Mysterious, modulated continuous oscillations of air pressure in Central Europe

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A comparison of the spectra of many European barometers shows that, despite the large distances between the sensors, the air pressure changes in phase at certain very low frequencies. The period lengths of around 60 hours are not related to the length of the day and do not provide any information about the possible causes of these oscillations. Over a period of twenty years, constant amplitudes and phase modulations are measured at a few discrete frequencies.

1 Motivation

The Earth never stands still. Neighbouring celestial bodies and earthquakes create forces that periodically deform the Earth and its surrounding atmosphere. The measured accelerations allow conclusions to be drawn about the location and strength of the causes. The Moon, Sun and planets produce about 13,000 perturbation frequencies, which are tabulated in [3]. Measurements show additional spectral lines from unknown sources. One possible cause could be continuous gravitational waves. To test this suspicion, extensive files of *air pressure* were examined, which, unlike gravimeters, are hardly affected by earthquakes. Irregular weather phenomena do not produce continuous signals.

2 The Spectrum

The air pressure is not measured continuously, but at fixed intervals of e.g. one hour ($T_s = 1$ hour). The reciprocal of T_s is referred to as the sampling frequency f_s. The analog low-pass filter with the cut-off frequency $0.5 \cdot f_s$ is usually omitted. Therefore, the measurement of atmospheric pressure violates the Nyquist-Shannon sampling theorem and the spectrum is ambiguous. The total spectrum, which may contain very high frequencies, is folded into the range $0 < f < 139$ μHz, as shown in Figure 1. A strong signal of the frequency 300 μHz appears at 22.2 μHz (aliasing) and can lead to misinterpretations.

If the analysis is restricted to $f < 20$ μHz, the ambiguity can be ignored, as the amplitudes in the lowest range are at least a factor of 10^5 higher than the spectral lines and the noise in the high frequency range ($f > 150$ μHz).

The spectrum in figure 1 obviously consists of a continuum and a few strong spectral lines. Since the noise amplitude at $f \approx 1$ μHz is about 10^7 times larger than at $f \approx 100$ μHz, it is neither the commonly observed $1/f$ noise nor the $1/f^2$ noise. Is it noise or are there other causes?

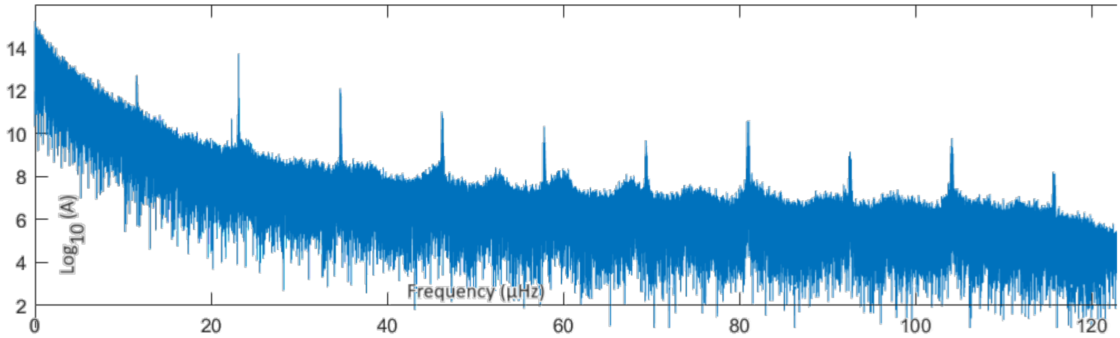

Figure 1): *Spectrum of air pressure in Germany, one sample per hour. The database is the average air pressure between the years 2000 and 2020. The prominent maxima are explained in the text.*

We know what causes the strong spectral lines:

- Although the atmosphere approximates the shape of the Earth, it is not perfectly spherical. Since the density, pressure and temperature of the atmosphere depend on the time of day, barometers measure periodic changes at the frequencies $f \approx n \cdot 11.57\ \mu$Hz $= n/(24$ hours$)$ with $n \in 1, 2, 3, ...$

- A special feature is the lonely peak at 22.3643 μHz. This is the strongest frequency at which the moon deforms the earth and atmosphere (tides). This and many other "astronomical" lines [3] are easy to identify because their frequencies are constant and unmodulated.

All the spectral lines in the figure 1 are well below the lowest natural frequency of the Earth ($_0S_2$ at 300 μHz). This refutes the common assumption that resonant antennas are needed to detect vibrations from extraterrestrial sources.

3 The search area

The table [3] contains several frequency ranges without spectral lines produced by celestial bodies in the solar system. In fact, the large gap at 4.1 μHz $< f <$ 7.45 μHz contains several consistent lines measured at widely separated locations in Europe (see figure 2). If you add the raw data *before* the spectrum is calculated, you can see that not only the frequencies of the pressure but also the phases are consistent across Europe. As there is no known cause for this synchronous pulsation of the air masses in Central Europe, the properties of several striking coincidences are examined in detail.

From the synchrony of the oscillations it follows that the wavelength λ is significantly larger than the distance between the locations shown in figure 2. Assuming $\lambda \approx 6 \times 10^7$ m, the propagation speed of these waves is calculated to be at least $v = \lambda f \approx 300$ m/s. This is approximately the speed of sound in air.

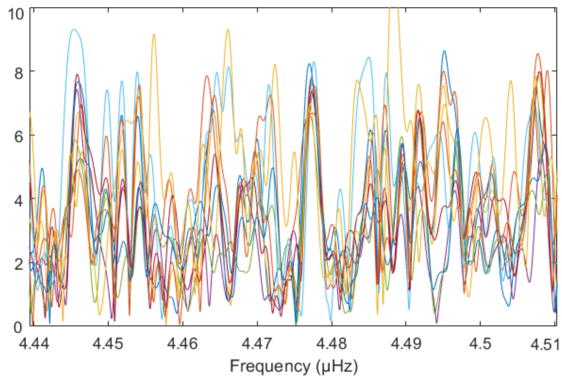

Figure 2): *Superimposing a narrow range of air pressure spectra from Amsterdam, Berlin, Brussels, Bern, Budapest, Dublin, London, Paris, Vienna and Stockholm over the period 1990-01-01 to 2022-07-01 reveals surprising similarities with no known cause.*

4 Data source and preparation

From the figure 2 you can see that the frequency resolution Δf should be better than 1 nHz. This value can only be achieved by analysing sufficiently long data chains. Using the equation

$$T_{min} \cdot \Delta f \geq 0.5 \tag{1}$$

from Küpfmüller [4], we calculate a minimum duration of 16 years. The DWD [2] stores air pressure data from many weather stations, which is a good data source after some preliminary work. In order to reduce the influence of local peculiarities and isolated data gaps, the records of as many barometers as possible, which are distributed throughout Germany and have been in operation for at least ten years, are added. In the period 2000 to 2009, 64 data chains were found, in the period 2010 to 2019 only 51 data chains. The coherent addition of many data sets improves the signal-to-noise ratio (SNR) and makes spectral lines visible that would disappear in the noise when analysing individual data chains.

5 Phase modulation broadens the bandwidth of the signal

Signals are never perfectly monochromatic, and the deviations allow conclusions to be drawn about the properties of the source and the transmission path. To obtain this information, it is necessary to identify and analyse the sidebands, i.e. the accompanying frequencies on either side of the carrier frequency. If the SNR is poor, no amplitude modulation can be detected because all the associated spectral lines would have to be significantly above the noise. This does not apply to frequency or phase modulation if one is limited to a few discrete modulation frequencies. A Modified SuperHet (MSH) is a suitable method for demodulating signals below the noise level: You modulate a local auxiliary oscillator so that its modulation matches the modulation of the signal. If the imitation is successful, the difference frequency $f_{signal} - f_{osz}$ is constant. This is a clear and easy to control criterion. Since all the energy of the signal is then concentrated in a single spectral line, the signal can be filtered in a very narrow band and easily identified in the noise (see figure 4). The following analysis is limited to this type of modulation.

Figure 3 shows the typical spectrum of a phase-modulated signal. The structure is usually very complex and sometimes hardly distinguishable from noise.

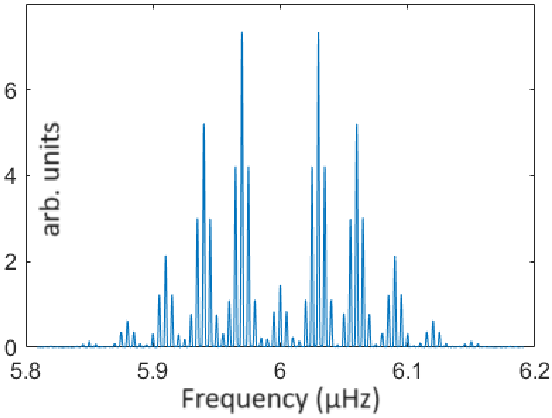

Figure 3): *Example of a signal spectrum of frequency 6 μHz phase modulated with **only** two different frequencies (without noise). The total energy is distributed over more than 40 weak spectral lines occupying a wide frequency range called the Carson bandwidth.*

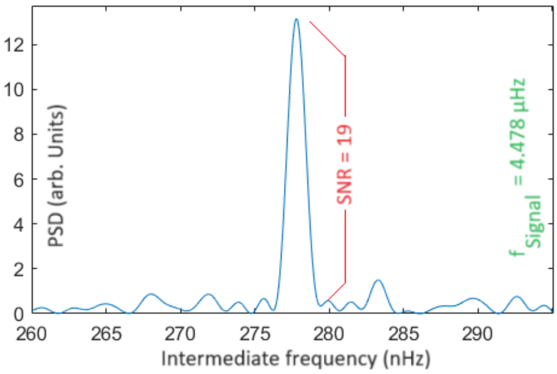

Figure 4): *Power spectrum (Welch method) of the signal at $f = 4.478$ μHz after applying the MSH method. Compensation of the phase modulations (see table 1) has eliminated the sidebands and increased the amplitude of the carrier frequency. The MSH method shifts the signal frequency to $f_{ZF} = 1/(1000$ hours).*

6 The search procedure

Any signal transmission requires a certain bandwidth, which is often much smaller than the signal frequency. This allows the frequency of a sufficiently wide range around the signal frequency to be reduced to about 0.3 μHz (superhet method) and then the distance between two data points to be spread by a factor of a thousand (decimation to $T_s =$ 1000 hours). There are two consequences: The time needed for all the calculations is significantly reduced and the demodulation is limited to slow modulations with periods of several weeks. This limitation can be overcome if the modulation frequencies are known.

It makes little sense to look for symmetrical structures as in Figure 3 in a noisy signal mixture as in Figure 2. This is mainly because a spectrum destroys all phase information. The MSH method avoids this problem: it does not involve any amount formation and does not destroy any phase information, so it can recognise and combine related spectral lines.

MSH iteratively determines the values of a slow frequency drift and several periodic phase modulations of a signal. In the end, all modulations are eliminated, the total energy of the signal is concentrated in a narrow band around the central frequency, and the amplitude of this spectral line is increased to a level significantly above the noise level. (Figure 4).

7 Results

The spectra of widely separated barometers in Germany show several consistent lines. The tables 1, 2 and 3 show the properties of some striking lines. The meaning of the rows:

–Row-2: The modulation frequency of the signal
–Row-3: The period $P = 1/f_{mod}$
–Row-4: The individual phase shift of the modulation. The reference time is the start of the measurements on January 2000
–Row-5: The modulation index η of the phase modulation (see section 8)

Table 1): *The signal at $f = 4.47803$ μHz is phase modulated with six different frequencies. The frequency drift is $\dot{f} = 45.2 \times 10^{-20}$ Hz/s.*

	Mod-1	Mod-2	Mod-3	Mod-4	Mod-5	Mod-6
f_{mod} (nHz)	0.934	3.42	14.28	31.638	38.70	94.96
P (years)	33.9	9.26	2.22	1.0012	0.819	0.334
φ	4.07	5.44	0.93	4.84	1.79	3.86
η	1.83	2.99	4.59	4.24	4.22	3.62

Table 2): $f = 5.854$ *μHz. The frequency drift is $\dot{f} = 0.88 \times 10^{-20}$ Hz/s*

	Mod-1	Mod-2	Mod-3	Mod-4	Mod-5	Mod-6	Mod-7
f_{mod} (nHz)	0.963	4.45	9.219	16.78	31.496	40.907	57.13
P (years)	33	7.1	3.44	1.89	1.006	0.775	0.55
φ	0.62	2.84	4.33	5.08	0.797	-0.017	0.766
η	0.39	0.93	2.32	1.59	1.795	0.917	2.07

Table 3): $f = 6.3158$ *μHz. The frequency drift is $\dot{f} = 35.5 \times 10^{-20}$ Hz/s*

	Mod-1	Mod-2	Mod-3	Mod-4	Mod-5	Mod-6	Mod-7
f_{mod} (nHz)	0.946	1.236	4.187	12.03	32.3021	39.26	57.51
P (years)	33.5	25.7	7.6	2.64	0.982	0.808	0.55
φ	1.69	0.671	4.724	2.87	0.074	4.56	1.96
η	1.44	1.595	4.90	2.652	3.383	5.722	2.00

In data sets that cover a period of only twenty years, it is difficult to detect periodic processes that extend over even longer periods. Since it is hard to distinguish from the (presumably) linear frequency drift, we did not look for slow modulations with $P \geq 40$ years.

Summary:

- All signal frequencies increase in proportion to time.
- Each signal is phase-modulated several times.
- The modulation with an oscillation period of $P \approx 1$ year (grey fields) is probably caused by the Earth's orbit. It follows that the source of the signal is *not* in the solar system.
- It has not been investigated whether the signals are modulated in a 24-hour rhythm, because the modulation index is too small due to the low rotation speed at the equator.

8 Interpretation of the results

There was no evidence that the signals were amplitude modulated. What could be the cause of the surprisingly strong and similar phase modulation (PM) of all the signals studied? The striking improvement in SNR between the original signal in figure 2 and the demodulated signal in figure 4 is the result of eliminating the phase modulations and can be explained by the following ansatz

$$y = sin(2\pi t \cdot f_{Signal} + \phi_{modulation}) \tag{2}$$

The two parameters f_{Signal} and $\phi_{Modulation}$ have to be adapted to the problem: The frequency f_{Signal} can change proportionally to the time and $\phi_{Modulation}$ can be the sum of several sine functions. If the modulation consists of a single frequency f_{mod}, the equation is

$$y = sin(2\pi t(f_{Signal} + t\dot{f}) + \eta \cdot sin(2\pi t f_{mod} + \varphi)) \tag{3}$$

A sinusoidal PM causes the instantaneous frequency of the signal to oscillate periodically between the limits $f_{Signal} + \Delta f$ (maximum blueshift) and $f_{Signal} - \Delta f$ (maximum redshift). Δf is called the frequency deviation. The instantaneous frequency is difficult and inaccurate to measure because it is never constant over time. It is easier to determine the modulation index η using the MSH method and calculate $\Delta f = \eta \cdot f_{mod}$. ($\varphi$ is discussed in section 8.2).

8.1 The speed of the waves

The frequency deviation Δf can be interpreted physically: If the signal source or the receiver or both are moving, the received frequency changes depending on the speed (Doppler effect). If the signal propagates at the speed of light c, then the relativistic equation

$$\Delta f = f_{Signal} \cdot \left(\sqrt{\frac{c+v}{c-v}} - 1 \right) \tag{4}$$

applies, where v is the relative velocity between the source and Earth. For $v_{signal} \ll c$ it is usually assumed that the wave propagates in a medium. There are two solutions: If the observer is at rest with respect to the medium and the source is moving with velocity v_{Source}, use the equation

$$\Delta f = \frac{v_{Source} \cdot f_{Signal}}{v_{Signal} - v_{Source}} \tag{5}$$

If the signal source is at rest and the observer moves with the speed $v_{Receiver}$, use

$$\Delta f = \frac{v_{Receiver} \cdot f_{Signal}}{v_{Signal}} \tag{6}$$

The measurements show that all signals are sinusoidally phase-modulated with $P \approx 1$ year (grey cells in the tables 1..4). Assuming that the sources are far outside the solar system and in the plane of the ecliptic, the distance between the source and the Earth decreases and increases every six months. Then the speed of the observer varies between the extreme values –30 km/s $< v_{Earth} <$ 30 km/s.

This means that equation (4) gives a value for Δf which is a factor of one hundred lower than the measurement result. Using equation (6) gives $v_{Signal} \approx c/100$. The table 4 shows the velocities v_{signal} for five studied signals in the right column. The average is $v_{signal} = (2.41 \pm 0.54) \times 10^6$ m/s. This speed is much smaller than the speed of light c, but much larger than the speed of sound in air (see also section 3) and does not correspond to any known wave phenomenon.

8.2 The direction of the sources

The phase angle φ in equation (3) allows us to calculate the day $B = 365 \cdot \varphi/2\pi$ (day of the year) on which we receive the maximum signal frequency. Six months later we measure the maximum value of the redshift.

The meaning of columns in table 4:
Column-1: The signal frequency
Column-2: Oscillation period of the signal modulation with $P \approx 1$ year
Column-3: The measured phase angle in equation (3)

Table 4): *Summary of the most important signal properties*

f_{Signal} (μHz)	P (Jahr)	φ	Blueshift DOY	Redshift DOY	η	v_{signal} $\times 10^6$ m/s
4.478	1.001	4.84	281	99	4.24	1.00
4.678	1.003	3.023	176	358	1.095	4.06
5.4992	0.989	3.81	221	39	2.425	2.12
5.854	1.014	0.797	46	229	1.795	3.13
6.316	0.981	0.074	4	187	3.383	1.73

Column-3: Day of the year when we measure the highest signal frequency
Column-4: DOY when we measure the lowest signal frequency
Column-5: Modulation index of PM-frequency 31.7 nHz ($P = 1$ year)
Column-6: Speed of propagation of the wave according to equation (6)

8.3 Other phase modulations

Additional PM ($P \neq 1$ year) have been measured, the origin of which can only be speculated. It is unclear whether these PM originate in the source or in the Earth's environment. The period durations P are similar to the sidereal orbital periods of the Sun's planets, but differ significantly. Ignoring the grey fields in the tables 1..3 and numbering the remaining periods accordingly, the figure 5 shows an astonishing regularity that is also observed in known planetary orbits.

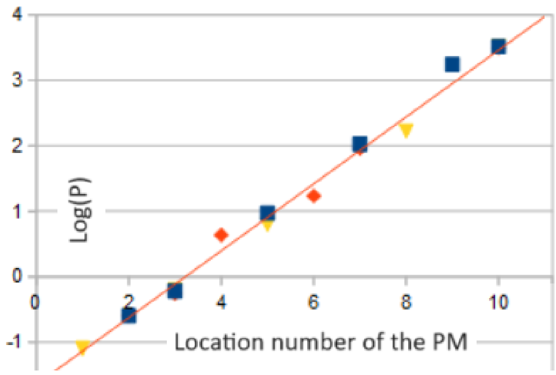

Figure 5): *Logarithm of period lengths (in years). The colours indicate different tables 1..3. The location numbers have been chosen to minimise deviations from linearity. Some location numbers are used more than once.*

Although the signals examined here arrive at different frequencies from different directions (phase φ), the modulation frequencies seem to follow a universal rule. The straight line in the figure 5 corresponds to the equation

$$P_n = P_0 \cdot e^{k \cdot n} \tag{7}$$

with $n \in 1, 2, 3, 4...$, $P_0 = 70$ days and $k = 0.51$. A similar equation was used by Dermott [5] to describe the orbital periods of planets. The assumption that the period durations in row 2 of the tables 1..3 actually describe planetary orbits around distant binary systems leads to a major problem: If the periodic fluctuations in air pressure are indeed caused by gravitational waves (this is contradicted by the far too low propagation speed compared to the usual assumption), we measure the phase modulations of heavy binary systems. Even massive planets can only move the two central stars a little, certainly slower than $v \approx 30$ km/s. However, such high speeds would be necessary to achieve the measured modulation indices of $\eta \approx 2.5$.

If you try to solve this problem numerically with realistic estimates for the masses involved using the equation (5), you get propagation velocities of the order of $v_{Source} \approx$ 100 m/s in the immediate vicinity of binary stars. Does the speed of the GW decrease so much in the presence of large masses? We don't know because no one has ever managed to solve Einstein's complete equations.

9 Summary

There are no known sources in the Earth's environment that produce waves in the frequency range 4.1 μHz $< f <$ 7.45 μHz. However, it is easy to find some consistent lines in the spectra of gravimeters and barometers from distant locations. Closer examination, using standard communications techniques, shows that all the lines are phase-modulated several times. The modulation frequencies follow a strange rule, with one exception: the rhythm of a PM is almost exactly 365 days (table 4). It is therefore likely that the Doppler effect causes the phase modulation due to the Earth's orbital speed and that the sources are outside the Solar System.

The evaluation of the equations (4) and (6) of the Doppler effect excludes that the waves travel at the speed of light ($c = 3 \times 10^8$ m/s) or the speed of sound ($v = 340$ m/s). Do these waves need a medium to propagate?

Perhaps the observed oscillations are gravitational waves from binary star systems. In our Galaxy there are probably more than 10^5 binary star systems with periods of several days, which can only be detected visually if the axis of rotation is specially aligned. It is likely that most of them have planets that force the central binary to move around the common centre of gravity. In this way, the additional PMs with periods ranging from a few months to many years can be qualitatively explained. However, the calculation using the Doppler effect leads to extremely low values for the propagation speed of the GW in the vicinity of large masses, which contradicts all previous assumptions.

10 Data availability

The DWD [2] stores many historical measurement results from German weather stations.

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