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Old Waves, New Waves: Changing Objects in Physical Oceanography

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Do ocean waves have a history? The question may sound odd: surely waves are simple facts of nature, matters of the substance of the sea. Waves may have diverse manifestations in marine and maritime lore, a variety of effects on economic and political enterprise and a range of meanings for fishers, surfers and swimmers. But as formal and material entities, the standard view might say, they are best known by a science arriving at ever-improving models of oscillation, undulation and movement.

Historians of oceanography have complicated such a view, documenting the changing systems through which scientists and seafarers have known waves. This essay builds on such work to argue that a cultural history of oceanographic apprehensions of waves can add texture to the sea as a subject for environmental history. I suggest that scholars take particular notice of how the history of wave science has been animated by a persistent concern with forecasting – with looking toward oceanic futures, near-term and, increasingly today, long-term.

WAVES, THEN

The first oceanographic accounts of waves arrive from cultural imperatives in Europe and the United States to know the sea as a site for the extension of land-based activities: shipping, trade, colonial travel, warfare. In the late 1800s, two primary approaches to waves emerged: observational and theoretical. The observational – watching waves – had a centuries-long history in maritime practice. The theoretical began with the treatment of waves as objects for study in hydrodynamic theory. Sir Horace Lamb's 1879 *Hydrodynamics* was a key text, one to which scientists turned as they sought to model waves as perturbations in a 'perfect fluid' (Irvine 2002).

As oceanographic wave science was elaborated in the early twentieth century, researchers sought to fuse the observational and theoretical. In her history of oceanography, *The Edge of an Unfamiliar World*, Susan Schlee (1973) discusses the work of British oceanographer, Vaughn Cornish. In his 1934 *Ocean Waves and Kindred Geophysical Phenomena,* Cornish sought to anchor the theoretical in the observational by calculating – from shore and sea – such measures as wave height and period.

That work of measurement continued in the work of American ocean engineer Willard Bascom, known for creating the wave-energy equation: $Energy = wLH^2/8$. One of the early questions before Bascom, who began his work at Berkeley and Scripps in the 1940s was, 'Did large waves in the ocean do the same things as those in a model tank?' Bascom was keenly aware of – and fascinated by – the difference between model and reality as well as by the sometime dissonance between explanation and experience. In his 1988 memoir, *The Crest of the Wave*, he wrote of his first encounter with the sea, in Humboldt Bay:

> The surf roared at us, which is to say that the wide spectrum of frequencies created by all the waves crashing, colliding, swashing, and releasing bubbles produced a high volume of white noise – a hiss of astonishing proportions broken only by the occasional crack of a large breaker (Bascom, as excerpted in Raban 1993, p. 463).

'Observation,' then, entailed not just the visual, but also the sonic. And the olfactory: Bascom was struck by the 'distinctive smell' of the sea. Like many early wave researchers, he revelled in waves as physical things with which it was necessary to wrangle in order to do science. In *The Crest of the Wave*, Bascom narrates a particularly visceral moment, when he is out in an amphibious truck (known nowadays to American tourists as a 'duck boat'), about to be swamped by a wave:

> While balancing under this incipient waterfall, I would estimate the height of the wave that was about to come crashing down, add one third of that … to the trough depth, call the answer into a microphone, and duck. Then the reaching crest of the plunging wave would collapse on us, not quite capsizing the dukw (Bascom, as excerpted in Raban 1993, p. 467; see Figure 1).

A dynamic sense of the entanglement of observation, audition, olfaction, and theory was a signature of Bascom's rhetoric. He wrote in his 1964 *Waves and Beaches: The Dynamics of the Ocean Surface*,

Figure 1. Bascom standing on duck boat with wave ruler, 1940s. Willard Newell Bascom Papers, 1945–2000, Collection 2008–21, BOX 3, Scripps Institution of Oceanography Archives, University of California, San Diego.

> now, full of confidence that we understand waves both in theory and by actual test, we fling open the laboratory door, stride to the edge of the cliff and look to the sea. Good grief! The real waves look nothing like the neat ones … that march across the blackboard in orderly equations. These waves are disheveled, irregular, and moving in many directions. Should we slink back indoors to our reliable equations and brood over the inconsistencies of nature? Never! Instead, we must become outdoor wave researchers. It means being wet, salty, cold – and confused (quoted in Hawk 2005, p. 20).

This is an expression of scientific affect simultaneously at home at the blackboard and outdoors. Bascom's biography can be situated in a history that has seen American natural science researchers seeking to conduct their work in rugged land- and seascapes of the sort institutionalised in the famous work-vacation sites that eventually became Woods Hole, Cold Spring Harbor, Los Alamos and Monterey Bay (see Kohler 2002, Pauly 2000). Of course, Bascom's declaration of salty confusion may also be a retrospective romantic embellishment, since wave science, particularly by the 1940s in the United States, had become a highly practical endeavour, primarily because of its connection to the war effort.

World War Two brought waves into relief as strategic entities, as oceanographers sought to predict wave action to smooth the amphibious landings of allied troops in Europe and Asia. In 1942, Scripps scientists Harald Sverdrup and Walter Munk were asked by the Oceanographic Section of the Army Air Force Weather Directorate to work on wave forecasting. Their report, *Wind, Waves and Swell: A Basic Theory for Forecasting*, published in 1943, 'found that the size of waves did not depend solely on wind speed but was also affected by the size and shape of the body of water over which the wind blew (the fetch) and the length of time that the wind had been blowing (the duration)' (Schlee 1973, 306; see also von Storch and Hasselmann 2010).

Schlee describes the network of scientists and observers put together in the wake of Sverdrup and Munk's report, a network specially assembled to enable the invasion of Normandy in 1944 (and relocated soon after to Ceylon, to enable the invasion of Burma and Indonesia, which expelled Japan). The 'Swell Forecast Section' comprised 51 wave-reporting stations, at each of which measures were taken of wind speed and direction, wave heights, and periods. A kindred British effort at wave prediction emerged at the Admiralty Research Laboratory, organized by a group of scientists who called themselves the 'W' group (Draper 1996). Predictions for Normandy turned out to be fairly accurate, though currents not yet fully known as well as rough weather complicated actual seashore conditions.

A scientist like Sverdrup might not have been surprised. In *The Oceans: Their Physics, Chemistry, and General Biology*, he had written with colleagues Johnson and Fleming that

> In physics the general picture of surface waves is that of sequences of rhythmic rise and fall which appear to progress along the surface … The actual appearance of the sea surface of the open sea, however, is mostly in the sharpest contrast to that of rhythmic regularity … from the point of view of physics [these real seas] can be termed 'waves' only by stretching the definition (quoted in Irvine 2002, p. 378).

After World War Two, wave science continued to be useful to large-scale institutional activities. Military research continued with researches into wave behavior during the detonation of nuclear weapons in the south Pacific (see Rainger 2004). The maintenance of oil drilling platforms became important (see Draper 1996 on 1970s oil- and gas licensing enabled by maps of extreme wave heights generated by the UK's National Institute of Oceanography).

Wave science came into its maturity because of human-scaled social and political economic imperatives, imperatives attached to military and commercial forecasting concerns of maritime nation-states. What Philip Steinberg (2001) has analysed as a European model of the ocean as a 'great void' or blank space between nations continued with wave science – as it had begun with wind charts in the nineteenth century – to acquire a surface texture. Wave science would increasingly make visible disturbances on the smooth surface of the blank map – 'When a breeze blows across a stretch of sea, the resulting friction stirs up tiny triangular fluctuations on the water's surface known to sailors as cat's paws and to scientists as capillary waves' (Hawk 2005, 13) – disturbances that could scale up to have large effects, oceanographic and geopolitical both.

A turning point in wave science came in 1961, at the Conference on Ocean Wave Spectra, convened in Easton, Maryland. The major innovation to come out of this gathering of seventy physical oceanographers was the mathematical formalism of the 'wave spectrum.' In a wave spectrum, 'wave records were represented as a weighted sum of sine waves; the relative weightings constituted the spectrum' (Irvine 2002, p. 379). Instead of wiggly lines representing the rise and fall of water, oceanographers turned to a visualisation that broke down a large wave into the smaller, diversely sized waves of which it might be composed. Waves came to be known not as individuals, but as collections of superimposed waves, little and big, with different origins and histories. A 'wave' might be made up of energy generated on some faraway shore, by a hurricane a week ago and by fresh energy from teeny wind-swept ripples. In the 'wave spectrum' model, waves would be rendered not as side views of undulating water, but as collisions of bell curves. The 'spectrum' would be a chart lining up, from left to right, from largest to smallest, the wave sizes (measured in wavelengths) of which a wave was constituted (see Figure 2).

Figure 2 offers a kind of a wavy graph, to be sure, but it is *not* to be seen as a side view of a wave! It is a second-order abstraction. With the arrival of this 1960s formalism, oceanographers stopped talking about individual waves, or about successions of waves, and more about 'wave systems', pro-

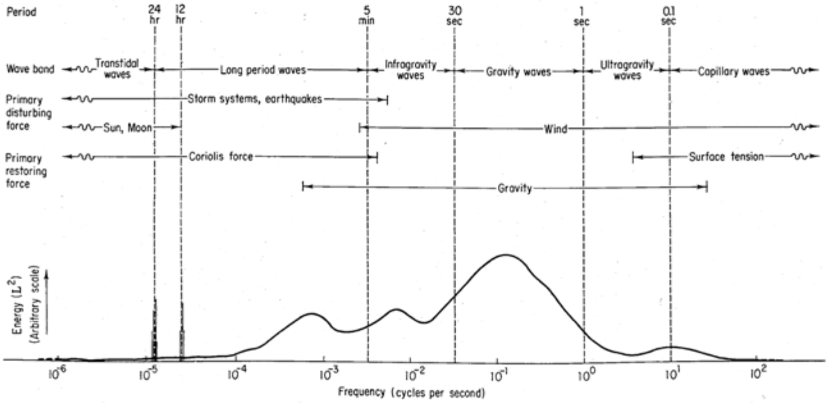

Figure 2. Qualitative wave power spectrum, from Kinsman 1965, p. 23.

cesses that might be understood statistically. The ‘nature’ of the wavy sea was becoming a question not simply of surveying, navigating and so forth, but a question for the sciences of probability. Insofar as the romantic sentiments of such figures as Bascom were still in the mix, the oceanic sublime was now meeting, and being translated into, the mathematical sublime.

One question for people at the Ocean Wave Spectra conference was: what was the best model for power spectra? And what *produced* spectra? Tides, gravity, wind: all these played a role. But which force was most important? And what were the boundaries of ‘waves’, anyway? For most of the waves that scientists cared about, wind action inaugurated waves, but should wind be considered part of the ongoing system?[1]

And was there such a thing as a ‘typical’ wave spectrum? Some conferees assumed that a ‘typical’ spectrum could be derived from thinking about a relatively smooth and extensive ‘fetch’ (the sea space across which wind blew at a particular speed) across a bounded ‘duration’ (the time over which a wind steadily blew).

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[1] ‘As Helmholtz reminds us, “The boundary between two fluids of different density cannot remain in equilibrium when they travel at different velocities”’ (Lane 1947, p. 63). Whether and how wind stays in the system shapes how observation and theory might be compared (scientists at theEaston conference differed. Some held that waves could travel faster than the wind that generated them; others disagreed). Scientists call ‘swells’ those bulges of water that travel after initiating wind energy has dissipated.

Others, such as Walter Munk, pointed out that 'fetch' and 'duration' were not things in the world, but formalisations:

> Inasmuch as these terms – 'fetches,' 'finite durations' – are really great idealizations of the wind field over the sea, to try and write spectra for given fetches and finite durations is to endow these meteorological notions with more claim to reality than they deserve (quoted in Irvine 2002, p. 380).

Munk's comment points to a key issue in wave science: while waves have a manifest materiality to them, the 'wave' is also an abstraction, one that takes a particular form depending on how waves are conceived, observed, modelled. David Irvine suggests that the character of that abstraction moved into a highly mathematical key with wave spectra; observation – to say nothing of listening, smelling, tasting and swimming! – was sidelined.[2] And when 'observation' *was* discussed, it was already an abstraction. As Irvine puts it, '"Observed" spectra are not really observed; they are the finished products of a sophisticated mathematical analysis … Spectra stood midway between raw observation and fundamental theory' (2002, p. 382). In this way, spectra share something in common with computer simulations – theoretically animated models within which scientists perform kinds of virtual experimental operations (see Galison 1997). By the middle twentieth century, waves had become scientific objects that could be known through what Daston and Galison (2007) have called 'mechanical objectivity', a representational idiom putatively free of human judgment (even if, for waves, such representations always attached to concerns sculpted by imperatives for prediction).

WAVES, NOW

If power spectra brought wave science into the realm of the mathematised sciences, the process has intensified as wave science has come to make central use of computer simulations and a host of other technical tools. *New York Times* journalist Susan Casey reports that today, 'the study of waves involve[s]

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[2] The tradition of Melanesian navigation offers a comparison. Anthropologists have suggested that while Melanesian stick and shell charts have been used on land to plan voyages, actual journeying has depended on feeling the sea in which a canoe travels. Taste may also be significant. David Lewis in his 1994 *We, The Navigators: The Ancient Art of Landfinding in the Pacific*, reports on one navigator: 'Kaho is said to have dipped his hand into the sea, tasted the spray and bade his son tell him the directions of certain stars. He then averred that the water was Fijian and the waves from the Lau group where they duly arrived the next day' (quoted in Mack 2011, 128).

quantum mechanics, chaos theory, advanced calculus, vortex turbulence equations and atomic physics' (2010, p. 67). Changing modes of representing waves transform what can be known about them. The kinds of waves that scientists are able to study have expanded. 'Freak' or 'rogue' waves, for example, have become newly legible scientific objects. 'Monster' waves of the sort sought out by extreme surfers have become easier to locate. A rising number of large, unexpected waves that some oceanographers argue may be consequent on anthropogenic global warming have also become visible.

I wish to experiment with calling these exceptional entities 'new' waves. Some are new epistemologically: newly discovered or characterised. Some may be new ontologically: new things in the world.

Let me begin with *rogue waves*. Rogue waves – waves that are undisciplined, abnormal, dangerous, out of place – are waves larger than one might expect from the sea around them. In the statistical idiom of wave sciences, these are waves that leap out of the realm of predictability; a 'wave power spectrum' tailored to explaining wave motion in a particular patch of sea will not forecast them. Such waves have been the stuff of legend, rumour and myth (and in that sense are not new discursively). Ferdinand Lane, in his 1947 *The Mysterious Sea*, writes that, 'Scientists, critical of untrained observers, discount such tales [of larger-than-expected waves], since gravity, they remind us, works steadily to prevent waves from vaulting above a certain height' (p. 65). But in 1995, the first such wave was documented in the North Sea, from a Norwegian offshore monitoring facility for an undersea gas pipeline. In a sea of 39-foot waves, this wave was 84 feet tall (see Parker 2010, p. 128).

New observational practices have made it possible to confirm that such waves exist. And new kinds of models have made it possible to guess at their possible origins. Rogue waves may emerge from the meeting of currents of opposite direction. Off the south-east coast of South Africa, for example, waves from the Agulhas current, which sweeps down East Africa, run into waves from South Atlantic storms coming in just south of Cape Town. '[W]aves forming out at sea off the Cape of Storms can grow almost 100ft tall from trough to crest, about the same as a ten-story building' (Pretor-Pinney 2010, p. 148; and see Rosenthal and Lehner 2008).

Rogue waves may also arise from non-linear effects – from, for example, wave-wave interaction, which can include the transfer of energy from one wave to another. To understand such phenomena, scientists have turned to such formulae as the nonlinear Schrödinger equation, once the province only of scientists working in quantum mechanics. Wave scientists have become ever more dedicated to forecasting using mathematical approaches. To get a flavour of the complexity of this enterprise, consider the following passage from a paper on the European Centre for Medium range Weather Forecasts (which gathers data from buoy systems around the world and feeds data into a wave-modelling programme):

> It appears that freak waves can only arise when the waves are sufficiently coherent. In these circumstances, when the waves are sufficiently steep, nonlinear focusing can act resulting in extreme sea states. These favorable conditions for the formation of freak waves can be quantified by means of a dimensionless parameter called the Benjamin-Feir Index (BFI). Noting the coherency of a wave system can be measured by the width of the corresponding wave spectrum, the BFI is basically a ratio of the steepness of the waves and the width of the spectrum. Large values of the BFI correspond to favourable conditions for freak waves to occur (Bidlot, Janssen, and Abdalla 2006; see also Janssen 2003).

The densely statistical character of this approach links us to a contemporary social domain in which such probabilistic thinking comes to matter: insurance. The global shipping industry operates businesses that embed their financial thinking within the calculus of risk they take to be attendant upon sea travel (see Crane 2010 for a narrative about Lloyds of London's lists of ship losses).

Outsized breaking waves are another sort of wave new to human cultural encounter. Casey describes the 'monster' waves that are increasingly sought out by today's extreme surfers. In the early 2000s, surfers began to look for waves by looking at global satellite information, which they could access quickly (and, now, wirelessly) to make snap decisions about where to go to catch the next wave, accessed through an ecology of standby flights, global-local connections and motor-boats. Bigger waves have not only become newly visible, they have also become newly accessible: 'In recent years, surfers assisted by jet-powered watercraft have been towed into breaking waves … with faces reliably measured in the 60- to 70-foot range. Such swells are too big and fast to paddle into, so the surfers use personal watercraft and water skiing ropes to tow each other into the waves' (Hawk 2005, 90). Monster waves, once the stuff of surfing legend, are now technical and social objects, the stuff of practical expertise (see Figure 3).

Figure 3. 2010 Mavericks competition, by Shalom Jacobovitz – SJ1_8558.

Rogue waves and the waves of extreme surfing are newly discovered, characterised, understood, accessed.[3] Do there exist waves 'new' in a more ontological sense, waves 'new' to the world?

According to Casey's report from the Tenth International Workshop on Wave Hindcasting and Forecasting, held in Hawaii in 2007, many oceanographers predict that climate change will not only change sea level, but sea activity. Climate change means warming water, and warming water is expanding water, which can connect to intensifying wind and storm systems, which can generate systems of higher waves. Not just the substance of the sea is under possible revision by anthropogenic activity (overfishing, acidification, pollution, irradiation), but also, perhaps, its very *form*. Russian oceanographers Sergey Gulev and Vika Grigorieva have suggested that waves may be getting taller. They suggest that waves in the North Atlantic have been rising fourteen centimetres each decade since the 1950s, while

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[3] Other waves new to science might include 'internal waves,' underwater waves composed of water of one density and temperature meeting another.

the Pacific has seen increases of eight to ten centimetres (Gulev and Grigorieva 2004). A few scientists have begun to ask whether the numbers of rogue waves may be on the rise, with increased frequencies and strengths of storms and with more interaction between storm systems (Bitner-Gregersen and Toffoli 2013).

We can look anew at Helen Rozwadowski's summary of how the sea has been rhetorically positioned outside human history: 'Although most glimpses out to sea reveal endless waves reaching to the horizon rather than any lasting evidence of human presence, there are myriad human activities through which historical connections between people and the oceans can be explored' (2010, 162). In the contemporary world, even 'endless waves' bear the marks of human agency. Human engagements with waves might no longer be imagined as a straightforward encounter of culture with nature. Waves have become hybrids of nature–culture.

Notable about these 'new' waves is their 'extreme' character. A survey of the proceedings of the Eleventh Workshop on Wave Hindcasting and Forecasting (in 2009) sees dozens of papers that use 'extreme' in their titles — 'extreme waves', 'extreme sea states', et cetera. The 'extreme' modifier is not simply empirical; it is a token of recent fascinations with things extreme, part of the same zeitgeist that has recently given us two popular science books with the title *Extreme Nature* (Curtsinger 2005, Cowardine 2008), part of the same episteme that sees marine biologists fascinated with *extremophiles*, organisms that thrive at extremes of temperatures, pressures, salinities and so on (Helmreich 2009). In the current day, the 'extreme' has become a frame for thinking about nature at its boundaries.

I indicated at the opening of this paper that the history of wave science has been bound up with forecasting — and therefore with the *future*. As a figure for environmental history, then, the wave offers a marker of how nature is brought into focus as an unfurling force. The difference between old and new waves, seen in this light, might be the lengths of futures that scientists in different historical periods imagine. For old waves, futures were near-futures (of wartime, weather forecasting). For new waves, these sorts of futures are implicated as well but, with 'extreme waves', there is a longer-term future at issue, too, one to do with century-long predictions about climate and its transformation.

Geographers Jon Anderson and Kimberley Peters note that 'geography' is 'earth-writing' (2014, p. 3). Insofar as oceanography — 'ocean-writing'

— has entered geography, it has not been as a companion interpretative, humanities-styled inquiry, but rather as a science. I hope here to have sketched out the beginnings of an environmental historical oceanography, one that considers waves as historical and cultural objects, subjects for an inquiry we might call 'wave-writing', which, to borrow from the Greek for wave, κύμα, we could name *kymography* – though since that word already exists to describe the tracing of cardiac pulse waves, we might nominate with a more unholy Latin+Greek neologism: *undulography*. Undulography will map out how the history of the sea has prepared a variety of oscillating futures, natural and cultural.

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