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The Meteorological Data of William Hutchinson and a Liverpool Air Pressure Time Series Spanning 1768-1999

Short title: The Meteorological Data of William Hutchinson

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Abstract

This paper discusses some of the meteorological measurements made at Liverpool by Captain William Hutchinson in the second half of the 18th century. It gives an overview of the various data sets, most of which are now in computer-accessible form, and provides assessments of their quality, the aim being to gain an overall impression of how good an observer Hutchinson was. His air pressure data have been studied in detail, through comparisons to information from other UK stations, and via investigation of the sea level response to air pressure change as observed in his own tidal measurements. A first attempt has been made to construct a Liverpool air pressure time series spanning 1768-1999, by means of combination of Hutchinson's data with later information from the Liverpool docks and Bidston Observatory.

1. Introduction

William Hutchinson was born near Newcastle-upon-Tyne in 1716, and rose from being a common sailor to the command of a privateer during the first part of the Seven Years War (1756-1763). He was appointed Dockmaster and Water Bailiff at Liverpool in 1759. He managed to combine these demanding positions with an extensive set of other activities. At various times he was an inventor, author, civic leader, philanthropist, trader and, what we would now call, scientific researcher. Anyone wanting to know more about this remarkable person can do no better than read his own publications (Hutchinson, 1777, 1791).

The research for which Hutchinson is most well-known is his compilation of data sets of tidal and meteorological information spanning almost 30 years. He measured the height and time of almost every Liverpool high water between 1764-1793, providing the UK's first record of long term sea level variability (Woodworth, 1999a,b; Woodworth and Blackman, 2002). The first four years of data were given to Richard and George Holden to produce some of the first publicly-accessible high water prediction tables (Woodworth, 2002) and are now lost. However, two copies of the remaining information were preserved safely in Liverpool libraries.

The high water data have been inspected by a number of tidal specialists through the years (e.g. Lubbock, 1836), with general agreement that the measurements are of good quality. However, Hutchinson was obviously a busy man and he left no detailed descriptions of how he worked. Therefore, a possibility needs investigating that the measurements (made twice a day for almost three decades at all times of day and night and in all weathers) might not be as good as one might believe. More recent quality control checks have confirmed that the tidal data are as good as we might hope (Woodworth, 1999a). However, it is impossible to apply the most sensitive test of all, comparison to data acquired over the same period (and ideally by the same method) from a nearby station.

Another way of forming an impression of the likely quality of the tidal measurements is to make use of Hutchinson's meteorological data. Over the same period, he collected a near-complete set of information on air pressure and temperature, rainfall and wind speed and direction, using instruments in, or on the roof of, his four-storey house situated close to the Liverpool Old Dock (adjacent to the present-day Albert Dock estate). Some of these meteorological data have been used by previous authors and found to be of good (or at least reasonable) quality. For example, the air temperature data were used in the construction of the Lancashire and Central England records (Manley, 1946, 1953, 1974), and the rainfall data were employed in a UK regional time series (Craddock, 1976). Consequently, if one can form an assessment of the quality of Hutchinson's meteorological data, and therefore of how good a weather observer he was, then one can form an indirect impression of how good a tidal observer he might have been.

The air pressure data are particularly important in that they can provide a direct, rather than an indirect, assessment of the quality of the tidal data. Sea levels along the west coast of England are known to have an approximate 'inverse barometer' response to changes in air pressure (e.g. Thompson, 1980). Therefore, a test of the quality of both the tidal and air pressure information is to see how well the anticipated response manifests itself in his data.

An assessment of Hutchinson's ability to make meteorological and tidal measurements was the main objective of the study. A second important objective was to employ his air pressure data in the construction of a near-continuous time series of Liverpool air pressure from 1768. While air pressure records of similar length are available from London, Edinburgh and Dublin (Figure 1), there are no comparable records from NW England. A Liverpool air pressure record spanning almost two and half centuries would be a major addition to the set of long European time series, which, when used in combination, provide insight into the magnitudes and timescales of variability in the European atmospheric circulation (Kington, 1980; Jones et al., 1999; Slonosky et al., 1999, 2000, 2001).

A third important objective was to assemble as much of Hutchinson's meteorological data as possible in computer-accessible form. This will enable any future researcher to make ready use of the data sets, without the need to consult either the original tabulations (permission for which has to be obtained from Liverpool Local Studies and Public Record Office) or the microfilmed copies of the tabulations (Woodworth, 2000). All computer data sets can be obtained through the British Oceanographic Data Centre (http://www.bodc.ac.uk).

2. Hutchinson's Tabulations

The original Hutchinson tabulations (sometimes known inappropriately as his 'Journals') consist of four bound volumes, for 1768-1772, 1773-1779, 1780-1786 and 1787-August 1793. The first volume shows evidence for sheets having been cut out, and it is possible that it contained the now missing data for 1764-1767.

The layout of the information for each month is essentially the same throughout with minor variations (see Woodworth, 2000 for full details). In 1768, the journals contained tabulations of:

- Day number and day of the week
- Lunar information including Age of the Moon (i.e. days since New Moon), lunar distance in miles, declination and southing. These will have been abstracted from a nautical almanac.
- Morning (with its usual meaning of midnight to noon) time of high water (hour and minutes). 'Time' here means apparent solar time (as measured by a sun dial).
- Morning height of high water (feet and inches)
- Wind direction measured from the true meridian and speed measured on a scale of 1-60 miles per hour 'according to Mr Smeaton's rules'.
- Weather conditions
- Evening time and height of high water, wind direction and speed and

weather conditions.

- Tides daily difference (hours and minutes). These appear to be sometimes the differences between consecutive morning tides, and sometimes between consecutive evening tides. In any case, this information is redundant as the times of the individual tides are recorded.
- Height of the barometer in inches of mercury.
- Height of the thermometer in degrees Fahrenheit. The thermometer kept in doors, at the head of a staircase four stories high.

In August 1769, the barometer and thermometer information was moved to the middle of the page and clearly labelled as ‘Noon’. From June 1774, the noon entries acquired an extra column for ‘Rain in 1/8ths’ (i.e. eighths of an inch as measured by a rain gauge, presumably for the 24 hours up to noon) and usually the total for each month was shown at the bottom of the page. At the end of each December, the total amount of rain for the year was stated and confirmation given that the measurements were made ‘from the top of my house about 41 feet above high water mark’.

A manuscript copy of the tabulations was made in 1814 by J. Lang, a local printer, and has been preserved in good condition in the Liverpool Athenaeum Library. The information in the copy is essentially the same as in the original, but in certain places it is easier to read. Microfilmed copies of the tabulations contain images of both versions (Woodworth, 2000).

The computer data sets constructed in the present project were made by inspection of the microfilm copies. The images of the original tabulations were naturally the primary reference, but the Lang images were consulted when the need arose (e.g. when the handwriting in the originals was unclear). All air pressure, air temperature and rainfall values were double (and sometimes treble) checked. Computer data sets of morning and evening wind speed and direction, and Hutchinson’s brief descriptions of morning and evening weather conditions, have also been assembled but have so far not been studied in detail. The wind measurements were made “according to Mr Smeaton's rules”. However, wind measurements in ports and towns are prone to many difficulties, even today, and one suspects that Hutchinson's wind data are less useful than his other tabulations, a fact which was recognised at an early stage (e.g. see pp.601-607 of Garnett, 1796).

3. Remarks on Each Parameter

3.1 Air Temperature

Hutchinson's first set of temperature measurements were made at noon only, but from 26 January 1778 he started to record at both 8 am and noon. There are many mentions in the tabulations of thermometers being 'broken' or 'out of order', and for the last 8 months of 1770 there were no temperature measurements at all. This suggests that systematic errors in the time series could be important. Computer data sets have been made of all temperature information but only the noon data have been inspected in detail. There is clear bias in the noon temperatures (tabulated in degrees Fahrenheit) towards even values, approximately twice as many even values being recorded than odd values. Idiosyncratic features of this kind also exist in Hutchinson's tidal data (Woodworth, 1999a).

Before the 17 January 1777 entry, a mark 'O.D.' in the tabulations denotes (one assumes) 'Out Doors'. This mark does not appear in the Lang copy, so there is some doubt as to whether it was made by Hutchinson himself. (Manley, 1946 gives this date as a day earlier.) Up to that date, Hutchinson had made use of a thermometer at the top of the stairs leading to the roof of his house. The outdoor measurements were made "under a table (to prevent the rain having any effect), facing the north, in an open observatory, as much exposed to the open air as possible" (Garnett, 1796). Garnett states that this information was extracted from Hutchinson's Journals, but such a statement about the observatory cannot be found in the surviving copies.

Figure 2 shows the time series of monthly mean noon air temperatures obtained from Hutchinson's measurements. The seasonal cycle is quite evident but with a smaller amplitude prior to 1777. As one might expect, the monthly mean summer temperatures recorded in-doors and out-doors were comparable, whereas monthly mean winter temperatures obtained inside the house were approximately 10 degrees higher than those obtained outside.

Manley (1946, 1953) discussed the curious 18th century practice of making air temperature measurements "in a shady room without fire" as recommended by Jurin (1723), or, as in Hutchinson's case, at the top of a house. Consequently, Hutchinson can hardly be blamed for following in his earlier years what had been accepted procedure. In spite of the biases, Manley was able to incorporate useful information from Hutchinson's data within his Lancashire and Central England temperature time series (Manley, 1946, 1953).

3.2 Air Pressure

3.2.1 Construction of an Adjusted Time Series

Hutchinson (1777) refers to a Tampion (*sic*, i.e. Tompion, the first maker of Hooke's wheel barometer and many other instruments) portable barometer which he had used during his time at sea.[1] However, the records provide no information on what kind of barometer was used at his house in Liverpool. One assumes it to have been some kind of wheel or cistern barometer, both of which were in common use at the time. The standard instruments of the day would have been prone to many problems (e.g. presence of trapped air in the mercury column) and effective long-term calibration would have been difficult if not impossible (Middleton, 1964). Nevertheless, one would have expected air pressure to have been one of the more robust of the meteorological parameters recorded by Hutchinson.

1 This would have been a good instrument for the time (Anita McConnell, private communication. See McConnell, 2005 for a history of the marine barometer).

However, on transferring the data into computer form, it immediately became apparent that there were a number of problems. A problem in the first six months is that Hutchinson noted air pressure to only 1/10 inch (approximately 3 mbar) which is a coarser resolution than one would like for time series analysis. On 16 June 1768 he ‘left town to go for London', which coincided with a change to include an extra decimal place (approximately 0.3 mbar), which became the standard for the rest of the record. However, at times towards the end of the record (e.g. in June 1791), even though the pressures are expressed to two decimal places, rounding to one decimal place again seems to have taken place.

A second problem became apparent when monthly mean pressures were compared to data from Edinburgh and London (Jones et al., 1999). These records start in 1770 and 1774 respectively and end in 1995, and are assumed to contain mean sea level pressures (MSLP) throughout. Figure 3 shows a scatter plot of Hutchinson and Edinburgh monthly mean pressures, indicating three main sections of data:

1: From January 1770 – December 1780 and December 1789 – August 1793, when Edinburgh minus Hutchinson pressure (ΔP) was approximately 1.7 mbar (using arithmetic average pressure differences, median pressure difference also being 1.7 mbar).

2: August 1787 – November 1789, when ΔP was approximately 15.5 mbar (or 15.8 mbar median pressure difference).

3: January 1781 - July 1787, when ΔP was approximately 6.0 mbar (or 5.3 mbar median pressure difference).

The beginning and end of each section of data was estimated partly by inspection of the time series of ΔP (and the corresponding pressure-difference series using London data) and partly from knowledge of possible problems with the Hutchinson barometer. For example, on 26 July 1787 the tabulations state that the barometer is ‘out of order’, and there is a gap until measurements recommenced on 4 August. Therefore, it seems likely that whatever changes were made at the beginning of August (perhaps a change of instrument) introduced a systematic shift. On the other hand, there are no ‘out of order’ statements towards the end of 1780 which would explain precisely when and why a shift had occurred. The years 1779 and 1780 contain many unexplained data gaps which could be alternative choices for the time of the shift, instead of the end of 1780 chosen. Inspection of the ΔP series (and the corresponding series using London pressure data) does not provide a definite conclusion. The shift towards the end of 1789 seems clear from the ΔP series but there are no data gaps at all in 1789, and then not until March 1790, and no informative remarks. Inter-comparison of time series shows that a small number of additional outliers exist in each section of the Hutchinson data, and are also present in the Edinburgh and London records.

An ‘adjusted’ Hutchinson air pressure data set was constructed by applying the above ΔP (arithmetic average) offsets to the three sections of data, such that Liverpool and Edinburgh air pressures were on average the same for 1770-1793. The resulting correlation coefficients between monthly means for the adjusted Hutchinson record and Edinburgh and London are 0.817 and 0.830 respectively. The high value for the latter is particularly gratifying as it provides an independent check on the adjustment. The correlation coefficient between Edinburgh and London monthly means in the same period is slightly lower at 0.691, which is partly explainable by the further distance apart.

No Edinburgh or London data exist for 1768-1769. Consequently, a comparison for these earlier years is not possible. Their ‘adjusted’ data were computed using the offset of section 1. The resulting time series of adjusted annual mean air pressures (defined as the average of the available monthly values for each year) for the entire Hutchinson record, and for Edinburgh and London, are shown in Figure 4. The low value in the first year is almost certainly an artifact of pressures being recorded to only 1/10 inch. Correlations between the adjusted series and Edinburgh and London yield coefficients of 0.662 and 0.605 respectively, which are lower than the coefficients from the monthly means. In addition, the root-mean-square (rms) of the adjusted annual means is approximately 25% larger than those for the other two sites for the years in common (which does not include the suspect year of 1768). This suggests (among other possibilities) the difficulty Hutchinson may have had of maintaining the accuracy of the pressure measurements over many years; this issue will be returned to below.

None of a long set of corrections has been made to the Hutchinson pressure data. However, it is important to list them, to demonstrate that they have not been forgotten and to estimate their importance. In principle, a temperature correction could be applied to some of the pressures as noon temperature data exist. One can assume that the barometer was located in-doors, the seasonal temperature variation of which was approximately ± 10 °F or 5 °C (first part of the time series in Figure 2). That would result in a seasonal correction to the pressure of approximately ± 1 mbar (Diem, 1962; Middleton, 1964; Slonosky et al., 2001). However, the correction could not be applied systematically on a daily basis for the second part of the time series when the temperature measurements were out-doors; one would be forced to resort to the use of average in-door seasonal temperatures. It was decided that corrections for temperature fluctuations were adequately small for present purposes and they have not been applied. An overall pressure correction for mean temperature has also been omitted, given that the Hutchinson pressure data were adjusted to the Edinburgh information (and in turn will be 're-adjusted' to a combination of Edinburgh, London and Bidston information below). A further set of corrections, such as scale errors and capillarity, which are dependent on the particular instrument used, should also be made (Middleton, 1964; Slonosky et al., 2001). However, as mentioned above, information on the instrument is not available. A correction for the height of the barometer above mean sea level would normally be applied to convert station pressure to MSLP. If the barometer was about 41 feet above high water, or approximately 20 m above mean sea level, then the correction would be around 2 mbar. However, as in the case of the overall pressure correction for mean temperature, it was unnecessary to consider this time-independent term in the present analysis.

A final consideration concerns bias in the Hutchinson data due to sampling air pressures only at noon, rather than the several times a day sampling used for most of the later

MSLP records. Again, this is largely a constant, rather than a time-dependent, bias. It can be estimated from knowledge of the worldwide distribution of solar diurnal and semi-diurnal atmospheric tides (Chapman and Lindzen, 1970; Dai and Wang, 1999), or empirically from local high-frequency (e.g. hourly) air pressure measurements over many years. From both sets of information we conclude that such an MSLP noon bias would be of the order of several 1/10 mbar, which is less than, or comparable to, the measurement precision.

One concludes that, even though the Hutchinson pressure record contains a number of systematic shifts, the time series in between them appears to be well-measured, even without applying temperature and other corrections. Furthermore, it is possible to identify the major shifts and to adjust the record for them (with greater confidence for sections 1 and 3 than 2, as reflected in the differences between average and median ΔP for each section). Even though one would like to know more about why the shifts occurred (e.g. if there was a change in recording position or instrument), and even though this somewhat *ad hoc* 'adjustment' procedure is not perfect (as discussed further below), it is gratifying that the resulting 'adjusted' time series is as good as it is, comparing well to both the Edinburgh and London records. From this evidence, one can recognize the care that Hutchinson must have taken in his routine recording.

3.2.2 Quality Assessment via the Inverse Barometer

Hutchinson (1777) observed "... Notwithstanding gales of winds affect the tides, I observe it is more in the height than in the time ...". This statement is correct: the ocean tide at Liverpool has such a large amplitude that the weather (winds and air pressure changes resulting in storm surges) has very little effect on the time of high and low tide. However, storm surges can modify significantly the height of the tide.

He also stated: "... I cannot perceive, as has been imagined, that the tides are affected ... by the different weight of our atmosphere, as shewn by the barometer ...". This statement is incorrect, sea level changes along the west coast of England being to a great extent an ‘inverse barometer’ (IB), whereby sea level is depressed (raised) by approximately 1 cm given an increase (decrease) of 1 mbar in air pressure.

The discovery of the ‘IB effect’ is often credited to Sir James Clark Ross (1854) based on observations at Port Leopold, Canada in 1848-49. However, analysis of Hutchinson’s data by Lubbock (1836), and also work by Daussy using data from Brest, had already demonstrated the effect many years previously, as Ross acknowledged in a postscript to his paper. The Swedish scientist Nils Gissler has also been credited with an early observation of the effect (Roden and Rossby, 1999).

For the purpose of the present study, the IB effect offers a means by which Hutchinson’s tidal and air pressure data can be validated. If one or both data sets were to be of poor quality, then the tidal and air pressure monthly mean time series would show low or no correlation. On the other hand, if both data sets were acceptable and if the IB effect was a good representation of the local sea level response to air pressure change, then there would be a high negative correlation between the two series and a linear regression, using air pressure as the independent variable, would yield a regression coefficient of approximately -1 cm/mbar. At some locations, the effects of winds and other meteorological and oceanographic factors can result in different coefficients. However, a close approximation of the IB response is known to be valid for the west coast of England at monthly time scales (Thompson, 1980).

Figure 5 shows time series of monthly mean air pressure (adjusted as described above) and Mean High Water (MHW), the latter computed from Hutchinson’s tabulations (Woodworth, 1999a,b). Each time series has been deseasonalised by removing its average seasonal cycle (defined so as to have zero mean), and an additional lunar nodal (18.61 year) term has been removed from the MHW time series. The latter has an amplitude of 11.0 cm with maximum values at times determined by the lunar equilibrium tide (i.e. 1773.8 and 1792.4) (Woodworth, 1999a). (A significant corresponding lunar term will not exist in an air pressure record. However, the record could contain energy at nodal period from other sources of atmospheric variability. Such a ‘nodal’ fit to the Hutchinson data yielded an amplitude of 1.5 mbar.)

If MHW responded to air pressure as suggested by the IB effect, and if the IB effect was the only process which resulted in MHW change, then the rms of the two series would be similar (MHW and air pressure measured in cm and mbar respectively). In fact, one sees that rms air pressure is smaller than that of MHW (5.4 mbar compared to 8.2 cm) and the correlation between the two series is -0.590 instead of -1. This can be easily accounted for by a realisation that it is far harder to measure variability in ocean level than in barometer level, that there are other oceanographic processes than the IB effect that contribute to MHW change, and, to a lesser extent considering the timescales of air pressure and non-tidal sea level change, that the air pressures were recorded at noon and not at the times of high water. In spite of the additional 'noise' in the MHW series, a regression analysis between the two yields a coefficient of -0.891 ± 0.072 cm/mbar, consistent with previous studies of monthly sea level change on the west coast of England (Thompson, 1980). The residuals of the regression have an approximately normal distribution. However, an exception to the generally good correspondence between parameters is evident in the first year of Figure 5 (1768), consistent with the concerns over the precision of the air pressure measurements at this time as demonstrated in Figure 4. Removal of that year from the analysis modifies the coefficient to -0.897 ± 0.074 cm/mbar. (Removal of the 'nodal' component of air pressure, as described above, modifies the coefficient by only 0.02 cm/mbar.)

An experiment was conducted in which the monthly MHW measurements were replaced by monthly MHW values computed using Proudman Oceanographic Laboratory tidal prediction software. This MHW time series contains signals of tidal origin only, and does not contain a predicted sea level response to air pressure. Seasonal and nodal components were removed as before. The correlation coefficient between that residual series and the measured monthly air pressures was found to be -0.053, which is consistent with zero correlation as expected. This altogether provides a confirmation that genuine air pressure effects are indeed reflected in the measured MHW values.

One concludes that the Hutchinson adjusted air pressure and MHW time series must both be of generally good quality, otherwise the anticipated IB correlation coefficient would not have been obtained. Therefore, Hutchinson must have been a good observer of both parameters.

3.3 Rainfall

Hutchinson began his rainfall measurements in June 1774 using a rain-gauge ‘on the roof of my house 41 foot above the highest water mark’. When away from home, rain totals were accumulated into a value shown on the day of return. As a result, some rainfall will be included in the total for the following month. The rain column often indicates ‘snow’; those days were treated as having no rain. Sometimes, Hutchinson showed a series of days of snow with the words 'snow accumulated to' followed by a rain value; that amount was treated as if it had been ordinary rain. The Hutchinson snow remarks were not consistent from year to year, and individual winter monthly totals may have been misrepresented to some extent. However, Liverpool tends to experience limited periods of snow, and one would expect the reported annual rainfall totals to be affected by only a small amount.

A monthly rainfall total was defined, provided that at least 20 days had a rain record. Any gaps in the month were then accounted for by scaling up the recorded total by the number of days in the month. Figure 6 shows the resulting monthly mean rainfall totals in the units Hutchinson used (eighths of an inch), demonstrating considerably higher rainfall in the later part of the record. These data were employed by Craddock (1976) within a study of changes in rainfall in the English regions since 1725. As a consequence, the values for the Liverpool region in his analysis for the late-1780s and early-1790s appear anomalously high compared to values for almost any period since.

One might suspect from Figure 6 that Hutchinson must have changed his rain gauge, its location or some other aspect of his method of working at some point in the late 1780s. However, it is clear from other data sets from the region, including the extensive rainfall information for Manchester which was not included in the Craddock analysis, that this part of England had at least 20% more rainfall than normal in this period (Manley, 1972). This high rainfall was not accompanied by especially low air pressure, as one might have expected (Woodworth, 1985; Murphy and Washington, 2001).

Ten years of the Hutchinson record possess monthly rainfall totals (calculated as above) for all 12 months and are unaffected by a large number of snow days. These have been averaged to compute an average annual rainfall total of 37.93 inches and an average rainfall seasonal cycle: 2.87, 1.99, 1.90, 2.47, 3.01, 2.69, 3.81, 4.15, 3.64, 3.72, 3.59, 4.07 inches for January-December respectively.

One can compare these totals to those presented by Reynolds (1953) for the nearby Bidston Observatory over the period 1867-1951, although absolute comparisons must always be problematic when different rain gauges have been used at different, even nearby, locations. Nevertheless, the annual average rainfall total obtained by Reynolds (28.68 inches) and the Hutchinson average total are consistent, when one recalls that the Hutchinson period is known to have been wetter than normal. The seasonal cycle in the two data sets is almost identical with lowest values in February-April. Summer (April-September) accounts for 52 and 50 % of the annual total in the Hutchinson and Reynolds data sets respectively. As far as one can make conclusions from short records, this suggests little long term change in the seasonal cycle of rainfall at Liverpool, in contrast with evidence from Paris which indicates increasing amounts of rain in winter over the last three centuries (Slonosky, 2002).

In summary, the Hutchinson rainfall record appears to be consistent with information from elsewhere in NW England and with later rainfall measurements obtained nearby. Consequently, there is good reason to claim that Hutchinson was a conscientious observer of rainfall also.

4. A Long Term Liverpool Mean Sea Level Pressure Record

In 1845, the Mersey Docks and Harbour Board established an Observatory at Waterloo Dock in order to provide services to shipping (calibration of chronometers, provision of tidal, meteorological and astronomical data etc.). In 1866, the Observatory transferred to Bidston on the Cheshire side of the Mersey, where meteorological measurements were to continue for more than a century (Reynolds, 1954; Jones, 1999). The quality of the measurements deteriorated after 1999, and they were discontinued in 2004 prior to the transfer of the work of the Observatory (now the Proudman Oceanographic Laboratory) to a new building in Liverpool. I shall refer to the combined Waterloo/Bidston MSLP time series to the end of 1999 as simply the 'Bidston' record. It can be downloaded from http://www.pol.ac.uk/appl/met.html.

Figure 7 shows annual MSLP values for Bidston, Edinburgh and London. Over the common observation period 1846-1995, the interannual variability in MSLP is similar at all three sites, correlation coefficients of the annual means being 0.849 (Bidston and Edinburgh), 0.856 (Bidston and London) and 0.818 (Edinburgh and London). Consequently, the time-dependence of each record is similar. However, there is a question concerning their average values. On average, Bidston MSLP is 0.67 mbar higher than at Edinburgh and 2.70 mbar lower than at London. In other words, MSLP at Bidston is on average higher than at Edinburgh by only 20 % of the London-Edinburgh MSLP difference. As Bidston is located roughly half-way between London and Edinburgh (Figure 1), one might have expected a higher percentage.

A check of the quality of the Bidston MSLP record was made by comparison of annual mean values to those from Dublin, the record of the latter spanning 1831-1995 (Jones et al., 1999). Dublin is at a similar latitude to Bidston (Figure 1) and one might expect MSLP values to be similar. The correlation coefficient of annual MSLP over the period 1846-1995 was found to be 0.893, while the rms of annual MSLP-difference was 0.74 mbar, and the average Dublin-Bidston MSLP difference was 0.71 mbar. One concludes that the two MSLP records are in excellent agreement with regard to their time-dependence, but one (or both) could have a systematic offset. A second check was made with the MSLP record from the nearby Manchester Airport for the period 1951-1999. Manchester is also at a similar latitude to Bidston, but in the opposite direction to Dublin (Figure 1). The Manchester record also demonstrated excellent correlation with Bidston (0.954), rms of annual MSLP-difference of 0.47 mbar, and average Manchester-Bidston MSLP of 0.60 mbar. One concludes that Bidston's entire MSLP record might be biased approximately 0.6 mbar too low; more detailed checks demonstrate that a similar bias throughout the record. (An identical conclusion is obtained with the use of median pressure-differences between Bidston and other sites as with average pressure-differences.)

Figure 7 includes the 'adjusted' Hutchinson record for 1768-1793, 're-adjusted' by means of an overall offset such that the London-Liverpool and Liverpool-Edinburgh pressure differences are in the same proportion as for the 1846-1995 data (i.e. 4:1). This re-adjustment was undertaken using the calibration period 1774-1792 (less 1785) for which data exist for all three sites. In fact, the average MSLPs for Edinburgh and London in this period are exactly the same as the averages during 1846-1995. Therefore, it was straightforward to construct the re-adjusted Hutchinson record by setting its average during the calibration period to equal MSLP at Bidston 1846-1995. This re-adjustment required a small increase to the pressures of the 'adjusted' series of 0.47 mbar.

As remarked on above in the discussion of Figure 4, the first years of the Hutchinson record appear far noisier than later, partly due to the lack of precision of the early measurements (especially for 1768). In addition, the Hutchinson annual means have a larger rms than Edinburgh and London values over a common period (2.12 and 1.70 mbar using 24 years of 'adjusted' Hutchinson and Edinburgh data respectively, and 1.90 and 1.50 mbar using 19 years of 'adjusted' Hutchinson and London data respectively), and a larger rms than the values from all sites during 1846-1995 (1.59, 1.54, 1.44 and 1.59 mbar for Bidston, Edinburgh, London and Dublin respectively). Therefore, the interannual component of the Hutchinson record almost certainly has a poorer accuracy than that of the other time series. This is in spite of the evident good quality at monthly timescales, and the reasonably successful attempts at 'adjustment' for the larger shifts. A difficulty in maintaining barometer calibration over many years might have been expected, especially given Hutchinson's use of (what seems to have been) a single instrument.

Figure 7 also includes 7 years of data spanning 1828-1834. These measurements were made at Prince's Dock on the Liverpool waterfront, under the supervision of Jesse Hartley, the Liverpool Dock Engineer, and were archived at the Royal Society. Similar barometer measurements supervised by Hartley were made at two other docks (Salthouse and Queen's) but their records have faded badly and have not been used. Air pressures were noted at each high water, providing approximately 60 samples for a monthly mean. No other measurement details are available. One suspects that the barometers were every-day instruments read by the dockmasters' assistants. The Prince's data have been 're-adjusted' to lie between Edinburgh and London using a similar procedure as for the Hutchinson data. The correlation coefficients between annual mean values at Prince's and those at Edinburgh and London are 0.555 and 0.638 respectively, compared to 0.897 between Edinburgh and London in the same period. (In principle, the Prince's high-water air pressures could be adjusted for the local lunar atmospheric tides. However, their amplitudes are an order of magnitude lower than the solar tides which were themselves demonstrated above to be small, Chapman and Lindzen, 1970.)

The 're-adjusted' time series still has major gaps between 1794-1827 and 1835-1845 during which several significant meteorological events are known to have occurred. For example, the 'Great Storm' of 6 January 1839, possibly the worst storm in Liverpool in the last few 100 years and in which about 200 people died, falls in one of the gaps (Lamb, 1991). Dublin MSLP could be 're-adjusted' to fill the second gap. However, an alternative procedure, suitable for both gaps, is simply to scale the Edinburgh and London values in a manner consistent with experience of the later Bidston record, such that the Liverpool value is higher than at Edinburgh by 20 % of the London-Edinburgh MSLP difference. Figure 7 demonstrates the resulting annual MSLP time series for

Liverpool from 1768 to 1999, based primarily on the Bidston record, together with a combination of Hutchinson, Prince's and scaled Edinburgh and London data. A systematic uncertainty of approximately 0.6 mbar can be attached to the entire Liverpool/Bidston time series for the reasons given above, with the series possibly biased low by that amount. The source of this bias is so far unknown.

5. Conclusions

This study has demonstrated that most of the Hutchinson meteorological information is of good quality. As a result, it has shown William Hutchinson to have been a conscientious and accurate observer of the weather. By implication, it is most probable that his tidal data were of good quality also. A test of the validity of the 'inverse barometer', using the Hutchinson monthly air pressure and tidal data sets, confirmed that both records must have been well-measured. The Hutchinson air pressure record has been combined satisfactorily with later data from Liverpool to make a near-continuous time series from 1768 to the end of the 20th century.

In spite of accuracy limitations of the Hutchinson air pressure data on longer (interannual) timescales, his time series is a valuable contribution from NW England to a developing set of UK and European meteorological 'data archaeology' (e.g. Ansell et al., 2006), with air pressure records from some northern European sites now extending back to the late 17th or early 18th centuries (e.g. Bergström and Moberg, 2002; Können and Brandsma, 2005). As more long air pressure records are extracted from archives, converted into computer-accessible form, and subjected to a level of quality control which is possible only when multiple time series are available for analysis, then significantly greater insight will be obtained into long term air pressure and atmospheric circulation change.

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Figure Captions

1. Locations of historical air pressure measurements discussed in the text. The two dots at Liverpool illustrate the Old Dock where Hutchinson made his measurements, located approximately 1.5 km south of the Waterloo Dock Observatory. Prince's Dock is located in between the two.

2. Monthly mean temperature (° F) at noon from Hutchinson's tabulations.

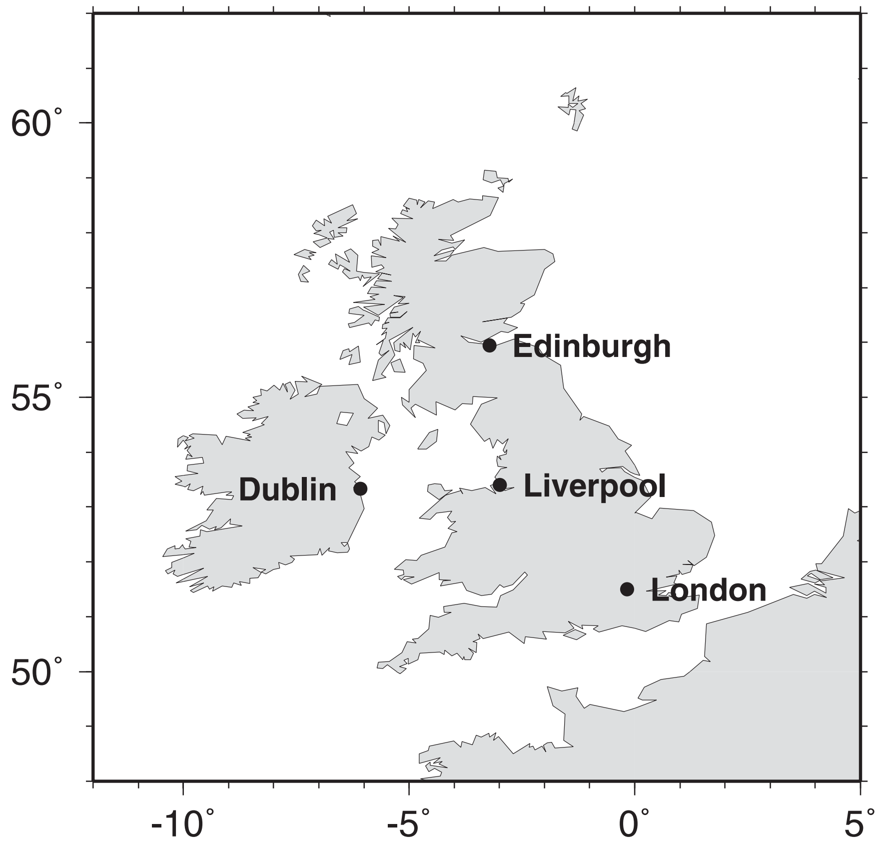
3. Scatter plot of Liverpool (Hutchinson) and Edinburgh monthly mean air pressures for sections of data (1) red dots (January 1770 – December 1780 and December 1789 – August 1793), (2) blue triangles (August 1787 – November 1789) and (3) green squares (January 1781 – July 1787).

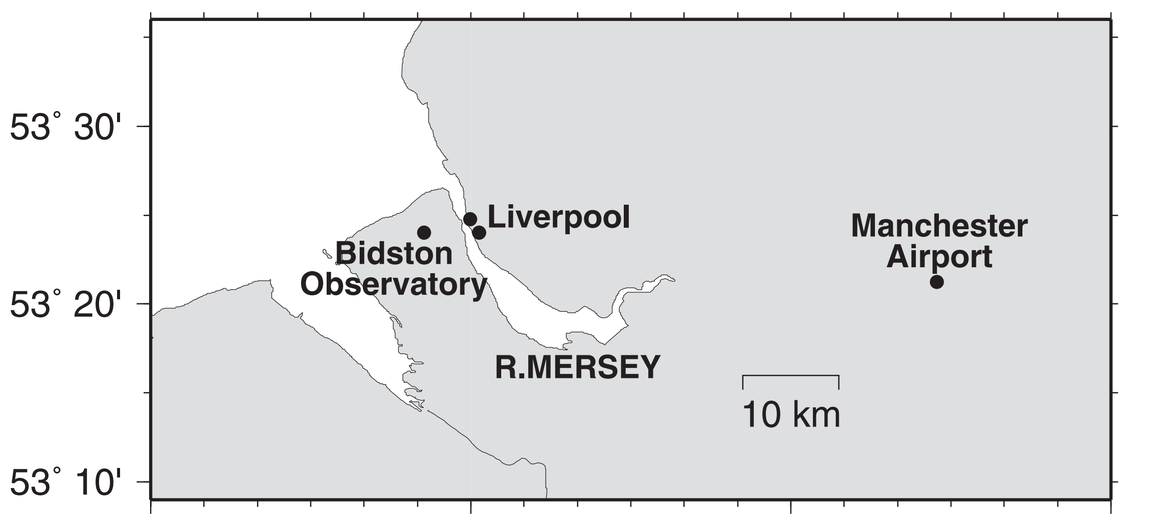
4. Annual mean air pressure for the 'adjusted' Hutchinson data (dots) together with values for Edinburgh (stars) and London (triangles). The average of the adjusted Hutchinson data has been constrained to be that of the Edinburgh data over each of the three sections of data described in the text.

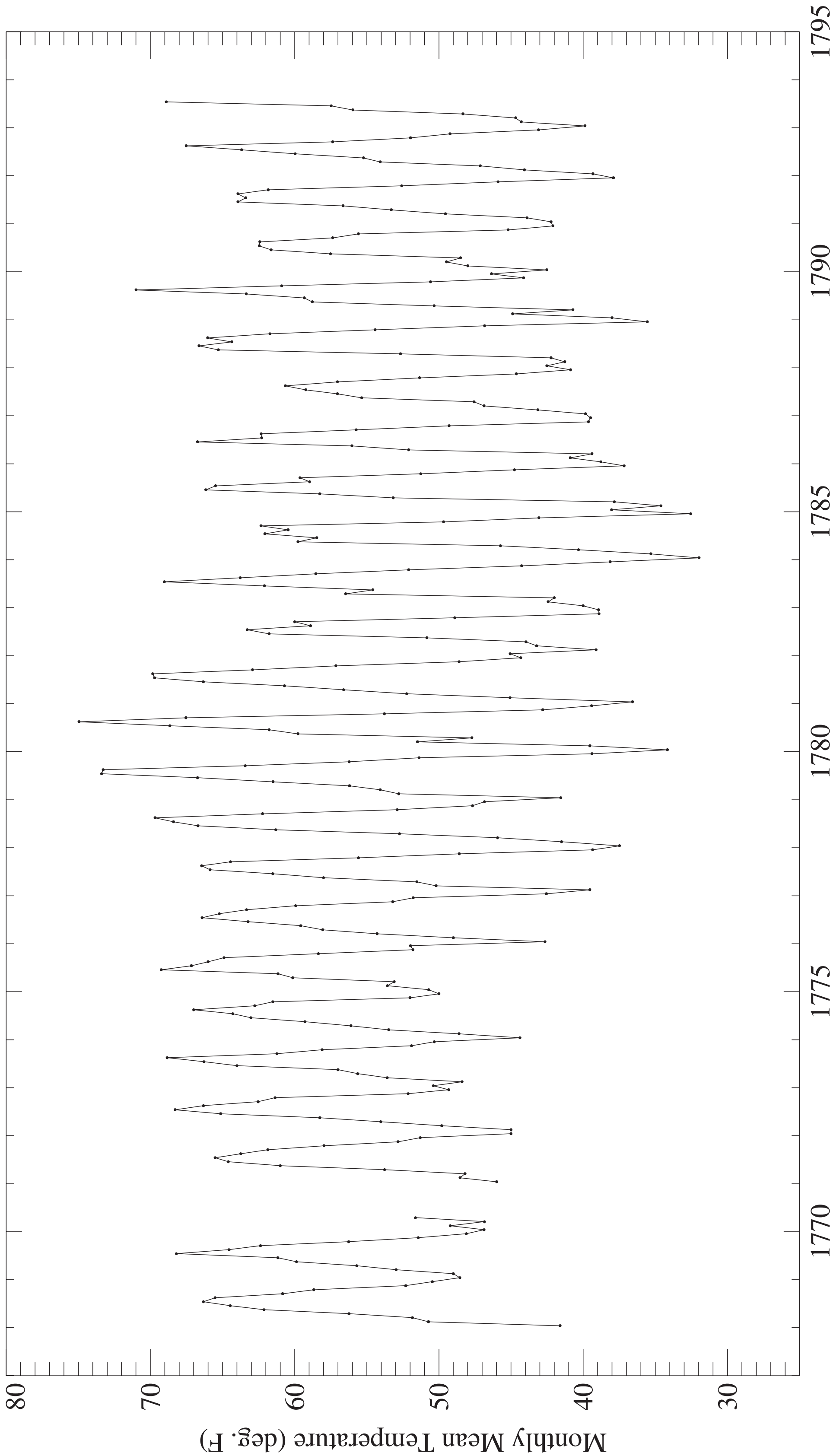
5. Time series of monthly mean air pressure for the 'adjusted' Hutchinson record (top, mbar) together with monthly mean high water (MHW) over the same period (bottom, cm). The latter time series is shown inverted for comparison to the former and is expressed relative to an arbitrary reference level. Both series have been deseasonalised and an additional nodal term has been removed from the MHW record.

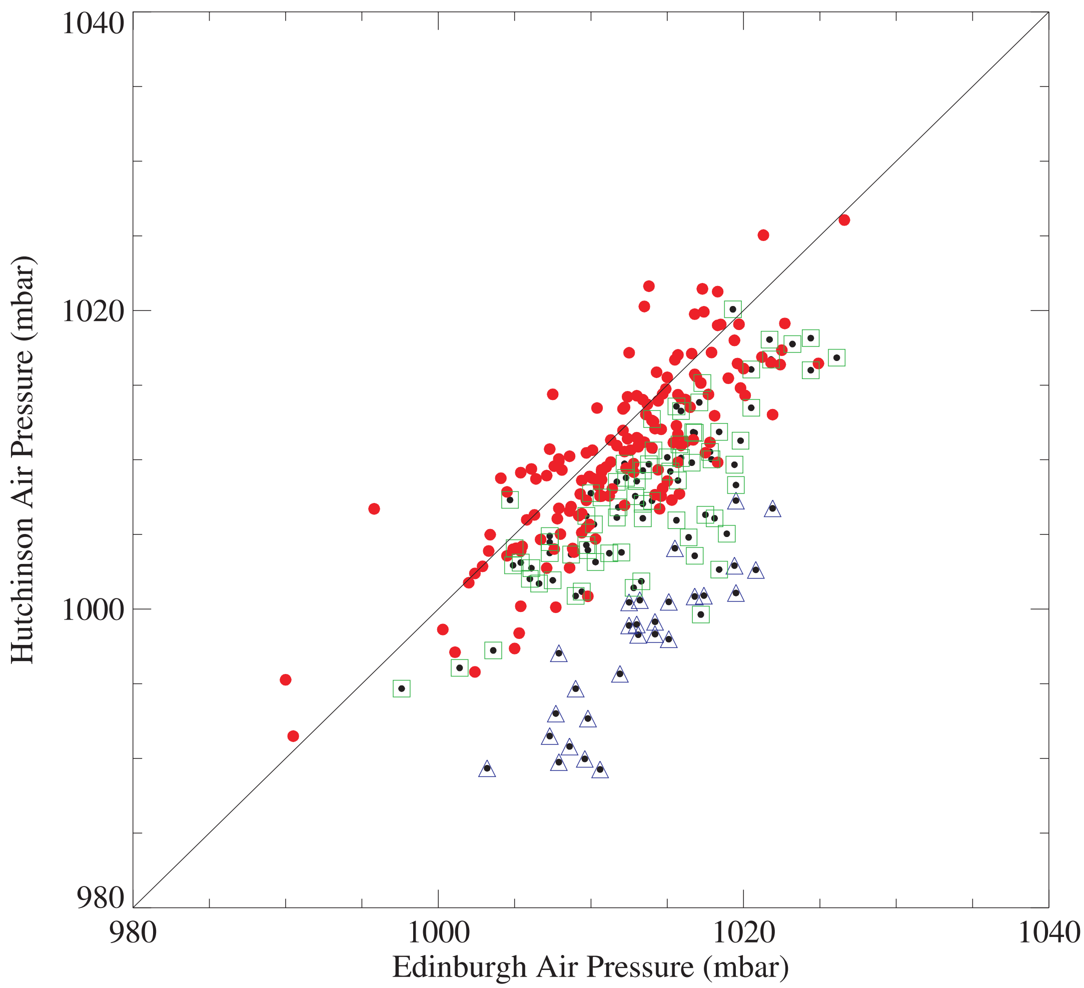
6. Monthly mean rainfall totals from the Hutchinson tabulations in units of eighths of an inch.

7. Time series of annual mean sea level pressure (MSLP) from Edinburgh (1770-1995) in blue, London (1774-1995) in green and Liverpool in red. The latter includes the 're-adjusted' Hutchinson (1768-1793), 're-adjusted' Prince's (1828-1834) and Bidston (1846-1999) records. Dashed red lines are shown for the years with no Liverpool data, obtained by scaling Edinburgh and London values.

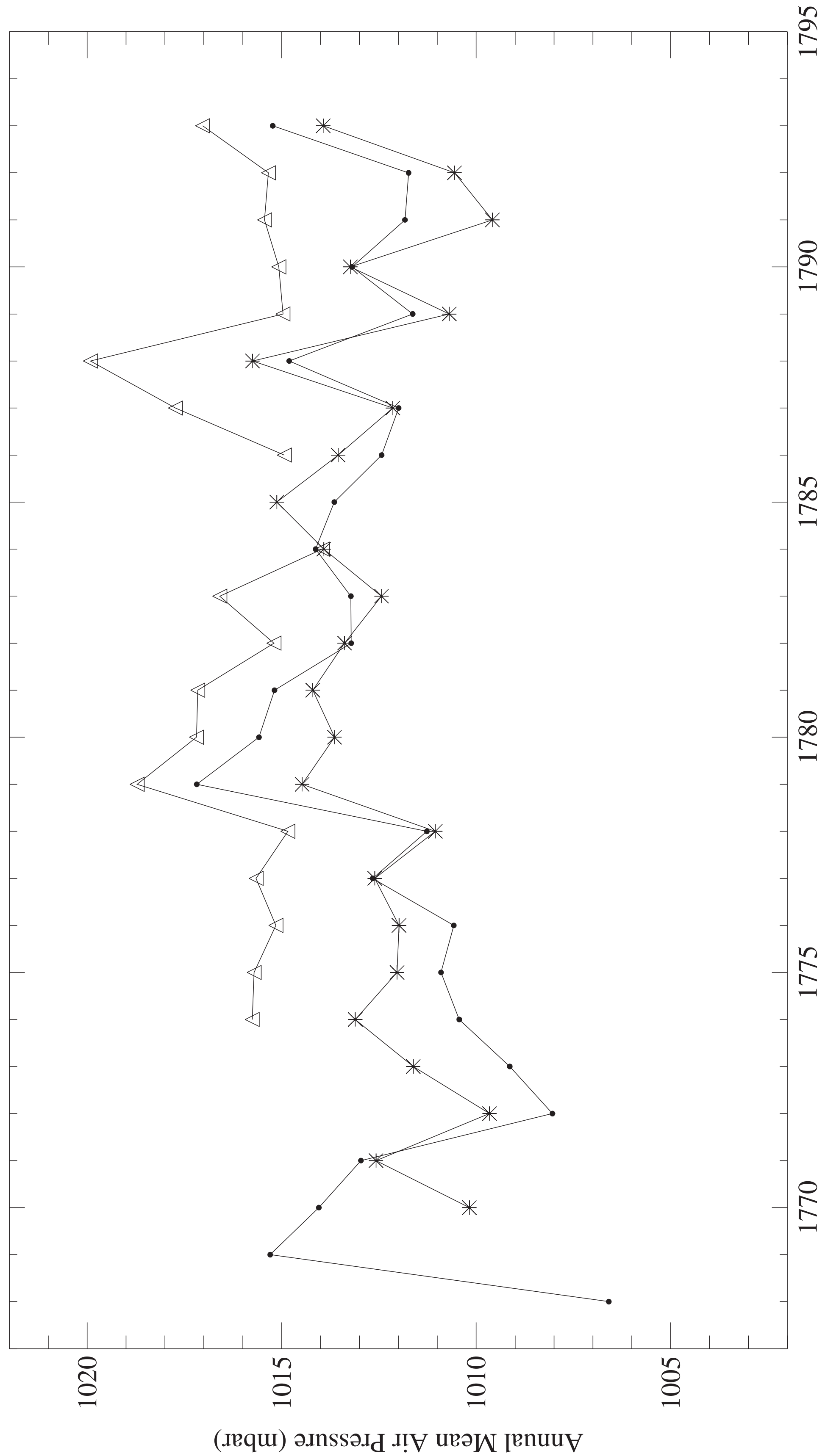

60°
55°
50°
-10°
-5°
0°
5°
Edinburgh
Dublin
Liverpool
London

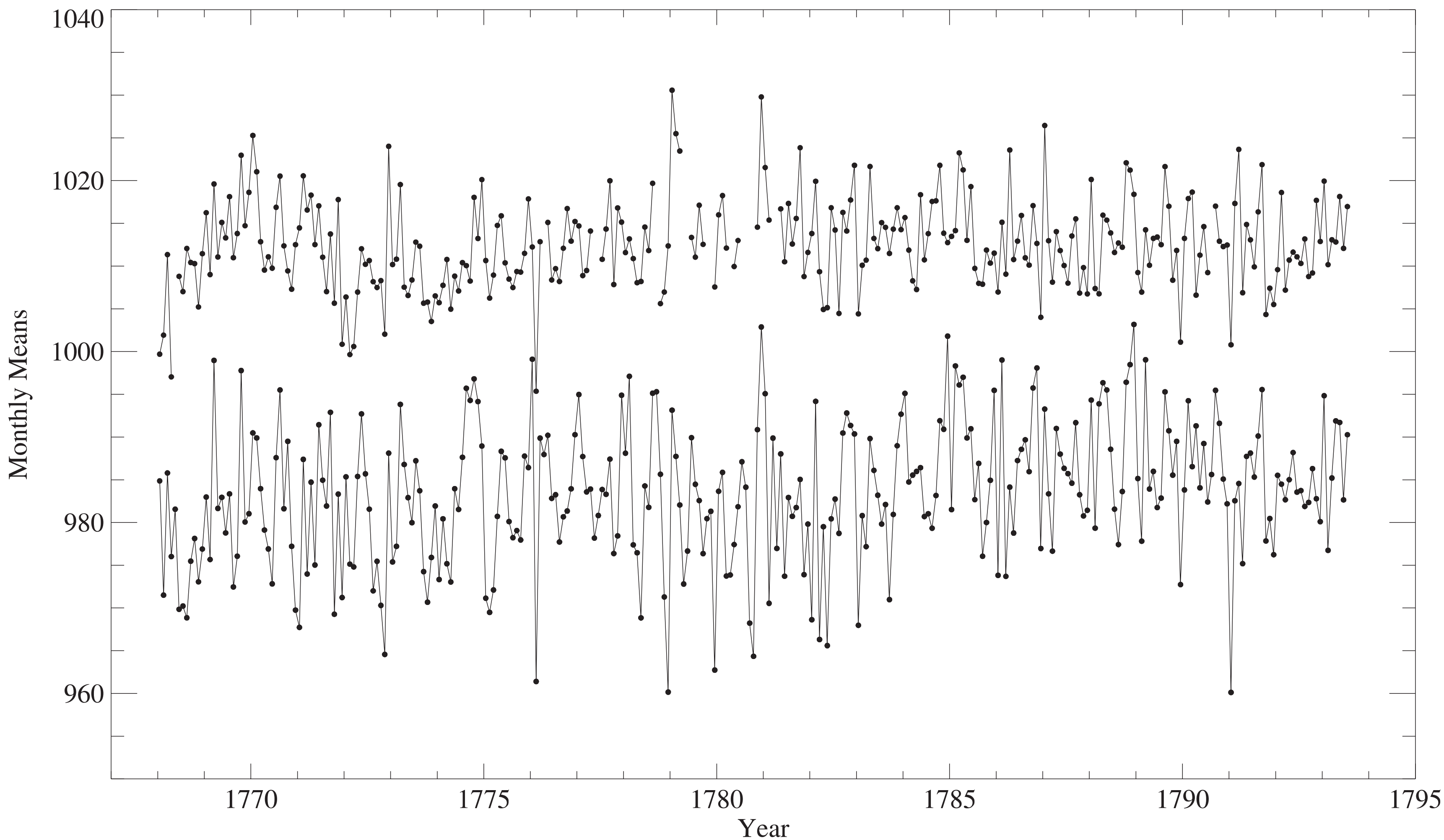

53° 30'
53° 20'
53° 10'
-3° 30'
-3° 00'
-2° 30'
-2° 00'
Liverpool
Bidston
Observatory
Manchester
Airport
R.MERSEY
10 km

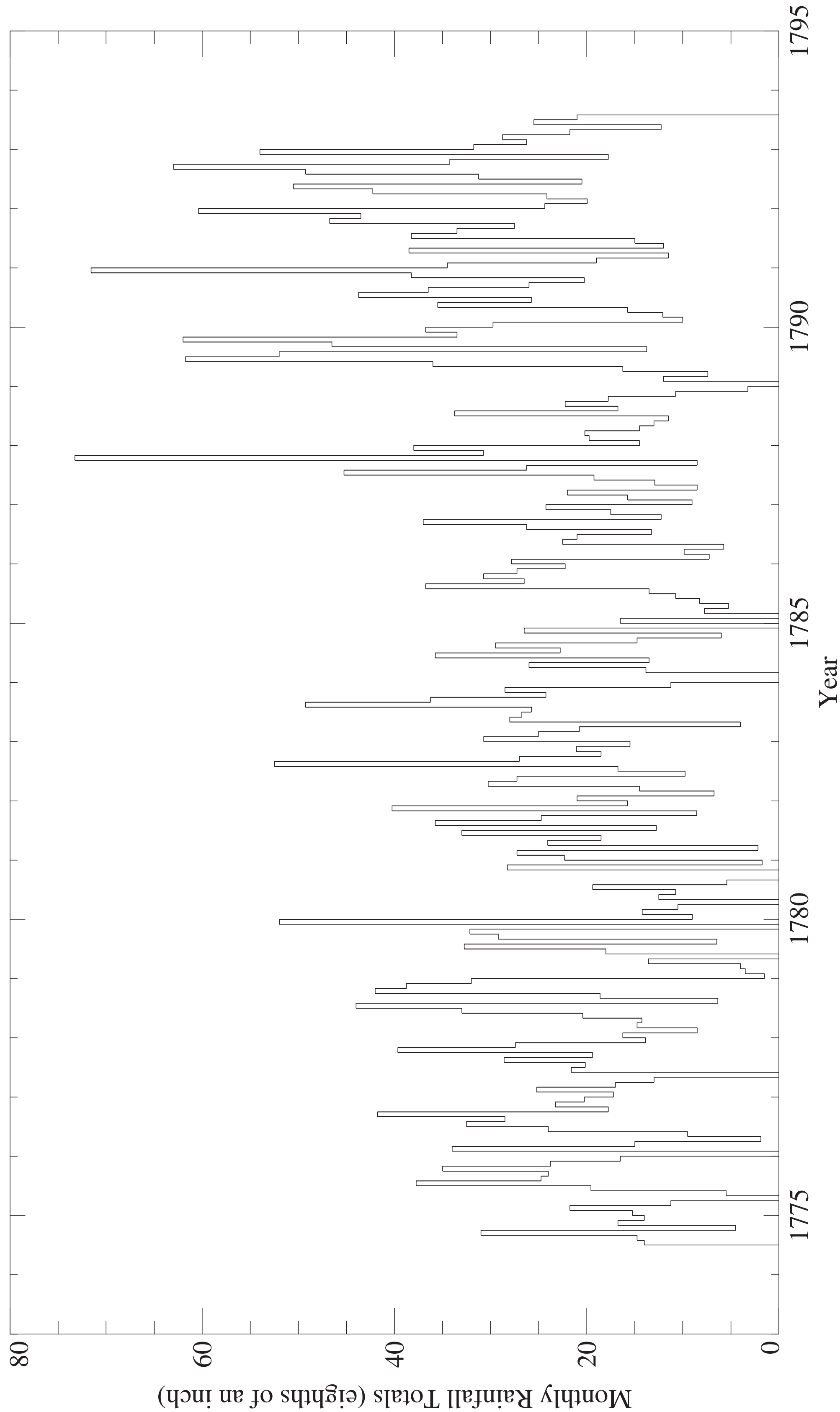

Monthly Mean Temperature (deg. F)
80
70
60
50
40
30
Year
1770
1775
1780
1785
1790
1795



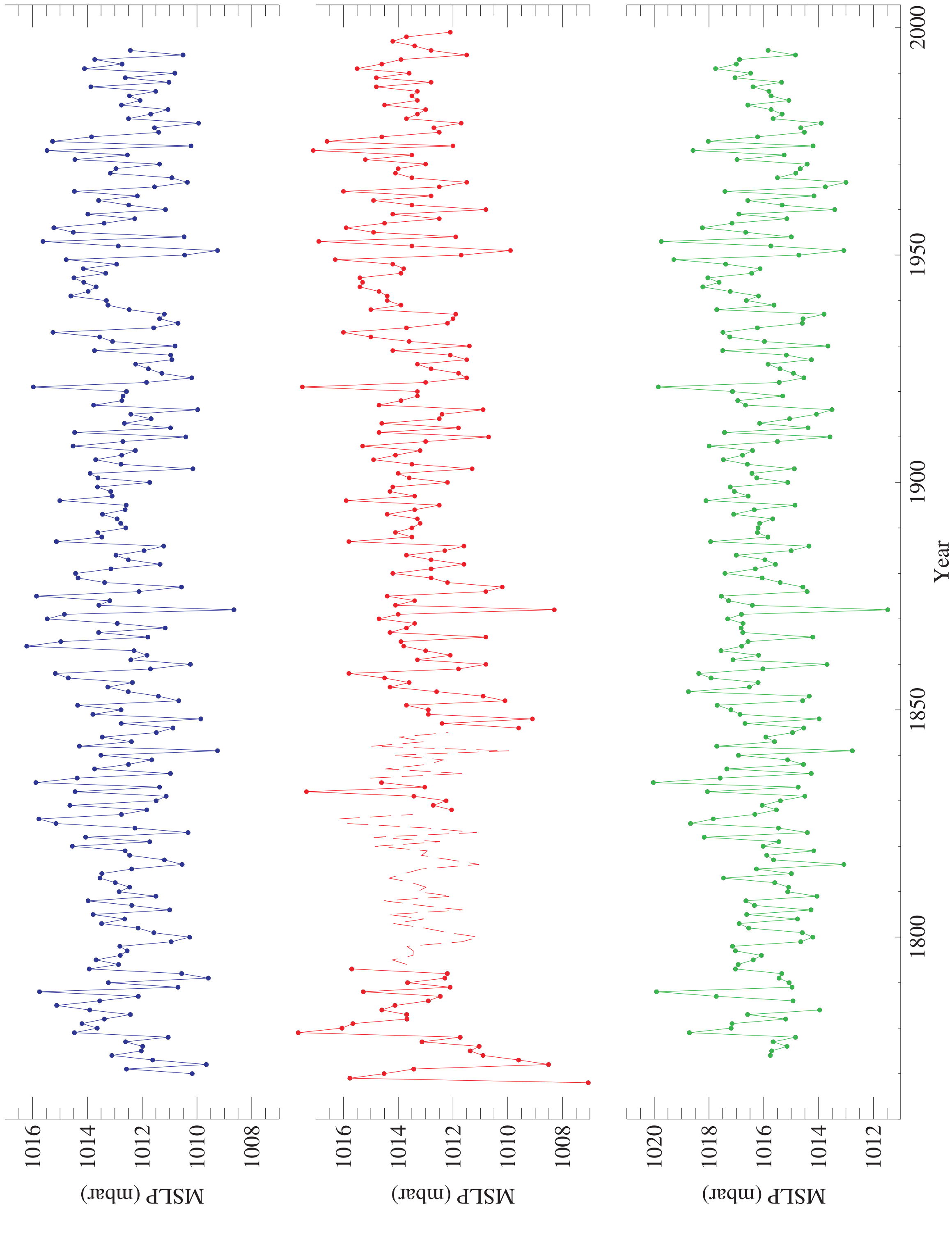
1040
1020
1000
980
980
1000
1020
1040
Hutchinson Air Pressure (mbar)
Edinburgh Air Pressure (mbar)


Annual Mean Air Pressure (mbar)
1005
1010
1015
1020
Year
1770
1775
1780
1785
1790
1795


1040
1020
1000
980
960
Monthly Means
1770
1775
1780
1785
1790
1795
Year



Monthly Rainfall Totals (eighths of an inch)
Year
0
20
40
60
80
1775
1780
1785
1790
1795


MSLP (mbar)
1016
1014
1012
1010
1008
MSLP (mbar)
1016
1014
1012
1010
1008
MSLP (mbar)
1020
1018
1016
1014
1012
1800
1850
1900
1950
2000
Year