



Naylor, S. (2015) Weather instruments all at sea: meteorology and the Royal Navy in the nineteenth century. In: MacDonald, F. and Withers, C. W.J. (eds.) Geography, Technology and Instruments of Exploration. Series: Studies in historical geography. Routledge: Farnham, pp. 77-96. ISBN 9781472434258.

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Deposited on: 26 February 2016

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Chapter 5

Weather instruments all at sea: Meteorology and the Royal Navy in the nineteenth century

Simon Naylor

Over the last two decades historians and geographers of science have paid increasing attention to science in the field. For one, ‘fieldwork has become the ideal type of knowledge’, so much so that much work in science studies asks not ‘about temporal priorities but about spatial coordination’.¹ This agenda has been pursued empirically through study of European exploration in the eighteenth and nineteenth centuries. One of the key problematics for historians and geographers has been how, exactly, science collaborated with state actors to extend European nations’ ‘spatial grip’. There have been three common empirical responses to this question: through the deployment of physical observatories; through fieldwork; and by means of ships. Studies of observatories – on mountains, on the edge of oceans, in the polar regions – are many, as are studies of the ephemeral fieldsite.² The ship has been seen to embody both of these types of scientific space. In his 1845 address to the British Association for the Advancement of Science (BAAS), the astronomer John Herschel referred to ships as ‘itinerant observatories’.³ Naval ships were deemed to be crewed by disciplined observers (the equivalent to observatories’ ‘obedient drudges’⁴), to run according to military discipline and were replete with the latest instruments. They were, then, no different to terrestrial physical observatories or laboratories, except for their mobility. Following Beaglehole, Sorrenson has arguing that ships were more than floating

laboratories; ships were themselves instruments of geographical discovery – conferring authority on their user, leaving traces on maps, and providing ‘superior, self-contained, and protected views of the landscapes’ viewed from them.⁵

This chapter engages with debates about the ship as a site of scientific labour through an examination of the study of meteorology at sea in the period between the conclusion of the Napoleonic Wars, and the Conference on Maritime Meteorology, in London in 1874. It examines the roles played by individuals and institutions, guidebooks and regulations, in promoting a culture of instrumental meteorology onboard voyages of exploration, and on Royal Naval and Hydrographic Office survey ships.⁶ Particular attention is paid to attempts to establish international standards for the study of meteorology at sea. The chapter illustrates how the British Admiralty was supportive of science in the nineteenth century in consenting to its ships being turned into floating meteorological observatories. The Admiralty did so to develop philosophical inquiry and to respond to more utilitarian concerns. Over the course of the nineteenth century an informal, even idiosyncratic, culture of meteorological inquiry was gradually formalised; uniform forms and meteorological instruments were introduced together with prescribed observations and practices. These, in turn, were authorised in Admiralty regulations and guidebooks. Voyages of exploration and the Hydrographic Office survey vessels were the experimental sites for this new culture, which was expanded to include all Royal Naval vessels, and, later, Britain’s merchant marine.

Schaffer reminds us that the ‘immutability’ of scientific inscriptions made during voyages of exploration ‘was a complicated and exhausting achievement’.⁷ This was true for meteorological inscriptions, whether on a ship’s log board, in a register, or on an instrument. In elucidating the adoption, use, and evaluation of meteorological

instruments onboard British and other European and American ships, the chapter supports Schaffer's insistence that philosophical instruments existed in various 'states of repair'.⁸ The term refers to the assumption that the demands of science routinely outstripped instruments' abilities and the humans that interacted with them. While I argue that the Admiralty was supportive of science, I also suggest that it was slow and conservative over the adoption of a new observational regime and the use of new instruments. Despite the adaptation of meteorological instruments for life at sea, the conduct of sea trials, the issuance of guides to observation and regulations for their use, Britain's naval ships and those of other countries, were by no means itinerant observatories.

The chapter begins by summarising the changes that affected meteorological science and the British Navy in the early nineteenth century. It then examines the role of the Royal Society in the organization of several voyages of exploration in the 1820s and 1830s. It details the role played by Francis Beaufort in the promotion of the study of meteorology onboard Royal Naval ships. The final section examines the aims and outcomes of two international conferences on maritime meteorology, in Brussels in 1853 and London in 1874.

<A>Reforming science and the Navy

Schaffer's claim that 'Managing states of disrepair is salient during scientific practices' periods of dislocation and reorganization, such as the later eighteenth- and early nineteenth-century scientific, industrial and political revolutions', is, I contend, applicable to the Admiralty and to meteorological science, in their periods of reform in the early nineteenth century.⁹ The early 1800s witnessed the emergence of natural science out of natural philosophy – the development of 'a comprehensive science (a

physics), which associated the separate branches of natural philosophy under a dynamic equilibrium model of natural order'.¹⁰ Its geographical scope was ambitious: to chart the variation of physical and biological features on a global scale.¹¹ The physical sciences placed emphasis on data collection during the early nineteenth century, with an insistence upon trained observation, developments in written recording, and repetition of numerical measurement as a result of an increased reliance upon instrumentation'.¹² Measurement, quantification and mathematically stated laws were upheld as ideals for terrestrial physics general, while the discipline of quantification shaped practice.¹³

These reforms are clearly evident in the study of weather. Meteorology moved away from what Jankovic has termed the 'place-centred and curiosity-driven authority of meteoric reportage', to become 'a constellation of physico-chemical enquiry into the nature of atmospheric air and its planetary circulation'. The atmosphere was gradually re-conceived as a laboratory and the promotion of its instrumental measurement was justified in those terms.¹⁴ Meteorology aimed to pursue this agenda on a global stage, employing trained observers and calibrated instruments, observing at fixed times of day using uniform methods and quantitative systems of notation, with a view to laying down 'the empirical laws of the atmosphere and perhaps extend them into a comprehensive meteorological theory'.¹⁵ Edwards has suggested that meteorologists in the early-to-mid-nineteenth century employed instruments and methodical and simultaneous observations to effect a shift from a culture of voluntarist internationalism, 'based on an often temporary confluence of shared interests, to quasi-obligatory globalism based on a more permanent shared *infrastructure*'.¹⁶ This was vital in studying localities with different weathers – such as between temperate northern Europe and its tropical colonies – and in the

production of global climate maps, both of which ‘required the fashioning of transnational and objective credibility supplied by instruments, standardized registers and regular observations’.¹⁷

The British Admiralty went through a period of reform in the 1810s and 1820s. In the aftermath of war with France, the Royal Navy experienced financial retrenchment and disarmament: many ships were decommissioned and thousands of enlisted men lost their jobs. Naval officers had greater political influence and so few of them were retired but perhaps 90 per cent of them found themselves unemployed and on the half pay list.¹⁸ The First Secretary of the Admiralty, John Wilson Croker, defended the reduced Navy Estimates. The Second Secretary of the Admiralty, John Barrow, argued that the Navy’s ships and personnel should be employed in global exploration, on the basis that ‘exploration would increase scientific knowledge, that it would be a boon to national commerce, and above all that it would be a terrible blow to national pride if other countries should open up a globe over which Britain ruled supreme’.¹⁹ The Royal Navy and the Admiralty Hydrographic Office made numerous contributions to science, including geographical exploration of the Northwest Passage, the Antarctic Ocean, and of Africa, such that ‘in the first half of the nineteenth century the Navy was the principal governmental subsidizer of science’.²⁰ For naval officers interested in science, a position on one of these voyages of exploration was a choice appointment. These ‘scientific servicemen’ gradually took on much of the scientific work from civilians and many became Fellows of the Royal Society.²¹

<A>Cultures of instrumentation on voyages of exploration

Voyages of exploration in the late 1810s and 1820s served to establish standards for the conduct of physical scientific inquiry at sea, particularly in relation to the use of philosophical instruments onboard ship. The Royal Society had long offered advice to the Admiralty on the scientific aspects of its expeditions, viewed by government and the military as a ‘state tool for consultation’.²² The period from Ross’s 1818 Arctic voyage to Foster’s South Atlantic expedition in 1828 was a tumultuous one for the Society. Joseph Banks’s reign as President of the Royal Society ended with his death in 1820. Successive presidents – Humphry Davy (1820-1827) and Davies Gilbert (1827-1830) – were caught up in wider contests over the character and direction of British science. Davy put the Royal Society on a course that aimed to satisfy both the remnants of Banks’s ‘Learned Empire’ and the reformist intentions of the ‘Cambridge Network’.²³ The changes experienced by the Society over this period were reflected in the composition and work of its committees. In the early years of Davy’s presidency in particular, increased use was made of scientific committees.²⁴ Over the course of the 1820s scientific reformers, such as John Herschel, Charles Babbage and Francis Baily, joined long-standing members like Thomas Young, Henry Kater, and William Hyde Wollaston, all taking a greater role in the running of these committees. Miller notes that members of the reform group ‘increasingly dominated public discussion of the most important objects of research for scientific voyages’.²⁵ Herschel, in particular, ‘maintained an ambition to make the surveying voyages commissioned by Barrow on behalf of the Admiralty more ‘scientific’.²⁶ The changes effected in this period had a direct bearing on the advice that the Royal Society provided to exploring expeditions.

During the final years of Banks’s presidency, William Thomas Brande, one of the Royal Society’s two secretaries, wrote to Barrow to supply the Admiralty with a list

of instruments that the Society recommended for use on the two 1818 expeditions then heading for the polar regions, to be led by John Ross and David Buchan respectively. These included compasses, barometers, magnetic instruments, bottom sampling and dredging equipment, chronometers, mercurial and sea thermometers, a Wollaston micrometer, artificial horizons, electrometers, hydrometers, and apparatus 'for ascertaining the quantity of air in water'.²⁷ Four laboratory tents were added to protect the instruments during observations to be made onshore, along with two transit instruments, four 'Small Altitude Instruments', a water sampler, and a tent for astronomical observations.²⁸

In 1821 a 'Committee for suggesting Experiments and Observations to Mr Fisher, about to proceed to the Arctic Seas under the command of Capt. Parry' was established.²⁹ John Herschel, William Hyde Wollaston, and Charles Hatchett bolstered a core group made up of the President, the two secretaries – Brande and Taylor Combe – as well as Henry Kater and Thomas Young. The expedition astronomer, George Fisher, was invited to attend.³⁰ While the advice given to Ross in 1818 laid out in detail the instruments to be used on his expedition, that provided to Fisher was more direct in the scientific agenda to be pursued, emphasising terrestrial physics. Twenty experiments were proposed. The majority focused on the effects of extreme cold on atmospheric chemistry, the behaviour of fluids (including mercury), and on humans, animals, food, and different metals. Of particular interest was the freezing point of pure mercury and of different amalgams of mercury and other metals. This was significant because of its effect on the performance of the thermometer and barometer.³¹ Other questions related to the operation and effects of the Aurora Borealis, and the investigation of sea temperature at different depths.

The advice supplied to Captain Henry Foster's 1828 voyage on the HMS *Chanticleer* to the South Atlantic was more comprehensive still. At this committee Davies Gilbert (now President), Herschel, and Kater were joined by William Fitton, President of the Geological Society of London, Edward Sabine, artillery officer and expert in magnetism, and the Admiralty Hydrographer, Francis Beaufort. James Horsburgh, the East India Company Hydrographer, and Captains Parry and Foster, were present by invitation. In line with the interests of Herschel, Sabine, and Beaufort, the principal objects of Foster's expedition were defined as the investigation of physical astronomy, the determination of the figure of the earth, and the investigation of the law of the variation of gravity, along with inquiries into ocean currents, magnetism, the longitude of significant locations, natural history, and meteorology. The Committee noted that meteorological observations 'form a branch of inquiry of no small amount in this and all similar expeditions' and it recommended that 'regular observations of the Barometer, Thermometer, Hygrometer, and the direction and force of the wind should be daily made; and of the actinometer or other instruments proper for measuring the Solar and terrestrial variation, at favorable opportunities and at various levels'. The result, it was hoped, would be a better understanding of 'the probable former and future climate of different regions of the Earth[,] the permanence or variability of the Solar influence at different epochs, and the stability of the actual equilibrium of meteorological agents.'³² In its findings, the voyage was judged a success and the results were later used by Royal Society reformers and members of the Astronomical Society to affirm the analytic importance of mathematics in accurate observation and experimental research.³³

The advice given to Foster was dwarfed, however, by that supplied to James Clark Ross for his 1839 voyage to the Antarctic Ocean as part of the magnetic

crusade. The committee convened to advise on the expedition was chaired by Herschel and included Beaufort, Sabine, John Ross, Michael Faraday, John Frederic Daniell, Peter Mark Roget, Charles Wheatstone, and William Snow Harris.³⁴ The expedition was principally intended as an investigation into terrestrial magnetism, but other sciences were pursued, including study of the tides, the figure of the earth, and meteorology. Meteorology was given greater emphasis than was necessary simply to correct the performance of the magnetic instruments.³⁵ The committee additionally advised on the instruments with which the naval expedition should be equipped. In terms of meteorology, these included actinometers, Lind's rain gauge, an Osler anemometer, and spirit thermometers for operation in Antarctic temperatures below those at which mercury freezes and mercurial thermometers became ineffective.³⁶ Procedures were recommended for the verification of the instruments, especially when the expedition was far from fixed observatories on land.³⁷ Both of the ships – HMS *Erebus* and HMS *Terror* – were to carry standard barometers and thermometers against which others were to be compared. This was especially important when instruments were taken ashore, 'so as to detect and take into account of any change which may have occurred in the interval'.³⁸ The standards on one ship were to act as checks upon the other.

The passage of the *Erebus* and *Terror* from the tropics to the Antarctic presented an opportunity to investigate von Humboldt's claim that atmospheric pressure at the equator was uniformly 'less in its mean amount than that at and beyond the tropics', a phenomena that was, in turn, believed to produce the trade winds.³⁹ The observation of changes in the barometer when approaching the line was therefore of great scientific value, as was the observation of the local effects that continents or oceanic currents had on atmospheric pressure. Periods spent at high southern latitudes also

presented opportunities to calibrate the instruments. For instance, Ross was asked to verify and to register the ships' standard thermometers at the freezing point of mercury whenever the opportunity arose. This was to be effected by placing four permanent marks on the tube of each standard thermometer, and Ross was 'requested occasionally to compare these marks with the degrees of the ivory scale'. A bottle of mercury was ordered to accompany each standard thermometer.⁴⁰

The scientific instructions presented to Ross contained, in Ross's words, 'a detailed account of every object of inquiry which the diligence and science of the several committees of that learned body could devise'.⁴¹ This report became a standard for subsequent scientific guides. Ward and Dowdeswell note that the Admiralty's 1849 *Manual of Scientific Enquiry* was effectively a reworking of the 1839 report, prefaced and edited by Herschel.⁴²

The deployment of philosophical instruments, and the supply of precise instructions for observations and experiments was not alone enough, however, to guarantee reliable inscriptions. The directions provided to the captains of scientific expeditions were often aspirational in tone and susceptible to compromise when in the field. The robustness of the scientific outcomes of an expedition relied as much on 'immense chains of delegated trust and labour' as they did on detailed instructions, calibrated instruments and well organised skeleton forms.⁴³ Instruments could not speak for themselves effectively. The determination of their accuracy relied on the person or persons operating them. Identifying and justifying who was to operate which instruments was a crucial matter in voyages of exploration. For John Ross's 1818 voyage to the Arctic, the Royal Society committee suggested to the Admiralty that Sabine was the 'proper person to conduct certain experiments', accompanied by a Sergeant of Artillery to 'take care of instruments'.⁴⁴ The Committee also suggested

the inclusion of Fisher – ‘a Gentleman of considerable mathematical talent’ – while Henry Kater reported that the naval officers John Franklin, Frederick Beechey, and William Parry ‘had been most assiduous in acquiring a due knowledge of the use of the Instruments to be employed in the Northern Expedition, and that he considers them fully competent to prosecute the required observations and experiments’.⁴⁵

Despite the various controversies surrounding Ross’s 1818 Arctic expedition, the Royal Society again recommended Sabine as a member of William Parry’s 1819 Arctic voyage:

It is of the opinion of this Committee that Capt’n Sabine has shown the greatest possible diligence in making the observations which were intrusted [sic] to his care and the greatest judgement and regularity in his method of recording them. And this Committee therefore suggests the propriety of recommending Capt’n Sabine to the Admiralty in the strongest manner, both as deserving every professional encouragement, and as a proper person to be again appointed to take charge of the Observations to be made in a new Expedition.⁴⁶

The reiteration of instrumental and observational competence was crucial. The practices employed and the vagaries of the instruments’ fate ‘governed the status of the data they produced and the interpretations they suggested.’⁴⁷ The reputation of the observer was intrinsically linked to the data and the instruments: ‘To question or doubt results or methodology was to question the character and morality of their creator’.⁴⁸

<A>Reforming meteorology

After 1820, Royal Society committee members were increasingly chosen on the basis of expertise, whether intellectual or professional. This was also true in other respects, such as over the quality and use of the Society's meteorological instruments. The committee formed in 1822 to study this matter incorporated Thomas Young, William Hyde Wollaston and Henry Kater, together with Humphry Davy, Davies Gilbert, the secretaries Brande and Combe, Babbage, Herschel, as well as Luke Howard and John Frederic Daniell, included given their standing in meteorology and related fields.⁴⁹ Amongst other recommendations, the Committee ordered the construction of new instruments for the Society, including two barometers from John Newman, of Lisle Street, London; these were, subsequently, the subject of experiments at the Society in December 1822.⁵⁰ The observational regime and the siting of the Society's instruments were also reviewed. At a meeting of the Society's Meteorological Committee in 1827, the astronomers and reformers James South and Francis Baily, along with Beaufort and Herschel, complained over recording forms and the quality and situation of its meteorological instruments. They argued that the 'local situation' of its headquarters at Somerset House did not allow for the production of 'any series of meteorological observations of material weight and importance in the present state of the science'.⁵¹

For Jankovic, 'Whether fairly or not, early nineteenth-century commentators ... erupted with criticisms of a general lethargy that supposedly prevailed in the investigation of weather-systems, of the insufficiency *and* profusion of observations, of the public uselessness of the existing stock of facts, and of the imprecision of means for standardizing and using meteorological instruments.'⁵² In his *Meteorological Essays*, John Daniell, Professor of Chemistry at Kings College, London, pointed to the Royal Society's meteorological observations as evidence of

the poor science undertaken in England. He extended his criticism to the operations of overseas observatories, where, he claimed, there had been insufficient coordination of efforts, such that their ‘labour and perseverance lose more than half their value by the want of a well-digested plan of mutual co-operation’.⁵³ Concerns about the level of training and expertise of meteorological observers similarly preoccupied James Forbes and William Whewell, who argued that science should centre on precision observations and be conducted by trained personnel. Forbes expressed these arguments in his 1832 report on British meteorology to the BAAS meeting in Oxford. For Forbes, meteorological instruments ‘have been for the most part treated like toys’, while few of the numerous registers ‘which monthly, quarterly, and annually are thrown upon the world’ could be expected to afford information useful to the development of the science.⁵⁴ The situation was, in his view, so bad as to require ‘a total revision upon which meteorologists have hitherto very generally proceeded’.⁵⁵

This troubled history of meteorology at the Royal Society is important given discussions over the deployment of meteorological instruments on Admiralty ships. The review of the Royal Society’s own instrumental practices was coincident with the Society’s advice to captains and scientific officers onboard exploring expeditions. The composition of the Society’s committees on these issues was almost identical. It is reasonable to assume, therefore, that the reform of meteorology at the heart of British science was part of attempts to improve the conduct of science at sea. The difficulties experienced at the Royal Society illustrate the difficulties inherent in the pursuit of an exacting instrumental regime. The committees established to advise Parry, Foster and others laid down scientific agendas and observational practices on the assumption that ships were floating observatories. At the same time, criticisms of the Society’s own meteorological practices illustrated the challenges of meeting such demands when on

dry land. When far away from instrument makers and scientific advisers, onboard a moving ship in challenging conditions, operating personnel had no choice but to 'make up and mend ways of recording and transmitting what they reckoned worth noting'.⁵⁶

<A>Francis Beaufort and instrumental cultures on hydrographic ships

Scientific and exploring expeditions, such as those discussed above, helped establish precedents for the collection of information about terrestrial physics onboard ships. The success of these and other voyages in the first half of the nineteenth century encouraged the belief that military vessels might be employed as floating observatories. In his work on French arctic expeditions, Locher notes that the regular maintenance of the systematic naval watch offered real advantages to science, particularly if officers could be compelled to collect data in addition to the other observations they were required to undertake.⁵⁷ Naval officers received training in mathematics, navigation and astronomy and would have been comfortable operating relatively sophisticated precision instruments. For observations to be scientifically useful, however, they had to be made regularly, specific instruments had to be employed and full details had to be supplied about their constitution and conditions of use. Particular reduction protocols and computing methods had to be followed. The situation of an instrument and the state of the atmosphere around it had to be given consideration and recorded so that measurements could be reduced to a virtual common environment. The man who spent much of his career persuading the Admiralty to adopt these procedures in the observation of the weather onboard naval ships was Francis Beaufort (1774-1857).

Beaufort began his naval career on an East India Company ship. He served in the Royal Navy in the Napoleonic Wars, reaching the rank of Captain in 1810. In 1829 he was appointed Admiralty Hydrographer of the Navy, a position he held until 1855. Beaufort has been credited with turning the Hydrographic Office into a world-leader in maritime survey.⁵⁸ He also played an active role in the administration and advancement of science in Britain. From 1831, he was head of the scientific branch of the Admiralty Board. He spent much of his career promoting the adoption of his wind scale and a system of weather notation onboard hydrographic, naval, merchant and packet ships, and in encouraging the proper use of barometers and thermometers at sea.

As Admiralty Hydrographer, Beaufort was in a position to promote his meteorological agenda amongst officers on the Royal Navy's surveying ships. His influence is evident in the instructions provided in 1831 to Captain Robert Fitzroy for the latter's hydrographic survey of the South American coastline. Beaufort ordered Fitzroy to keep a 'steadily and accurately kept' meteorological register in which the wind and weather should be observed using Beaufort's own notations. Barometer readings were to be kept and entered into the register, at 9 am and 4 pm. Temperature readings were to be taken at the same times and the extremes of the self-registering thermometer were to be noted daily. The temperature of the sea at the surface was to be taken and compared to that of the air.⁵⁹ Beaufort cautioned Fitzroy that no reflected heat should act on the instruments. This was a challenge onboard a ship at night, the more so given the generally warm atmosphere surrounding the vessel.⁶⁰

These duties were extended to other surveying vessels, but Beaufort struggled to ensure that they were met. The log books from various hydrographic surveys during the 1830s demonstrated that what was observed, and when, varied from ship to ship.

Beaufort expressed his frustration at the rather haphazard adoption of his meteorological standards in surveying instructions provided to Lieutenant Edward Barnett in 1837, about to take command of HMS *Thunder*. Beaufort justified the use of the barometer and thermometer on the grounds that they would ‘provide authentic data collected from all parts of the world’, and aid ‘future labourers’. He conceded, however, that those hours of entry ‘greatly interfere with the employments of such officers as are capable of registering those Instruments with the precision and delicacy which alone can render meteorologic data useful’.⁶¹ Given that meteorological data’s future utility was so uncertain, Beaufort suggested that Barnett should do no more than to record the height of the barometer twice a day, along with the extremes of the thermometer.

Frustrated by the slow pace of change, Beaufort and his assistant, Alexander Bridport Becher, mounted a campaign in the late 1830s to persuade the Admiralty to impose a uniform meteorological culture on its ships. Becher was chief Naval Assistant in the Hydrographic Office.⁶² In 1838 he wrote a strongly worded memorandum on the subject. As well as urging officers to make use of the log book to record wind and weather as suggested by Beaufort, Becher noted that ‘no seaman in command of a ship ever thinks of going to sea without a barometer or sympiesometer’. Becher pointed to the ‘great advantage that would arise from the observations of it being recorded in every weather, not to mention during extreme events such as storms and hurricanes, when ‘changes in its height during their progress and times of change should be carefully noted’.⁶³ Beaufort also urged officers to use the ship’s logboard to record the height of the barometer and the thermometer at least once in every watch, suggesting that additional columns be added for this purpose.

The apparent inability of the Admiralty to enforce the meteorological suggestions of its Hydrographer encouraged Beaufort to make use of the Royal Society. He was aided in this by Lieutenant-Colonel William Reid, a Royal Engineer. Reid's interest in meteorology stemmed from his employment as Resident Engineer on Barbados, and centred particularly on Atlantic hurricanes. He published a book on this, *An Attempt to Develop the Law of Storms*, in 1838, which the Admiralty ordered to be supplied to naval officers. In January 1839 Reid wrote to John Herschel, then Chair of the Royal Society's Meteorological Committee, forwarding a letter from Lord Glenelg (Secretary of State for War and the Colonies). The letter announced the intention of the Admiralty to make additions to the log books of naval ships, including columns for observations of the height of the thermometer and barometer.⁶⁴

Courtney claims that it was the Royal Society's intervention that led to the formal issue of marine barometers to the naval fleet in 1843, a matter administered through the Hydrographic Office.⁶⁵ This development was reflected in the 1844 edition of the *Admiralty Instructions*, where captains were told to have the barometer 'carefully suspended in some secure and accessible part of the Ship' (and to note its location at the beginning of the log book), and to make observations at 6 am, noon, 6 pm, and midnight.⁶⁶ The BAAS was quick to utilise this new development. In 1845, survey ships on the Home Station were ordered to assist the Association, which was interested in observing meteorological phenomena that affected the British Isles during the autumn. Officers were asked to keep registers of barometric observations during October and November using printed directions and blank forms issued especially, and were required to again do so in 1846.⁶⁷

Interest in the value of meteorological instruments at sea spread beyond the survey fleet. In February 1847 Beaufort received a letter from Sir Henry John Leeke,

flag-captain of HMS *Queen*, a 110-gun first-rate ship of the line and the last sailing battleship to be completed before the widespread introduction of steam power.⁶⁸ Leeke wrote to Beaufort to promote the work of his Major of Marines, David M. Adam, whose knowledge of the barometer and attention to changes in the weather had been of ‘great use’ to him onboard. Adam was ‘half a very clever scientific man’, claimed Leeke, and he requested additional meteorological instruments to aid Adam.⁶⁹ Attached to Leeke’s letter was one from Adam himself, addressed to Leeke although presumably targeted at Beaufort, forwarding his readings of the barometer, thermometer, wind direction and force, and weather while HMS *Queen* was at Plymouth Sound in November and December 1846. Adam requested a hygrometer, anemometer, rain gauge, electrometer, and dipping circle, on the grounds that ‘If there is one place where accurate knowledge of [the weather], is more useful than another, that place is a Man of War – on ship-board.’ For Adam, instruments ‘may give the young officers a scientific turn’, and that the serious study of meteorology on a flagship could only lead to ‘a more accurate knowledge of that science’ throughout the fleet.⁷⁰ He promised the Admiralty Lords weekly or monthly meteorological reports in return.

Even with these and other developments, Beaufort remained dissatisfied with the scope and quality of meteorological work in the naval and merchant fleets.⁷¹ Writing to the Admiralty in June 1852, Beaufort argued that naval officers were still not ‘imbued with a sense of [meteorology’s] importance’, despite the ease with which a meteorological culture could be engendered:

The mere record of the Air, & of the Sea at different depths – the force & direction of the winds – the set of the currents – the fluctuations of the Barometer &c. &c. would be easily procured as they would give but little

trouble & require but little skill – & after a little time when the officers became familiar with the instruments & warmed to the undertaking, the nicer observations on the state of the atmosphere, the quantity of rain, the indications of changes in the wind & weather, and minute descriptions of mutual phenomena would be duly registered according to the forms which might be prescribed in what might be called a supplementary log.⁷²

Beaufort again turned to the Royal Society, hoping that it could provide a skeleton form, a list of instruments and duplicates to go to each vessel, advice on who should build them, and 'by whom compared & verified.' He also hoped that the Admiralty and the Board of Trade might persuade the directors of mail packet companies and merchant ships respectively to entice their crews to do something similar.

<A>The Brussels and London Maritime Conferences

In 1853 a maritime conference was convened to establish a uniform international system of meteorological observation at sea, its justification being the improvements that could be made to navigation and scientific knowledge.⁷³ Although the idea for the conference came from William Reid and his former commanding officer, Sir John Fox Burgoyne, it was organised by the US Government and held in Belgium, chaired by the astronomer Adolphe Quetelet. The British delegates were Captain Henry James of the Ordnance Survey and Captain Frederick Beechey, head of the Marine Department of the Board of Trade. The principal aim of the conference was to design a meteorological register for use on naval and, if possible, merchant ships. Delegates were wary of extending the conference remit, although discussion strayed inevitably onto instrumentation. Beechey argued that it was impossible to recommend the adoption of any particular instruments, let alone any specific instrument makers,

given that different scales and standards were in use internationally; and that any standardization of instruments would ‘interfere too abruptly with long established usages and long established records, with which the observations now to be collected would require a reduction, before they could be compared’.⁷⁴

Despite a general reluctance to standardise instruments and instrumental cultures, there was some debate over the use of the thermometer and barometer at sea. Delegates recommended that ships should carry both, along with ‘at least one good chronometer, one good sextant, [and] two good compasses’. The conference acknowledged the widespread use of barometers onboard seagoing vessels of all types and their value as indicators of changes in relative pressure, but their use as recorders of absolute pressure was lamented: ‘That an instrument so rude and so abundant in error, as is the marine barometer generally in use, should in this age of invention and improvement be found on board any ship, will doubtless be regarded hereafter with surprise’.⁷⁵

Similar sentiments were expressed of the thermometer. The conference noted that too many were in use at sea despite users having no idea of their degree of error, which rendered the results worthless. The French delegate, Alexandre Delamarche, argued that a uniform thermometer should be adopted internationally, but, as for the barometer, he acknowledged the difficulty of introducing a single universal design. It was, nevertheless, agreed that the centigrade scale should be added to all thermometers (although not to the thermometer attached to the barometer), alongside any other scale currently in use. This was justified on the grounds of the possible *future* adoption of the centigrade scale – ‘to accustom observers in all services to its use’ – rather than its immediate use; the conference rejected the proposal that a separate centigrade column should be added to the meteorological register.⁷⁶

The immediate consequences of the conference were positive, at least as far as the British contingent was concerned. Beechey reported on the outcomes of the conference to the British government and, in February 1854, the First Lord of the Admiralty, Sir James Graham, announced in the House of Commons that a new government department was to be formed, called the Meteorological Department, to be funded through the Board of Trade and the Admiralty. Its aims were to effect the recommendations of the conference: to collect and analyse meteorological observations taken at sea; to promote the observation of the weather onboard ships; and, in the spirit of international cooperation, to convey reduced observations to the US Naval Observatory.⁷⁷ This Department, led by Robert Fitzroy, began to supply instruments, instructions and registers to Royal Navy ships and British merchantmen, and to collect and compile weather logs. The Department was not long in attracting criticism, notably from Francis Galton, the African explorer, meteorologist and eugenicist, who took issue with FitzRoy's attempts at weather forecasting.⁷⁸ The workload and criticism took its toll on FitzRoy, who committed suicide on Sunday 30 April 1865. The committee of inquiry formed to consider the Department's work in the aftermath of FitzRoy's death was chaired by Galton and identified several shortfalls and proposed some suggestions for improvement. While Galton's Report complimented the Department on overseeing the provision of ships with instruments and registers, it was felt that too few registers had been collected and that there was insufficient global coverage.⁷⁹

There were several attempts to develop trans-national networks of meteorological observations and stations in the 1860s, but these proved unsuccessful, due in part to the unstable political situation in Europe.⁸⁰ Several conferences on the topic were eventually convened in the 1870s. The first was held in Leipzig in 1872, followed by

an international congress in Vienna in 1873. In 1874 a private conference on maritime meteorology was held in London. The London conference set out to review participating nations' implementation of the recommendations of the 1853 Brussels conference, and to promote the recommendations of the 1872 and 1873 meetings; namely, that 'Thorough uniformity in methods and instruments should be aimed at'; 'Unity of measures and scales is desirable, and to this end the introduction of millimètres for the barometer and the Centigrade scale for the thermometer should be aimed at'; and that 'the importance of the co-operation of the Navies' should be promoted.⁸¹ In its aims the conference was part of wider movements in the 1870s to establish international standards, such as the international gold standard and the Treaty of the Metre.⁸²

Participants' responses revealed differences of opinion on the aims and successes of the 1853 conference and over subsequent attempts to introduce a uniform international approach to the study of meteorology at sea. Brigadier-General Myer, Chief Signal Officer in the US Army, reported that the USA had followed the Brussels plan. J.C. de Brito-Capello, the Director of the Nautical and Meteorological Observations at the Lisbon Observator. The Danish were also supportive, although Captain Hoffmeyer of the Danish Royal Meteorological Institute conceded that some compromises had been made, such as the use of aneroid barometers on smaller vessels where a mercurial barometer 'cannot appropriately be placed'.

Other nations were less positive. Professor Buys Ballot, the Dutch meteorologist and the meeting's President, argued that the Brussels conference had 'asked for too many observations' and that the hours of observation were inconvenient. The French made similar complaints. The report of Captain Rikatcheff of the Imperial Russian Navy was perhaps the most pessimistic. The thermometers used onboard Russian

vessels had continued to use the Reaumur scale, without the recommended addition of the centigrade scale, because of worries that ‘one would often be read instead of the other’. The barometers had not been compared since 1853 and the necessary corrections not been determined, due to the want of a dedicated office to do so. Rikatcheff complained that meteorological observations obtained at sea were not discussed or utilized in his country, or shared with other countries. For Rikatcheff, ‘You ought not to be astonished, Sir, if from these answers you see that the greater part of our Maritime Meteorological Observations lie dormant till now.’⁸³

Discussion of the various recommendations made at the 1874 conference was similarly wide-ranging and conflicting. Disagreements remained over which scales to use when measuring temperature; to what degree of accuracy readings should be taken; what scale should be used to record wind force; how the labour of global meteorological study should be divided; what form the meteorological register should take; and how the resultant data should be dealt with, analysed and archived. The various formal conference resolutions reflected these differences.⁸⁴ Attempts to fashion a unifying, international language of science, which would allow meteorologists of all nations to communicate with one another, was part of a wider effort to effect a system of liberal internationalism in the 1870s; to foster economic and social progress; and popularize a language of progress. As with concurrent attempts to encourage the universal adoption of the metric system, however, the implementation of a single international system of marine meteorology was stymied by national rivalries and resistance to new measures and practices onboard the ships of the various European navies.

<A>Conclusion

This chapter has shown that during the nineteenth century Britain's Admiralty gradually adopted and honed the practice of observing and recording the weather onboard its ships. The polar expeditions of the 1810s and 1820s served as important test sites for the development of new observation protocols, registers and instrumental practices, which, in turn, were informed by scientific reforms then taking place. These practices were then introduced more widely, initially to the Hydrographic Office's survey ships and then to the naval fleet.

The implementation of a universal schedule of observations and the correct siting and use of various instruments onboard surveying and fighting ships was not easily achieved. Beaufort and others struggled to persuade the Admiralty of the value of systematic meteorological observations on its ships. Getting officers to conform to protocols once they were laid down remained a challenge, especially on ships whose main purpose was not scientific or hydrographic. Observations were made at irregular times of the day and instruments were sited inappropriately. Observers failed to check instruments against standards, entered readings into the registers retrospectively and made erroneous reductions. Attempts in the later nineteenth century to institute a single meteorological culture across European navies further exposed the highly localized nature of a supposedly universal science.

It is not, then, straightforwardly possible to conceive of British naval and surveying vessels as itinerant observatories, if, that is, we assume the observatory to have been an uncompromised site for science and its observers obedient drudges. The evidence examined here makes it difficult to agree entirely with Edward's claim that mid-nineteenth-century meteorology conformed to or was productive of a quasi-obligatory globalism. Scientific manuals and conference proceedings give the impression of international consensus, but closer reading reveals differences over

issues of instrument type, the scales to use, when and how to observe, and so on. All that said, if we assume that observatories and their instruments always existed in various states of repair and that observational practices internal to them were always liable to compromise and dissent, and if we proceed on the basis that international scientific networks were always performative and subject to translation, then it does become possible to include the man-of-war and its various barometers, thermometers and log books as critical components in the extension of European power over space.

Notes to chapter 5

¹ Simon Schaffer, ““On Seeing Me Write”: Inscription Devices in the South Seas”, *Representations*, 97 (2007): 90–122, quote from page 91.

² Henrika Kuklick and Robert Kohler, eds, *Science in the Field* (Chicago: Chicago University Press, 1996); Michael Reidy, “From the Oceans to the Mountains: Spatial Science in an Age of Empire”, in J. Vetter, ed, *Knowing Global Environments: New Historical Perspectives on the Field Sciences* (New Brunswick: Rutgers, 2011): 17–38.

³ Alison Winter, ““Compasses All Awry”: The Iron Ship and the Ambiguities of Cultural Authority in Victorian Britain’, *Victorian Studies* 38 (1994): 69–98, quote from page 75.

⁴ ‘Obedient drudges’ was the term the Astronomer Royal, George Airy, used to describe the workers in the Royal Greenwich Observatory: Winter, ““Compasses All Awry””.

⁵ Richard Sorrenson, “The Ship as a Scientific Instrument in the Eighteenth Century”, in Kuklick and Kohler, *Science in the Field* (Chicago: Chicago University Press, 1996): 221–236, quote from page 222.

⁶ Richard Dunn, ““Their Brains Over-Taxed’: Ships, Instruments and Users”, in Don Leggett and Richard Dunn, eds, *Re-inventing the Ship: Science, Technology and the Maritime World* (Aldershot: Ashgate, 2012): 131–155.

⁷ Schaffer, ““On Seeing Me Write””, 107.

⁸ Simon Schaffer, “Easily Cracked: Scientific Instruments in States of Disrepair”, *Isis* 102 (2011): 706–717.

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- ⁹ Schaffer, “Easily Cracked”, 709.
- ¹⁰ Michael Dettelbach, “Humboldtian Science”, in Nicholas Jardine *et al*, eds, *Cultures of Natural History* (Cambridge: Cambridge University Press, 1996): 287-304, quote from page 300, original emphasis.
- ¹¹ Gregory Good, “A Shift of View: Meteorology in John Herschel’s Terrestrial Physics,” in J. R. Fleming, V. Jankovic and D. R. Coen, eds, *Intimate Universality: Local and Global Themes in the History of Weather and Climate* (Sagamore Beach: Science History Publications, 2006): 35–68.
- ¹² Charles W. J. Withers, “Science, Scientific Instruments and Questions of Method in Nineteenth-Century British Geography,” *Transactions of the Institute of British Geographers* 38 (2012): 167–179, quote from page 170. See also David Cahan, ed, *From Natural Philosophy to the Sciences: Writing the History of Nineteenth-Century Science* (Chicago: Chicago University Press, 2003).
- ¹³ Good, “A Shift of View”, 36; Fabian Locher, “The Observatory, The Land-Based Ship and the Crusades: Earth Sciences in European Context, 1830–50,” *British Journal for the History of Science* 40 (2007): 491–504, quote from page 501; Ben Marsden and Crosbie Smith, *Engineering Empires: A Cultural History of Technology in Nineteenth-Century Britain* (Basingstoke: Palgrave, 2005), 24.
- ¹⁴ Vladimir Jankovic, *Reading the Skies: A Cultural History of English Weather, 1650-1820* (Manchester: Manchester University Press, 2000), quotes from pages 164, 143, and 166 respectively.
- ¹⁵ Vladimir Jankovic, “Ideological Crests versus Empirical Troughs: John Herschel’s and William Radcliffe Birt’s Research on Atmospheric Waves, 1843–50,” *British Journal for the History of Science* 31 (1998): 21–40, quote from page 28.

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- ¹⁶ Paul N. Edwards, “Meteorology as Infrastructural Globalism”, *Osiris* 21 (2006): 229–250.
- ¹⁷ Jankovic, *Reading the Skies*, 158.
- ¹⁸ Christopher Lloyd, *Mr. Barrow of the Admiralty: A Life of Sir John Barrow* (London: Collins, 1970), 91–2.
- ¹⁹ Fergus Fleming, *Barrow’s Boys: A Stirring Story of Daring, Fortitude and Outright Lunacy* (London: Granta, 1999), 11.
- ²⁰ Alfred Friendly, *Beaufort of the Admiralty: The Life of Sir Francis Beaufort 1774–1857* (New York: Random House, 1977), 289.
- ²¹ David Philip Miller, “The Revival of the Physical Sciences in Britain, 1815–1840”, *Osiris* 2 (1986): 107–134; Randolph Cock, “Scientific Servicemen in the Royal Navy and the Professionalisation of Science, 1816–55”, in David M. Knight and Matthew D. Eddy, eds, *Science and Beliefs: From Natural Philosophy to Natural Science, 1700–1900* (Aldershot: Ashgate, 2005): 95–112.
- ²² Sophie Waring, “The Board of Longitude and the Funding of Scientific Work: Negotiating Authority and Expertise in the Early Nineteenth Century’, *Journal for Maritime Research* 16 (2014): 55–71, quote from page 57.
- ²³ David Philip Miller, “Between Hostile Camps: Sir Humphrey Davy’s Presidency of the Royal Society of London, 1820–1827”, *British Journal for the History of Science*, 16 (1983): 1–47; Roy M. MacLeod, “Whigs and Savants: Reflections on the Reform Movement in the Royal Society, 1830–48”, in Ian Inkster and Jack Morrell, eds, *Metropolis and Province: Science in British Culture, 1780–1850* (London: Hutchinson, 1983): 55–90.
- ²⁴ Maria Boas Hall, “Public Science in Britain: The Role of the Royal Society”, *Isis* 72 (1981): 627–629.

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- ²⁵ Miller, “Between Hostile Camps”, 34.
- ²⁶ Waring, “The Board of Longitude”.
- ²⁷ Copy of letter from William T. Brande to John Barrow, 29 January 1818, Minutes of Committees of the Royal Society Appointed From Time to Time for Particular Purposes, CMB1/25, Archives of the Royal Society, London, 9.
- ²⁸ “At a Committee for ascertaining the Length of the Seconds Pendulum”, Minutes of Committees of the Royal Society Appointed From Time to Time for Particular Purposes, 26 March 1818, CMB1/25, Archives of the Royal Society, London, 14.
- ²⁹ “Hints of Experiments to be made in the Arctic Expedition ... of 1821”, Minutes of Committees of the Royal Society Appointed From Time to Time for Particular Purposes, 12 April 1821, CMB1/25, Archives of the Royal Society, London, 26–31.
- ³⁰ G.W. Roberts, “Magnetism and Chronometers: The Research of the Reverend George Fisher”, *British Journal for the History of Science* 42 (2009): 57–72.
- ³¹ Catherine Ward and Julian Dowdeswell, “On the Meteorological Instruments and Observations Made during the 19th Century Exploration of the Canadian Northwest Passage”, *Arctic, Antarctic, and Alpine Research*, 38 (2006): 454–464, quote from page 455.
- ³² “At a meeting of the Committee for considering and resolving on the most advantageous objects to be attained by Capt’n Foster in the course of his intended scientific Voyage”, Minutes of Committees of the Royal Society Appointed From Time to Time for Particular Purposes, 28 January 1828, CMB1/25, Archives of the Royal Society, London, 230.
- ³³ Miller, “The Revival of the Physical Sciences”.
- ³⁴ Joint Committee of Physics and Meteorology; 1838–39, 19 June 1839, CMB/284, Archives of the Royal Society, London.

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- ³⁵ Royal Society, *Report of the President and Council of the Royal Society on the Instructions to be Prepared for the Scientific Expedition to the Antarctic Regions* (London: Richard and John E. Taylor, 1839), 13.
- ³⁶ Ward and Dowdeswell, “On the Meteorological Instruments”, 459.
- ³⁷ Joint Committee of Physics and Meteorology; 1838–39, 22 August 1839, CMB/284, Archives of the Royal Society, London.
- ³⁸ Royal Society, *Report ... on the Instructions ... for the Scientific Expedition to the Antarctic Regions*, 13.
- ³⁹ *Ibid.*, 14
- ⁴⁰ Joint Committee of Physics and Meteorology; 1838–39, 22 August 1839, CMB/284, Archives of the Royal Society, London.
- ⁴¹ James Clark Ross, *A Voyage of Discovery and Research in the Southern and Antarctic Regions, During the Years 1839–43*, 2 volumes (London, 1847), 1: xxvii.
- ⁴² Ward and Dowdeswell, “On the Meteorological Instruments”, 455.
- ⁴³ Schaffer, ““On Seeing Me Write””, 113.
- ⁴⁴ Minutes of Committees of the Royal Society Appointed From Time to Time for Particular Purposes, 12 February 1818, CMB1/25, Archives of the Royal Society, London.
- ⁴⁵ Minutes of Committees of the Royal Society Appointed From Time to Time for Particular Purposes, 26 March 1818, CMB1/25, Archives of the Royal Society, London.
- ⁴⁶ Minutes of Committees of the Royal Society Appointed From Time to Time for Particular Purposes, 18 March 1819, CMB1/25, Archives of the Royal Society, London.
- ⁴⁷ Schaffer, ““On Seeing Me Write””, 112.

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- ⁴⁸ Waring, “The Board of Longitude”, 66.
- ⁴⁹ Anon, Committee for examining into the state of the Meteorological Instruments belonging to the Royal Society, 10 and 12 December 1822, in Minutes of Committees Appointed From Time to Time for Particular Purposes, CMB/1/25, Archives of the Royal Society, London.
- ⁵⁰ Anon, Committee for examining into the state of the Meteorological Instruments.
- ⁵¹ Anon, Minutes of the Meteorological Committee, 2 August 1827, Meteorological Committee Minutes and Letters 1830-1837, Domestic MSS Volume III, Archives of the Royal Society, London.
- ⁵² Jankovic, “Ideological Crests”, 24.
- ⁵³ John Daniell, *Meteorological Essays* (London: Thomas & George Underwood, 1823), viii.
- ⁵⁴ On the use, and misuse, of meteorological instruments, see Jan Golinski, *British Weather and the Climate of Enlightenment* (Chicago: University of Chicago Press, 2007).
- ⁵⁵ Forbes, “Report”, quote from pages 196–7. See also Jankovic, “Ideological Crests”, 24.
- ⁵⁶ Schaffer, ““On Seeing Me Write””, 106.
- ⁵⁷ Locher, “The Observatory, The Land-Based Ship and the Crusades”, 498.
- ⁵⁸ Friendly, *Beaufort of the Admiralty*.
- ⁵⁹ “Admiralty Instructions for the Beagle Voyage” are included in Appendix One of Charles Darwin, *Voyage of the Beagle* (London: Penguin, 1989 [1839]), 396.
- ⁶⁰ Ward and Dowdeswell, “On the Meteorological Instruments”, 461–2.
- ⁶¹ Surveying instructions from Beaufort to Lieutenant Edward Barnett of HMS *Thunder*, 9 December 1837, Miscellaneous Files, UKHO, 26 and 27.

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- ⁶² Nicholas Courtney, *Gale Force 10: The Life and Legacy of Admiral Beaufort* (London: Review, 2002).
- ⁶³ Alexander Becher, Proposals for Improving the Meteorological Registers in the Log Books of HM Ships, 14 November 1838, Minute Book 3/HH11, UKHO, 91–3.
- ⁶⁴ 3 Jan 1839, Letter from Lt Col William Reid, Royal Engineers, to John Herschel, Chair of Met Com of RSL, DM/3, Archives of the Royal Society, London.
- ⁶⁵ Courtney, *Gale Force 10*.
- ⁶⁶ British Admiralty, *Admiralty Instructions for the Government of Her Majesty's Naval Services* (London: Stationary Office, 1844), 173. What was meant exactly by 'secure and accessible' is not explained.
- ⁶⁷ Anon, 2 September 1845 and 6 October 1846, Circulars to Surveyors on the Home Station, LB13/HH18 and LB14/HH19, UKHO Archives, Taunton.
- ⁶⁸ J. J. Colledge, *Ships of the Royal Navy: The Complete Record of all Fighting Ships of the Royal Navy from the Fifteenth Century to the Present* (London: Greenhill Books, 1970).
- ⁶⁹ Letter from Sir Henry Leeke to Francis Beaufort, 9 February 1847, Incoming Letters L301–669, UKHO Archives, Taunton.
- ⁷⁰ Letter from David Adam to Henry Leeke, 30 January 1847, appended to the letter from Leeke to Beaufort.
- ⁷¹ In 1848 sea trials were carried out at Woolwich of a new wind gauge, designed by Colonel W.H. Rochfort, which he claimed eliminated the effects of the ship's movement on measurements of wind force: Memoranda written by Beaufort from 27 January 1848 to 29 April 1848, MB6/HH21, UKHO Archives, Taunton.

⁷² Francis Beaufort, *Meteorological Observations – General System of Observing By Foreign and Home Men of War – Packets – & Merchant Vessels*, 25 June 1852, MB8/HH28, Letterbooks, UKHO, Taunton, 79–80.

⁷³ Malcolm Walker, *History of the Meteorological Office* (Cambridge: Cambridge University Press, 2012).

⁷⁴ Anon, *Maritime Conference held at Brussels for Devising an Uniform System of Meteorological Observations at Sea*, MS, 1853, Archive of the Royal Meteorological Society, Meteorological Office, Devon, 60.

⁷⁵ Anon, *Maritime Conference*, 18. In relation to relative pressure, the conference noted the value of the aneroid barometer at sea but preferred the more delicate mercurial barometer given its ability to provide absolute results.

⁷⁶ Anon, *Maritime Conference*, 14.

⁷⁷ Walker, *History of the Meteorological Office*, 21–22.

⁷⁸ Nicholas Wright Gillham, *A Life of St Francis Galton: From African Exploration to the Birth of Eugenics* (Oxford: Oxford University Press, 2001).

⁷⁹ J. Burton, “Robert FitzRoy and the Early History of the Meteorological Office”, *British Journal for the History of Science* 19 (1986): 147–76.

⁸⁰ Walker, *History of the Meteorological Office*.

⁸¹ Meteorological Committee, *Report of the Proceedings of the Conference on Maritime Meteorology held in London, 1874* (London: HM Stationary Office, 1875), 4.

⁸² Martin H. Geyer, “One Language for the World: The Metric System, International Coinage, Gold Standard, and the Rise of Internationalism, 1850–1900”, in Martin H. Geyer and Johannes Paulmann, eds, *The Mechanics of Internationalism: Culture*,

Society, and Politics from the 1840s to the First World War (Oxford: Oxford University Press, 2001), 55–92.

⁸³ Meteorological Committee, *Report of the Proceedings. Appendix B*, quotes from pages, 28, 26, 31, and 32 respectively.

⁸⁴ In an attempt to encourage the more uniform pursuit of maritime meteorology, the ‘Proposed English Instructions for keeping the Meteorological Log’ were appended to the conference proceedings.