Meteorologische Zeitschrift, PrePub DOI 10.1127/metz/2015/0654

MetZet Classic Papers

On monthly weather anomalies in the Northern Hemisphere in winter[1]

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Original citation:
EXNER, F., 1914: Über monatliche Witterungsanomalien auf der nördlichen Halbkugel im Winter. – Meteorol. Z. **31**, 104–109.

Suggested citation:
EXNER, F., 1914: Über monatliche Witterungsanomalien auf der nördlichen Halbkugel im Winter (On monthly weather anomalies in the Northern Hemisphere in winter). – Meteorol. Z. **31**, 104–109. (translated and edited by VOLKEN, E. and S. BRÖNNIMANN. – Meteorol. Z. **24** (2015), DOI:10.1127/metz/2015/0654).

Abstract

This paper is the edited translation of a short paper by FELIX EXNER "Über monatliche Witterungsanomalien auf der nördlichen Halbkugel im Winter" (On monthly weather anomalies in the Northern Hemisphere in winter), which was published in *Meteorologische Zeitschrift* **31**, 104–109. The paper is a summary of a more extensive paper by the same author published in full in the *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften.*

Keywords: classic paper, F.M. Exner, Northern Hemisphere

Superscript numbers indicate original footnotes (translated at the bottom of the page), E… numbers indicate editorial endnotes (at the end of the article), square brackets [] indicate editorial comments in the text.

In the years between 1897 and 1910, H.H. HILDEBRANDSSON[E2] published four studies about the atmospheric centres of action[2], in which he dealt with relationships among different weather anomalies in distant parts of the world. HILDEBRANDSSON represented the relationships using the graphical method, that is, the visual comparison of two curves, which is hardly satisfactory. Recently, G.T. WALKER[3,E3] applied the correlation method[E4] to similar studies based on weather conditions in India[E5] and Egypt, and introduced a method of representation that seems to make such studies more valuable. It seems reasonable to use this method to study and represent such relationships in extratropical countries.

A grant from the "Royal Academy of Sciences in Vienna I" enabled me to collect observational materials for such a study and to examine the materials using the correlation method. From the beginning, I focused on the examination of monthly anomalies, that is, deviations of single monthly values from multi-annual mean values of air pressure and temperature on the Northern Hemisphere in the winter months.

Fifty stations on the Northern Hemisphere were selected because they had the most complete observations of air pressure and temperature from 1897 to 1906. Later, it was necessary to include observations from 1887 to 1896 to confirm the relationships that we found. For individual stations, observations from a third and even earlier decade were also considered.

The study consists of two parts. The first part deals with the correlations of simultaneous anomalies that are of interest for global atmospheric circulation, climate, etc. The second part deals with anomalies in subsequent months. Such relationships can be useful for forecasting because an anomaly at one location may point to an anomaly at another location in a following month.

It is beyond the scope of this paper to introduce the correlation method. To determine a simple correlation coefficient, the reader should consult my technical paper in *Meteorologische Zeitschrift*, 1910, page 263[E6]. The method of partial correlation coefficients, which is used to represent the dependence of one variable on several others, can be found, for instance, in the beautiful book by C. UDNY YULE, "An introduction to the theory of

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[1]Excerpt from a study by the same title published in the Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften (Proceedings of the Vienna Academy), Vol. 122, Section IIa, 1913[E1]
[2]Kungl. Svenska Vet. Akad. Handl., Vol. 29, 32, and 45.[E2]
[3]Mem. India Met. Deptmt. Vol. XX/XXI.[E5]

statistics"[4] or (without theoretical basis) in my paper "About the correlation method," published by G. Fischer in Jena[E8].

This method requires first calculating mean [absolute] anomalies to express existing anomalies of single months in units of the mean [absolute] anomaly. At the same time, mean [absolute] values reflect the variability of the monthly values of air pressure and temperature. Among my stations, the largest mean [absolute] monthly pressure anomaly could be found in Stykkishólmur[E9] (6 mm) and the largest [mean absolute] temperature anomaly could be found in Jakobshavn [Ilulissat], West Greenland[E9,E10] (4.8 ° [C]). The relationship between the mean [absolute] pressure [anomaly] and the mean [absolute] temperature anomalies is a reciprocal measure for the continentality of a site. It is largest in Ponta Delgada, Azores[E9] (7.4 mm/°C), and smallest in inner Asia and the interior of North America (0.6 mm/°C). Drawing these values on a global map, the curves with a ratio equal to one enclose the interior regions of North America and Asia quite well. Western Europe appears strongly oceanic (ratio of 2 to 3).

It would go beyond the scope of this paper to discuss all of the relationships that could be found between simultaneous anomalies of air pressure and temperature at different stations. Instead, I confined myself to a brief discussion of several that were chosen arbitrarily.

In inner Asia (i.e., Siberia), a positive pressure anomaly corresponds to a negative temperature anomaly; air pressure is a thermal consequence. This is different in polar regions. To measure polar anomalies, the mean values of the anomalies at two stations were calculated: Gjesvær[E9] (North Cap) and Markovo[E9] (in north-eastern Siberia). Markovo is a very interesting station. Unfortunately, observations at Markovo are only available from 1897 onwards (in Russian year books).

Following this method, positive pressure anomalies were found to be related to positive temperature anomalies in polar regions. Lower temperatures in polar regions coincided with a stronger pressure reduction and general atmospheric circulation on the Northern Hemisphere. The correlation coefficients r between the pressure anomaly Δp and the temperature anomaly Δt in Siberia and the polar regions were −0.74 and 0.43, respectively.

A comparison of Δp in the polar regions with the simultaneous west–east component of the wind path in Potsdam showed that a negative Δp in the polar regions corresponds to a particularly strong general circulation of the atmosphere. A value of $r = -0.57$ was found for these anomalies. A decrease of polar pressure by 1 mm [Hg] corresponds to an increase of the westerly component [of the wind path] of 90 km compared to a mean value of the westerly component of 500 km per month.[E11]

High pressure in the polar regions usually corresponds to low pressure in the tropics, because mass abundance in the former indicates a lack of mass elsewhere. The calculation gave a correlation coefficient of $r = -0.74$ between pressure anomalies in the polar regions and those at 20 ° latitude.

The polar pressure anomaly was found to have considerable influence on simultaneous climatic anomalies in the Northern Hemisphere. This is expected because the polar pressure anomaly is a measure of general atmospheric circulation. Correlations between the polar pressure anomaly and pressure or temperature anomalies at all stations show a peculiarly regular geographical distribution, which is very similar for two decades and which is represented as a map.[E12]

Concurrently, the areas neighbouring the polar regions also show positive pressure anomalies. Towards the south, the pressure anomalies become smaller and approach zero. An area with negative pressure anomalies in Europe and North Africa is noteworthy and has values of r between −0.6 and −0.7 (Algiers[E9], the Mediterranean, and Italy). The situation is similar in the Gulf of Mexico region. These contrasts are so distinct that the correlations of the pressure anomalies calculated for the station Lugano[E9] are opposite to the correlations of the polar regions. For instance, the correlation of polar pressure with the pressure of Barnaul[E9] is $r = 0.46$; the correlation of the pressure of Lugano with the pressure of Barnaul is $r = -0.44$.

It would go beyond the scope of this paper to discuss these patterns in detail. I will only point out several conclusions regarding the climate. The correlations show that Europe as well as Siberia and continental Russia are being warmed by atmospheric circulation. Siberia would be even colder without this (thermal) effect. On the other hand, the western coast of Greenland and the eastern coast of North America are very cold for dynamical reasons. A slowdown of atmospheric circulation results in a warming (1 mm [Hg] increase in polar pressure means an average warming of 0.4 °–0.6 ° [C]; whereas the corresponding cooling in Barnaul, Siberia, would be 0.6 °–0.7 ° [C]). Mediterranean countries are also cooled by atmospheric circulation, especially in the east (however, the temperature effect only amounts to 0.2 ° [C]). Therefore, atmospheric circulation warms the north-western and central but cools the south-eastern parts of Europe.

In North America, the north-western and the western parts are warmed by a slowdown of atmospheric circulation; the eastern (south-eastern) part is cooled. The changes are small but appear to occur regularly. At first, this observation was surprising. It is common to attribute the west coast's high temperatures to sea winds. However, these conditions can be understood by imagining that without general atmospheric circulation, the northern part of the North American continent would be covered by a high-pressure area. There would be warm southerly winds in the west and cold northerly winds in the east. The increasing circulation compensates for these differences rather than causing them.

[4] London, by C. Griffin & Co., 1911, 2nd Ed., 1912.[E7]

The strongest pressure increases due to a slowdown of general atmospheric circulation occur in the Greenland–Iceland region (1.1–1.4 mm per 1 mm [Hg] polar pressure increase), and in the north of Siberia (Obdorsk [Salekhard][E9] 1.1 mm [Hg]). Thus, the minimum in Iceland is caused dynamically by atmospheric circulation, whereas the high pressure in northern Asia in winter occurs despite atmospheric circulation.

The strongest pressure decreases associated with a slowdown of general atmospheric circulation can be found in central Europe and the western Mediterranean Basin (0.6–0.8 mm [Hg]). Relatively low pressure in winter is caused by the high temperature of the ocean and increasing circulation. In Ponta Delgada, the pressure is relatively high (Azores maximum). A slowdown of atmospheric circulation results in a weakening of this high-pressure area, which is, as in the Iceland minimum, dynamically caused by the atmospheric circulation.

To briefly summarise the remaining results of this study on simultaneous correlations:

1. General atmospheric circulation fluctuates in intensity, resulting in peculiar pressure and temperature anomalies at various locations. Generally, the pressure contrasts occur between north and south, showing a zonal distribution. Such contrasts are especially intense between the polar regions and the Mediterranean countries.

2. With constant polar pressure, contrasts between pressure anomalies occur longitudinally in such a way that positive and negative anomalies are separated by about 180 ° longitude.

3. Pressure anomalies that closely surround a location are naturally in agreement with local pressure anomalies. However, such positive correlations can also occur far from that location. This phenomenon seems to concern specifically shaped, larger regions that are anchored to specific locations.

4. The distribution resembles the expected temperature anomalies if the air flow in areas with positive or negative pressure anomalies is similar to that in high- and low-pressure areas, transporting temperature [anomalies] to other locations. In these areas, the position of the isotherms indicates the direction, from the centre of the pressure anomaly, in which the temperature anomalies can be found.

As already mentioned, the second part of the study shows the results from attempts to relate non-simultaneous anomalies of air pressure or temperature at different stations.

In the following, the results are summarised:

On average, a positive anomaly of polar pressure is followed by another positive anomaly in the following month ($r = 0.47$). A month appears to be a period that is shorter than the average lifetime of a polar air pressure anomaly in winter, which is also true for anomalies of general atmospheric circulation. Furthermore, high polar pressure in one month is usually followed by high pressure in Greenland–Iceland, but low pressure in Suez[E9]. These correlations are largely explained by the first correlation, because high polar pressure in the following month is usually accompanied by high pressure in the north and low pressure in Suez. High polar pressure is also followed by high temperatures in Jakobshavn and low temperatures in Nerchinsk[E9] and Vladivostok[E9].

Similarly, we find negative correlations between the pressure anomalies in Obdorsk[E9] (northern Siberia) and the temperature anomalies in the following month at the eastern coast of Asia, in particular Vladivostok. The study also points to a tendency to maintain the Siberian pressure anomalies from one winter month to another.

To represent a pressure anomaly as a consequence of another anomaly, which would be of significance for a forecast, attempts were made to find correlations between pressure anomalies at one station and anomalies at other stations in the previous month.

Values of Δp for previous months were examined for Δp at Stykkishólmur[E9]. Positive correlations could be found with Δp in Ivigtuut[E9] (Greenland) for the previous month ($r = 0.45$) and with Δp in Stykkishólmur itself ($r = 0.38$). Therefore, the tendency to maintain a pressure anomaly can also be observed here. There is also a negative correlation with Δp in central and southern Europe (Lemberg [Lviv][E9] [$r =$] -0.53); and a positive correlation with Δp in Yakutsk[E9] which is striking. Furthermore, there is a relationship with temperature in Novorossiysk[E9], which corresponds to the simultaneous relationship with local and central European air pressure (warm temperatures on the eastern side of a low-pressure area).

Thus, several relationships can be used to evaluate the pressure anomaly in Stykkishólmur for an upcoming winter month. By summarising several of these relationships, an equation can be formed using the partial correlations method, in which the pressure anomaly in Stykkishólmur is a function of several anomalies from the previous month. In simple notation, this is:

$$\Delta P \text{ Stykkishólmur} = -0.78\,(\Delta p \text{ Lemberg}) + 0.24\,(\Delta p \text{ Ivigtuut}) + 0.27\,(\Delta p \text{ Yakutsk})$$

ΔP is the pressure anomaly one month after Δp. All values of Δp are expressed in millimetres of mercury (Hg) and their signs need to be taken into consideration. Therefore, ΔP is also expressed in this unit. Obviously, the anomaly ΔP does not exactly correspond to the term on the right-hand side of the equation. The correlation coefficient between the term on the right and ΔP is, in our example, $r = 0.62$. The prediction of ΔP using the above equation only succeeds to the extent given by r.

Similarly, the pressure anomaly of Ponta Delgada (Azores) was examined in terms of relationships with its anomalies, mostly revealing correlations with previous temperature anomalies. The corresponding equation, which can be used to make a prediction, is given as follows (using three predictors):

$$\Delta P \text{ Ponta Delgada} = -0.32\ (\Delta t \text{ Novorossiysk}) + 0.33\ (\Delta t \text{ Gjesvær}) + 0.52\ (\Delta t \text{ Yakutsk})$$

All Δt are given in degrees Celsius and ΔP is given in millimetres of mercury (Hg). Here, r equals 0.6, meaning that the reliability is about the same as above.

To predict the air pressure for a location in central Europe, Δp from preceding months in Lemberg were examined. The correlation coefficients are considerably smaller than both previous cases, making the result of these experiments less favourable. The months preceding a positive pressure anomaly in Lemberg are characterised by low pressure to the east and north-east of the location, and by high pressure to the southeast. A particular emphasis should be placed on Δp in Barnaul (−0.33) and Palermo[E9] (0.28).

Meanwhile, the preceding months have negative temperature anomalies on the eastern coast of North America (St. John's[E9] [$r =$] −0.38).

Similar to Stykkishólmur, negative correlations of air pressure are located to the east; the positive correlation is located to the west. Thus, it seems that the anomaly Δp for a location approaches from the west, and monthly anomalies of air pressure move from the west to the east, as in the daily anomalies. However, there is insufficient data to support the existence of this process.

The attempt to express the pressure anomaly in Lemberg using the past anomalies in three locations resulted in a weaker result than in the case described above. Coefficient r is 0.44 and the corresponding equation is:

$$\Delta P \text{ Lemberg} = -0.47\ (\Delta t \text{ St. John's}) + 0.15\ (\Delta p \text{ Palermo}) + 0.34\ (\Delta p \text{ Barnaul})$$

Δp is given in millimetres of mercury (Hg); Δt is expressed in degrees Celsius.

The most important variable for these three cases is:

for ΔP Stykkishólmur	Δp Lemberg
for ΔP Ponta Delgada	Δt Novorossiysk and Δt Lemberg
for ΔP Lemberg	Δt St Johns.

The most recent calculations used to predict anomalies do not claim to be more than attempts in this direction. However, they are promising and support continued exploration of available statistical material. Regarding the remaining results, the reader is directed to the original paper.

Endnotes

E1 Exner, F.M., 1913: Über monatliche Witterungsanomalien auf der nördlichen Erdhälfte im Winter. – Sitzungsberichte d. Kaiserl. Akad. der Wissenschaften **122**, 1165–1241.

E2 Hildebrandson, H.H., 1897: Quelques recherches sur les centres d'action de l'atmosphère. Kongl.-Svenska Vetenskapsakad. Handl. **29**, Fasc. 3.

E3 Sir Gilbert Thomas Walker, 1868–1958, was a British mathematician and meteorologist. In 1903 Walker moved to the India Meteorological Department, where he worked for the next 21 years. Being confronted with the interannual variability of the Indian monsoon and trying to establish a scientific basis that could be used for predictions, he started extensive correlation studies on world weather. Walker not only applied the concept of correlation to climatology (introduced by Galton (1888)), but contributed significantly to its further development and is known in statistical sciences for his work on autoregressive processes (see Katz, 2002). Walker's publication series "World Weather" presented the three major modes of large-scale variability in global circulation: the Southern Oscillation, the North Atlantic Oscillation, and the North Pacific Oscillation.
Katz, R.W., 2002: Sir Gilbert Walker and a connection between El Niño and statistics. – Statistical Sci. **17**, 97–112.

E4 Galton, F., 1888: Co-relations and their Measurement, chiefly from Anthropometric Data. – Proc. Roy. Soc. London **45**, 135–145.

E5 Walker, G.T., 1909: Correlation in seasonal variation of climate. – Mem. Ind. Met. Dept. **20**, 122.

E6 Exner, F., 1910: Der Korrelationsfaktor und seine Verwendung in der Meteorologie. – Meteorol. Z. **27**, 263–266.

E7 Yule, U.G., 1911: Introduction to the Theory of Statistics. – Charles Griffin & Co., Ltd., London, 376 pp.

E8 Exner, F.M., 1913: Über die Korrelationsmethode. – G. Fischer, Jena, 36 pp.

E9 Map showing all locations mentioned in the text.

E10 HANN, J., 1890: Zur Witterungsgeschichte von Nord-Grönland Westküste. – Meteorol. Z. **7**, 109–110 (translated and edited by VOLKEN, E. and S. BRÖNNIMANN. – Meteorol. Z. **19** (2010), 199–205).

HENSE, A., R. GLOWIENKA-HENSE, 2010: Comments on: On the weather history of North Greenland, west coast by Julius Hann. – Meteorol. Z. **19**, 207–211.

E11 1 mm Hg corresponds to 1.33 hPa.

E12 The map is reproduced in the accompanying paper by HURRELL and DESER.