leave their primary assets in the ground, and investors to put their money elsewhere.

Deep change is necessary. Klein emphasizes that it will centre on expressions of collective action, such as the global youth climate movement, and the anti-oil-pipeline protests in North Dakota in 2016–17. But Klein goes further. Her thesis is that neoliberalism — the prevailing global policy model, predicated on privatization and free-market capitalism — must be overthrown through mass resistance. She holds that climate change can't be separated from other pressing social problems, each a symptom of neoliberalism: income inequality, corporate surveillance, misogyny and white supremacy.

I share her concern over each of these societal afflictions, but I wonder at the assertion that it's not possible to address climate change without solving all that plagues us. My worry is this. Saddling a climate movement with a laundry list of other worthy social programmes risks alienating needed supporters (say, independents and moderate conservatives) who are apprehensive about a broader agenda of progressive social change.

The pessimist in me also doubts that we'll eliminate greed and intolerance within the next decade. As Klein rightly notes, this is precisely the timescale over which we must make substantial progress in decarbonizing our economy to avert catastrophic climate change. The optimist in me, meanwhile, recalls the response to past global environmental threats, such as depletion of the ozone layer that protects us from ultraviolet radiation. Action to reduce ozone-damaging chlorofluorocarbons under the 1987 Montreal Protocol averted environmental catastrophe. Alas, it did not obviously solve any social problems in the process.

So do we work within the system, or overthrow it? There is another way: to recognize this dilemma as false. We can, after all, work within the system (organizing, voting, demonstrating and using all the levers of democracy) while seeking to change it (for example by routing corporate money out of politics through regulations and governmental reform). I have not yet given up on this dual escape route from climate chaos.

I am also not completely convinced by the GND in its current form. I broadly support its goals, but I question its rejection of market mechanisms for pricing carbon. Klein dismisses such measures as both inadequate for reducing carbon emissions and inconsistent with a just energy transition; her argument is that the wealthy, who expend the most carbon, will not be deterred by having to pay for it.

> ***"Do we work within the system, or overthrow it? There is another way: to recognize this dilemma as false."***

Such a rejection of one of the most potent tools for reducing carbon emissions is misguided, in my view. Achieving the needed emissions cuts depends on the price. As long as that matches an objectively determined social cost of carbon pollution, it should produce the needed result. And whether a carbon tax is progressive or regressive depends on precisely what is done with the revenue. A dividend, for example, could be paid preferentially to those most affected by climate change — particularly people with low incomes.

It's advisable to decouple economic justice and environmental issues, given the turbulence in US politics under President Donald Trump. Otherwise, as one individual said to me, the Republican Party can easily cry 'socialism' to convince voters to oppose the kinds of policy we need to mitigate climate change.

Klein sometimes overreaches in building the case for climate concern. For example, she states that "oceans are warming 40 percent faster than the United Nations predicted just five years ago". However, the article on which this claim is based isn't original research, but a commentary (L. Cheng *et al.* *Science* **363**, 128–129; 2019). It notes that when errors in historical data that had led to a mismatch with climate-model predictions are corrected, the model predictions and observations are in very good agreement.

And Klein ties the current refugee crisis around the world more closely to climate change than can be objectively justified, in my view. Although climate change is an increasingly important driver of migration, myriad other factors are at work. These include conflict, economic disparity and oppressive political regimes. When it comes to making the case for climate action, the truth is bad enough. We don't need to stretch it.

These are minor quibbles, however. In *On Fire*, Klein once again provides a provocative and evocative manifesto deserving of our attention. I urge anyone who cares about the defining threat of our time to read it, and talk about it. ■

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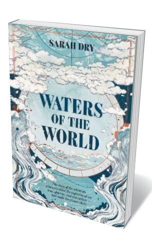
CLIMATE SCIENCE

Making the planetary personal

Ruth Morgan lauds a chronicle of Earth-systems science and its luminaries.

The roots of climate science stretch back further than many suspect — long into the nineteenth century. Victorian physicist John Tyndall's work on glaciers, for instance, helped to pave the way for twentieth-century science by the likes of meteorologist Joanne Simpson, oceanographer Henry Stommel and palaeoclimatologist Willi Dansgaard. In her remarkable *Waters of the World*, historian Sarah Dry brings to life this chain of researchers who helped to reveal the dynamics of Earth's planetary systems and humanity's growing impact on them.

Dry makes the planetary personal, drawing on archival and published sources, oral histories and memoirs. She shows how the seemingly global has always been the product of individuals, places and moments in time. That approach effectively downscales the formidable nature of science that probes deep-time phenomena, from the dawn of Earth's climate billions of years ago to human-driven change, particularly from the late-eighteenth-century start of industrialization.



Waters of the World: The Story of the Scientists Who Unravelled the Mysteries of our Seas, Glaciers, and Atmosphere — and Made the Planet Whole
SARAH DRY
Scribe UK (2019)

Most of the pioneering researchers featured in *Waters of the World* were outsiders. The mathematician Gilbert Walker knew "next to nothing" about weather when, in 1904, he took charge of the India Meteorological Department in Simla. Stommel never earned a doctorate; Simpson became, in 1949, the first woman in the United States to gain one in the male-dominated field of meteorology. These scientists were, however, inevitably influenced by particular intellectual and institutional contexts: imperial networks of ▶

In the 1850s, Irish physicist John Tyndall traced the movement of the Mer de Glace (pictured) near Chamonix in France to gain insight into Earth's ice ages.

meteorological record-keeping and cold-war science. These scientific milieux shaped their inquiries and practices, and enabled them to contest and advance knowledge. Far from narrating a steady march to scientific triumph, Dry is keen to shed light on the messier experiences of knowledge gathering.

Tyndall, an outstanding experimentalist, is renowned for his 1859 account of the physical basis of Earth's greenhouse effect. (US scientist Eunice Newton Foote had, however, beaten him to it three years earlier.) Tyndall's research built on earlier theories, including those of geologist Louis Agassiz on prehistoric glaciations, and physicist Joseph Fourier on how Earth's atmosphere traps heat.

On summer forays to the Alps, Tyndall measured motion in the Mer de Glace near Chamonix in France to gain insight into glacial movement during ice ages. He worked, too, on the heat-trapping capacity of water vapour and carbon dioxide, and surmised that variations in atmospheric levels would produce a "change of climate" — ideas that Swedish physicist Svante Arrhenius later advanced. At around the same time, Charles Piazzi Smyth, the Astronomer Royal for Scotland, was scaling volcanic Mount Teide in Tenerife, loaded with bulky telescopes. His observations prompted him to posit that researching water vapour might lead to successful weather prediction.

As Dry shows, water — as ice and clouds, and in ocean currents — became the way into understanding climate and climate change. Investigating tangible phenomena made hidden planetary mechanisms more mentally manageable. Varied in form but singular in essence, water demonstrated the unity of nature, described by the German polymath Alexander von Humboldt in his opus *Cosmos* (1845) as "the phenomena of physical objects in their general connection" and "nature as one great whole". In atmosphere, land and ocean, transmuted continually by solar energy, water was revealed as the mechanism for global energy flow.

> *"Stommel used parsnips as 'experimental apparatus' to study turbulent flow."*

The breakthroughs of the nineteenth century enabled twentieth-century conceptualizations of Earth's climate system. Walker's 1928 idea of "world weather", for instance, focused on alternating high and low pressure across the globe. The statistical methods of climatology pioneered in Europe in the 1880s by Julius von Hann and Wladimir Köppen enabled Walker, among others, to investigate the interlinked processes driving monsoons. And because observations had to be made in many places at once, they were aided by a world increasingly 'shrunken' by rail, telegraph and steamship. Walker's identification of oscillations — cyclical weather patterns — was derived from pressure data collected from balloons, kites, photographs and correspondences around the world. Meanwhile, burgeoning scientific communities ensured that researchers in the new century were far from isolated.

The scale of climate research grew apace, inviting multidisciplinarity. Dansgaard, for instance, had begun collecting rainwater in his Copenhagen backyard in mid-1952 to show the isotopic profile of a local storm. That became a "great global rain hunt" for samples testable with a mass spectrometer. This project in turn allowed him to show that oxygen isotopes bound in water could reveal global patterns of evaporation and condensation. Later, in 1958, Simpson and fellow meteorologist Herbert Riehl discovered the role of certain clouds — "hot towers" — in transferring energy (as heat rising from the ocean) from lower to higher altitudes in the tropics.

Some of the era's influential experimentation was rudimentary, even playful. Dry describes how, in the late 1940s, Stommel used parsnips as "experimental apparatus" to study turbulent flow. With the like-minded Lewis Fry Richardson, Stommel dropped pairs of the vegetables into Loch Long in Scotland, tracing their relative motion. The pair concluded that atmosphere and oceans exhibited similar forms of energy diffusion. It was not until the early 1970s that Stommel could test these ideas with the Mid-Ocean Dynamics Experiment in the Atlantic, which showed how turbulence drove ocean circulation.

Meanwhile, in 1946, General Electric chemists Vincent Schaefer and Irving Langmuir were amusing themselves with the experimental potential of a domestic freezer. They discovered that dropping dry ice into supercooled water vapour could produce precipitation. Their colleague Bernard Vonnegut (brother of the novelist Kurt) then demonstrated that silver iodide was even more effective: cloud seeding had arrived. It would be deployed in US government programmes such as the 1962–83 Project Stormfury, which also drew on work by Simpson to control weather through the modification of hurricanes. Later, in the 1950s, a timber cabin on the grounds of the Woods Hole Oceanographic Institution in Falmouth, Massachusetts, became a hub for annual meetings where Simpson, meteorologist Jule Charney and other innovators teased out geophysical fluid dynamics. As Dry shows, imagination has been as important as mathematical skill in advancing planetary knowledge.

Today's hugely sophisticated climate models have fed off all these developments. The numerical general circulation model (GCM) was first established by US meteorologist Norman Phillips in 1956. Now, it relies on the world's most powerful computers to calculate how observed data respond to sets of physical equations that mimic climate processes. The GCM attempts to calculate all these processes across land, oceans and atmosphere, at different time intervals, to produce scenarios of future conditions.

Climate science is the study of change: the discovery of the climate system coincided with the emergence of methods for tracking climatic shifts. From the late 1950s, the advent of ice-core analysis revolutionized the field, as scientists such as Dansgaard and Wally Broecker read Earth's archives in the cryosphere. The extent and rate of human impacts on climate could be deciphered only once natural climate change — glaciations and warmer periods — was fully understood. With the entry of isotope analysis, ice cores and other palaeoclimate records have become invaluable yardsticks for checking future climate uncertainty.

Waters of the World demonstrates how impoverished science might become if stripped of the stories of the people who shaped it. As we live through a climate crisis of our own making, the book reveals how researchers, over more than 150 years, defined and measured the processes that got us here — and gave us the knowledge we need to curb their worst impacts. ■

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ENVIRONMENT

Into the light: nature, culture, change

Kathleen Jamie's lens on human and planetary crises bends time and illuminates place, finds **Barbara Kiser**.

What are nature and culture on a planet we have exhaustively mapped and immeasurably changed? How are we ourselves altered in that process? In *Surfacing*, the poet and writer Kathleen Jamie explores this liminal space. Through 12 essays, she charts the passage of time in the environment and in us, examining ancient artefacts, dreamscapes and memories as they emerge into the light, and what they tell us about being human in a rapidly shifting world.

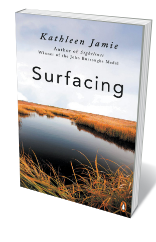
Surfacing ranges over Jamie's stints on archaeological digs on a Scottish archipelago and in the High Arctic; a sojourn in China; half-submerged familial memories. Seemingly disparate, the pieces are subtly entangled. There are echoes of Jamie's previous essay collections, *Findings* (2005) and *Sightlines* (2012). These established her unclassifiability as a writer, able to capture with equal depth a peregrine falcon intent on its prey, a Bronze Age burial, the feel of a dissected lymph node.

As in those books, there are no rhapsodies in *Surfacing*. There is a poet's economy with words, a stripped clarity.

Jamie begins in a cave in the West Highlands of Scotland, contemplating glaciations and climate change. Deep within it in 1995, divers discovered bear bones some

GRAEME WILSON

Kathleen Jamie in Orkney, UK.



Surfacing
KATHLEEN JAMIE
Penguin Press (2019)

40,000 years old — a find like "reaching the memory of the hill itself". An aficionado of deep time (she has described her young self as a "teenage antiquarian, thrilled by standing stones"), she trawls museums on the east coast of Britain to view Arctic objects brought back by nineteenth-century whalers. Among narwhal tusks and taxidermied polar bears are beautifully worked Inuit relics, traded for guns.

One such visit leads her to archaeologist Rick Knecht, who runs a dig in a Yup'ik community in the Alaskan region of Beringia. There, fast-melting permafrost is exposing objects crafted from caribou antler, stone, wood and walrus ivory 600 years ago, before missionaries and hunters arrived from the south. 'In Quinhagak' records Jamie's time on the dig. But the essay shape-shifts. It becomes a compelling portrait of a culture recovering its resilience at a climate front line, where ice-less winters and burning tundra are the new normal. And where the colonial legacy, not least addiction, is just a few villages away.

At Quinhagak, "light cascaded down from the whole sky. A ravishing, energising light." Under it, Jamie mingles with villagers amid long moments looking for bears on the tundra, or shifting mud on the site. In unearthed knife hafts shaped like seals, in villagers' stories of cranes and walruses, the human and natural coalesce.

Jamie is struck by the Yup'ik habit of attentiveness, and the cohesion it nurtures. She finds her own vision sharpening as she scans the land, and sees herself in some way as scanned by it. In the village, she "noticed that people notice", surmising that the "whole place must be in constant conversation with itself, holding knowledge collectively". When elders handle and name the long-buried artefacts — antler-scrapers, root-picks — she feels she is listening to the language of landscape, and to a people coming home.

Half a world away, she reflects on another dig. But this community, on Westray in the Orkney archipelago, moved on five ▶