Working paper No. 10/07

GLOBAL WARMING
STATIONARITY IN SEA TEMPERATURE DATA

by
Torbjørn Lorentzen

SNF Project No. 5000: Centre for Fisheries Economics
The project is funded by The Research Council of Norway

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, JUNE 2007
ISSN 1503-2140

Global Warming
Stationarity in Sea Temperature Data

Torbjørn Lorentzen

Centre for Fisheries Economics, SNF
E-mail address: torbjorn.lorentzen@snf.no

Abstract

According to the UN's Intergovernmental Panel of Climate Change (IPCC), the earth's climate is already changing. The objective of the paper is to analyze how the average yearly sea temperature has evolved at two different geographical spots along the coast of Norway during the period 1936-2003. The statistical analysis is related to the concept and properties of stationary time series. Augmented Dickey-Fuller and non parametric Phillips-Perron tests are applied in the uncovering of the data generation process behind the sea temperature.

JEL classification number: C1, C12, Q25, Q56
Keywords: Climate change, sea water temperature, stationarity, coast of Norway

1 Introduction

According to the UN's Intergovernmental Panel of Climate Change (IPCC 2003), the earth's climate is already changing. Certain geographical areas will experience dramatic changes in weather conditions; the temperature will increase, and wind and rain will become more volatile. More "extreme" weather is expected, and some areas have already had a foretaste. During the coming hundred years and beyond the average global air temperature is expected to increase by between 1.5 and 6 degrees centigrade, depending on what scenario is assumed to prevail (IPCC 2001, 2003, 2007 and ACIA 2004). The phenomenon is diagnosed as 'global warming', caused by the technology applied by modern society. The demand for energy and materials leads to emission of enormous quantities of greenhouse gases; carbon dioxide, nitrous oxide, methane and the sulphur (di)oxides, which are spin-off materials from the combustion of fossil fuel.

A climate change will, depending on how fast it is, induce different socioeconomic effects. First and foremost, industries based on living natural resources will be directly affected, for example fishing, aquaculture, forestry and agriculture. It is an empirical question whether the change in climate will have a positive or negative economic effect.

Some reports conclude that global warming will raise the sea temperature in the Northeast Atlantic and that the future temperature in the waters off the coast of Norway will be affected (IPCC 2003, Stenevik and Sundby 2004, ACIA 2004 and NERSC 2005). Temperature is an essential indicator for climate change, and temperature is also a critical factor for the life conditions of cold blooded animals such as fish. Therefore it is import to know in what direction the sea temperature will change in the future.

The objective of this paper is to analyze how the average yearly sea temperature has evolved during the period 1936-2003. Two geographical spots along the coast of Norway are being compared, respectively Lista in Rogaland county in the south and Skrova in Nordland county in the north (see Figure 1). The statistical analysis focuses basically on testing the following hypotheses:

H_0: There is no climate change.

If there is no climate change, then we should identify a time series which fulfils stationary properties. The alternative hypothesis is:

H_A: Negation of H_0.

The paper focuses on the following questions: What kind of data generation process (DGP) can describe the temperature data at these geographical areas? Are changes in temperature just an indication of white noise, or is the process non-stationary due to trend or change in volatility? Is it possible to detect any climate change in the temperature data?

However, it is not possible to conclude that a climate change has taken place merely because a weather indicator has changed. Such change is a necessary condition for detecting a climate change, but it is not a sufficient condition because the detected change could be temporary and part of a natural variation. The topic whether a climate change is taking place involves important methodological aspects. How is it possible to differentiate between natural, normal changes (changes which have occurred on earth for hundreds of years) and changes directly related to the human or anthropogenic activity, for example induced by the emission of greenhouse gases? And further, what time span is necessary for analyzing and drawing valid conclusions about climate change?

The remainder of the paper is structured as follows. The next section, Section Two, describes the evolvement of the sea temperature off Lista and Skrova for the period 1936-2003 and 1942-2003, respectively. Section Three presents methodological criteria for evaluating potential climate change. The stationary condition for times series is essential in the analysis of climate change. This section analyses one of the stability conditions by testing whether the variance is stable for each temperature series. Bartlett's chi-square test and Levene's F-test are applied. Further, the section analyses the data generation process behind the observation by applying an extended Dickey-Fuller test and the non-parametric Phillips-Perron test. The section also takes advantage of Ljung-Box-Pierce, Jarque-Bera, McLeod-Li, Kolmogorov-Smirnov tests in diagnosing the properties of the temperature series. Finally, Section Four concludes.

2 Geographical differences in temperature

This chapter analyses geographical differences and similarities in the sea temperature at Lista and Skrova. Figure 1 shows where Lista and Skrova are located in Norway. Skrova is located about 1180 km north of Lista.

Figure 1: Geographical location of Lista and Skrova.
Source: Senior Research Engineer Kjell Helge Sjøstrøm, Institute of Geography, University of Bergen.

The sea temperature data presented in this section are measured in the 1-50 m layer, and the reported temperature is the average of 2 to 4 measurements per month. The data which are used in the analysis were obtained from the Institute of Marine Research (IMR) in Bergen, Norway.

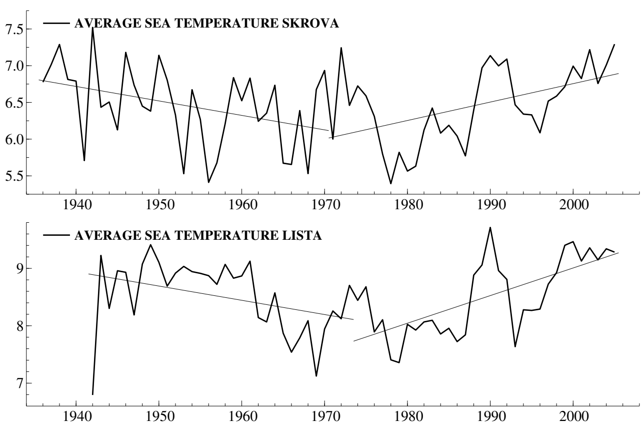

Figure 2: Average yearly sea temperature for Skrova and Lista.
Source: IMR-Bergen.

Figure 2 shows that the trend and fluctuations are quite similar between the annual average time series. Figure 2 shows that the temperature has a negative trend from the 1930ties to the end of the 1960ties. After 1970 the average temperature is increasing and the trend is positive. The linear regression lines for each sub-sample indicate roughly the direction of the temperature trend. The slopes of the negative and positive trends are almost identical for Lista and Skrova. Notice the extremely low 1942-value for Lista. According to Institute of Marine Research it was an unnaturally cold year, and the observation is probably an outlier. Notice also the low volatility of the temperature during the 1950s for Lista. Missing values for the 1950s are substituted by weighted temperature observations close to the missing values (see Appendix A).

Table 1: Descriptive statistics for Lista (1942-2003) and Skrova (1936-2003)

	Min.	Max.	Mean	Standard-deviation	Coefficient of variation
Lista	6.71	9.71	8.47	0.637	0.0751
Skrova	5.41	7.29	6.43	0.472	0.0734

The average temperature off Lista is about 2 degrees centigrade higher than the temperature level off Skrova. The averages are significantly different (5% level). Bartlett's test cannot reject the hypothesis of equal variance. The coefficient of variation shows that the volatility is marginally higher at Lista than at Skrova.

3 Criteria for detecting climate change

Climate change can in statistical terms be defined as a change in the statistical parameters which characterize the distribution of the climate variable in question. If for example the average temperature (or the variance) changes over time, this probably signals a climate change. A necessary and sufficient condition for a climate change is a change in the statistical distribution which normally characterizes the climate variable. A change in the distribution of the climate variable $\{y_t\}$ for $t = 0, 1, 2, ..., \infty$ implies that the variable is non-stationary. A non-stationary variable implies a break in one or more of the following stationary conditions; (1) the expectation $E\{y_t\} = \mu < \infty$, (2) variance $V\{y_t\} = E\{(y_t - \mu)^2\} = \gamma_0 < \infty$ and (3) the covariance $Cov\{y_t y_{t-k}\} = E\{(y_t - \mu)(y_{t-k} - \mu)\} = \gamma_k$ for all $k = 1, 2, 3, ...$

The stationary conditions require autonomy, i.e., that the statistical moments are invariant to any time shift (independent of time date). A "weak stationary" process means that the mean and variance are constant but not higher orders (i.e. skewness, kurtosis etc.). A "strictly stationary" process means stationary of order two and, in addition, that the series is normally distributed.

How do we detect whether a climate variable is stationary or not, i.e., whether or not the variable satisfies the said conditions? In the following we will apply different methods to identify the data generation process (DGP) that is behind the realization of the already presented temperature data. An Augmented Dickey-Fuller (ADF) test and Phillips-Perron tests are applied for unit root testing and for statistical testing (5% significant level) of whether the series are difference stationary (DSP) or time series stationary processes (TS). Further we apply Bartlett's and Levene's test for stable variance and a sample of white noise, normality and autocorrelation tests.

What kind of trend characterizes the series? Is it a deterministic trend or is it a stochastic trend induced by a random walk process? Is the realization of the data a stationary process with a long-run equilibrium? An ADF and a Phillips-Perron non-parametric test are applied in diagnosing the data generation process (DGP).

3.1 Testing for stable variance

We tested whether the variance of the temperature has changed over time by dividing the temperature series for Skrova and Lista into sub groups and tested the following hypotheses H_0: The variances are not significantly different between the subgroups, i.e. $\sigma_1 = \sigma_2 = \sigma_3$, against the alternative hypothesis, H_A: At least one of the variances is significantly different from the others. The temperature series for Skrova was divided into the following three groups presented in table 2.

Table 2: Descriptive statistics annual average Skrova 1936-2003

Sample	Frequency	Mean	Variance
Skrova group 1	(1936-56) 22	6.526	0.329
Skrova group 2	(1957-79) 23	6.283	0.267
Skrova group 3	(1980-03) 23	6.509	0.198

Table 3: Bartlett's test for equal variance for the annual average temperature off Skrova

Chi-square (Observed value)	1.344
Chi-square (Critical value)	5.991
DF	2
p-value (Two-tailed)	0.511
Alpha α	0.05

Table 4: Levene's test of equal variance for the annual average temperature off Skrova

F (Observed value)	0.528
F (Critical value)	3.906
DF1	2
DF2	65
p-value (Two-tailed)	0.592
Alpha α	0.05

At the level of significance $\alpha = 0.05$, the null hypothesis of equality of the variances between the sub samples cannot be rejected. We can conclude that the variance has been stable during the test period 1936-2003.

Table 5: Descriptive statistics, annual average, Lista 1942-2003

Sample	Frequency	Mean	Variance
Lista group1	(1942-62) 21	8.768	0.307
Lista group 2	(1963-83) 21	8.003	0.171
Lista group 3	(1984-03) 20	8.671	0.412

Table 6: Bartlett's test for equal variance for the annual average temperature off Lista

Chi-square (Observed value)	3.602
Chi-square (Critical value)	5.991
DF	2
p-value (Two-tailed)	0.165
Alpha α	0.05

Table 7: Levene's test of equal variance for the annual average temperature off Lista

F (Observed value)	3.083
F (Critical value)	3.929
DF1	2
DF2	59
p-value (Two-tailed)	0.053
Alpha α	0.05

Even though the hypothesis of equal variance cannot be rejected, given a significance level of 5%, Levene's test shows that the p-value is close to rejecting the hypothesis. We conclude that the variance has been relatively stable during the test period 1936-2003.

3.2 Conclusion

A stable variance is a criterion a series must fulfil to be evaluated as a stationary process. The analysis shows that the hypothesis of equal variance for the annual average temperature cannot be rejected. We can therefore conclude that the variance has been stable throughout the period 1936-2003 for Skrova and 1942-2003 for Lista.

3.3 Testing for unit root and non stationarity

An extended Dickey-Fuller (ADF) and a Phillips-Perron (PP) nonparametric test[1] are applied for testing each variable for unit root and stationarity, and for diagnosing whether the variables are trend-stationary (TS) or difference stationary (DS) processes (Dickey and Fuller 1979, Phillips 1987). The following general test function is applied for the ADF-test[2]:

$$\Delta y_t = a_0 + \gamma y_{t-1} + a_2 t + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_t \tag{1}$$

where y_t is the time series to be analyzed, a_0, γ, a_2 and β are estimated constants, t is the time (measured in years) variable, ε_t is a normally distributed residual and a white noise process, $\Delta y_t = y_t - y_{t-1}$, p number of lagged

[1]The PP-test is called nonparametric test because no parametric specification of the error process is involved.

[2]PP-test applies the test function in equation 1, but without any lags. The Student's t-statistics in the PP-test is corrected as a function of autocorrelated residuals.

first differences of the dependent variable to capture autocorrelated omitted variables that would otherwise, by default, enter the error term. The most important test is the test of the unit root, i.e. if $\gamma = 0$, but to absorb all sides of the underlying DGP, the test function also includes the deterministic factor as constant a_0 and the deterministic trend $a_2 t$. The following tables present the estimated t-values, t_γ, for the y_{t-1} variable and the adjusted critical values (MacKinnon 1991). Three addition tests (F-tests) are also a part of the analysis. The statistics are called Φ_1, Φ_2 and Φ_3 and they test joint hypotheses on the coefficients. The hypothesis H_0: $a_0 = a_2 = \gamma = 0$ tests the pure random walk model against the alternative that the data contain an intercept and/or an unit root and/or a deterministic time trend. The hypothesis H_0: $a_2 = \gamma = 0$ tests for unit root and/or deterministic trend. The hypothesis H_0: $a_0 = \gamma = 0$ tests for unit root and/or drift. The test procedure applied here is consistent with the procedure recommended by Perron 1988, Sims, Stock and Watson (1990) and Dolado, Jenkinson and Sosvilla-Rivero (1990). All tests apply significance level of 5%.

3.3.1 Lista 1942-1973

Table 8: Test statistics for the sample period 1942-1973

VARIABLE	PP TEST*	PP TEST*	ADF**	ADF**
LISTA	Constant	Constant and trend	Constant	Constant and trend
Temperature t_γ	-21.95	-27.65	-2.08	-2.35
Critical value***	-14.10	-21.70	-2.86	-3.41
H_0: $a_0 = \gamma = 0$	10.33 $\Phi_1 = 4.59$		2.19 $\Phi_1 = 4.59$	
H_0: $a_0 = a_2 = \gamma = 0$		13.42 $\Phi_2 = 4.68$		2.13 $\Phi_2 = 4.68$
H_0: $a_2 = \gamma = 0$		19.8 $\Phi_3 = 6.25$		3.17 $\Phi_3 = 6.25$

*Truncation lag is 1. **Lag order p in the ADF test is 5. The number of lag terms p is chosen to ensure the errors are uncorrelated. By default Shazam (Whistler et al., 2006) sets the order as the highest significant lag order from either the autocorrelation function or the partial autocorrelation function of the first difference series. *** z_c, z_{ct}, τ_μ (intercept) and τ_τ (intercept and deterministic trend) are the critical values for respectively the PP and the ADF test.

The ADF test indicates a pure random walk process which can generate a stochastic trend. The lag length of $p = 5$ minimizes the AIC information criteria. The tests neither indicate a deterministic trend (H_0: $a_2 = \gamma = 0$) nor a stochastic drift (H_0: $a_0 = \gamma = 0$). On the other hand, the pure random walk process will meander and occasionally map a stochastic trend which by visual inspection can look like a deterministic trend. Notice that the PP-test does not correspond to the results of the ADF test. The nonparametric test is not robust enough to be able to adjust for the effect from the 1942 outlier. A change in the number of truncation lags does not change the result from the PP test. But, notice, by excluding the 1942 observation, the PP-test cannot reject the unit root hypothesis and the conclusion of the tests corresponds to the conclusion based on the ADF test. The PP-test seems to be sensitive to outliers. ADF and PP test of the first difference of the series show that the transformed series are stationary. The annual average temperature series for the period *1942-1973* is a unit root process, i.e. $\{y_t\} \sim I(1)$.

The temperature series is also tested for white noise and normal properties by applying the following tests. Testing of the sub-sample 1943-1973 for Lista, give the following results: The white noise test, Fisher's kappa equal 8.449 (p = 0.000), Bartlett's Kolmogorov-Smirnov = 0.602 (p = 0.000). The empirical spectral density function indicates a cycle of 3.1 years periods. Test for normality Jarque-Bera $\chi^2_{(2)} = 2.615$ (p = 0.270), Shapiro-Wilk test, Anderson-Darling and Lilliefors tests reject the normality hypothesis, tests for autocorrelation: Ljung-Box (4 df) = 34.279 ($p < 0.0001$), Ljung-Box (16 df) = 56.097 ($p < 0.0001$), McLeod-Li (4 df) = 39.199 ($p < 0.0001$) and McLeod-Li (16 df) = 124.451 ($p < 0.0001$). The tests show that the temperature process is not a white noise process. The result of the tests supports the results from the ADF and PP tests because a unit root process has these properties. The results of testing the sub-sample 1974-2003 are presented in table 9.

Table 9: Test statistics for the sample period 1974-2003

VARIABLE	PP TEST*	PP TEST*	ADF**	ADF**
LISTA	Constant	Constant and trend	Constant	Constant and trend
Temperature t_γ	-7.03	-13.23	-2.23	-3.88
Critical value***	-14.10	-21.70	-2.86	-3.41
H_0: $a_0 = \gamma = 0$	1.74 $\Phi_1 = 4.59$		2.63 $\Phi_1 = 4.59$	
H_0: $a_0 = a_2 = \gamma = 0$		3.01 $\Phi_2 = 4.68$		5.14 $\Phi_2 = 4.68$
H_0: $a_2 = \gamma = 0$		4.46 $\Phi_3 = 6.25$		7.53 $\Phi_3 = 6.25$

*Truncation lag is 1. **Lag order p in the ADF-test is 2. *** z_c, z_{ct}, τ_μ and τ_τ are the critical values for respectively the PP and the ADF test.

The ADF-test indicates that the sub-sample 1974-2003 has no unit root. The selection of numbers of lags p is based on the AIC information criteria. The ADF-test shows a significant deterministic trend in the temperature data. The result also holds for $p = 3$. The PP-test shows on the other hand that it is not possible to reject the unit root hypothesis, and varying numbers of truncation lags do not change the result. The table shows that the ADF test without the deterministic trend variable cannot reject the unit root hypothesis. The following test function measures the deterministic trend in the data (Student's t-values in brackets).

$$\Delta y_t = \underset{(3.440)}{4.0367} + \underset{(2.907)}{0.040372} \cdot t - \underset{(-3.878)}{0.74037} y_{t-1} + \underset{(1.326)}{0.24059} \Delta y_{t-1} + \underset{(2.774)}{0.46932} \Delta y_{t-2}$$

The estimated equation shows that the temperature increases by about 0.04 degrees centigrade per year, and the increase is significantly different from zero.

Further testing of the sub-sample *1974-2003* for Lista, gives the following results: The white noise test Fisher's kappa equal 4.976 (p = 0.046), Bartlett's Kolmogorov-Smirnov = 0.645 (p < 0.0001). Empirical spectral density indicates a cycle of 3.1 years. Jarque-Bera normality test $\chi^2_{(2)} = 1.928$ (p = 0.381), tests for autocorrelation: Ljung-Box (4 df) = 24.905 (p < 0.0001), Ljung-Box (16 df) = 27.238 (p < 0.0039), test for non linear autocorrelation McLeod-Li (4 df) = 28.257 (p < 0.0001) and McLeod-Li (16 df) = 100.841 (p < 0.0001).

The test battery indicates that sub-sample 1974-2003 is clearly not a white noise process. The sample 1974-2003 is probably a trend stationary process (TS) with a deterministic increase in the temperature.

3.3.2 Skrova 1936-1970

The same test battery is applied on the average sea temperature off Skrova. The time period 1936-1970 is first tested. The results are summarized in table 10.

Table 10: Test statistics for the sample period 1936-1970

VARIABLE	PP TEST*	PP TEST*	ADF**	ADF**
SKROVA	Constant	Constant and trend	Constant	Constant and trend
Temperature t_γ	-24.60	-27.32	-4.20	-4.30
Critical value***	-14.10	-21.70	-2.86	-3.41
H_0: $a_0 = \gamma = 0$	8.85 $\Phi_1 = 4.59$		8.82 $\Phi_1 = 4.59$	
H_0: $a_0 = a_2 = \gamma = 0$		6.34 $\Phi_2 = 4.68$		6.26 $\Phi_2 = 4.68$
H_0: $a_2 = \gamma = 0$		9.50 $\Phi_3 = 6.25$		9.39 $\Phi_3 = 6.25$

*Truncation lag is 1. **Lag order in the ADF test is 0. *** z_c, z_{ct}, τ_μ and τ_τ are the critical values for respectively the PP and the ADF test.

The ADF and PP tests show identical results. The number of lags is determined by the AIC information criterion. The tests indicate no unit root. On the other hand, the F-test shows that the series can have a deterministic trend. By looking closer at the test function, we can evaluate the effects, for example the deterministic trend. The ADF function was estimated (Student's t-values in brackets):

$$\Delta y_t = \underset{(4.195)}{5.2405} + \underset{(-1.043)}{0.0091667} \cdot t - \underset{(-4.298)}{0.78897 y_{t-1}}$$

Durbin-Watson (DW) = 1.8706. The test function shows that the deterministic trend is not significant. Durbin-Watson (DW) = 1.87 and $R^2 = 0.12$. Jarque-Bera $\chi^2_{(2)} = 1.108$ (p = 0.575). The deterministic trend is not significant. The results from the white noise tests are as follows: Fisher's kappa = 3.986 (p = 0.231) and Bartlett's Kolmogorov-Smirnov white noise test shows 0.263 (p = 0.161). Ljung-Box (4 df) = 2.503 (p = 0.644), Ljung-Box (16 df) = 14.432 (p = 0.567) test for non linear autocorrelation McLeod-Li (4 df) = 2.955 ($p < 0.565$) and McLeod-Li (16 df) = 82. 772 ($p < 0.001$). The last test indicates non linear autocorrelation. Finally, Jarque-Bera's normality test $\chi^2_{(2)} = 1.365$ (p = 0.509).

If we sum up the results from the tests, we can conclude that the sea temperature for the sub-sample 1936-1970 is a stationary white noise process even though one of the white noise tests indicates an element of non-linear autocorrelation. Table 11 presents the results from the ADF and PP tests applied on the sample period 1971-2003.

Table 11: Test statistics for the sample period 1971-2003

VARIABLE	PP TEST*	PP TEST*	ADF**	ADF**
SKROVA	Constant	Constant and trend	Constant	Constant and trend
Temperature t_γ	-10.94	-13.69	-2.07	-3.46
Critical value***	-14.10	-21.70	-2.86	-3.41
H_0: $a_0 = \gamma = 0$	3.21 $\Phi_1 = 4.59$		2.15 $\Phi_1 = 4.59$	
H_0: $a_0 = a_2 = \gamma = 0$		2.68 $\Phi_2 = 4.68$		4.23 $\Phi_2 = 4.68$
H_0: $a_2 = \gamma = 0$		3.95 $\Phi_3 = 6.25$		6.35 $\Phi_3 = 6.25$

*Truncation lag is 1. **Lag order in the ADF-test is 3. *** z_c, z_{ct}, τ_μ and τ_τ are the critical values for respectively the PP and the ADF test.

The ADF test indicates that the sub-sample 1971-2003 has no unit root. The F-tests are rejected, which could indicate a deterministic trend. The number of lags $p = 3$ is determined by the AIC information criterion. The following test function is estimated (Student's t-values in brackets)

$$\Delta y_t = \underset{(2.91)}{2.69} + \underset{(2.696)}{0.020752} \cdot t - \underset{(-3.460)}{0.597 y_{t-1}} + \underset{(1.856)}{0.349 \Delta y_{t-1}} + \underset{(0.941)}{0.166 \Delta y_{t-2}} + \underset{(1.009)}{0.156 \Delta y_{t-3}}$$

DW = 2.6913 and Jarque-Bera's normality test $\chi^2_{(2)} = 1.0800$ (p = 0.583). The estimated function shows that the deterministic term is statistically different from zero and that the temperature increases by about 0.02 degrees centigrade per year. The tests show that it is *not* possible to reject the H_0 hypothesis that the temperature series is a unit root process, given 5% significance level. On the other hand, if the significance level is 1%, the ADF test *cannot* reject the unit root hypothesis.

The following tests support the hypothesis of a stationary process. The white noise tests were also applied on the sub-sample, and the results are as follows: Fisher's kappa = 3.196 (p = 0.509) and Bartlett's Kolmogorov-Smirnov white noise test shows 0.133 (p = 0.920). Ljung-Box (4 df) = 22.430 (p < 0.0001), Ljung-Box (16 df) = 35.029 (p = 0.004) test for non linear autocorrelation McLeod-Li (4 df) = 24.199 (p < 0.0001) and McLeod-Li (16 df) = 101. 776 (p < 0.0001). Finally, Jarque-Bera's normality test $\chi^2_{(2)}$ =

1.367 (p = 0.505). The conclusion we can draw is that the sub-sample series is probably not a white noise process. Compared to the preceding sub-sample (1932-1970), the 1971-2003 sample indicates a change in the process. It looks like the temperature process has changed from a stationary white noise process to a process with a deterministic trend – or towards a non-stationary unit root process. The detected deterministic trend is not necessarily a valid discovery.

The sub samples for each geographical region are also tested for integration of second order, by applying the ADF and PP tests on the differenced time series. The null hypothesis for unit process is rejected for both sub-samples.

3.4 Test of complete samples

The following paragraph presents the unit root and white noise tests applied on the total sample range for respectively Lista and Skrova.

3.4.1 Lista 1942-2003

Table 12: Test statistics for the sample period 1943-2003

VARIABLE	PP TEST*	PP TEST*	ADF**	ADF**
LISTA	Constant	Constant and trend	Constant	Constant and trend
Temperature t_γ	-28.41	-28.50	-2.35	-2.29
Critical value***	-14.10	-21.70	-2.86	-3.41
H_0: $a_0 = \gamma = 0$	10.59 $\Phi_1 = 4.59$		2.78 $\Phi_1 = 4.59$	
H_0: $a_0 = a_2 = \gamma = 0$		7.08 $\Phi_2 = 4.68$		1.87 $\Phi_2 = 4.68$
H_0: $a_2 = \gamma = 0$		10.44 $\Phi_3 = 6.25$		2.78 $\Phi_3 = 6.25$

*Truncation lag is 1. **Lag order in the ADF test is 1. *** z_c, z_{ct}, τ_μ and τ_τ are the critical values for respectively the PP and the ADF test.

The results from the ADF and PP are diverging. It is not possible to reject the unit root hypothesis by applying the ADF test, whilst the PP test rejects the null hypothesis. The lag order of the ADF test is based on the AIC information criterion, and p = 1 corresponds also to the criterion of selecting the highest significant last β_i. The result of ADF and PP test is *not* affected by changing the lags and number of truncations.

Note the extremely low temperature level in 1943. According to the Institute of Marine Research (IMR) it was an extremely cold period in the south in 1943. The observation is probably an outlier. The observation is included in the tests. An exclusion of the observation affects the test values, but the conclusion is *not* changed for the ADF-test. The outcome of the Phillips-Perron (PP) test is, on the other hand, changed. Given 1% significance level, the PP-test cannot reject the hypothesis of a unit root. If we relay the diagnostic on the ADF-test, we conclude that the process is a non-stationary unit root process. The F-test shows that the random walk process has no stochastic trend, i.e. the hypothesis H_0: $a_0 = \gamma = 0$ is not rejected.

The results of the white noise and normality test applied on the complete sample (1942-2003) for *Lista* are as follows: Fisher's kappa = 13.597 ($p < 0.0001$) and Bartlett's Kolmogorov-Smirnov white noise test shows 0.566 ($p < 0.0001$). Ljung-Box (4 df) = 57.752 ($p < 0.0001$), Ljung-Box (16 df) = 70.362 ($p = 0.0001$) test for non linear autocorrelation McLeod-Li (4 df) = 57.652 ($p < 0.0001$) and McLeod-Li (16 df) = 70.424 ($p < 0.0001$). Finally, Jarque-Bera's normality test $\chi^2_{(2)} = 2.578$ ($p = 0.275$). The temperature series is normally distributed. The process is strongly autocorrelated and according to the McLeod-Li's test, the process seems to be non-linearly autocorrelated. The ADF and PP tests indicate that the temperature data for the period 1942-2003 map a pure random walk process, $\{y_t\} \sim I(1)$, without any deterministic or stochastic trend.

3.4.2 Skrova 1936-2003

Table 13: Test statistics for the sample period 1936-2003

VARIABLE	PP TEST*	PP TEST*	ADF**	ADF**
SKROVA	Constant	Constant and trend	Constant	Constant and trend
Temperature t_γ	-40.90	-41.00	-2.24	-2.08
Critical value***	-14.10	-21.70	-2.86	-3.41
H_0: $a_0 = \gamma = 0$	12.39 $\Phi_1 = 4.59$		2.51 $\Phi_1 = 4.59$	
H_0: $a_0 = a_2 = \gamma = 0$		9.77 $\Phi_2 = 4.68$		1.85 $\Phi_2 = 4.68$
H_0: $a_2 = \gamma = 0$		14.66 $\Phi_3 = 6.25$		2.77 $\Phi_3 = 6.25$

*Truncation lag is 1. **Lag order in the ADF-test is 7. *** z_c, z_{ct}, τ_μ and τ_τ are the critical values for respectively the PP and the ADF test.

The conclusions drawn from the ADF and PP tests are diverging. The ADF test indicates a unit root, non-stationary process while the PP test indicates a stationary no unit root process. The selected lag structure of $p = 7$ is based on the highest lag p with the significant last estimated β_i (Doornik and Hendry 2001). The statistical results based on the PP are not affected by changes in the number of truncated lags. The ADF test indicates no deterministic trend. A first difference of the series made it stationary, and no unit root was detected by the ADF test. If the process is a random walk, we have the following properties: According to the preceding findings, the sea temperature evolves as a random walk process without any drift, i.e. $y_t = y_{t-1} + \epsilon_t$ where ϵ_t is the normal distributed white noise process. The initial temperature level at Skrova was $y_0 = 6.77$ in 1936. The solution of the difference equation is $y_t = y_0 + \sum_{i=1}^{t} \epsilon_t$. According to this model, the expected temperature level at time period t is $Ey_t = Ey_{t-s} = y_0$, thus the mean of the random walk is constant. All stochastic shocks have a non-decaying effect on the $\{y_t\}$ sequence. Given the first t realizations of the $\{\epsilon_t\}$ process, the conditional mean of the temperature level in period s is; $y_{t+s} = y_t + \sum_{i=1}^{s} \epsilon_{t+1}$, so that $E_t y_{t+s} = y_t + E_t \sum_{i=1}^{s} \epsilon_{t+1} = y_t$, which shows that the conditional mean temperature levels for all values of y_{t+s} are equivalent. The model shows that the best expected prediction of the next s periods average temperature is the observation for the last year t.

The diagnosis of the data generation process (DGP) is determined by selected method: If we select the number of lags p by applying the AIC information criterion, we end up with a parsimonious model with no lags, i.e. $p = 0$. The model fulfils the criterion of no first or higher order of autocorrelated residuals. When $p = 0$, the H_0 hypothesis of a unit root is rejected. The result from the test is presented in table 14.

Table 14: ADF test given $p = 0$.

VARIABLE	ADF**	ADF**
SKROVA	Constant	Constant and trend
Temperature t_γ	-5.53	-5.48
Critical value***	-2.86	-3.41
H_0: $a_0 = \gamma = 0$	15.31 $\Phi_1 = 4.59$	
H_0: $a_0 = a_2 = \gamma = 0$		10.05 $\Phi_2 = 4.68$
H_0: $a_2 = \gamma = 0$		15.08 $\Phi_3 = 6.25$

Lag order in the ADF-test is 7. * z_c, z_{ct}, τ_μ and τ_τ are the critical values for respectively the PP and the ADF test.

The outcome of the F-test could indicate a deterministic trend. A closer look at the estimated model can control the effect from the deterministic trend. The following parsimonious model is estimated (Student's t-values in brackets):

$$\Delta y_t = \underset{(5.371)}{4.1302} - \underset{(-0.0795)}{0.00024807} \cdot t - \underset{(-5.484)}{0.64072 y_{t-1}}$$

DW $= 2.12$, LM autocorrelation test $\chi^2_{(2)} = 10.895$ and Jarque-Bera's normality test $\chi^2_{(2)} = 0.1601$ (p = 0.923). There is no autocorrelation in the model, and coefficient estimate shows that there exists *no* significant deterministic time trend in the data.

The result of the white noise tests applied on the complete sample (1936-2003) for *Skrova* is as follows: Fisher's kappa = 5.853 (p = 0.063) and Bartlett's Kolmogorov-Smirnov white noise test shows 0.356 ($p < 0.000$). Ljung-Box (4 df) = 16.352 ($p < 0.003$), Ljung-Box (16 df) = 25.283 (p = 0.065) test for non linear autocorrelation McLeod-Li (4 df) = 15.764 (p = 0.003) and McLeod-Li (16 df) = 25.034 ($p < 0.069$). Finally, Jarque-Bera's normality test $\chi^2_{(2)} = 2.278$ (p = 0.320). The McLeod-Li tests indicate that there exists non-linear autocorrelation. The fact that the spectral density function indicates cycles of 13.6 years is probably a verification of the non-linearity in the realization of the time process.

The test statistics indicates clearly that the process is not a white noise process. But is the temperature process stationary? The conclusion is dependent on which method we apply in revealing the properties of the data generation process (DGP). The parsimonious ADF model (based on the AIC criterion) and also the non-parametric Phillips-Perron test, indicate that the evolvement of the sea temperature is a stationary autoregressive process. On the other hand, if we apply the highest p with the significant last β_i, the process is a non-stationary unit root process.

4 Summing up and concluding remarks

The paper addresses the question of whether there is any indication of climate change in the sea water temperature along the coast of Norway. Climate change can be defined as changes in climate related variables relative to expected statistical properties for a given time period. In practice climate change means significant changes in respectively rainfall, intensity and frequency of storms, variation and temperature range and changes in sea temperature and circulation of the water current.

The paper applies criteria for stationary time series in the testing of sea water temperature measured at two spots along the coast of Norway. If there is any indication of climate change, we should detect a break in the condition for stationarity. We can report the following findings:

Each temperature series is divided into three subgroups and tested for equal variance. The hypothesis of equal variance is tested by applying the Bartlett's chi-square test and the Levene's F-test. The result of the analysis shows that the null hypothesis of equal variance between the sub-samples cannot be rejected. The variance for each time series is stable and the constant volatility fulfills the stationarity criterion. Next, the annual average temperature series are split into two sub-samples and the data generation process behind the sub-samples are analyzed. The results of the findings are as follows:

Lista: Sample 1943-1973. The tests indicate that the data generation process for this sub-sample is a unit root process. The process has no deterministic or stochastic trend. The series is probably a random walk process. It is a difference stationary process, i.e. $\{y_t\} \sim I(1)$. The temperature series is normally distributed, however under doubt, non white noise and (non-linear) autoregressive process.

Lista: Sample 1974-2003. The tests indicate that the data generation process is a trend stationary process with a significant deterministic trend. The temperature observation is normally distributed, non-white, (non-linear) autoregressive process.

Lista: Total sample 1942-2003. The ADF test indicates that the temperature series is a non-stationary, pure random walk process (without a stochastic trend), whilst the PP test indicates a stationary process and without any deterministic trend, given 5% significance level. However, the PP-test indicates a random walk process if the outlier 1942-observation is excluded from the sample and given a 1% significance level. The total sample is normally distributed, however under doubt, and with non-white noise and probably non-linear autoregressive process properties.

Skrova: Sample 1936-1970. The tests indicate that there exists no unit root and the data generation process is probably a stationary white noise process. Statistical test rejects the hypothesis of a negative deterministic trend. The series is normally distributed and a white-noise process. However, the McLoad-Li test indicates a non-linear autoregressive process.

Skrova: Sample 1971-2003. The tests indicate that the sub-sample maps a trend stationary process with a significant deterministic trend. The observations are normally distributed, non-white noise, (non-linear) autoregressive process. Note, however, that the series is diagnosed as a pure random walk process if evaluated at 1% significance level. The series is probably a border case between a trend stationary and a difference stationary process.

Skrova: Total sample 1936-2003. The tests show that the process probably is a border case between a stationary white noise process and a non stationary, pure random walk process. Whether it is a stationary or a non-stationary process, is conditioned on the lag structure of the test function. The temperature series is normally distributed and a (border case) non-white (non-linear) noise, autocorrelated process.

Is it possible to draw any conclusions whether the temperature series show any traits of global warming or climate change in general? The "key-hole" perspective is interesting, i.e. the analysis based on sub-samples: The findings show that the temperature process at Lista changed from being a pure random walk process (1942-1973) to a trend stationary process with a significant deterministic increase in temperature (1974-2003).

The temperature series from Skrova show also a change in the properties of the data generation process. The temperature series change from being a stationary, white noise process (1936-1970) to being a trend stationary process with a deterministic increase in the temperature level (1971-2003). Is the change in the data generation processes an indication of climate change, or is the diagnosis a result of long range oscillating temperature? The last sub-sample for each of the geographical spots has a deterministic, positive temperature trend. The change from being a white noise or a random walk process to mapping a significant deterministic trend could indicate that the water masses are getting warmer. But, the conclusion is based on the "key-hole" perspective, i.e. based on sub-samples, and the local perspective is not necessarily the valid one if the samples are extended.

The analysis based on the total sample shows that the temperature at Lista (1942-2003) has random walk properties, with no deterministic or stochastic trend. The Phillips-Perron test indicates that the process is stationary. The analysis based on the total sample (1936-2003) shows that the temperature off Skrova probably is a border case between a stationary, white noise process and a non-stationary random walk. We expect that an extension of the sample period, i.e. applying a longer time period, will normally increase the validity of the statistical tests and result. However, we should keep in mind that a unit process has no asymptotic properties. From the fact that the tests have a tendency to diagnose the series as non stationary, it follows that we are inclined to reject the null hypothesis with which the paper initially started, and conclude that there is some indication of climate change and global warming in the water masses.

The additional tests, i.e. test of normality, white noise tests etc. give valuable information about the data generation process (DGP). The normality tests show diverging results – first of all with regard to the sub-samples. The complete samples show normally distributed observations which could be an indication of stability. On the other hand, the white noise tests show that the series are autoregressive. The strong autoregressive element and the McLeod-Li test of non linearity could be an indication of oscillation or periodicity in the data generation process or it could alternatively be explained by the meandering process (unit root). The ADF and PP tests indicate that the hypotheses of deterministic and/or stochastic trend are rejected for the complete samples.

It should also be emphasized that the water masses and sea temperature along the coast of Norway are a part of a larger physical system. The analysis shows indication of unit root and non-stationarity in the temperature data. The unit root and non-stationarity imply that the temperature time series are expected to meander. The non-stationarity could be a sign of climate change. But we should also be aware that temperature is a physical variable among a set of other variables which are building blocks of a larger system. We know from the cointegration theory (Engle and Granger 1987) that individually non-stationary variables can be in a long run-equilibrium because they are part of a system with other non-stationary variables. We can exclude the possibility that a set of non-stationary variables can constitute a dynamic system which converges to or oscillates close to the long-run equilibrium.

But what are the relevant system variables the temperature variable is a part of – and is it possible to test whether the system variables are cointegrated? Some of the variables could individually be non stationary variables and meander, but in a system-combination of the variables they are stationary and converge toward the long run equilibrium.

Global climate is subject to feedback. Positive feedback from a set of variables can accelerate the temperature, and negative feedback can keep the system stable in the long run. There are probably an infinite number of positive and negative feedback loops in an ecological system, and it could be severe to predict which direction the climate will take in the long run. The weather can therefore repeat itself several times, i.e. the weather pattern can "copy" itself several times; warm winters – hot summers can repeat itself several times because the climate system (the trajectory) is circling before it changes again but not necessarily repeats itself. A series of warm winters and hot summers may simply mean that the system is revolving around one part of the phase space. It does not necessarily mean that a long-term, permanent change in climate has set in.

References

[1] ACIA (2004): *Impacts of a Warming Arctic*: Arctic Climate Impact Assessment: Overview Report, Cambridge University Press.

[2] Dickey, D. and W.A. Fuller (1979): Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, 74, pp. 427-431.

[3] Dickey, D. and W. A. Fuller (1981): Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica* 49 (July 1981), pp. 1057-72.

[4] Doldado, J., T. Jenkinson and S. Sosvilla-Rivero (1990): Cointegration and Unit Roots. *Journal of Economic Surveys* 4, pp. 249-73.

[5] Engle, R. F. and C. W. J. Granger (1987): Cointegration and Error Correction: Representation, Estimation and Testing. *Econometrica*, 55, pp. 251-276.

[6] Hendry, D. and J. A. Doornik (2001): Empirical Econometric Modelling, Vol.1. *PcGive -Version 10.* Timberlake Consultants Ltd, London.

[7] IPCC (2001) - Intergovernmental Panel on Climate Change: Climate Change 2001: Synthesis Report, Intergovernmental Panel on Climate Change. Cambridge University Press.

[8] IPCC (2003) - Intergovernmental Panel on Climate Change: International Panel for Climate Change. Website, www.ipcc.ch.

[9] IPCC (2007) - Intergovernmental Panel on Climate Change: *Climate Change 2007: Physical Science Basis.* Summary for Policymakers. IPCC Secretariat, c/o WMO, Geneva, Switzerland.

[10] MacKinnon, J. (1991): Critical values for co-integration tests, in R. F. Engle and C. W. J. Granger (eds), *Long-Run Economic Relationships*, pp. 267-276, Oxford University Press.

[11] Nansen Environmental and Remote Sensing Center (NERSC): CECA – Climate and Environmental Change in the Arctic. EU Descartes Laureate 2005.

[12] Phillips, P. C. B. (1987): Time series regression with a unit root. *Econometrica*, 55, pp. 277-301.

[13] Perron, P. (1988): Trends and random walks in macroeconomic time series: Further evidence from a new approach. *Journal of Economic Dynamics and Control*, 12, pp. 297-332.

[14] Phillips, P. C. B. and P. Perron (1988): Testing for a unit root in time series regression, *Biometrica*, 75, pp. 335-446.

[15] Sims, C., J. Stock and M. W. Watson (1990): Interference in Linear Time Series Models with some Unit Roots. *Econometrica* 58, pp. 113-44.

[16] Stenevik, E.K. and S. Sundby (2004): Impacts of climate change on commercial fish stocks in Norwegian waters. Discussion paper no. 76/04. Institute of Marine Research (MIR) and Institute for Research in Economics and Business Administration (SNF).

[17] Sundby, S. (2004): Addendum to: Impacts of climate change on commercial fish stocks in Norwegian waters by Stenevik and Sundby (2004).

[18] Whistler, D., K. J. White, S. Donna Wong and D. Bates (2006): *Shazam*, Version 10. Northwest Econometrics, Ltd, Vancouver, B.C., Canada.

A Missing values

Unfortunately the data set is not complete. Some of the years have missing values. Especially Lista has few observations for the 1950s. Tables 1 and 2 show for which year there exist no data. It is not possible to apply the suggested estimators if the time series have missing values and missing values will in general weaken any statistical analysis. Unfortunately there exists no objective methodology for solving the problem of missing values. No artificial data can replace actual data. However, we have replaced missing values by using the following ad hoc methods: The missing data are calculated as a combination of (average) neighbouring values, i.e. the average of the preceding and the succeeding actual observation (or calculated value) of the missing value. The chosen method will in any case put a restriction on the time series, and the series is in no respect the same as observed data

Table 15: Missing sea temperature data for Lista

			MISSING VALUES FOR LISTA									
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1936												
1937												
1938												
1939												
1940												
1941												
1942	x										x	x
1943												
1944									x	x	x	x
1945	x											
1946												
1947						x	x	x	x			
1948	x	x				x	x	x	x	x	x	
1949				x	x	x	x	x	x	x	x	
1950												
1951		x	x		x	x	x	x		x	x	
1952			x	x	x		x	x	x	x	x	x
1953		x	x	x	x	x	x	x		x	x	
1954	x	x	x	x	x	x	x	x	x	x	x	x
1955	x	x	x	x	x	x	x	x	x	x	x	x
1956	x	x	x	x	x	x	x	x	x		x	x
1957	x	x	x	x	x	x	x					
1958	x	x	x		x	x	x	x				x
1959	x											
1960										x	x	
1961		x	x			x						x
1962	x			x	x							
1963												
1964											x	x
1965											x	x
1966					x				x	x	x	x
1967	x	x	x	x	x				x	x	x	x
1968	x	x	x	x								
1969				x						x	x	x
1970		x										
1971												
1972												
1973												x
1974	x											x
1975												
1976												
1977		x	x	x								
1978			x	x	x	x						
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993	x	x	x	x								x
1994												
1995												
1996												
1997												
1998												
1999												
2000												
2001												
2002												
2003		x									x	x

Table 16: Missing temperature data for Skrova

Year	January	February	March	April	May	June	July	August	September	October	November	December
		MISSING VALUES FOR SKROVA										
1936												
1937												
1938												
1939											x	x
1940				x		x						
1941												
1942	x		x									
1943												
1944												
1945												
1946												
1947												
1948												
1949												
1950												
1951												x
1952												
1953											x	
1954												
1955												
1956												
1957												
1958												
1959												
1960												
1961												
1962												
1963												
1964												
1965										x		
1966												
1967												
1968												
1969												
1970												
1971												
1972												x
1973	x											
1974												
1975												
1976												
1977												
1978										x		
1979												
1980												
1981	x		x									x
1982	x	x	x									
1983	x		x									
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												
1995												
1996										x	x	
1997												
1998												
1999												x
2000												
2001												
2002												
2003												