DANISH METEOROLOGICAL INSTITUTE

——— TECHNICAL REPORT ———

97-3

North Atlantic-European pressure observations 1868-1995 (WASA dataset version 1.0)

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CDROM containing appendices A-B encloced

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1 Introduction

This report describes the compilation of a dataset consisting of time series of mean sea level (msl) pressure ranging back to the beginning of the instrumental period, i.e. latter part of the 19th century and with 3-4 daily observations from 22 stations in the Atlantic-European region.

The compilation of this dataset is part of the EU project: 'The impact of storms on waves and surges: Changing climate in the past 100 years and perspectives for the future' - abbreviated WASA - which aims at evaluating trends in storminess throughout the past 100 years in the Northeast Atlantic region and giving perspectives for the future.

The dataset contained in this report may in many respects be seen as a sister-dataset to the 'North Atlantic Climatological Dataset' - abbreviated NACD - (Frich et al., 1996), which is a dataset containing monthly values of five different climatological elements from the period 1890-1990. Many procedures and methods used in WASA have been taken over from NACD.

2 Overall description of data

Regular pressure observations started in the European/North Atlantic area during the latter part of the 19th century. Therefore it has to a wide extent been possible to select stations covering the period 1875-1995, and with the temporal resolution of 3-4 observations/day, although also shorter time series is included in the dataset. The ideal case would be an approximately equally-spaced selection of stations but this was not possible. In practice the distance between the stations varies between 200 and 1000 km.

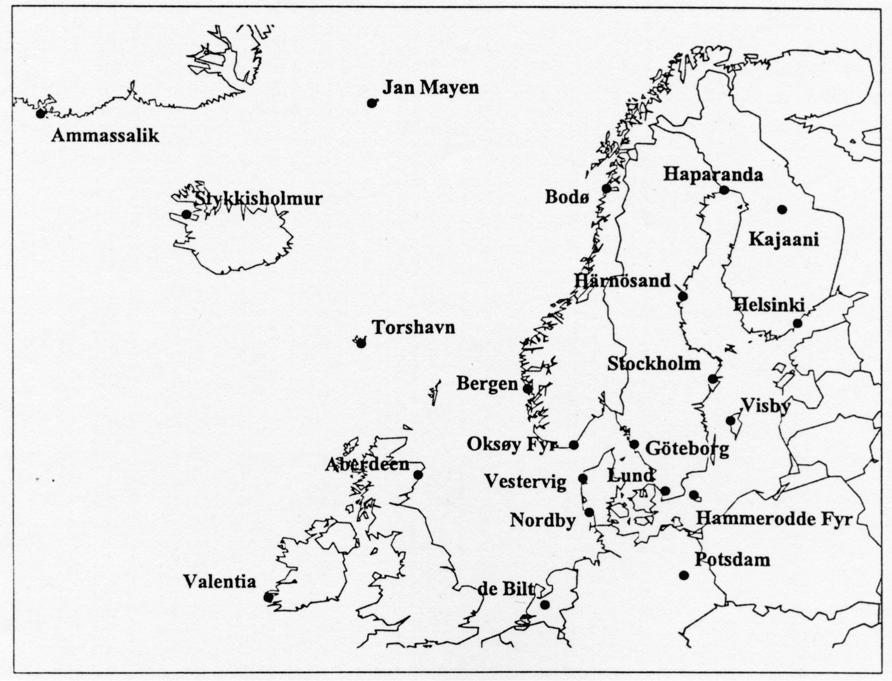

Figure 1 Map of geographical positions of stations

The map on figure 1 shows the geographical positions of the 22 selected stations. A complete station catalogue with positions and observing periods can be found in the appendix A.

The dataset is included as the appendix B of this report.

3 Limitations on use

This dataset is for scientific purposes only and when using the dataset proper reference should always be made to this report.

4 The concept of homogeneity

According to Conrad & Pollack (1962) a climatological time series is called homogeneous when its variations are caused only by variations in weather and climate, i.e. inhomogeneities are caused by changes in instrumentation, observation practice, environment etc.

4.1 Homogeneity of pressure observations

Pressure observations have the advantage of being rather insensitive to changes in instrumentation and station surroundings. It is therefore one of the better elements to study over a longer span of time (Heino, 1994). But it turns out that inhomogeneity problems show up also in pressure records. This will be demonstrated on the following pages.

4.2 Standard Normal Homogeneity Test

In this work most series have been tested for homogeneity by means of a statistical test, the 'standard normal homogeneity test' (SNHT). This test compares a series (the test series) against other series which are known to be homogeneous (the reference series) and it points out the particular year, when the test series jumps to another level compared with the reference series. Such an inhomogeneity is known as a break. The SNHT is described in detail in Alexandersson (1986) and Steffensen et al. (1993).

4.3 Correction vs. adjustment

At this point we will introduce the difference between the concepts *correction* and *adjustment*. Both are quantities to be added or multiplied to the original quantity to get an improved series. But in the case of a correction there is some kind of agreed standard behind, e.g. temperature correction of a barometer, wind correction of a precipitation gauge etc. On the other hand an adjustment is a result of a purely statistical test as the SNHT, often in combination with some explanation such as relocation or change of instrument. Therefore it is important that we first apply all relevant corrections to the original data and then test for homogeneity by SNHT and apply adjustments if necessary.

5 Metadata

Metadata can be described as data describing data. Thus the station catalogue concept known from climatology is a kind of metadata. However, the scope of metadata is wider, including all aspects that might influence the observations such as: instrumental conditions, environmental conditions and calculations applied to the observed data at or just after observation time.

The importance of metadata is connected with the process of using SNHT. The statistical test can only point out candidate-years for homogeneity-breaks. These breaks should be supported in metadata, e.g. recorded instrument failure.

The collection of metadata consists ideally of the systematic inspection of the files, from which the relevant information is extracted and stored in a systematic way in a database. This process is usually very laborious. Going hundred years back in time, big holes of missing documentation may show up in the paper archives. One may say that not only data but also metadata are inhomogeneous.

The systematic approach to the metadata concept is rather new and therefore still in the evolving phase. A step forward within the field has been taken within the NACD project (Frich et al., 1996). Larsen et al (1993) describes the metadata system presently used at the Danish Meteorological Institute.

When working with historical pressure records, one must keep track of which procedures were applied where and when, since these often have changed through time and from country to country. Therefore the most important metadata are: height of barometer, barometer conditions (e.g. known malfunctions of barometer) and calculations made on data at observation time.

6 Calculating msl pressure from barometer reading

Basically, what is observed is a barometer reading, often calibrated in millimetres or inches of mercury, from which it is possible to calculate the pressure at the station level by adding several corrections. These corrections are related to the construction and calibration of the barometer, and the procedure varies with the barometer type.

Once having calculated the station pressure one can calculate a msl pressure by applying a height reduction.

The procedure for correction and reduction follows WMO (1983). Slight differences between the formulas used in the different countries may have occurred but generally they follow the principles described in 6.1-6.3.

6.1 Corrections applied to mercury barometer measurements

The reading of a mercury barometer is proportional to the length of a mercury column which is balanced against the weight of the entire atmospheric air column. Therefore the barometer is only calibrated at ‘standard conditions’ ($0^o C$ and standard gravity $g_n = 9.80665\ m\ s^{-2}$). At other conditions corrections must be applied. Also index error (instrumental error) must be corrected for.

6.1.1 Correction for index error

This correction is the residual errors of a barometer when compared with the normal barometer. According to WMO (1983) the index error should not exceed a few tenth of a hPa when the barometer is working properly. However, in case of malfinction of the barometer, it may be larger due to e.g. impurities in the mercury or defective vacuum, according to WMO (1983) up to 5 hPa. Only by regular inspection and maintenance of the instrument large index errors can be avoided.

6.1.2 Correction for barometer temperature

Suppose that the level difference in the barometer is l and the barometer temperature t . As the barometer is calibrated to standard conditions, the reading will be

$$B_t = r_0 \, g_n \, l \,,$$

r_0 being the density of mercury at standard conditions.

On the other hand the air pressure is given by

$$\begin{aligned} p_t &= r_t \, g_n \, l \\ &= \frac{r_0}{(1 + at)} g_n \, l \\ &\approx r_0 \, (1 - at) \, g_n \, l \end{aligned}$$

where r_t is the density at temperature t and $a = 0.0001818 \, K^{-1}$ the volume thermal expansion coefficient for the combined mercury-scale system.

From this we can get the correction C_t to be applied to the barometer reading as

$$C_t = p_t - B_t = - aB_t t$$

Putting in realistic values we get $C_t \cong -4 hPa$. According to WMO (1983) the uncertainty in the correction is below 0.1 hPa.

A more accurate elaboration gives slightly different formulae for the different types of barometers. These formulae can be found in WMO (1983).

6.1.3 Correction for gravity

To get the best estimation of station pressure the local value of gravity g, depending on latitude, height above msl and local topography, must be used. If g is not known from geophysical measurements WMO (1983) gives several formulas, of which this simple one may be used in most cases, taking only the latitude into account:

$$g = 9.80616 \cdot (1 - 0.0026373 \cdot \cos(2j))$$

Suppose that the level difference in the barometer is l and the local gravity g . As the barometer is calibrated to standard conditions, the reading will be

$$B_g = r_0 \, g_n \, l \,,$$

whereas the pressure will be given as

$$p_g = r_0 \, gl \,.$$

Therefore one gets the correction to be applied as

$$C_g = p_g - B_g$$

$$= B_g \left[\frac{g}{g_n} - 1\right]$$

Putting $j = 60^0$ one gets $g = 9.81909 m\, s^{-2}$ and we get an estimation of the magnitude of the correction as $C_g \cong 1hPa$.

6.1.4 Obtaining the station pressure

According to the previous the pressure at the station corrected for temperature and gravity is given by

$$p_s = B_t + C_t + C_g.$$

6.2 Corrections applied to aneroid barometer measurements

For these instruments no correction for gravity is needed. The temperature compensation is usually done as a calibration instead of a correction constant. Thus we are only left with a index correction

However, it must be pointed out that this does not mean that aneroid barometers are more accurate than mercury barometers. Generally mercury barometers are considered to be more accurate.

6.3 Reduction to mean sea level

Having determined the station pressure p_s, it is desirable to reduce the pressure to msl. Combining the hydrostatic pressure approximation

$$\frac{dp}{dz} = -rg$$

and the equation of state

$$\frac{p}{r} = RT$$

where T is the (strictly speaking virtual) absolute air temperature yields

$$\frac{dp}{p} = -\frac{g\, dz}{RT}$$

which can be integrated to the hypsometric equation

$$\ln\frac{p_s}{p_0} = -\frac{g}{R}\int_0^h \frac{dz}{T},$$

h being the station height. This equation is the foundation of all the different reduction formulae.

For low level stations, i.e. when station height is below app. 100 m, the hypsometric equation can be integrated to the simpler formula

$$\ln\frac{p_s}{p_0} \approx \frac{p_s - p_0}{p_0} = -\frac{g}{R}\frac{h}{T_s},$$

where T_s is the air temperature measured at the station. This gives the reduction to be added

$$R_h = p_0 - p_s = p_0\frac{g}{R}\frac{h}{T_s} \approx p_s\frac{g}{R}\frac{h}{T_s}$$

Putting $h \cong 100m$ gives the order of magnitude of the reduction for low level stations as $R_h \cong 10hPa$.

There are several matters to be discussed concerning the reduction procedure. It is essential that T_s is representative for the (fictious) air mass between the station and msl. This might not be the case in inversion situations and might be the reason why WMO (1983) suggests using annual normal temperature instead of observed temperature.

Furthermore, to increase the accuracy, one should use virtual temperature in order to incorporate the humidity of the air. Usually the difference between temperature and virtual temperature is below 5 K.

Lets try to evaluate what factors influence the uncertainty in the reduction. We estimate this uncertainty as

$$d\,R_h \cong p_s\frac{g}{R}\left[\frac{dh}{T_s} + \frac{h\,d\,T_s}{T_s^2}\right] \cong 1hPa + 0.5hPa$$

where we have put $d\,T_s = 10K$, and $dh = 10m$. From this we can conclude two things. Firstly, we must know the station height with a better accuracy than 10m, rather 1m or so. Secondly, the uncertainty due to temperature is 0.5hPa

7 Further error sources

7.1 The influence of obstacles

Local obstacles to the airflow, in scale from houses to mountains, cause perturbations to the pressure field. As we are interested in the large scale atmospheric features we want to correct for these dynamic effects. This is, however, generally very difficult, but we can try to get an estimate of the magnitude of the effects. Here we must distinguish between small-scale and large-scale obstacles.

7.1.1 Small-scale (buildings)

Generally, a complicated dynamic pressure perturbation pattern builds up around a building (or other obstacle) during windy conditions. This perturbation is then through small leakages etc. propagated into the interior of the building and thus represents an error source of the pressure measurement. The case of such a perturbation is treated in Koschmieder (1941) based on Bernoulli's equation

$$\tfrac{1}{2}v^2 + \frac{p}{r} = \tfrac{1}{2}v_0^2 + \frac{p_0}{r},$$

where '0' refers to the unpertubated values. From this equation it is seen that an increase of the wind causes a dynamic pressure deficit. We can find an order of magnitude by putting $v_0 = 25m/s$ and $v = 30m/s$ from which we get

$$\Delta p = p - p_0 = \tfrac{1}{2} r v_0^2 - \tfrac{1}{2} r v^2 \cong -2hPa,$$

in agreement with Koschmieder and also Emmrich (1971). An important conclusion is therefore to prefer pressure data from stations not too exposed to wind, e.g. avoid lighthouse stations.

7.1.2 Large-scale (mountains)

Also mountains cause pressure perturbations but these can not be calculated as above since adiabatic cooling of the air must be taken into account. Koschmieder (1941) treats the problem and gets pressure deficits in the order of -3hPa for a speeding up from 20 m/s to 30 m/s. Emmrich (1971) contains an investigation of orographic wind enhancement near Cape Farewell. Note also the secondary effect, that the speeding up of the wind will increase the small-scale effect described in the previous section. On the Icelandic station Vestmannaeyjar this type of correction is done on a routine basis.

In the present WASA-dataset no mountain stations have been selected and this phenomenon should not cause a too serious problem.

7.2 Different observation hours

Observation practice including observation hours have changed from station to station and also through time. Therefore, when using more time series for e.g. calculating geostrophic winds, it may be necessary to interpolate a time series to other hours than the original observation hours.

An estimation of the error introduced by various interpolation methods was carried out in the following way: On pressure data from a reliable airfield synoptic station in Denmark from the period 1980-1994 several kind of interpolation methods were tested on the intermediate synoptic hour values, i.e. values at 03, 09, 15 and 21 utc were interpolated from the values at 00, 06, 12 and 18 utc. In total four interpolation methods were tested:

A: Usage of neighbour observation three hours before

B: Simple linear fitting between neighbour observation three hours before/after.

C: Fitting of 3rd degree polynomial to the two neighbours on each side of the observation.

D: A method where 2nd degree polynomials were fitted to one neighbour on one side and two neighbours on the other. From these two interpolated values the minimum was taken as the final interpolated value.

For each interpolation statistics was calculated on the interpolation error, i.e. the interpolated subtracted from the observed pressure value. In table 1a results of the comparison between the four methods are summarised:

Method	Interpolation error (=observed - interpolated value)		
	Median	1% percentile	99% percentile
A. Neighbour	0.0	-3.8	4.2
B. Linear fit	-0.1	-1.2	1.6
C. 3rd deg. fit	0.0	-1.1	1.1
D. Min. of two 2nd deg. fits	-0.2	-1.6	0.9

Table 1a Intercomparison of interpolation methods(hPa), all cases.

To put emphasis on cases with strong wind another intercomparison was performed, in which only pressure values below 990 hPa was included. Results are shown in table 1b.

Method	Interpolation error (=observed - interpolated value)		
	Median	1% percentile	99% percentile
A. Neighbour	0.2	-6.3	8.2
B. Linear fit	0.3	-1.7	4.4
C. 3rd deg. fit	0.0	-1.9	3.2
D. Min. of two 2nd deg. fits	-0.2	-2.9	2.7

Table 1b Intercomparison of interpolation methods(hPa), cases less than 990 hPa.

It is seen that going from the simple method A to a more refined method means a significant improvement. Going from the simple method B to the more complicated methods C and D there is not a very big improvement, in all cases errors up to 5 hPa must be expected. Moreover, when looking at the pressure values below 990 hPa, there is a skewness in the error distributions (except for method D) toward large positive errors, i.e. there is a tendency to overestimate low pressure values. A general guideline could be to use linear interpolation, more refined methods do not give much improvement.

In order of completeness, the semi-diurnal variation of the msl air pressure should also be briefly mentioned. At mid- and high latitudes it has an amplitude of about 0.3 hPa (Heino, 1994), meaning an error in the order of 0.1hPa in 3hrs, which is negligible in comparison with the interpolation errors in table 1a and 1b.

7.3 Horizontal movement of station

Primary criterion for including a station in the dataset was a long and unbroken record of observations. Nevertheless, it could not be entirely avoided to combine a station, which stopped operation, by a near-by which continued operation. Such stations should not be more than a few kilometres apart, and whenever that is not the case the new positions should always be used.

7.4 Single errors

Single scattered errors make out a major problem for extreme studies like WASA and must be avoided to the greatest possible extent. Therefore double-keying, which effectively eliminates keying-errors, was widely used when digitising. However, still we are left with mis-readings of the instrument or mis-writings in the original material. This was demonstrated for the three Danish stations, where all pressure values bringing about a geostrophic wind above a certain threshold(=38 m/s) were checked against weather-maps and monthly summaries. It was thereby possible to tell whether the particular value was likely and if that was not the case it was in some cases even possible to correct the erroneous values. Of these checked values for the three stations 6, 19 and 22% were in error. An often occurring error was a multiple of 5 mmHg mis-reading.

8 Summary of potential inhomogeneities and errors.

Let us try to summarise the results from the previous sections. The magnitude and uncertainty of a typical correction/reduction/interpolation is shown in table 2.

	Magnitude (hPa)	Uncertainty (hPa)
Correction for index error.(Mercury bar.)	0.1	0.1
Correction for temperature (Mercury bar.)	-4	0.1
Correction for gravity (Mercury bar.)	1	0.1
Reduction, 100 m - msl	10	1
Dynamical pressure (building), 25 m/s	-2	2
Interpolation in time, 3 hours	-2/+4	4

Table 2 The magnitude and uncertainty of a typical correction/reduction/interpolation.

Any item in table 2 above represent candidates for inhomogeneities and errors. From table 1 it can be concluded that correction for temperature and gravity as well as index error can be done with only minor uncertainty. The same is valid for the reduction to msl, provided the barometer altitude is known within 1m. Dynamical pressure effect as well as interpolation errors should be regarded as the most severe errors when analysing the data.

9 Acknowledgements

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Appendix A: Station catalogue

Stat. no.	Ctr. code	Station name	lat.	long.	Start year	End year
3342	D	POTSDAM	52 23 N	13 04 E	1893	1994
06193	DK	HAMMERODDE FYR	55 18 N	14 47 E	1874	1996
21100	DK	VESTERVIG	56 46 N	8 19 E	1874	-
		19870801-	56 42 N	8 13 E	-	1996
25140	DK	NORDBY	55 26 N	8 24 E	1874	-
		19870801-	55 31 N	8 34 E	-	1996
0304	FIN	HELSINKI	60 10 N	24 57 E	1881	-
		19610101-	60 19 N	24 58 E	-	1995
4601	FIN	KAJAANI	64 13 N	27 46 E	1887	-
		19570101-	64 17 N	27 40 E	-	1995
06011	FR	TORSHAVN	62 1 N	6 46 W	1874	1996
04360	G	AMMASALIK	65 36 N	37 38 W	1894	1996
03091	GB	ABERDEEN OBS.	57 10 N	2 06 W	1871	
		19570101-	57 12 N	2 12 W	-	1995
03953	IRL	VALENTIA OBS.	51 56 N	10 15 W	1892	1995
04013	IS	STYKKISHOLMUR	65 5 N	22 44 W	1874	1995
01001	N	JAN MAYEN	70 56 N	8 40 W	1922	1994
01152	N	BODOE	67 16 N	14 26 E	1900	1994
01316	N	BERGEN-FLORIDA	60 23 N	5 20 E	1868	1994
01448	N	OKSOEY FYR	58 4 N	8 3 E	1870	1994
06260	NL	DE BILT	52 6 N	5 11 E	1902	1994
5343	S	LUND	55 42 N	13 12 E	1879	-
		19510101-19601231	55 23 N	12 49 E	-	-
		19780101-19941231	55 23 N	12 49 E	-	1994
7243	S	GOETEBORG	57 42 N	11 59 E	1879	-
		19510101-	57 46 N	11 53 E	-	1994
7839	S	VISBY	57 38 N	18 17 E	1879	-
		19510101-	57 40 N	18 20 E	-	1994
9821	S	STOCKHOLM	59 20 N	18 03 E	1879	1994
		19510101-19601231	59 21 N	17 57 E	-	-
12738	S	HAERNOESAND	62 37 N	17 56 E	1879	-
		19810101-	62 31 N	17 26 E	-	1994
16395	S	HAPARANDA	65 49 N	24 8 E	1879	1994

Appendix B: Dataset

The dataset is contained on the enclosed CD-ROM, compliant with ISO 9660. The data is separated into files with names on the form cccsssss.dat, where ccc is country-code (right-filled with ‘_’) and sssss is station-number (left-filled with ‘_’). Thus each of these files contains data from one station.

Each record of these files contains one pressure value. The record layout is as follows:

1-5 Station number

7- 9 Country code

11-14 Year

16-17 Month

19-20 Day

22-23 Hour

25-29 MSL-pressure in hPa*10