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# The Code of Long-term Fluctuations of Norwegian Spring spawning herring

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## Abstract

Norwegian Spring spawning herring (*Cluea harengus*) been associated with large fluctuations. The fluctuations of the biomasses has been poor understood and caused problems in biomass management. Better long-term forecasting thus is crucial for an economical and sustainable utilization of the herring biomass.

In this investigation time series of the Kola section sea temperature and the biomass of herring have been investigated by a wavelets analysis to identify the source of long-term cycles. The wavelet analysis shows that the Kola section temperature series has dominant cycles correlated to the 18.6 yr lunar nodal tide and harmonic cycles of 18.6/3=6.2, and 3*18.6=55.8 years. The identified dominant temperature cycles in the Kola section temperature series are explained by a deterministic 18.6 yr lunar nodal tide that influences Atlantic inflow to the Barents Sea.

The biomass of Norwegian spring spawning herring has adopted a dominant eigen frequency close to stationary 6.2 years temperature cycle. An investigation of long-term dynamics shows that long-term growth is dependent on a the biomass eigen frequency and the phase-relation between 6.2 years and the 18.6 years Kola temperature cycles. This phase-relation is slowly changing and introduces periods of biomass growth, reduction and collapse in a cycle period of 55 to 75 years.

Key words: 18.6 year cycle, climate clock, long-term herring cycles, wavelet analysis

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# 1. Introduction

Norwegian records document good herring periods from 1500-1570, 1600-1650, 1690-1774, and from 1808-1874 (Vollan, 1971). Since the herring biomass had a fluctuation of about 50-80 years, early marine science was looking for a fundamental cause of the biomass fluctuations. Helland-Hansen and Nansen (1909) analyzed time series from 1875 to 1905 and found close relations between variations in the number of sun-spots, the quality of cod roe, the quality of cod liver and the anomaly of mean air temperature at Ona in Norway. This relation was explained by the periodicity in the sun-spots, or rather in the energy received from the Sun which caused variations in the ocean currents through processes in the atmosphere. They concluded that the sea temperature is only an indicator of the variations from an other primary cause. Johan Hjort (1914) analyzed the length distribution of Northeast Arctic cod. He explained fluctuations in the biomass by a match between the spawning time and food to the larvae.

Izhevskii (1961, 1964) reconditioned a system view of the interacting processes between the hydrosphere, the atmosphere and the biosphere. He argued that the heat in the ocean is an non-homogeneous system flowing from a warm equator to the cold pole. In this flow of heat, influenced by tidal forces, the ocean controls the atmospheric processes. Izhevskii analyzed the Kola section temperature data series and estimated stationary cycles of 4-6, 8-10, and 18-20 years. Russian records of Northeast Arctic cod estimated the same cycles of 8-10 and 18-20 years. In an analysis of Norwegian Spring spawning herring he concluded that cod and herring do not represents substantially different ecological types as regards their modes of reproduction. Yndestad (1996,1999) has estimated a 18.6 yr nodal spectrum in the Kola temperature series and Thoresen and Østvedt (2000) has reported a correlation between the spawning stock biomass and the 19 yr mean of the Kola temperature series.

In this presentation, time series of the sea temperature in the Barents Sea, Norwegian spring spawning herring are analyzed to find a common cause of long-term biomass fluctuations. The investigation is based on a wavelet analysis to identify the frequency and phase information in time series of dominant biomass fluctuations. The result shows that the long-term fluctuation in the biomass of herring is caused by a match or mismatch between a biomass eigen frequency cycle and stationary Kola section temperature cycles. The biomasses have a long-term growth when the 6.2 and the 18.6 years Kola temperature cycle are positive at the same time, a long-term reduction when the temperature cycles are not positive at the same time, and a collapse when the temperature cycles are negative at the same time.

# 2. Materials and methods

### *2.1. Materials*

Russian scientists at the PINRO institute in Murmansk have provided monthly temperature values from the upper 200 m in the Kola section along the 33°30'E medial from 70°30'N to 72°30'N in the Barents Sea (Bochkov, 1982). The data series from 1900 until 2000 has quarterly values from the period 1906-1920 and monthly values from 1921, partly measured and partly interpolated. In this presentation the annual mean temperature is analyzed. The time series of Norwegian spring spawning herring (*Cluea harengus*) covers the time from 1907 to 2001 and provided from ICES (2001).

### *2.2 Systems theory*

The Barents Sea is a complex dynamic system of currents, temperature fluctuations, nutrients, phytoplankton, zooplankton, and fish biomasses. The system may be represented by the simplified general system model

$$S(t) = \{B_B(t), \{S_n(t), S_o(t), S_f(t), S_b(t), S_v(t)\}\} \qquad \text{Eq. 1}$$

where $S_n(t)$ is the lunar nodal system, $S_o(t)$ is the ocean system, $S_f(t)$ is the food chain system to fish, $S_b(t)$ is the fish biomass system, $S_v(t)$ is an unknown source and $B_B(t)$ is the mutual binding between the Barents Sea system elements. According to the general system model the Barents Sea is expected to be a time varying, structurally unstable and mutually state dependent system. If there is a dominant energy cycle in one element, the cycle is expected to influence the others. In this case the dominant lunar nodal system $S_n(t)$ is expected to influence the ocean system $S_0(t)$, the ocean system is expected to influence the food chain to fish $S_f(t)$, and the food chain is expected to influence the fish biomass $S_b(t)$.

The lunar nodal system $S_n(t)$ represents gravity energy from the 18.6 years lunar nodal cycle, caused by a mutual interaction between the Earth, the Moon, and the Sun. This gravity energy introduces an 18.6 years lunar nodal tide (Maksimov and Smirnov, 1964,1965,1967; Keeling and Whorf, 1997) in the Atlantic Ocean and a 18.6 yr wobbling of the Earth axis (Pugh, 1996). A 18.6 yr lunar nodal cycle introduces an 18.6 years lunar nodal tide in the Atlantic Ocean. This lunar nodal tide may be described by the model

$$u_{nt}(t) = u_{nt} \sin(\omega_0 t + \varphi_{nt}) \qquad \text{Eq. 2}$$

where $u_{nt}$ is the lunar nodal tide cycle amplitude, the nodal angle frequency $\omega_0=2\pi/T_0=2\pi/18.6134$ (rad/yr) is the lunar nodal angle frequency, t (yr) is the time from t=1900, and the phase is about $\varphi_{nt}=0.5\pi$ (rad) when the tide had a maximum in January 8, 1974 (Keeling and Whorf, 1997). This tide cycle $u_{nt}(t)$ has a phase delay of about $\pi/2$ (rad) or 18.6/4 years compared the Moon high cycle (Pugh, 1996).

### *2.3. Cycle identification*

A stationary cycle will introduce cycles of a time variant amplitude and phase in a system element when the elements have a time variant binding B(t) (Eq. 1). In a long time series this will introduce a time variant amplitude and phase in the estimated cycles. This property makes it difficult to identify stationary climate cycles by strait forward statistical methods. A second problem is that, it may be difficult to identify low frequent cycles and to separate the high frequent cycles from noise in short time series.

Wavelet transforms is an appropriate method to analyze time variant data series. A continuous wavelet spectrum is computed by the transform

$$W(a,b) = \frac{1}{\sqrt{a}} \int_R x(t) \Psi\left(\frac{t-b}{a}\right) dt \qquad \text{Eq. 3}$$

where x(t) is the analyzed time series, Ψ( ) is a wavelet impulse function, W(a,b) are the computed wavelet cycles, b is a translation in time and a is a time scaling parameter in the wavelet filter function. The computed wavelets W(a,b) represents a set of filtered time series between the time series x(t) and the impulse functions Ψ( ). In the following wavelet analysis a Coiflet3 wavelet was chosen (Matlab, 1997; Daubechies, 1992). Computed low frequent wavelets will have a shorter cycle at the beginning and at the end of the time series. To reduce this effect, the 'sym' property in Matlab is used.

# 3. Results

## *3.1 Kola section temperature*

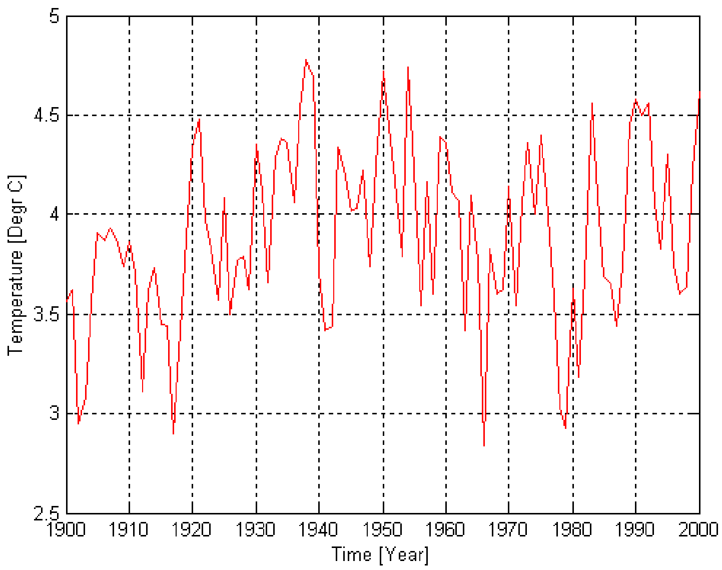


Figure 1 Kola section time series from 1900 to 2000

The Kola section time series is an indicator of inflow of Atlantic water to a more cooled Barents Sea. Figure 1 shows the Kola section temperature time series from 1900 to 2000 along the 33°30'E medial from 70°30'N to 72°30'N in the Barents Sea. The temperature looks like a random process shifting between an upper and a lower state.

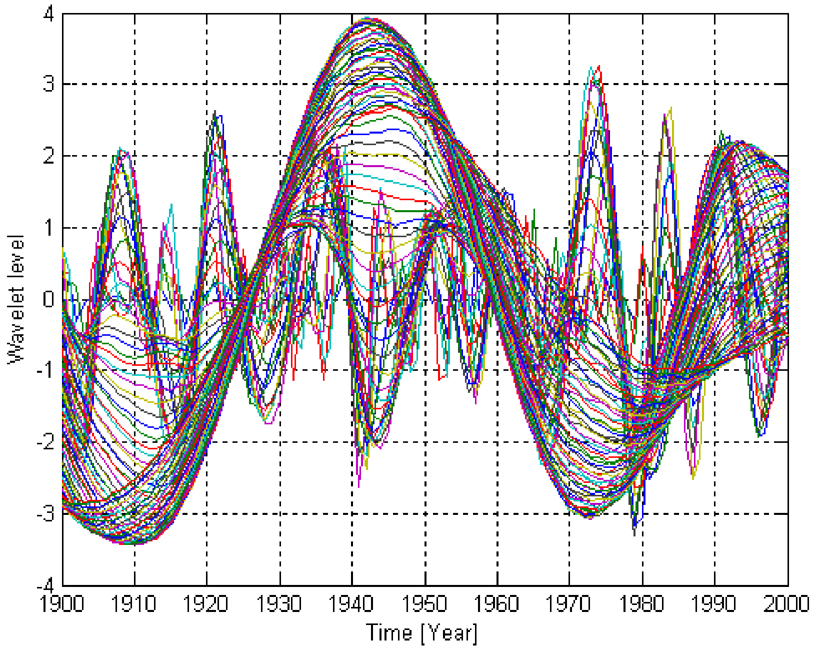


Figure 2 Computed wavelet cycles of the Kola section temperature series.

Figure 2 shows the computed wavelets (1 to 80 yr) of the Kola section time series from the year 1900 until 2000 (Eq. 3). A frequency analysis of the computed wavelets has identified dominant wavelet cycles of about 6, 18, 55 and 74 years.

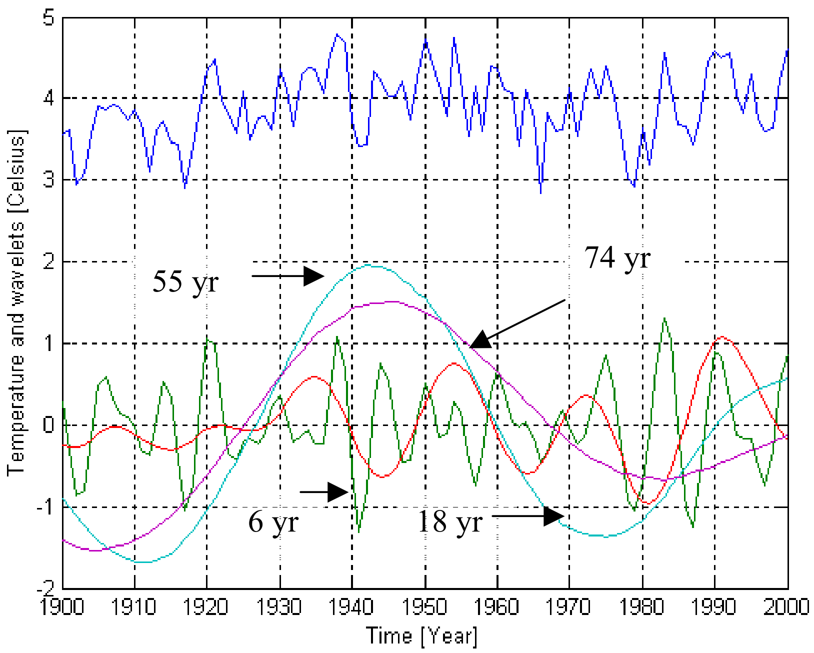


Figure 3 Time series of Kola section data temperature series and the dominant 6, 18, 55 and 74 years wavelet cycles.

Figure 3 shows the Kola section temperature series $x_K(nT)$ from 1900 to 2000 and the dominant wavelet cycles of 6, 18, 55 and 74 years. A wavelet analysis of the time series has estimated the dominant wavelet cycles $W_K(6,nT)$, $W_K(18,nT)$, and $W_K(55,nT)$, which have a cycle time of 6, 18, and 55 years (Figure 1). The correlation coefficients between the data series $x_K(nT)$ and the estimated dominant wavelet cycles $[W_K(55,nT)+W_K(18,nT)+W_K(6,nT)]$ are estimated to 0.73. All dominant wavelet cycles have a cycle time close to the lunar nodal spectrum. The estimated wavelet cycles may be represented by the stationary model

$$\begin{aligned} W_K(74,nT) &= a_K(74,nT)\sin(\omega_n nT/4+0.29\pi) \\ W_K(55,nT) &= a_K(55,nT)\sin(\omega_0 nT/3+0.90\pi) \\ W_K(18,nT) &= a_K(18,nT)\sin(\omega_0 nT+0.48\pi) \\ W_K(6,nT) &= a_K(6,nT)\sin(3\omega_0 nT-0.09\pi) \end{aligned} \qquad \text{Eq. 4}$$

where $\omega_0=2\pi/18.613$ (rad/yr), T=1 year, n=1900..2000, $w_K(55,nT)$, $w_K(18,nT)$, and $a_K(6,nT)$ are time variant amplitudes. The correlation coefficients between the estimated dominant wavelet cycles $W_K(a,nT)$ and the estimated stationary cycles (Eq. 4) are estimated to $R_6=0.37$, $R_{18}=0.87$, and $R_{55}=0.88$ when the time variant cycle amplitude $a_K(a,nT)=1$.

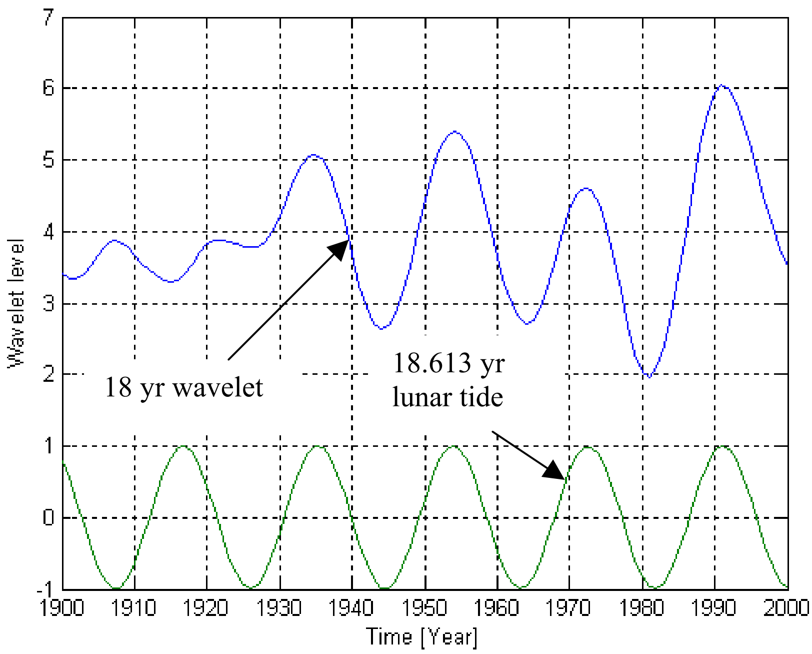


Figure 4 18 yr wavelet cycle and the lunar nodal 18.613 yr lunar nodal tide cycle.

Figure 4 shows the computed 18 yr wavelet cycle and the estimated stationary 18.6 yr cycle $W_K(18,nT)$ form Eq. 4. This stationary cycle has the same frequency and phase as the 18.613 yr lunar nodal tide (Eq.2). The figure shows that the 18 yr wavelet cycle has the same cycle time as the 18.613 yr lunar nodal cycle in the period 1930 to 2000. The cross correlation coefficient between the 18 yr wavelet cycle and the 18.6 yr lunar nodal tide is 0.9 in the period 1930 to 2000. This good correlation is a strong indicates that 18.6 yr nodal cycle controls the velocity of Atlantic inflow to the Barents Sea.

The correlation coefficient between the 6 yr wavelet and $W_K(6,nT)$ is estimated to 0.4. The estimated 6 yr cycle has the same frequency as the 6.2 yr nodal tide (Keeling and Whorf, 1997). This means that the dominant cycles in the Kola section temperature series are correlated to cycles of 18.6/3=6.2 yr, 18.6 yr and 3*18.6=74.5 yr. The cycle amplitude of the dominant 74 yr cycle controls the amplitude of the other cycles. The 74 yr cycle has a negative period from 1900 until 1925. In the same period the 18 yr wavelet cycle is inverted by π rad (18.6 yr).

The dominant wavelet cycles and the stationary nodal spectrum have some identified errors. The 55 years wavelet cycle is suppressed at the beginning and at the end of the time series and the estimated 6 yr wavelet cycle has some noise. A closer analysis of the Kola-section temperature and ice extent in the Barents Sea has identified a 18.6*4=74.5 years cycle in the times series. This 74 cycle controls the 18 yr amplitude and phase of the wavelet cycles $w_K(a,nT)$ and introduces a phase shift of π rad from 1900 until 1925 in the estimated 18 years wavelet cycle.

**The Barents Sea temperature Climate clock**

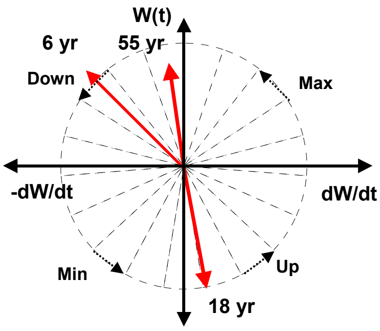


Figure 5 The Kola section "Climate clock" at the year 2001.

The current state of the dominant wavelet cycles $W_{ko}(6,nT)$, $W_{ko}(18,nT)$, and $W_{ko}(55,nT)$ (Eq. 4) may be represented as vectors. A vector diagram then may represent a "Climate clock" where the 18 cycle is turning anticlockwise in a period of 18 years and the 6 yr cycle is turning in a period of 6 years (Figure 5). Current and future climate state then is dependent on the vector sum. Figure 5 shows that the 55 yr cycle $W_{ko}(55,nT)$ has a maximum in 2000 and we may expect that the mean Barents Sea temperature will be cooled down the next 25 years. At the same time, the 18 yr cycle $W_{ko}(18,nT)$ has a minimum and this cycle is expected to increase the temperature the next 9 years. The 6 yr cycle $W_{ko}(6,nT)$ has a maximum in 2000 and the cycle will reduce the temperature the next 3 years. From this analysis we may expect a cooled Barents Sea the next years when the 6 yr and the 18 yr cycle is at a negative state. At about 2009 the 6 yr and the 18 yr cycle will turning to a positive and the Barents Sea will have a temporary increased temperature.

### *3.2. Norwegian spring spawning herring*

The spawning biomass time series of Norwegian Spring Spawning herring has a mean weight of age vector $Xs_{he}$(age)=[0 0.5 14.0 94.8 37.4 569.9 561.2 428.7 332.9 281.0] 1000 tons. Maximum spawning biomass is 569.000 tons at the age of 6 years. The herring biomass then has eigen frequency of about $X_{he}(j\omega_e)=2\pi/T_{he}=2\pi/6.2$ (rad/yr) (Yndestad and Stene, 2001).

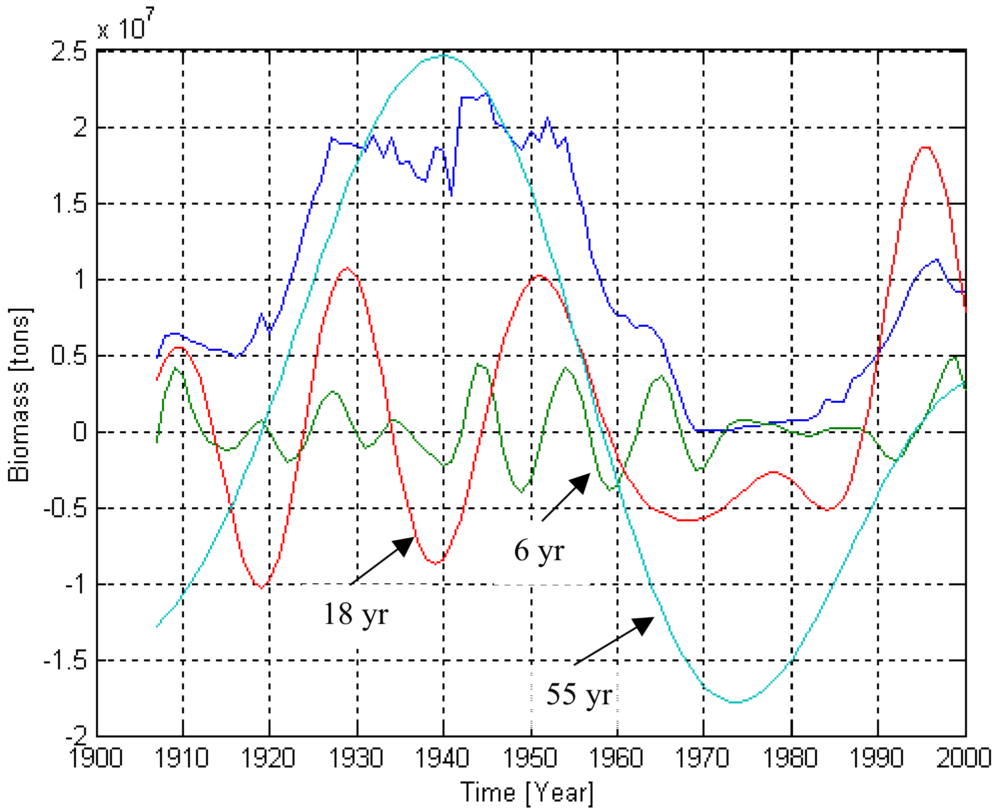


Figure 6 Biomass of Norwegian spring spawning herring and 6, 18 and 55 years wavelets.

Figure 6 shows the biomass time series of Norwegian spring spawning herring from 1906 to 2000 and the dominant 6, 18, and 55 years wavelet cycles. In this data series the biomass had a collapse in the period 1965-1990 which was caused by overfishing. The estimated wavelet cycles show the biomass has dominant cycles of about 6, 18, and 55 years which are harmonic cycles of the biomass resonance cycle time of 6.2 years. The cross correlation coefficient between the herring spawning biomass and the dominant wavelet cycles $[Wb_{he}(6,nT)+Wb_{he}(18,nT)+Wb_{he}(55,nT)]$ is estimated to 0.81.

The long-term biomass growth of herring started around years 1920 and 1990. During these years the 6 years and the 18 years Kola temperature cycle and the recruitments rate cycles had a maximum, the 55 years cycle shifted from a negative to a positive state, and the 55 years recruitment rate shifted from a negative to a positive state. In the period from 1920 to about 1940, the 55 years Kola temperature was growing and the 6 years and the 18 years temperature cycle were positive at about the years 1922, 1930, and 1938. In the same period the recruitment rate had cycles of about 6 years. This estimate shows that the phase of the Kola temperature cycles introduces the 6 yr cycles of recruitments rates. The biomass did not grow in 1975 when the 55 years cycle was in a negative state. The long-term reduction of herring started at about the year 1945. When the 6 years Kola temperature cycle was at a maximum the 18 years Kola temperature cycle was at a minimum.

**The code of long-term growth**

The biomass had a long-term growth in the time period when the 6 year and the 18 year Kola temperature cycle were in a positive state at the same time. In this period there was a match between the 6-7 year biomass cycle and the 6-7 recruitment cycle. Long-term biomass reduction is associated with the period when the 6 and 18 years Kola temperature were not positive at the same time. In this period there was no match between the 6 year biomass cycle and the recruitment rate cycle.

**The herring biomass clock**

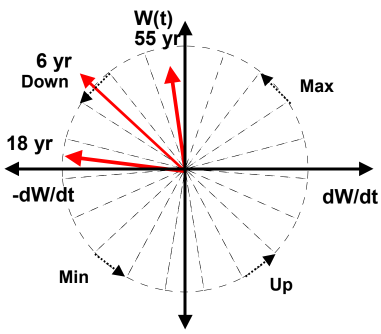


Figure 7 The state of Norwegian spring spawning herring biomass phase clock at the year 2001.

Figure 7 shows the phase state of Norwegian spring spawning herring biomass phase-clock at the year 2001. This is about the same state as in 1945. The 55 yr cycle shows we may expect a mean long-term biomass reduction of herring the next 25 years. This indicated that the biomass has reached a maximum state at about the year 2000. In 1945 the herring biomass was about 20 mil tons and in 1997 the biomass was about 10 mil tons. The difference in the maximum biomass may be explained by the collapse in the biomass and the short period of biomass growth from the 1980’s when the 55 yr Kola cycle started to turn in a positive direction. In a short-term the biomass is expected to be reduced the next 3 years when the 6 years cycle is turning in a negative direction. There is expected to be a new growth period in 9 years when the 18 yr cycle is turning to a positive state.

# 4. Discussion

The dominant biomass dynamics in the Barents Sea is a result of different environmentally random mutual interactions between the ocean system, the food chain, catch, and a multi spices system (Eq. 1). An analysis of the long-term time data series from this system is expected to be dominated by a non-deterministic and non-correlated red spectrum. The analysis in this investigation has a different result.

**The code of biomass dynamics**

In this investigation fluctuations in Kola section temperature and the Norwegian spring spawning herring are analyzed by a wavelet transformation. The results shows a common source of long-term biomass fluctuations.

1. **The forced oscillator**
   The Kola section temperature has dominant temperature cycles of about 6.2, 18.6, and 55 years which are related to the 18.6 years lunar nodal tide. The 18.6 years temperature cycle is expected to be a deterministic cycle controlled by gravity from the Moon. This cycle is a forced oscillating temperature cycle which will influence the Barents Sea food chain.
2. **The long-term biomass growth**
   Long-term biomass growth is related to a optimal recruitment period when the 6 and 18 years Kola section temperature cycles are positive at the same time. In this period the 6 years eigen frequency of recruitment has an optimal growth in 4-5 life cycles. The total long-term biomass cycles of herring and cod was about 3*18.6/2=55.8 year.
3. **Long-term biomass reductions**
   Long-term biomass reduction is related to a period when the 6 and 18 years Kola section temperature cycles are not positive at the same time. In this period the 6 years eigen frequency of recruitment has an optimal growth in a smaller number of life cycles. The growth and reduction of biomass thus is not related to the absolute value of the temperature, but rather to the phase relation between the dominant eigen frequency cycle and the Kola temperature cycles.
4. **The biomass collapse**
   The biomass collapse is related to a period when the 6 and 18 years Kola section temperature cycles are negative at the same time. In this period there are poor conditions of recruitment and growth in a period of 2-3 life cycles.
5. **The 3 causes of fluctuation**
   There are three causes of fluctuation in the biomass. The 6 year cycle in herring biomass is caused by the biomass eigen frequency, which is a feedback property where optimal recruitment is adapted to the 6.2 years Kola temperature cycle. The 18 years biomass cycle is related a period of about 9 years when there was good recruitment. The long-term 55 years cycle is caused by a chain of optimal life cycles.

The Norwegian spring spawning herring stock has an eigen frequency cycle of about 6.2 years. The match between the eigen frequency cycle and the Kola section temperature cycles of 6.2 and 18.6 years explains the long-term growth period of about 25 years and the reduction period of about 25 years. This analysis indicates that the biomass was in a natural reduction process from about 1950 to a natural minimum level of 5 million tons. There is a common belief that the collapse in 1965 was caused by overfishing. The biomass grew from 1992 when the 6.2, 18.6, and 55.8 years Kola section temperature cycle again was in a positive state. The results in this paper shows that the biomass reduction was started by a climate driven process. In the long-term period of less recruitment from 1940-65, overfishing increased the biomass reduction and the biomass collapsed in 1965.

Norwegian spring spawning herring has been characterized by large fluctuations. Norwegian historical records document good herring periods from 1500 until 1570, from 1600 until 1650, from 1690 until

1774 and from 1808 to 1874 (Vollan, 1971). These records shows biomass fluctuations of about 50-80 years. The investigation in this paper supports the theory that long-term biomass fluctuations in Barents Sea the have a cycle of 55-74 years. The changes from 50 to 80 years may be explained by a time variant phase in the biomass cycle which is controlled by the 74 years temperature cycle.

The results has identified a good correlation between the time series and the dominant wavelet cycles, and there is a good correlation between the dominant wavelet cycles and the lunar nodal cycles of 18.6/3=6.2, 18.6, and 3*18.6=55.8 years. The close relation between the lunar nodal tide cycles and the biomass eigen frequency is a strong indication of a long-term adopted property. Since this the Kola section temperature has dominant stationary cycles, the cycles are of most importance in forecasting future biomasses cycles.

The 18.6 year Kola section temperature cycle has a stationary frequency but not always a stationary phase. A closer analysis of the Kola section temperature series and Barents sea ice extent, has identified that the phase of the 18.6 year temperature cycle has shifted 180 degrees in the period from about 1890 until 1925 when a 74 year was in a negative state. In this analysis a long-term temperature cycles of 55 and 74 years are estimated. The relation between the two cycles are still unclear. The wavelet analysis of the Kola temperature series indicates that the 55.8 year temperature cycle is the sum of the 6.2 and the 18.6 year tide cycles where the phase relation between the cycles are slowly changing in a period of 3*18.6=55.8 years. The 55.8 year cycle may the be explained as the envelope of the two cycles. An analysis of Arctic ice extent indicates that the 74 years cycle has its source from the Arctic Ocean. Then the 74 year Kola cycle has the energy to control the phase of the 18 year Kola cycle, this explains why the herring biomass has a fluctuation of 50 to 80 years.

This analysis shows that the 18.6 year Kola section temperature cycle has a fundamental influence on the long-term growth of the biomasses of herring. This temperature cycle is related to the 18.6 years lunar nodal tide which is a deterministic cycle controlled by gravity from the Moon. These results implies that we may be able to explain the cause of long-term biomass in the Barents Sea. The deterministic property of the 18.6 years lunar nodal tide opens a new possibility for long-term biomass forecasting in periods of 50-80 years or more.

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