CHAPTER 2

Historical Background of Big Data in Astro and Geo Context

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2.1 HISTORY OF BIG DATA AND ASTRONOMY

2.1.1 Big Data Before Printing and the Computer Age

Astronomy began in prehistoric times by the observation of the apparent motions of the sun, moon, stars, and planets in the Earth's sky. Big Data was not easy to define before the computer age. According to Zhang and Zhao (2015), Big Data is defined by ten characteristics, each beginning with a V: volume, variety, velocity, veracity, validity, value, variability, venue, vocabulary, and vagueness. This list comes from previous studies of Big Data in other domains, such as marketing and quality control. They consider that the four terms volume, variety, velocity, and value apply to astronomy.

Velocity did not exist before the computer age, as the acquisition of observations and their recording and publishing were entirely manual until the printing and the electric telegraph.

However, volume was already present in the early descriptions of the night sky: "as the stars of heaven" is a biblical equivalent of infinite, meaning "which cannot be counted."

Variety corresponds to the different observed objects; the ancients had only optical observations, but the conditions of these observations differed between observer sites. Their eye sight was also probably better trained. An ethnological study (Griaule and Dieterlen, 1950) revealed that the cosmogony of the Dogon people in present-day Mali indicated two companions of Sirius, four satellites of Jupiter, a ring around Jupiter, and knowledge of Venus phases. This kind of oral tradition will probably be difficult to verify in other ethnic groups, as more and more literacy is spreading over the entire world and oral transmission is disappearing.

Value corresponds to the progress in general knowledge associated with the observations and to their practical application in navigation or the calendar. For example, the heliacal rise of Sirius had an extreme importance for the Egyptian calendar related to its coincidence with the flooding of the Nile (Nickiforov and Petrova, 2012). In this respect, the corpus of Egyptian observations led to the Egyptian calendar, which was adopted by Julius Caesar when he became the ruler of Egypt and which, with a minor revision in the late 16th century, became our current calendar.

Big Data cannot exist without data preservation. The first steps were the compilation of star catalogues, which began in Hellenistic times when the infrastructure of the Alexandria museum and library were available (Thurmond, 2003). Star catalogues not only give the name of stars but also their position. Hipparcos combined previous Babylonian observations, Greek geometrical knowledge, and his own observations in Rhodes, and he was the first to correct his data for precession, but as his manuscripts are lost, he is essentially known by his distant successor, Claudius Ptolemy from Alexandria, whose catalogue, the Almagest, has been preserved (Grasshoff, 1990). The number of stars of the original manuscript is not absolutely clear; Thurmond indicates a number of 1028. See Fig. 2.1.

The precision of the observations was sometime unequal as different observation sites had been used and refraction was not corrected for. The Almagest became the main reference until the end of the Middle Ages, when several versions made their way to the Arab world and Arab astronomers both added new observations and adapted the book to their own epochs. Finally, the Almagest came back to the Western world by the Latin translation from an Arabic version of Gerard of Cremona in 1175. None of the Arabic versions increased the number of stars; some, due to the observation latitude, even mention less stars than Ptolemy. The first new catalogue to appear was endeavored by Ulugh Beg in Samarkand in the 15th century using only original observations from an especially designed large observatory, correcting the errors made by Ptolemy in converting the Hipparcos observations. This time, only 996 stars were observed. This catalogue was fully translated in Europe only in 1665, but it was known in the Arab, Persian, and Ottoman worlds.

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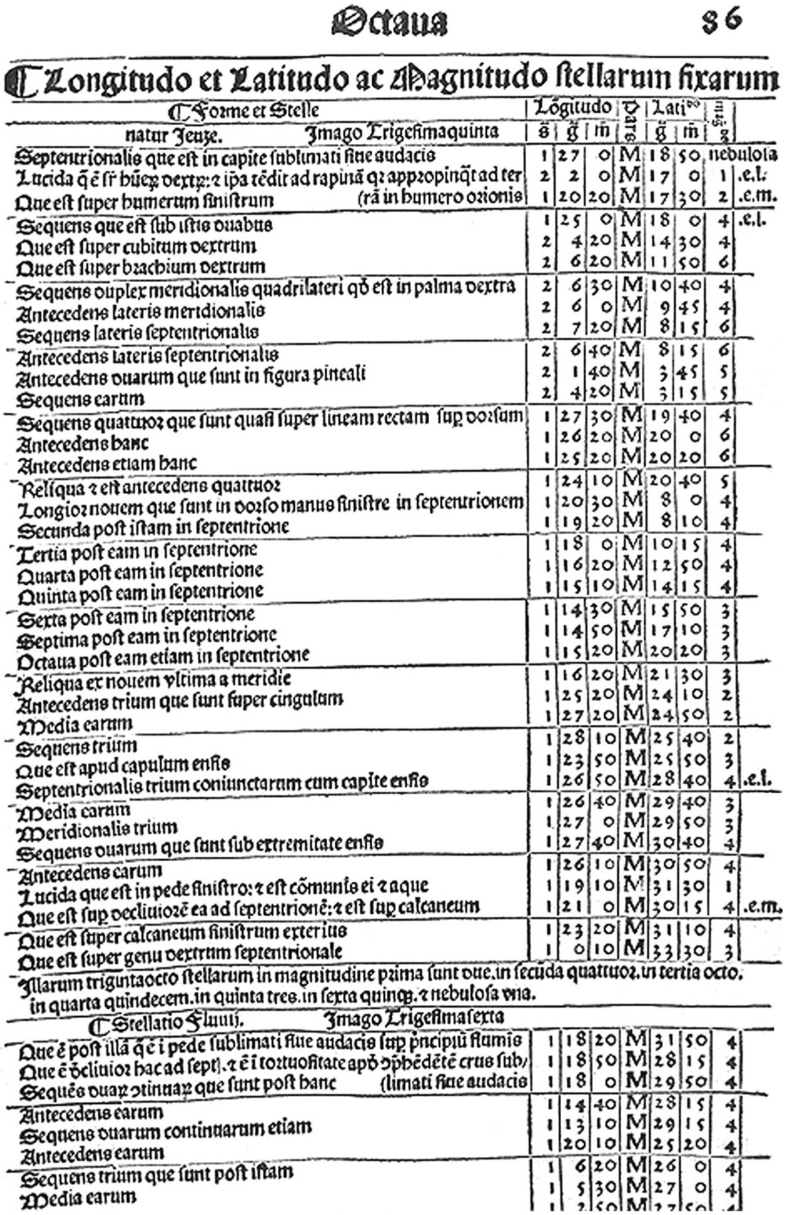
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Longitudo et Latitudo ac Magnitudo stellarum fixarum

Forme et Stelle — natur Ienze. Imago Trigesimaquinta	Longitudo s	g	m	Pars	Latitudo g	m	Magnitudo	
Septentrionalis que est in capite sublimati flue audacis	1	27	0	M	18	50	nebulosa	
Lucida que est super humerum dextrum: et ipsa tendit ad rapinam que appropinquat ad ter	2	2	0	M	17	0	1	.e.l.
Que est super humerum sinistrum (ram in humero orionis)	1	20	20	M	17	30	2	.e.m.
Sequens que est sub istis duabus	1	25	0	M	18	0	4	.e.l.
Que est super cubitum dextrum	2	4	20	M	14	30	4	
Que est super brachium dextrum	2	6	20	M	11	50	6	
Sequens duplex meridionalis quadrilateri quod est in palma dextra	2	6	30	M	10	40	4	
Antecedens lateris meridionalis	2	6	0	M	9	45	4	
Sequens lateris septentrionalis	2	7	20	M	8	15	6	
Antecedens lateris septentrionalis	2	6	40	M	8	15	6	
Antecedens duarum que sunt in figura pineali	2	1	40	M	3	45	5	
Sequens earum	2	4	20	M	3	15	5	
Sequens quattuor que sunt quasi super lineam rectam sup dorsum	1	27	30	M	19	40	4	
Antecedens hanc	1	26	20	M	20	0	6	
Antecedens etiam hanc	1	25	20	M	20	20	6	
Reliqua et est antecedens quattuor	1	24	10	M	20	40	5	
Longior novem que sunt in dorso manus sinistre in septentrionem	1	20	30	M	8	0	4	
Secunda post istam in septentrione	1	19	20	M	8	10	4	
Tertia post eam in septentrione	1	18	0	M	10	15	4	
Quarta post eam in septentrione	1	16	20	M	12	50	4	
Quinta post eam in septentrione	1	15	10	M	14	15	4	
Sexta post eam in septentrione	1	14	30	M	15	50	3	
Septima post eam in septentrione	1	14	50	M	17	10	3	
Octava post eam etiam in septentrione	1	15	20	M	20	20	3	
Reliqua ex novem ultima a meridie	1	16	20	M	21	30	3	
Antecedens trium que sunt super cingulum	1	25	20	M	24	10	2	
Media earum	1	27	20	M	24	50	2	
Sequens trium	1	28	10	M	25	40	2	
Que est apud capulum ensis	1	23	50	M	25	50	3	
Septentrionalis trium coniunctarum cum capite ensis	1	26	50	M	28	40	4	.e.l.
Media earum	1	26	40	M	29	40	3	
Meridionalis trium	1	27	0	M	29	50	3	
Sequens duarum que sunt sub extremitate ensis	1	27	40	M	30	40	4	
Antecedens earum	1	26	10	M	30	50	4	
Lucida que est in pede sinistro: et est communis ei et aque	1	19	10	M	31	30	1	
Que est sup decliviorem ea ad septentrionem: et est sup calcaneum	1	21	0	M	30	15	4	.e.m.
Que est super calcaneum sinistrum exterius	1	23	20	M	31	10	4	
Que est super genu dextrum septentrionale	1	0	10	M	33	30	3	

Illarum trigintaocto stellarum in magnitudine prima sunt due. in secunda quattuor. in tertia octo. in quarta quindecem. in quinta tres. in sexta quinque. et nebulosa una.

Stellatio Fluvij. Imago Trigesimasexta

Stellatio Fluvij	Longitudo s	g	m	Pars	Latitudo g	m	Magnitudo
Que est post illam que est in pede sublimati flue audacis sup principium fluminis	1	18	20	M	31	50	4
Que est declivior hac ad sept. et est in tortuositate apud comprehendentem crus sub/	1	18	50	M	28	15	4
Sequens duarum continuarum que sunt post hanc (limati flue audacis)	1	18	0	M	29	50	4
Antecedens earum	1	14	40	M	28	15	4
Sequens duarum continuarum etiam	1	13	10	M	29	15	4
Antecedens earum	1	20	10	M	25	20	4
Sequens trium que sunt post istam	1	6	20	M	26	0	4
Media earum	1	5	30	M	27	0	4

FIG. 2.1 Almagest zodiac in the first complete printing by Petri Liechtenstein (1515), United States Library of Congress. Printing had two advantages: the multiplication of copies and thus a better dissemination, and protection against copyist's errors or "improvements."

2.1.2 The Printing and Technological Renaissance Revolution

The 16th century was marked by three important evolutions: the generalization of open sea navigation using astronomical positioning techniques, the appearance of accurate mechanical clocks, and the development of astrology. All these necessitated better star catalogues and planetary ephemerides. At the same time, the printing technology allowed the diffusion of the astronomical writings and was followed by a real explosion of the number of publications (Houzeau and Lancaster, 1887). Printing secured two important elements of Big Data: preservation of controlled copies and availability to a larger number of users.

Astronavigation was already used in the 15th century by the Portuguese, Arab, and Chinese navigators, but proved to be very risky during the first intercontinental explorations. It is in this context that the Ottoman sultan Murad III ordered the construction of a large observatory in Constantinople superior to the Ulugh Beg observatory and equipped with mechanical clocks. The chief astronomer, Taqi ad-Din, wanted to correct the previous catalogues and ephemerides to promote improvement in cartography (Ayduz, 2004). He improved and designed new instruments much superior to previous versions. Unfortunately, the observatory was destroyed in 1570 due to a religious decree condemning astrology.

Almost simultaneously, Tycho Brahe equipped a huge observatory in Denmark with instruments and not only used up to 100 assistants, but also spent for 30 years about 1% of the total budget of Denmark (Couper et al., 2007), Tycho Brahe was the first to take refraction into account and to analyze observational errors. His huge accomplishments were transferred to Prague where he became the astronomer of emperor Rodolph II and was assisted by Johannes Kepler, who succeeded him. Kepler demonstrated the existence of the heliocentric system and determined the parameters of the planetary elliptical orbits using Tycho's data. The quantity of data measured and reduced by Tycho Brahe and their accuracy were an order of magnitude greater than what existed before, representing maybe the first instance of Big Data improving science.

Astrology was the main application of this scientific project and the tables produced by Kepler. The Rudolphine Tables are still used by present-day astrologers, who usually do not have the means to adapt the epoch. Astrology at the time was the equivalent of present-day business intelligence and was commonly used for any kind of forecasts. Galileo taught medical students the art of establishing the horoscopes of their patients. Galileo was in this respect accused in a first inquisition trial of fatalism, which is the catholic sin of believing that the future can be certainly known to human intelligence (Westman, 2011). At the same time, Lloyd's of London were determining marine insurance fees by the expected technique of inspecting the ships and crew records, but the last judgment was left to astrologers (Thomas, 2003). Astrology cannot be considered a precursor of Big Data and their role in business intelligence, as large-scale statistical treatments of economic data were first given by Adam Smith (1778) at the end of the 18th century. Astrologers would rely on a feeling based on their knowledge which they could not quantify for everything outside their analysis of the sky. Astrology became suspected of being linked to superstition during the English Reformation, but luckily, astronomy became a respected science in Great Britain. For example, the founder of the London stock exchange, Thomas Gresham, established Gresham College in the late 16th century for the education of the young bankers and traders with the following professorships: astronomy, divinity, geometry, law, music, physics, and rhetoric. "The astronomy reader is to read in his solemn lectures, first the principles of the sphere, and the theory of the planets, and the use of the astrolabe and the staff, and other common instruments for the capacity of mariners." This program did not make any mention of astrology and its use as a predictive tool in commodity trading.

Robert Hooke, who was professor at Gresham college, insisted on the use of telescopic observations in order to increase the number of stars and their positional accuracy, but this important progress was only initiated by John Flamsteed, the first Astronomer Royal who exceeded the precision of Tycho Brahe's observations and published a catalogue of 2866 stars in 1712 (Thurmond, 2003). At that time, a marine chronometer accurate by one minute in six hours existed and an able seaman was for the first time able to determine an accurate position by using the sextant without any other information. Better marine chronometers were progressively developed (Landes, 1983), but due to their high price, their generalization had to wait until the 19th century. Flamsteed got a commission to build the Greenwich observatory in close connection with the British Admiralty; the accurate chronometers designed by John Harrison for this observatory were essential to the exploration of the Southern hemisphere oceans by Captain Cook and his followers.

Later, in the 18th and 19th century saw the astronomical observations being extended to the Southern hemisphere. At the end of the 19th century, the photographic technique allowed to win again an order of magnitude in the number of stars. At the beginning of the 20th century, about 500,000 stars had been identified and several catalogues were under development. The last catalogue before the space age was the Smithsonian Astrophysical Observatory catalogue in 1965, with 258,997 stars listed with 15 description elements for each. The SAO catalogue used electronic data treatment since the middle of the 1950s and is the first to fully meet the definition of Big Data given in the first paragraph.

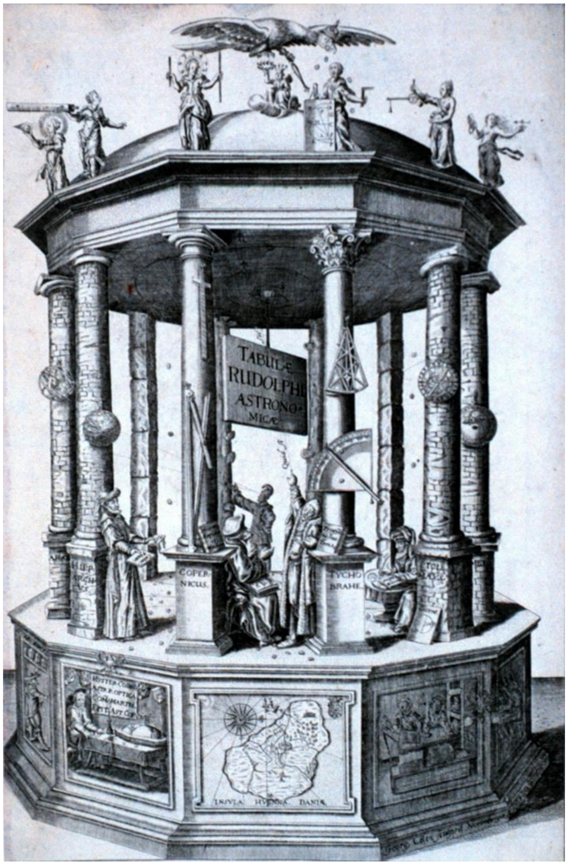


FIG. 2.2 Frontispiece of the Rudolphine Tables: Tabulae Rudolphinae, quibus Astronomicae scientiae, temporum longinquitate collapsae Restauratio continetur by Johannes Kepler (1571–1630) (Jonas Saur, Ulm, 1627).

It is now succeeded by the new efforts based on space age techniques and the massive use of large databases which constitute the basis of the BigSkyEarth COST action. See Fig. 2.2.

2.2 BIG DATA AND METEOROLOGY: A LONG HISTORY

2.2.1 Early Meteorology

The study and comparison of large amounts of observations constituted the early base of meteorology. The repetition of phenomena proved very early to be less regular than astronomical events, and even extreme events were the unpredictable action of the gods. The Babylonians and Egyptians compiled a lot of observations without relating them. A big step forward was the classifications and typologies assembled by Aristotle and the structuring of these early sources. Aristotle was also the successor of the Greek natural philosophers who attempted to relate the observations to their causes so that they could explain them and even attempt forecasts. Aristotle was the first to describe the hydrologic cycle. His knowledge of prevailing winds as a function of season proved to be essential to the conquest of Greece by the Macedonian army, the Greek islands being unable to send troops to their allies in the continental cities in time due to contrary winds. The meteorology of Aristotle covered a wider context than now because it included everything in the terrestrial sphere up to the orbit of the moon and thus would have included geology and what is now called space weather (Frisinger, 1972).

Unfortunately, Aristotle's efforts were not continued for long. His successor Theophrastus compiled signs which in combination could lead to a weather forecast. These progresses did not prevent most of the population to attribute weather to divine intervention and when Christianity and Islam took over, the pagan gods were replaced by demons. No systematic records of weather were kept, and present climate historians have to resort to agricultural records or indications in chronicles. During the Renaissance, the revival of Hippocratic medicine led physicians to consider the relation between the environment and health and record meteorological data again; similarly the logbooks of the ships at sea became more systematic, leading in the 18th century to the first large set of meteorological data which began to follow a standardization process, as exemplified by the Societas Meteorologica Palatina (Meteorological Society of Mannheim) (Kington, 1974) which started in 1780, and established a network of 39 weather observation stations; 14 in Germany, and the rest in other countries, including four in the United States, all equipped with comparable and calibrated instruments: barometers, thermometers, hygrometers, and some with a wind vane. During the 19th century, more meteorological observatories were established in Europe, North America, and in the British Empire. The progress of telegraphic communications led to consider the establishment of a synoptic database of identical meteorological parameters measured at different observatories.

2.2.2 Birth of International Synoptic Meteorology

The breakthrough occurred with Leverrier in 1854. Leverrier was a French astronomer who reached celebrity by predicting the position of Neptune from perturbations of the Uranus orbit. Gelle at the Berlin observatory was then able to observe the planet at the predicted position. Following a disastrous storm in the Black Sea during the Anglo-French siege of Sebastopol, the French government commissioned Leverrier to determine if with an extensive network of stations, the storm could have been predicted. After analysis, he determined that the storm had originated in the Atlantic several days before the disaster and that a synoptic network would have allowed to follow it and to make a raw forecast of its arrival in the Black Sea (Lequeux, 2013). Unfortunately, Leverrier could never assemble the legions of laborers necessary to study the long-term physical causes of weather and climate. His efforts were however the first steps to the creation of an international synoptic network in parallel to the geomagnetic network already developed by Gauss, Sabine, and Quetelet (Kamide and Chian, 2007). The extension of the geophysical network to meteorology was rapid due to the establishment of meteorological services in most observatories and the development of the electric telegraph. These founding fathers made an unpreceded effort to internationalize the effort, and most notably, the Dutch meteorologist Buys-Ballot, founder of the Royal Dutch Meteorological Institute, published the empirically discovered relation between cyclones, anticyclones, and wind direction, introducing fluid physics to meteorology and the basis of future forecasting models (WMO, 1973).

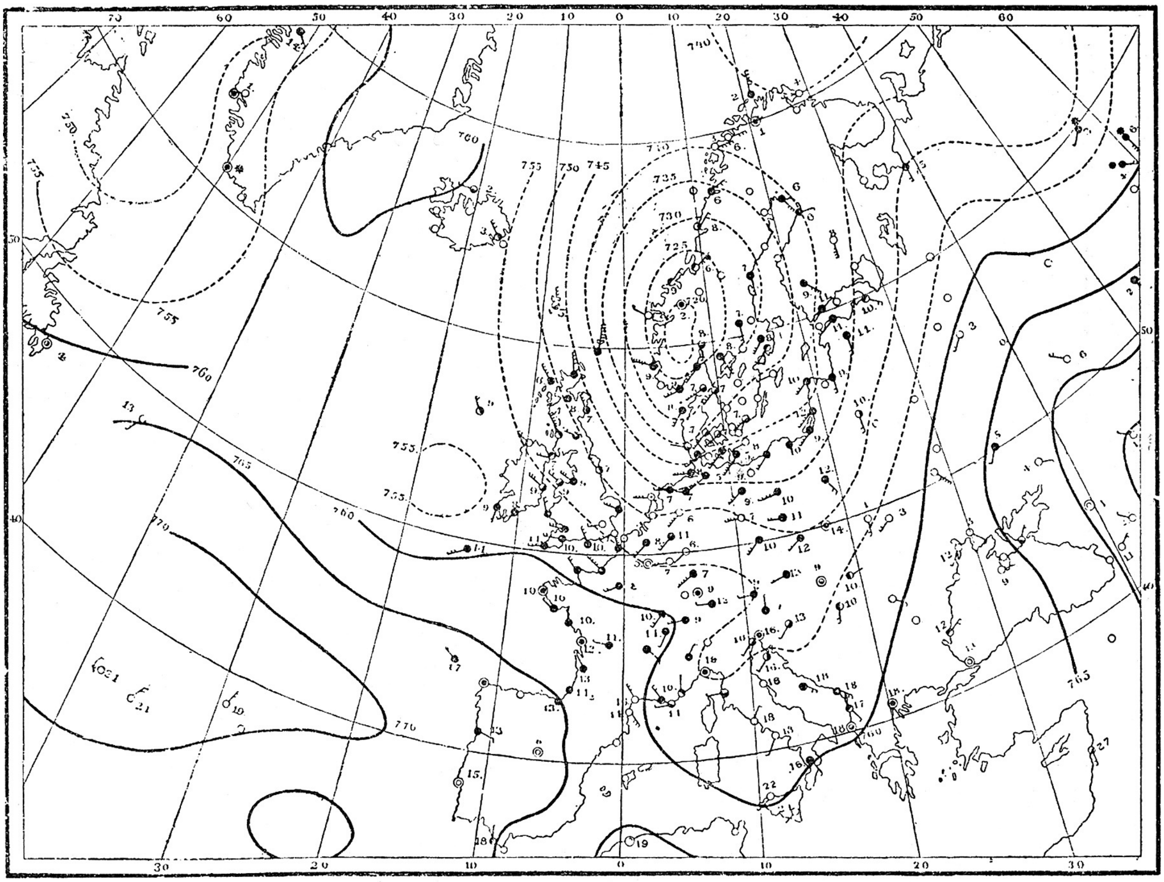
These early networks hardly fit the definition of Big Data: the telegraphic systems of the different countries were not standard, the archiving of the data was not uniform, and a lot of parameters were station- or operator-dependant. The exchange of processed data as hourly averages was not evident. However, around 1865, the generalization of the Morse telegraphic protocols together with the application of the newly discovered Maxwell equations improved the reliability of the telegraph, and regular exchange of data between stations became the norm. International meteorological conferences regularly met, beginning in 1853 at the initiative of the United States Naval Observatory, the first one presided by the director of the Brussels Observatory, Adolphe Quetelet. Even though fewer than 15 countries were represented, no explicit resolutions came from this first meeting because any recommendation would have led to modifications of the practice of the signatories; the wording was very general, e.g., "that some uniformity in the logs for recording marine meteorological observations is desirable." Anyway, a process was started, which led in 1873 to the foundation of the International Meteorological Organization at a Vienna international conference led by Buys-Ballot (WMO, 1973). This new organization proved to be strong enough to standardize practices in the entire world. It established a permanent scientific committee who began by adopting common definitions of the meteorological parameters. See Fig. 2.3.

2.2.3 Next Step: Extension of Data Collection to the Entire Globe

The distribution of stations of this first network was heavily biased to Western Europe and the Eastern United States. It was clear at the beginning that a real network should extend to the entire world, including the Southern hemisphere. As a permanent extension was beyond the means of the early International Meteorological Organization, periodic campaigns for the study of polar regions were proposed by several countries, combining exploration and maritime observations. The first one, in 1883, was concentrated on the Arctic ocean and a few sub-Antarctic stations. The observations took place between 1881 and 1884 and demonstrated the feasibility of a network extension.

The success of the first campaign led to the second International Polar Year in 1932–1933. This campaign was initiated and led by the International Meteorological Organization and extended to geomagnetism and ionospheric studies; more countries participated, and the program included simultaneous observations at low latitudes. This campaign should have included a network of Antarctic stations, but the financial crisis of the time limited the funding means of the participating countries. The collection and use of Big Data was already envisaged by the establishment of World Data Centers centralizing data by themes.

The Second World War extended to the entire Northern hemisphere and parts of the Southern Pacific. Meteorological forecasts were essential, and the allies decided on a very wide synoptic network. This effort was led by the UK Met Office, which exfiltrated qualified meteorologists from Norway and several other occupied European countries. The Germans took a more theoretical approach, demanding less stations. The Anglo-American meteorological forecasts, with a better time resolution, were essential in planning successful amphibious operations at the end of the war, as well as air force support. After the war, the extension of this network to the Southern hemisphere led to the 1947 US Navy Highjump operation, combining the exploration of Antarctica and the establishment of stations. This expedition led to numerous accidents, which confirmed that military claim and occupation of Antarctica were beyond the means of any nation. Most of these accidents were related to errors in the positioning of ships and aircrafts related to the proximity of the South Pole and weather conditions. The staff of this huge expedition included the ionospheric scientist Lloyd Berkner,



Väderlekskarta på morgonen den 22 oktober 1874.

FIG. 2.3 Early synoptic map of Swedish origin (https://en.wikipedia.org/wiki/Timeline_of_meteorology#/media/File:Synoptic_chart_1874.png). Sea level pressure is indicated, as well as an indication of surface winds, demonstrating the success of the International Meteorological Organization at its foundation in 1873. Until the early 1970s, isobar lines were drafted by hand to fit the results of the stations; it was only in the last quarter of the 20th century that they were automatically plotted integrating data from other origins as airplanes and satellites.

who after designing the radio communications of the 1929 Byrd Antarctica expedition multiplied the executive roles in scientific unions while continuing research. He later played an important role in coordinating electronic operations for the US Navy in the Second World War. His positions as a rear admiral, a presidential adviser, and the president of the International Council of Scientific Unions (ICSU) helped him to initiate in 1950 the International Geophysical Year (IGY) project and to take the first steps of the Antarctic treaty. The purpose of IGY was to extend the observations to the entire globe with the cooperation of the Soviet Union and all other scientifically active countries (National Academy Press, 1992). See Fig. 2.5.

The Second World War had seen an increase in the number of weather ships, as these supported also transatlantic air traffic. This network was officialized, and these stations are shown in Fig. 2.4. Unfortunately, their high cost led to their progressive retirement after IGY when their function was taken over by instrumented merchant ships and commercial airliners. Also, beginning in 1960, experimental satellites were devoted to meteorological observations until evolving into the present network of civilian operational meteorological satellites operated by both EUMETSAT and NOAA.

FIG. 2.4 The 12 Arctic stations of the 1883 International Polar Year, NOAA, https://www.pmel.noaa.gov/arctic-zone/ipy-1/index.htm.

FIG. 2.5 Photograph of one of the first preparatory meetings of the IGY at the US Naval Air Weapons Station at China Lake (California) in 1950. The scientists present around Lloyd Berkner and Sydney Chapman on this image represent three quarters of the world authorities on ionosphere and upper atmosphere at the time. A similar group today would include much more than 10,000 participants (Pr. Nicolet private archive).

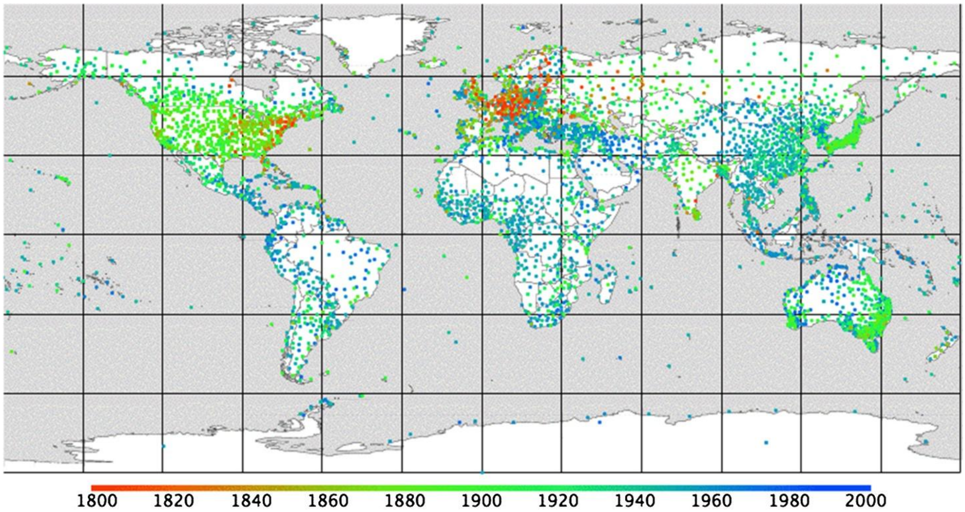


FIG. 2.6 Extension of the network of WMO stations from a European network in the middle of the 19th century to the current network. The stations are color-coded to indicate the first year in which they provided 12 months of data (Hashemi, 2009).

EUMETSAT is a consortium of meteorological organizations regrouping most of Western and Central Europe, including Turkey. It operates both its own network of geostationary METEOSAT satellites and METOP in polar orbit. Since the 2010s, it collaborates with COPERNICUS Sentinel satellites managed by ESA for the European Union. The data are used for forecasts by the European Centre for Medium Range Weather Forecasts (ECMWF) to produce forecast maps for the entire world. In 2019 these have a 20 km resolution, and should reach the 5 km resolution during the 2020s. See Fig. 2.6.

The total amount of data coming from all these sources is difficult to estimate as the definition of data covers all aspects of the raw and processed data. Currently, COPERNICUS, which is not yet in complete operation, generates about 10 petabytes per year; ECMWF claimed in 2017 to have archived more than 130 petabytes of meteorological data, beginning essentially in the 1980s, when EUMETSAT and NOAA data flows started their exponential increase.[1]

Big Data have clearly become a part of the observational database. More and more, Big Data enter the world of forecasts by techniques as assimilation, where the model is tuned to minimize the gaps between observations and the forecast and the ensemble techniques in which a large number of instances of one or several models are run in parallel and in which the final analysis uses statistical techniques (WMO, 2012).

[1] http://copernicus.eu/news/what-can-you-do-130-petabytes-data.

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