BAMS Article

On the Value of Early Marine Weather Observations

The Malaspina Expedition (1789–94)

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ABSTRACT: Great advances in meteorological science were made in the late eighteenth century. In particular, meteorological instruments were carried on ships and the first systematic meteorological readings over the oceans were made. One of these collections of instrumental meteorological readings was carried out by the Malaspina expedition (1789–94), organized by the Spanish Crown to study its vast possessions around the world. We have recovered meteorological variables such as air temperature (maximum and minimum), atmospheric pressure (maximum and minimum), wind (intensity and direction), and appearance (state of the sky) from the documentation generated by the explorers during the journey. In total, nearly 13,000 instrumental data have been digitized and rescued from this maritime expedition. The comparison of daily temperature and pressure observations with reanalysis and weather stations data shows a good overall agreement. Moreover, apparent discrepancies during several anchored periods have allowed for testing the consistency and quality of these early instrumental marine weather readings.

KEYWORDS: North America; Pacific Ocean; South America; Databases; Ship observations; History

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Between 1789 and 1794, the sailor Alejandro Malaspina led a Spanish expedition around the world. The expedition was funded by the Spanish Crown during the reign of Carlos III. The initial name "Viaje científico y político alrededor del mundo" (Scientific and political journey around the world) reflects the main objectives of the expedition. With this project, the Spanish Crown sought to be at the forefront of science and research, following the same path as other countries, for instance, France and the United Kingdom. The expedition consisted of two corvettes, *Atrevida*, captained by José Bustamante y Guerra, and *Descubierta*, captained by Alejandro Malaspina. The circumnavigation was not completed due to political reasons, but the scientific advances in astronomy, geography, ethnology, linguistic, botany, and zoology have no precedents in Spanish navigation (e.g., Martín Meras 1984; Jaramillo 2006; King 2010; Fernandez-Alonso and Morales 2013). Figure 1 shows the map with the route of the corvette *Descubierta*, where the meteorological annotations were recorded (Malaspina et al. 1885). Due to a political prosecution by Manuel de Godoy, the Spanish king's favorite, Malaspina was taken to prison after his arrival and the documentary legacy of the expedition was dispersed and even buried (Pimentel 1998; Puig-Samper 2016). In fact, the Malaspina's expedition has been the subject of public awareness only in recent years, in remembrance of the bicentenary of the original expedition and Malaspina's death in 1810. In particular, the meteorological data had not been abstracted and were not reachable for the climatological community. All of these early observations taken in the ocean with anchorages in ports all around the world are valuable to be used in a lot of tasks that require meteorological information from the past, especially in regions with scarce or no known records.

In recent decades, early weather observations have been used increasingly to improve our understanding of long-term weather and climate variability (Brunet and Jones 2011). This has led to numerous efforts aimed at rescuing early instrumental data, such as Improved Understanding of Past Climatic Variability from Early Daily European Instrumental Sources (IMPROVE) (Camuffo and Jones 2002), Early Meteorological Records from Latin America and Caribbean (EMERLAC) (Domínguez-Castro et al. 2017), Atmospheric Circulation Reconstructions over the Earth (ACRE) (Allan et al. 2011, 2016) (www.met-acre.org/), or the Copernicus Climate Change Service (C3S) Data Rescue Service (Brönnimann et al. 2018). There is a mass of historical marine weather observations from ship logbooks recovered by the international ACRE initiative—in 2019 alone, around 2.6 million were scanned and 1.6 million digitized.

Marine weather descriptions started since the beginning of the sailing era; for example, by the mid-sixteenth century the Spanish fleets had to produce a detailed report of the sailing conditions and circumstances along the journey, including weather (García-Herrera et al. 2005).

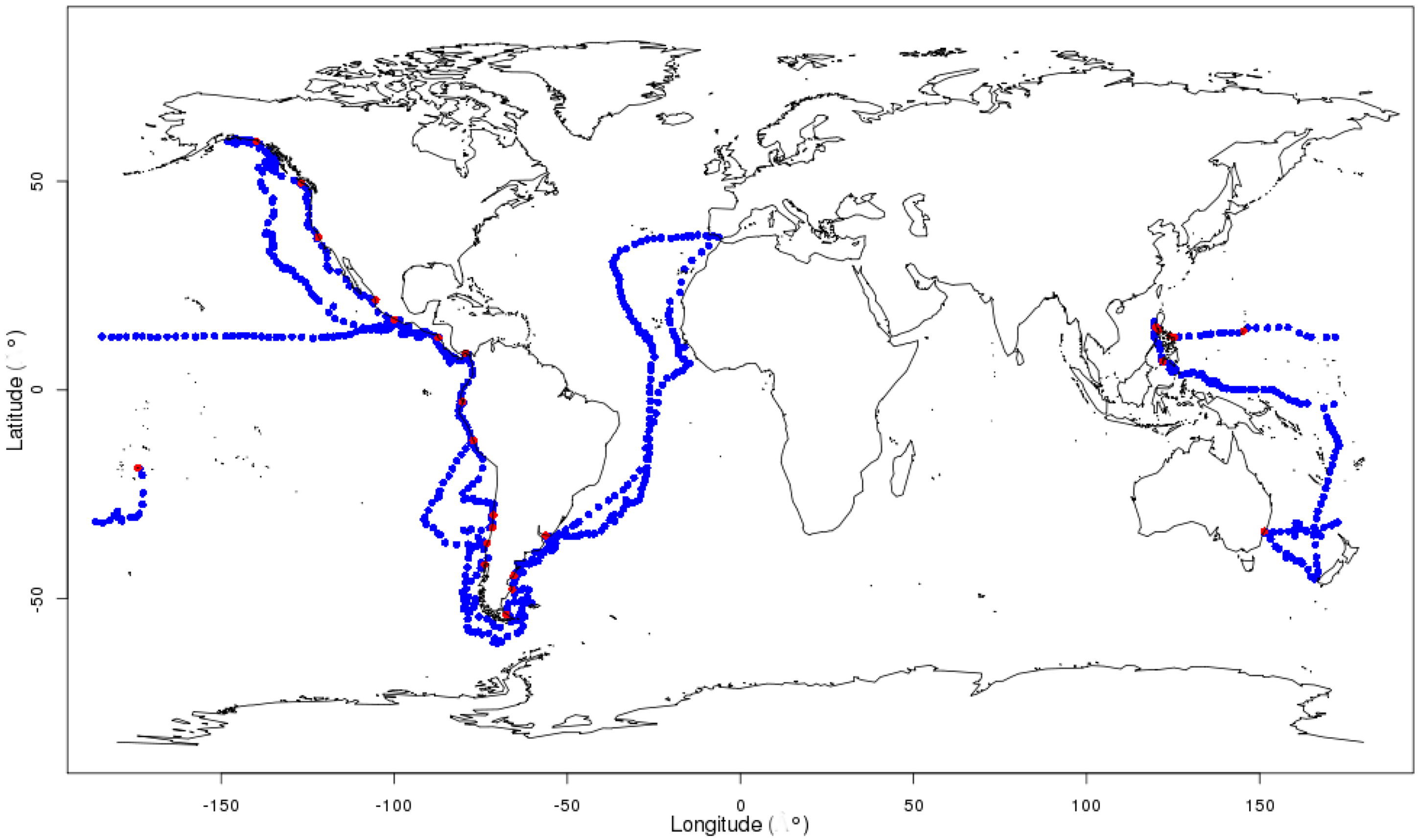

Fig. 1. Route of the corvette *Descubierta* between 31 Jul 1789 and 21 Sep 1794. The points indicating the trajectory have been obtained from the original meteorological annotations document. The places where the corvette anchored are marked in red.

In fact, the observation of the sea and the atmosphere was not only a matter of curiosity; the safety of lives and properties depended on the skill of the crews to interpret favorable winds and weather. They had to avoid storms and dead calms, and this determined the sailing course and season of the transatlantic journeys. Consequently, meteorological conditions were a key question in decision-making, and critical to the success of the voyages. For this reason, meteorological observations (mainly wind direction and intensity) were recorded precisely, with extreme care and they were preserved for future consultation by other mariners. They were collected in logbooks, which kept a daily record of the weather and navigation circumstances along the trip. The earliest that have been preserved come from the late seventeenth century and thousands of them have yet to be abstracted (Wheeler and García-Herrera 2008).

Currently the observations across the oceans are coordinated by the International Comprehensive Ocean–Atmosphere Dataset (ICOADS) (https://icoads.noaa.gov/). ICOADS is the world's largest collection of marine surface in situ observations with 456+ million records for 1662 through the present (Freeman et al. 2017), although data prior to 1800 are quite sparse. There are few eighteenth century expeditions included, such as those by Edmund Halley (1699), James Cook (1772–75 and 1776–79), La Perouse (1785–88), First Fleet (1787–88), and George Vancouver (1791–95) (Freeman et al. 2017). However, the international effort on searching, scanning and digitalizing eighteenth century observations under the ACRE initiative is continually retrieving meteorological information from other expeditions, e.g., Phipps (1773), Abercrombie (1775), Portlock and Dixon (1785–88), Bligh (1787–89 and 1792–93), Marchand (1790–92), Tobin, Bond, and Flinders (1791–93), d'Entrecasteaux (1791–92), Colnett (1793–94), or Broughton (1796–97) that will be incorporated into ICOADS. Meteorological instruments were not included systematically on board until the end of the nineteenth century, being wind the main meteorological variable recorded until then. Even when the observation practices were not standardized until the end of the nineteenth century following several efforts, including the first International Meteorological Conference, promoted by Matthew Fontaine Maury and held in Brussels in 1853 (Ashford 1953), the value of the early wind observations has been established through the CLIWOC project (García-Herrera et al. 2005) was focused on the rescue of wind observations from logbooks from 1750 to 1850. Many more such expeditions have been recovered, scanned and/or digitized and are being processed by ACRE. These early observations, taken across the World Ocean, are valuable to feed long-term reanalysis (e.g., Slivinski et al. 2019), to create long-term atmospheric circulation indices (e.g., Barriopedro et al. 2014; Mellado-Cano et al. 2019, 2020), to generate monsoon indices (e.g., Gallego et al. 2015, 2017), to define hurricane tracks (e.g., Vaquero et al. 2008), or to analyze temperature changes (e.g., Brohan et al. 2012), among others. See García-Herrera et al. (2018) for a detailed review. However, the quality of the early instrumental observations on board has been scarcely tested (Wheeler 2005; Brohan et al. 2012; Brönnimann 2015), probably because the validation of these observations is not an easy task. As mentioned above, there were no observation rules until 1853 and the quality of the instruments was highly variable. Furthermore, they were taken mostly in isolation, so the comparison with other series is limited to fleets or convoys (Wheeler 2005). This type of data has been used by other authors. Thus, for example, Garcia et al. (2001) obtained results suggesting that the atmospheric circulation of the western Pacific underwent large, multidecadal fluctuations during the seventeenth century, Brohan et al. (2009) digitized meteorological observations in Royal Navy logbooks for the period between 1938 and 1947, and Brohan et al. (2010) demonstrated that marine climate in 1810–25 was marked by consistently cold summers, with abundant sea ice.

This work focuses on the meteorological record of the Spanish expedition led by the sailor Alejandro Malaspina between 1789 and 1794. In particular, only meteorological pressure and temperature data between November 1792 and July 1793 had been published by ACRE; most of the meteorological data had not been abstracted and were not reachable for the climatological community. Therefore, the objective of this work is to make accessible and validate the quality of the meteorological records from the Malaspina's expedition. The sample size, nearly 13000 daily instrumental meteorological data, provides a unique opportunity for testing the quality of these early marine weather observations.

The route

The Malaspina expedition departed from Cádiz to the Philippines, traveling the entire west coast of the American continent. Figure 1 shows the map with the route of the corvette *Descubierta*, where the meteorological annotations were recorded (Malaspina et al. 1885). The journey began in Cádiz on 31 July 1789, arriving in Montevideo 52 days later. After two months of stay in the Uruguayan capital, the expedition headed toward the Falkland Islands, where they stayed until the end of 1789. At the beginning of 1790, they began their route along the west coast of South America, anchoring in Ancud, Talcahuano, Valparaíso, Coquimbo, and Callao, on the Peruvian coast. In Callao, the expedition remained 122 days. The journey continued through the ports of Guayaquil, Panama, and Acapulco. In Acapulco, the corvettes separated. The crew of the *Descubierta* set course to the north of the American continent, in search of a passage that would connect the Pacific and Atlantic Oceans. During this journey, the corvette anchored in Mulgrave (Alaska) and Nutka and Monterrey (United States), to finally return to Acapulco with the *Atrevida*. At the end of 1791 they headed for the most important Spanish colony on the Asian continent, the Philippines. On this journey they anchored in Marag, Palapag, and Cavite (Manila's port), where they remained 219 days, from April to November. The return to Spain began with the passage through New Zealand and Vavaú. After anchoring again in Callao and Talcahuano at the end of 1793 and Montevideo at the beginning of 1794, the expedition reached the Bay of Cádiz on 21 September 1794.

Fig. 2. Representative illustrations corresponding to some places of the route painted by the draftsmen of the Malaspina expedition.

Some representative illustrations of places of the route painted by the draftsmen of the Malaspina expedition are shown in Fig. 2.

The meteorological observations

The expedition led by Alejandro Malaspina took notes of meteorological observations on a daily basis, each day of the journey. Data were recorded both during the maritime journeys and in the ports where the corvettes anchored. The result is a daily database, made up of nearly 13 000 data of pressure measurements (maximum and minimum), temperature (maximum and minimum), wind (intensity and direction), and appearance (state of the sky). It is worth mentioning that temperature observations ended in Montevideo Port upon their return to Spain. The manuscripts containing the data are preserved in the Naval Museum Archive in Madrid, in the bundle with reference AMN 0172 Ms.0269/000, entitled "Observaciones meteorológicas y azimutales hechas a bordo de las corbetas de S.M. 'Descubierta' y 'Atrevida' en sus viajes de vuelta al mundo en las correspondientes latitudes y longitudes al rendir sus singladuras, con los rumbos navegados en cada una de ellas y las alteraciones de estima contraídas" (Meteorological and azimuthal observations made on board of H. M. corvettes "Descubierta" and "Atrevida" in their travels around the world, in the corresponding latitudes and longitudes). This document is scanned and freely accessible in the National Defense Library (https://bibliotecavirtual.defensa.gob.es/BVMDefensa/es/consulta/registro.do?id=13801). The layout can be seen in Fig. 3.

However, during the data abstraction process we detected the absence of sheets with annotations of some periods, probably misplaced among so many documents of the journey. To fill

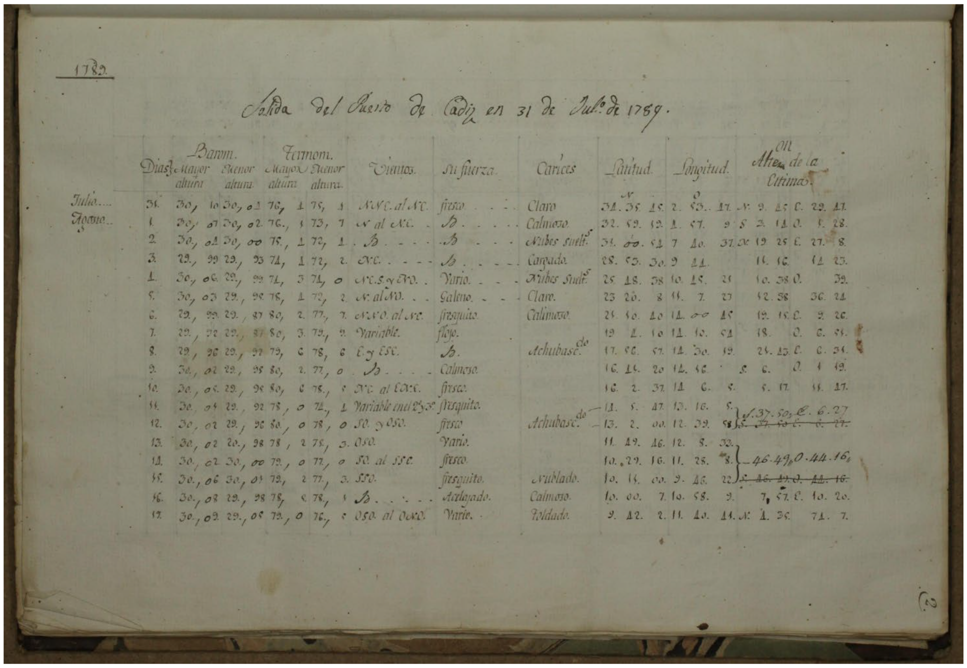
1789.
Salida del Puerto de Cádiz en 31 de Jul.e de 1789.
Dias | Barom. Mayor altura | Menor altura | Termom. Mayor altura | Menor altura | Vientos | Su fuerza | Caracter | Latitud | Longitud | Altera. de la Estima

Fig. 3. Page from the original notebook with the first meteorological observations after the departure of the expedition from Cádiz Port. The first two columns indicate month and day of the month. The highest and lowest barometer (inches and lines) and temperature (Fahrenheit degrees) readings are in the following four columns. Wind direction and force occupy the next columns, followed by the appearance, latitude, longitude, and alteration of dead reckoning.

these gaps, the manuscript AMN 0281 Ms.0548/000 from the Naval Museum Archive entitled "Diario meteorológico del viaje de las corbetas 'Descubierta' y 'Atrevida'. Con introducción del contenido y tablas con los principales datos" (Meteorological diary of the journey of the corvettes "Descubierta" and "Atrevida") was used. It contains a clean notebook of observations, including the data tables, an introduction describing the instruments, the measurement procedure, and other annotations related to the collection of these data.

According to Claverán (1988), the instruments used in this expedition were the following: "Two hygrometers of the best construction, a thermometer to measure the temperature of the sea, an aerometer from M. Perica, a portable hydrostatic balance and of the simplest construction, a Dollond thermometer, a cork diving suit or bathing suit, the Manheim collection of meteorological instruments, a pocket goniometer, an eudiometer (used to determine the relative volume of oxygen in air), and two air guns." Furthermore, Malaspina navigated with two Berthoud marine chronometers to guide the expedition. Due to the magnitude and high cost of the expedition, the officers, midshipmen, and ship's naturalists were very rigorous and precise in all the observations made (Malaspina et al. 1885).

Notes describing the observational methodology are detailed in the manuscript AMN 0281 Ms.0548/000, such as the following: "Our observations are reduced to the highest and lowest elevation of the marine Barometer and Fahrenheit thermometer each day, to the direction and intensity of the prevailing winds, and to appearance; we have added for the greater utility of the diary, so as not to fruitlessly multiply the tables, the latitude and longitude positions for each half day and the errors in the daily dead reckoning. The longitudes are always referred to the western meridian of Cádiz and depend on the marine clocks, always chosen from among them the one that served as a master for the topographic work. Its results are also corrected by the celestial observations, made in different parts of America.... We can assure that in these exams not the slightest care has been omitted.... the meteorological observations come from the records that the duty officers records every four hours.... the marine barometer that we have used was of the excellent construction of Mr. Nairne of London.... the barometer was always in a place where the air ran freely.... Our thermometers were the common Fahrenheit; they were placed in a small box outdoors." Finally, in relation to the winds and the state of the sky, it was remarked that "the dominant during most of the day were recorded."

It is important to note that the Nairne barometer is the first successful marine barometer, and it was used in the most important scientific expeditions of the time, e.g., second Cook's voyage (1772–75), Constantine Phipps voyage to North Pole (1773), George Vancouver to the Pacific (1790–95), and later, e.g., Matthew Flinders to Australia (1801–03), the circumnavigation of Johann von Krusenstern (1803–06) (McConnell 2005). So the Malaspina expedition had the most advanced instruments in order to record the meteorological observations.

The 13 000 meteorological records were digitized by key entry. A visual check was performed after transcriptions in order to detect errors.

In the original document, temperature was expressed on the Fahrenheit scale and pressure was expressed in English inches. These units have been conveniently converted to units accepted by the International Maritime Meteorological Archive (IMMA) format (Woodruff 2010; Smith et al. 2017), which is the international format accepted for projects dedicated to recovery and analysis of meteorological data. Specifically, the temperature and pressure data have been converted to Celsius degrees and hectopascals, respectively.

The retrieved daily records are publicly available at the World Data Center PANGAEA at https://doi.pangaea.de/10.1594/PANGAEA.930344. Detailed information about the data structure can be found in this link.

Validation of Malaspina meteorological records

To validate the observations recorded during the Malaspina expedition, temperature and pressure observations have been compared with the NCEP–NCAR 40-Year Reanalysis (Kalnay et al. 1996). In this work, the reanalysis variables selected for the comparison are temperature at 2 m and sea level pressure, since the observatories were located on board the ships. For every location and calendar day included in the Malaspina record, the mean and standard deviation were computed for the closest grid point during the whole reanalysis period. The standard deviation was used as a measure of the variability range during the modern period.

Data measured at land surface stations near the ports where the crew anchored have also been used for the validation of the temperature observations, in addition to reanalysis data. This decision was adopted because the 2.5° × 2.5° cell reanalysis temperature values in coastal areas, containing both land and sea areas, are not representative of the value recorded in the port. Specifically, daily maximum and minimum temperatures data from the Global Historical Climatology Network (GHCN) (Menne et al. 2012) (www.ncei.noaa.gov/products/land-based-station/global-historical-climatology-network-daily), corresponding to the ports where the expedition anchored, have been used. In ports where there is no coincidence with a station from the GHCN database, data from the closest stations and with an altitude as close as possible to sea level have been used. Therefore, the temperature observations recorded during the Malaspina expedition have been compared with reanalysis data on the marine routes and data from the GHCN during the anchorage periods.

Figure 4 shows the comparison for temperature, obtaining a similar behavior in both data series. Most of temperature data recorded during the expedition are within the marked variability range, except for those periods corresponding to the anchorages in Puerto Jackson and Callao in 1793. In these ports values 5° lower than the modern records were registered because they set up a distant observatory where it was cooler.

From the data found in another document entitled "Continuation of the astronomical and meteorological diary, astronomical tasks carried out by the corvettes 'Descubierta' and 'Atrevida' on their expedition around the world in Cavite, seas of Asia and coasts NW of America; and meteorological journal and position status of the corvettes from Manila to

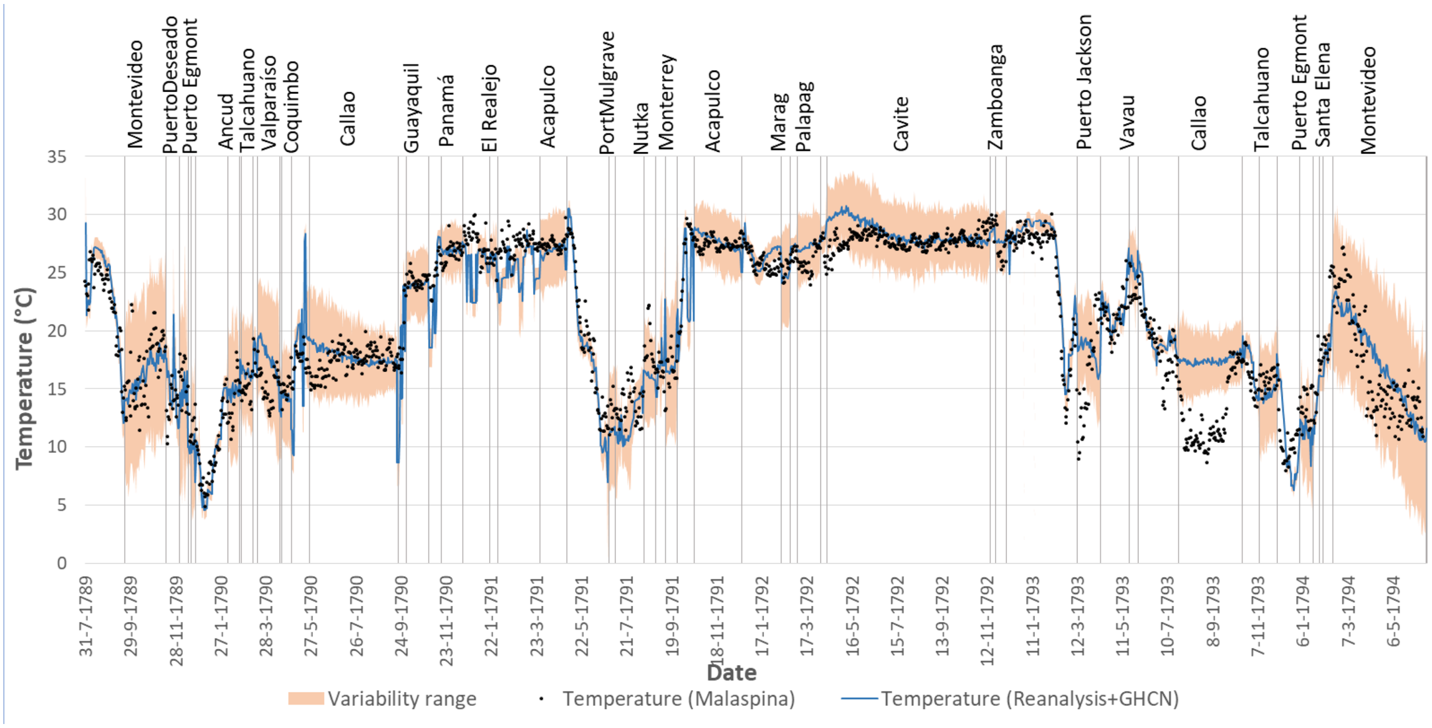

Fig. 4. Change over time of temperature values recorded during the Malaspina expedition (black) and of the mean values of reanalysis temperature + GHCN (blue). The variability range is shown in light brown.

the port of Callao" (AMN 0343 Ms.0744/000) the temperature values have been compared with those of marine clocks. The results obtained show a very good correlation although, in general, the clock temperatures are higher, probably because the observations of the clocks are indoors and those of the thermometers are outdoors.

Figure 5 shows the change over time of pressure values recorded during the expedition and the mean values of atmospheric SLP from reanalysis, as well as the variability range. It can be seen that the Malaspina pressure observations show a behavior similar to the reanalysis data, with most of data found within the variability range, both at open sea and while anchored in port. This can be checked for Montevideo and Cavite, where the crew stayed for two long periods of time, data fit perfectly. Interestingly, significant discrepancies appear in the cases of Panama in 1790, Puerto Jackson in 1793, or Callao also in 1793, where temperature also showed discrepancies with the modern record.

Therefore, overall, these results show that the observations recorded during the Malaspina expedition are within the range of present-day values. However, the discrepancies detected in Callao and Puerto Jackson in 1793 needed an explanation. Thus, we have investigated the possible reasons that could explain these biases. Figure 6 shows the pressure and temperature records during the Callao stay. As it can be seen from this figure, during the first and last days of anchoring in Callao, the values of these variables are similar, but differ during the rest of the period. Reading the Malaspina's travel diary (Cerezo Martínez 1990) we could check that the members of the expedition did not stay in Callao, but in Magdalena. Magdalena, currently called Pueblo Libre District, is around 10 km from Callao and 80 m MSL (Fig. 7). The village showed a markedly different climate and better conditions for astronomical observations. In Malaspina's diary, there is not precise information about the date on which the expedition arrived at La Magdalena from the Callao, but the diary is clear in the departure date. They left La Magdalena on 26 September, and they started to record the meteorological measurements on board on 1 October. Figure 6 shows that the temperature and atmospheric pressure differences among Malaspina's records and current climate are greater prior to 26 September when the expedition was in La Magdalena, and the records start to fit well when the measurements were taken on board at Callao port from

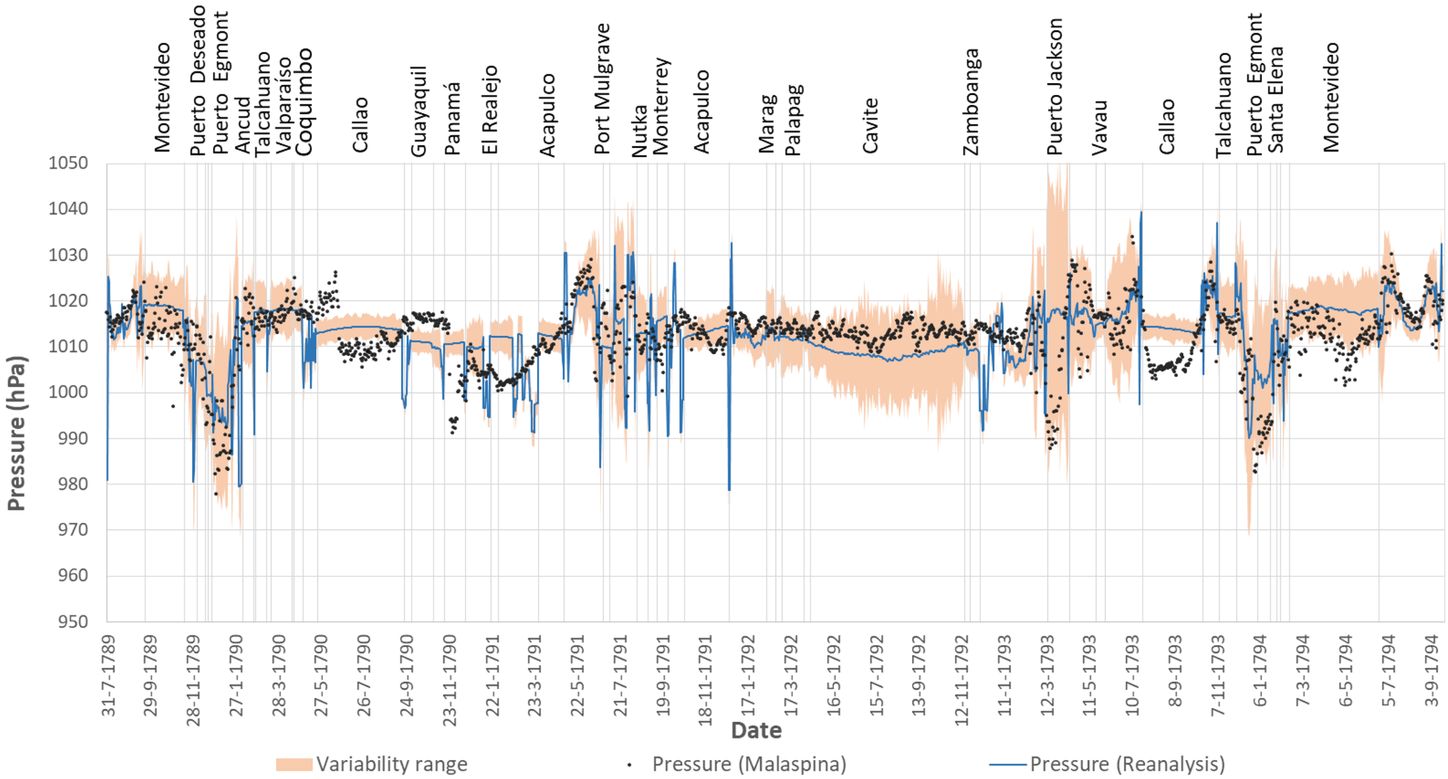

Fig. 5. Change over time of pressure values recorded during the Malaspina expedition (black) and of the mean values of reanalysis pressure (blue). The variability range is shown in light brown.

1 October until they left on 15 October (red and green dots in Fig. 6). This fact suggests that the difference between Malaspina's records and the current climate is due to a misunderstanding of the position of the expedition or lack of temperature correction and not due to an error in the instrument or in the observation methodology.

The mean atmospheric pressure biases among the reanalysis and the observations from 8 August (probable date of arrival at La Magdalena) to 26 September is 8.43 hPa. A possible explanation to this bias is that the observations were not corrected by altitude. We must take into account that most of the observations were taken on board at 0 m MSL. Considering the hypsometric equation, this pressure difference corresponds to 68 m of altitude, very close to the altitude of the la Magdalena (around 80 m). Nevertheless, the temperature bias, i.e., −6.5°C, is clearly greater than the possible bias caused by the difference in altitude among Callao and La Magdalena that could be considered around −0.5°C. This difference probably is more related with changes in land cover because currently La Magdalena is part of the metropolitan area of Lima, a megacity with more than 10 million of people.

Concluding remarks

A dataset including nearly 13 000 meteorological observations recorded during the Malaspina expedition (around the world) from 1789 to 1794 have been digitized and their observations have been summarized in this work. Meteorological variables such as air temperature (maximum and minimum), atmospheric pressure (maximum and minimum), wind (intensity and direction), and appearance (state of sky) were retrieved. All of them are currently available for the scientific community. They were taken in areas where meteorological observations were very scarce, such as South America or Oceania. Nevertheless, they can be used as benchmark to test the quality of the early marine weather observations.

The observations were registered during more than five years, under very different environments and climates, from Alaska to the Magallanes Strait, from the Pacific to the Atlantic Oceans, at open sea and anchored in port. The Malaspina expedition recorded more than

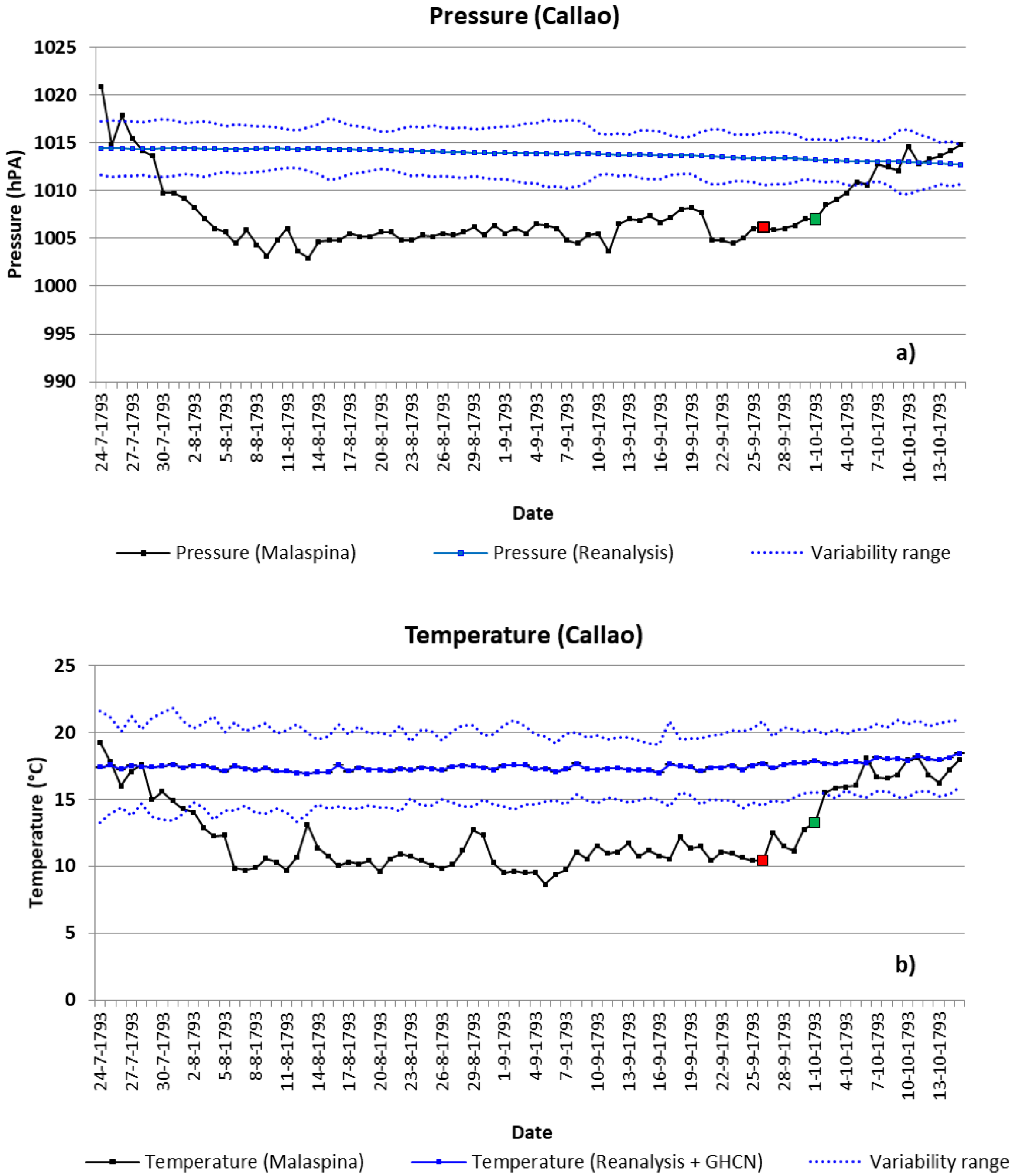

Fig. 6. Change over time of the mean (a) pressure and (b) temperature values recorded during the stay in Callao, and of the mean values of reanalysis or GHCN. The red dots indicate values corresponding to 26 Sep, the date they left Magdalena. The green dots indicate values corresponding to 1 Oct, the date on which the measurements began to be registered again on board in the port of Callao.

twice the contemporary observations currently available in ICOADS and they are in all circumstances and times, consistent with the modern records, providing a robust example of the quality and reliability of the early marine observations. The onboard observation conditions were not standardized until 1853, but it must be considered that the different nations and fleets shared most of the procedures and instruments (García-Herrera et al. 2005; Wheeler 2005). Consequently, it may be suggested that the quality of the contemporary observations in other expeditions must have been similar to those shown in the Malaspina data. But the expedition led by Malaspina not only provides us with data of great interest to the current scientific community. This expedition also provides us with an example of scientists who dedicated an important part of their lives to explore and discover unknown geographical

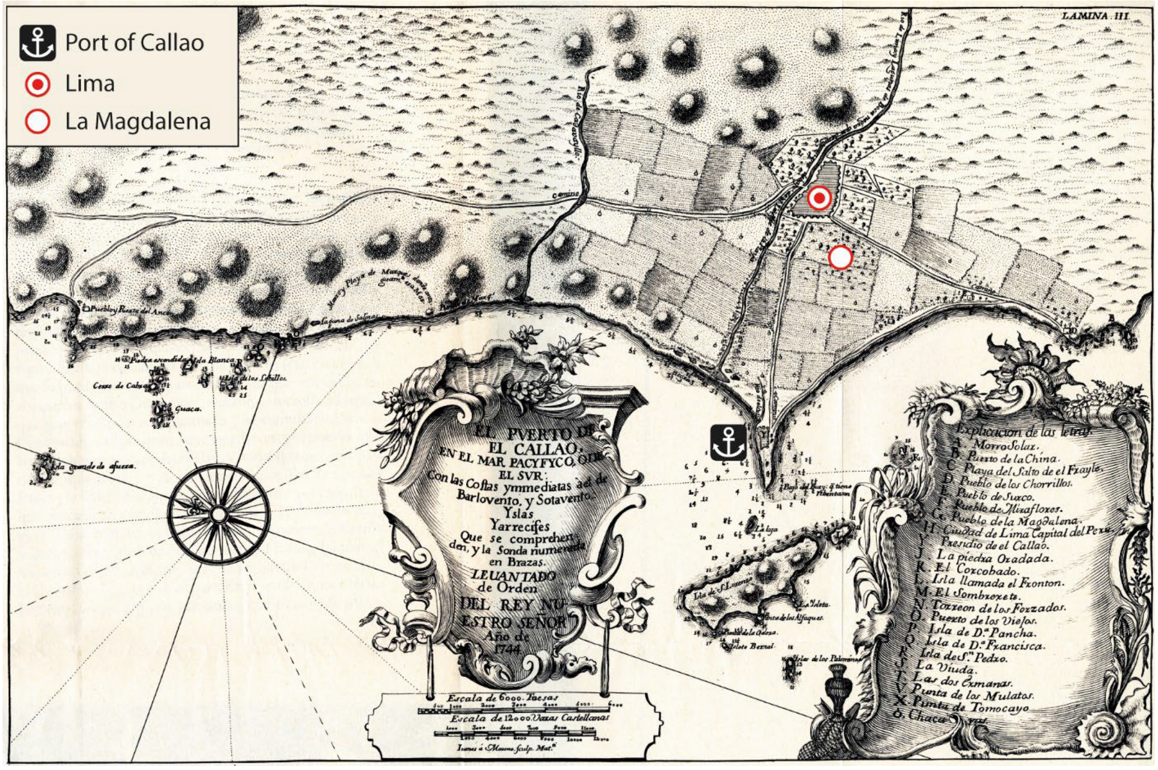

Fig. 7. Historical map of the Callao area (modified from Juan and De Ulloa 1748).

regions and to obtain meteorological data for future generations. In this sense, this work tries to recover his legacy of meteorological data, but it is also a recognition of his work and, in general, of the dedicated and hidden work of so many meteorological observers on board ships throughout history.

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Data availability statement. All meteorological data recovered from the Malaspina Expedition are openly available from the PANGAEA Data Publisher at https://doi.pangaea.de/10.1594/PANGAEA.930344.

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