doi.org/10.1073/pnas.0913780107>.

Midlatitude melt

Combining space shuttle imagery with topographic data...

Rignot, E., A. Rivera, and G. Casassa, 2003: Contribution of the Patagonia Icefields of South America to sea level rise. *Science*, **302**, 434–437, <https://doi.org/10.1126/science.1087393>

So quickly is the Southern Patagonia Ice Field losing its ice...

Dietric, R., E. R., Ivins, G. Cassa, H. Lange, J. Wendt, and M. Fritsch, 2010: Rapid crustal uplift in Patagonia due to enhanced ice loss. *Earth and Planetary Science Letters*, **289**, 22–29, <https://doi.org/10.1016/j.epsl.2009.10.021>.

At heights of 1800 m (5900 ft)...

Durand, Y., M. Laternser, G. Giraud, P. Etchevers, B. Lesaffre, and L. Mérindol, 2008: Reanalysis of 44 Yr of Climate in the French Alps (1958–2002): Methodology, Model Validation, Climatology, and Trends for Air Temperature and Precipitation. *Journal of Applied Meteorology and Climatology*, **48**, 429–449, <https://doi.org/10.1175/2008JAMC1808.1>.

A stunning “warm wave” at the end of 2015...

Colucci, R. R., F. Giorgi, and C. Torma, 2017: Unprecedented heat wave in December 2015 and potential for winter glacier ablation in the eastern Alps. *Scientific Reports*, **7**, 7090, <https://doi.org/10.1038/s41598-017-07415-1>.

In Montana, Glacier National Park...

USGS, 2019: Retreat of Glaciers in Glacier National Park. U.S. Geological Survey, accessed 10 February 2019, <https://www.usgs.gov/centers/norock/science/retreat-glaciers-glacier-national-park>

Temperatures across the heart of the Himalayas...

Ren, Y., and Coauthors, 2017: Observed changes in surface air temperature and precipitation in the Hindu Kush Himalayan region over the last 100-plus years. *Advances in Climate Change Research*, **8**, 148–156, <https://doi.org/10.1016/j.accre.2017.08.001>.

The vast Columbia Glacier...

Hinsdale, J., 2018: The Columbia Glacier: Climate Change and Glacial Dynamics. Earth Institute/Columbia University (23 February 2018), accessed 10 February 2019,

<https://blogs.ei.columbia.edu/2018/02/23/columbia-glacier-climate-change-glacial-dynamics>.

However, these advances were easily explained...

Nesje, A., and J. A., Matthews, 2011: The Briksdalsbre Event: A winter precipitation-induced decadal-scale glacial advance in southern Norway in the AD 1990s and its implications. *The Holocene*, **22**, 249–261, <https://doi.org/10.1177/0959683611414938>.

...Norway's coastal glaciers again started to decline...

Hart, J. K., K. C. Rose., R. I., Waller, D. Vaughan-Hirsch, and K., Martinez, 2011: Assessing the catastrophic break-up of Briksdalsbreen, Norway, associated with rapid climate change. *Journal of the Geological Society*, **168**, 673–688, <https://doi.org/10.1144/0016-76492010-024>.

The bigger picture becomes clear in global analyses...

World Glacier Monitoring Service, 2017: Global Glacier Change Bulletin No. 2 (2014-2015), <https://doi.org/doi:10.5904/wgms-fog-2017-10>.

A rocky future for skiers

Temperatures in parts of the Alps...

CREA, 2019: Climate change and its impacts in the Alps. Research Center for Alpine Ecosystems, accessed 10 February 2019, <http://creamontblanc.org/en/climate-change-and-its-impacts-alps>

A 2003 report from the United Nations Environment Programme...

UNEP, 2003: Many ski resorts heading downhill as result of global warming. UNEP Press Release (2 December 2003), accessed 10 January 2019, <https://www.un.org/press/en/2003/unep191.doc.htm>.

Switzerland's Tortin Glacier, which supports the Verbier ski area...

Harding, L., 2005: Plastic sheet saves Swiss glacier from meltdown. *The Guardian* (11 May 2005), accessed 10 January 2019, <https://www.theguardian.com/environment/2005/may/12/climatechange.climatechange>

In response to all this, more than 70 of the nation's ski areas...

NRDC, 2004: Keep Winter Cool: Ski areas team with conservation group to fight global warming. Natural Resources Defense Council press release (19 February 2004), accessed 10 February 2019, <https://www.nrdc.org/media/2004/040219>

Australian Climate Commission, 2013: *The Critical Decade 2013: Climate Change Science, Risks and Responses*. Commonwealth of Australia, 110 pp., <http://www.climatecouncil.org.au/uploads/b7e53b20a7d6573e1ab269d36bb9b07c.pdf>

CSIRO predicted in a 2015 report...

CSIRO and Bureau of Meteorology, 2015: Climate Change in Australia, Information for Australia's Natural Resource Management Regions: Technical Report. CSIRO and Bureau of Meteorology, Australia, https://www.climatechangeinaustralia.gov.au/media/ccia/2.1.6/cms_page_media/168/CCIA_2015_NRM_TechnicalReport_WEB.pdf

CHAPTER 7

Oceans

Many scientists suspected as much for years...

Levitus, S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov, 2009: Global ocean heat content 1955–2008 in light of recently revealed instrumentation problems. *GRL*, **36**, L07608, doi:10.1029/2008GL037155.

The oceans' heat content has only continued to increase...

Johnson, G. C., and Coauthors, 2018: Ocean heat content [in State of the Climate in 2017]. *BAMS*, **99**, S72–S77, <https://www.ametsoc.org/ams/index.cfm/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/>

Some studies have estimated that if global greenhouse gas emissions...

Meehl, G. A., W. M. Washington, W. D. Collins, J. M. Arblaster, A. Hu, L. E. Buja, W. G. Strand, and H. Teng, 2005: How much more global warming and sea level rise? *Science*, **307**, 1769–1772, <https://doi.org/10.1126/science.1106663>.

From sticks to satellites: Measuring sea level

A team led by Jonathan Gregory (University of Reading/Met Office)...

Gregory, J. M., and Coauthors, 2013: Twentieth-century global-mean sea-level rise: Is the whole greater than the sum of the parts? *Journal of Climate*, **26**, 4476–4499, <https://doi.org/10.1175/JCLI-D-12-00319.1>.

... as confirmed in a 2018 analysis led by Steven Nerem...

Nerem, R. S., B. D. Beckley, J. T. Fasullo, B. D. Hamlington, D. Masters, and G. T. Mitchum, 2018: Climate-change–driven accelerated sea-level rise detected in the altimeter era. *Proceedings of the National Academy of Sciences U.S.A.*, **115**, 2022–2025, <https://doi.org/10.1073/pnas.1717312115>.

An analysis led by John Fasullo (NCAR)...

Fasullo, J., C. Boening, F. W. Landerer, and R. S. Nerem, 2013: Australia's unique influence on global sea level in 2010–2011. *GRL*, **40**, 4368–4373, <https://doi.org/10.1002/grl.50834>.

How high will the sea get?

The 2013 IPCC report assigned likely ranges...

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. 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>.

... it was joined by a Science paper from Stefan Rahmstorf...

Rahmstorf, S., 2007: A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science*, **315**, 368–370, <https://doi.org/10.1126/science.1135456>.

The IPCC explicitly acknowledged the ongoing debate...

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. 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>.

A major 2011 analysis led by Valentina Radić...

Radić, V., and R. Hock, 2011: Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise. *Nature Geoscience*, **4**, 91–94, <https://doi.org/10.1038/NCEO1052>.

A new and disturbing wrinkle emerged...

Pollard, D., R. M. DeConto, and R. B. Alley, 2015: Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure. *Earth and Planetary Science Letters*, **412**, 112–121, <https://doi.org/10.1016/j.epsl.2014.12.035>.

Are the Maldives and Tuvalu doomed?

This perspective is championed by geographer Paul Kench...

Kench, P. S., M. R. Ford, and S. D. Owen, 2018: Patterns of island change and persistence offer alternate adaptation pathways for atoll nations. *Nature Communications*, **9**, article 605, <https://doi.org/10.1038/s41467-018-02954-1>.

Donner, S., 2012: Sea level rise and the ongoing Battle of Tarawa. *Eos*, **93**, 169–170, <https://doi.org/10.1029/2012EO170001>.

A 2018 study of the Marshall Islands found that...

Storlazzi, C. D., and Coauthors, 2018: Most atolls will be uninhabitable by the mid-21st century because of sea-level rise exacerbating wave-driven flooding. *Science Advances*, **4**, eaap9741, <https://doi.org/10.1126/sciadv.aap9741>.

Risks of a rising ocean

At Norfolk, the average ocean height since 1990...

Sallenger, A. H. Jr., K. S. Doran, and P. A. Howd, 2012: Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change*, **2**, 884–888, <https://doi.org/10.1038/nclimate1597>.

The northeastern U.S. coast is vulnerable to particularly large MSL rises...

Yin, J., M. Schlesinger, and R. J. Stouffer, 2009: Model projections of rapid sea-level rise on the northeast coast of the United States. *Nature Geoscience*, **2**, 262–266, <https://doi.org/10.1038/ngeo462>.

One analysis led by the Potsdam Institute's Anders Levermann...

Levermann, A., P. U. Clark, B. Marzeion, G. A. Milne, D. Pollard, V. Radić, and A. Robinson, 2013: The multimillennial sea-level commitment of global warming. *PNAS*, **110**, 13,745–13,750, <https://doi.org/10.1073/pnas.1219414110>.

Looking centuries ahead, the geographic picture of MSL rise...

de Boer, B., P. Stocchi, P. L. Whitehouse, and R. S. W. van de Wal, 2017: Current state and future perspectives on coupled ice-sheet – sea-level modelling. *Quaternary Science Reviews*, **169**, 13–28, <https://doi.org/10.1016/j.quascirev.2017.05.013>.

According to some estimates, sea levels ran...

Dutton, A., and K. Lambeck, 2012: Ice volume and sea level during the last interglacial. *Science*, **337**, 216–219, <https://doi.org/10.1126/science.1205749>.

Climate change and El Niño

The switch flipped again in the mid-2010s...

Rahmstorf, S., 2017: El Niño and the record years 1998 and 2016. RealClimate (4 November 2017), accessed 11 February 2019, <http://www.realclimate.org/index.php/archives/2017/11/el-nino-and-the-record-years-1998-and-2016/>.

When the ups and downs from ENSO...

Skeptical Science, 2019: ENSO Temperature Trends. Accessed 11 February 2019, <https://skepticalscience.com/graphics.php?g=67>.

...is an eastward expansion of the western Pacific's warm pool...

Stevenson, S., B. Fox-Kemper, M. Jochum, R. Neale, C. Deser, and G. Meehl, 2012: Will There Be a Significant Change to El Niño in the Twenty-First Century? *Journal of Climate*, **25**, 2129–2145, <https://doi.org/10.1175/JCLI-D-11-00252.1>.

According to Gerald Meehl...

Meehl, G., H. Teng, and G. Branstator, 2006: Future changes of El Niño in two global coupled climate models. *Climate Dynamics*, **26**, 549–566, <https://doi.org/10.1007/s00382-005-0098-0>.

High-tide flooding: More than a nuisance

A 2018 study from NOAA sounded a red alert...

Sweet, W. V., G. Dusek, J. Obeysekera, and J. Marra, 2018: Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold. NOAA Technical Report NOS CO-OPS 086, 44 pp., https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.pdf.

Miami Beach has spent years working...

Allen, G., 2016: As waters rise, Miami Beach builds higher streets and political willpower. NPR (10 May 2016), accessed 11 February 2019, <https://www.npr.org/2016/05/10/476071206/as-waters-rise-miami-beach-builds-higher-streets-and-political-willpower>.

Meanwhile, Miami residents voted in 2017...

Smiley, D., 2017: Miami gets \$200 million to spend on sea rise as voters pass Miami Forever. *Miami Herald* (7 November 2017), accessed 11 February 2019, <https://www.miamiherald.com/news/politics-government/election/article183336291.html>.

The NAM, the NAO, and other climate cycles

From the 1960s into the 2010s, the SAM trended...

Visbeck, M., 2007: A station-based southern annular mode index from 1884 to 2005. *Journal of Climate*, **22**, 940–950, <https://doi.org/10.1175/2008JCLI2260.1>.

This trend is projected by climate models...

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. Mccray, 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](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-](https://www.gpo.gov/fdsys/pkg/CHRG-109shrg38918/html/CHRG-109shrg38918.htm)

[109shrg38918.htm](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>.

Just a few days later, on the opening day...

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. Fichet, 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>.

The true scope of this challenge was highlighted...

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>.

“Each of these wedges represents...

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/360/content/view/full/4211)

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. Diewald, 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>.

... activists say that such monoculture plantations...

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. Holtmark, 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>.

...it gained new attention when it was put forth...

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>.

The message was underscored in 2007...

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>.

Such claims were debated by other scholars...

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%209_01_2015%29.pdf.

Another approach to cleaning up coal...

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...

UK Committee on Climate Change, 2018: An independent assessment of the UK's Clean Growth Strategy: From ambition to action, accessed 4 September 2018, <https://www.theccc.org.uk/publication/independent-assessment-uks-clean-growth-strategy-ambition-action>.

Along with sequestration, the other puzzle piece...

Kunze, C., and H. Spliethoff, 2012: Assessment of oxy-fuel, pre- and post-combustion-based carbon capture for future IGCC plants. *Applied Energy*, **94**, 109–116, <https://doi.org/10.1016/j.apenergy.2012.01.013>.

The United States had originally planned to have its own IGCC-CSS plant...

Marshall, C., 2015: Clean coal power plant killed, again. E&E News (4 February), accessed 4 September 2018, <https://www.scientificamerican.com/article/clean-coal-power-plant-killed-again>.

Construction was well under way in 2013...

Wagman, D., 2017: The three factors that doomed Kemper County IGCC. *IEEE Spectrum* (30 June), accessed 4 September 2018, <https://spectrum.ieee.org/energywise/energy/fossil-fuels/the-three-factors-that-doomed-kemper-county-igcc>.

Two other initiatives—the 421-megawatt Hydrogen Energy California project...

Trihey, M., 2016: "David has slain Goliath" - \$4 billion Kern HECA project dies. KGET.com (3 March), accessed 4 September 2018, <https://www.kget.com/news/top-stories/david-has-slain-goliath-4-billion-kern-heca-project-dies/388271413>.

...and the 400-megawatt Texas Clean Energy Project...

Collier, K., 2018: Audit: Company behind Texas "clean coal" project used federal funds for liquor, limousines and lobbying. *Texas Tribune* (15 February), accessed 4 September 2018, <https://www.texastribune.org/2018/02/15/audit-company-behind-texas-clean-coal-project-spent-millions-liquor-li>.

And not all environmentalists are thrilled with CSS...

Nace, T., 2008: Stopping Coal in its Tracks. *Orion* (January/February 2008), accessed 4 September 2018, <http://www.energyjustice.net/files/coal/orion.pdf>.

Beyond fossil fuels: Renewables and nuclear

The *Renewable Electricity Futures Study (RE Futures)*...

National Renewable Energy Laboratory, 2012: Renewable Energy Futures Study. M. M. Hand et al., Eds., 4 vols., NREL/TP-6A20-52409, National Renewable Energy Laboratory, accessed 4 September, <https://www.nrel.gov/analysis/re-futures.html>.

Despite the challenges of energy storage and transmission...

Jacobson, M. Z., and Coauthors, 2017: 100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world. *Joule*, **1**, 108–121, <https://doi.org/10.1016/j.joule.2017.07.005>.

Solar power

As of 2016, about 300 gigawatts of grid-based electric capacity...

IEA, 2018: Solar Energy. International Energy Agency, accessed 4 September 2018, <https://www.iea.org/topics/renewables/solar/>.

The costs of solar technology have been steadily dropping...

Carrington, D., 2017: 'Spectacular' drop in renewable energy costs leads to record global boost. *Guardian* (6 June), accessed 4 September 2018, <https://www.theguardian.com/environment/2017/jun/06/spectacular-drop-in-renewable-energy-costs-leads-to-record-global-boost>.

The scope of the largest PV plants has mushroomed...

SolarInsure, 2017: Top 5 Largest Solar Plants of the World, accessed 4 September 2018, <https://www.solarinsure.com/largest-solar-power-plants>.

...was topped only by the Ivanpah Solar Electric Generating System...

NREL, 2014: Concentrating Solar Power Projects: Ivanpah Solar Electric Generating System. National Renewable Energy Laboratory, accessed 4 September 2018, https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=62.

However, Dubai is planning to build the world's largest CSP facility...

Government of Dubai, 2018: Mohammed bin Rashid Al Maktoum Solar Park, accessed 4

September 2018, <https://www.dewa.gov.ae/en/customer/innovation/renewable-energy/mohammed-bin-rashid-al-maktoum-solar-park>.

David MacKay estimated that a square in the Sahara...

Mackay, D. J. C., 2009: *Sustainable Energy — Without the Hot Air*. UIT Cambridge, 384 pp.

A plan called Desertec, which aimed to build huge solar power installations...

Casey, T., 2017: The Desertec Sahara solar dream didn't die after all — it's baaaack... *Clean Technica* (11 August), accessed 4 September 2018,

<https://cleantechnica.com/2017/08/11/desertec-sahara-solar-dream-didnt-die-baaaack>.

A still more audacious plan was put forth in 2018...

Wald, E. R., 2018: Saudi Arabia to build massive solar power installation. *Forbes* (29 March), accessed 4 September 2018,

<https://www.forbes.com/sites/ellenwald/2018/03/29/saudi-arabia-to-build-massive-solar-power-installation/#ee56a0177a90>.

Wind power

As of 2017, wind accounted for about 540 GW...

WWEA, 2018: Wind Power Capacity Reaches 539 GW, 52,6 GW Added in 2017. World Wind Energy Association, accessed 4 September 2018,

<https://wwindea.org/blog/2018/02/12/2017-statistics>.

The American Bird Conservancy has recommended mandatory design standards...

Sander, L., 2017: Can Wind Energy Be Bird Safe? American Bird Conservancy (5 January), accessed 4 September 2018, <https://abcbirds.org/can-wind-energy-be-bird-safe>.

The last few years have seen a boom...

Hill, J. S., 2018: Ørsted begins construction of world's largest offshore wind farm, The 1.2 Gigawatt Hornsea Project One. *Clean Technica* (29 January), accessed 4 September 2018,

<https://cleantechnica.com/2018/01/29/orsted-begins-construction-world-largest-offshore-wind-farm-1-2-gw-hornsea-project-one>.

The London Array—the world's largest offshore wind farm as of 2017...

London Array, 2018: The Project, accessed 4 September 2018,

<http://www.londonarray.com/the-project-3>.

Cape Wind was finally abandoned in 2017...

Seelye, K. Q., 2017: After 16 years, hopes for Cape Cod wind farm float away. *New York*

Times (19 December), accessed 4 September 2018,
<https://www.nytimes.com/2017/12/19/us/offshore-cape-wind-farm.html>

...but an even more ambitious plan has been put forth...

New York State, 2018: Governor Cuomo Releases First-in-The-Nation Offshore Wind Master Plan to Guide New York's Development of Renewable Energy, accessed 4 September 2018, <https://www.governor.ny.gov/news/governor-cuomo-releases-first-nation-offshore-wind-master-plan-guide-new-yorks-development>.

More than 13 GW of electric capacity was available...

World Energy Council, World Energy Resources: Geothermal | 2016, accessed 4 September 2018, https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Geothermal_2016.pdf.

...where the world's biggest plant—The Geysers, in California...

Power Technology, The Geysers Geothermal Field, California, accessed 4 September 2018, <https://www.power-technology.com/projects/the-geysers-geothermal-california/>

A completely different approach to geothermal...

Olasolo, P., M.C. Juárez, M. P. Morales, S. D'Amico, and I. A. Liarte, 2016: Enhanced geothermal systems (EGS): A review. *Renewable and Sustainable Energy Reviews*, **56**, 133–144, <https://doi.org/10.1016/j.rser.2015.11.031>.

A successful test of large-scale EGS...

Fedorowytch, T., 2016: Geothermal power project closes in SA as technology deemed not financially viable. ABC (30 August), accessed 4 September 2018, <http://www.abc.net.au/news/2016-08-30/geothermal-power-plant-closes-deemed-not-financially-viable/7798962>.

Storing the energy of tomorrow

Hydroelectric, tidal, and wave power

This approach currently provides far more energy...

World Energy Council, World Energy Resources: Hydropower | 2016, accessed 4 September 2018, <https://www.worldenergy.org/data/resources/resource/hydropower>.

Brazil is now pouring more than US\$150 billion...

Fearnside, P., 2017: How a dam building boom is transforming the Brazilian Amazon. *Yale Environment 360* (26 September), accessed 4 September 2018, <https://e360.yale.edu/features/how-a-dam-building-boom-is-transforming-the-brazilian-amazon>

Similar protests also occurred around Colombia's biggest hydropower project...

Harindranath, A., 2018: Hidroituango dam remains on red alert as surrounding communities brace for the worst. *Bogota Post* (2 June), accessed 4 September 2018, <https://thebogotapost.com/2018/06/02/hidroituango-dam-remains-on-red-alert-as-surrounding-communities-brace-for-the-worst>.

China's Three Gorges Dam—the largest on Earth...

USGS Water Science School, 2018: Three Gorges Dam: The world's largest hydroelectric plant. U.S. Geological Service, accessed 4 September 2018, <https://water.usgs.gov/edu/hybiggest.html>.

A 2011 study in *Nature Geoscience* led by Nathan Barros...

Barros, N., J. J. Cole, L. J. Tranvik, Y. T. Prairie, D. Bastviken, V. L. M. Huszar, P. del Giorgio, and F. Roland, 2011: Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. *Nature Geoscience*, **4**, 593–596, <https://doi.org/10.1038/ngeo1211>.

The Sihwa Lake station opened in 2011...

Kim, Y. H. 2016: Technology case study: Sihwa Lake tidal power station. International Hydropower Association (2 August), accessed 4 September 2018, <https://www.hydropower.org/blog/technology-case-study-sihwa-lake-tidal-power-station>.

In 2017, about 109 GW of global electric capacity was derived from biomass...

IRENA (2018), Renewable capacity statistics 2018. International Renewable Energy Agency, accessed 4 September 2018, <http://irena.org/publications/2018/Mar/Renewable-Capacity-Statistics-2018>.

The world's 450-plus nuclear reactors as of 2016...

World Nuclear News, 2017: Worldwide nuclear capacity continues to grow in 2016,

accessed 5 September 2018, <http://www.world-nuclear-news.org/NP-Worldwide-nuclear-capacity-continues-to-grow-in-2016-0301175.html>.

...and roughly 11% of global electricity production...

International Energy Agency, 2017: Tracking progress: Nuclear Power, accessed 5 September 2018, <https://www.iea.org/etp/tracking2017/nuclearpower>.

France now gets more than 70% of its electricity...

World Nuclear Association, 2018: Nuclear power in France, accessed 5 September 2018, <http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx>.

The United States produces more nuclear power...

World Nuclear Association, 2018: Nuclear power in the United States, accessed 5 September 2018, <http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx>.

China had some 20 nuclear reactors...

World Nuclear Association, 2018: Nuclear power in China, accessed 5 September 2018, <http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx>.

In 2003, Finland's legislature voted narrowly...

Finland Ministry of Employment and the Economy, 2011: Nuclear Power in Finland, accessed 5 September 2018, <https://tem.fi/documents/1410877/2937056/Nuclear+Energy+in+Finland>.

...construction on a sixth reactor...

Marx, E., 2016: The collective effort behind Finland's new nuclear power plant. *Energy Post* (20 October), accessed 5 September 2018, <http://energypost.eu/collective-effort-behind-finlands-new-nuclear-power-plant2>.

In 2006, France and the United States agreed...

Bajoria, J., and E. Pan, 2010: The U.S.–India Nuclear Deal. Council on Foreign Relations, accessed 5 September 2018, <https://www.cfr.org/backgrounders/us-india-nuclear-deal>.

Instead of slashing emissions by 25%...

Vivoda, V., 2013: Climate targets are the fallout from Japan's nuclear disaster. *The Conversation* (19 November), accessed 5 September 2018,

<http://theconversation.com/climate-targets-are-the-fallout-from-japans-nuclear-disaster-20481>.

Nine out of the 59 Japanese reactors...

World Nuclear Association, 2018: Nuclear power in Japan, accessed 5 September 2018, <http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-power.aspx>.

The IEA's 2017 World Energy Outlook envisioned a tiny increase...

International Energy Agency, World Energy Outlook 2017: Executive Summary, accessed 5 September 2018, <https://www.iea.org/weo2017>.

In 2013, a group of four esteemed climate researchers...

Hansen, J., K. Emanuel, K. Caldeira, and T. Wigley, 2015: Nuclear power paves the only viable path forward on climate change. *Guardian*, 3 December, accessed 5 September 2018, <https://www.theguardian.com/environment/2015/dec/03/nuclear-power-paves-the-only-viable-path-forward-on-climate-change>.

...the integral fast reactor can use almost all...

Argonne National Laboratory, 2017: Integral Fast Reactor. U.S. Department of Energy, accessed 5 September 2018, <https://www.ne.anl.gov/About/reactors/integral-fast-reactor.shtml>.

The U.S. government operated a test reactor of this type...

Cochran, T. B., and Coauthors, 2010: Fast Breeder Reactor Programs: History and Status. Research Report 8, International Panel on Fissile Materials and Princeton University, accessed 5 September 2018, <http://fissilematerials.org/library/rr08.pdf>.

Transporting people and goods by road, sea, and air...

International Energy Agency, 2017: Tracking Progress: Transport, accessed 5 September 2018, <https://www.iea.org/etp/tracking2017/transport>.

New fuel standards across the globe...

International Council on Clean Transportation, 2018: Chart library: Passenger vehicle fuel economy, accessed 5 September 2018, <https://www.theicct.org/chart-library-passenger-vehicle-fuel-economy>.

The fate of these new standards was thrown into doubt...

Lavelle, M., 2018: Trump's auto efficiency rollback: Losing the climate fight, 1 MPG at a time. *InsideClimate News* (2 August), accessed 5 September 2018,

<https://insideclimatenews.org/news/02082018/trump-fuel-efficiency-standards-rollback-climate-change-epa>.

In a 2013 report, the group found...

Yawitz, D., A. Kenward, and E. D. Larson, 2013: A Roadmap to Climate-Friendly Cars: 2013. Climate Central, accessed 5 September 2018, http://assets.climatecentral.org/pdfs/ClimateFriendlyCarsReport_revised.pdf.

The Union of Concerned Scientists estimated in 2015...

Union of Concerned Scientists, 2015: Cleaner Cars from Cradle to Grave (2015), accessed 5 September 2018, <https://www.ucsusa.org/clean-vehicles/electric-vehicles/life-cycle-ev-emissions#.W5DEy5NKjgE>.

By the late 2000s, the EU had mandated...

TransportPolicy.net, 2018: EU: Fuels: Biofuels Policy, accessed 5 September 2018, <https://www.transportpolicy.net/standard/eu-fuels-biofuel-policy>.

In the United States, the tellingly named...

U.S. Environmental Protection Agency, 2018: Overview for Renewable Fuel Standard, accessed 5 September 2018, <https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard>.

...less than 20% the size of the ethanol market...

U.S. Department of Energy, 2017: 2015 Bioenergy Market Report, accessed 5 September 2018, <https://www.nrel.gov/docs/fy17osti/66995.pdf>.

The economic case for advanced biofuels...

Liska, A. J., H. Yang, M. Milner, S. Goddard, H. Blanco-Canqui, M. P. Pelton, X. X. Fang, H. Zhu, and A. E. Suyker, 2014: Biofuels from crop residue can reduce soil carbon and increase CO₂ emissions. *Nature Climate Change*, **4**, 398–401, <https://doi.org/10.1038/nclimate2187>.

Thousands of facilities in Europe...

Scarlat, N., J. Dallemand, and F. Fahl, 2018: Biogas: Developments and perspectives in Europe. *Renewable Energy*, **129**, 457–472, <https://doi.org/10.1016/j.renene.2018.03.006>.

... and the United States are using organic crop and animal waste...

Homebiogas, 2018: Industrial Biogas in the United States of America, accessed 8 September 2018, <https://faq.homebiogas.com/en/article/industrial-biogas-in-the-united-states-of-america>.

However, unfavorable economics and the general cooling of attitudes...

Flynn, K., 2017: Algal biofuel production is neither environmentally nor commercially sustainable. *The Conversation* (8 August), accessed 6 September 2018, <https://theconversation.com/algal-biofuel-production-is-neither-environmentally-nor-commercially-sustainable-82095>.

How much can hydrogen help?

In the United States, the Bush administration launched a program in 2004...

Energy.gov, Hydrogen & Fuel Cells Program | Background. U.S. Department of Energy, accessed 6 September 2018, <https://www.hydrogen.energy.gov/background.html>.

...and Honda began rolling out its first mass-market hydrogen vehicle...

Fackler, M., 2008: Latest Honda runs on hydrogen, not petroleum. *New York Times* (17 June), accessed 6 September 2018, <https://www.nytimes.com/2008/06/17/business/worldbusiness/17fuelcell.html>.

One Swiss study found that hauling a hydrogen-filled truck...

Bossell, U., B. Eliasson, and G. Taylor, 2003: The Future of the Hydrogen Economy: Bright or Bleak? 2003 Fuel Cell Seminar, accessed 6 September 2018, <http://planetforlife.com/pdffiles/h2report.pdf>.

Around 250 such public stations were in service worldwide...

Mearian, L., 2017: Hydrogen refueling stations for cars to reach 5,000 by 2032. *Computerworld* (23 January), accessed 6 September 2018, <https://www.computerworld.com/article/3159642/car-tech/hydrogen-refueling-stations-for-cars-to-reach-5000-by-2032.html>.

Critics such as veteran researcher and blogger Joseph Romm...

Romm, J. J., 2004: *The Hype About Hydrogen: Fact and Fiction in the Race to Save the Climate*. 2nd ed., Island Press, 256 pp.

A 2016 study in the journal *Energy*...

Felgenhauer, M. F., M. A. Pellow, S. M. Benson, and T. Hamacher, 2016: Economic and environmental prospects of battery and fuel cell vehicles for the energy transition in German communities. *Energy Procedia*, **99**, 380–391, <https://doi.org/10.1016/j.egypro.2016.10.128>.

Ethanol

According to the Renewable Fuels Association...

Renewable Fuels Association, 2018: Industry Statistics, accessed 6 September 2018, <https://ethanolrfa.org/resources/industry/statistics>.

...mostly in Brazil...

Curcio, M., 2018: Carro flex chega aos 15 anos com 30,5 mil milhões de unidades. *Automotive Business* (23 March 2018), accessed 17 February 2018, accessed 6 September 2018, <http://www.automotivebusiness.com.br/inovacao/56/carro-flex-chega-aos-15-anos-com-305-milhoes-de-unidades>.

... and the United States...

U.S. Department of Energy, 2019: Alternative Fuels Data Center: Flexible Fuel Vehicles. Accessed 6 September 2018, https://afdc.energy.gov/vehicles/flexible_fuel.html.

Tad Patzek (University of California, Berkeley) has estimated...

Patzek, T., 2004: Thermodynamics of the corn-ethanol biofuel cycle. *Critical Reviews in Plant Sciences*, **23**, 519–567, <https://doi.org/10.1080/07352680490886905>.

One group of researchers from the University of Minnesota...

Tessum, C. W., J. D. Marshall, and J. D. Hill, 2012: A spatially and temporally explicit life cycle inventory of air pollutants from gasoline and ethanol in the United States. *Environmental Science and Technology*, **46**, 11408–11417, <https://doi.org/10.1021/es3010514>.

As a result, 100 units of cellulosic ethanol...

Hammerschlag, R., 2006: Ethanol's energy return on investment: A survey of the literature 1990–Present. *Environmental Science and Technology*, **40**, 1744–1750, <https://doi.org/10.1021/es052024h>.

However, the EPA was forced to slash interim targets drastically...

Lane J., 2015: EPA slashes biofuels targets for 2014, 2015, 2016 under Renewable Fuel Standard. *Biofuels Digest* (29 May), accessed 6 September 2018, <http://www.biofuelsdigest.com/bdigest/2015/05/29/epa-slashes-biofuels-targets-for-2014-2015-2016-under-renewable-fuel-standard>.

Diesel and biodiesel

A team of scientists at West Virginia University discovered...

Thompson, G. J., and Coauthors, 2014: In-Use Emissions Testing of Light-Duty Diesel Vehicles in the United States. Center for Alternative Fuels, Engines & Emissions, West Virginia University, accessed 6 September 2018, https://www.theicct.org/sites/default/files/publications/WVU_LDDV_in-use_ICCT_Report_Final_may2014.pdf.

Investigations showed that Volkswagen had been rigging its vehicles...

Jaffe, E. 2015: The study that brought down Volkswagen. *CityLab* (24 September), accessed 6 September 2018, <https://www.citylab.com/equity/2015/09/the-study-that-brought-down-volkswagen/407149>.

“The problem is that governments often fail to grasp...

Khan, S., 2017: Fact check: are diesel cars really more polluting than petrol cars? *The Conversation* (2 May), accessed 6 September 2018, <https://theconversation.com/fact-check-are-diesel-cars-really-more-polluting-than-petrol-cars-76241>.

By 2016, global production of biodiesel...

OECD-FAO, 2017: Commodity Snapshots: Biofuels. OECD-FAO Agricultural Outlook 2017–2026, accessed 6 September 2018, <http://www.fao.org/3/a-BT092e.pdf>.

Low-power towers

An award-winning, pickle-shaped tower...

Moussavi, F., 2012: 30 St. Mary Axe. *Harvard Design Magazine*, No. 35, accessed 7 September 2018, <http://www.harvarddesignmagazine.org/issues/35/30-st-mary-axe>.

In New York there's Four Times Square...

U.S. Department of Energy, 2001: 4 Times Square, New York City: Highlighting high performance, accessed 7 September 2018, https://www1.eere.energy.gov/buildings/publications/pdfs/commercial_initiative/29940.pdf.

New York also hosts the 58-story Bank of America Building...

Green Education Foundation, 2017: Bank of America Tower, accessed 7 September 2018, <http://www.greeneducationfoundation.org/green-building-program-sub/case-studies/892-bank-of-america-tower.html>.

...although a 2013 report by New Republic magazine...

Roudman, S., 2013: Bank of America's toxic tower. *New Republic* (28 July), accessed 7

September 2018, <https://newrepublic.com/article/113942/bank-america-tower-and-leed-ratings-racket>.

New York is also home to the new 26-story Cornell Tech tower...

Gray, A., 2018: The House at Cornell Tech Is the world's tallest certified passive house. *Metropolis* (24 January), accessed 7 September 2018, <https://www.metropolismag.com/architecture/passive-house-cornell-tech/>.

Completed in 2011, the 71-story Pearl River Tower...

AEI Professional Project Awards, 2014: Pearl River Tower. Architectural Engineering Institute, accessed 7 September 2018, https://www.asce.org/uploadedFiles/Technical.../SOM_Chicago_Pearl%20River.pdf.

The Shanghai Tower—which opened in 2016...

Roxburgh, H., 2016: Inside Shanghai Tower: China's tallest skyscraper claims to be world's greenest. *Guardian* (23 August), accessed 7 September 2018, <https://www.theguardian.com/cities/2016/aug/23/inside-shanghai-tower-china-tallest-building-green-skyscrapers>.

Making buildings more efficient

Buildings and the appliances they contain...

U.S. Energy Information Administration, 2017: International Energy Outlook 2017, accessed 7 September 2018, https://www.eia.gov/outlooks/archive/ieo17/exec_summ.php.

In the United States, it's an eye-opening 40%...

U.S. Energy Information Administration, 2018: Frequently Asked Questions: How much energy is consumed in U.S. residential and commercial buildings? Accessed 7 September 2018, <https://www.eia.gov/tools/faqs/faq.php?id=86&t=1>.

“Commercial and public buildings in the developed world...

Rogers, R., Foreword, in J. Hacker, S. Belcher, and R. Connell, 2005: *Beating the Heat: keeping UK buildings cool in a warming climate*. U.K. Climate Impacts Programme Briefing Report, accessed 7 September 2018, https://ukcip.ouce.ox.ac.uk/wp-content/PDFs/Beating_heat.pdf.

Since the 1970s, the size of the average new single-family U.S. home...

U.S. Census Bureau, 2016: 2016 Characteristics of New Housing, accessed 7 September 2018, <https://www.census.gov/construction/chars/pdf/c25ann2016.pdf>.

...and the fraction of homes with air conditioning...

U.S. Census Bureau, 1975: American Housing Survey (AHS): Data, accessed 7 September 2018, <https://www.census.gov/programs-surveys/ahs/data.1975.html>.

Amazingly, per capita energy use in U.S. homes...

U.S. Energy Information Administration, 2018: Monthly Energy Review, Table 1.7, accessed 7 September 2018, <https://www.eia.gov/totalenergy/data/monthly/#summary>.

EU electricity generation peaked in the mid-2000s...

Eurostat, 2018: Electricity production, consumption and market overview. European Union, accessed 7 September 2018, https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview.

The American Institute of Architects has entrained more than 400 firms...

American Institute of Architects, 2018: The 2030 Commitment, accessed 7 September 2018, <https://www.aia.org/resources/6616-the-2030-commitment>.

In the United States, lighting and office equipment...

U.S. Environmental Protection Agency, 2018: ENERGY STAR by the numbers, accessed 7 September 2018, https://www.energystar.gov/about/origins_mission/energy_star_numbers.

More than a million such units...

Renewable Energy World, 2008: Geothermal Heat Pumps, accessed 7 September 2018, <https://www.renewableenergyworld.com/articles/print/volume-11/issue-4/geothermal-energy/geothermal-heat-pumps-53531.html>.

Geoengineering: Practical solutions or potential disasters?

Famed computer scientist John von Neumann...

von Neumann, J., 1955: Can we survive technology? *Fortune* (June 1955), 106-108, 151-52.

Klaus Lackner (Arizona State University) has prototyped “synthetic trees” ...

Schiffman, R., 2016: Why CO₂ ‘air capture’ could be key to slowing global warming. *Yale Environment 360* (23 May), accessed 7 September 2018, https://e360.yale.edu/features/pulling_co2_from_atmosphere_climate_change_lackner.

The eventually cancelled plan drew scrutiny...

<http://www.imo.org/en/OurWork/Environment/LCLP/EmergingIssues/geoengineering/OceanFertilizationDocumentRepository/OceanFertilization/Pages/default.aspx>.

Among other ocean-based proposals for removing CO₂...

Lovelock, J. E., and C. G. Rapley, 2007: Ocean pipes could help the Earth to cure itself. *Nature*, **449**, 403, <https://doi.org/10.1038/449403a>.

...it's found little support in mainstream field studies...

Nordborg, M., 2016: Holistic management—a critical review of Allan Savory's grazing method. Swedish University of Agricultural Sciences, accessed 7 September 2018, <https://www.fcrn.org.uk/research-library/holistic-management-%E2%80%93-critical-review-allan-savory%E2%80%99s-grazing-method>

Globally, the land area employing no-till techniques...

CropLife International, 2014: Global Snapshot of No-Till Farming, accessed 7 September 2018, <https://croplife.org/news/global-snapshot-of-no-till-farming>.

A 2015 meta-analysis in *Field Crops Research*...

Pittelkow, C. M., and Coauthors, 2015: When does no-till yield more? A global meta-analysis. *Field Crops Research*, **183**, 156–168, <https://doi.org/10.1016/j.fcr.2015.07.020>.

Field trials back up these claims, especially in the tropics...

Biederman, L. A., and W. S. Harpole, 2012: Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *Global Change Biology Bioenergy*, **5**, 202–214, <https://doi.org/10.1111/gcbb.12037>.

Astronomers Roger Angel and Pete Worden...

Angel, R., 2006: Feasibility of cooling the Earth with a cloud of small spacecraft near the inner Lagrange point (L1). *Proceedings of the National Academy of Sciences U.S.A.*, **103**, 17,184–17,189, <https://doi.org/10.1073/pnas.0608163103>.

On a less grand scale, David Keith (Harvard University)...

Rotman, D., 2013: A cheap and easy plan to stop global warming. *MIT Technology Review* (8 February), accessed 7 September 2018, <https://www.technologyreview.com/s/511016/a-cheap-and-easy-plan-to-stop-global-warming>.

A closer-to-Earth idea, first put forth...

Latham, J., A. Gadian, J. Fournier, B. Parkes, P. Wadhams, and J. Chen, 2014: Marine cloud brightening: Regional applications. *Philosophical Transactions of the Royal Society A*, **372**, 20140053, <https://doi.org/10.1098/rsta.2014.0053>.

The late climatologist Stephen Schneider likened it...

Schneider, S. H., 1996: Geoengineering: Could—or should—we do it? *Climatic Change*, **33**, 291–302. <https://doi.org/10.1007/BF00142577>.

Klaus Lackner has responded to such concerns...

Wharton, K., 2017: The carbon catcher: Q&A with Klaus Lackner. Arizona State University (16 November), accessed 7 September 2018, <https://research.asu.edu/stories/20171116-carbon-capture-klaus-lackner>.

A 2013 study led by Simone Tilmes (NCAR)...

Tilmes, S., and Coauthors, 2013: The hydrological impact of geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP). *Atmospheres*, **118**, 11036–11058, <https://doi.org/10.1002/jgrd.50868>.

In a 2009 report, the U.K. Royal Society...

The Royal Society, 2009: Geoengineering the climate: Science, governance and uncertainty. The Royal Society, 81 pp., accessed 7 September 2018, <https://royalsociety.org/topics-policy/publications/2009/geoengineering-climate>.

...and the American Geophysical Union adopted a 2009 position statement...

Landau, E., 2018: Revised AGU Position Statement Addresses Climate Intervention. *Eos* (18 January), accessed 7 September 2018, <https://doi.org/10.1029/2018E0091015>.

A pair of 2015 reports from the U.S. National Academies...

U.S. National Academies, 2015: Climate intervention reports (2015), accessed 7 September 2018, <https://nas-sites.org/americasclimatechoices/other-reports-on-climate-change/climate-intervention-reports>.