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Chapter 4

"On the ... Importance of *Deviations*," or Buys Ballot's Pursuit of Turning Meteorology into an Exact Science[1]

In the 1870s meteorology, by a contemporary ranked as 'the youngest of the sciences', was booming.[2] Advances in the rapidly developing field attracted the attention of young and old. Some people put their interest into practice by engaging in the science, for instance by purchasing meteorological instruments to carry out weather observations themselves. Alexander Buchan, author of a handbook in meteorology, welcomed the growing interest of these enthusiasts and praised their voluntary services as observers. Nonetheless he feared that their imperfect knowledge of elementary meteorology and the instruments and methods of observation would make their efforts useless. His *Handy Book of Meteorology* was meant to meet this lack of knowledge by offering guidelines on the use of instruments, giving directions for positioning and reading them, and by explaining the methods of reducing the observations.[3]

Although Buchan's instructions to volunteer observers conveyed the impression that there was a consensus among meteorologists, there was actually no general agreement at the time about standard methods of observation, the scales to be used, a form of publication of statistical data, the choice of instruments, or even the variables to be observed; but, whereas volunteer observers were free to adopt or reject Buchan's or any other guidelines, the employees of the meteorological services who carried out observations had to comply with certain rules.

With the establishment of storm warning systems in different parts of Europe, which relied on information about the weather from surrounding areas, the national and international exchange of

[1] A shortened version of this chapter is currently in review.
[2] Alexander Buchan, *Handy Book of Meteorology,* second edition (Edinburgh and London, 1868), p. iv.
[3] Buchan, *Handy Book* (cit. n. 2), p. viii.

meteorological reports proliferated, posing challenges to individual modes of observation and measurement, and to the publication of data. In 1866, for example, the Paris observatory sent daily observations to 20 stations in France and 42 stations in 11 different European countries. The Austrian observatory received reports from French, Irish, Spanish and Dutch stations. The communications varied from exact measurements of meteorological variables to general reports of the weather.[4]

The increasing exchange of meteorological observations among countries required some form of coordination if uniformity of observation and publication, and thus comparability of the data, was to be achieved. How else could readings of different instruments at varying times of observation and carried out by different observers be compared? While presenting an image of consensus among meteorologists, Buchan could not avoid acknowledging the importance of coordinating and standardizing methods and procedures, and he contended that the only means of securing uniformity of observation and of publication was "a second Brussels conference."[5] He was not alone in this view and he gave voice to the opinions of many other meteorological practitioners. In fact, the nineteenth century witnessed a large number of international scientific meetings. Cities like Brussels, Paris and Vienna hosted international conferences inviting the cream of scholarly Europe to discuss matters like standardization of units, weights and measures, methods of quantified research, and the establishment of international scientific unions and institutions. The Metric Convention of 1875 is perhaps the international scientific meeting of the period best-known for the long-lasting controversies that reverberated in the series of meetings that followed in its wake.[6]

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[4] "Die Witterungs- Vorherbestimmungen der Pariser Sternwarte," *Zeitschrift der Österreichischen Gesellschaft für Meteorologie*, 1866, *1* (6):81–87, on pp. 84–85.

[5] Buchan, *Handy Book* (cit. n. 2), p. x. In 1853 an international meteorological conference was held in Brussels for the first time to develop and coordinate a global system of uniform atmospheric and marine observations. *Maritime Conference Held at Brussels for Devising an Uniform System of Meteorological Observations at Sea: August and September 1853* (Brussels, 1853).

[6] Nico Randeraad, "Triggers of Mobility, International Congresses (1840–1914) and their Visitors," *Jahrbuch für Europäische Geschichte/European History Yearbook*,

The plan to organize an international meteorological meeting was advanced by Christopher Buys Ballot in 1872, four years after the publication of Buchan's handbook. In January of that year, he published a pamphlet in which he summed up the main points that he considered important to discuss in preparation for a second international conference of meteorology. The issues he considered were the same as those raised by Buchan. In general Buys Ballot hoped to reach agreement on the instruments to be used, the number and distribution of observatories to cover large areas, and a uniform method of observation, reduction and publication of data. An issue to which he returned several times in the pamphlet was how to guarantee the accuracy of meteorological facts deduced from large series of observations carried out by different observers at different places and different hours, who used instruments that were often relocated or replaced by other instruments.[7]

Buys Ballot's concerns with the quality of observations were not his alone, but should be viewed as an expression of a widespread preoccupation with exactness in nineteenth-century science. In Britain, for instance, the scientific advisors of the meteorological office insisted that "any progress in the science of the weather depended above all on exact observations."[8] As Buys Ballot put it, "we trust that all of us will try to give the most exact observations. It is a great question how to get exact observations of the different phenomena."[9]

2015, *16*:63–82; Maurice Crosland, "The Congress on Definitive Metric Standards, 1798–1799, The First International Scientific Conference?" 1969, *Isis 60*:226–231; Frans van Lunteren, "'Beati possidentes', the Royal Dutch Academy and the Standard Metre," in Hart Grob and Hans Hooijmaijers, *Who Needs Scientific Instruments* (Leiden, 2006), pp. 17–27; Geert Somsen, "A History of Universalism, Conceptions of the Internationality of Science from the Enlightenment to the Cold War," *Minerva*, 2008, *46*:361–379.

[7] Buys Ballot often complained about the frequent relocation of observing barometers from their position, which affected the uniformity of data in considerable ways. In his pamphlet he explained how a change of an hour of observation is as if the climate of a place has changed. C. H. D. Buys Ballot, *Suggestions on a Uniform System of Meteorological Observations* (Utrecht, 1872), p. 15.

[8] Katharine Anderson, *Predicting the Weather. Victorians and the Science of Meteorology* (Chicago and London, 2005), p. 140.

[9] C. H. D. Buys Ballot, *A Sequel to the Suggestions on a Uniform System of Meteorological Observations* (Utrecht, 1873), p. 2.

In "The Meaning of Precision" Kathryn Olesko argues that exactitude, now taken as a timeless ideal obviously associated with science, is a cultural construct having a history of its own. Quantitative exactness as in precision or accuracy, qualities not distinguished by nineteenth-century scientists, acquired its meaning in early nineteenth-century astronomical and geodetic practices. Exactitude became a shared norm in the physical sciences as the consensus reached by scientific practitioners. [10] In geodesy and astronomy, refined measurements by sophisticated instruments were supplemented by mathematical constructions as a tool of data analysis to increase the precision of the results. The method of least squares, used by both Gauss and Legendre in the early 1800s, guaranteed that the most probable value of a number of observations was their arithmetical average. The method also proved that the most likely value of a large number of measurements was obtained by minimising the squared sum of the errors, or the differences between the individual measurements and the average of all measurements.[11] According to the astronomer, Friedrich Bessel, the best way to achieve more accurate results was not by improving instruments, but by reducing measurement errors mathematically. As he claimed, "the task of the present-day art of observation [is] to eliminate the apparatus from the results."[12] In the 1830s and 1840s least squares appeared in physics, chemistry and other natural sciences and were used as a tool to control and reduce the effect of measurement errors and guarantee the reliability of measurements.[13]

Taking astronomy and later physics as an example, university-trained meteorological investigators sought to make their field more scientific by adopting the creed of exactness. However, although they agreed that exactitude was a necessary step for meteorology to become more scientific, consensus was lacking as to the ways to obtain accurate

[10] Kathryn M. Olesko, "The Meaning of Precision, the Exact Sensibility in Early Nineteenth-Century Germany" in M. Norton Wise, *The Values of Precision* (Princeton, NJ, 1995), 103–134, pp. 103–105.
[11] Olesko, "The Meaning" (cit. n. 10), pp. 106–108.
[12] Kathryn M. Olesko, *Physics as a Calling. Discipline and Practice in the Königsberg Seminar for Physics* (Ithaca and London, 1991), p. 73.
[13] Olesko, "The Meaning" (cit. n. 10), p. 109.

results in the science of the weather. Indeed, accuracy as a criterion for meteorological observations was a matter of contention in the international meteorological meetings held in the 1870s. Whereas the method of least squares was used in astronomy to reduce measurement errors, it could not be applied to meteorology in the same way. In *Science outside the Laboratory* Marcel Boumans shows that "simply averaging" the measurements did not lead to greater accuracy. Whereas in astronomy the fixed positions of stars allow for repeated measurements as often as desired, in meteorology the atmosphere is in constant motion.[14] With the emergence of synoptic mapping and storm warning services, nineteenth-century meteorologists became interested in short-term variations in atmospheric conditions rather than in long series of observations.

How then were trustworthy meteorological facts to be obtained? By calibrating and improving instruments, even though costs were involved? By drawing up protocols of observation? But how to ensure that observers complied with the rules? Was manipulation of the data feasible somehow? Or could the quality of the observer be ensured by imposing criteria for the selection of practitioners such as integrity and academic qualifications?

This chapter takes the discussions about methods of meteorological observation and measurement among participants of the international meetings in the 1870s as a starting point to examine how pioneer meteorologists, while shaping their field of study as a branch of physical science, tried to use standards of exactness that they adopted from established disciplines such as astronomy and physics. The late nineteenth-century debates about quantification and accuracy in meteorology offer an ideal angle to show how contemporaries assessed different types of measurement and observation, and what criteria they used to judge each other's results. A special role is reserved in this chapter for Buys Ballot, who used the international meetings as a platform to promote and disseminate his programme of synchronous measurements and his calculus of deviations from barometric mean

[14] Marcel Boumans, *Science outside the Laboratory, Measurement in Field Science and Economics* (Oxford, 2015), pp. 68, 77.

values as ways of achieving reliable meteorological results. However, by doing so, he achieved the opposite. This chapter argues that standards of precision had a divisive effect in meteorology, creating boundaries and distinguishing professional meteorologists from an older generation of natural philosophers. By trying to find adherents for his system of deviations, Buys Ballot, in effect, eventually placed himself outside the core of meteorological scientists.

Meeting in Leipzig in 1872

In the preface to the pamphlet, *Suggestions on a Uniform System of Meteorological Observations*, published in preparation for the second international meteorological conference, Buys Ballot announced that the proposed meeting would be held in Vienna in the course of 1872, the same year in which he wrote and published this booklet.[15] This suggests that he knew about existing plans or that he had already made some arrangements with other meteorologists, among them Carl Jelinek, director of the Central Institute for Meteorology in Vienna. As it will be shown, Buys Ballot must have played an important role behind the scenes in organizing the international meeting. However, his careful style of writing suggests that he did not want to attract too much attention to his self-appointed leadership. Since his correspondence on the subject with his peers has unfortunately been lost, the pamphlet, the conference reports and other official publications are the only means to gain an impression of what went on during the months of preparation until the international congress finally assembled.[16]

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[15] Buys Ballot, *Suggestions* (cit. n. 7), p. i.

[16] At the Utrecht Archive (UA) a book of letter copies is kept of Buys Ballot's letters to other meteorological researchers in the period between 15 February 1870 until 13 December 1873, UA, 90 KNMI, 686. Some letters are copied in full, while the contents of other letters are summarised in one or two sentences. In this book Buys Ballot refers several times to a specific book of letter copies concerning the Leipzig and Vienna Congress. However, this book is not listed as such in the inventory of the Royal Dutch Meteorological Institute (KNMI). Buys Ballot's biographer, Ewoud van Everdingen, also noticed the unfortunate missing of these letters at the archive. E. van Everdingen, *C.H.D. Buys Ballot 1817–1890* (The Hague, 1953), p. 97. In fact, in the introduction of

In the official reports it is mentioned that the directors of three continental meteorological observatories took the lead in the spring of 1872 and formed a group that was to prepare a meeting. Jelinek, head of the Viennese observatory, Heinrich Wild, director of the Central Physical Observatory in St. Petersburg, and Karl Bruhns, director of the University Observatory in Leipzig, were all relative newcomers to meteorology compared to Buys Ballot. Backed by their imperial governments, they proposed a preparatory consultative meeting to be held in Leipzig in August 1872, a year before the official congress would assemble in Vienna.[17]

They published an open invitation in the journal of the Austrian meteorological society explaining their common objectives.[18] This journal, of which Jelinek was the editor, was actually the first German-language journal dedicated solely to meteorology. When it was launched, some people expressed their doubts about the merits of such a specialized periodical. As the Berlin professor of physics Heinrich Dove put it, "For a long time I did not find it useful to discuss meteorology in a specialised journal, but thought it preferable to incorporate this in the general journals for physics so as to retain a general interest in this discipline among physicists. However, I have changed my mind".[19] The quote can be seen as a sign that meteorology

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the KNMI inventory it is mentioned that some material was destroyed as a result of a fire in the main building of the meteorological institute in 1933. The book of letter copies may have been destroyed at the time. P. van Beek, *Inventaris van het archief van het Koninklijk Nederlands Meteorologisch Instituut (1852) 1854–1951* (Utrecht, 1994), p. 13. Unfortunately my own research journeys did not take me to East-European archives, where Buys Ballot's letters may be found.

[17] *Report of the Proceedings of the Meteorological Conference at Leipzig, Protocols and Appendices, Translated from the official report, Appendix to Vol. VII, No. 24, of the Zeitschrift für Meteorologie* (London, 1873), pp. 5–7.

[18] C. Bruhns, H. Wild and C. Jelinek, "Einladung zu einer im August d. J. in Leipzig abzuhaltenden Meteorologen-Versammlung,“ *Zeitschrift der Österreichischen Gesellschaft für Meteorologie*, 1872, *7* (12):193–196.

[19] Dove's quote in original language: "Ich habe es lange für nicht zweckmäßig gehalten, die Meteorologie in einer besonderen Zeitschrift zu behandeln, sondern es für wünschenswerter angesehen, sie in den Journalen für allgemeine Physik mit zu bearbeiten, um in dem Physikalischen Publikum überhaupt ein allgemeines Interesse für diese Disziplin zu erhalten. Ich bin aber davon zurückgekommen.“ C. Jelinek and J. Hahn, "Kleinere Mittheilungen," *Zeitschrift der Österreichischen Gesellschaft für Meteorologie*, 1866, *1* (1):12–13. The translation is mine.

was maturing as an autonomous field of study. The periodical soon became the leading journal in the field.

Buys Ballot found the journal "highly interesting."[20] Already in 1850 he had suggested the creation of such a specialised journal for meteorology "similar to Schumacher's *Astronomische Nachrichten*."[21] He published multiple papers in the journal after its first volume appeared in 1866, and he probably became acquainted with Jelinek as a result of these publications. His first contribution discussed the convention of reducing meteorological observations to sea level and ways of keeping a record of deviations from daily mean barometric values in order to make observations comparable.[22] This latter issue proved to be one of the most important discussion points at subsequent meteorological meetings, something that the hosts of the meetings could not have guessed. For the moment, Jelinek, Bruhns, and Wild hoped for a high turnout at their planned Leipzig meeting.

The first sentence of their invitation began with a reference to Buys Ballot's pamphlet. Inspired by his *Suggestions*, the three directors presented the points they wished to propose for discussion at the meeting, in order to be better prepared for the definitive congress of Vienna.[23] The chief aim of the meeting was to "lay down the programme for the actual Congress, … thereby to render it possible for the Congress to arrive at immediate conclusions."[24] The points they listed were very similar to those presented by Buys Ballot. In fact, Jelinek, who published an excerpt of Buys Ballot's pamphlet in his

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[20] Buys Ballot, *Suggestions* (cit. n. 7), p. 7.

[21] C. H. D. Buys Ballot, "Meteorologische Preisfrage," *Die Fortschritte der Physik im Jahre 1847*, 1850, *3*:565–574, on p. 574.

[22] C. H. D. Buys Ballot, "Ueber die Reduction auf das Niveau des Meeres und die Abweichungen von den Normalwerthen," *Zeitschrift der Österreichischen Gesellschaft für Meteorologie*, 1866, *1* (13):199–202.

[23] Bruhns, Wild and Jelinek, "Einladung" (cit. n. 18), pp. 193–196. The English translation of the invitation was included in the *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 5.

[24] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 8.

journal, praised him for the work he had done in highlighting the important questions in meteorology.[25]

Of the twenty-six questions that were posed in the invitation, more than half were about the instruments used and the methods of observing pressure, temperature, wind, rain, evaporation, moisture, hours of sunshine, hail, thunderstorms and clouds. The other questions concerned units of scale, hours of observation, calibration of instruments, calculation of mean values, publication and exchange of data, establishment and classification of institutes, weather telegraphy, and how to follow up on decisions made at the Vienna congress.

Given the large number of questions, it is striking that the meeting was planned to last just three days. Equally remarkable was the grand gesture to invite "all Meteorologists by profession," not only "heads of Meteorological Institutes" but also "private scientific men and practical observers in the domain of Meteorology" to attend the meeting, or if they were unable to do so, then send in their opinions on the individual questions by mail.[26]

When the day finally arrived, 52 "professional" and "private" meteorologists attended the meeting, most of whom had an advanced academic degree. Among the participants were of course Buys Ballot and Buchan. The latter represented the Scottish meteorological society. The director of the London-based meteorological office, Robert Henry Scott, represented England. The majority of those present however, consisting of professors and directors of several meteorological services and observatories, came from Austria-Hungary and the newly united German empire.[27] France was not represented, perhaps because of the recent war, or as Katharine Anderson has shown, because of a stand-off between the country's two competing authorities in meteorology, the director of the Paris observatory, LeVerrier, and the chief of the

[25] Carl Jelinek, "Literaturbericht," *Zeitschrift der Österreichischen Gesellschaft für Meteorologie*, 1872, *7* (15):268–271, on p. 271.
[26] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), pp. 8–9.
[27] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 10.

Montsouris observatory, Charles Deville.[28] Despite the call in the invitation the two men did not even send a reply to the questionnaire, in contrast to many other observatory directors who were not able to attend the meeting.

There were about fifteen letters, one of which was a reply by Dove, who wrote on behalf of the Prussian meteorological institute. As has been shown in the previous chapter, Dove and Buys Ballot had a long history of friendship and rivalry as creators of two competing meteorological laws. In his letter Dove excused himself for not being able to come to Leipzig, because he needed "mountain air in August."[29] Whether his health was really fragile, or whether he wanted to spare himself the embarrassment of meeting his former protégé and now more successful rival, Buys Ballot, is not clear. Clearly the latter's leading position in the community of meteorologists became instantly apparent when the participants unanimously chose him to preside over the meeting, just minutes after Bruhns officially opened the conference.[30]

The aim of the meeting was to discuss the 26 questions posed by the organisers one by one, and formulate proposals for each issue to be presented at the next meeting. Immediately from the start of the deliberations it became clear that agreement on the discussion points would be hard, if not impossible, to reach. It would take us too far to discuss every point individually, although the troublesome discussions that followed each point are actually interesting from a historical perspective. They give the reader a real sense of what went on during the meetings. Most of the times when the participants disagreed with one another on some point, they did so because of other underlying issues that were important to them. By looking into the discussions these issues are made visible and it is shown how the participants dealt with them.

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[28] Anderson, *Predicting* (cit. n. 8), p. 246.
[29] Dove's letter was included in the appendix of the *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 45.
[30] *Ibid.*, p. 11.

The first issue on the agenda, viz. uniform measuring units, made nationalist sensitivities painfully visible. Bruhns sensibly suggested postponing the discussion of this point until after the Metric Conference to be held in Paris. Scott, representing England, recommended leaving this matter to governments, while Buchan as secretary of the Scottish meteorological society expressed himself in favour of the metric scale. Buys Ballot diplomatically suggested using the metric scale alongside the scale used in the different countries. Scott responded by mentioning the advantages of the Fahrenheit scale and claimed that another meteorologist, the Norwegian Henrik Mohn, who was not present at the meeting, would agree with him on this point. However, in a report that Mohn sent to the conference, he favoured the metric scale. In short, the first issue showed how disagreements would characterise the rest of the meeting's deliberations. In the end Buys Ballot's suggestion was adopted as a proposal to be discussed at the next meeting.[31]

At the close of the first sitting, it became quite apparent that a day was hardly enough to discuss four issues, let alone a total of 26 questions in just three days. Wild, one of the organizers who had anticipated this problem prudently suggested at the next session to take up "the more important questions" first, which mostly concerned procedures and methods of observation.[32]

In general, the participants tended to agree on questions concerning weather conditions and instruments. Deliberating over some of these points proved to be premature. Systematic observations of evaporation, and moisture, for instance, were rare in those days. Most participants were not familiar with instruments or techniques for carrying out observations of such phenomena. Therefore, the assembly decided to postpone these issues until better techniques and instruments were available.

Discussions about the barometer exceptionally revealed large discrepancies between levels of observational sophistication and stringency in the different countries. Buys Ballot, for example, saw the

[31] *Ibid.*, pp. 11–12, 56.
[32] *Ibid.*, p. 20.

use of the aneroid (non-liquid) barometer as not sufficiently accurate, and therefore useless for scientific purposes, while others found it "not a bad instrument for the determination of differences in pressure" and good enough "as an interpolation instrument." As Buchan explained, the aneroid barometer was convenient to use as a portable instrument for the comparison of mercurial barometers, because of its small size. But Bruhns remarked decidedly that "aneroids could not be accepted as scientific instruments," and suggested forming a subcommittee to resolve this issue. Scott went further and claimed that they should "not be used at all." On Buys Ballot's suggestion, the participants finally agreed that "the Aneroid should not be used instead of the Mercurial Barometer, but only as an interpolation instrument, in addition thereto."[33] Only such a half-baked compromise could keep everyone happy and prevent the assembly from endlessly debating a topic without really discussing or actually reaching an outcome about the accuracy and practicability of the instruments in question.

On the subject of the calibration of instruments the participants showed the same concessive attitude, nicely confirming some nationalist stereotypes in the process. The German-speaking participants, Bruhns, Wild and Von Oettingen for instance, tried to top each other in offering the most exact way of calibrating standard instruments and boasting about their smallest margins of error, while their British counterparts, Buchan and Scott, displayed a nonchalant confidence in the accuracy of their instruments. After a lengthy parade of precision, the participants reached a non-committal agreement that "it was desirable to make a periodical inspection of the stations of each system as frequently as possible."[34] It is striking that Buys Ballot, who expounded his opinions clearly in his pamphlet, refrained from sharing his views at the sitting. As will become clear later, he preferred another way of securing accurate observations. His method will be discussed in the next part of this chapter.

Questions about observation, reduction and publication protocols were the hardest to deal with. Opinions on these matters diverged

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[33] *Ibid.*, pp. 13–14.
[34] *Ibid.*, pp. 23–25.

widely and the participants were less inclined to make concessions. One of the proposals that were discussed was whether it was desirable to introduce uniform times of observation. Until then, observations were being carried out at regular time intervals but at unspecified hours, not necessarily because of a lack of conformity, but so as to accommodate the observers, most of whom made the measurements voluntarily. Weather investigators did hope to coax each other and their observers into carrying out observations at the same hours or at least mentioning the exact hours of observation in their reports, in order to obtain comparability of the results.[35]

At the Leipzig meeting Buys Ballot seized the opportunity to present one of his most ambitious plans, to which he had also drawn attention in his pamphlet. He went further than all the other participants and proposed to model meteorological observations after Gauss's 1830s geomagnetic project and to carry out observations "according to astronomical time … in order to obtain actual simultaneity." He wanted the air pressure and temperature to be measured three times a day synchronously at intervals of eight hours at all stations across the globe so as to "get [a] very correct notice of the distribution of atmospheric phenomena over the whole earth, at the same point of time."[36]

Some participants like von Oettingen and Jelinek were immediately drawn to this bold plan. Others with a more practical attitude like Bruhns questioned the advantages of astronomical time over local time of carrying out meteorological observations. Buys Ballot countered Bruhn's argument by pointing out that "for magnetic observations absolute simultaneity was required," which was not an answer to the question at all. He seemingly claimed that meteorological observations could only emulate those of geomagnetic research and attain successful results, if they were carried out everywhere at exactly the same time. In the pamphlet he had written: "from a theoretical point of view it appears highly recommendable to do for other atmospheric

[35] Buchan, *Handy Book* (cit. n. 2), pp. ix, 58.
[36] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 18), p. 21; Buys Ballot, *Suggestions* (cit. n. 7), pp. 17–18.

phenomena, what has been done by Gauss with respect to the study of the magnetism of the earth with great success."[37] In a later publication he explained that "by this [plan] every one, without being compelled to apply to the different Directors, can immediately draw up a synoptic chart of simultaneous observations."[38] Thus it made sense to ask for simultaneity of observations, if he had synoptic charts in mind. However, his plan required calculating "the means of the three or more observations taken at synchronous hours."[39] If he wanted to work with averages, what was then the need for synchronous hours of observations, and why were observations carried out at local hours not good enough? Indeed, one wonders whether the study of temperature and pressure distributions across the earth would have benefitted at the time from such meticulous measurements. His writings do not provide a clue. At best it can be said that Buys Ballot conveyed a sense of exactitude typical of his time.

Bruhns was easily satisfied with Buys Ballot's reply and agreed to the plan. So it looked as if it would get enough support to be implemented. However, as Wild sharply pointed out, "an agreement on simultaneous hours of observation brought with it the hateful question of the first meridian."[40] Indeed, the plan entailed agreement among the members on a fixed point of reference in time. Where should the first meridian be drawn? In his pamphlet, Buys Ballot had anticipated the problem and he had proposed to "let the ballot decide," but he did not mention this at the conference.[41] After Wild's stirring remark, the members dodged the issue by raising all sorts of trivial questions, for instance about the hours running from 0-23h or 1-24h and so on, until the ever sensible Bruhns finally proposed to postpone formulating a proposal until the Vienna congress.

Opinions about modes of publication of meteorological data also differed widely. Some of the participants preferred the publication of

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[37] *Ibid.*, p. 18.
[38] Buys Ballot, *A Sequel* (cit. n. 9), p. 27.
[39] *Ibid.*, p. 26.
[40] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 22.
[41] Buys Ballot, *Suggestions* (cit. n. 7), p. 20.

daily observations of different elements, while others wanted the averages published as well. Some wanted to publish their results once yearly, while others preferred monthly publications.[42] The calculation of averages itself was a separate point of debate, which ended with a vote. The meeting distinguished four optimal ways of calculating mean values. Besides daily, monthly and yearly averages a majority of the meeting opted for dividing the year into units of 5 days so as to come at a round number of 73 intervals. It is striking how almost everyone agreed on the importance of mean values without questioning their relevance to the investigations or discussing their use.[43] As it will be shown in the next section, calculating averages had been a chief task in the study of the weather for decades.

Buchan was the only one who made a remark about this point.[44] In his *Handy Book of Meteorology* he had strongly criticised the custom of publishing daily barometric averages instead of the actual observations. He believed that the publication of means rendered the data absolutely useless for the study of storms, and he complained, for instance, that the annals of the central physical observatory in St. Petersburg, "the greatest storehouse of meteorological observations in the world," were "deprived of a great part of their value" by this style of publication.[45]

The critique must have had an impact on Wild, the director of the observatory, who adopted a new style of publishing his data. At the conference, he announced that he would publish "original observations" of pressure, temperature, humidity, wind direction and force, and rainfall three times a day, "so that the corresponding data of different stations and different countries could be immediately compared with each other." Although meteorology would benefit from the elaborateness of these publications, some participants like Scott

[42] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 29.
[43] *Ibid.*, pp. 25–27.
[44] Buchan remarked that "when only the means of observations for five-days were published, many investigations, for which daily data were required, were rendered impossible." *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 27.
[45] Buchan, *Handy Book* (cit. n. 2), pp. ix–x.

worried about the costs of printing if so much information was to be published. The participants could not reach an understanding and decided to prepare a plan to be discussed at the next meeting.[46]

The issue of weather telegraphy ended with the same outcome. The assembly decided to hand over the topic to a subcommittee consisting of Buys Ballot, Scott, and the director of the Hamburg storm warning service, Georg Neumayer, to produce a report for the Vienna conference. This subcommittee was formed for the special purpose of deciding on the practicability and utility of forecasting and maritime observations.[47] Although it had a preparatory role, the subcommittee was very influential in deciding what the discussions were to be about. It seems odd at first sight that the participants were willing to hand over weather reports and storm warnings to a subcommittee consisting of only three people, especially considering the past history of meteorological investigations. The thirty years before the Leipzig meeting had shown intense competition among academically trained meteorologists and naval officers who strove to claim authority in marine and atmospheric research. In that process the latter group was gradually excluded from the top layers of meteorological departments and offices in Europe.[48] This policy of deliberate separation was reinforced at Leipzig, for the conference agreed that in each country meteorological divisions "for sea and land observations should be separate."[49] But even among meteorologists themselves competition was rampant. As Anderson cynically (but quite rightly) remarks, "the work of the Sub Committee … appeared to have been designed *not* to reach conclusions," for the assembly declared that the question should be left 'open' in order to 'be in unison with most authorities of science.'[50] Thus the subcommittee claimed control over weather

[46] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), pp. 29–31.
[47] *Ibid.*, pp. 32, 33, and 44.
[48] Azadeh Achbari, "Building Networks for Science, Conflict and Cooperation in Nineteenth-Century Global Marine Studies," *Isis*, 2015, *106*:257–282.
[49] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 32.
[50] *Ibid.*, p. 44; Anderson (cit. n. 8), p. 246.

telegraphy, but apparently only to avoid being forced into adopting a specific system of storm warnings and forecasting.

As a last important point of discussion, the participants considered the implementation of the decisions made by the assembly. The commission agreed on the proposal that a permanent body be nominated that would publish the proceedings of the meeting and prepare for the congress to be held in the following year. The proceedings of the conference were to be published in the journal of the Austrian meteorological society. At Buys Ballot's suggestion, Wild, Jelinek and Bruhns were chosen as candidates of the proposed permanent committee.[51] At the end of the third day, Jelinek thanked the assembly and closed the meeting.

Deviations and Nature's Rhythms

In March 1873, six months before the planned Vienna congress would convene, Buys Ballot published a *Sequel to the Suggestions on a Uniform System of Meteorological Observations*, in which he elaborated on the questions that had been discussed at the Leipzig meeting. He explained his reasons by saying that although "different savants sent in their observations and their opinion … it may not be superfluous to give once more my opinion on several propositions … mentioned by me in the suggestions."[52]

He was apparently not entirely satisfied with what had been discussed and he felt that it was necessary to recapitulate the main research objectives in meteorology: "we must try to have observations taken at every equidistant point of the globe, and we must deliberate on the means, how and in what form they must be published, [so] that every one … may get them ready for the investigation of the laws, which regulate the [atmospheric] disturbances."[53]

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[51] *Report of the Proceedings of the Meteorological Conference at Leipzig* (cit. n. 17), p. 34.
[52] Buys Ballot, *A Sequel* (cit. n. 9), pp. 1–2.
[53] Ibid., p. 2.

He claimed that after Dove's achievement of mapping periodical changes in the weather for a large number of places, it was time to study the disturbances, or in his more complete phrasing, "the non-periodical changes" in meteorological quantities. This was "the next phase of meteorology." He voiced the opinion that the best way to study these non-periodical changes was by looking at the deviations from the mean values of pressure and temperature at different places at the same time.[54]

His research agenda of studying deviations puzzled many of his fellow meteorological practitioners when he first came up with the idea in 1850, as it has puzzled later generations of meteorologists.[55] Let us take a closer look at what Buys Ballot hoped to achieve by studying these deviations and why he attached so much importance to them. But before turning to deviations, it is relevant to explain first the nature of the investigations of periodical changes in the weather.

As one of his biographers, van der Stok, claimed, "Buys Ballot, like almost all meteorologists, began [his investigations of the weather by] studying periodical changes in meteorological and geomagnetic variables, which were perceived as occurring synchronously with known or presumed cosmic phenomena."[56] On the assumption that the rotation of the sun and the moon had an effect on meteorological periods, Buys Ballot took up the study of a long series of temperature observations that were carried out between 1729 and 1846 at Haarlem and Zwanenburg. In 1847 he published a brochure, in which he reported the results of his investigations. He had discovered a period of

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[54] Buys Ballot, "Meteorologische Preisfrage" (cit. n. 21), pp. 565–566, 572.

[55] He presented his program of deviations in Buys Ballot (cit. n. 21), pp. 565–574; and C. H. D. Buys Ballot, "On the great importance of *Deviations* from the mean state of the Atmosphere for the Science of Meteorology," *Philosophical Magazine*, 1850, *37*:42–49. On his puzzling his fellow meteorological practitioners and later meteorologists see J. P. van der Stok, "Levensbericht C. H. D. Buys Ballot," in *Jaarboek der Koninklijke Nederlandsche Akademie van Wetenschappen* (Amsterdam, 1899), 59–100, on pp. 76–79; and E. van Everdingen, *Buys Ballot* (cit. n. 16), p. 57.

[56] Van der Stok, "Levensbericht" (cit. n. 55), p. 76.

27.682 days for the rotation of the sun around its axis, which concurred with a fluctuation in temperature of about 0.5 degree Celsius.[57]

According to another of his biographers, van Everdingen, the period of 27 days could not be confirmed by further research.[58] Even though Buys Ballot did not find many supporters for his finding, he held to the calculated period of 27 days for forty years.[59] All the while he hoped to discover more of these sorts of interrelated connections in meteorological, astronomical and geomagnetic phenomena. In the following years he studied other presumed connections. He studied, for example, the relation between the orbital period of the moon and temperature oscillations on earth, the influence of the moon on cloud formation, and the influence of sunspots on the earth's surface temperature.[60]

As van der Stok observed, much of the investigations of the weather in the first half of the nineteenth century focussed on finding and mapping cycles of meteorological variables by calculating mean values from observations carried out daily over various intervals of time. These cycles were then related to each other or other periodical phenomena, in the hope of discovering hidden patterns. Alexander von Humboldt had set the example with his graphical displays of meteorological, geomagnetic and hydrographical measurements. His global maps of isotherm curves, connecting places of the same average temperature, became iconic. The colourful *Physikalischer Atlas*, which accompanied his masterpiece *Kosmos*, also displayed many graphs of periodic data. The hydrographical section, for instance, displayed combined graphs of air temperature, the amount of rainfall and

[57] C. H. D. Buys Ballot, *Les changements périodiques de Température dépendants de la Nature du Soleil et de la Lune, mis en rapport avec le pronostic du temps, déduits d'Observations Néerlandaises de 1729 à 1846* (Utrecht, 1847), pp. 115–117; Buys Ballot, "Ueber den Einfluss der Rotation der Sonne auf die Temperatur unserer Atmosphäre," *Annalen der Physik und Chemie*, 1846, *68*:208.
[58] Van Everdingen, *Buys Ballot* (cit. n. 16), pp. 119–120.
[59] C. H. D. Buys Ballot, "Étude d'une variation périodique de la température en 27,675 jours, d'après les observations de 155 années = 2046 périodes successives," in *Archives néerlandaises des sciences exactes et naturelles*, 1886, *20*:348–360.
[60] Van der Stok, "Levensbericht" (cit. n. 55), pp. 76–79; Van Everdingen, *Buys Ballot* (cit. n. 16), pp. 119–120.

average high water levels, suggesting that there were hidden connections between fluctuations in these quantities.[61]

The search for cycles and periodicities affected other researchers who followed Humboldt's course. In the 1840s, for example, Luke Howard who gained fame for his classification of clouds, identified an 18-year cycle of barometer fluctuations, which he connected with the moon's position relative to the sun and earth. From studying long records of weather observations Buchan found predictable abrupt changes in temperature between the seasons, which later became known as Buchan spells. They are now believed to be random.[62]

Norton Wise has located the origins of this type of investigation of natural cycles in nineteenth-century Prussia. As he pointed out, "toward the middle of the 19th century … scientists of every stripe acquire[d] the habit of trying to represent natural processes in terms of curves, or better, to read nature as curves."[63] Wise traced the use of the mathematical curve as expressing nature's laws back to the discovery of the French mathematician, Joseph Fourier, and connected it with the maps and graphs of "the patron of the curve," Humboldt, and the work of his protégés Gustav Lejeune-Dirichlet and Heinrich Dove. As Wise explains, Dirichlet provided the proof for the generality of Fourier's discovery that many mathematical functions could be represented in terms of an infinite sum of sine and cosine waves. Dirichlet proved that an arbitrary curve, for example, of barometer readings over a period of time, could be written as a mathematical function in the form of a Fourier series, as a set of simple periodic curves. As Wise phrased it beautifully, "the most non-lawlike looking

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[61] Heinrich Berghaus, *Physikalischer Atlas oder Sammlung von Karten, auf denen die hauptsächlichsten Erscheinungen der anorganischen und organischen Natur nach ihrer geographischen Verbreitung und Vertheilung bildlich dargestellt sind. Zu Alexander von Humboldt, Kosmos* (Frankfurt am Main 2004), pp. 56–57.

[62] Luke Howard, *A Cycle of 18 Years* (London, 1842); and Luke Howard, *Barometrographica, Twenty Years Variation of the Barometer in the Climate of Britain, Exhibited in Atmospheric Curves with the Attendant Winds and Weather* (London, 1847). Both books are cited in Anderson, *Predicting* (cit. n. 8), p. 47.

[63] M. Norton Wise, "What's in a Line?," in Moritz Epple and Claus Zittel, *Science as Cultural Practice Vol. I, Cultures and Politics of Research from the Early Modern Period to the Age of Extremes* (Berlin, 2010), 61–102.

curve could be analysed into the simplest of harmonic laws, often taken to represent the underlying rhythms of nature."[64]

Dove in fact succeeded in representing the average yearly barometric pressure as a periodic function of the direction of the wind making a full circle around the compass. For this purpose he used series of accumulated records of wind and pressure observations carried out at different locations. He indexed the main wind directions in numbers, used the method of least squares and borrowed another astronomical technique from Bessel, the interpolation formula, to determine the constants of the first three terms of the series to arrive at an approximation of a continuous periodic function.[65] When the wind turned half a circle around the compass from northeast to southwest, the average pressure fell. The turning of the wind from southwest to northeast, making a full circle, corresponded with the average rise of the barometer. He made similar calculations for temperature and humidity and published his findings in the *Annalen der Physik* in 1827.[66]

In the same publication, Dove remarked: "we will obtain an approximation … by calculating formulas from direct observations, and if differences between observed and calculated values come from irregularities, … then the formula will at least show how a value deviates from the norm, and give its quantitative value. Further research will have to be done to explain the physical causes of such deviations."[67] He wondered whether the deviations themselves also behaved according to rules. In a paper presented at the meeting of the Prussian Academy in Berlin in 1838, he summed up the triple task of meteorology: "calculating averages, defining the laws of periodic changes, and finding the rules of the deviations."[68]

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[64] Wise, "What's in a Line?" (cit. n. 63), p. 82.

[65] *Ibid.*, pp. 83–84.

[66] H. W. Dove, "Einige meteorologische Untersuchungen über den Wind," *Annalen der Physik*, 1827, *87* (12):545–590, pp. 555–558 on barometer, pp. 566–567 on temperature, and p. 587 on humidity.

[67] Dove, "Einige meteorologische" (cit. n. 66), p. 558.

[68] H. W. Dove, "Über die nicht periodischen Änderungen der Temperaturvertheilung auf der Oberfläche der Erde," in *Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin* (Berlin, 1839), 285–415, on p. 285.

Return now to Buys Ballot, whose statement: "one has to investigate the deviations from the rules in order to find the rules of the deviations" clearly shows how he was inspired by Dove's investigations.[69] In fact, his meteorological programme was the offspring of the research that Dove carried out in the 1830s and 1840s. On the basis of published weather observations from dozens of places over a period from about 1796 to 1838, Dove calculated among other things deviations from monthly temperature means over a span of decades per month of each year. He published these tables filling more than a hundred pages as an accompaniment to the paper presented at the Berlin meeting. The comparison of these numbers showed him the spread of temperature anomalies across Europe for different months over the years. He could demonstrate, for example, that March 1836 temperatures were on average a couple of degrees higher in German states and Russia compared to the American northeast coast, Britain and France.[70] He used these statistics for the preparation of maps depicting monthly isotherms and isanomals – lines connecting places warmer or colder than they should be for their latitude. These atlases earned him the praise of the scientific elite, embodied in the Royal Society's highest honour, the Copley Medal, which he received in 1853.[71]

Buys Ballot, eager as he was, wanted to go one step further than Dove. He emphasized that whereas Dove had calculated deviations from monthly temperature means, he rendered meteorological investigations "a bit more precise, … by calling attention to the *simultaneous* deviations from mean meteorological values." He proposed that meteorological investigators compose tables of daily temperature and pressure deviations from means calculated over intervals of five days for a period of two years at as many places in

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[69] C. H. D. Buys Ballot, "Theoretische Meteorologie," *Die Fortschritte der Physik im Jahre 1847*, 1850, *3*:620–663, on p. 629.
[70] Dove, "Über die nicht periodischen Änderungen" (cit. n. 68), pp. 290–291, 340.
[71] H. W. Dove, *Monatsisothermen* (Berlin, 1849); H. W. Dove, *Die Verbreitung der Wärme auf der Oberfläche der Erde erläutert durch Isothermen, thermische Isanomalen und Temperaturkurven* (Berlin, 1852). On Dove receiving the Copley Medal, see Anderson, *Predicting* (cit. n. 8), p. 89.

Europe and Asiatic Russia as possible. Using the data they could map the simultaneous movement of deviations in time and space. The deviations could then be linked with concurring winds.[72] He assumed that the deviations were somehow directly related to atmospheric disturbances. In sum, he hoped to emulate Dove's discovery of the interrelationship between average yearly pressure and temperature, and wind direction, but he also hoped to find regularities between temperature and pressure *deviations* and wind direction over a much shorter span of time. His confidence that this programme would succeed was partly fed by the recent introduction of the electric telegraph which made a rapid exchange of information possible.[73]

What is more, he argued that the study of deviations had two advantages. It was cheaper to publish only the deviations instead of the actual temperature and pressure readings, because they took less space. Also, the method of deviations had the advantage of "greater, almost complete and after some years absolute precision." As he explained, the accumulation of data over the years made the mean values more complete and the study of deviations allowed the readings to be more precise, for "it has also to be borne in mind that the deviations do not become uncertain due to bad placement when the mean values are determined with the same instruments in their original position."[74] This latter point, the elimination of instrument errors, seemed to be directly borrowed from Dove. In the 1838 paper presented at the meeting of the Prussian Academy, Dove claimed that "the introduction of [deviations]

[72] Buys Ballot, "Meteorologische Preisfrage" (cit. n. 21), pp. 565–566. Emphasis is mine. See also C. H. D. Buys Ballot, "Erläuterung einer graphischen Methode zur gleichzeitigen Darstellung der Witterungserscheinungen an vielen Orten," *Annalen der Physik*, 1854, *167* (S4):559–576, on pp. 575–576.
[73] Buys Ballot, "Theoretische Meteorologie" (cit. n. 69), p. 629.
[74] Buys Ballot, "Erläuterung" (cit. n. 72), pp. 560–561. Quote in original language: "meine Methode, die Abweichungen in Zahlen zu geben, … hat ... zweitens den Vorzug der größeren, beinahe vollkommenen und nach einigen Jahren ganz absoluten Genauigkeit…. Mit dem Verlaufe der Jahre wird eben durch diese Abweichungen unsere Kenntnis genauer…. Es ist auch zu bedenken, dass die Abweichungen durch eine schlechte Aufstellung der Instrumente nicht unsicherer werden, wenn nur die mittleren Werthe mit denselben Instrumenten in der nämlichen Stellung bestimmt sind...."

has the remarkable advantage that as each instrument is only compared with itself, the constant errors of the instruments are eliminated."[75]

In a recent study on the subject, Boumans argues that Buys Ballot used the arithmetical mean, not to neutralise measurement errors, but to "capture" them. He claims that Buys Ballot came up with a "calculus of observations" to deal with instrument errors, which runs as follows:

> The facts to be established are the daily variations in, for example, pressure. They have to be inferred from daily readings of unreliable instruments. … The mean, which includes the instrument's error, is compared with the measured observation, which also includes the same instrument's error. By taking the difference between these two values, the deviation, the instrument's error is eliminated.

Buys Ballot also believed that, by looking at deviations, differences between the instruments' readings due to their position at different latitudes and heights above the sea, were likewise normalised, because the relative rise or decrease of the barometer readings as compared to the mean values, which were computed for each specific location with the same instruments, were taken into account.[76] For this reason, he was against reducing the measurements to sea level. In his *Suggestions* he remarked: "Departures are perfectly independent of the daily and annual range, and of the local disposition and correction of the instruments, because the normals [mean values] are likewise computed for these circumstances."[77]

Boumans connects Buys Ballot's study of deviations with his long-felt desire to establish a worldwide network of meteorological observations. He argues that the global reach of Buys Ballot's programme aggravated the problem of uncalibrated instruments and

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[75] Dove, "Über die nicht periodischen Änderungen" (cit. n. 68), p. 340. Quote in original language: "Die Einführung derselben [der Abweichungen] gewährt außerdem den sehr erheblichen Vortheil, dass, indem jedes Instrument nur mit sich selbst verglichen wird, die constanten Fehler derselben eliminiert werden."
[76] Boumans, *Science outside* (cit. n. 14), pp. 75–76.
[77] Buys Ballot, *Suggestions* (cit. n. 7), p. 18.

uncertain observations. Deviations were thus a remedy to deal with observations that were initially considered incomparable. Buys Ballot's role model, Dove, had once remarked, "the art of observation owes its high perfection in recent times more to the development of the mathematical methods on which it rests than to the technical perfection of the means of observation."[78] Buys Ballot too preferred arithmetic calculations that allowed him to use large numbers of observations from scattered places, than relying on the technical perfection and standardisation of meteorological observation practices. Furthermore, his principle of deviations did not even require complex mathematical computations like the method of least squares.

Just like his search for meteorological periodicities, Buys Ballot's study of deviations was a lifelong commitment. In 1888, at the age of seventy, he published yet another paper on temperature deviations.[79] Even after his discovery of the connection between atmospheric pressure and the force and direction of the wind, he continued to emphasize the importance of studying deviations. While his wind rule had proved that the best indication of strong winds could just as well be derived from "differences between simultaneous *absolute* readings" as from differences between "*deviations* from the normal readings," he still preferred to study the deviations.[80]

This may have to do with the early criticism of his peers on the quality of meteorological observations as compared to observations in other scientific disciplines, especially astronomy. The criticism by the Dutch physicist, van der Willigen for example, had a major impact on Buys Ballot.[81] In the late 1840s, van der Willigen, who had been a student of the much-respected astronomer, Frederik Kaiser, had claimed:

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78 Olesko, "The Meaning" (cit. n. 10), p. 119.

79 Van der Stok, "Levensbericht" (cit. n. 55), p. 76; C. H. D. Buys Ballot, *Verdeeling der warmte over de aarde* (Amsterdam, 1888).

80 *Verslagen en Mededeelingen der Koninklijke Akademie van Wetenschappen, Afdeeling Natuurkunde*, 1857, *7*:75–77, on p. 76. Emphasis added.

81 Boumans, *Science outside* (cit. n. 14), p. 73; Frans van Lunteren, "De oprichting van het Koninklijk Nederlands Meteorologisch Instituut, Humboldtiaanse wetenschap, internationale samenwerking en praktisch nut," *TGGNWT*, 1998, *21*:216 –243, on p. 231.

> For me it is impossible to suppress a feeling of distrust whenever I consider these immense series of observations, from which one hopes to attain knowledge of the laws and causes of the phenomena in our atmosphere. Nobody will assert that *these* fully meet the requirements of precision, and that no greater correctness is now achievable and necessary; but one should also note the relatively minor knowledge that is inferred from them, and the uncertainty to which this is still rightly subjected.[82]

In his reply to this criticism in 1848, Buys Ballot stressed that meteorology was "not yet advanced enough" to be practiced according to astronomical standards, but even simple observations, "less precise" than astronomical ones, "could still be useful." He reminded his readers that astronomy too was once a developing science and "had to confine itself to observations of a lesser degree of precision."[83] Thus, in 1848, he could only maintain that meteorology was a young science. However, later when his discovery of the wind rule was generally accepted as a law of nature, he was confident that his principle of deviations could advance meteorological investigations and render observations more accurate, someday perhaps even attaining astronomical standards. The publication of the *Sequel to the Suggestions* in 1873 was meant to find supporters for his method of deviations. He hoped to have the system accepted at the forthcoming congress.

The Vienna Congress of 1873

On 2 September 1873 the Vienna congress convened. The Austrian Minister of Education, Carl von Stremayer, who welcomed the

[82] Van der Willigen's quote is included in C. H. D. Buys Ballot, "Iets over de Meteorologische Waarnemingen aan het Observatorium te Utrecht," *Algemeene Konst- en Letterbode*, 1848:379–384, on p. 380; the translation is by Boumans, *Science outside* (cit. n. 14), p. 73.
[83] Buys Ballot, *Suggestions* (cit. n. 82), p. 381.

delegates to the congress on behalf of his government, declared "that the history of the exact sciences will mark the *First International Meteorological Congress* in Vienna as an important turning point in the development and importance of meteorology." These words show that the study of the weather was beginning to be classified as an exact science.[84]

The growing scientific status of meteorology was further strengthened in Vienna by a policy of exclusion of non-scientific meteorological researchers to the meeting. This was a clear break with the previous meeting in Leipzig. As Jelinek remarked in his opening speech, "it was … to be regretted that by the mode of the constitution of the Congress, which only admitted delegates of Governments, it [had] become impossible for many eminent meteorologists, who had been present at the Leipzig Conference, to take part in the labours of the Meteorological Congress."[85] But in fact, the decision to exclusively admit official delegates to the congress, almost all of whom were academically trained, came from the committee who organised the meeting. Jelinek himself was a member of this committee.

The Vienna congress attracted only slightly more than half the number of participants of the Leipzig conference. From a total of 32 participants, 13 had also participated in the Leipzig meeting. France was again not represented at the congress for the same reasons as the previous time. In general the congress did not differ much from the Leipzig meeting in content or execution. The original twenty-six questions as topics of discussion remained unaltered and only three new ones were added.

One of them came from Emile Plantamour, director of the Geneva observatory, who proposed a bold plan for establishing an international central meteorological institute that would unite all

[84] *Report of the Proceedings of the Meteorological Congress at Vienna, Protocols and Appendices, Translated from the official report* (London, 1874), pp. 5–6. It took until around the turn of the twentieth century for meteorology to be generally viewed as an exact science. Gabriele Gramelsberger, "Conceiving Meteorology as the Exact Science of the Atmosphere, Vilhelm Bjerknes's paper of 1904 as a Milestone," *Meteorologische Zeitschrift*, 2009, *18*:669–673.

[85] *Report of the Proceedings of the Meteorological Congress at Vienna* (cit. n. 84), p. 6.

meteorological departments into one overarching central organ. He hoped that by discussing this proposal first, many other questions would become superfluous and that this would shorten the meeting.[86] As was to be expected, his plan was not accepted. No one was prepared to hand over his autonomy to an overarching central institute. Not only was this point postponed until almost the end of the congress – when it was finally discussed, the assembly decided that "the moment had [not] quite arrived, nor was the matter ripe enough to lay before the Congress definite proposals for the immediate establishment of such an Institute."[87]

Instead the meeting elected a permanent committee of seven members as had been anticipated in Leipzig. The duties of the committee were defined as carrying out the decisions of the congress, organising future meetings, and informing the delegates of its actions and proceedings. Besides Bruhns, Jelinek, and Wild, who were nominated at the previous meeting, Scott, Mohn, and the physics professor at the university of Pavia, Giovanni Cantoni, were chosen as members. The delegates then chose Buys Ballot as president.[88]

The inauguration of the permanent committee was the only definite and substantial resolution that was decided by the congress. All other questions were discussed in an equally open and evasive way as at the Leipzig meeting. The question of uniform units of measure, for example, again produced a heated debate between Scott and some continental delegates. The matter was finally resolved by adopting the Leipzig resolution, "that the results of observations or the means should be published in the Metric scale, as well as in their original scales," allowing Scott, the only protester against metrication, the use of British standards.[89]

Buys Ballot's plan of uniform astronomical hours of observation resulted in a complete failure. The meeting decided that it was "not prepared to propose a definite combination of hours for the

[86] *Ibid.*, p. 9.
[87] *Ibid.*, p. 50.
[88] *Ibid.*, pp. 31–32.
[89] *Ibid.*, p. 21.

meteorological observations of all countries, since regard must be had for the customs of the country."[90] Uniform local hours were not considered feasible, let alone astronomical (synchronous) ones. As Jelinek explained, synchronous hours of observation could be very inconvenient to the observers, who were not remunerated for their voluntary services and who were also often occupied with other tasks.[91]

On the issue of calculating averages, there were no changes to the four divisions of daily, 5-daily, monthly and, yearly means as defined in Leipzig.[92] On a uniform manner of publication of meteorological observations, several proposals were made, but none of them received the majority of the votes. The congress was only prepared to agree to the final proposal that the permanent committee determine a best form for publication and recommend it to all directors for general adoption.[93] As for determining which barometer to use at the observing stations, the meeting decided to "postpone" the question, "inasmuch as it is desirable previously to obtain reports from all directors on the barometers employed in their systems, with reference to construction and price."[94]

The congress further showed the unwillingness of the delegates to give up their individual habits and customs of dealing with instruments and accept a standard protocol. For example, to the question of whether universally applicable rules could be laid down for the calibration of instruments and inspection of stations, the appointed subcommittee replied that "careful verification of all instruments … [and] inspection of stations … [were] necessary, and the latter should take place if possible yearly." For this purpose, Buchan had prepared very detailed instructions for comparing instruments, determining errors of observation, explaining how they were likely to happen, and giving guidelines as to how to minimise them. He presented the

[90] *Ibid.*, pp. 52–53.
[91] Carl Jelinek, "The Leipzig Conference," *Symons's Monthly Meteorological Magazine*, 1873, *89*:69–77, on p. 75.
[92] *Report of the Proceedings of the Meteorological Congress at Vienna* (cit. n. 84), pp. 23–24.
[93] *Ibid.*, p. 35.
[94] *Ibid.*, p. 20.

instructions to the delegates and they were printed as a supplement to the official congress report. They were so comprehensive that everyone could adopt them instantly. However, without providing any explanation, the subcommittee stated that it did "not think it possible to institute rules of general applicability on this question," and therefore only proposed that "the mode of verification of the instruments and of regular inspection [be] left to the decision of the Central Offices."[95]

Weather telegraphy was the last remaining issue to be settled. At Leipzig it had been decided that a subcommittee consisting of Buys Ballot, Scott, and Neumayer would furnish "a report on the practicability and utility of weather telegrams and of storm prognosis" to be discussed at Vienna.[96] As a basis for the discussion, the committee had drawn up a survey of questions and had distributed it to a great number of senior clerks and directors of meteorological services. The survey's outcome was discussed at the congress and a year later it was published as a separate report. The report, which includes the individual responses to the survey, is a very interesting testimony of opinions on weather forecasting and storm warnings.[97]

For two reasons the survey was especially important to Buys Ballot. First, it asked whether the respondents preferred the exchange of information about the actual state of the atmosphere or the conditions of approaching weather. It examined whether the directors applied Buys Ballot's wind law based on barometric differences in their storm warning services, and if so, whether they mentioned pressure gradients in their weather telegrams. Second, the survey examined the directors' individual opinions on Buys Ballot's system of deviations. It specifically asked the respondents in what form barometric gradients should be reported in weather telegrams:

[95] *Ibid.*, p. 61. For Buchan's report on the inspection of stations, see pages 93–95.
[96] *Ibid.*, pp. 63–64.
[97] *Report on Weather Telegraphy and Storm Warnings, Presented to the Meteorological Congress at Vienna, By a Committee Appointed at the Leipzig Conference. Published by the Authority of the Meteorological Committee* (London, 1874).

a. As "differences between the actual readings at the different stations."

b. As differences between readings reduced to "[a scale of 0 to] 30 inches [of mercury at a standard temperature], at sea level."

c. As differences between readings reduced to "the mean normal heights of the barometer at the stations" or, in other words, as barometric deviations.[98]

Much depended on the outcome of this question, for if the majority of the respondents agreed to the last option, the principle of deviations could be adopted by all meteorological services. The acceptance of the method of deviations instead of actual observations would be a major accomplishment for Buys Ballot, who had been recommending it to meteorological directors for almost a quarter of a century. However, as the subcommittee reported to the congress, the survey did not result in a clear outcome for one of the three options, though nearly everyone was in favour of issuing storm warnings and cautious weather forecasts based on the wind law, and saw benefits in reporting pressure gradients in weather telegrams. The committee reported that no one had opted for option *a*, and that the respondents' opinions were divided between *b* and *c*.[99] But, in fact, the report of the subcommittee was overly reticent about the general appraisal of Buys Ballot's system of deviations.

Examination of the individual replies, which came mostly from European, but also from North American, Indian and Russian stations, shows that there were quite a few objections to the logic behind recording deviations. Out of twenty-seven replies, six were in favour of reporting deviations. Among them were Wild and von Oettingen, who had supported Buys Ballot's system since the Leipzig conference.[100] As the latter put it, "[the system of deviations] recommends itself as the

[98] *Report on Weather Telegraphy and Storm Warnings* (cit. n. 97), p. 8.
[99] *Report of the Proceedings of the Meteorological Congress at Vienna* (cit. n. 84), p. 65.
[100] Buys Ballot, *A Sequel* (cit. n. 9), pp. 26, 39; *Report on Weather Telegraphy and Storm Warnings* (cit. n. 97), pp. 42–43, 56.

best, because the errors of the instruments are almost entirely eliminated."[101] A majority of fifteen respondents, however, preferred the exchange of actual readings of the barometer, in most cases preferably reduced to sea level, as they gave more accurate results. Three respondents did not see any advantage in giving gradients and another three did not make a choice between the options.[102]

As Buchan had explained in his *Handy Book*, it was theoretically possible that deviations from the mean were null at several places at the same time, while there are always absolute pressure differences at different latitudes. From looking at the deviations, it could be concluded that there were no disturbances, while differences between absolute readings indicated that strong winds were to be expected.[103] As he propounded his opinions again in his reply to the survey, this was "a fatal objection" since "the method [did] not represent the actual atmospheric disturbance.... There [was] another objection to the method..., viz., the difficulty of obtaining the requisite number of good comparable normal." Therefore, the system of deviations was "not to be recommended in any general system of weather telegraphy."[104] Buchan's influence on his fellow countrymen must have been great, for all those who preferred the exchange of actual readings came from Great Britain.

Richard Strachan, who replied in the capacity of second senior clerk at the meteorological office in London, took the opportunity to question whether Buys Ballot should be "accredited with the generalization of the law of storms to all winds," because he "arrived at this important result by an imperfect induction." As he explained, "normal heights of the barometer" have nothing to do with "the actual distribution of atmospheric pressure." He went further by posing: "had it not been that his [Buys Ballot's] stations were at short distances apart, and consequently that their barometric normals differed inappreciably, he would have arrived at a false conclusion." In other

[101] *Report on Weather Telegraphy and Storm Warnings* (cit. n. 97), 42.
[102] *Ibid.*, pp. 19–60.
[103] Buchan, *Handy Book* (cit. n. 2), p. 240
[104] *Report on Weather Telegraphy and Storm Warnings* (cit. n. 97), p. 50.

words, Buys Ballot had been lucky to find a wind rule, because the Netherlands was a small country and, therefore, there were only small variations between the daily average barometric values observed at the stations. These small differences allowed the differences between deviations to approximate true values. He would not have made his discovery, Strachan thought, if his research area had been larger. Finally, Strachan claimed that Francis Galton, who "used the proper method of isobars, and enunciated in explicit terms the law of wind in relation to statical pressure … was the first to prove this fundamental law upon correct principles."[105]

Another respondent to the survey was none other than Dove, who replied on behalf of a German committee. Apparently, a meeting had been held in Berlin under his presidency to arrive at a widely supported recommendation for a system of storm signals for the coast of Germany. The meeting was held from 26 April until 9 May 1873, just a few months before the Vienna congress convened. In the report that Dove sent in, he concluded that "the establishment of a system of Meteorological Telegraphy throughout the entire German Empire [had] become a necessity" and recommended that such a service "be connected as closely as possible to the systems of adjacent countries."[106] This remark was the closest that Dove came to referring to other systems, let alone Buys Ballot's storm warning service in the Netherlands. In the past, he had ignored the Dutch wind rule. This passage reads as if he was determined not to say a word about it. On the question of pressure gradients, the hallmark of Buys Ballot's wind law, he responded, "the Commission is of the opinion that the results of a system so organized can and should be utilized for the communication of weather conditions in the sense of storm warnings (for the entire German Empire), in so far as they are warranted by the further development of the scientific knowledge of atmospheric disturbances."[107] This was to be the last occasion when Dove could have appraised Buys Ballot's scientific discovery. He decided to

[105] *Ibid.*, p. 52.
[106] *Ibid.*, p. 27.
[107] *Ibid.*, p. 27.

withhold his opinion. In the years after the meeting Dove's health declined and he died in April 1879.

A last relevant reply was by the director of the Norwegian meteorological institute and professor in meteorology, Henrik Mohn, who together with a professor of applied mathematics, Cato Guldberg, won acclaim for their mathematical formalization of Buys Ballot's wind law in the mid 1870s.[108] Mohn's status was probably the reason behind his election as member of the permanent committee. His letter to the subcommittee rather resembled a written lecture than a response to a survey. He began by asserting that the "first condition which determines the direction and force of the wind, according to the most recent meteorological inquiries, is the distribution of pressure … at one and the same level."[109]

He explained how he used the latest meteorological knowledge to "form a decision on the probable change of pressure in the course of [a] day, and subsequently on the probable changes of wind and weather." On a more detailed level, he described that he kept a record of the absolute readings of the barometer height "in millimeters reduced to zero [degree Celsius] and sea level" at fourteen stations in and around Norway. He prepared charts on which he drew isobars based on these observations. By studying "the change of the barometer from [an] afternoon to the morning of the [next] day" and changes of other meteorological elements, he made an estimation of the probable wind and weather in the next 24 hours. When there was "fear of a storm, a storm-warning telegram [was] sent to all the telegraph stations which [were] threatened." In the warnings he drew "attention to the fact that they [were] not prophecies, but announcements [of probable storms]."[110]

In short, the Norwegian storm warning service was based on the same principles as Buys Ballot's system in the Netherlands, but with

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[108] Eric L. Mills, "Mathematics in Neptune's Garden. Making the Physics of the Sea Quantitative, 1876–1900," in Helen M. Rozwadowski and David K. van Keuren, *The Machine in Neptune's Garden, Historical Perspectives on Technology and the Marine Environment* (Sagamore Beach, MA, 2004), 39–63, on pp. 48–49.
[109] *Report on Weather Telegraphy and Storm Warnings* (cit. n. 97), p. 36.
[110] *Ibid.*, p. 39.

two exceptions. First, he made explicit that "the gradient, according to my [Mohn's] idea, gives the actual wind, and gives no warning for a future wind."[111] He used the simultaneous and relative change of the barometer at his stations in the course of a day, to estimate the force and direction of approaching winds. Second, for his calculations he used absolute readings instead of deviations from the mean.

In fact, Mohn questioned the use of calculating daily and annual meteorological periods for weather forecasts. He was one of the first to break with the traditional study of meteorological averages. As he explained, average weather conditions "only seldom appear in nature."[112] The atmosphere is in constant change, and the changes in meteorological conditions manifest themselves in various ways in the course of 24 hours. Other than most meteorologists of his time, Mohn dismissed the global view in favour of local factors that had a greater influence on weather conditions. As he explained,

> The difference in pressure at the sea level, … is an accelerating force which [sets] the air in [motion]; but the motion of the air, as a rule, does not follow the direction of the gradient, for there are forces which cause it to diverge, viz., the rotation and spherical form of the earth, … together with the centrifugal force of the air….
>
> The motion of the air is constantly meeting with obstacles which oppose an acceleration of motion…. The obstacles are of various kinds, and so are their actions. Hence for one and the same gradient we have a velocity of wind which is greater in the higher strata than in the lower, greater on sea than on land, on plains than on mountains. *Ceteris paribus* the velocity of the wind seems in some way to be proportional to the magnitude of the gradient.[113]

[111] *Ibid.*, p. 42.
[112] *Ibid.*, p. 36.
[113] *Ibid.*, p. 37.

However, as he claimed, "the exact rule for the proportion of the wind to the gradient" was not known. Neither were the rules of the variation of pressure. Therefore, he claimed, "our next task is to determine the direction and magnitude of this gradient, with its changes at various places, to determine the law of the variation of pressure; … at present we can only say that we are standing at the threshold of its discovery."[114]

Buys Ballot, who probably did not intend to send a reply to a survey that he had helped to draw up in the first place, felt compelled to react to Mohn's report and he composed a letter. The letter is included as an appendix to the report. He admitted that winds did not behave uniformly in cases of equal pressure differences. Easterly winds, for instance, were not as strong as westerly winds, when there was respectively a positive or a negative pressure difference of 4 mm between northern and southern stations in the Netherlands. However, he strongly protested against the use of actual barometer differences. As he claimed,

> I have fully proved in my 'Suggestions' that it is inadmissible with heights of any magnitude to reduce [barometer readings] to sea level, and I should have illustrated this by example if I had not thought it well to omit such a step out of regard for some highly valued physicists and fellow workers. There is also a certain difference of opinion between Professor Mohn and myself, but this is in the second place. Perhaps I should confess myself entirely convinced; but under any circumstances we should not [under no circumstances should we] reduce [barometer readings] to sea level. I know myself the normal levels sufficiently accurately for every place in Europe, so that we can trust the deviations.[115]

In his *Suggestions* he had indeed explained why he dismissed the practice of reducing barometer heights to sea level, but more than that,

[114] *Ibid.*, p. 37.
[115] *Ibid.*, p. 58.

he explained why deviations were a better means to calculate accurate pressure gradients, because they eliminated instrument errors and corrected for location and height differences. In addition, he rejected Mohn's interpretation of gradients in favour of his own, "gradients give a much longer indication of the wind, at times as much as 24 or 48 hours in advance."[116]

At the congress, the various opinions on the matter of gradients were discussed and it was agreed that "the barometer readings [should be reduced] to the Mean Sea-Level."[117] Buys Ballot had to accept that his system of deviations had failed to win general backing. Bruhns tried to sympathise with him by proposing the following amendment to the resolution: "The Congress agrees to the proposal of the sub-committee [i.e. reduction to sea level], although it is *not perfectly correct theoretically*. It is hoped, however, by a reduction to the level of the sea at the time, to obtain a greater uniformity among the different systems." He implied that although deviations were more accurate, uniformity among the systems was considered preferable. However, Mohn, Scott, Buchan, and Neumayer immediately opposed the proposal, forcing Bruhns to withdraw it.[118]

And so it was decided that barometer readings were to be reduced to sea level. Buys Ballot's campaign for registering deviations had proved unsuccessful. Even his close associates abandoned the idea. In July 1874, Jelinek, his faithful supporter, announced that the Austrian observatory had since the beginning of the year "begun to introduce the reduction of Barometer readings to sea level in the Daily Weather Bulletin instead of the barometrical deviations."[119] Wild, at the observatory of St. Petersburg, found the arguments in the weather report so compelling that he also became convinced to reduce

[116] *Ibid.*, p. 58.
[117] *Report of the Proceedings of the Meteorological Congress at Vienna* (cit. n. 84), p. 65.
[118] *Ibid.*, p. 37. Emphasis added.
[119] *Report of the Permanent Committee of the International Meteorological Congress at Vienna. For the Year 1874. Meetings held at Vienna and at Utrecht, 1873, 1874. Published by Authority of the Meteorological Committee* (London, 1875), p. 30.

barometric readings to sea level instead of using deviations from the means.[120]

Turning back to the Vienna congress, the most concrete outcome of the meeting was the election of a permanent committee. Its seven newly elected members met on the day the congress closed to briefly discuss some organisational matters. The meeting took barely an afternoon and ended with setting a date for a next meeting of the permanent committee to be held in Utrecht in September 1874. Buys Ballot's position as president was thereby established.[121] In the following years, he remained active in organising, presiding and participating in international meteorological meetings at different centres in Europe.

The permanent committee met several times between 1874 and 1878, when it called for a second international meteorological congress to convene in Rome in 1879. At the Rome congress a resolution was adopted to form an international meteorological committee of nine members to replace the permanent committee. Buys Ballot was again chosen as president, but he could not be present at the congress himself because of illness and the passing away of his wife, which forced him to withdraw from his international commitments. While not being able to act as the president of the committee, he was still elected as one of the members. In that capacity he attended several subsequent meetings of the committee under the presidency of his close associate Wild, until old age prevented him from travelling.[122]

The Leipzig and Vienna meetings illustrate the slow progress of international cooperation in meteorology. But although progress was slow, the meteorological committee did over the years eventually reach agreement on issues of international importance such as the classification of different weather phenomena, a set of international meteorological codes, the expansion of a worldwide network of

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[120] H. Wild, "Beitrag zur Frage der Reduction der Barometerstände auf das Meeresniveau," *Zeitschrift der Österreichischen Gesellschaft für Meteorologie*, 1874, *9* (8):113–118, on pp. 113–114.

[121] *Report of the Permanent Committee* (cit. n. 119), p. 1.

[122] Van Everdingen, *Buys Ballot* (cit. n. 16), pp. 101, 107; *Report of the Proceedings of the Second International Meteorological Congress at Rome, 1879. Published by Authority of the Meteorological Council* (London, 1879), p. 1.

observation, and the establishment of an international meteorological institution. In 1950 the international meteorological committee was succeeded by the still active world meteorological organisation (WMO), the foundations of which, as this chapter has shown, were laid at the Vienna congress in 1873.[123]

Conclusion

Looking back at the Leipzig and Vienna meetings, one cannot but feel rather sorry for the man who left his mark on the field of meteorology. Buys Ballot entered the international meetings with high expectations. In fact, one could say that he had nothing to complain about afterwards. During the Vienna congress, he was elected president of the permanent committee, a most honourable position for a man of science who had committed his entire career to meteorology.

However, his presidency of the permanent committee was hardly more than a ceremonial position without real influence. The major thread that ran through the discussions at the international meetings was how to obtain exactness of meteorological observations that were carried out at different stations. Buys Ballot offered two direct solutions to the problem of exactitude: synchronous measurements and the principle of deviations. On both these points he was disappointed badly. While the first proposal was impractical to carry out, the meteorological assembly at Vienna questioned the validity of the second proposal. Buys Ballot failed to obtain general backing for his favourite programmes.

With a perseverance that marked his character, he kept promoting the principle of deviations even after many of his associates had abandoned the idea. In his obituary of Buys Ballot, van der Stok explained why he could not find it in his heart to openly disagree with him on the importance of deviations. He recalled that Buys Ballot

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[123] E. I. Sarukhanian and J. M. Walker, *The International Meteorological Organization (IMO) 1879–1950*,
published by the World Meteorological Organization (2004), pp. 1–2. Retrieved 2016-09-22.

wrote to him in 1887: ‘if you and others ask me, then I shall quit publishing deviations, but I cannot accept that the study [of deviations] is supposed not be beneficial.’ Van der Stok then turned directly to the reader and “confessed that he did not have the courage to advise against the publication [of deviations] as he was well aware that it would hurt the old man to dismiss his favourite idea.”[124]

Van Everdingen was less sympathetic in his judgement of the principle of deviations. He claimed that Buys Ballot “should have realised that this method would lead to quite false results, because he implicitly assumed that without deviations, there would be no wind blowing at all. And that is wrong ….” According to van Everdingen, the principle of deviations produced a lot of unnecessary errors in the yearbooks of the Dutch meteorological institute, which took considerable trouble to correct years later.[125]

As the responses to the questionnaire on weather telegraphy showed, his younger peers like Strachan and Buchan questioned Buys Ballot’s methods of predicting winds. They were already being viewed as out of date or even plain wrong. It was Mohn who offered a mathematical formula for his wind law and he questioned Buys Ballot’s assumptions of wind behaviour. It is ironical that Buys Ballot’s principle of deviations, which he formulated to make meteorology more exact, was rejected by a younger generation of meteorologists just at a time when meteorology began to be seen as an exact science, on an equal footing with physics.

Buys Ballot acknowledged that he was past his prime and that his knowledge was being outpaced by the state-of-the art research in the exact sciences. When he retired from his professorship as he turned seventy in 1888, he told van der Stok: ‘it was about time that I was replaced, especially for the experimental part, … at the same time I am happy that I don’t have to know everything about physics anymore, as should be expected from a professor.’[126] Indeed, van der Stok agreed with him. In his obituary he portrayed Buys Ballot as “more of a

[124] Van der Stok, “Levensbericht” (cit. n. 55), p. 78.
[125] Van Everdingen, *Buys Ballot* (cit. n. 16), pp. 86–87.
[126] *Ibid.*, p. 107.

philosopher than a physicist."[127] He mocked Buys Ballot's fetish for precision and his attempts to find connections between astronomical phenomena and periodical weather patterns by observing that "for a philosophical and enthusiastic mind, like Buys Ballot's, it should be pleasant to think about the possibility of determining astronomical features with astronomical precision but from very indirect non-astronomical observations."[128]

As this chapter has shown, many of the contours of the field of meteorology that took shape from the mid 19th century onwards were borrowed from the astronomical tradition of Gauss and Bessel. Astronomical observations served as an example for other exact field observations that were carried out in the period. Buys Ballot's call to meteorologists abroad to carry out synchronous meteorological measurements was clearly inspired by Gauss's 1830s geomagnetic project. His efforts to collect and tabulate meteorological observations, his calculations of averages, and his insistence on keeping records of deviations, were a direct continuance of Dove's research programme of the 1840s. He borrowed the latter point, the study of deviations, from Dove as a means to neutralise measurement errors. With his investigations he hoped to discover the rules of atmospheric disturbances just as Dove had defined a mathematical formula from direct observations, and had thus given a lawful expression of the relationship between wind direction and average barometric pressure in a periodic curve.

At the international meetings of Leipzig and Vienna, Buys Ballot campaigned to find support for his double programme of synchronous observations and the study of deviations. However, by that time his methods were outmoded. While determination of measurement errors was once a standard practice to obtain reliable results, statistical data analysis was now being replaced by exact experiments and improved instrumentation as ways to produce precision measurements in the exact sciences. As Olesko argues, achieving accuracy by means of mathematical techniques such as the method of least squares was by

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[127] Van der Stok, "Levensbericht" (cit. n. 55), p. 64.
[128] *Ibid.*, p. 77.

the end of the century being viewed as incredibly old-fashioned.[129] The younger generation of meteorologists, most of whom were trained in physics and who kept a close track of new developments, saw Buys Ballot more as a member of the old school of physical sciences than as a disciplinary role model.

The rising star in meteorology at Vienna, Mohn, was actually also trained in physics. With his investigations he broke with the traditional mid nineteenth-century research of meteorological averages as practiced by Buys Ballot and his contemporaries. Mohn promoted the study of the local dynamics of the weather paying special attention to the specific geographical shape of his research area. He distanced himself from the study of averages and promoted the practice of keeping records of the actual state of the weather. Mohn's Norwegian background leads one to speculate on his connection with the Bergen School of Meteorology, known for its great successes in predicting the weather in the early twentieth century. Knowing that he was a former student of Carl Anton Bjerknes, Vilhelm Bjerknes's father, makes the connection more than just a coincidence.[130] How Mohn's research specifically related to the Bergen School, is indeed an interesting topic and a logical follow-up to the current study of Buys Ballot's role in the emergence of meteorology as a field. As such it marks a natural end to this story.

[129] Olesko, "The Meaning" (cit. n. 10), p. 127.
[130] Mills, "Mathematics" (cit. n. 108), p. 58.