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POSSIBLE LUNAR TIDE EFFECTS ON CLIMATE AND ECOSYSTEM VARIABILITY IN THE NORDIC SEAS AND THE BARENTS SEA

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Abstract

The inflow of North Atlantic Water to the Norwegian Sea and the Barents Sea has a major influence on northern Europe climate and ecosystem dynamics in the Nordic Seas and the Barents Sea. In the period from 1900 to 2005, the temperature variability of North Atlantic Water and the Barents Sea temperature was correlated with the 18.6 year amplitude tide and the 9.3 yr phase tide. The deterministic property of these fluctuations suggests that forecasting climate and biomass fluctuations over the next 10 to 20 years might be possible. This study investigated the predicted fluctuations of North Atlantic Water and the temperature, zooplankton, and capelin of the Kola section of the Barents Sea over the next 15 years. The forecast is based on historic data and identified lunar nodal cycle periods trained in a Neural Network.

Results of this study show that the ecosystem of the Barents Sea is controlled by the same 9.3, 18.6 and 74.4 tidal cycles of North Atlantic Water flowing into the Barents Sea. The Barents Sea plankton biomass has a negative correlation with warm Atlantic inflow. The biomass of Barents Sea capelin and the North Arctic cod have a positive relationship with warm Atlantic inflow. The close relationship between ecosystem fluctuations and the lunar nodal spectrum indicates that the expected ecosystem variability is dependent on the time scale. Over a time scale of about 10-20 years, the Barents Sea ecosystem fluctuations are expected to follow tidal fluctuations of about 18.6 and 9.3 years. At a time scale of about hundred years, the average mean biomass is expected to follow a longer cycle of about 75 years. This indicates that the Barents Sea ecosystem growth from 1990 is similar to the ecosystem growth period from about 1930 to 1950. The warm climate period and the optimum growth conditions observed presently are expected to decline from about 2020.

Keywords: lunar nodal tide; climate oscillation forecast; ecosystem oscillation; wavelet analysis.

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Introduction

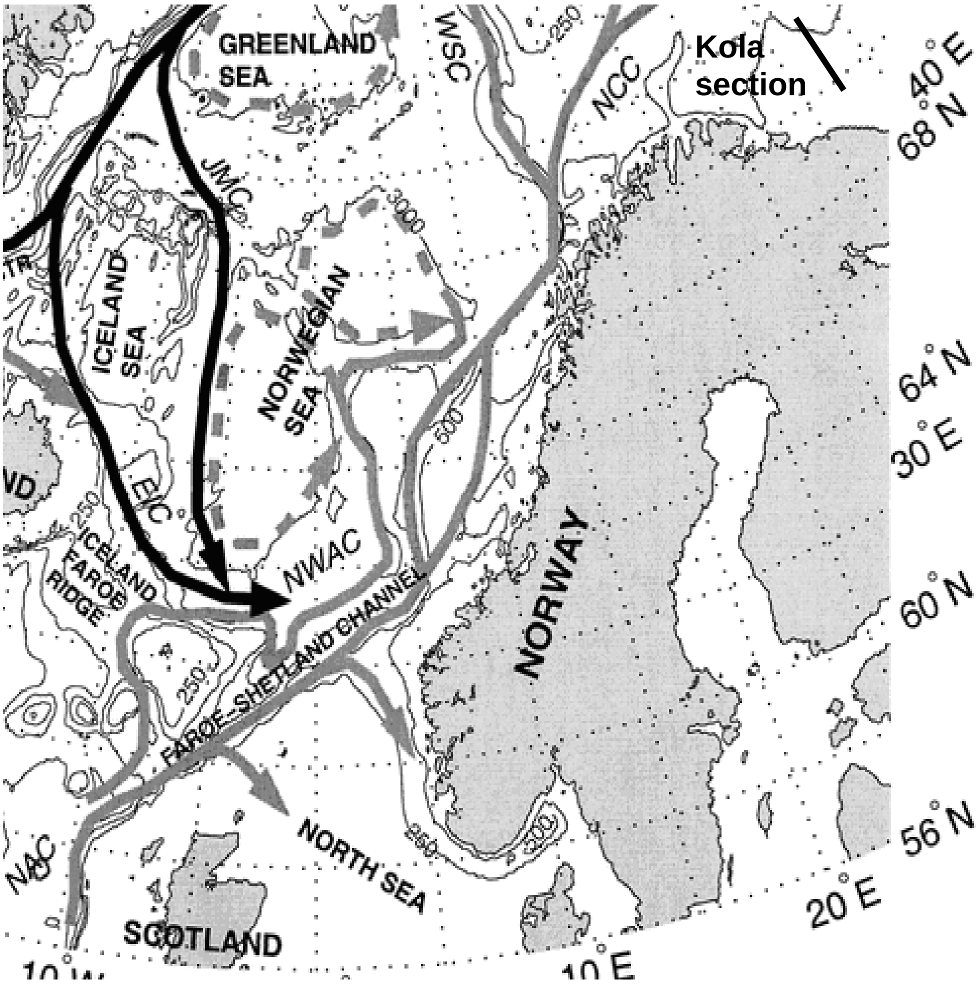

Figure 1. Currents in the Faroe-Shetland channel and the Kola section.

North Atlantic Water has a major influence on the climate of northern Europe. Inflowing water from the North Atlantic passes through the Faroe-Shetland Cannel and into the Norwegian Sea. This current continues north, at which point one part returns to the Greenland Sea and one part flow into the Arctic Ocean through the Fram Strait. A minor part has an inflow to the Barents Sea. This part has a major influence on the climate and the ecosystem in the Barents Sea.

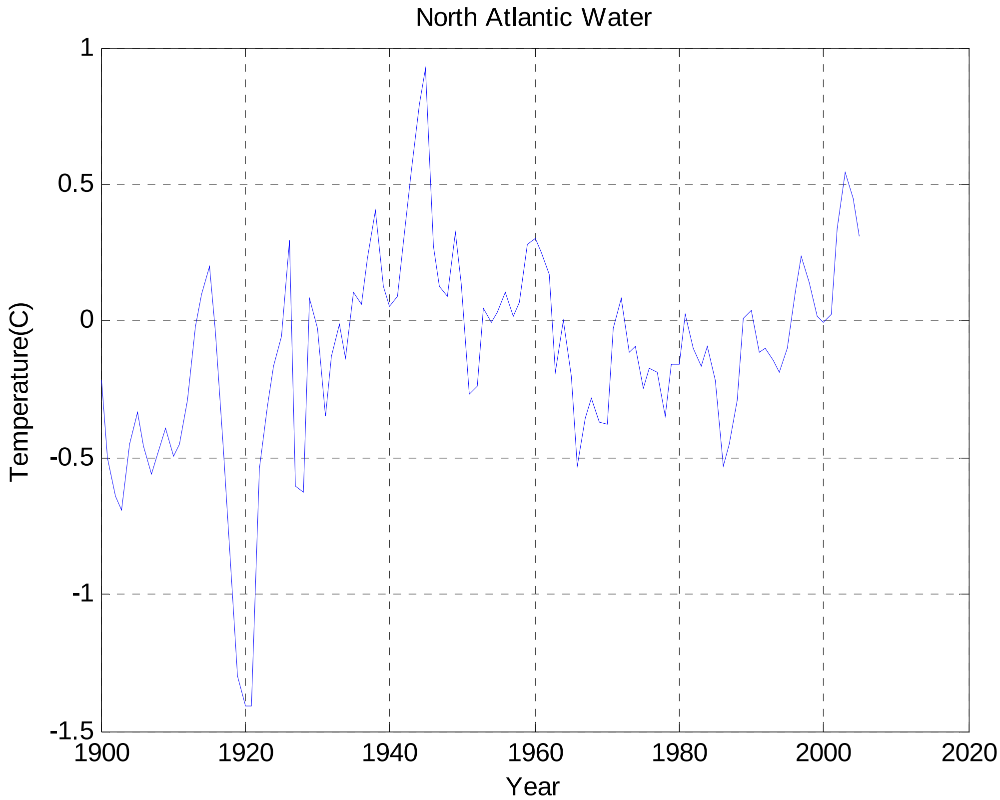

Figure 2. The North Atlantic data series from 1900 to 2005.

The temperature of the North Atlantic waters within the Faroe-Shetland Channel has been monitored since 1893 and the temperature in the Barents Sea Kola section since 1900 (Figures 2 and 3). These data series represent two of the longest oceanographic data series in the world and thus can be used as important indicators of climate change over the last hundred years. The North Atlantic data series shows that there was a warm period from about 1925 to 1965 and that a new warm period started in about 1990. At the same time there was a large fluctuation in the cold and warm periods. In 1945 the temperature increased from about 0.1 to 0.9 degrees Celsius.

The objective of this study was to predict what can be expected in the North Atlantic in coming years. Will the North Atlantic Water temperature continue to grow or decline as it did from 1945? How is temperature variability over the next several years expected to influence the ecosystem in the Nordic Seas and the Barents Sea?

Future climate and ecosystem change must predicted by deterministic information. A wavelet analysis of water temperatures of the North Atlantic and of the Kola section temperature has shown that the dominant fluctuations are correlated with lunar nodal tidal cycles of 9.3, 18.6 and 74.4 years (Yndestad et al, 2004, Yndestad, 2006). Lunar nodal tides have a deterministic property. This correlation may thus be of most importance to estimate future climate and ecosystem variability.

Climate change will influence the ecosystem food chain in the Nordic Seas and the Barents Sea. When climate variability is related to strong stationary long-term tidal fluctuation, climate change may be thought of as a set of forced oscillators on the ecosystem. This paper investigates how major long-term temperature fluctuations in North Atlantic Water and the Barents Sea Kola section have an influence on the Barents Sea ecosystem. The sea temperature is predicted up to the year 2020 by a Neural Network to estimate how the climate may fluctuate the next 15 years. When climate change is a forced oscillator on the ecosystem, the adaptive ecosystem reacts as a coupled oscillator. This coupled ecosystem will have a dynamic property dependent on biomass feedbacks and the phase-relation between the climate oscillation and biomass oscillations (Yndestad, 2004). In this paper, the major fluctuations in the Barents Sea plankton biomass, the Barents Sea capelin recruitment rate and the Barents Sea biomass are investigated to determine how predicted climate oscillations are expected to influence the Barents Sea ecosystem. The results indicate that over the next 15 years we may expect climate and ecosystem variability similar to those in the period from 1940 to 1955.

Materials and methods

North Atlantic Water temperature data series

The North Atlantic Water data series is provided by the FRS Marine Laboratory, Aberdeen, Scotland (William R. Turrell, personal communication). The data is monitored within the core of the Slope Current on the Scottish side of the Faroe-Shetland Channel. The data series covers the period between 1893 and 2002 and has no values from 1895 to 1902, 1915 to 1922, 1930 to 1933 and 1941 to 1946. Data in these periods are cubic interpolated.

Kola section temperature data series

The Kola section temperature data series is provided by the Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Mermansk in Russia (Vladimir Ozhigin, personal communication). The data used here are monthly temperature values from the upper 200 m of the Kola section along the 33°30'E medial from 70°30'N to 72°30'N in the Barents Sea (Bochkov, 1982; Tereshchenko, 1997). The temperature data series contains quarterly and annual values from the period 1900 to 2005 and monthly values from 1921 to 2005, some of which are measured and some of which are calculated. The gaps in the time-series were filled by Bochkov (1982) by means of calculations by multiple regression models.

Barents Sea zooplankton data series

The Barents Sea zooplankton data series represents zooplankton by average biomass (dry weight, g m^{-2}). The data series is provided by ICES (ICES, 2006) and covers the period 1984 to 2005.

Barents Sea capelin data series

The Barents Sea capelin (*Mallotus villosus)* data series is provided by ICES (ICES, 2006) and covers the period 1965 to 2005.

Time-series spectrum

The present analysis is based on the hypothesis that the astronomic 18.6-year lunar nodal cycle introduces a set of harmonic and sub-harmonic gravity cycles that introduce a lunar nodal tide spectrum. The lunar nodal tide spectrum may be represented by the time-variant model:

$$x(t) = u(t) + v(t)$$
$$x(t) = \sum_k a_k(t)\sin(k\omega_T t + \varphi_{kT}(t)) + v(t) \quad , \qquad (1)$$

where $x(t)$ represents a measured time-series, $u(t)$ the lunar nodal harmonic cycles, $v(t)$ a disturbance from an unknown source, $a_k(t)$ represents the cycle amplitude, $\omega_T=2\pi/T$ (rad y^{-1}) the cycle period, and $\varphi_{kT}(t)$ is the time dependent phase angle. A cycle number k may have values k=1,2,3,… on harmonic cycles, k=1/2,1/3,… on sub-harmonic cycles in the lunar nodal spectrum with time t=1900 to 2005.

The astronomic lunar nodal amplitude cycle time of T=18.6134 years introduces a periodic tide that has a vertical and a horizontal component. The vertical component has a global influence on the sea level and has maximum influence at Equator and at the Arctic Ocean and a minimum at about 30 degrees from Equator. The horizontal component influences the tidal current which has a maximum at about 30 degrees from Equator. This amplitude tide has a maximum in November 1987 which represents a phase delay of about $\varphi_T(t)=0.90\pi$ (rad) in Equation 1. The vertical tide causes a current component that has a phase delay of about $\varphi_T(t)=(0.90-0.50)\pi$ (rad). The resulting current phase is dependent on latitude and current conditions. The lunar nodal phase cycle has a period time of $T/2$=9.3 years and a phase-angle of about $\varphi_{T/2}(t)=1.41\pi$ (rad) (Pugh, 1996; Boon, 2004). In this analysis a 74 yr tidal fluctuation was identified in which the phase angle $\varphi_{4T}(t)=0.29\pi$ (rad) is used as a reference (Yndestad, 2006).

Time series spectrum identification

Traditional methods of spectrum analysis cannot identify cycle periods and cycle phase in time-variant stochastic processes, so in this study, the time-series have been analysed by wavelet transformation to identify the dominant cycle periods $u_k(t)$ and the time-variant phase angle $\varphi_{kT}(t)$. The periodicity was identified by a three-step investigation. The first step was to compute the wavelet spectrum by the transformation:

$$W_{a,b}(t) = \frac{1}{\sqrt{a}}\int_R x(t)\Psi\left(\tfrac{t-b}{a}\right)\mathrm{d}t \quad , \qquad (3)$$

where $x(t)$ is the time-series analysed, and $\Psi(\ )$ is a coiflet wavelet impulse function (Daubechies, 1992; Matlab, 1997). The second step was to identify dominant cycles by computing the autocorrelations of the wavelet spectrum. The dominant cycle period is then identified by a cross-correlation to a known spectrum (Yndestad, 2006).

Temperature and biomass forecast

The temperature and biomass forecasts are based on set of one year predictions based on the model:

$$x(t+1) = f(\sum_n w_n, x_n(t), u_n(t+1)), \quad (4)$$

where w_n represents n weights in a trained Neural Network, x(t) the data series and u(t+1) represents the deterministic lunar nodal cycles of 9.3, 18.6 and 74.4 years.

Results

North Atlantic Water temperature

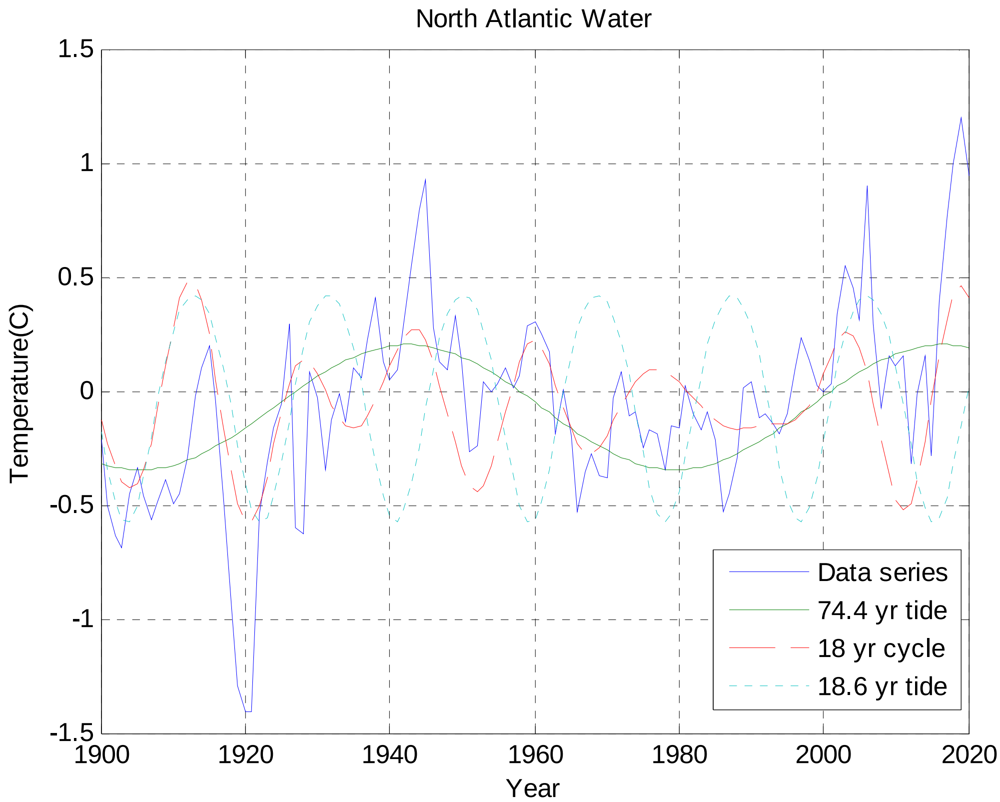

Figure 3. North Atlantic Water temperature from 1900 to 2005 and temperature predictions from 2005 to 2020. The estimated 74.4 yr tide cycle, the identified 18 yr wavelet cycle and the 18.6 yr tide cycle are also shown.

Figure 3 shows the North Atlantic Water temperature in the Faroe-Scotland Channel between 1900 and 2005, the predicted temperature from 2005 to 2020, the estimated 74 yr tide cycle, the identified dominant 18 yr wavelet cycle and the 18.6 yr tide cycle. The data series shows there was a cold period from about 1900 to 1925, a warm period from about 1925 to 1970, another cold period until about 1990 and then the onset of a new warm period.

The North Atlantic Water temperature fluctuations are related to the sum of the 18.6 yr lunar nodal amplitude tide, 9.3 yr lunar nodal phase tide and a sub-harmonic tide of about 18.6*4=74.4 years. The correlation with the lunar nodal tide cycles are estimated to be R=0.59, R=0.68 and R=0.93 (Yndestad et al., 2004; Yndestad, 2006). The tidal properties have a temporary deterministic property which opens a possibility to predict expected future temperature fluctuations. The temperature is predicted by a Neural Network from 2005 to 2020. In the predicted period there is a warm period from about 2000 to 2008 and a new warm period from about 2016. In this period the fluctuations is similar the period from 1939 to 1950.

The consequences of these predicted fluctuations is that we may expect the average temperature to continue to increase up until about bout 2020 before a decrease for about 75/2 or 37 years is initiated. We may expect maximum warm periods from about 2000 to 2008 and from about 2016 when the tidal cycles of 74.4, 18.6 and 9.3 are positive at the same time. These estimates indicate that the warm climate fluctuation from 1990 has the same deterministic fluctuation properties as identified from about 1925. In the time period of about hundred years the average fluctuation was related to the 74 yr tide.

The Kola section temperature

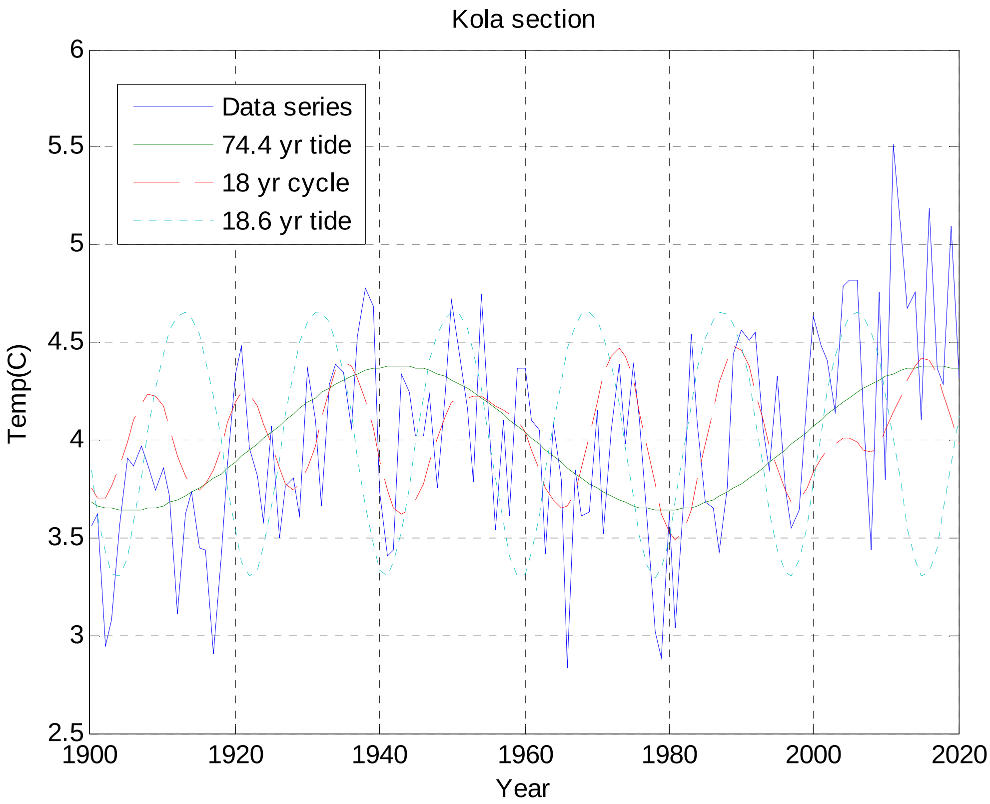

Figure 4. Temperature series from 1900 to 2005, temperature forecast to 2020, the 18.6 yr tide, the 74,4 yr tide and the identified 18 yr cycle are shown for the Kola section of the Barents Sea.

The Kola section temperature is an indicator of warm Atlantic inflow to the Barents Sea. The annual mean temperature showed large fluctuations during the period from 1900 to 2005 (Figure 4). The average mean temperature had a maximum period from about 1940 to 1950 and a minimum period around 1980. From about 1980, the average temperature has continued to increase. The temperature is predicted by a Neural Network from 2005 to 2020. Predictions suggest that the average temperature continues to increase so that the predicted temperature in 2015 is approximately at 5.5 degrees.

The large fluctuations in the annual mean Kola section temperature data series were related to the sum of the 18.6 yr lunar nodal amplitude tide, 9.3 yr lunar nodal phase tide and a sub-harmonic tide of about 18.6*4=74.4 years. The correlation with the lunar nodal tide cycles were estimated to be R=0.74, R=0.77 and R=0.95 (Yndestad et al., 2004, Yndestad, 2006). Figure 4 shows the annual mean Kola section temperature series, the astronomic 18.6 yr tide cycle, the identified dominant 18 yr wavelet cycle and the identified 74.4 yr sub-harmonic tide cycle. The 74.4 yr tide cycle follows average mean fluctuations in the data series from 1900 and explains why the temperature had a maximum at about 1940 and why the annual mean temperature has continued to grow since 1980. The identified 18 yr cycle has a phase delay of about 0.2π (rad) or 2-3 years behind the lunar nodal phase angle 0.9π (rad). The relationship between the 18 yr wavelet cycles and the nodal tide cycles shows the 18 yr cycle phase may have a phase-reversal when the 74.4 yr tide changes from a negative to a positive state.

The Kola section temperature has the same fluctuations as identified in inflowing North Atlantic Water. The consequence of these estimates is that the average Barents Sea temperature may continue to increase until approximately 2015. At this point, the average temperature is expected to be reduced in a period of about 37 years. These fluctuations are expected to influence the ecosystem dynamics in the Barents Sea.

The Barents Sea zooplankton biomass

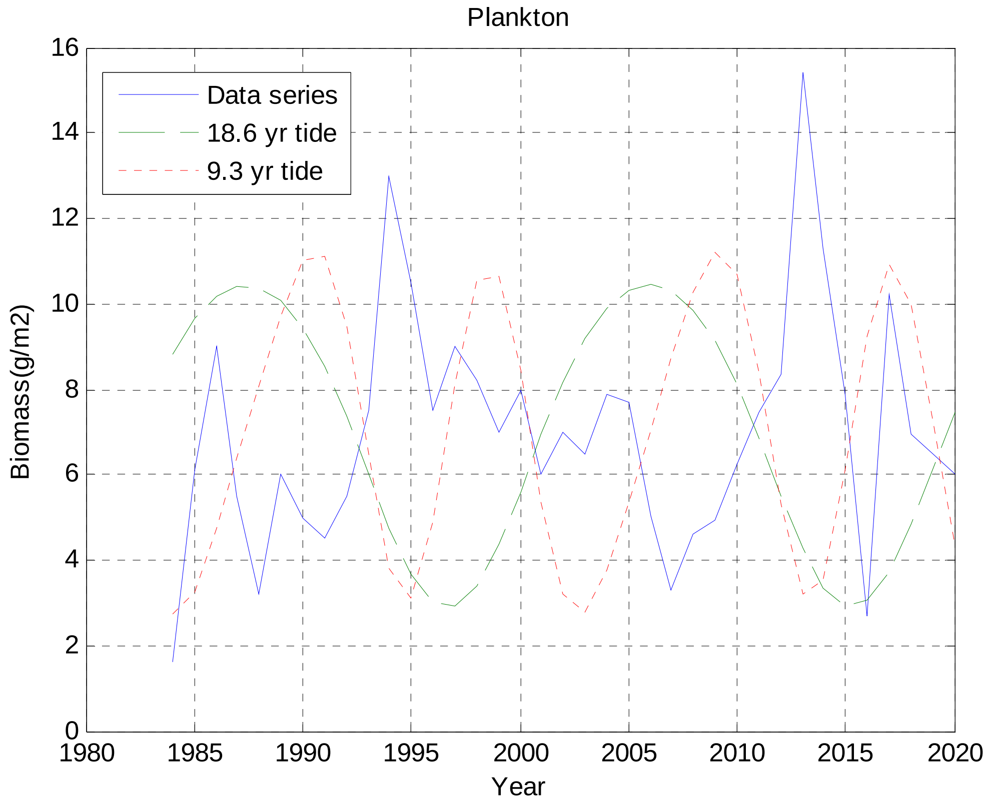

Figure 5. Barents Sea zooplankton dry weight biomass data series from 1984 to 2005 is shown, along with the biomass prediction from 2005 to 2020, the astronomic 18.6 yr amplitude tide, and the 9.3 yr phase tide.

Figure 5s shows the Barents Sea zooplankton dry weight biomass data series from 1984 to 2005, the predicted biomass from 2005 to 2020, the 18.6 yr lunar nodal tide cycle and the 9.3 yr lunar nodal phase tide cycle. In the period between 1984 to 2005, the biomass increased from about 2 g m^{-2} in 1984 to about 13 g m^{-2} in 1994 and then continues to decrease. The predicted biomass from 2005 to 2020 is based on predictions from a Neural Network.

The plankton biomass fluctuations are related to the inverse 18.6 and 9.3 year tidal cycles. The biomass reached a minimum at about 1990 when astronomic lunar nodal tide cycles were simultaneously positive and reached a maximum in 1994 when they are negative. The correlation between the plankton data series and the 18.6 and the 9.3 yr lunar nodal tide cycles are estimated to be R=-0.5 in the period between 1984 to 2005.

The negative correlation with the lunar nodal cycles shows that Barents Sea zooplankton is maximal in the cold period when the 18.6 yr and 9.3 yr tidal inflows are minimal. The zooplankton biomass has a one year life cycle. The biomass is than expected to follow the tidal inflow to the Barents Sea during the next 15 years.

The Barents Sea capelin biomass

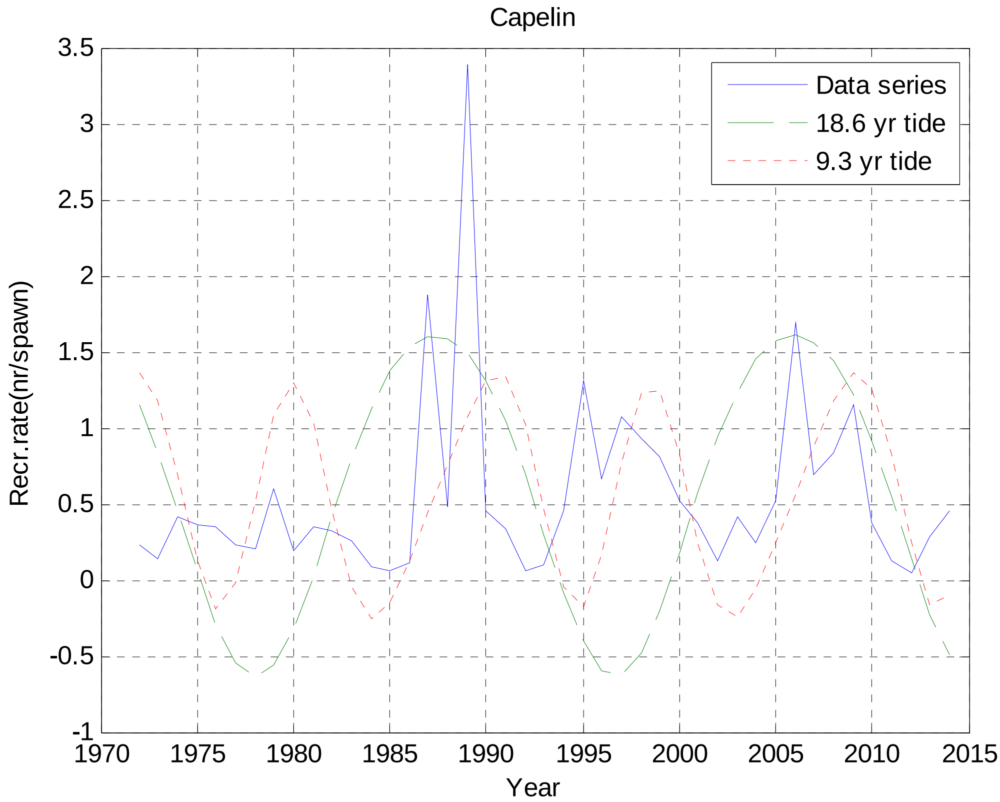

Figure 6. Barents Sea capelin recruitment rate from 1972 to 2005 are illustrated alongside the rate prediction from 2005 to 2020, the astronomic 18.6 yr amplitude tide cycle and the 9.3 yr phase tide cycle.

The Barents Sea capelin (*Mallotus villosus)* has a northerly circumpolar distribution. In the Atlantic the capelin is located in the Barents Sea (ICES areas I and IIa), Iceland, Greenland, Labrador and Newfoundland. The capelin stock in the Barents Sea is the largest in the world and has maintained a fishery with annual catches of up to 3 million tons. The capelin stock is of vital importance in the Arctic food web; it is the main plankton feeding predator in the area and serves as an important forage fish for other fish stocks, seals, whales and sea birds. The capelin is therefore influenced by its abiotic environment and by the abundance of food, predators, and fisheries. The capelin stock typically consists of a few year classes of fish. The Barents Sea capelin stock has large fluctuations, with collapses in biomass registered during 1985 and 1993. For these reasons, it is important to determine how the capelin biomass dynamics is related to North Atlantic Water temperature variability.

Recruitment rate is an indicator of how climate dynamics influence growth dynamics. This investigation has shown that there is a close correlation between the fluctuation of long tides, fluctuations of the Kola section sea temperature and the Barents Sea plankton biomass. A next step may be to investigate the biomass fluctuation of Barents Sea capelin. Figure 6 shows the computed recruitment rate (calculated as Recruitment rate(t)=Recruitment(t)/Spawning biomass(t-1)) from 1972 to 2005, the recruitment prediction from 2005 to 2020, the 18.6 yr amplitude tide and the 9.3 yr phase tide (ICES, 2006). The figure demonstrates that the recruitment rate has a maximum from 1985 to 1993. In this period there was a maximum 9.3 yr and 18.6 yr tidal inflow of Atlantic water to the Barents Sea. The next maximum was in about 1995 when the 9.3 yr cycle became positive.

The figure shows the predicted growth rate from 2005 to 2015. It shows that growth rate has a maximum from about 1985 to 1990 when 18.6 yr and 9.3 yr tidal cycles were maximal. In this period, warm Atlantic inflow to the Barents Sea was also maximal. The forecasted time series indicates that we may expect a new maximum growth period between 2005 and 2010. The capelin biomass has a maximum recruitment cycle of about 3 years, which will influence capelin biomass dynamics.

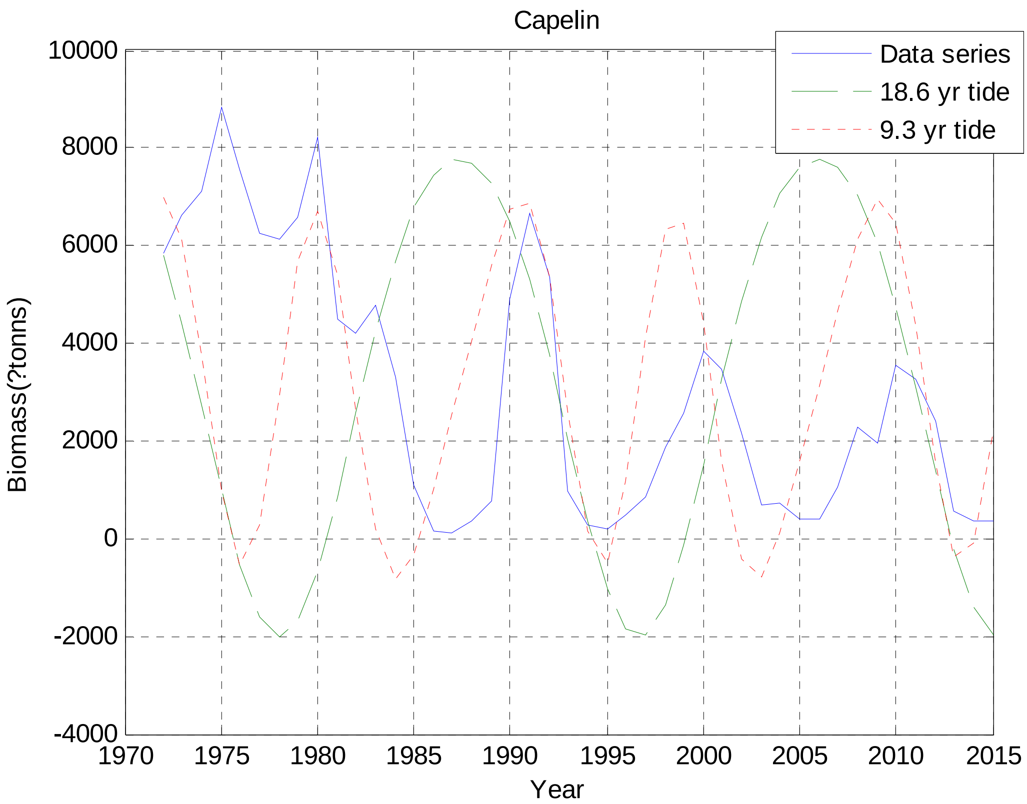

Figure 7. Barents Sea capelin biomass from 1972 to 2005, with the biomass prediction from 2005 to 2015, the astronomic 18.6 yr tide cycle and the 9.3 yr tide cycle.

Figure 7 shows the Barents Sea capelin biomass between 1972 and 2005, the biomass prediction from 2005 to 2015, the astronomic 18.6 yr tide and the 9.3 yr tide cycle. The figure shows that the biomass has fluctuations related to tidal cycles. The capelin biomass has a mean live cycle time of about 3 years. This 3 yr cycle time has caused peaks in biomass at about 1975 and 1980. In the period between 1980 and 1985, the recruitment rate was minimal and there was a biomass collapse caused by overfishing. From 1985 to 1990, the recruitment rate increased due to tidal inflow and the capelin biomass increased to a maximum level. After, 1992 the tidal cycles became negative. There was no new growth period and after the 3 yr life cycle period there was a new biomass collapse. The new growth period came from about 1997 to 2000 when there was a new 9.3 yr tidal inflow. The same happened between 2000 to 2005, when the 9.3 yr tide became negative.

The predicted biomass from 2005 to 2015 suggested that we can expect a new biomass growth period from 2006 to 2010 when the 9.3 yr tide is positive. The biomass collapses between the maximum 9.3 yr tidal inflows indicate that biomass growth is not related to a linear increasing temperature, but rather to synchronization between the 9 yr Atlantic tidal inflow to the Barents Sea and the 3 yr capelin biomass life cycle dynamics.

Discussion

The analysis in this paper is based on quality data series from FRS, PINRO and ICES. The identified lunar nodal spectrum has a correlation with the data series which is stronger than R=0.6 (Yndestad et. al, 2004, Yndestad, 2006). This suggests that long-term deterministic fluctuations in North Atlantic Water temperature and the Barents Sea ecosystem can potentially be predicted . There are, however, other potential errors; 15 year forecasting of sea temperature and biomass fluctuation will inevitably contain errors. In this case the prediction error was reduced by introducing deterministic lunar nodal cycles into a Neural Network. Both the data series of North Atlantic Water temperature and the Kola section temperature prediction were based on a network trained as a two layer, 18 node Feed Forward Numeric Predictor network (for the North Atlantic Water, tested mean error=0,32; Std. abs. error =0.28, while for the Kola section tested mean error=0.12; Std. abs. error=0.35). The zooplankton prediction was based on a two layer 9 node Feed Forward Numeric Predictor network (tested mean error=0.53; Std. abs. error=1.5), and the capelin biomass predictions are based on a two layer General Regression Network (tested mean error=27, Std. abs. error=70) (NeuralTools, 2005). A second potential error source is that the lunar nodal tides may have phase-reversals. A phase-reversal is identified in the North Atlantic Water data series in 1925 when the 74 yr cycle moved from a negative state (Yndestad, 2006). A new potential phase-reversal in 2000 will delay the sea temperature fluctuation and will introduce a synchronisation disturbance in Barents Sea ecosystem dynamics.

The results

This investigation showed that the temperature of North Atlantic Water and the Kola section has dominant cycles that are correlated with the lunar nodal tide cycles of 9.3, 18.6 and 74.4 years. The North Atlantic Water temperature forecast to 2020 indicates that the temperature fluctuation from 2000 to 2020 is expected to have the same properties as in those observed in the warm period from 1930 to 1950. The lunar nodal spectrum has harmonics and sub-harmonic cycles related to the 18.6 yr lunar nodal amplitude cycle. In this analysis it is identified as a harmonic 9.3 yr phase tide and sub-harmonic tide of about 4*18.4=74.4 years. The 9.3 yr tide is an astronomically forced tide. The 74 yr tide is most likely caused by circulating water in the Arctic Ocean (Yndestad, 2006). The estimated temperature fluctuations are of larger magnitude than those in the warm period from 1930 to 1950. This increase suggests that temperature fluctuations periods longer than a hundred years may exist. At the same time there may be interference between the cycles that may introduce phase-reversals (Yndestad, 2006).

The investigation of the Barents Sea zooplankton data series and capelin data series shows that the biomass growth is correlated to deterministic tidal cycles in the Barents Sea. This means that we may be able to think of biomass life cycles in the Barents Sea as set oscillators coupled to the forced oscillating tides. The ecosystem growth is then not related to the mean climate change, but to the synchronization between the climate oscillation and the biomass feedback recruitment oscillation. The capelin biomass has a life cycle of about three years. In 1985 the biomass collapse was most likely caused by over fishing. The timing difference between the 9.3 yr tidal cycle and the 3 yr recruitment cycle explains why the collapse is repeated by nature causes.

Conclusions

The climate and ecosystem variability is correlated to the lunar nodal spectrum. This means that the expected ecosystem fluctuations are dependent on the time scale. In a time scale of about 10-20 years, the Barents Sea ecosystem is expected to follow the tidal fluctuations of approximately 18.6 and 9.3 years. At time scale of about one hundred years, the average mean biomass is expected to follow the long-term cycle of about 75 years. This indicates that from 1990 the Barents Sea ecosystem is expected to have similar growth conditions as it did between 1930 and 1950. The warm climate period and this optimum growth condition period are expected to decline after about 2020.

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