NINETEENTH-CENTURY SURVEY SCIENCES: ENTERPRISES, EXPEDITIONS AND EXHIBITIONS

INTRODUCTION

by

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This special issue of *Notes and Records of the Royal Society* addresses important aspects of the new kinds of intensive and ambitious schemes launched by early nineteenth-century British public agencies for worldwide surveys of the phenomena of astronomy and geography, physics and meteorology. Historians and historical geographers of science have already provided separate and increasingly detailed studies of several of these initiatives.[1] Such focused scholarship now invites a comparative and synthetic approach to the development and practice of these surveys. In particular, this nineteenth-century work of surveys and observatories, maritime sciences and global physics, has typically been defined through the deployment of collections of ingenious hardware and material instruments. For this reason, many of the essays gathered here examine the apparatus and the equipment involved in the nineteenth-century surveys; and the means through which they can be understood in historical scholarship, in collections and exhibitions.

Their original users hoped that survey instruments could help generate precise data so that information could be juxtaposed and analysed at central sites. Charts and maps would be produced of the global variation and correlation of various physical phenomena. Very large printed data sets in the form of almanacs, catalogues and graphs could, so it was supposed, then be used to aid communication, administration and commerce. The early decades of the nineteenth century provide especially clear cases of the territorial reorganisation of scientific enterprises and their long-range connexions. Combinations of British colonial, economic and military interests helped establish the Ordnance Survey by 1790-1791. Initially a branch of the Ordnance Survey, the Geological Survey was established in 1835, while the Great Trigonometric Survey of India was launched from Madras in 1802. This was also the period of the establishment of a network of colonial and company observatories, first at Madras in 1786, then in the 1820s at such sites as the Cape of Good Hope, Parramatta, St Helena and Bombay.[2] Many were commissioned to generate huge catalogues of transit times and positions, to monitor meteorological and atmospheric conditions, and to serve as bases for geodetic surveys. From the 1830s, magnetic surveys, backed by a powerful alliance of military and scientific interests, sponsored worldwide maritime and observatory measures of geomagnetic phenomena and the production and refinement of supposedly robust and precise navigational and field equipment.[3] The overhaul of the Admiralty's Hydrographic Office in the 1830s for coastal and tidal surveys, the establishment of Kew as a metropolitan physical observatory in 1842 and of a meteorological department within the Board of Trade in the 1850s all drew on this recent record of institutional investment.[4] Expert staff moved between the surveys, as did the hardware and interests of the makers who furnished equipment. These surveys' information order was exploited in ambitious if often compromised attempts to furnish the state with an imperial archive. In many such cases, what began as transient survey projects, involving the despatch of temporarily mobilised manpower and equipment, were often gradually transmuted into more rigidly defined official surveys, with associated bureaucratic regulation and formal institutional resources.[5]

The specific linkage between the work of the surveys and their instrumentation has often been understood by appeal to Alexander von Humboldt's well-publicised schemes for lavishly equipped investigative travel and of big data presented in thematic maps, precision graphs and aesthetically charged graphic print.[6] It is timely to subject the Humboldtian model to scrutiny, especially in view of complementary analyses of the significant roles of innovative navigational, astronomical and observatory sciences that were contemporary with the Humboldtian moment and in many ways diverged from or challenged its precedent.[7] In her highly influential cultural history of nineteenth-century science, Susan Faye Cannon introduced the term 'Humboldtian science' as a replacement for the category of 'Baconian science', which in turn was taken to denote 'a naïve, encyclopaedic empiricism relying entirely on the collection and collation of facts, a fascination with the particular, and a rejection of theory.'[8] Instead, Cannon argued that Humboldtian science was 'the great new thing in professional science in the first half of the 19th century', defined and marked out by a 'new insistence on accuracy … for all instruments and all observations'; a 'new mental sophistication, expressed as contempt for the easy theories of the past'; a 'new set of conceptual tools: isomaps, graphs, theory of errors'; and the application of these elements to 'the immense variety of real phenomena, so as to produce laws dealing with the very complex interrelationships of the physical, the biological, and even the human' that could work at a global geographical scale.[9] Sciences that conformed to this model included astronomy, botany, terrestrial magnetism, hydrology, oceanography, meteorology, geodesy and physical geography. Cannon identified all of these characteristics in the work of Humboldt, especially his promotion of science that promoted 'widespread but interconnected real phenomena in order to find a definite law and a dynamical cause.'[10]

Cannon's term gained significant purchase in studies of the history of nineteenth-century science in the years following the publication of her *Science in Culture*. Morrell and Thackray adopted the term to discuss the British Association for the Advancement of Science's involvement in various scientific enterprises, including the study of the tides, meteorology and terrestrial magnetism. Nicolson used the term in his analysis of Humboldt's 'morphological' plant geography; Zeller discussed British imperial applications of the Humboldtian sciences to surveys of northwest Canada; and Cushman examined the political motivations and social dimensions of Humboldtian science as it was developed in South American climatological debates.[11] Others have been more critical. Dettelbach argued that Cannon's Humboldtianism relied on Humboldt's status 'to define a 'style' or 'complex' and that it gave the term explanatory force, at the same time as it black-boxed various concerns and practices.[12] He noted the lack of unity to the collection of observational and descriptive concerns provided by the term, apart from 'an encyclopedic dedication to the systematic and precise measurement of as many physical parameters as possible'.[13] Dettelbach argued that Humboldt needed to be distinguished from the Humboldtians. In doing so, he mapped out the shape of Humboldt's terrestrial physics, which he differentiated from the descriptive sciences through its attention to the 'the great and constant laws of nature'. Dettelbach claimed that his account of Humboldt's science 'illuminates the reorganization of knowledge and disciplines in the early nineteenth century that defined the emergence of natural science out of natural philosophy.'[14]

The sciences that Cannon labelled components of the Humboldtian sciences have received increasing attention in recent years. For instance, Cawood's work on the magnetic surveys has been built on by scholars including Good, Josefowicz and Mawer.[15] Mawer noted that Humboldt did a lot to improve understandings of the relations between declination, inclination and intensity and their connections to other natural forces, notably electricity, and was often credited as the progenitor of the magnetic campaigns.[16] Good argued that promoters of these surveys 'elevated Humboldt's vision of observatory-based studies of strange magnetic phenomena and allied their research proposals with the precision instruments and hard-nosed, mathematical methods of [mathematician Carl Friedrich] Gauss.' Terrestrial magnetism, along with meteorology, became the most data-intensive geo-sciences of the period, with study of the tides and earthquakes lagging behind, while the former was the most fully organised in terms of the coordination of empirical research and 'most self-consciously directed toward answering questions of laws and causes.'[17] Josefowicz argued that Humboldt, Christopher Hansteen, Gauss and Wilhelm Weber 'located the value of terrestrial magnetic research not only in its contribution to the progressive march of scientific knowledge, but also in the salutary habits of perception that its study promoted – those same habits of obedience, thoroughness, and careful attentiveness, that were esteemed by members of a rising, professional middle class.'[18] Reidy provided a comprehensive study of tidology in Britain, with a focus on the work of scientific polymath William Whewell, who 'wanted to establish tidology as a viable research frontier based on adequate funding, the necessary equipment, and a worldwide network of observers.' Whewell viewed his project as synoptic, a legacy Reidy argues found precedents in Edmond Halley's work and its most obvious contemporary resonance in Humboldt's programme.[19] Addressing meteorology's emergence as a component of terrestrial physics, Fleming et al argued that attempts to standardize and coordinate world-wide weather observations in the nineteenth century created a 'meteorological "synopticon"'. They noted that the astronomer John Herschel saw meteorology as an 'empirical science that required precise measurements and intimate, first-hand knowledge of local airs', while also insisting that 'meteorological phenomena were subject to universal laws, accessible through induction and the testing of hypotheses.'[20]

While a lot of recent work in the history of science has attended to the shape and meaning of the laboratory sciences and the field sciences one to the other, Aubin drew our attention to an emerging family of nineteenth-century sciences that he described as observatory sciences. Aubin noted that, as a place of knowledge, the observatory has a longer history than either laboratory or field.[21] The number of astronomical observatories globally grew from around thirty to between 200 and 300 in the nineteenth century, during which time the endowment of expensive observatories became an indispensable requirement for any modern state intent on preserving its political independence and securing its integration into the world system.'[22] Astronomy was the archetypal observatory science but was joined by others in the first half of the nineteenth century: magnetism and meteorology, geodesy and cartography, mathematical statistics and metrology. The editors of *Heavens on Earth*, Aubin, Bigg and Sibum, asserted that these various traditions were bound together by their commitment to a set of practices – what they called 'observatory techniques' – that placed great store on the use of precision instruments for making observations and taking measurements; that 'embraced methods of data acquisition, reduction, tabulation, and conservation, along with complex mathematical analyses'; made use of visualisation techniques and other representations of heavens and earth; and incorporated the social management of personnel and networks of international collaboration. These techniques defined a common space of knowledge.[23]

In this collection we use the term 'survey science' to group a range of complementary sciences together, all of which mainly conform to aspects of the definition of observatory science put forward by Aubin.[24] The term is not therefore intended to supplant or replace other collective nouns for scientific practice. That said, the term survey science, with its emphasis on the conduct of large-scale and yet fine-grained information collection across space, productively incorporates actors otherwise marginal to the operations of the observatory – geographers, explorers, property and revenue surveyors, as much as astronomers and meteorologists. Heroic explorers and East India Company surveyors placed as great an emphasis on precision instrumentation and measurement, statistical methods, data visualisation and forms of collaboration as Cannon's Humboldtian scientists and Aubin's observatory scientists. The survey sciences are also crucially differentiated from the observatory sciences, partly through their emphasis on the importance of the mobility of both instruments and observers. Indeed, the epistemic value of observations collected at rest in the controlled environment of the observatory as against those from beyond its walls was a critical topic of debate in the nineteenth century. During and after his South African residence in the 1830s, John Herschel strongly urged the co-ordination of travel accounts under the control of fixed survey stations in a general programme to produce what he called 'complete acquaintance with our globe as a whole'. Indeed, Herschel's vision was peculiarly oriented towards visions of the globe as the object of knowledge and surveillance. In 1839 he told the French administrator and man of science François Arago that the magnetic surveys offered 'an opportunity such as may never again occur of fixing for future ages' a vast array of sets of data 'upon a scale which may be said without exaggeration to embrace the whole globe'.[25]

The pursuit of survey sciences at this period therefore raised especially acute problems of infrastructure, recruitment and management on a worldwide scale. Familiar patterns of natural historical accumulation and of individually equipped travellers, characteristic of past inventory programmes, had to be radically transformed. Encounters with indigenous informants and intermediaries were crucial moments in making an effective information order. They inevitably involved surveyors in the work of defining the scope and authority of different knowledge traditions. Historians such as Raj have linked some of these transformations, such as the fraught contrast between data accumulation and charismatic travel, and the imposition of disciplinary training on surveyors and delegates on mission and on the workforce charged with data analysis and comparison, with a radical change of the entire global circulation of scientific knowledge and practices during the earlier nineteenth century.[26] As Outram has suggested in her studies of debates about Humboldt's repute and the wider authority of travellers' tales, this was what prompted and directed the debates about the comparative authority of indigenous experts, mobile scientific observers, or established survey bases.[27]

Part of the fundamental puzzle of the survey sciences was their apparent dependence on reliable action at a distance, both through the despatch of delegates, whether human travellers or material apparatus, who could then be trusted to behave appropriately and accountably elsewhere, whether at sea or on land. Simon Naylor's contribution to this collection addresses this problem directly. He points out how in a survey science such as nineteenth-century meteorology, its explicitly global orientation forced its dependence on extensive networks of highly variable and often undisciplined observers. It was just for this reason, his paper shows, that the provision of standardised equipment might begin to address challenges of data reliability and accumulation. Part of the fascinating history of such sciences lies precisely in how what Fabien Locher, in his study of the European magnetic surveys of the 1840s, calls different 'regimes of observation' were put to work not merely to extract data but to attempt, often vainly, to control the hardware and personnel involved under such regimes.[28] In her contribution to this collection, Jenny Bulstrode offers evidence from episodes of the 1820s and 1830s in which very different observation regimes, whether based on the practices of the whaling ships in the north Atlantic or the Arctic, or on the systems of Royal Naval discipline shared by scientific servicemen, were in play in the production and discussion of the major magnetic surveys. Using the techniques of historical anthropology, her essay shows how intricate aspects of whalers' lore and custom could affect the production of magnetic data and, indeed, of the modelling of magnetic survey equipment and its physical function. These were questions both of legal control and cosmological significance. In the case of the career of the whaler commander and evangelical preacher William Scoresby, highly influential protagonist of magnetic instrumentation and magnetic world-views, Bulstrode demonstrates how his surveys and his models of combinations of force, apparatus and practice could forge very different visions of the physical globe and the moral world.

There was thus a set of important connexions between specific changes in institutions, hardware and personnel, and the very notion, in Herschel's terms, of a 'complete acquaintance' with the globe as a whole. This was the moment of the imperial meridian, when political crises in the Caribbean and Latin America, the Levant and southern Asia, all involved intense mobilisation of military and economic agents reliant on fragile information networks and long-range systems of commercial exchange.[29] Jessica Ratcliff's essay in this collection analyses the very close relationship between the expansive enterprises of the East India Company and the systems of survey and collection that characterised Company agents' work in south and south-east Asia, especially in the period of the Napoleonic wars, when territories in the Indian subcontinent were occupied and charted, and when forces were despatched to the East Indian archipelago, especially to the west coast of Sumatra and to Java. Ratcliff argues that the surveys mounted under the direction of the military officer Colin Mackenzie, and under the aegis of the governor Stamford Raffles by the American medic Thomas Horsfield, could be seen as forms of seizure of rival intellectual capital, booty then to be accumulated in the new India Museum in London. Mackenzie noted in 1799 that the inhabitants of Mysore 'can scarcely separate the idea of taking possession of a country from that of surveying it'. As several scholars have argued, survey practice and collecting was a crucial feature of the establishment of difficult, tenuous and multilateral relations of circulation and of knowledge production both within the Asian territories and in those institutions of political power and scholarship that emerged in this decisive period of imperial aggression.[30] Reidy has argued in the cases of the new tidal and geodetic sciences of the earlier nineteenth century that 'the practice of science helped transform unmapped spaces into imperial places'.[31]

One concern of this scholarship has therefore been to understand how the techniques of survey sciences, not least the hardware and equipment they employed, helped make certain models of the globe as an object both of scrutiny and governance. Historians have recently signalled and disputed enthusiasm for global approaches in the studies of past sciences, especially for the period of the eighteenth and nineteenth centuries.[32] Critics have convincingly pointed to hastily simplistic identification of the global with the imperial; wrong-headed imposition of local (often European) chronologies on systems for which their relevance is dubious; and misrecognition of mixtures of violent exploitation with collaboration in the work of the field sciences.[33] Important in these concerns is the awareness that the work of the sciences, especially the surveys, defined phenomena and systems as worldwide in principle, then in an intriguingly circular tactic of self-validation drew their legitimacy and their resources from this very definition of global extension. Examples include the remodelling of geography, meteorology and of magnetism as survey sciences in this period. In the opening decades of the nineteenth century, Humboldt, Arago, Gauss and their interlocutors constructed schemes of magnetic survey which insisted that the patterns of magnetic dip, variation and strength could only be understood on a global scale and would thus somehow reveal the physical system governing the planet. This argument was used to legitimate the magnetic campaigns of the 1830s and 1840s, and especially their recruitment of a workforce among naval personnel and in the nascent observatory systems of North America and Australasia, whose disciplined assemblages of personnel, apparatus and data analysis were then supposed to demonstrate the geographical facts of the worldwide magnetic system.[34]

Several essays in this volume explore the intriguing methods of practical management and ingenious tactics that governed this production of allegedly global sciences. Matthew Goodman's provides a close study of the methods used by Edward Sabine's bureau at Woolwich arsenal from 1841, under which many millions of distributed observations of magnetic direction and strength were to be processed, stored and juxtaposed. Goodman explains the decisive practices of error management: on the assumption of modes of normal variation, the effects of parasitic disturbances and systematic errors had to be detected and effaced. There was therefore a vital relation between the stability and reach of models of discipline – in the case of the Woolwich system, this discipline was military – and the construction of effective worldwide systems of governance and knowledge. Similar issues were clearly in play in the workings of the new Geographical Society, established in 1830, which would lend equipment to no less than 436 expeditions in the following century. In their careful study of the Society's records presented in their contribution to this issue, Jane Wess and Charles Withers demonstrate many ways in which questions of the robustness and reliability of apparatus were apparently to be dealt with through discipline of the delegates. They cite striking claims from a figure such as Francis Galton, scientific traveller and social statistician, that it was precisely the moral and physical quality of the instruments' users that underwrote their capacity to act worldwide as tools for making reliable scientific knowledge.

The relation between quantitative standards and field practice in the use of instruments during the surveys was therefore highly complex. From the later eighteenth century, exact measurement had emerged as a general characteristic of the physical sciences. There was a widespread enthusiasm for precision instruments and the numbers they could generate. Particularly important for the new sciences were instruments that measured quantities of matter and were used for calculation and counting.[35] This interest in instruments and the establishment of agreed physical constants and standards of measurement only grew and became an important part of the culture of the sciences in the nineteenth century: MacDonald and Withers remind us that by the 1830s 'method in science insisted upon trained observation, improved written recording, repetition of numerical measurement, and a reliance upon precision instrumentation.'[36] The observatory was of critical importance in shaping the culture of precision that transformed scientific practices during that century.[37] Men of science like Herschel and geomagnetic experts Edward Sabine and Humphrey Lloyd cultivated this idea of precise instruments, built to exacting standards in metropolitan workshops, calibrated in metropolitan hubs and put to work in observatories at home and abroad.[38]

The practice of precision measurement using exquisitely crafted instruments did not stop at the boundaries of the observatory. The survey sciences extended observatory techniques into uncertain terrain on land and at sea. The deployment of instruments provided a focus to the work of science in the field and conferred epistemic authority on the user.[39] Action at a distance both relied on, and urgently challenged, the networks binding the producers of survey hardware with exceptionally various users and environments. For instance, Schaffer has shown that East India Company surveyors were very concerned with the reliable status of their hardware and the integrity of their connections with major instrument makers.[40] Withers has noted that it became something of a 'scientific and moral necessity' that users continuously wrote down their instrumental observations, maintained accuracy and repeated processes again and again 'so as to be habit forming'.[41] Edney observes that the geographer-traveller, 'when armed with suitable instruments, was able to situate his distanced, privileged, and disciplined observations according to their geographical relationships. …[T]he geographer carried at least a compass for directions, a timepiece for estimating distances, and – if he was wealthy – perhaps also a sextant or octant for astronomical determinations of location. So armed, the geographer could observe and record the abstract quantities of location as he passed through the land. He could *survey*.'[42] For the property and revenue surveyors of the East India Company, as Mackenzie's remarks about the Mysore identification of survey science with the act of territorial possession implied, scientific instruments cohabited with weapons and themselves functioned as armaments, with military surveyors often contesting the grounds they had to measure.[43] The same principles held for the other survey sciences, even if the instruments themselves measured different natural phenomena and features. Instruments were used as weapons in conflicts over epistemology and priority as much as over territory, as is well shown by Bulstrode's analysis in this collection of the controversies over both property and propriety in the fraught exchanges between Scoresby and the Admiralty's magnetic committee during the 1830s.

The nineteenth-century physical sciences, with their global data-gathering ambitions, relied heavily on a wide and varied cast of participants to collect observations. Whilst often remembered for his own adventures with instruments in Central and South America, Humboldt's wider scientific project involved a large spectrum of participants and informants from around the world, including naval officers, colonial administrators, physicians, diplomats, gentlemen of science, and other travellers. These miscellaneous observers provided 'relatively cheap methods for surveying extensive territories with sufficient accuracy'.[44] For Humboldt, precision survey of global terrestrial physics using a diverse body of observers was itself a 'civilizing mission', whereby all participants were improved, while the risks attendant with the use of volunteer or poorly trained observers was offset by the application of new statistical techniques, such as the method of least squares. In the case of military personnel, or 'scientific servicemen', some training might have been provided in instrument use prior to deployment.[45] Scientific societies also operated as hubs for advice to volunteers, which was disseminated through dense networks of correspondence, as Naylor shows in his analysis of the Royal Meteorological Society's group of meteorological observers in this issue. Naylor's essay concludes with the significant observation that it was precisely by domesticating meteorological equipment that the household garden might somehow come to resemble a scientific site in miniature, while the routine of idealised and aestheticized domestic harmony could be transiently reconciled with the values of exact observation. In their contribution, Wess and Withers similarly explain how carefully circumscribed manuals were also produced, to be read alongside instruments, where epistolary instruction was not available. Manuals like the Royal Geographical Society's *Hints to Travellers* demonstrated and demarcated the methods scientific travellers ought to follow in order to produce credible science while out and about with their instruments.[46] Josefowicz has noted the high degree of faith that British protagonists, particularly Herschel, editor of the Admiralty's 1849 *Manual of Scientific Inquiry,* placed on written guidance.[47] The use of instruments in survey programmes was deemed to benefit the user. Josefowicz argues that 'Gauss and Weber located the value of terrestrial magnetic research not only in its contribution to the progressive march of scientific knowledge, but also in the salutary habits of perception that its study promoted – those same habits of obedience, thoroughness, and careful attentiveness, that were esteemed by members of a rising, professional middle class.'[48]

One of the most important modes in which these forms of bourgeois value were aligned with the survey sciences was in the active and expanding complex of museums and exhibitions characteristic of nineteenth-century forms of public knowledge. As Holger Hoock points out in his history of the relation between imperial expansion and the practices of public museology and display in the earlier nineteenth century, 'empire building was an intensely visual affair', involving not merely allegorical images of survey and control but material goods accumulated and exhibited in artful order. Humboldt was eminent but by no means unusual in advocating the construction of such public displays, involving panoramic, material and photographic shows of the surveyed globe: 'the knowledge of the works of creation…would be powerfully increased if besides museums, and thrown open like them, to the public, a number of panoramic buildings, containing pictures of landscapes of different geographical latitudes and from different zones of elevation, should be erected in our large cities'.[49] Withers and Wess note the challenges of converting survey experience into publication; it is important to reflect on the various modes in which the outcomes and the materials of the surveys entered the metropolitan public sphere. As Ratcliff's study here demonstrates in detail in the cases of the loot accumulated by the projects of Mackenzie and of Raffles, the transition between surveyed spaces and those of the museum collections was very often both decisive and significantly transformative. What she characterizes as a hierarchy of museums and gardens, archives and storerooms, extended across the networks of imperial economy.[50]

In their contributions to this special issue, museologists and curators Charlotte Connelly, Alison Morrison-Low and Claire Warrior reflect on the commemorative and often politically expansive interests that have characterized major public collections of materials of scientific voyaging and survey, in Greenwich, Cambridge and Edinburgh as examples. These museums hold much of the extant material equipment of the earlier nineteenth-century survey sciences, and the establishment of relations between its conservation and exhibition has been understandably challenging. Connelly and Warrior refer to one of the most celebrated such devices, the brass dip circle produced by the London instrument maker Thomas Charles Robinson and supplied to the 1845 Franklin expedition to the Arctic. They point out the ways in which this object's connexions with its Devonshire Street maker and with the practices of magnetic survey have been displaced, within the exhibition complex, by its status as a relic of a doomed and fatal voyage. After Franklin's disappearance, the apparatus was recovered at King William island in the Victoria Strait in 1859 by the search expedition led by Leopold McClintock. In one of the more widely-read histories of the Franklin enterprise, an image of this dip circle is simply labelled, in suitably Tennysonian terms, 'the reason why'.[51]

There was a close relationship between national and parochial accounts of material heritage and the image of the sciences, especially the field sciences, produced within nineteenth-century exhibitions and their aftermath. A recent collection of essays on nineteenth-century science museums in Britain and the United States of America points out the important connexions between survey projects and the establishment of museum collections with specifically patriotic and often chauvinist ambitions.[52] As Martin Hewitt has pointed out, relationships between the materials and images collected during the surveys, and the apparatus and equipment designed to project them to wide publics, was by no means always efficient nor effective in the absence of potent rhetoric and heroic performers. In the collection of essays gathered here, several essays attend to the relation between the surveys and the fascinating relation between the alleged powers of its authors such as Mackenzie or Scoresby and those of the equipment they used and the materials they accumulated.[53]

There has thus been a long-term and intriguing relation between the museology of the surveys, the plunder and the precision of their outputs, and the production of exemplary heroes under a somewhat hagiographic system of exploration tales and theatrics. In her account of the arrangement of one of the most interesting modern public exhibitions on the history of geomagnetism, that held at Edinburgh in 1981, Morrison-Low notes that Humboldt was entirely excluded from the display, the role of protagonist taken instead by the Anglo-Irish military surveyor Sabine. She also points out that a Robinson dip circle was also acquired at that point by the then Royal Scottish Museum as part of its representative collections of scientific apparatus. The key term in these reflections on the relationship between exploration and expedition is perhaps 'representation'. The very function of such devices was to act as representatives. They were to represent the disciplines that organised their production and use: and their current display very often depends on the current notions of appropriate subject areas and scientific authority to which they best belong. They were also representatives as reliable means through which seemingly remote or otherwise inaccessible phenomena could be brought to presence, captured, noted, juxtaposed and analysed. When the very material equipment of these enterprises itself became part of systems of storage and accountability, whether those charted in the case of the Royal Geographical Society by Wess and Withers or in the military systems of painstaking editing and sifting at Sabine's Woolwich as described by Goodman, real puzzles of maintenance, of commemoration and of integrity became newly salient. As Adriana Craciun notes in her critical history of the commemoration of the Arctic surveys, the period that saw the launch of the principal northern survey projects was also that of an intensified cult of relics and memorabilia, a characteristic of the material culture of nineteenth-century exhibits and expeditions. The pathways travelled by such materials, instruments, artefacts and souvenirs have much to tell about the life of nineteenth-century survey sciences, and the many and changing senses of their practice in the past and their resonances now.[54]

This special issue on the nineteenth-century survey sciences emerged initially from two highly successful collaborative doctoral awards funded by the Arts and Humanities Research Council, started independently of each other in 2014 as studies of aspects of the instrumentation and practice of the magnetic surveys of the earlier nineteenth century. Matthew Goodman worked with Simon Naylor at Glasgow and Keith Moore at the Royal Society; Jenny Bulstrode worked with Richard Dunn at the National Maritime Museum and Simon Schaffer at Cambridge. Support for a day-long workshop was then obtained from the Scottish Alliance for Geoscience, Environment and Society (SAGES), which ran in May 2017 at the University of Glasgow. It brought together historical geographers and historians

interested in aspects of the nineteenth-century survey sciences, as well as museum curators and librarians who work with relevant instrument and manuscript collections. The Hunterian Museum hosted a subsequent meeting of the workshop's participants, where plans were hatched for this issue. We warmly thank the participants and audience at the SAGES workshop for their contributions; to Mungo Campbell at the Hunterian Museum for hosting us at the Kelvin Hall; to Ben Marsden, then-editor of *Notes & Records* for managing the early stages of our special-issue proposal, and Anna Marie Roos, the current editor, for her close support through the referee and production stages; and finally to the various referees, who provided excellent thoughts and advice on all the papers.

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[1] For examples: Matthew Edney, *Mapping an empire: the geographical construction of British India, 1765-1843* (Chicago University Press, Chicago, 1997); Steven Ruskin, *John Herschel's Cape Voyage: private science, public imagination and the ambitions of empire* (Aldershot, Ashgate, 2004); Randolph Cock, 'Scientific servicemen in the Royal Navy and the professionalisation of science, 1816-55', in *Science and beliefs: from natural philosophy to natural science, 1700*-1900 (ed. David Knight and Matthew Eddy), pp. 95-112 (Aldershot, Ashgate, 2005); Michael Reidy, *Tides of history: ocean science and Her Majesty's Navy* (Chicago University Press, Chicago, 2008); Christopher Carter, *Magnetic fever: global imperialism and empiricism in the nineteenth century* (American Philosophical Society, Philadelphia, 2009).

[2] Edney, *op.cit.* (note 1), pp. 179-184; James A. Secord, 'The Geological Survey of Great Britain as a research school, 1839-1855', *History of Science* 24, 233-275 (1986); John McAleer, 'Stargazers at the world's end: telescopes, observatories and 'views' of empire in the nineteenth-century British Empire', *British Journal for the History of Science* 46, 1-25 (2013).

[3] J. Cawood, 'The Magnetic Crusade: Science and Politics in Early Victorian Britain', *Isis*, 70, 492-518 (1979).

[4] Lee Macdonald, 'Making Kew Observatory: the Royal Society, the British Association and the politics of early Victorian science', *British journal for the history of* science 48, 409-433 (2015); Simon Naylor, 'Log books and the law of storms: maritime meteorology and the British Admiralty in the nineteenth century', *Isis* 106, 771-797 (2015); Katherine Anderson,

Predicting the weather: Victorians and the science of meteorology (Chicago University Press, Chicago, 2005), pp. 86-105.

[5] C.A.Bayly, *Empire and information: intelligence gathering and social communication in India, 1780-1870* (Cambridge University Press, Cambridge, 1996), pp. 247-314.

[6] John Tresch, 'Even the tools will be free: Humboldt's romantic technologies', in *The Heavens on Earth: observatories and astronomy in nineteenth-century science and culture* (ed. David Aubin, Charlotte Bigg, and H.Otto Sibum), pp. 253-285 (Duke University Press, Durham and London, 2010).

[7] Fraser Macdonald and Charles W.J. Withers (ed.), *Geography, technology and instruments of exploration* (Farnham: Ashgate, 2015); Richard Dunn and Rebekah Higgitt (ed.), *Navigational enterprises in Europe and its empires, 1730-1850* (Basingstoke: Palgrave Macmillan, 2016).

[8] Michael Dettelbach, 'Humboldtian science', in *Cultures of Natural History* (ed. Nick Jardine, James A Secord and Emma C. Spary), pp. 287-304 (Cambridge University Press, Cambridge, 1996), at p. 287.

[9] Susan Faye Cannon, *Science in Culture: The Early Victorian Period* (Science History Publications, New York, 1978), at p. 105 and p. 104 respectively.

[10] Cannon, *op. cit.* (note 9), p. 105.

[11] Malcolm Nicolson, 'Alexander von Humboldt, Humboldtian Science and the origins of the study of vegetation', *History of Science* 25, 167-194 (1987); Suzanne Zeller, 'Humboldt and the habitability of Canada's Great Northwest', *Geographical Review* 96, 382-398 (2006); Gregory Cushman, 'Humboldtian science, creole meteorology, and the discovery of human-caused climate change in South America', *Osiris* 26, 19-44 (2011).

[12] Dettelbach, *op. cit*. (note 8), p. 288.

[13] Michael Dettelbach, 'Alexander von Humboldt between Enlightenment and Romanticism', *Northeastern Naturalist* 8, 9-20 (2001), at p. 10.

[14] Dettelbach, *op. cit.* (note 8), p. 289 and p. 304.

[15] J. Cawood, 'Terrestrial magnetism and the development of international collaboration in the early nineteenth century', *Annals of Science*, 34, 551–587 (1977); Cawood, *op.cit.* (note 3), p. 497.

[16] Granville Allen Mawer, *South by Northwest: The Magnetic Crusade and the contest for Antarctica* (Edinburgh, Birlinn, 2006).

[17] Gregory Good, 'Between data, mathematical analysis and physical theory: research on Earth's magnetism in the 19th century', *Centaurus*, 50, 290-304 (2008), at p. 299 and p.301.

[18] D.G. Josefowicz, 'Experience, pedagogy, and the study of terrestrial magnetism', *Perspectives on Science*, 13, 452-494 (2005), at p. 490.

[19] Reidy, *op.cit.* (note 1), p. 124.

[20] James R. Fleming, Vladimir Jankovic and Deborah R. Coen, 'Introduction', in *Intimate universality: local and global themes in the history of weather and climate* (eds. James R. Fleming, Vladimir Jankovic and Deborah R. Coen) pp. ix-xx (Science History Publications, Sagamore Beach, 2006), at p. x.

[21] David Aubin, 'A history of observatory sciences and techniques', in *Astronomy at the frontiers of science* (ed. J.-P. Lasota) pp. 109-121 (Springer, Berlin, 2011) at p. 111.

[22] D. Aubin, C. Bigg and H. Otto Sibum, 'Introduction: Observatory techniques in nineteenth-Century science and society', in Aubin *et al*., *op.cit.* (note 6), pp. 1-32, at p. 2.

[23] Aubin *et al., op. cit.* (note 22), pp. 6-7. See also Lee T. Macdonald, *Kew Observatory and the evolution of Victorian science* (Pittsburgh University Press, Pittsburgh, 2018).

[24] See S. Schaffer, 'Oriental metrology and the politics of antiquity in nineteenth-Century survey sciences', *Science in Context* 30, 173-212 (2017).

[25] John Herschel, *Preliminary Discourse on the Study of Natural Philosophy* (Longman, London, 1831), p. 350; Carter, *op.cit*., (note 1), p. 70. See Gregory Good, 'A shift of view: meteorology in John Herschel's terrestrial physics', in Fleming *et al., op.cit.* (note 20), pp. 35-68.

[26] Tim Fulford, Debbie Lee and Peter L. Kitson (eds.), *Literature, science and exploration in the Romantic era: Bodies of Knowledge* (Cambridge University Press, Cambridge, 2004), part 1: 'Exploration, science and literature'; Kapil Raj, *Relocating modern science: Circulation and the construction of knowledge in south Asia and Europe, 1650-1900* (Palgrave Macmillan, New York, 2007); Simon Schaffer, Lissa Roberts, Kapil Raj and James Delbourgo (ed.), *The brokered world: go-betweens and global intelligence, 1770-1820* (Science History Publications, Sagamore Beach, 2009).

[27] Dorinda Outram, 'On being Perseus: new knowledge, dislocation and Enlightenment exploration', in *Geography and Enlightenment* (ed. David N. Livingstone and Charles W. J. Withers), pp. 281-294.

[28] Fabien Locher, 'The observatory, the land-based ship and the crusades: earth sciences in European context 1830-1850', *British Journal for the History of Science* 40, 491-504 (2007).

[29] C.A.Bayly, *Imperial meridian: the British Empire and the World 1780-1830* (Longman, London, 1989).

[30] Mackenzie, 6 December 1799, cited in Peter Robb, 'Completing 'our stock of geography', or an object 'still more sublime': Colin Mackenzie's survey of Mysore, 1799–1810', *Journal of the Royal Asiatic Society* 8, 181–206 (1988), on p. 189. See Rama Sundari Mantena, *The Origins of Modern Historiography in India: Antiquarianism and Philology, 1780-1880* (Palgrave Macmillan, New York, 2012) and Tobias Wolffhardt, *Unearthing the past to forge the future: Colin Mackenzie, the early colonial state and the comprehensive survey of India* (Oxford, Berghahn, 2017).

[31] Michael Reidy, 'From the oceans to the mountains: spatial science in an age of empire', in *Knowing global environments: new historical perspectives on the field sciences* (ed. Jeremy Vetter), pp. 17-38 (Rutgers University Press, New Brunswick, 2011), on p.18.

[32] Lissa Roberts, 'Situating science in global history: local exchanges and networks of circulation', *Itinerario* 33, 9-20 (2009); Sujit Sivasundaram, 'Sciences and the global: on methods, questions and theory', *Isis* 101, 146-158 (2010); Fa-ti Fan, 'The global turn in the history of science', *East Asian Science, Technology and Society* 6, 249-258 (2012).

[33] See Suman Seth, 'Colonial history and postcolonial science studies', *Radical History Review* 127, 63-85 (2017).

[34] Carter, op.cit. (note 1); Cawood, op.cit. (note 15); James O'Hara, 'Gauss and the Royal Society: the reception of his ideas on magnetism in Britain, 1832-1842', *Notes and Records of the Royal Society* 38, 17-78 (1983).

[35] M. Norton Wise (ed.), *The values of precision* (Princeton University Press, Princeton, 1997).

[36] Fraser MacDonald and Charles W.J. Withers, 'Introduction', in *Geography, technology and instruments of exploration* (eds. Fraser MacDonald and Charles W.J. Withers) pp. 1-14 (Ashgate, Farnham, 2015), at p. 2.

[37] Aubin et al, *op. cit.* (note 22), p. 11.

[38] Simon Schaffer, "Keeping the books at Paramatta Observatory," in Aubin *et al.,* op.cit. (note 5), 118-147, at p. 131.

[39] Simon Naylor, 'Weather instruments all at sea: Meteorology and the Royal Navy in the nineteenth century', in MacDonald and Withers, *op.cit.* (note 7), pp. 77-96.

[40] Schaffer, op. cit. (note 24), p. 180. See John McAleer, 'Stargazers at the world's end: telescopes, observatories and views of empire in the nineteenth-century British Empire', *British Journal for the History of Science* 46, 389-413 (2013).

[41] Charles W.J. Withers, 'Science, scientific Instruments, and questions of method in nineteenth-century British geography', *Transactions of the Institute of British Geographers*, 38, 167-179 (2012), at p. 174.

[42] Edney, *op.cit.* (note 1), p. 91.

[43] Schaffer, op. cit. (note 24), p. 180.

[44] Dettelbach, *op. cit*. (note 8), p. 301.

[45] Cock, *op.cit.* (note 1).

[46] Felix Driver, 'Scientific exploration and the construction of geographical knowledge: hints to travellers', *Finisterra* 65 pp21-30 (1998).

[47] Josefowicz, *op.cit.* (note 18), p. 466.

[48] Josefowicz, *op. cit*. (note 18), p. 490.

[49] Holger Hoock, *Empires of the imagination: politics, war and the arts in the British world 1750-1850* (Profile, London, 2010), p.276; Alexander von Humboldt, *Cosmos volume 2* (Bohn, London, 1849), trans. E.C.Otte, p.457.

[50] Jessica Ratcliff, 'The East India Company, the Company's Museum and the political economy of natural history in the early nineteenth century', *Isis* 107, 495-517 (2016).

[51] Andrew Lambert, *Franklin: tragic hero of polar navigation* (London, Faber and Faber, 2009), p. 61 and figure 4.

[52] Carin Berkowitz and Bernard Lightman (eds.), *Science museums in transition: cultures of display in nineteenth-century Britain and America* (University of Pittsburgh Press, Pittsburgh, 2017).

[53] Martin Hewitt, 'Beyond scientific spectacle: image and word in nineteenth-century popular lecturing', in *Popular exhibitions, science and showmanship 1840-1910* (eds. Joe Kember, John Plunkett and Jill A. Sullivan), pp. 79-95 (Pickering and Chatto, Abingdon, 2012).

[54] Adriana Craciun, *Writing Arctic disaster: authorship and exploration* (Cambridge University Press, Cambridge, 2016), pp. 35-37.