JHA, xxii (1991)

A NATIONAL OBSERVATORY TRANSFORMED: GREENWICH IN THE NINETEENTH CENTURY

ROBERT W. SMITH, Smithsonian Institution and
The Johns Hopkins University

The Royal Observatory at Greenwich was one of the leading institutions of nineteenth-century astronomy. It was certainly a national observatory, but for much of that period the high regard with which astronomers viewed the results it produced and its position at the heart of a network of international observatories were such that Greenwich's importance transcended national boundaries. When in 1884 an international conference was held to choose a common zero of longitude, it was the Greenwich meridian that the conferees selected.[1] In some ways, it was *the* international observatory.

Dominating the Royal Observatory's history for almost half of the nineteenth century was Sir George Biddell Airy, Astronomer Royal from 1835 to 1881 (Figure 1). Under Airy, the Observatory's complement and types of instruments, as well as methods of management, were transformed from those characteristic of a pre-industrial society to those of a society that had undergone the second phase of the Industrial Revolution. The result was that, although the Observatory was certainly notable for its scientific results, it was perhaps even more important for the new ways of pursuing astronomy fashioned there. I shall follow E. W. Maunder and argue that under Airy, Greenwich to a large degree resembled a kind of accountant's office, a very different sort of workplace from that common for astronomical institutions in, say, the 1820s when Airy began his career.

The Observatory's astronomical goals, however, display a strong strand of continuity throughout the century. Airy nevertheless played a key role in leading the Observatory in new directions and scholars agree that he put his stamp on the institution to a much greater degree than the other nineteenth-century directors, Nevil Maskelyne, John Pond, and Sir William Christie. In discussing the Royal Observatory in the nineteenth century, I shall therefore concentrate upon Airy's directorship.

In a short paper it is impossible to do justice to the full range of endeavours pursued under Airy. I shall instead focus on two areas that I believe are particularly revealing of the Observatory's place in nineteenth-century astronomy and in science in general. Both areas have attracted attention recently: first, the changing responsibilities of the Observatory, which in turn reveal the Observatory's shifting position in the political economies of astronomy and British science, and, second, the extent to which Airy altered the astronomer's workplace and turned Greenwich into a kind of factory and the degree to which Airy was himself a sort of factory manager.

The history of nineteenth-century astronomy is a relatively neglected area of

0021-8286/91/2201-0005 $2.50

FIG. 1. Airy in later life (from E. W. Maunder, *The Royal Observatory Greenwich* (London, 1900), 103).

study. There is nevertheless a body of writing on the Royal Observatory, and in very considerable part this paper is a review and critique of the existing literature.[2] However, I shall suggest that in interpreting nineteenth-century Greenwich we need to view it from more than one perspective. In particular, to capture fully the nature of the institution it should not be seen just as a factory

manned by 'factory hands', but, as I have already suggested, also as resembling a highly organized accountant's office.

Reshaping the Royal Observatory

In 1819, George Biddell Airy entered the University of Cambridge. He proceeded systematically to work "his way through Cambridge as a sizar, scholar and Fellow of Trinity [College], eventually holding the University to ransom for a substantial increase in salary before he would accept — at the age of 27 — the directorship of the observatory and Plumian Professorship".[3] The University Observatory had been re-founded by George Peacock in the early 1820s. Once in charge, Airy (a student of Peacock's) quickly secured new instruments, added staff, ensured that observations were promptly reduced and published, and extended the Observatory's researches. In Airy's hands, the University Observatory became, in S. F. Cannon's words, "one of the pace-setting scientific centers of England".[4]

Such was Airy's reputation that once John Herschel had taken himself out of the reckoning, Airy, although only 33 years old in 1834, was the first choice to succeed the ailing John Pond when Pond was forced to resign as Astronomer Royal.[5] After characteristically canny bargaining to increase his salary, Airy took up his new office in October 1835.[6]

What sort of Observatory did Airy inherit? First, it is important to note that although Pond left many serious problems to be solved, the weight of historical opinion is that his tenure, taken overall, was certainly not a disaster. At the start of Pond's 25 years as Astronomer Royal new instruments were purchased, others were later added, the accuracy of observations was markedly improved, and during his tenure the number of assistants rose from one to six. As Eric Forbes argued in 1975, Pond's "contributions as a whole were entirely technical, but his reform of the Royal Observatory was fundamental".[7] In his 1832 "Report of the progress of astronomy during the present century", Airy was, implicitly if not explicitly, somewhat critical of the activities at Greenwich.[8] However, in 1836, Airy, although unimpressed by Pond's administrative practices, wrote in support of a pension for Mrs Pond by contending that in terms of the accuracy of the principal observations, "Astronomy is quite a different thing from what it was, and this is mainly due to Mr. Pond".[9]

Pond, then, was a very talented astronomer. But, by the 1830s, being Astronomer Royal required far more. Unfortunately, Pond "was a poor administrator, he found the business of compiling the *Nautical Almanac* irksome, was unable to control his staff, and disliked the burden of rating chronometers offered by government purchase".[10] As noted on numerous occasions, Pond's frequent absences from the Observatory towards the end of his tenure and the inefficiency of the first assistant exacerbated these difficulties. It is little wonder that the British government turned to Airy as Pond's successor, a man who had already demonstrated at Cambridge his mathematical and technical brilliance as well as the ability to run an observatory

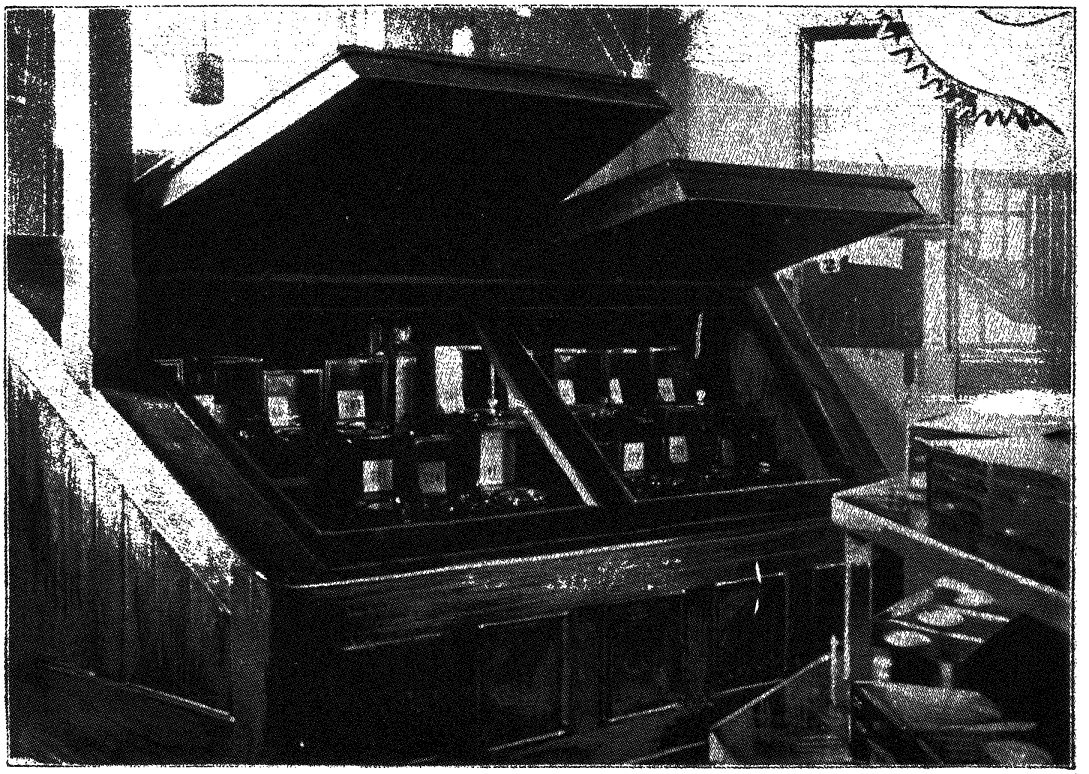


FIG. 2. Throughout Airy's tenure at Greenwich, a considerable fraction of the Observatory's work was devoted to testing of chronometers. The illustration shows the chronometer oven, a device introduced during Airy's time for testing chronometers at varying temperatures. (From Maunder, *The Royal Observatory Greenwich*, 171.)

efficiently, the guiding force of which was his demand for, and command of, order.

In the words of the Observatory's original royal warrant, its task was to tend to "the rectifying the tables of the motions of the heavens, and the places of the fixed stars, so as to find out the so much-desired longitude of places for the perfecting the art of navigation".[11] Under Pond, the Royal Observatory's historic charge of charting stellar coordinates and the shifting positions of the Moon and Sun had been maintained, although he had paid little attention to the motions of the planets.

But other responsibilities had fallen on Greenwich by the early 1830s. Chief among these were the rating and maintenance of chronometers. Many of Pond's problems in the later years of his administration were due to the escalating demands placed on the Observatory from these sources. On becoming Astronomer Royal, the main point of contact for Airy with his political masters was the Hydrographic Office. But this Office — which Airy judged one of the "inferior departments of the Admiralty" — regarded the Observatory as more a place for managing Government chronometers than as a place of science".[12] Airy was, as events would prove, certainly not averse to the Observatory's involvement with chronometers and the annual chronometer trials. Rather,

what he did resent was, as J. A. Bennett has emphasized, not the *improvement* of chronometers, but the routine administration of working Admiralty chronometers.[13] Airy was firm on this point: "the persons of this establishment are astronomical observers and calculators, not clerks; and the Observatory is an astronomical institution, not a storehouse."[14] Airy pressed hard on this issue very early in his administration, and won some concessions. Nevertheless, in 1840, one-third of the staff time was devoted to chronometers (see Figure 2), and in 1865, thirty years after he had become Astronomer Royal, the fraction was still one-quarter.[15]

Why was the Observatory so involved with chronometers in the first place? The chronometer work was not really related to the Observatory's scientific charge, at least not by the 1830s. Instead, it was tied to what Bennett has termed its "social function", what through custom and practice as well as instructions from the British government it was expected to do. Under Airy, the Observatory's social function grew. For example, it was from the mix of a variety of technical developments and Airy's vision of the Observatory's appropriate social function that his extensive development of the public time service sprang.[16] Airy deemed it appropriate to "connect the scientific Observatory with the practical world". Writing in 1856, he referred to "the distribution of accurate time, the improvement of marine timekeepers, the observations and communications which tend to the advantage of Geography and Navigation, and the study, in a practical sense, of the ramifications of Magnetism; a careful attention to these is likely to prove useful to the world, and conducive to the material prosperity of the Observatory: and these ought not to be banished from our system".[17]

Students of Greenwich nevertheless agree on the fundamental point that throughout his tenure Airy regarded, or at least sought to present, the central charge of the Observatory as scientific. To make this point is not to state the obvious, for it is not difficult to envisage the Observatory having followed a different path with its focus, for example, as a chronometer depot and its activities tied even more tightly to the interests of the Admiralty.

Moreover, at the start of his tenure as Astronomer Royal Airy viewed the scientific charge in a way entirely consistent with his predecessors. "It is not to the gazing at planets or nebulae", Airy wrote in a brief history of the Observatory in the *Penny cyclopaedia* in 1838,

> or to the watching the appearances of the spots in the sun or the mountains in the moon, with which the dilettante astronomer is so much charmed; it is not to the measures of the relative positions and distances of double stars, or the registering the present state of nebulous bodies which appear liable to change — measures and registers of great importance, but which possess a charm sufficient to persuade private observers to undertake the observations, and which do not demand extreme nicety of adjustment of the instruments, nor require much calculation afterwards. But it is to the regular observation of the sun, moon, planets, and stars (selected according to a previously arranged system), when they pass the

> meridian, at whatever hour of the day or night that may happen, and in no other position; observations which require the most vigilant care in regard to the state of the instruments, and which imply such a mass of calculations afterwards, that the observation itself is in comparison a mere trifle. From these are deduced the positions of the various objects, with an accuracy that can be obtained in no other way; and they can then be used as bases to which observations by amateur astronomers, with different instruments, can be referred.[18]

Airy had "little doubt" that restricting the Observatory's work to meridional observations was "advantageous. The part retained is the most laborious, and is also that which best admits of being reduced to a system working well under official superintendence", particularly telling reasons for Airy. The sort of astronomy pursued by the Herschels also required large telescopes. Ramages's 20-ft reflector had been mounted at Greenwich during Pond's directorship, but it had, Airy contended, attracted so many visitors that it had greatly disrupted the Observatory's business.[19] So "Mr Pond himself was glad to have it dismantled". Airy did not intend to turn the Observatory into a place of public spectacle again.

Airy, of course, also expanded the positional work of the Observatory. At first this meant modifying existing practice, but by 1843 he was seriously proposing to introduce new instrumentation.[20] The 'Altazimuth' was completed in 1847 and Airy designed it to observe the Moon in positions of its orbit not usually examined. As Airy was to write in 1858, "I trust that I shall always be supported by the Visitors in my desire to maintain the fundamental and meridional system of the Observatory absolutely intact". But, he went on, this "does not impede the extension of our system in any way whatever, provided that such means are arranged for carrying out the extension as will render unnecessary the withdrawal of strength from what are now the engrossing subjects of the Observatory".[21]

Such extension not only occurred in areas of positional astronomy. Meadows has argued that this growth was due in part to changing trends in astronomical work. Hence in discussing the introduction of the 'Great Equatoreal' — a refractor with an objective of 12.8 inches in diameter — into the Observatory's routine in 1859, Meadows links it to a greater emphasis on non-meridional astronomy. No "major observatory of the future", Meadows writes, "would be able to lay claim to that title unless it possessed a telescope of moderate size".[22] Here was an adjustment at Greenwich that reflected broad changes in astronomy. But, Meadows also suggests, two of the major developments at Airy's Greenwich — the introduction of daily photographs of the Sun and spectroscopic observations — must be interpreted not only in terms of the evolution of the goals of astronomers, but also in the light of the shifting political economy of nineteenth-century British science. Hence the issue of what types of knowledge were to be generated at Greenwich was intimately tied to political issues.[23]

In particular, Airy was always anxious to increase the Observatory's prestige and maintain its central position in British science (a position which of course

also buttressed his own authority and power), especially with respect to long-term programs of observations. Such programs, Airy believed, were in general the natural responsibility of the Royal Observatory or its network of supporting observatories. When potential usurpers of Greenwich's hegemony appeared in the shapes, for example, of Edward Sabine and Norman Lockyer — Sabine with magnetic observations at Kew in the 1860s and Lockyer in the 1870s with solar physics at a proposed national observatory — Airy moved quickly to try to beat off challenges to what he saw as his and the Observatory's authority.[24] Crowther, for instance, has noted that Airy "believed in the principle of the division of labour in astronomy. But in practice, he claimed the right to make the division, so that sole authority tended to remain with himself."[25]

The case of Greenwich and astrophysics in the 1870s also has to be seen in part in the light of Airy acting to defend his own position and authority. The Devonshire Committee met during the first half of the decade and, as part of its charge, it examined the issue of Government support for science. The Commission's secretary was Norman Lockyer. In the words of Meadows, Lockyer's biographer, he was "already something of a controversial character, and became more so when the Commission recommended that an independent State-aided observatory for the study of astronomical physics should be established; for it was generally understood, both by Lockyer's supporters and by his opponents, that he would be the probable head of such an institution".[26] In his own testimony before the Commission, Airy suggested an observatory for the study of astronomical physics was not needed, but if it did go ahead, it should be under the control of Greenwich.[27] However, as Dreyer and Turner, Meadows, and Schaffer have underlined, this debate derived its intensity not only because it was about government support, but also because it was permeated by the issues of the power of amateur astronomers and the "overwhelming authority of Airy's regime".[28]

When it seemed likely that a state-aided Solar Physics Observatory was indeed to be established, Lockyer's opponents arranged for the Royal Astronomical Society to hold a special meeting in April 1881 to discuss four resolutions. The first opposed the spending of public money for non-utilitarian research or where it seemed that the research would be conducted anyway by private individuals and public bodies, and the second was "That this meeting consider it inexpedient that a Physical Observatory should be funded at the national expenses".[29] After initially sitting on the fence, Airy predictably came down against the Government "endeavouring to force, at public expense, investigations of undefined character, and, at best, of doubtful validity: and I think it probable that any such attempt will lead to consequences disreputable to science".[30] But, of course, Airy *had* already introduced what would come to be termed 'astrophysics' into the practice of the Royal Observatory. Hence one interpretation of Airy's actions is to see his attitude to astrophysics as shaped by his knowledge that in the late nineteenth century the British government provided little financial support for science.[31] So, funds devoted to a Solar Physics Observatory would, unless the Government increased its spending on science, mean less money for Greenwich. Self-interest and conservatism might

have combined to induce Airy to introduce astrophysics in part to forestall developments elsewhere.[32]

Airy was very sensitive to the Observatory's interests in other matters too. In his semi-popular history of the Observatory, a one-time assistant under Airy, E. W. Maunder, asserted that "Attacks which would have agonized Flamsteed's every nerve, and have called forth full and dignified rejoinders by Maskelyne, were absolutely and entirely disregarded by Airy".[33] But does the evidence always support this view? Maunder knew Airy only towards the end of his career, when by all accounts he had mellowed somewhat. The young and middle-aged Airy could be a very determined adversary. A telling example comes from early in Airy's career. In 1827, he engaged in a controversy with J. Ivory on the figure of the Earth. When Airy claimed that he could not derive one of Ivory's equations, Ivory "attacked me for this with great heat". Airy fired off a response, "and I think it soon became known that I was not to be attacked with impunity".[34]

Whatever his public demeanour, Airy vigorously sought to rebut any criticism of the operations of the Royal Observatory. For example, in 1848, John Hartnup, director of the Liverpool Observatory, sent some chronometers to Greenwich for testing. The chronometers contained a new form of balance wheel of his own design and he hoped for a strong endorsement of their performance. When the test results were not as good as he had expected, he publicly suggested in the *Monthly notices of the Royal Astronomical Society* that this was because of a failing in the test procedures. Airy was aghast. He moved quickly with the help of his close friend and ally in various controversies and disputes, Richard Sheepshanks, to rebut the reports.[35] This was easy because Sheepshanks was in effect the editor of the *Monthly notices*. Airy and he exchanged several drafts of a possible rebuttal. The one finally printed pleased Airy. He told Sheepshanks that it was "entirely satisfactory, and goes even further than I could desire. I do not think there is need of stating more than (what I suggested) that there was no knowledge of the system [adopted] at Greenwich." This claim, however, is not easy to accept. Hartnup had worked at Greenwich some years earlier and the Liverpool maker who built the new 'Hartnup balances' did report to Hartnup on his visit to the Observatory to witness part of their testing. Whatever the accuracy of Airy's claims, the essential point here is that Airy, working very closely with Sheepshanks, had acted to prevent battles over priority, and arguments over quality, between various chronometer-makers being fought out in the pages of the *Monthly notices*. Airy thereby helped to maintain his control over such debates by denying critics an influential forum. He had at the same time successfully quashed what he saw as a challenge to the competence of the Royal Observatory.[36]

Bennett has placed Airy's activities under three headings: (1) the scientific charge and reputation of the Observatory, (2) work related to Greenwich's social function, and (3) Airy's endeavours as a scientific and technical advisor to the government. We have already discussed the first and touched upon the second. The third is significant here because Airy was sometimes strongly

attacked for neglecting the Observatory's operations to pursue his advisory role. For example, in 1846 Sir James South — a long standing enemy of Airy's[37] — stridently criticized Airy's running of the Royal Observatory. These criticisms led Sir Robert Inglis, Tory M.P. for Oxford University and president of the British Association for the Advancement of Science in 1847, to prepare an Order of the House of Commons for the printing of a copy of a paper by South. The paper was supposedly on a railway passing through Greenwich Park, but it levelled accusations of incompetence at Airy. Airy was certain it sought to undermine "almost everything that I did in the Observatory",[38] and South's assault drew a very spirited reply. At one point in his letter to *The Athenaeum* Airy was moved to urge "Shame on the ignorant caluminator who wantonly throws about these insinuations", hardly the response of the Airy whom Maunder would have us believe "entirely disregarded" the sorts of attacks which would have "agonized Flamsteed's every nerve".[39]

The Royal Observatory as a Form of Factory

While there is disagreement among writers on the interpretation of various areas of Greenwich's history, on one point there is unanimity: the key to, and a major reason for the importance of, Airy's rule at the Royal Observatory was his introduction of factory-like methods into the Observatory. As Simon Newcomb, the dean of late nineteenth-century American astronomers and who has been described as Airy's "most loyal disciple and imitator",[40] recalled in 1903,

> We may look back on Airy as the most commanding figure in the astronomy of our time. He owes this position not only to his early works in mathematical astronomy, but also to his ability as an organizer. Before his time the working force of an observatory generally consisted of individual observers, each of whom worked to a greater or lesser extent in his own way ... so far as the doing of work was concerned, he introduced the same sort of improvement that our times have witnessed in great manufacturing establishments, where labor is so organized that unskilled men bring about results that formerly demanded a high grade of technical ability. He introduced production on a large scale into astronomy.[41]

What, however, does it precisely mean to talk of Airy and large-scale production in astronomy? Newcomb pointed to Airy's reduction of a large part of the Royal Observatory's work to that "of a kind that almost any bright schoolboy could learn to do in a few weeks, and that in most of the remaining part plodding industry, properly directed, was more important than scientific training".[42] A central element in this system was the so-called skeleton form. Such forms were employed for various purposes at Greenwich, but those for the computers were designed so that using only an elementary knowledge of the rules of arithmetic, they could carry through intricate and laborious calculations. Airy had devised his first such skeleton form while a student at Cambridge, and had then developed other versions for use at the University

Observatory. During late 1835 and in his first few months at Greenwich he prepared and printed some thirty skeleton forms for the reduction of observations and other business. In 1841, 18,000 copies of the skeleton form for computing the "Lunar planetary tables" were printed.[43] Like factory owners of the time, Airy exploited what has become known as 'deskilling'.[44] That is, by turning the principal tasks of observation and calculation into a string of specialized rote exercises, the skills demanded of many staff members could be lowered. Hence much of the labour at the Observatory was conducted by young men, hired as fifteen- or sixteen-year-olds, and then forced to leave early in their twenties.

It was Airy's talents as an administrator and organizer that lay at the heart of J. G. Crowther's telling character sketch of Airy in his *Scientific types*, published in 1968. Here Crowther claimed that Airy belonged partly to the world of Newton and partly to that of nineteenth-century industrialism.[45] Meadows has argued more concretely that Airy's reorganization of both the measurement and reduction of astronomical positions, first at Cambridge and then at Greenwich, derived from the new procedures being developed by F. W. Bessel — whom Airy admired greatly — on the Continent.[46] Meadows nevertheless agreed that Airy introduced the methods of mass production into astronomy,[47] and for him Airy did so by reorganizing the work of the assistants and introducing greater standardization and simplification. To support this claim, Meadows points to the use of the skeleton forms as well as to changes in instrumentation. The German influence too has been emphasized by Cannon. Airy, Cannon argued, "turned Greenwich into a cooperative, almost factory-like, enterprise possessing all the characterisitics of precision and thoroughness with which the great German astronomers were transforming positional astronomy".[48]

In Allan Chapman's opinion, "Airy was impressed by the power of contemporary industrialists and engineers to transform both society and the manufacturing arts by the imposition of an efficient, rational discipline based upon the utilisation of mechanical devices, and all that separated him from them, was the fact that his profit was measured in terms of public utility and scientific prestige, rather than Pounds Sterling".[49] That Airy introduced a factory-like mentality to Greenwich is central to Chapman's analysis, and in its support he draws on three points widely noted in the literature.

First, Airy "established a rigid hegemony of staff, in which all personnel knew their places in a strict chain of command".[50] Second, Airy sought to improve the accuracy of the Greenwich observations by emphasising the instruments, not the men (and in Airy's time it was only men) using them. Thus Airy was deeply concerned with the personal errors of the individual observers and strove to remove them where he could by various mechanical, electrical, and photographic devices.[51] For Chapman, "Precision demanded instruments, which in turn were the products of new techniques of engineering. These subsequently led to a reduction in dependence on the physical skills of the observer, and the replacement of that skill by the ceaseless automatic vigilance of a photographic plate or an electrical pulse."[52] Third, earlier Astronomers Royal had been tardy to varying degrees in publishing the results of their labours. Instead, for Airy,

the speedy publication of the Observatory's work, be it annual reports, observations, monographs or tables, was an essential part of its efficient functioning. These publications were then the output of Greenwich's factory-like operation.[53]

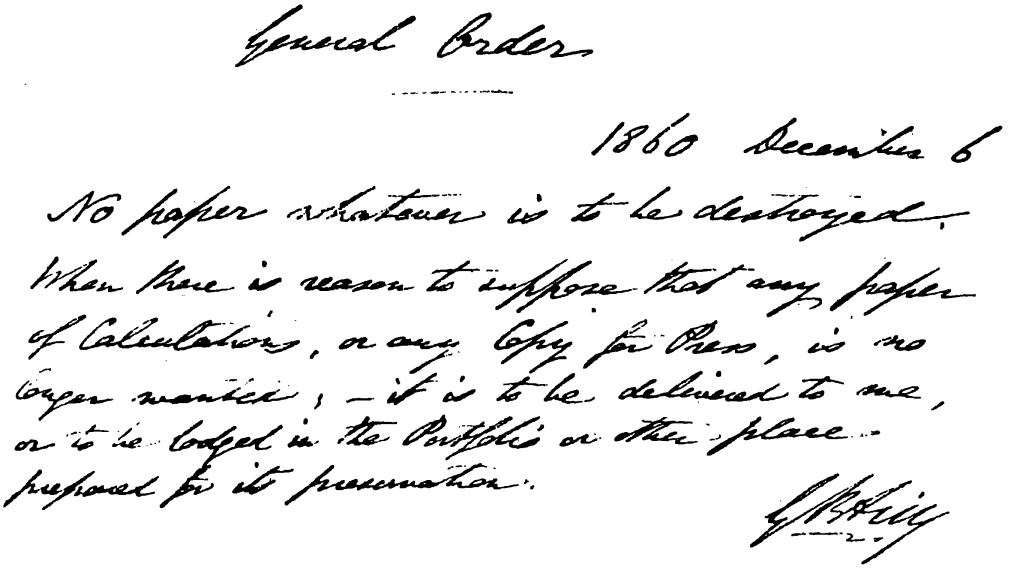
In a recent paper, Simon Schaffer too explores the theme of Greenwich as a factory, but he does so in a way very different from other scholars. Schaffer's approach is to place Airy's regime at the Royal Observatory in the context of the efforts of various 'observatory managers' to account for the fact that different observers would produce disparate results for supposedly identical observations, in other words, the problem of personality in observation. For Schaffer, measurement "is given its meaning when situated in specific contexts of styles of work and institutions".[54] In examining in this light the way astronomers tackled the personality problem, Schaffer produces an extremely convincing and stimulating study that puts the historiography of nineteenth-century Greenwich onto a new footing.

Schaffer argues that there was a fundamental shift in the early nineteenth century in the way in which observations in positional astronomy were secured. Through the researches of Bessel and his German colleagues, astronomers decided that astronomy's "own historical continuity and contemporary power" was "provided by an enterprise of reduction of accumulated observation through the analysis of error".[55] But the errors to be analysed no longer resided only in the instruments:

> The observer was part of the "instrument" to be calibrated. Artificial stars and galvanic clocks substituted eye-and-ear methods. The act of observation was destroyed and then painstakingly rebuilt through a range of surrogates for some notional "direct" experience. This rebuilding accompanied a process of social reorganization. The observatory became a factory, if not a "panopticon". "Mere" observers were relegated to the base of a hierarchy of management and vigilance, inspected by their superiors with as much concern as were the stars themselves. Observation was mechanized, and observers transformed into machine minders. At Greenwich, such workers clocked in, kept regular hours, and were supervised by an ever-watchful management [see Figure 3]. The same fate was meted out to the calculators. Division of labor demanded precise control over an increasing range of menials.[56]

His analysis of the response of observatory managers to the problem of the personal equation also permits Schaffer to establish Greenwich as a chief, if not the chief, element in an international network of observatories. Such networks were central, he argues, not only to Airy's developing interest in the global science of geomagnetism, but also the cross-checking and calibration of observations taken at different sites.[57]

Making the main model for nineteenth-century Greenwich that of a factory nevertheless raises a problem: What did writers of Airy's period mean by a factory? One of the leading theorists of the factory in the mid-nineteenth


General Order

1860 December 6

No paper whatever is to be destroyed. When there is reason to suppose that any paper of Calculations, or any Copy for Press, is no longer wanted: — it is to be delivered to me, or to be lodged in the Portfolio or other place prepared for its preservation.

G B Airy

FIG. 3. An example of Airy's managerial style: "No paper whatever is to be destroyed. When there is reason to suppose that any paper of Calculations, or any Copy for Press, is no longer wanted: — it is to be delivered to me, or to be lodged in the Portfolio or other place prepared for its preservation." (RGO Archives, Airy Papers: RGO 6/40 f10r, by permission of the Syndics of Cambridge University Library and of the Royal Greenwich Observatory.)

century was Andrew Ure. His most famous work is *The philosophy of manufactures*. It was published in 1835, the year Airy became Astronomer Royal.

In *The philosophy of manufactures*, Ure points to the principle of the factory as the substitution of mechanical science for handskill, and the partition of a process into its constituents, "for the division or graduation of labour among artisans ... on the automatic plan, skilled labour gets progressively superseded, and will, eventually, be replaced by mere overlookers of machines".[58] The resonance here with Airy's attitude to the "trivial" act of observing — he wrote of "mere" observers in the same way Ure spoke of "mere overlookers of machines" — is striking.[59] Nevertheless, Ure goes on to argue that:

> The term *Factory*, in technology, designates the combined operation of many orders of work-people, adult and young, in tending with assiduous skill a system of productive machines continuously impelled by a central power.... Some authors, indeed, have comprehended under the title *factory*, all extensive establishments wherein a number of people co-operate towards a common purpose of art.... But I conceive that this title, in its strictest sense, involves the idea of a vast automaton, composed of various mechanical and intellectual organs, acting in uninterrupted concert for the production of a common object, all of them being subordinated to a self-regulated moving force. If the marshalling of human beings in systematic order for the execution of any technical enterprise were allowed to constitute a factory, this term might embrace every department

> of civil and military engineering; a latitude of application quite inadmissible.[61]

Ure's point therefore is that if the word 'factory' is to have any meaning, it should not be indiscriminately applied to any institution in which the activities are subject to a routine and are standardized. Also following Ure's definition, the activities at Greenwich were not impelled by a "self-regulated moving force", nor did its workers spend much of their time minding machines.

We can turn to E. W. Maunder's 1900 history of the observatory for another side to Airy's regime. As already noted, Maunder was himself an assistant under Airy (and later Christie), and his account has been very influential in establishing the questions later historians have asked about Greenwich. However, in one area, his remarks have perhaps not drawn the attention they deserve.

Maunder argued that for the astronomer, "life on the one side, approximates to that of the engineer; on the other, to that of the accountant".[61] But for most of the time the astronomer acted as a kind of accountant, for, as Maunder noted in describing the work of the Observatory in 1900 (there was relatively little change in routine from the Airy era), "observing, though the first duty of the Observatory, makes the smallest demand on its time". A daytime visitor to the Observatory would therefore find the "official rooms not unlike those of Somerset House or Whitehall, and its occupants for the most part similarly engaged in what is, apparently, merely clerical work. An examination of the big folios would of course show that instead of being ledgers of sales of stamps, or income tax schedules, they referred to stars, planets, and sunspots; but for one person actively engaged at a telescope the visitor would see a dozen writing or computing at a desk".[62] Despite Airy's protestations to the contrary,[63] most of his staff spent most of their time as clerks of a sort, and as Chapman notes, when the computers left the Observatory, it was generally to become *clerks*.[64] Chapman's point suggests than in social status the observer/calculators were indeed much more like clerks than either skilled or unskilled factory workers, and so was the work they performed. This area, however, is one that needs further study.

The existing literature nevertheless points to the fact that the development of Greenwich is an example of the large-scale social process of rationalization, a process in which the factory was the most important symbol and component in the nineteenth century but which went beyond the factory. Part of that process was the routinization and reorganization of white-collar work, leading to deskilling and, later in the century, the widespread introduction of women into secretarial tasks. In line with this trend, women were first introduced into the Greenwich workforce by Airy's successor, Christie.

Conclusions

Much more than astronomy was pursued at Airy's Greenwich. It was, nonetheless, one of the leading sites for nineteenth-century astronomy. However, its interest to the historian of science derives not just from its astronomical and

other results. Under Airy, the Observatory was transformed. Through a rigorous application of business methods, allied to the development and application of novel forms of existing instruments as well as the development of new instruments, Airy had redefined how the Observatory went about its work and revolutionized it as a workplace for astronomy. He had also responded to pressures to pursue additional areas of research. In so doing, Airy had adjusted the Observatory's 'supply' in order to meet shifts in 'demand'.

Why and how particular researches were conducted are certainly extremely important questions to be answered if we are to secure a fully-rounded account of the Royal Observatory. The outlines and at least some of the major features of what such an account should look like do exist, particularly through the studies of Meadows and Schaffer, and Schaffer also put his study of the personality problem into a comparative setting. But the lack of more analyses comparing the Royal Observatory to other observatories, especially national observatories, is perhaps the chief weakness of the Greenwich historiography. It would be extremely interesting to know, for example, the extent to which Airy's Greenwich influenced other national observatories. While much has been written about Greenwich, the subject is far from exhausted and until more comparative studies are made, this and some other central questions for the history of nineteenth-century astronomy can at best have only tentative answers.

Acknowledgements

I am most grateful to David DeVorkin, Steven Dick, Michael Hoskin, John Lankford, and Michael Neufeld for their comments on an earlier version of this paper.

REFERENCES

1. D. Howse, *Greenwich time and the discovery of longitude* (Oxford, 1980), 138–51.
2. A great many works deal to varying degrees with the Royal Observatory, and I make no claims to covering all of those works that treat even the limited number the themes I address in this paper.
3. Allan Chapman, "Sir George Airy (1801–1892) and the concept of international standards in science, timekeeping and navigation", *Vistas in astronomy*, xxviii (1985), 321–8, p. 321. Despite his great importance for nineteenth-century science and technology, there is no published biography of Airy. Chapman, however, is currently at work on such a volume.
4. S. F. Cannon, *Science and culture: The early Victorian period* (New York, 1978), 38.
5. *Ibid.*
6. A. J. Meadows, *Greenwich Observatory*, ii: *Recent history (1836–1975)* (London, 1975), 1.
7. Eric G. Forbes, *Greenwich Observatory*, i: *Origins and early history (1675–1835)* (London, 1975), 176.
8. G. B. Airy, "Report on the progress of astronomy during the present century", *Report on the First and Second Meetings of the British Association for the Advancement of Science* (London, 1833), 125–89.
9. Quoted in G. B. Airy, *Autobiography of Sir George Biddell Airy*, ed. by Wilfrid Airy (Cambridge, 1896), 128.
10. H. C. King, "Instrumentation of the nineteenth centuries and early twentieth centuries", *Vistas in astronomy*, xx (1976), 157–63, p. 159.
11. Quoted in Forbes, *op. cit.* (ref. 7), 19.

12. Airy, *op. cit.* (ref. 9), 124.
13. J. A. Bennett, "Airy and horology", *Annals of science*, xxvii (1980), 269–85, p. 270.
14. Astronomer Royal's Report, 1836, quoted in Bennett, *op. cit.* (ref. 13), 270.
15. Meadows, *op. cit.* (ref. 6), 63.
16. Pond of course had begun the time-ball service at Greenwich in 1833.
17. Airy, *op. cit.* (ref. 9), 227–8.
18. G. B. Airy, entry on "Greenwich Observatory", *The penny cyclopaedia of the Society for the Diffusion of Useful Knowledge*, xi (London, 1838), 440–2, p. 442. Airy undertook to write this entry, and another on gravitation, after being urged by Sheepshanks that his (Airy's) and the Cambridge Observatory's interests could be advanced by Lord Brougham, then Lord Chancellor. Brougham, Sheepshanks knew, took a great interest in the *Penny cyclopaedia*: Airy, *op. cit.* (ref. 9), 97 and 101.
19. On Ramage's telescope see H. C. King, *The history of the telescope* (London, 1959), 199–201. Airy's fears remind one of Wordsworth's lines, quoted at the beginning of King's classic work: "What crowd is this? what have we here! we must not pass it by; A Telescope upon its frame, and pointed to the sky."
20. Meadows, *op. cit.* (ref. 6), 34.
21. Airy, *op. cit.* (ref. 9), 232.
22. Meadows, *op. cit.* (ref. 6), 42. A superb account of the instruments employed at Greenwich is contained in Derek Howse, *Greenwich Observatory*, iii: *The buildings and instruments* (London, 1975).
23. On the relationship between the generation and protection of knowledge and the problem of the political order, see Steven Shapin and Simon Schaffer, *Leviathan and the air pump: Hobbes, Boyle, and the experimental life* (Princeton, 1985).
24. Elsewhere I have argued that his actions surrounding the discovery of Neptune have to be interpreted in a similar light: Robert W. Smith, "The Cambridge network in action: The discovery of Neptune", *Isis*, lxxx (1989), 395–422.
25. J. G. Crowther, *Scientific types* (London, 1968), 390.
26. Meadows, *op. cit.* (ref. 6), 121.
27. Meadows, *op. cit.* (ref. 6), 121–2.
28. Simon Schaffer, "Astronomers mark time: Discipline and the personal equation", *Science in context*, ii (1988), 115–45, p. 132, J. L. E. Dreyer and H. H. Turner (eds), *History of the Royal Astronomical Society 1820–1920* (Oxford, 1923), 173–8 and 207–11, and A. J. Meadows, *Science and controversy: A biography of Sir Norman Lockyer* (Cambridge, Mass., 1972), chap. 4.
29. Dreyer and Turner, *op. cit.* (ref. 28), 209.
30. G. B. Airy, *English mechanic*, xxxii (1881), 586, cited in Meadows, *op. cit.* (ref. 27), 319.
31. The relationship between the state and science in nineteenth-century Britain was characterised by a mix of *laissez-faire* and state intervention, but the very limited financial support offered generally went to projects that promised practical applications. See, for example, Peter Alter, *The reluctant patron: Science and the state in Britain 1850–1920* (Leamington Spa, 1987) and R. M. Macleod, "Resources of science in Victorian England: The Endowment of Science Movement, 1868–1900", in P. Mathias (ed.), *Science and society, 1600–1900* (Cambridge, 1972), 111–66.
32. A. J. Meadows, "The Airy era", *Vistas in astronomy*, xx (1976), 197–201, p. 200.
33. E. Walter Maunder, *The Royal Observatory Greenwich: A glance at its history and work* (London, 1900), 116. In his recent reexamination of Airy's role in the discovery of Neptune, Chapman makes essentially the same point as Maunder but sets his argument in a much more convincing historical context: Allan Chapman, "Public research and private duty: George Biddell Airy and the search for Neptune", *Journal for the history of astronomy*, xix (1988), 121–39.
34. Airy, *op. cit.* (ref. 9), 76. See also J. Ivory, "Some remarks on a memoir by M. Poisson", *Philosophical magazine*, n.s., i (1827), 324–331, especially pp. 328–9, and G. B. Airy, "On some passages in Mr Ivory's remarks on a memoir by M. Poisson relating to the attraction of spheroids", *Philosophical magazine*, n.s., l (1827), 442–8.
35. Airy's son noted that in "the various polemical discussions on scientific matters in which Airy was engaged, Sheepshanks was an invaluable ally": Airy, *op. cit.* (ref. 9), 121. For another example of Airy and Sheepshanks in action together, see M. A. Hoskin, "Astronomers at war: South *v.* Sheepshanks", *Journal for the history of astronomy*, xx (1989), 175–212.

36. For a fuller account of this episode see Robert W. Smith, "The Hartnup balance", *Antiquarian horology*, March 1983, 39–45. Pond, we should remember, had been forced to resign as Astronomer Royal, and perhaps Airy's actions reflect not only his dislike of criticism but a concern to avoid the same fate as Pond.
37. See Hoskin, *op. cit.* (ref. 35).
38. Airy, *op. cit.* (ref. 9), 179.
39. G. B. Airy, 21 July 1846, to *The Athenaeum*, printed in the issue of 25 July 1846 under the heading "Greenwich Observatory", 760–2, p. 761.
40. Schaffer, *op. cit.* (ref. 28), 133.
41. Simon Newcomb, *Reminiscences of an astronomer* (Boston and New York, 1903), 288.
42. *Ibid.*, 287.
43. Airy, *op. cit.* (ref. 9), 37, 110, and 148.
44. There is a very large body of literature on the topic of deskilling. See, for example, Roger Penn, *Class, power, and technology: Skilled workers in Britain and America* (New York, 1990) and the works cited therein.
45. Crowther, *op. cit.* (ref. 25), 391.
46. Meadows, *op. cit.* (ref. 32), 197, and Meadows, *op. cit.* (ref. 6), 30.
47. Meadows, *op. cit.* (ref. 32), 199.
48. Cannon, *op. cit.* (ref. 4), 38.
49. Chapman, *op. cit.* (ref. 3), 332.
50. *Ibid.*, 322.
51. *Ibid.*, 323. Many writers point to Airy's great engineering expertise. Meadows, for example, suggests that Airy should be regarded as an engineer *manqué*: Meadows, *op. cit.* (ref. 6), 6.
52. Chapman, *op. cit.* (ref. 3), 326.
53. A striking contrast to Airy's Greenwich is provided by Dunsink Observatory under William Rowan Hamilton. Hamilton was a brilliant theoretical scientist, but he did not begin to have Airy's expertise or interest in the orderly running of an observatory. Nor did Hamilton have the resources – human, physical, or financial – to attempt to do so, at least on anything approaching the scale of Greenwich. Hamilton, moreover, did not possess the political skills that might have been translated into additional resources. Compared to the stream of astronomical results issuing from Greenwich, Dunsink's output was at best a trickle. On Dunsink see P. A. Wayman, *Dunsink Observatory, 1785–1985: A bicentinnial history* (Dublin, 1987).
54. Schaffer, *op. cit.* (ref. 28), 115.
55. *Ibid.*, 129. For an analysis of how this drive to eliminate errors was key in Bessel's measurement of annual stellar parallax, see M. E. W. Williams, "Attempts to measure annual stellar parallax: Hooke to Bessel" (Ph.D dissertation, University of London, 1981).
56. Schaffer, *op. cit.* (ref. 28), 119.
57. *Ibid.*, 122.
58. Andrew Ure, *The philosophy of manufactures: Or, An exposition of the scientific, moral, and commercial economy of the factory system of Great Britain* (London, 1835), 20.
59. See, for example, the quotation at ref. 18 above.
60. Ure, *op. cit.* (ref. 58), 13.
61. Maunder, *op. cit.* (ref. 33), 15.
62. *Ibid.*, 137. These remarks were noted and commented upon by Schaffer. See Schaffer, *op. cit.* (ref. 28), 120.
63. See above, ref. 14.
64. Chapman, *op. cit.* (ref. 3), 322.