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# Stationary temperature cycles in the Barents sea

*The cause of causes*

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**Abstract**

This paper is based on the data series from PINROE institute in Murmansk where the temperature in the Barents Sea is measured since 1900. It presents a hypothesis that the 18.6 years cycle of the earth nutation is modulating stationary low frequency temperature cycles in the Barents Sea. A spectre analysis of the data series has identified cycles of 18.6/3=6.3 years, 18.6 years and 3*18.6 =55.8 years temperature cycles. The 55.8 years cycle is correlated to the mean temperature in the data series and has a maximum in 1995-97. If his hypothesis is confirmed by oceanographic measurements, it means the Barents Sea will be cooled down for a new period of 55 years. This hypothesis may open up for a new perspective on climate and fishery forecasting.

**Key words**

Temperature forecasting; Barents Sea; Stationary cycles; Earth nutation

## 1 INTRODUCTION

The cause of dynamics in nature, has been a main issue of scientific research since ancient time. Aristotle introduced the doctrine on teleology. This doctrine explained the dynamics of objects in nature by the four causes. The objects initial state, the material, the objects form under movement and objects predestined fate. The predestined fate was decided by the cause of causes. The cause of causes was the positions of the sun, moon and the stars.

In 1994 a life cycle analysis of a Norwegian fishing trawler was conducted. The analysis showed that the outcome of the fishing boat's profit was limited by the quota of cod in the future. The future quota is limited by the future stock, which is limited by future fry of cod. A next question was, what will decide the future abundance of cod fry ? The cause of causes.

By chance, it was found that the time series of the quantities for North Atlantic cod has a 6-7 years cycle in the Fourier amplitude spectrum. This cycle was found in the fry abundance and even in the quota quantities of cod. The question then was: Is this a stationary cycle ? If so, there is a possibility of a more precise prediction of future cod resources. Then there is a better chance of predicting proper fishery investments.

If the 6-7 years cycle of cod is based on a stationary cycle, it must be based on something fundamental in nature. This could be a stationary cycle in the temperature. If there is such a stationary cycle in the sea temperature, it must be based on an even heavier force. This could be changes in earth rotation, which is influenced by the moon.

This paper is based on the unique data series from PINROE institute in Murmansk (1). The series have been Fourier analysed earlier and several dominant Fourier coefficients were found in the spectrum (4), (5). In this paper it is presented a closer study of the time series and it introduces a theory of a stationary dominant power spectrum in the data series. According to this theory, a multiple cycles are harmonically modulated and synchronised to an earth nutation cycle of 18.6 years. Spectral analyses shows good correlation between a low pass filtered temperature series and the estimated stationary cycles.

## 2 CYCLES THEORY

The energy E of the sampled temperature data series x(nT) is a stochastic process. The energy E may be estimated by Parseval theorem (8)

$$E = \sum_{n=-\infty}^{+\infty} |x(nT)|^2 = \frac{1}{2\pi} \int_{-\omega_s/2}^{+\omega_s/2} \left|X^*(j\omega)\right|^2 d\omega$$

If the power spectrum is white noise, then the spectral density is constant

$$S_{xx}(z) = |X^*(j\omega)|^2 = V_o$$

where $V_0$ is the noise variance. If there are white noise, the maximum frequency $\omega_0$ is infinitive. In this case the energy will be infinitive. This is impossible by the law of thermodynamics (2) and means the temperature power spectrum must be coloured and thus have a limited bandwidth. A such process may be modulated by as a Wiener process.

$$\dot{x}(t) = -a \cdot x(t) + n(t)$$

where n(t) is non-correlated white noise. The frequency transfer function of this process is:

$$H(j\omega) = \frac{X(j\omega)}{N(j\omega)} = \frac{1}{j\omega + a}$$

This means that the amplitude of the Fourier spectre of a time series, taken from nature, is expected to fall bay $1/\omega$.

The autocorrelation of the Wiener process is:

$$R_{xx}(\tau) = E[x(t) \cdot x(t+\tau)]$$

where

$$R_{xx}(\tau) = \frac{{N_0}^2}{2a} \cdot e^{-a|\tau|}$$

and $No^2$ is the noise variance. This indicates that the autocorrelation function is expected to fall exponentially. The parameter a is the same as the pole placement in the transfer function. This indicates that a rapid falling autocorrelation has a high bandwidth and a noisy time series.

The auto power density spectre is computed by the Fourier transform of the autocorrelation:

$$S_{xx}(j\omega) = F\{R_{xx}(\tau)\} = \frac{{N_0}^2}{1 + \left(\omega/a\right)^2}$$

This indicates that when computing the auto power density spectre, the amplitude is expected to fall by $1/\omega^2$ . If there is a stationary cycle in the time series, it may be modulated by a time function:

$$u(t) = c \cdot \sin(\omega t + \varphi)$$

The autocorrelation of this function will be the function

$$R_{uu}(\tau) = E[u(t) \cdot u(t+\tau)] = \frac{A^2}{2}\cos(\tau)$$

This means that if there are a stationary cycle in the time series, it may be discovered by a cycle in the autocorrelation function and as a peak in the auto power density spectre.

**The stationary source**

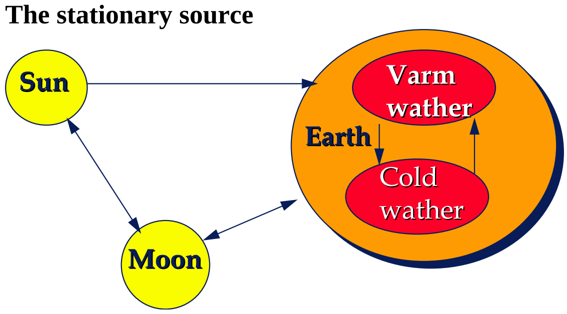


*Figure 1 System objects*

Our hypothesis is that there are some stationary cycles in the temperature time series. The appearance of these cycles may be explained by a larger system of forces. The main objects in this system is the sun, the moon, the earth and the sea water. The sun is the heating source of the earth and the sea water. The orbit of the sun, moon and the earth is predestined by the gravitational forces between the objects.

The gravitational relationship between the planetary systems influences the earth rotation which influences the sea tide and the balance between cold and warm sea water. The Earth has a complex movement of cycles. These more or less stationary Earth cycles, are the axis rotation, sun orbit rotation, the nutation and the longitude rotation.

In the 18'th century the English astronomer Bradley discovered periodic variation in meridian measurements of the declinations of stars. Later it was discovered that the earth is not exactly spherical and this influences the orbit of the moon. This introduces changes in the moon orbit which introduces a small instability in the earth axis rotation. It is found (2) that this forced movement of the earth axis has the cycle

$$u_3(t) = 9'' \cdot \sin(\frac{2\pi}{T} \cdot t + \varphi_3)$$

where the cycle time T is 18.6 years.

In the second century BC the Greek Hipparchus of Rhodes compared his observation with 150 year earlier records. Then he discovered displacement in the star position. Now it is known that this effect is due to a long term movement in earth axis angle. The changes in pole placement have the stationary cycle

$$u_4(t) = 50'' \cdot \sin(\frac{2\pi}{T} \cdot t + \varphi_4)$$

where the cycle time T is 2600 years. This long period is probably of importance, but not measurable in a time series of 100 years. The sum of these movements are

$$u(t) = \sum_{i=1}^{4} u_i(t) = \sum_{i=1}^{4} c_i \cdot \sin(\omega_i \cdot t + \varphi_i)$$

where $u_1(t)$ represents the Earth's daily rotation and $u_2(t)$ represents the Earth's rotation around the sun.

**Non-linear modulation**

The sea is running in a complex global circular system. In the Barents Sea a warm Gulf stream is meeting the could stream from the North. Thus there is a feedback between these streams. This feedback between warm and cold sea water is non-linear by nature. From the theory of non-linear dynamics, it is well known that non-linear feedback systems introduces a harmonic frequency modulated spectrum.

$$U^*(j\omega) = \sum_{n=-\infty}^{n=\infty} C_n \cdot U(jn\omega_s)$$

That will appear as the time series:

$$u(t) = \sum_{n=0}^{\infty} c_n \cdot e^{j(n\omega t + \varphi_n)}$$

where $C_n$ is a cycle amplitude and $\varphi_n$ is the phase.

**Filter by resonance**

Modulated cycles may be suppressed by energy loss or amplified by resonance properties in the sea system.

In 1665 the Dutch physicist Christian Huygens, the inventor of the pendulum clock, noticed something strange. Two pendulum were swinging in perfect harmony. He tried disturbing them, but after some time they were synchronised. Small vibrations between the clocks were sufficient to synchronise the pendulum and thus saving energy. This is an example of resonance in nature. In recent years many such examples have been found (9).

The Earth's nutation amplitude is only 9 ". This is a small movement, but the coupled oscillator theory may explain why a small nutation movement in the long run may synchronise a stationary temperature cycle in the Barents sea.

# 3 CYCLE ESTIMATES

## 3.1 Temperature estimate

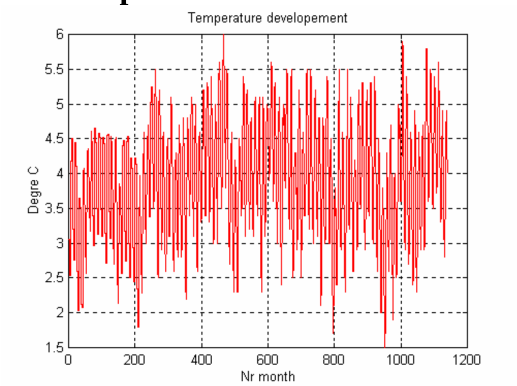


*Figure 2 A temperature time series from the Barents Sea*

The sea temperature is a stochastic variable in time and space. Russian scientists have provided and refined measurements of the average temperature each month since 1900 in the Barents Sea (1). In this case, an estimate of the temperature development x(nT) in a given target volume may be written.

$$x(nT) = E[y(nT) + w(nT)]$$

where y(nT) is a local measurement and w(nT) is a measurement error, T is the sampling time of one month and n is the number of months from the year 1900. Figure 2 illustrates that the development of the temperature series looks random between 1.5 - 6 degrees Celsius.

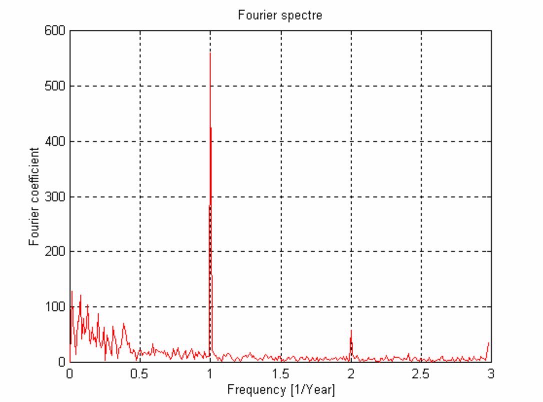


*Figure 3 Fourier spectrum of the temperature series*

The Fourier spectrum of a time series shows the correlation between the time series and a complex sinus frequency spectrum. The discrete Fourier spectrum is computed by

$$X(jk) = \frac{1}{N}\sum_{k=0}^{N-1} x(nT)e^{-j2\pi nTk/N}$$

where N is the number of samples in the time series and X(jk) is the Fourier spectrum. The feature of the Fourier transform has a high peak at one cycle per year. The peak is so dominant that low pass filter must be introduced to study other characteristics more closely.

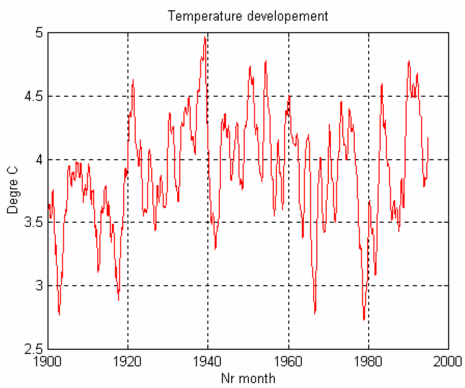


*Figure 4 A year average temperature in the Barents Sea from the year 1900*

The one year cycle is easily suppressed by a one year phase linear moving average filter. This may be expressed by

$$x_y(nT) = \frac{1}{M+1}\sum_{n=-M}^{n=M} x(nT)$$

where M is 12 months. Figure 4 shows a low pass filtered version of the temperature series by a one year moving average of the temperature time series from the year 1900 to 1994. In this case the one year temperature changes have disappeared. The figure now indicates two kinds of changes in the time series, one slowly and one rapidly changing process. The rapid process is a noisy process changing one degree around a dynamic mean value.

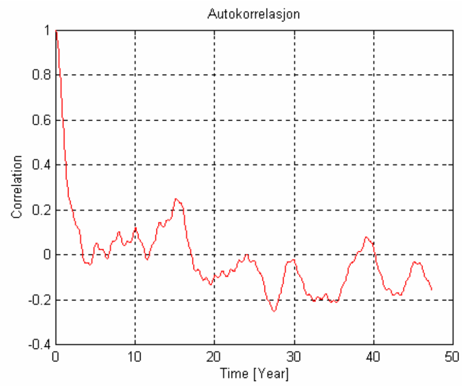


*Figure 5 Autocorrelation function*

Noise properties and stationary properties of the time series may be analysed by the autocorrelation. The discrete autocorrelation of a coloured noise spectrum is expected to have a calculated time series

$$R_{xx}(mT) = E\left[x(nT)\cdot x(nT+mT)\right]$$

Figure 5 shows the computed normalised discrete autocorrelation of the one year filtered time series. The rapidly falling autocorrelation indicates a high level of noise. In this case some cycles are visible in the autocorrelation. This is different from what would be expected from a Wiener-process. The figure indicates a stationary cycle in the time series. As the time increases, there is a first peak at 6 years, then the autocorrelation has positive and negative peaks, mostly in intervals of 6 years. This indicates the existence of a stationary cycle of about 6 years in the time series.

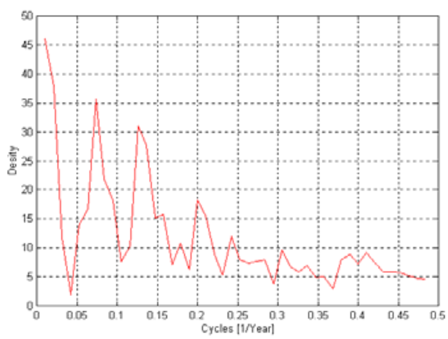


*Figure 6 Auto power spectrum*

The auto power density spectrum indicates stationary properties of the autocorrelation function. This spectrum is computed by the inverse discrete Fourier transform

$$X(k) = \sum_{n=0}^{N-1} R_{xx}(mT) \cdot e^{-jkmT/N}$$

Figure 6 indicates that there are harmonic cycles of 18.6 years.

| Cycle | Nutation (years) | Spectrum (freq.) | Cycle (years) |
|---|---|---|---|
| $u_{13}$ | 6.2 | 0.135 | 7 |
| $u_{11}$ | 18.6 | 0.055 | 18 |
| $u_{31}$ | 55,8 | 0.02 | 50 |

*Table 1 Cycles in earth nutation and computed cycles in power spectrum*

Table 1 shows harmonic cycles according to the earth nutation and computed discrete cycles in the power density spectrum. It shows approximately the same cycles.

The mean value of the N=1140 samples temperature series, is computed and found to be

$$\bar{x}_t(N) = E_t[x(nT)] = \frac{1}{N}\sum_{n=0}^{N-1} x(nT) = 3.9$$

degrees of Celsius. In this case the mean temperature is dependent on the sampling interval, thus it has no absolute mean value. Hence, the autocorrelation function and the auto power spectrum may have stationary cycles lower than a cycle per 50 years.

## 3.2 Amplitude and phase estimate

The amplitude of the stationary cycles u(nT) is easily estimated from the auto power spectrum:

$$c_i = \sqrt{X(jk)}$$

where $c_i$ is a peak of the discrete power density spectrum at the stationary cyclic peaks. Then we have a set of cyclic functions

$$u(nT) = \sum_{i=1}^{M} c_i \cdot \sin(\omega_i \cdot nT + \varphi_i)$$

In the power density spectrum the information about the phase φ is lost. The phase shift may be estimated by an optimal crosscorrelation between the estimated cycles and a variable u(nT)

$$R_{xu} = E[x(nT) \cdot u(nT)]$$

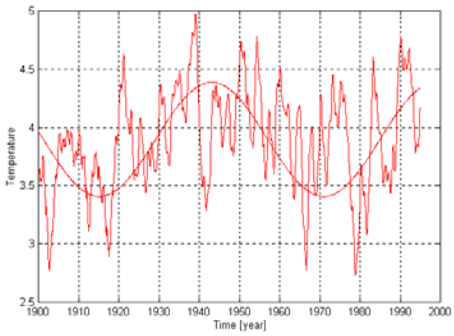


*Figure 7 Temperature series and a 55.8 year cycle*

Figure 7 shows the temperature series and the estimated third sub harmonic cycle

$$u_{31}(nT) = \cdot 3.9 + 0.4 \cdot \sin(\frac{2 \cdot \pi}{3 \cdot 18.6} \cdot nT + 336T_i)$$

where T is the sampling time of one month and n is the number of months from the year 1900. In this case the crosscorrelation $R_{xu}$ is 0.41.

The figure indicates that the cycle is the mean value of the temperature development. If this is true, the Barents Sea now is at a maximum temperature level and will be cooled down for a new period of 55 coming years.

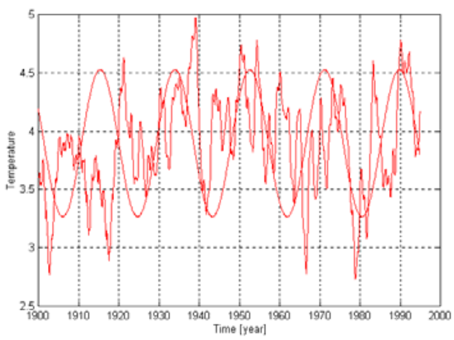


*Figure 8 Temperature series and a 18.6 year cycle*

Figure 8 shows the temperature series and the estimated 18.6 year cycle

$$u_{11}(nT) = \cdot 3.9 + 0.6 \cdot \sin(\frac{2 \cdot \pi}{18.6} \cdot nT + 9.6T_i)$$

In this case the crosscorrelation $R_{xu}$ between x(nT) and u(nT) is 0.2.

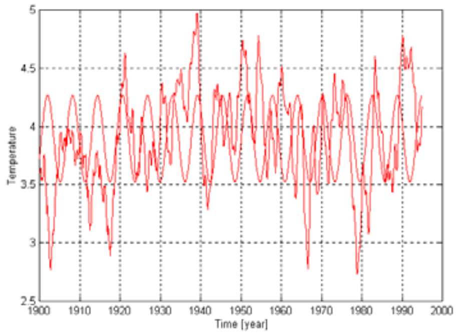


*Figure 9 Temperature series and a 6.2 year cycle*

Figure 9 shows the temperature series and the estimated T=18.6/3=6.2 years cycle

$$u_{13}(nT) = \cdot 3.9 + 0.4 \cdot \sin\left(\frac{3 \cdot 2 \cdot \pi}{18.6} \cdot nT + 12T\right)$$

In this case the crosscorrelation $R_{xu}$ is 0.1.
This cycle seams not to be completely stationary. At some time interval there seams to be an error in the cycle. This happens at the year 1930, 1955, 1960, 1973 and 1992.

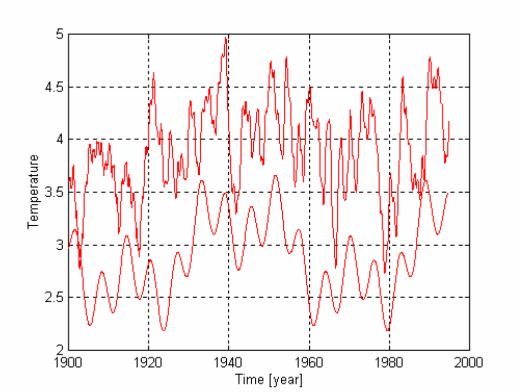


*Figure 10 Temperature time series and estimated cycles*

Figure 10 shows the temperature series x(nT) and the estimated stationary cycle u(nT) (in the figure 10 multiplied by 0.75).

$$u(nT) = u_{13}(nT) + u_{11}(nT) + u_{31}(nT)$$

The crosscorrelation between temperature series x(nT) and the estimated stationary cycle u(nT) is 0.43. After more low pass filtering of the time series x(nT), the cross correlation is increased to 0.5.

### 3.3 Phase plane attractor

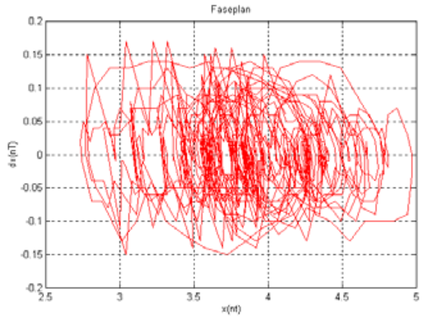


*Figure 11 Phase-plane analysis*

Figure 11 shows a phase-plane analyses of the time series. The x-axis shows the time series x(nT) and on the y-axis we have the velocity

$$y(nT) \approx \frac{x(nT) - x(nT - T)}{T}$$

This figure indicates an chaotic attractor in the phase plane at the temperature x = 3.73 degrees of Celsius. This attractor in the phase-plane supports the theory of a fundamental stationary cycle in the 100 year time series.

## 4 DISCUSSION

The autocorrelation function indicates that the one year filtered time series has a noise component and a stationary component. Studying the discrete power density spectrum shows harmonic cycles of about 18 years. These estimates are also identified by an autoregressive method and by the Welsh method (7, 8,10). The autoregressive method shows more of the 1/frequency properties and the Welsh method separates better the low frequency spectrum. The phase-plane analysis indicates an chaos attractor at 3.75 degrees. This supports the theory of a low frequency stationary cycle in the temperature series.

In this time series, the dominant cycles seems to be the cycles T = 3*18.6 = 55.8 years, T = 18.6 years and T = 18.6/3 = 6.2 years. The cycle of 6.2 years seams to be of great importance for the growth cycles of cod fry in the Barents Sea. We have observed surprisingly good correlation between this cycle and the fry of North Atlantic cod (15).

The 6.2 years cycle seems to have an unstable phase. At some years there is a phase shift in the cycle. The phase shift seems to be permanent from the year 1980. An explanation may be that the cycles are not strictly additive. The phase of the 6.2 year cycle may than shift when the 55.8 year cycle is about a maximum level.

The temperature series is too short to detect lower frequency cycles. A lower frequency cycle may be synchronised by the 18.6 years cycle and by the 2600 year cycle. If we look at only harmonic cycles in this time series, the 55.8 year cycle now has a maximum level. Then we might expect that the Barents Sea will be cooled down for the next 55 years.

Any time series will generate a set of cycles in the power spectrum. In this case the cycles are correlated to harmonic cycles of the stationary earth nutation. From what we know of coupled oscillators and non-linear dynamic systems, this is a strong indication of the earth rotation as the source of these periodic cycles.

If this modulation theory is confirmed by oceanographic measurements, we will know more about the cause of causes, and new perspectives of forecasting is opened. Then we may more precisely forecast climatic changes and the recruitment of cod in the Barents Sea.

# 5 CONCLUTION

The temperature in the Barents Sea has been registered monthly by Russian scientists since the year 1900. The autocorrelation and the auto power density spectrum of the time series indicate a correlation between the low frequency cycles and a 18.6 year periodic changes in the Earth rotation.

The spectrum analysis of the time series indicates a harmonic modulation of the time series. The most dominant cycles is 3*18.6 = 55.8 years, 1*18.6 = 18,6 years and 18,6/3 = 6.2 years. The 55.8 years cycle seams to follow the mean temperature in the time series.

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