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GLOBAL WARMING
AN UNIVARIATE ESTIMATION OF SEA TEMPERATURE DATA

By

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1. INTRODUCTION

According to the UN's Intergovernmental Panel of Climate Change (IPCC 2003, 2007), 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,[1] 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 socio-economic 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. Centre for fisheries economics at SNF has analyzed the possible but highly uncertain effects of global warming on some of the most important Norwegian fisheries and the aquaculture industry (Lorentzen and Hannesson 2005 and 2006), and Hannesson, Barange and Herrick Jr (eds., 2006) analyse the economic effect a climate change could have on small pelagic stocks located in different areas of the seven seas.

For example, the optimal temperature for farming Atlantic salmon and cod is respectively about 14-15 degrees for salmon and 10-12 degrees for the North Atlantic cod. The Norwegian coastal area which is suitable for aquaculture of salmon and trout stretches from the areas off Rogaland in the southwest and about 1800 km north to Finnmark, the northernmost county. A systematic difference in sea temperature between areas will most likely result in different growth rates of the fish. In Lorentzen and Hannesson (2006) it is shown that differences in growth, due to climate differences, result in different economic outcomes.

[1] In this report, all degrees are on the centigrade (Celsius) scale.

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 for 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 report is to analyse how the sea temperature off Lista in Rogaland in the south and Skrova in Nordland in the north has evolved during the period 1936-2003. More precisely, is there a difference between “South” and “North”? Furthermore, we analyse whether the temperature has changed over time. Are changes in temperature just 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? We ask what kind of data generating process can describe the temperature data at Lista and Skrova.

It is not possible to conclude that a climate change has taken place just 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 a 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 conclusions about climate change?

The remainder of the report is structured as follows. The next section, Section Two, describes the evolvement of the sea temperature off, respectively, Lista and Skrova for the period 1936-2003. Statistical tests for equal mean and variance between the series are also presented. Section Three presents methodological criteria for evaluating potential climate change. Section Four analyses one of the stability conditions by testing whether the variance is stable for each temperature series. Section Five estimates the data generating processes behind the temperature processes by applying a linear filtering estimator called autoregressive, integrated moving average. The section also presents forecast scenarios of the sea temperature for the period 2003-2023 and beyond. Finally, Section Six 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: Location of Lista and Skrova

Source: Senior Research Engineer Kjell Helge Sjøstrøm, Institute of Geography, University of Bergen

The temperatures 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. We present temperature data for (1) the coldest and (2) the warmest month, and (3) the average (arithmetic mean) annual sea temperature for the said geographical areas. The data which are used in the analysis were obtained from the Marine Resource Institute (IMR) in Bergen, Norway.

2.1 Missing values

Unfortunately the data set is not complete. Some of the years have missing values. Table 1 shows the years for which values are missing.

Table 1: Missing values for Lista and Skrova

	AUGUST	**MARCH**	**AVERAGE**
Lista	1947-49, 1951-56, 1958	1951-58, 1961, 1967-68, 1977, 1993, 2003	
Missing data: Percentage of total sample	16.4%	23%	23%
Skrova	0	1942, 1981-83, 1996	
Missing data: Percentage of total sample	0	7.4%	3%

It is not possible to apply the suggested methodology if the time series have missing values and missing values will in general weaken any conclusion. 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 method: 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 methods will in any case put some restriction on the time series, and the series is in no respect the same as observed data.

2.2 The August temperature off Lista and Skrova

August is the warmest month for both areas. Figure 2 shows the August sea temperature off Lista and Skrova over the period 1936-2003, respectively.

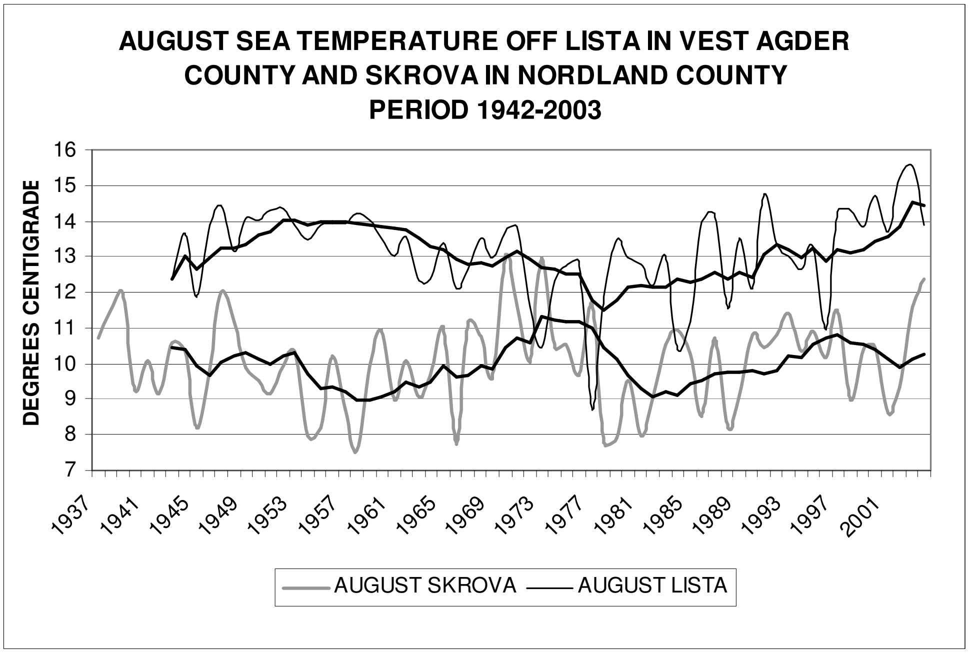

Figure 2: August temperature off Lista and Skrova

Figure 2 shows that the August temperature for both geographical areas fluctuates without any distinct general trend. The bold lines are the seven years moving averages. The smoothing of the temperatures gives information about whether there exist cycles and trends in the material. The moving average shows that the temperature off Lista evolves almost "counter cyclical" to Skrova during the period from 1940 to 1974. Both temperature series follow approximately the same positive trend in the period 1983 to 1997. Based on a visual inspection it is difficult to say anything distinct about a general temperature increase for either Lista or Skrova during the period 1940-2003. The smooth thick lines indicate that the temperature in both places fluctuates periodically. The length of the cycles is not identical; the cycle at Lista is about 40 years and about 20 years for Skrova. On the other hand, if we narrow the time interval, it looks like the sea water temperature off Lista has had a positive trend since the beginning of the 1980s. The August temperature off Skrova does not follow the same pattern. The period 1970 to 1980 shows a negative trend, but apart from that the temperature fluctuates around a virtually constant level.

The August temperature off Lista is higher than off Skrova for all years. We tested the null hypotheses of equal means and variance (Bartlett's homogeneity of variance test). Table 2 shows the result of the tests.

Table 2: Test of equal means sea temperature and variances off Lista and Skrova August 1942-2003

Name	N	Mean	St. Dev	Variance	Minimum	Maximum
AUGUST SKROVA	62	10.02	1.2937	1.6736	7.57	13.00
AUGUST LISTA	62	13.16	1.2299	1.5127	8.69	15.55

Difference Between Two Samples Tests	Statistic	D.F.		P-Value
APPROXIMATE T-TEST OF EQUAL MEANS:	-13.853	121		0.0000
EQUAL VARIANCE T-TEST OF EQUAL MEANS:	-13.853	122		0.0000
F-TEST OF EQUAL VARIANCES:	1.1064	61	61	0.6943

BARTLETTS HOMOGENEITY OF VARIANCE TEST	0.15452
P-VALUE	0.69425

The tests show respectively that the mean August temperature is significantly higher off Lista than off Skrova, and that the variances are not statistically different during the time period 1942-2003.

2.2 The March temperature off Lista and Skrova

Figure 3 shows the March temperature, the month with the lowest sea temperature, for Lista and Skrova.

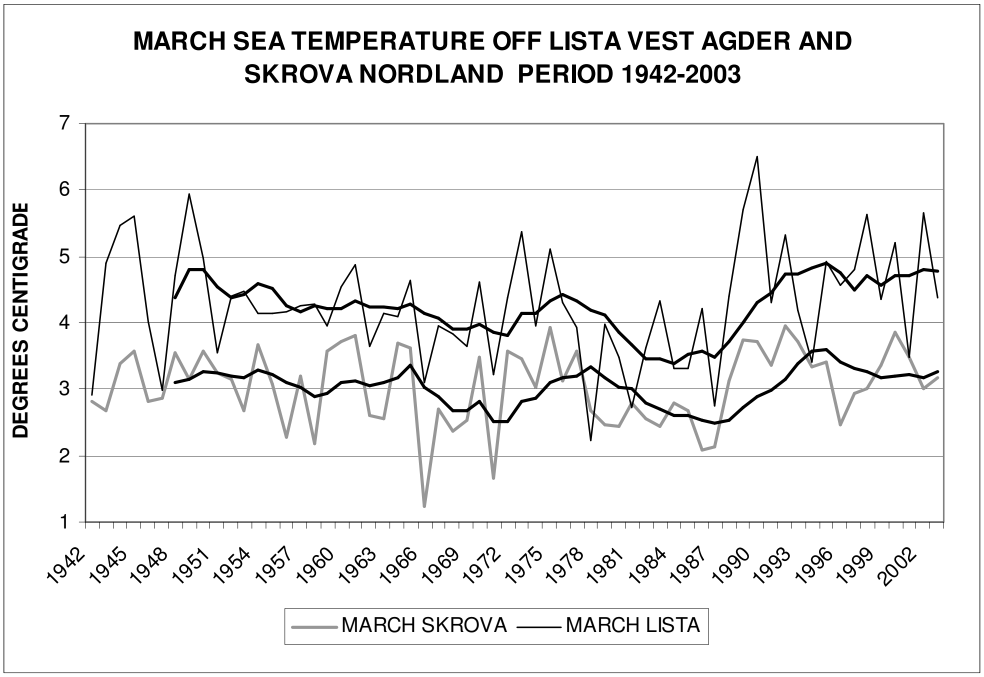

Figure 3: March temperature off Lista and Skrova

The figure shows that the temperature paths have a high degree of covariation and with almost identical oscillations, but on different levels. The temperature trajectories have no overall trend. On the other hand, if we select a shorter time interval, we will probably draw a different conclusion. For example during the period 1985-2003, the March temperature off Lista shows a slightly positive trend. A general impression is that the volatilities of the time series have not changed over time. Statistical tests confirm that impression. The hypotheses for equal means and variances for March temperature between Lista and Skrova were also tested. The results are presented in table 3.

Table 3: Test of equal means sea temp and variances off Lista and Skrova March 1942-2003

Name	N	Mean	St. Dev	Variance	Minimum	Maximum
MARCH SKROVA	62	3.0464	0.58333	0.34027	1.2378	3.9425
MARCH LISTA	62	4.2743	0.85463	0.73039	2.2339	6.4927

Difference Between Two Samples Tests	Statistic	D.F.		P-Value
APPROXIMATE T-TEST OF EQUAL MEANS:	-9.3442	107		0.0000
EQUAL VARIANCE T-TEST OF EQUAL MEANS:	-9.3442	122		0.0000
F-TEST OF EQUAL VARIANCES:	2.1465	61	61	0.0033

BARTLETTS HOMOGENEITY OF VARIANCE TEST	8.6186
P-VALUE	0.00333

The tests show that the hypotheses of equal mean and variance are rejected. The mean March temperature and variance are significantly higher off Lista than off Skrova.

2.3 The average annual temperature off Lista and Skrova

Figure 4 shows the average annual sea temperature off respectively Lista and Skrova for the period 1942 to 2003.

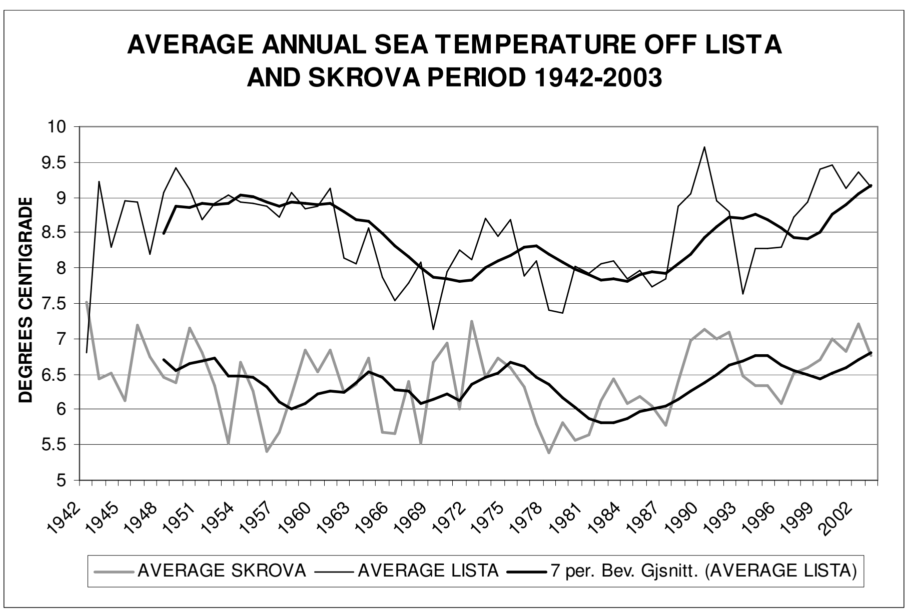

Figure 4: Average annual sea temperature off Lista and Skrova

Figure 4 shows that the annual average temperature has no overall positive or negative trend. The temperature paths oscillate, and in subintervals it looks like the temperature fluctuates around a trend which is negative for some periods and positive for others. The mapping of the average annual sea temperature has some features in common with the individual trajectory for each month. The bell shaped form of the annual average and August temperature off Lista is similar for the period 1942-1970.

The impression is that the average temperature is increasing off Lista and fluctuating around a positive trend from the beginning of the 80s and to 2003. The average sea temperature off Skrova follows the same pattern as off Lista from 1965. Both curves show a positive trend from the beginning of the 80s, and the trend might be slightly stronger for the annual data. It follows that a similar pattern could also be identified in months other than March and August. The smoothing of the temperature by using a seven year moving average indicates that both temperature trajectories oscillate with a 10-15 years cycle after 1970. The figure also indicates that the series probably have another, much longer cycle. Test of equal means and variances is presented in the table 4.

Table 4: Test of equal means sea temperature and variance off Lista and Skrova Average, annual data 1942-2003

Name	N	Mean	St. Dev	Variance	Minimum	Maximum
Average Lista	62	8.4772	0.63654	0.40518	6.7646	9.7133
Average Skrova	62	6.4092	0.46231	0.21373	5.4121	7.2185

Difference Between Two Samples Tests	Statistic	D.F.		P-Value
APPROXIMATE T-TEST OF EQUAL MEANS:	20.698	111		0.0000
EQUAL VARIANCE T-TEST OF EQUAL MEANS:	20.698	122		0.0000
F-TEST OF EQUAL VARIANCES:	1.8958	61	61	0.0136

BARTLETTS HOMOGENEITY OF VARIANCE TEST	6.0855
P-VALUE	0.01363

APPROXIMATELY CHI-SQUARE WITH 1 DEGREES OF FREEDOM

The tests show that the annual average sea temperature and variance are significantly higher off Lista than off Skrova.

2.4 Conclusion

The statistical tests show that the mean temperature off Lista is significantly higher than at Skrova for respectively March, August and the annual average. The variance is significantly higher at Lista than at Skrova except for the August temperature where there is no significant difference.

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, it 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 $\{x_t\}$ for $t = 0, 1, 2,\ldots.., \infty$ 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 $E\{x_t\} = \mu < \infty$, (2) variance $V\{x_t\} = E\{(x_t - \mu)^2\} = \gamma_0 < \infty$ and (3) the covariance $Cov\{x_t x_{t-k}\} =$ $E\{(x_t - \mu)(x_{t-k} - \mu)\} = \gamma_k \;\; \forall k = 1,2,3, ,,$. The stationary conditions require autonomy, i.e., that they are independent of time date.

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 apply a method to identify what kind of data generating process (DGP) that is behind the realization of the already presented temperature data. An Augmented Dickey-Fuller test (ADF) is 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). The said test also provides information about the element of deterministic or/and stochastic trend. The tests are presented in detail in an appendix.

4. TESTING FOR STABLE VARIANCE

4.1 Detection of changes in variance for the March temperature off Skrova

We tested whether the variance of the temperature has changed over time by splitting 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 another. The March temperature off Skrova was divided into the following three groups:

Table 5: Descriptive statistics, March Skrova 1936-2003

Sample	Frequency	Mean	Variance
MARCH1 SKROVA	(1936-59) 23	3.059	0.237
MARCH2 SKROVA	(1960-83) 23	2.985	0.503
MARCH3 SKROVA	(1984-03) 22	3.108	0.301

The Bartlett's and Levene's tests are applied in the analysis of the hypothesis of equal variance in each sub sample. The tests gave the following results:

Table 6: Bartlett's test of March Skrova

Chi-square (Observed value)	3.269
Chi-square (Critical value)	5.991
DF	2
p-value (Two-tailed)	0.195
alpha	0.05

Table 7: Levene's test of March Skrova

F (Observed value)	2.473
F (Critical value)	3.906
DF1	2
DF2	65
p-value (Two-tailed)	0.092
alpha	0.05

The hypothesis of equal variance between the three sub periods cannot be rejected at the 5% significance level, and we therefore conclude that the variance of the temperature has not changed during the period 1936-2003. According to Levene's test the risk to reject the null hypothesis while it is true is 9.2%.

4.2 Detection of changes in variance for the March temperature off Skrova

Test of equal variance for sub groups of the March temperature off Lista is presented in tables 9 to 10.

Table 8: Descriptive statistics, March Lista 1942-2003

Sample	Frequency	Mean	Variance
MARCH LISTA 1	(1942-63) 21	4.377	0.597
MARCH LISTA 2	(1964-85) 21	3.934	0.547
MARCH LISTA 3	(1986-03) 20	4.523	0.937

Table 9: Bartlett's test of March Lista

Chi-square (Observed value)	1.654
Chi-square (Critical value)	5.991
DF	2
p-value (Two-tailed)	0.437
alpha	0.05

Table 10: Levene's test of March Lista

F (Observed value)	1.060
F (Critical value)	3.929
DF1	2
DF2	59
p-value (Two-tailed)	0.353
alpha	0.05

For the tests of the March sea temperature off Lista, we can conclude that the variance has not changed during the period 1942-2003.

4.3 Detection of changes in variance for the August temperature off Skrova

Table 11: Descriptive statistics, August Skrova 1936-2003

Variable	Observations	Mean	Std. deviation
AUGUST SKR 1	(1936-56) 23	9.832	1.241
AUGUST SKR 2	(1957-79) 23	10.093	1.489
AUGUST SKR 3	(1980-03) 23	10.236	1.100

Test of equal variance for sub-groups of the August temperature off Skrova is presented in tables 12 to 13.

Table 12: Bartlett's test of the August temperature Skrova

Chi-square (Observed value)	2.022
Chi-square (Critical value)	5.991
DF	2
p-value (Two-tailed)	0.364
alpha	0.05

Table 13: Levene's test of August temperature Skrova

F (Observed value)	0.801
F (Critical value)	3.906
DF1	2
DF2	65
p-value (Two-tailed)	0.453
alpha	0.05

At the level of significance $\alpha = 0.05$ the null hypothesis of equal variance cannot be rejected.

4.4 Detection of changes in variance for the August temperature off Lista

Table 14: Descriptive statistics, August Lista 1942-2003

Sample	Frequency	Mean	Variance
AUGUST LISTA 1	(1942-62) 21	13.618	0.495
AUGUST LISTA 2	(1963-83) 21	12.378	1.569
AUGUST LISTA 3	(1984-03) 20	13.503	1.653

Test of equal variance for sub groups of the August temperature for Skrova is presented in tables 15 to 16.

Table 15: Bartlett's test of the August temperature Lista

Chi-square (Observed value)	7.640
Chi-square (Critical value)	5.991
DF	2
p-value (Two-tailed)	0.022
alpha	0.05

Table 16: Levene's test of August temperature Lista

F (Observed value)	2.454
F (Critical value)	3.929
DF1	2
DF2	59
p-value (Two-tailed)	0.095
alpha	0.05

The analysis shows that Bartlett's test rejects the hypothesis of equal variance whilst the Levene's test does not. The rejection of the hypothesis indicates that there were some structural changes in the volatility of the temperature during the period 1942-2003. According to Levene's test the risk to reject the null hypothesis while it is true is 9.5%.

4.5 Detection of changes in variance for the annual average temperature off Skrova

Test of equal variance for sub groups of the annual average temperature off Skrova is presented in tables 18 to 19.

Table 17: Descriptive statistics, annual average Skrova 1936-2003

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

Table 18: 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	0.05

Table 19: 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	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.

4.6 Detection of changes in variance for the annual average temperature off Lista

Test of the equal variance for sub groups of the annual average temperature off Lista is presented in tables 21 to 22.

Table 20: Descriptive statistics, annual average Lista 1942-2003

Sample	Frequency	Mean	Variance
AVERAGE LISTA 1	(1942-62) 21	8.768	0.307
AVERAGE LISTA 2	(1963-83) 21	8.003	0.171
AVERAGE LISTA 3	(1984-03) 20	8.671	0.412

Table 21: Bartlett's test of 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	0.05

Table 22: 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	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.

4.7 Conclusion

The analysis shows that the hypothesis of equal variance for respectively March, August and annual average temperature cannot be rejected, except for one border case, August Lista, where the Bartlett's test indicates a change in variance. We can therefore conclude that the variance has been stable throughout the period 1936-2003 for Skrova and 1942-2003 for Lista. A stable variance is an important criterion for a stationary time series.

5. ESTIMATION OF THE DATA GENERATING PROCESS – ARIMA MODELS

The following section estimates the data generating processes for the sea temperature data.

5.1 August sea temperature off Skrova

The analysis of August sea temperature off Skrova is based on data for the period 1936-2003. The result of the unit root test is dependent on the formulation of the ADF-function, i.e. whether it includes a constant and an exogenous variable for covering a deterministic trend. The number of lags in the ADF-function and the significant level influence also on the test result. The applied lag order is the highest significant lag order from either the autocorrelation function (SACF) or the partial autocorrelation function (PACF) of the first differenced series.

A visual inspection of the time plot indicates no "global" trend. The ADF-test with a constant rejects the hypothesis of a unit root. The test shows no sign of a deterministic trend, which is also confirmed by the visual inspection of the plot. The hypothesis of unit root is also rejected by using the non parametric Phillips-Perron test. We therefore conclude that the series is a stationary process of order zero. The DG-process is integrated of order zero, i.e. $x_t \sim I(0)$ process. Jarque-Bera test for normality gave the following result (subscript shows the degrees of freedom): $\chi^2_{(2)} = 0.718$ (p = 0.698), which indicates normality which is a precondition for applying a linear estimator. Ljung-Box-Pierce statistics applied to the temperature data indicates no autocorrelation, and the temperature series probably is a white noise process. On the other hand, the sample autocorrelation function (SACF) indicates a significant correlation at lag 3. The SPACF and Bartlett's single correlation test of the SACF and SPACF indicate an almost significant correlation at lags 3, 11 and 15. (See appendixes A and B). The values of the autocorrelation and partial autocorrelation do not converge to zero, which is expected with increasing lags, given a stationary series. The change in value of the correlation with increasing lags could indicate oscillations in the temperature. We applied the Akaike information criterion (AIC) and the Schwarz criterion (SC) as a model selection criterion. B is the backward shift operator. The following ARIMA model is estimated for mapping the DGP behind the August temperature off Skrova.

$$(1+\phi_3 B^3 + \phi_{11} B^{11} + \phi_{15} B^{15}) x_t = \alpha + \varepsilon_t$$

ϕ_3	0.24070	t = 2.194
ϕ_{11}	-0.27011	t = -2.493
ϕ_{15}	-0.32203	t = -2.950
α	13.534	t = 7.115
AIC	0.42569	
SC	0.55625	
Q(4)	3.72	Critical value (1 d.f): 3.84
Q(6)	7.18	Critical value (3 d.f): 7.81
Q(10)	9.46	Critical value (7 d.f): 14.07
Q(15)	11.54	Critical value (12 d.f): 21.03

The estimated coefficients are significantly different from zero. The numerical value of the sum of the coefficients is less than one, so the stationarity condition is fulfilled. The AIC and SC are the abbreviations for respectively the Akaike and Schwarz information criteria for model selection. Q(*L*) is the Ljung-Box-Pierce portmanteau statistics (LBP), and *L* stands for number of lags. This test is constructed from the first *L* squared autocorrelations. The LBP shows that the model is close to having an element of joint autocorrelation for the forth and sixth lag. Figure 5 shows the observed and model-predicted August temperature.

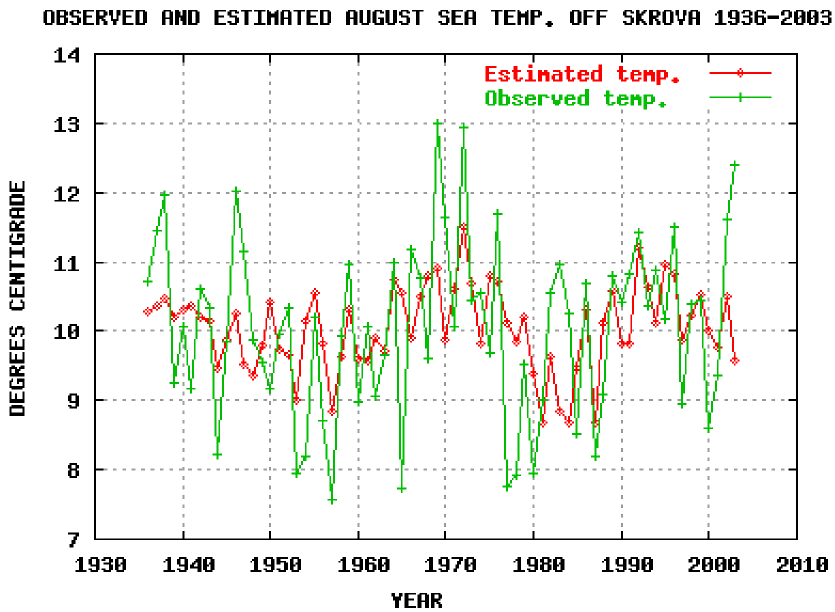

Figure 5: Observed and estimated August temperature for Skrova

The model was also applied for forecasting the future sea temperature. Figure 6 shows the forecast temperature path for the period 2003 to 2043.

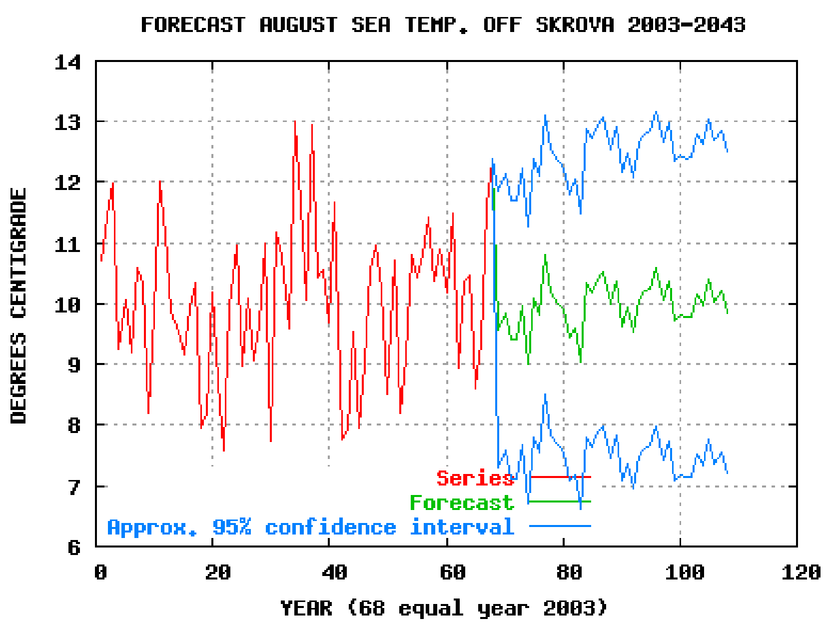

Figure 6: Forecast August sea temperature off Skrova 2003-2043

Figure 6 shows that the predicted temperature will oscillate with a length of the cycle of about 10 years, and the expected future temperature level converges to a level slightly above 10 degrees. The in-sample average August sea temperature off Skrova is 10.02 degrees. The figure shows that the forecast temperature converges to about 10 degrees, and the figure also includes the 95% confidence interval for temperature.

5.2 August sea temperature off Lista

The ADF-test for the August sea temperature off Lista indicates a unit root process for the period 1942-2003. The test statistic further shows that there is no indication of deterministic trend or stochastic drift, given a 5% significance level. The ADF-test indicates therefore that the temperature is a nonstationary DG-process of order one, i.e. $x_t \sim I(1)$. The Phillips-Perron tests reject the hypothesis of a unit root. Jarque-Bera test for normality gave the following result: χ_2 = 17.931 (p = 0.000), which implies a rejection of the null hypothesis of normality. A first difference of the series gave the following result of the JB-normality test: $\chi^2_{(2)}$ = 0.801 (p = 0.670), which shows that the series fulfils the normality condition after being transformed (first order difference). The Ljung-Box-Pierce portmanteau statistics (LBP) shows clearly that the temperature process is not white noise. The SACF and SPACF indicate oscillations or periodicity in the temperature data. The SACF and SPACF with confidence intervals included show that the process is neither stationary nor non-stationary. The data are differenced to reveal information of the data generating process and to make it stationary. Based on SACF and SPACF, the following model was estimated:

$$(1+\phi_1 B+\phi_2 B^2+\phi_3 B^3)(1-B)x_t = (1+\theta_1 B^1+\theta_{11} B^{11})\varepsilon_t$$

ϕ_1	-0.52165	t = -3.122
ϕ_2	-0.46591	t = -3.021
ϕ_3	-0.33212	t = -2.430
θ_1	0.30238	t = 2.252
θ_{11}	-0.58992	t = -6.053
AIC	0.091759	
SC	0.26478	

Q(6)	1.02	10% level Critical value (1 d.f):2.71
Q(10)	4.39	10% level Critical value (5 d.f): 7.78
Q(15)	7.09	10% level Critical value (10 d.f): 15.99
Q(20)	9.67	10% level Critical value (15 d.f):22.31

The stationary condition is fulfilled, i.e. $\phi_1 + \phi_2 + \phi_3 < 1$. The table shows that probability that there is no joint autocorrelation in the model is over 90%. Figure 7 shows the relation between observed and estimated August sea temperature off Lista for the period 1942-2002.

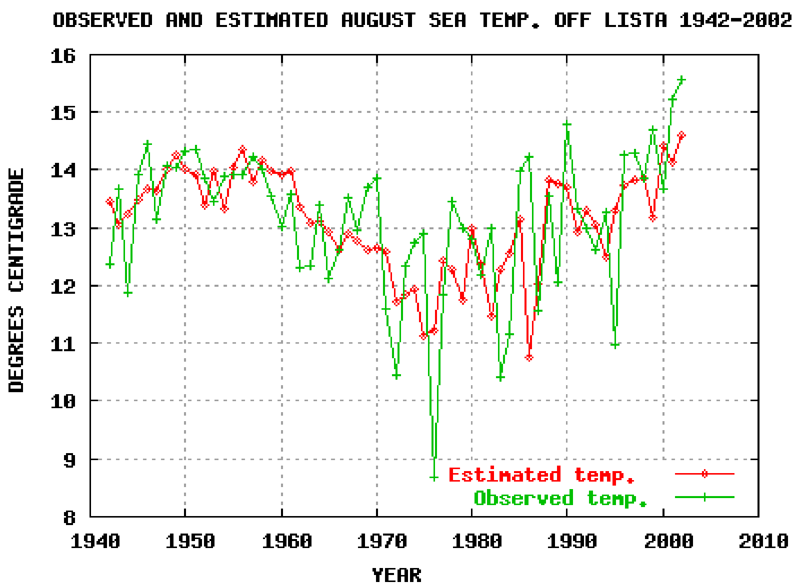

Figure 7: Observed and estimated August temperature for Lista

The model was also applied to forecaste the August temperature off Lista (1-50m water column) for the period 2003 to 2023.

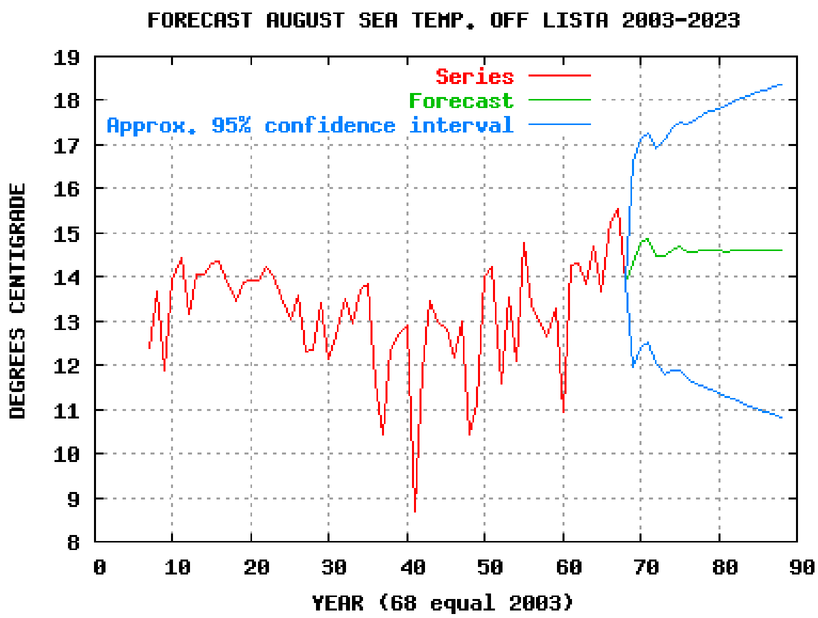

Figure 8: Forecast August sea temperature off Lista 2003-2043

Figure 8 shows that there are some oscillations in the predicted temperature. The forecast process is stationary, and the expected temperature converges to 14.6 degrees centigrade. The August temperature off Lista has had a negative trend in the period from about 1950 to 1978 and a positive trend in the period from the last part of the 1970s to 2003. ADF test of the temperature data for the time span 1978-2003 indicates no unit root, but the hypothesis for no deterministic trend is rejected. The August temperature off Lista probably follows a deterministic positive trend, and the process is a trend stationary process (TS). Notice also by looking at the plot, that the temperature level around 2003 has never been higher, given the sample period 1942-2003. An OLS estimation of a linear trend model for the period 1978-2003 shows that the temperature on average has increased by 0.0865 degrees per year. The statistics for the estimated trend coefficient is $t = 2.900$ and the Durbin-Watson statistics is DW = 2.03. An ARIMA(0,1,1), based on data for the period 1978-2003, which gives the same results for the trend as the OLS-model. A random walk process can typically be modelled by an ARIMA(0,1,1). With regard to global warming, the question of whether the trend will continue or the temperature rise is part of a bigger cycle and will follow the estimated DGP which is applied in the forecasting of the temperature for the period 2002-2023. Figure 9 shows the model used in mapping figure 8 *except* for integrating explicitly a constant in the difference equation for reflecting the trend element. The figure shows that the temperature increases by a trend of 0.126 degrees per year.

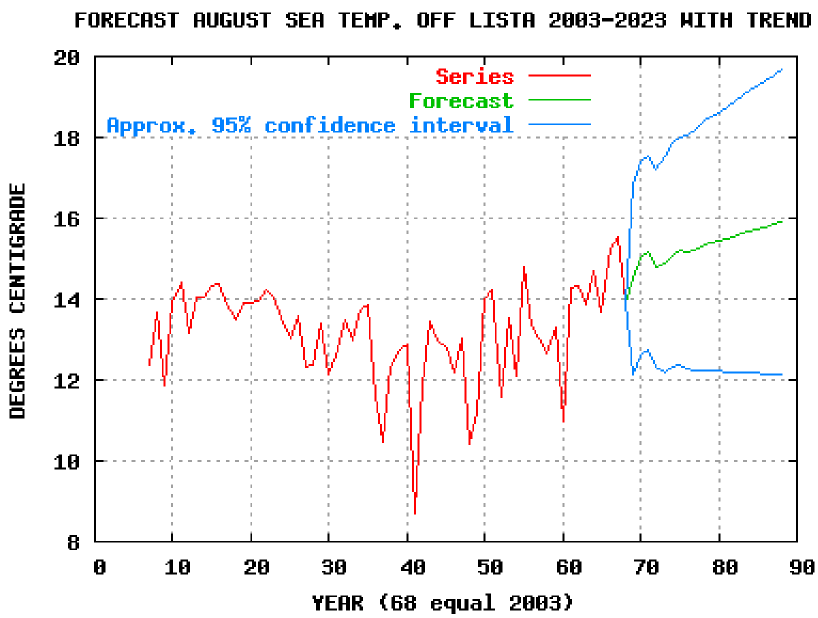

Figure 9: Forecast August sea temperature off Lista 2003-2023

The model predicts that the expected future August sea temperature off Lista will reach a level of 16 degrees after a period of about 20 years, i.e. in 2023. The estimated deterministic trend is *not* significant, i.e. α = 0.126 and t = 0.809, and the weak result can be explained by the change in trend, from negative to positive, during the period 1942-2003. The remaining coefficients are significant and the model has no autocorrelation in the residual term. Figure 10 shows the August temperature off Lista for the forecast period 2003-2023. The forecast is built on the model ARIMA(0,1,1) and the sample period 1978-2003.

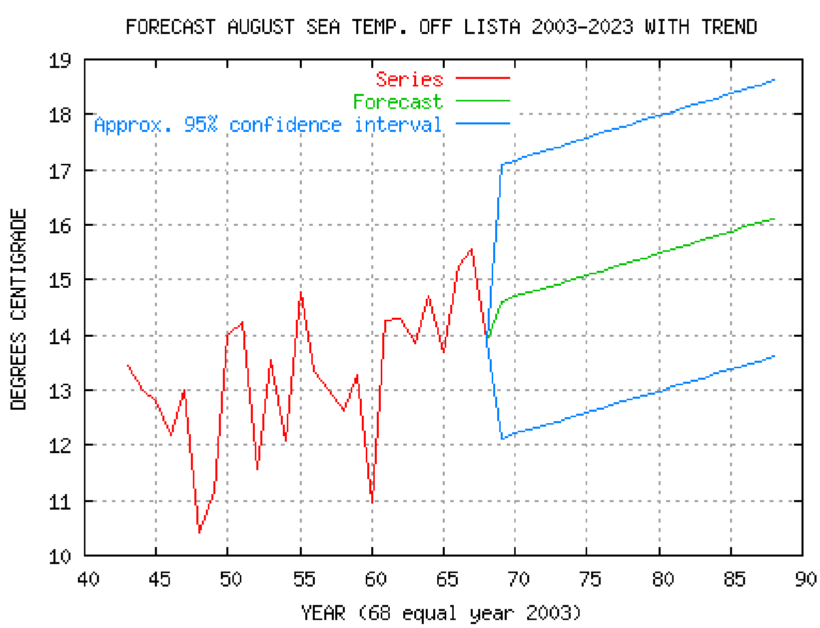

Figure 10: Forecast August sea temperature off Skrova 2003-2023

5.2 March sea temperature off Skrova and Lista

ADF tests of the March sea temperature off Skrova reject the hypothesis of a unit root. Phillips-Perron tests give the same results. Nor are there any statistical indications of a deterministic trend or stochastic drift. The Ljung-Box-Pierce chi square statistics for a joint autocorrelation shows that the trajectory of the temperature follows a stationary, non-autocorrelated white noise process of order zero, i.e. $x_t \sim I(0)$. Both series fulfil the normality criterion, i.e. Jarque-Bera is respectively: $\chi^2_{(2)} = 3.497$ (p = 0.174) and $\chi^2_{(2)} = 0.205$ (p = 0.903). The SACF and SPACF show no indication of statistically significant correlations, but the correlations do not converge to zero with increasing lags, and the correlation pattern indicates an oscillating temperature path. The curve for the seven year moving average shows more clearly the oscillatory pattern. A non-stationary time series may have a pronounced trend and/or meander without a constant long-run mean or variance. A visual inspection of the observed temperature series and the statistical tests of the March temperature do not show any clear non-stationary properties. Since the March temperature has no correlation structure, the best guess of the future temperature is the average temperature, i.e. 3.05 Celsius centigrade, and that is also the best guess if the March temperature follows a pure random walk process.

ADF tests of the March sea temperature off Lista gave the same results as for the analysis of March sea temperature off Skrova, i.e. no random walk, no drift and/or deterministic trend. The temperature process is stationary of order $I(0)$. The Ljung-Box-Pierce chi square statistics show that the temperature behaves as a white noise process, and it is not possible to construct a deterministic model for the process. Figure 11 shows the March temperature off Lista together with four simulated random walk temperature paths. The random walk process has no constant and it reflects no drift. The starting temperature value in 1942 is 2.91 and the standard deviation of the first difference of the temperature is 1.08.

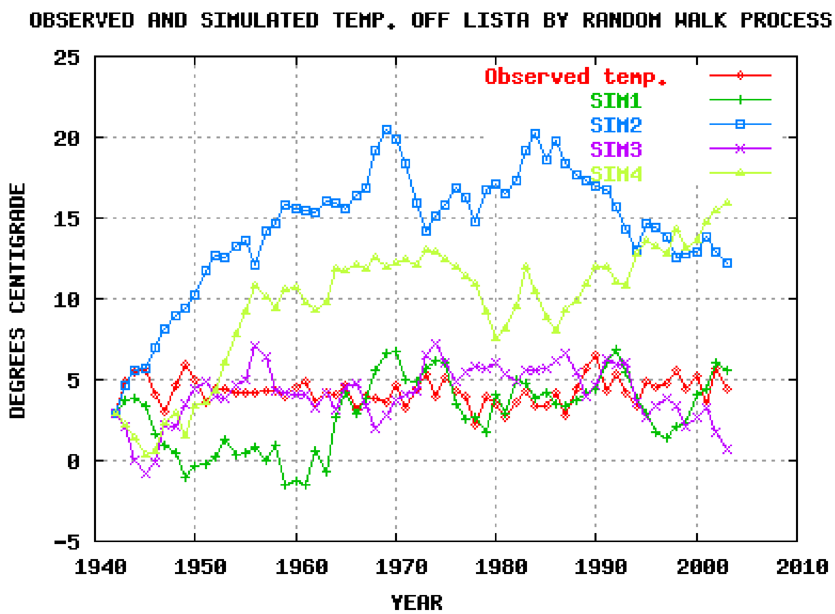

Figure 11: Observed and simulated March temperature off Lista as a random walk process

The figure shows that some of the simulated random walk processes are in some selected time intervals similar to the observed process, for example Sim 1 and Sim 3. But visual inspection of the whole time period 1942-2003 and statistical test (not presented here) show that the random walk processes are neither stationary nor independent white noise processes. Figure 12 shows three simulations of the stationary March temperature off Lista. The figure also includes the observed time series.

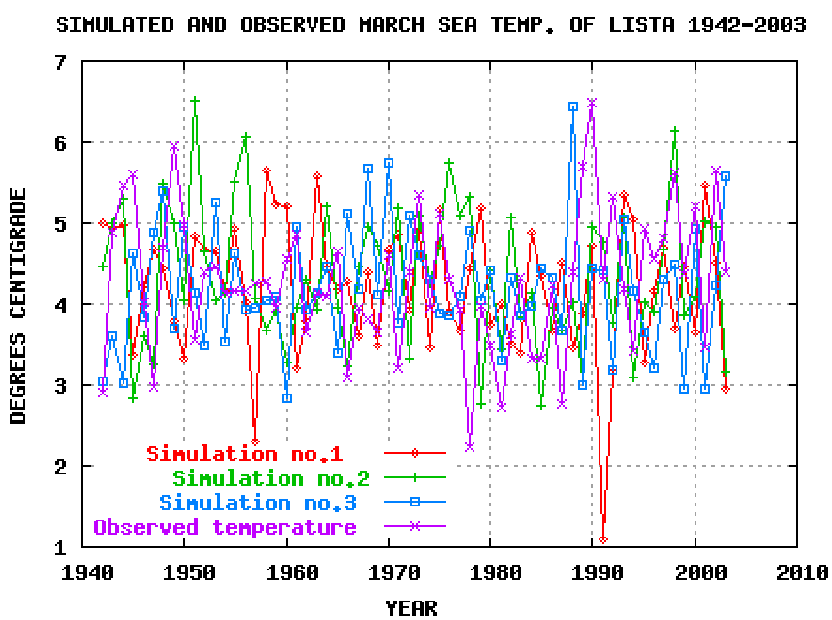

Figure 12: Simulations of the random Mach sea temperature off Lista

5.3 The annual average temperature off Skrova

The ADF-test of the annual average sea temperature off Skrova indicates a unit root process if the lag length is determined by the first significant SACF or PACF coefficient. An ADF-test, which includes a constant, indicates a unit root if the lag length (p) is seven. There is no indication of unit root if shorter lag length is chosen. Phillips-Perron tests show no indication of unit root in the time series. The SACF shows no (visual) indication of non-stationarity (See Appendix). Suppose that the process is stationary and that the temperature is integrated of order zero, i.e. $x_t \sim I(0)$. The series has an element of cycle, and the process will probably be a border case between a stationary and a non-stationary series. Jarque-Bera test for normality gave the following result: $\chi^2_{(2)}$ = 2.278 (p = 0.320), which indicates normality. The Ljung-Box-Pierce chi square statistics for autocorrelation shows that the temperature does not follow a white noise process (See Appendix). The SACF and SPACF show statistically significant correlations, the correlations do not converge to zero with increasing lags and the correlation pattern indicates an oscillating temperature path with a cycle of about 6-7 years. The lack of convergence is probably a result of the periodicity. The curve for the seven year moving average shows the oscillatory pattern (See Figure 4). The following model was identified after analyzing the SACF and SPACF. Notice that the autocorrelation structure does not map significant, individual correlations, except for the first lag.

$$(1+\phi_1 B)x_t = \delta + \varepsilon_t$$

ϕ_1	- 0.44521	t = - 4.037
δ	3.5715	t = 5.023
AIC	-1.6449	
SC	-1.5796	
Q(2)	0.24	Critical value (1 d.f): 2.71
Q(4)	0.31	Critical value (3 d.f): 6.25
Q(6)	1.12	Critical value (5 d.f): 9.24
Q(10)	3.52	Critical value (9 d.f): 14.68
Q(15)	5.67	Critical value (14 d.f): 21.06

The estimated parameters are significantly different from zero and the LBP-statistic shows that the model fits the data well. The residuals of the model are statistically independent. Figure 13 shows the plot of the observed and estimated temperature.

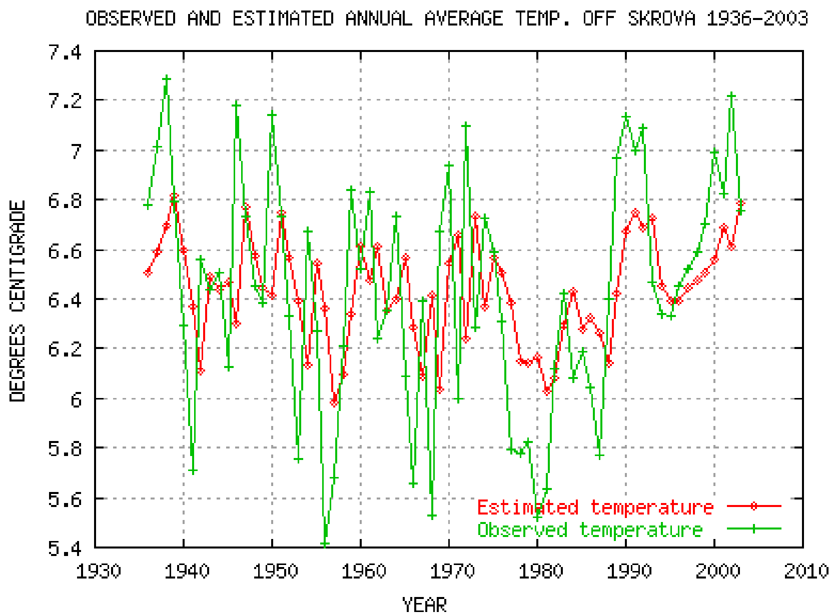

Figure 13: Observed and estimated annual average temperature off Skrova

The model was also applied to forecast the future annual average sea temperature off Skrova. Figure 14 shows the temperature path from 2003 to 2025.

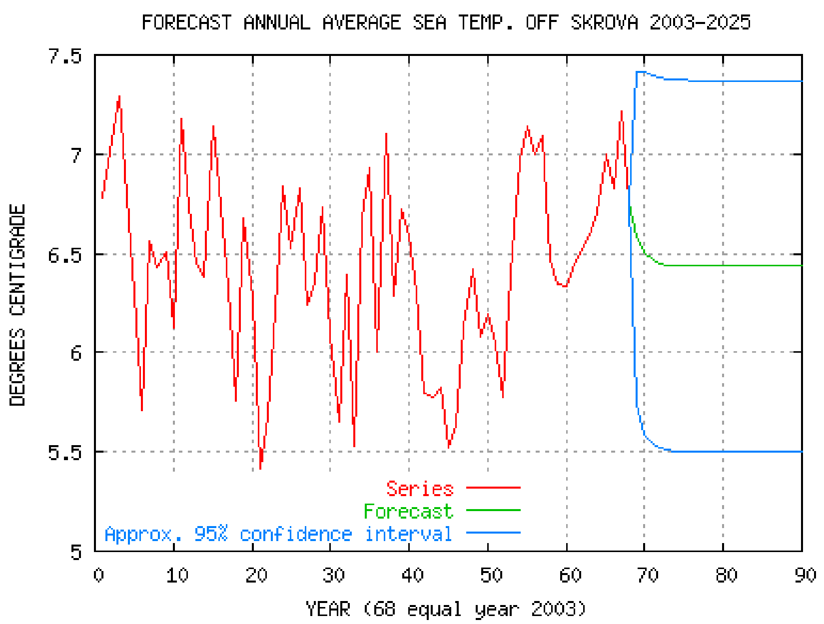

Figure 14: Forecast annual average temperature off Skrova 2003-2025

Figure 14 shows that the expected forecast annual average temperature off Skrova converges to 6.44 centigrade. The plot shows that the 95% confidence interval is not increasing for increased forecast periods, and the width of the confidence interval is not wider than the volatility in the historical data. The upper band is 7.37 centigrade and the lower band is 5.5 centigrade. However, suppose that the average temperature is difference stationary, i.e. it has a unit root and is integrated of order one $x_t \sim I(1)$. The following model is identified:

$$(1+\phi_1 B+\phi_2 B^2+\phi_7 B^7)(1-B)x_t=\varepsilon_t$$

ϕ_1	0.43329	$t = 3.626$
ϕ_2	0.22199	$t = 1.864$
ϕ_7	0.20082	$t = 1.848$
AIC	-1.4773	
SC	-1.3786	
Q(4)	2.55	Critical value (1 d.f): 2.71
Q(6)	4.96	Critical value (3 d.f): 6.25
Q(8)	5.21	Critical value (5 d.f): 9.24
Q(12)	5.33	Critical value (9 d.f): 14.68
Q(17)	9.57	Critical value (14 d.f): 21.06

The estimated parameters are significantly different from zero and the LBP-statistic shows that the model fits the data well. The estimated coefficients have properties which satisfy the stability condition $\phi_1+\phi_2+\phi_7<1$. The residuals of the model are statistically independent and show a white noise pattern. Figure 15 shows the estimated and observed temperature path for the period 1936-2002.

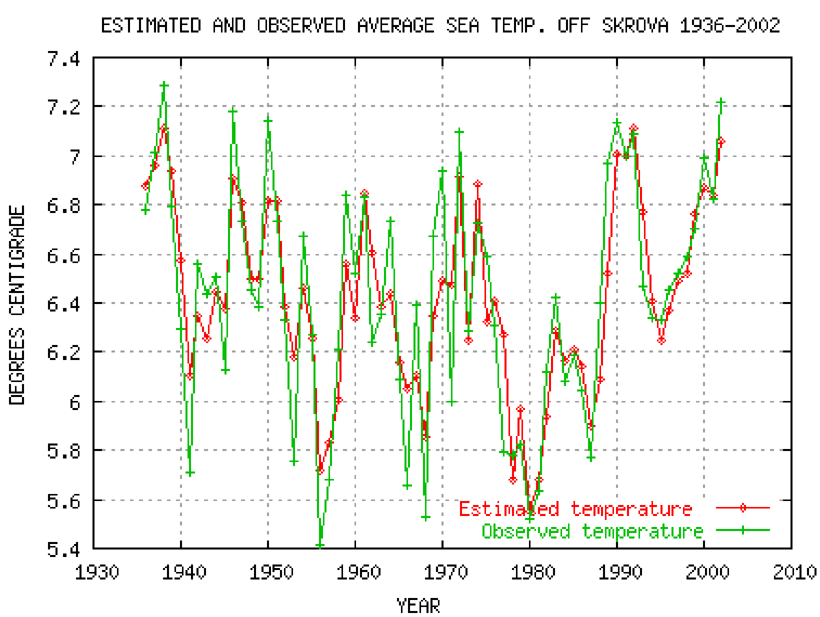

Figure 15: Observed and estimated annual average temperature off Skrova

Figure 15 shows that the model based on differenced data fits the observed values better compared to the preceding model. The model was also applied for forecasting the future annual average sea temperature off Skrova. Figure 16 shows the temperature path from 2003 to 2025.

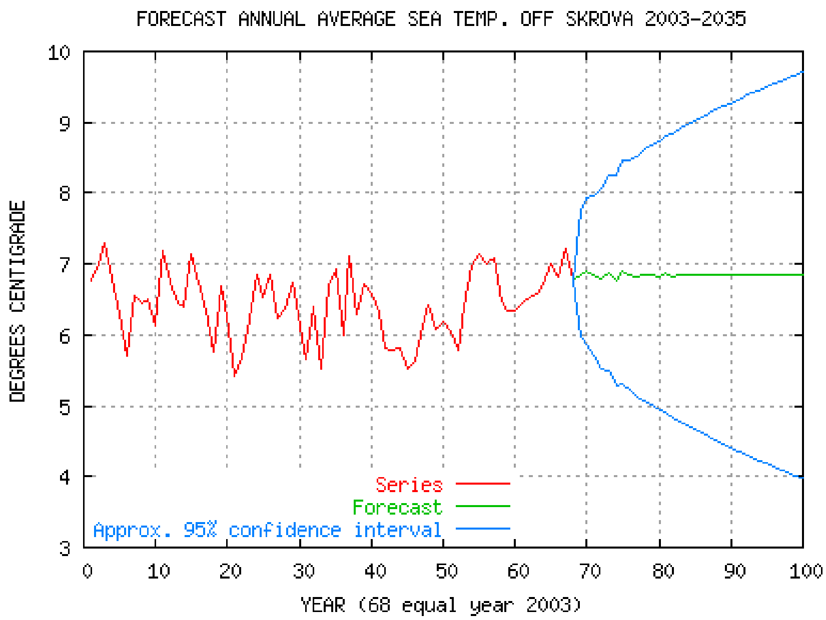

Figure 16: Forecast annual average temperature off Skrova 2003-2035

Figure 16 shows that the model forecasts that the expected future temperature will fluctuate around 6.8 degrees. Notice that the confidence intervals are increasing. It is a consequence of the assumption that the temperature process has a unit root and is non-stationary.

5.4 The annual average temperature off Lista

The following section presents the results from the analysis of the annual average sea temperature off Lista. The data are based on the time period 1943-2003. Notice that the observation for 1942 is excluded because this particular year was a non-normal, cold year. The hypothesis for random walk was not rejected at the 5 % significant level. The test shows no significant drift or deterministic trend. The SACF and SPACF show that the time series is not a white noise process, which also confirms the result from the ADF-test. We conclude that the series is homogeneous non-stationary of order one, i.e $x_t \sim I(1)$. The hypothesis of unit root is rejected by using the Phillips-Perron test, given 5% significance level. However, the

Phillips-Perron test can not reject the unit root hypothesis if the significance level is 1%. The structure of the correlations with lags indicates clearly that the process is oscillating. The SACF shows oscillations which do not converge with increased lags, but at the same time the oscillations do not cross the border of the upper and lower confidence interval. This could indicate stationary oscillation similar to a deterministic, trigonometric function. Jarque-Bera test for normality gave the following result: $\chi^2_{(2)} = 2.133$ (p = 0.344), which indicates normality. The time series was made stationary by differencing the data. The following differenced ARIMA model was estimated for the annual average sea temperature for Lista.

$$(1+\phi_5 B^5 + \phi_6 B^6 + \phi_{15} B^{15})(1-B)x_t = (1+\theta_1 B)\varepsilon_t$$

ϕ_5	0.3564	t = 3.515
ϕ_6	0.18120	t = 1.834
ϕ_{15}	-0.5517	t = -5.163
θ_1	-0.4272	t = -3.522
AIC	-1.6953	
SC	-1.5552	
Q(5)	2.03	Critical value (1 d.f): 2.71
Q(7)	4.00	Critical value (3 d.f): 6.25
Q(9)	5.06	Critical value (5 d.f): 9.24
Q(13)	6.51	Critical value (9 d.f): 14.68
Q(18)	8.50	Critical value (14 d.f): 21.06

The estimated parameters are significantly different from zero, and the LBP-statistics shows that the model fits the data well. The estimated coefficients have properties which satisfy the stability condition $\phi_5 + \phi_6 + \phi_{15} < 1$. The residuals of the model are statistically independent. The estimated and observed temperatures are showed in figure 17.

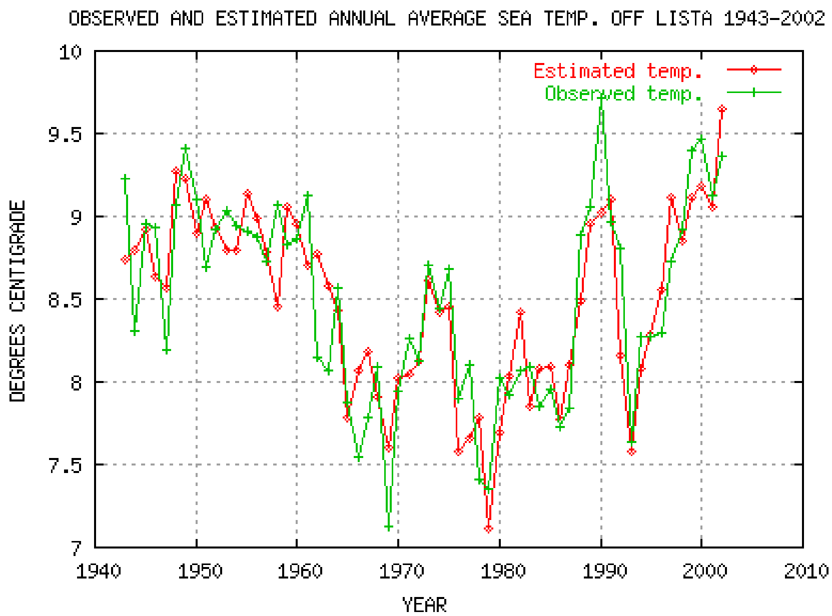

Figure 17: Observed and estimated annual average temperature off Lista

The model was also applied for forecasting the future annual average sea temperature off Lista. Figure 18 shows the temperature path from 2003 to 2023.

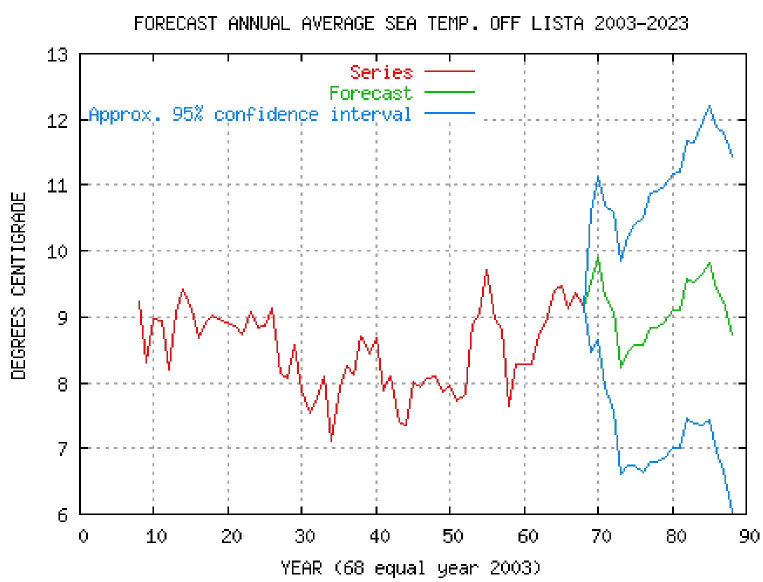

Figure 18: Forecast annual average sea temperature for Lista

Figure 18 shows that the estimated model has picked up the complex, oscillating structure in the historical data. It was mentioned that a stable, cyclical variation was identified in the raw data, and that it was confirmed by the SACF and SPACF. Figure 19 shows the forecast of the temperature based on the presented model, but the period of forecast is extended to 2043.

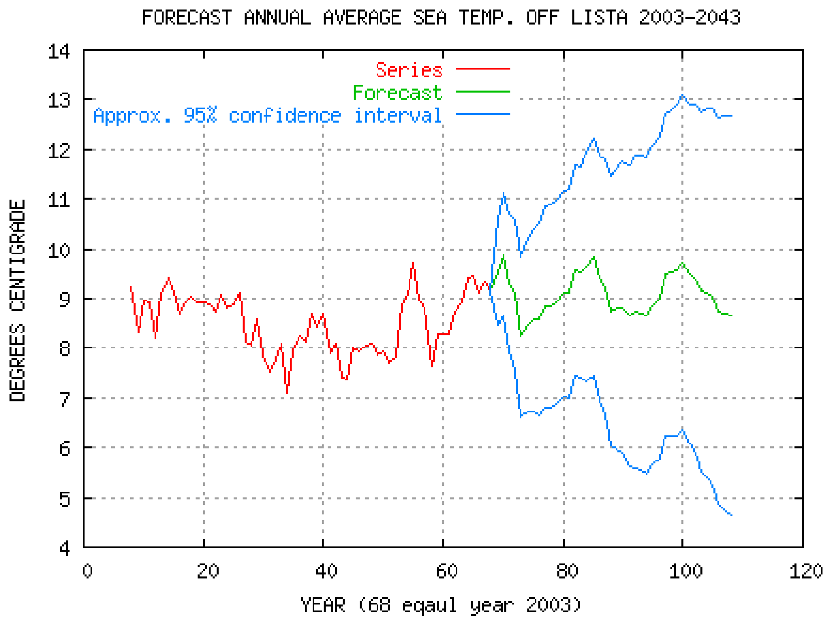

Figure 19: Forecast annual average sea temperature for Lista 2003-2043

Figure 19 shows that the expected temperature will oscillate around 9 centigrade with amplitude of, roughly, 0.7 degrees centigrade. The model predicts that the expected temperature off Lista will fall in the period 2007-2013, and after the turning point in 2013 the temperature will start to rise for the period 2014-2023.

6. CONCLUDING REMARKS AND DISCUSSION

One important statistical criterion for measuring climate change is to detect non-stationarity in the time series. It is therefore important to test what kind of data generating process is that the "engine" behind the series. ADF-test and Phillip-Perron test were applied for analyzing and detecting respectively unit root, drift and deterministic trend in the temperature series for Skrova and Lista. Ljung-Box-Pierce, Bartlett's and Levene's tests, Jarque-Bera test, SACF and SPACF were applied for testing respectively autocorrelation, test of variance (homogeneity tests), test of normality and for identification and diagnostics of the ARIMA models.

The ADF-test shows that the August temperature off Skrova has no unit root and is a stationary time series. On the other hand, the August temperature for Lista probably has a unit root, and it indicates a pure random walk process. The series is therefore probably a non-stationary time series. A statistical test also indicates a change in the variance of the August sea temperature off Lista. This diagnosis could be an indication of a beginning climate change. It should also be mentioned that the August-series for Lista has missing values especially for the 1950s, and substituted values are based on methods which reduce the variance. The March temperature series for Skrova and Lista have no unit root and are probably stationary white noise time series. According to the ADF-test, the annual average sea temperature off Lista has a unit root. ADF-test also indicates that the annual average temperature off Skrova has a unit root and is therefore a non-stationary time series. SACF and PACF indicate cyclical elements in the annual average for both geographical areas. The average temperature is a linear combination with equal weights for each of the 12 months. The annual series for Lista, as a weighted sum, is non-stationary. This implies that the "random walk" of the temperature of one or more of the months is strong and influences the data generating process for the annual average.

Each temperature series was divided into three subgroups and tested for equal variance. The hypothesis of equal variance was tested by applying respectively 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, except for the August temperature for Lista where the Bartlett's test was significant but Levere's test was not. The variance for each time series, except for August at Lista, is stable and the constant volatility contributes to stationarity.

The analysis also tested the null hypothesis of equal mean and variance between respectively Lista and Skrova. The statistical tests show that the mean temperature in the sea off Lista is significantly higher than at Skrova for respectively March, August and annual average. The variance is equal for Lista and Skrova for the August series. The variance is significantly higher at Lista than at Skrova for the March series and for the annual average temperature.

The analysis shows that the data generating processes for the temperature series satisfy the stationary conditions except for August Lista and the average annual temperature for Lista and Skrova. The analysis shows that it is not possible to conclude unambiguously that there is no sign of climate change in the sea along the coast of Norway for the said period. On the other hand, if the sample period is extended or reduced, the statistical conclusion could be different. We have illustrated that time series analysis of the August temperature for Lista for the selected period 1975-2003 shows a process which is not stationary because of a deterministic increase in the temperature level. If the process continues, it would definitely be an indication of climate change.

ARIMA models were applied in modelling the stochastic process for each temperature series, and the models were also applied in the forecasting of the future temperature span for 2003-2023 and beyond. The forecasting of the August sea temperature off Lista shows that the temperature will fluctuate around an expected level of about 15 degrees. But the identification of a unit root will map a meandering time series, which over time can be identified as a deterministic trend. A model (based on the complete sample) which includes a deterministic trend element shows that the temperature increases by about 0.13 degrees per year, and a level of about 16 degrees will be reached by 2025. However, the estimated yearly increase is not significant. Estimation based on the sample period 1978-2003 measures a significant increase in temperature by 0.0865 degrees per year. The forecast of the August sea temperature off Skrova shows that the temperature will oscillate, with a cycle length of about 10 years, and around an expected level of about 10 degrees. The analysis shows that the March temperature for Lista and Skrova is pure white noise and stationary processes. The future temperature will fluctuate randomly around the level of respectively 4.3 and 3.1 degrees. The forecast analysis of the annual average sea temperature off Skrova shows that it will oscillates around an expected level of 6.4-6.8 degrees. The forecast analysis of the annual average temperature off Lista shows that the future sea temperature will oscillate more heavily compared to the average for Skrova. The model predicts that the expected future temperature will oscillate around 9 centigrade with amplitude of about 0.5 centigrade. The length of the oscillating period is about 10-15 years.

The statistical analysis shows for example that the August temperature off Lista probably has a significant positive trend for the period 1970-2003, and that the temperature has increased by about 2 degrees during the said period. The process is modelled as an integrated moving average process with a constant (deterministic) trend, i.e. ARIMA(0,1,1). The estimation of the August temperature off Skrova for the same period shows that the process has no significant trend. The process was differenced, and an autoregressive model with complex roots shows that the temperature also has a periodic behaviour.

We have argued in the introduction that the temperature level is important for the growth of the fish in general, and for how fast the fish reaches a weight which maximizes the discounted profit. The statistical analysis shows that the sea temperature is significantly higher in the southernmost counties compared to the coast water in the north. We have emphasized that the growth rate of the fish is a concave function of the temperature. Whether the sea temperature in the south of Norway is more favourable than in the north depends on how close the temperature level is to biologically critical or optimal values before the change in the climate starts. The temperature data we have applied in the analysis are from the 1-50 m layer. In the summer months the surface temperature can reach 20 degrees, and this level is dysfunctional with respect to growth of the salmon and trout (and in particular for cod). We can therefore not exclude the possibility that a continuous temperature increase within the next 10 years will make farming of salmon and trout impossible at the coast of Rogaland and Hordaland. The sea temperature in the northernmost counties does not reach this level.

Statistical models based on data for the last 10-15 years indicate that the temperature level may continue to increase in the future, especially in the south. But is this change sufficient to draw the conclusion that we are facing a climate change? We have so far not analysed whether we find the same traits other places along the coast. The statistical analysis of the full sample shows on the other hand that there is no clear, overall, significant indication of climate change in the sea water off Skrova and Lista. On the other hand, if sub-samples are selected, it is possible to detect non-stationarity and climate change. The estimation also indicates that more sophisticated, nonlinear models which include temperature cycles should be applied. The annual average temperature off Skrova indicates a 9-10 year cycle. The data for the August temperature indicate cycles or periodic behaviour of 9-10 years and a longer cycle of about 40 years. It should be mentioned that the annual average temperature is a weighted combination of all 12 months, but that August is not a combination of observations.

If the last 10-15 years' trend is extrapolated into the future, a 20 year forecast shows that the temperature off the coast of Rogaland and the neighbouring areas will probably increase, and the economic risk of farming salmon and trout will increase. The analysed sub-temperature data show a local increase in the temperature. Higher temperature in Rogaland and Hordaland does not imply that the temperature will increase in the northernmost counties, according to the empirical findings. But the temperature cannot continue to increase for ever without affecting the temperature level along the total coast. This follows from the fact that the geographical areas and water masses are connected via the Gulf Stream and a one way interaction is therefore expected. If the temperature increases sufficiently in the sea off the west coast of Norway, it must be expected that the temperature will increase in the north as well, and it follows that the relative growth rate of farmed salmon and trout will increase there. A climate change will increase the economic risk and reduce the economic value of plants located in Rogaland and Hordaland, and the firms located in the north will probably experience the opposite effect.

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APPENDIX A

APPLICATION OF AUGMENTED DICKEY-FULLER TEST FOR IDENTIFYING DATAGENERATING PROCESS, UNIT ROOT, STATIONARITY

```
VARIABLE : AUGUST SKROVA 1936-2003

TOTAL NUMBER OF OBSERVATIONS =   68

  CORRELOGRAM - FIRST DIFFERENCES OF AUG
  LAG    ACF         STD.ERROR        PACF        STD.ERROR
    1 -0.42908      0.12217       -0.42908      0.12217
    2 -0.18813      0.14290       -0.45624      0.12217
    3  0.30238      0.14655       -0.16925E-01  0.12217
    4 -0.13360      0.15559       -0.57909E-01  0.12217
    5 -0.30615E-01  0.15729       -0.13159E-02  0.12217
    6  0.89349E-02  0.15738       -0.11135      0.12217
    7 -0.34952E-01  0.15739       -0.12516      0.12217
    8  0.47047E-02  0.15750       -0.12907      0.12217

  VARIABLE : AUGUST SKROVA 1936-2003
  DICKEY-FULLER TESTS - NO.LAGS =   3   NO.OBS =   64

      NULL              TEST      ASY. CRITICAL
   HYPOTHESIS         STATISTIC     VALUE  5%
 ---------------------------------------------------------------------------
    CONSTANT, NO TREND
  A(1)=0  T-TEST       -3.0589     -2.86
  A(0)=A(1)=0           4.6927      4.59
                                              AIC =     0.528
                                               SC =     0.697
          ESTIMATE      STD.ERROR   T-RATIO
  LAG  1  -0.17064     0.20322     -0.83969
  LAG  2  -0.19799     0.17235      -1.1488
  LAG  3   0.82477E-01 0.13354      0.61764
 ---------------------------------------------------------------------------
  CONSTANT, TREND
  A(1)=0  T-TEST       -3.1566     -3.41
  A(0)=A(1)=A(2)=0      3.5354      4.68
  A(1)=A(2)=0           5.2887      6.25
                                              AIC =     0.539
                                               SC =     0.741
          ESTIMATE      STD.ERROR   T-RATIO
  LAG  1  -0.16418     0.20298     -0.80883
  LAG  2  -0.19564     0.17208      -1.1369
  LAG  3   0.82353E-01 0.13332      0.61771
 ---------------------------------------------------------------------------

  VARIABLE : AUGUST SKROVA 1936-2003
  PHILLIPS-PERRON TESTS - TRUNCATION LAG =   1

      NULL              TEST      ASY. CRITICAL
   HYPOTHESIS         STATISTIC     VALUE  5%
  ---------------------------------------------------------------------------
  CONSTANT, NO TREND
  A(1)=0  Z-TEST       -55.923     -14.1
  A(1)=0  T-TEST       -6.6809     -2.86
  A(0)=A(1)=0           22.327      4.59
 ---------------------------------------------------------------------------
  CONSTANT, TREND
  A(1)=0  Z-TEST       -55.952     -21.7
  A(1)=0  T-TEST       -6.6676     -3.41
  A(0)=A(1)=A(2)=0      14.907      4.68
  A(1)=A(2)=0           22.348      6.25
 ---------------------------------------------------------------------------


VARIABLE: MARCH SKROVA 1936-2003
  TOTAL NUMBER OF OBSERVATIONS =   68

  CORRELOGRAM - FIRST DIFFERENCES OF MAR
  LAG    ACF         STD.ERROR        PACF        STD.ERROR
    1 -0.46874      0.12217       -0.46874      0.12217
    2 -0.21996E-01  0.14657       -0.30977      0.12217
    3  0.86428E-01  0.14662       -0.10246      0.12217
    4 -0.18472      0.14738       -0.26524      0.12217
```

```
  5  0.23464      0.15080        0.31983E-01  0.12217
  6 -0.14434      0.15615       -0.64711E-01  0.12217
  7 -0.50949E-01  0.15813       -0.14259      0.12217
  8  0.44809E-01  0.15838       -0.16798      0.12217

VARIABLE : MARCH SKROVA 1936-2003
DICKEY-FULLER TESTS - NO.LAGS =   4   NO.OBS =   63

    NULL              TEST      ASY. CRITICAL
 HYPOTHESIS          STATISTIC     VALUE  5%
 ---------------------------------------------------------------------------
CONSTANT, NO TREND
A(1)=0  T-TEST       -2.9980     -2.86
A(0)=A(1)=0           4.5072      4.59
                                           AIC =    -0.988
                                            SC =    -0.784
        ESTIMATE      STD.ERROR   T-RATIO
LAG  1  -0.94995E-01 0.21820     -0.43536
LAG  2  -0.38059E-01 0.19855     -0.19168
LAG  3   0.54031E-01 0.17023      0.31740
LAG  4  -0.84076E-01 0.12692     -0.66241
---------------------------------------------------------------------------
CONSTANT, TREND
A(1)=0  T-TEST       -2.9809     -3.41
A(0)=A(1)=A(2)=0      2.9823      4.68
A(1)=A(2)=0           4.4604      6.25
                                           AIC =    -0.958
                                            SC =    -0.720
        ESTIMATE      STD.ERROR   T-RATIO
LAG  1  -0.95985E-01 0.22001     -0.43627
LAG  2  -0.40396E-01 0.20035     -0.20163
LAG  3   0.51319E-01 0.17189      0.29855
LAG  4  -0.85094E-01 0.12801     -0.66472
---------------------------------------------------------------------------


VARIABLE : MARCH SKROVA 1936-2003
PHILLIPS-PERRON TESTS - TRUNCATION LAG =   1

    NULL              TEST      ASY. CRITICAL
 HYPOTHESIS          STATISTIC     VALUE  5%
 ---------------------------------------------------------------------------
CONSTANT, NO TREND
A(1)=0  Z-TEST       -58.135     -14.1
A(1)=0  T-TEST       -7.0868     -2.86
A(0)=A(1)=0           25.116      4.59
---------------------------------------------------------------------------
CONSTANT, TREND
A(1)=0  Z-TEST       -58.179     -21.7
A(1)=0  T-TEST       -7.0343     -3.41
A(0)=A(1)=A(2)=0      16.498      4.68
A(1)=A(2)=0           24.742      6.25
---------------------------------------------------------------------------


VARIABLE : ANNUAL AVERAGE SEA TEMP. SKROVA 1936-2003
DICKEY-FULLER TESTS - NO.LAGS =   7   NO.OBS =   60

  NULL               TEST      ASY. CRITICAL
 HYPOTHESIS          STATISTIC     VALUE  5%
---------------------------------------------------------------------------
CONSTANT, NO TREND
A(1)=0  T-TEST       -2.0594     -2.86
A(0)=A(1)=0           2.1486      4.59
                                           AIC =    -1.512
                                            SC =    -1.198
---------------------------------------------------------------------------
CONSTANT, TREND
A(1)=0  T-TEST       -2.0212     -3.41
A(0)=A(1)=A(2)=0      1.6347      4.68
A(1)=A(2)=0           2.4243      6.25
                                           AIC =    -1.491
                                            SC =    -1.142
---------------------------------------------------------------------------
```

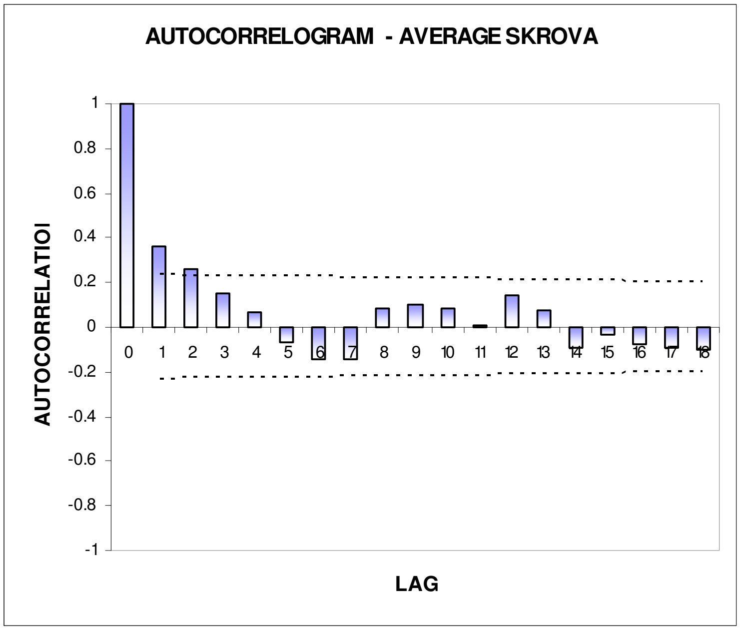

Figure A1: SACF for average sea temperature off Skrova

```
PHILLIPS-PERRON TESTS - TRUNCATION LAG =   7

      NULL              TEST       ASY. CRITICAL
   HYPOTHESIS         STATISTIC     VALUE  5%
 ---------------------------------------------------------------------------
  CONSTANT, NO TREND
  A(1)=0  Z-TEST       -38.172     -14.1
  A(1)=0  T-TEST       -5.3911     -2.86
  A(0)=A(1)=0           14.479      4.59
 ---------------------------------------------------------------------------
  CONSTANT, TREND
  A(1)=0  Z-TEST       -38.493     -21.7
  A(1)=0  T-TEST       -5.3566     -3.41
  A(0)=A(1)=A(2)=0      9.5229      4.68
  A(1)=A(2)=0           14.278      6.25
 ---------------------------------------------------------------------------


VARIABLE : AUGUST LISTA 1942-2003
  TOTAL NUMBER OF OBSERVATIONS =   62

  CORRELOGRAM - FIRST DIFFERENCES OF AUGL
  LAG    ACF        STD.ERROR        PACF       STD.ERROR
    1 -0.39445      0.12804       -0.39445      0.12804
    2 -0.14446      0.14661       -0.35534      0.12804
    3  0.52793E-02  0.14893       -0.28750      0.12804
    4  0.73739E-01  0.14893       -0.16229      0.12804
    5  0.27276E-01  0.14953       -0.60221E-01  0.12804
    6 -0.78268E-02  0.14961        0.84546E-02  0.12804
    7 -0.13345      0.14961       -0.14383      0.12804

  VARIABLE : AUGUST LISTA 1942-2003
  DICKEY-FULLER TESTS - NO.LAGS =   3   NO.OBS =   58

      NULL              TEST       ASY. CRITICAL
   HYPOTHESIS         STATISTIC     VALUE  5%
  ---------------------------------------------------------------------------
  CONSTANT, NO TREND
  A(1)=0  T-TEST       -1.8909     -2.86
  A(0)=A(1)=0           1.8680      4.59
                                              AIC =      0.392
                                               SC =      0.570
          ESTIMATE      STD.ERROR   T-RATIO
  LAG  1  -0.33354      0.19618      -1.7002
  LAG  2  -0.33484      0.17184      -1.9486
```

```
 LAG  3  -0.19132     0.13666      -1.3999
---------------------------------------------------------------------------
 CONSTANT, TREND
 A(1)=0  T-TEST       -1.7729     -3.41
 A(0)=A(1)=A(2)=0      1.2529      4.68
 A(1)=A(2)=0           1.8004      6.25
                                                  AIC =     0.425
                                                   SC =     0.638
         ESTIMATE      STD.ERROR   T-RATIO
 LAG  1  -0.34531     0.20187      -1.7105
 LAG  2  -0.34485     0.17662      -1.9525
 LAG  3  -0.19617     0.13883      -1.4130
---------------------------------------------------------------------------

  VARIABLE: AUGUST LISTA 1942-2003
 PHILLIPS-PERRON TESTS - TRUNCATION LAG =   1

     NULL               TEST      ASY. CRITICAL
  HYPOTHESIS          STATISTIC     VALUE  5%
 ---------------------------------------------------------------------------
 CONSTANT, NO TREND
 A(1)=0  Z-TEST       -40.868     -14.1
 A(1)=0  T-TEST       -5.5032     -2.86
 A(0)=A(1)=0           15.156      4.59
---------------------------------------------------------------------------
 CONSTANT, TREND
 A(1)=0  Z-TEST       -40.930     -21.7
 A(1)=0  T-TEST       -5.4626     -3.41
 A(0)=A(1)=A(2)=0      9.9552      4.68
 A(1)=A(2)=0           14.914      6.25
---------------------------------------------------------------------------

VARIABLE : MARCH LISTA 1942-2003
 TOTAL NUMBER OF OBSERVATIONS =   62

 CORRELOGRAM - FIRST DIFFERENCES OF MARL
 LAG    ACF        STD.ERROR        PACF       STD.ERROR
   1 -0.38607      0.12804       -0.38607      0.12804
   2 -0.83411E-01  0.14588       -0.27318      0.12804
   3 -0.25147E-01  0.14666       -0.21793      0.12804
   4  0.28557E-01  0.14673       -0.13487      0.12804
   5 -0.40777E-01  0.14682       -0.15141      0.12804
   6 -0.10858E-01  0.14700       -0.14982      0.12804
   7  0.15411      0.14702        0.75274E-01  0.12804

 VARIABLE : MARCH LISTA 1942-2003
 DICKEY-FULLER TESTS - NO.LAGS =   2   NO.OBS =   59

     NULL               TEST      ASY. CRITICAL
  HYPOTHESIS          STATISTIC     VALUE  5%
 ---------------------------------------------------------------------------
 CONSTANT, NO TREND
 A(1)=0  T-TEST       -3.8004     -2.86
 A(0)=A(1)=0           7.2246      4.59
                                                  AIC =    -0.274
                                                   SC =    -0.133
         ESTIMATE      STD.ERROR   T-RATIO
 LAG  1  -0.57809E-01 0.17044     -0.33918
 LAG  2  -0.30035E-01 0.13414     -0.22391
---------------------------------------------------------------------------
 CONSTANT, TREND
 A(1)=0  T-TEST       -3.7912     -3.41
 A(0)=A(1)=A(2)=0      4.8664      4.68
 A(1)=A(2)=0           7.2964      6.25
                                                  AIC =    -0.246
                                                   SC =    -0.070
         ESTIMATE      STD.ERROR   T-RATIO
 LAG  1  -0.58158E-01 0.17149     -0.33913
 LAG  2  -0.26318E-01 0.13513     -0.19476
---------------------------------------------------------------------------
 VARIABLE : MARCH LISTA 1942-2003
 PHILLIPS-PERRON TESTS - TRUNCATION LAG =   1

     NULL               TEST      ASY. CRITICAL
  HYPOTHESIS          STATISTIC     VALUE  5%
 ---------------------------------------------------------------------------
 CONSTANT, NO TREND
```

```
  A(1)=0  Z-TEST       -50.304     -14.1
  A(1)=0  T-TEST       -6.4919     -2.86
  A(0)=A(1)=0           21.104      4.59
 ---------------------------------------------------------------------------
  CONSTANT, TREND
  A(1)=0  Z-TEST       -50.334     -21.7
  A(1)=0  T-TEST       -6.4309     -3.41
  A(0)=A(1)=A(2)=0      13.840      4.68
  A(1)=A(2)=0           20.739      6.25
 ---------------------------------------------------------------------------


VARIABLE : AVERAGE LISTA 1943-2003

  TOTAL NUMBER OF OBSERVATIONS =   61

  CORRELOGRAM - FIRST DIFFERENCES OF AVLI
  LAG    ACF        STD.ERROR        PACF       STD.ERROR
    1 -0.27122      0.12910       -0.27122      0.12910
    2 -0.47918E-01  0.13827       -0.13113      0.12910
    3  0.99122E-01  0.13855        0.53660E-01  0.12910
    4 -0.13111      0.13972       -0.10171      0.12910
    5 -0.19378      0.14176       -0.27415      0.12910
    6 -0.74439E-01  0.14611       -0.28227      0.12910
    7  0.18276      0.14674        0.59168E-01  0.12910

  VARIABLE : AVERAGE LISTA 1943-2003
  DICKEY-FULLER TESTS - NO.LAGS =   6   NO.OBS =   54

      NULL               TEST      ASY. CRITICAL
   HYPOTHESIS          STATISTIC     VALUE  5%
 ---------------------------------------------------------------------------
   CONSTANT, NO TREND
  A(1)=0  T-TEST       -1.4120     -2.86
  A(0)=A(1)=0          0.99808      4.59
                                              AIC =    -1.562
                                               SC =    -1.267
          ESTIMATE      STD.ERROR   T-RATIO
  LAG  1  -0.20518     0.17729      -1.1573
  LAG  2   0.20468E-01 0.16398      0.12481
  LAG  3   0.51963E-01 0.15529      0.33462
  LAG  4  -0.99124E-01 0.15363     -0.64520
  LAG  5  -0.24830     0.14892      -1.6673
  LAG  6  -0.20911     0.13514      -1.5474
 ---------------------------------------------------------------------------
  CONSTANT, TREND
  A(1)=0  T-TEST      -0.88547     -3.41
  A(0)=A(1)=A(2)=0      1.3198      4.68
  A(1)=A(2)=0           1.9785      6.25
                                              AIC =    -1.566
                                               SC =    -1.235
          ESTIMATE      STD.ERROR   T-RATIO
  LAG  1  -0.29408     0.18688      -1.5737
  LAG  2  -0.49372E-01 0.16999     -0.29043
  LAG  3  -0.19985E-01 0.16227     -0.12316
  LAG  4  -0.17121     0.16075      -1.0650
  LAG  5  -0.30458     0.15294      -1.9916
  LAG  6  -0.25515     0.13786      -1.8508
 ---------------------------------------------------------------------------

  VARIABLE : AVERAGE LISTA 1943-2003
  PHILLIPS-PERRON TESTS - TRUNCATION LAG =   1

      NULL               TEST      ASY. CRITICAL
   HYPOTHESIS          STATISTIC     VALUE  5%
  ---------------------------------------------------------------------------
  CONSTANT, NO TREND
  A(1)=0  Z-TEST       -18.510     -14.1
  A(1)=0  T-TEST       -3.3040     -2.86
  A(0)=A(1)=0           5.4461      4.59
 ---------------------------------------------------------------------------
  CONSTANT, TREND
  A(1)=0  Z-TEST       -18.224     -21.7
  A(1)=0  T-TEST       -3.2169     -3.41
  A(0)=A(1)=A(2)=0      3.6071      4.68
  A(1)=A(2)=0           5.4104      6.25
 ---------------------------------------------------------------------------
```

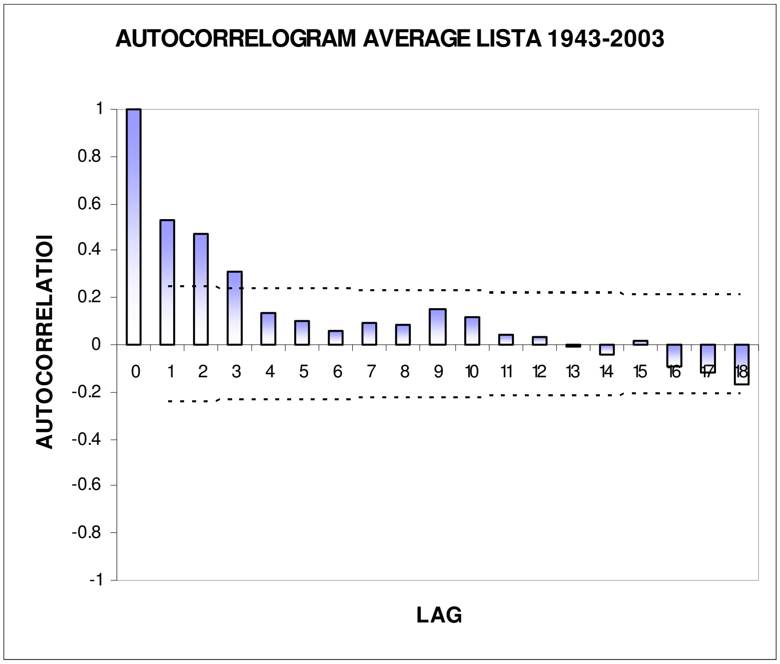

Figure A2: SACF for average sea temperature off Lista

APPENDIX B

SACF AND SPACF FOR AUGUST SEA TEMPERATURE OFF SKROVA 1936–2003

AUTOCORRELATIONS FOR AUGUST TEMPERATURE OFF SKROVA 1936–2003

NET NUMBER OF OBSERVATIONS = 68
MEAN= 10.057 VARIANCE= 1.6363 STANDARD DEV.= 1.2792

LAGS	AUTOCORRELATIONS												STD ERR
1 –12	0.15	0.02	0.24	0.00	–.06	–.07	–.07	–.07	–.03	0.05	–.21	–.03	0.12
13 –24	–.03	–.12	–.21	–.25	–.03	–.18	–.18	0.17	0.07	0.06	0.14	0.15	0.14

MODIFIED BOX–PIERCE (LJUNG–BOX–PIERCE) STATISTICS (CHI–SQUARE)

LAG	Q	DF	P–VALUE	LAG	Q	DF	P–VALUE
1	1.66	1	.197	13	11.61	13	.560
2	1.70	2	.428	14	12.82	14	.540
3	6.09	3	.108	15	16.84	15	.329
4	6.09	4	.193	16	22.50	16	.128
5	6.37	5	.272	17	22.57	17	.164
6	6.74	6	.345	18	25.55	18	.110
7	7.14	7	.414	19	28.65	19	.072
8	7.51	8	.483	20	31.39	20	.050
9	7.59	9	.576	21	31.82	21	.061
10	7.79	10	.649	22	32.24	22	.073
11	11.49	11	.403	23	34.40	23	.060
12	11.54	12	.483	24	36.83	24	.046

LAGS	PARTIAL AUTOCORRELATIONS												STD ERR
1 –12	0.15	0.00	0.25	–.08	–.05	–.12	–.03	–.03	0.03	0.08	–.24	0.04	0.12
13 –20	–.11	0.02	–.25	–.19	0.02	–.16	–.07	0.13					0.12

```
SACF AND SPACF FOR MARCH SEA TEMPERATURE OFF SKROVA 1936-2003

   NET NUMBER OF OBSERVATIONS =   68
 MEAN=    3.0499       VARIANCE=   0.34005       STANDARD DEV.=   0.58314

   LAGS                      AUTOCORRELATIONS                          STD ERR
   1 -12    0.13 0.08 0.07 -.08 0.06 -.19 -.19 -.10 -.09 0.02 0.02 -.06   0.12
  13 -24    0.11 -.09 0.15 0.20 -.03 0.00 -.14 0.09 -.16 -.07 -.09 -.09   0.14

  MODIFIED BOX-PIERCE (LJUNG-BOX-PIERCE) STATISTICS  (CHI-SQUARE)
     LAG     Q    DF  P-VALUE       LAG    Q    DF  P-VALUE
      1    1.21   1  .271          13   11.25  13  .590
      2    1.73   2  .421          14   12.03  14  .604
      3    2.12   3  .548          15   13.98  15  .527
      4    2.57   4  .632          16   17.56  16  .350
      5    2.87   5  .719          17   17.63  17  .413
      6    5.54   6  .476          18   17.63  18  .480
      7    8.33   7  .304          19   19.46  19  .428
      8    9.16   8  .329          20   20.22  20  .444
      9    9.79   9  .368          21   22.78  21  .356
     10    9.83  10  .455          22   23.33  22  .383
     11    9.86  11  .543          23   24.26  23  .389
     12   10.12  12  .606          24   25.11  24  .400


 LAGS                 PARTIAL AUTOCORRELATIONS                         STD ERR
   1 -12    0.13 0.07 0.05 -.10 0.08 -.20 -.15 -.06 -.01 0.03 0.04 -.08   0.12
  13 -20    0.08 -.17 0.16 0.15 -.03 -.10 -.10 0.12                      0.12
```

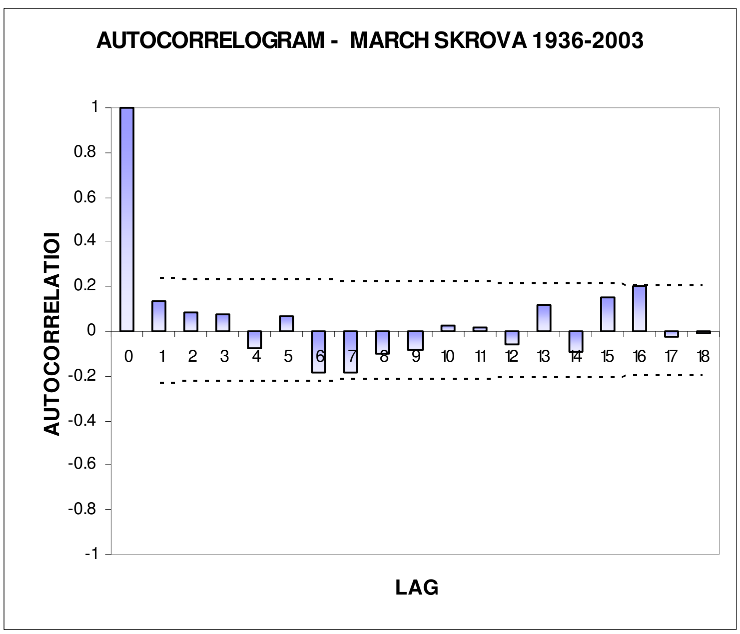

Figure A3: SACF for March sea temperature off Skrova 1936-2003

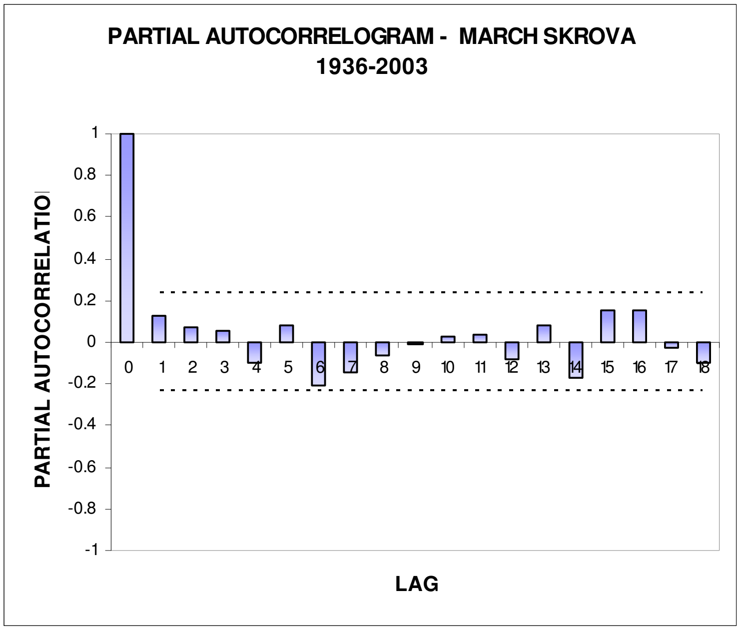

Figure A4: PACF for March sea temperature off Skrova 1936-2003

SACF AND SPACF FOR AUGUST SEA TEMPERATURE OFF LISTA 1943-2003

```
 NET NUMBER OF OBSERVATIONS =   61
 MEAN=    13.174       VARIANCE=    1.5276       STANDARD DEV.=    1.2360

   LAGS                      AUTOCORRELATIONS                          STD ERR
   1 -12    0.33 0.16 0.21 0.28 0.22 0.14 0.07 0.18 0.02 0.05 0.31 0.16   0.13
  13 -24    -.02 -.20 -.11 -.04 -.11 -.15 -.10 -.22 -.10 -.16 -.16 -.14   0.18

  MODIFIED BOX-PIERCE (LJUNG-BOX-PIERCE) STATISTICS  (CHI-SQUARE)
     LAG     Q    DF  P-VALUE       LAG     Q    DF  P-VALUE
      1     7.00   1  .008          13   34.03  13  .001
      2     8.69   2  .013          14   37.39  14  .001
      3    11.73   3  .008          15   38.48  15  .001
      4    16.95   4  .002          16   38.63  16  .001
      5    20.23   5  .001          17   39.66  17  .001
      6    21.59   6  .001          18   41.65  18  .001
      7    21.91   7  .003          19   42.55  19  .001
      8    24.22   8  .002          20   47.05  20  .001
      9    24.24   9  .004          21   47.95  21  .001
     10    24.40  10  .007          22   50.33  22  .001
     11    31.95  11  .001          23   52.90  23  .000
     12    33.98  12  .001          24   54.84  24  .000

   LAGS                  PARTIAL AUTOCORRELATIONS                      STD ERR
   1 -12    0.33 0.06 0.16 0.18 0.08 0.01 -.06 0.11 -.15 0.04 0.32 -.04   0.13
  13 -20    -.12 -.33 -.15 -.09 -.01 0.12 0.02 -.12                       0.13
```

SACF AND SPACF FOR MARCH SEA WATER TEMPERATURE OFF LISTA 1943-2003

```
  NET NUMBER OF OBSERVATIONS =   61
 MEAN=    4.2968       VARIANCE=   0.71084       STANDARD DEV.=   0.84311

   LAGS                      AUTOCORRELATIONS                          STD ERR
   1 -12    0.21 0.07 0.08 0.08 0.01 0.05 0.14 -.05 0.00 0.04 -.18 -.01   0.13
  13 -24    0.00 -.05 0.04 0.12 -.07 -.12 -.06 -.05 -.14 -.12 -.01 -.12   0.14

  MODIFIED BOX-PIERCE (LJUNG-BOX-PIERCE) STATISTICS  (CHI-SQUARE)
     LAG     Q    DF  P-VALUE       LAG     Q    DF  P-VALUE
      1    2.86   1  .091          13    8.44  13  .814
      2    3.22   2  .200          14    8.66  14  .852
      3    3.67   3  .299          15    8.81  15  .887
      4    4.15   4  .386          16   10.11  16  .861
```

```
     5    4.16   5  .527          17   10.51  17  .881
     6    4.31   6  .635          18   11.89  18  .853
     7    5.73   7  .572          19   12.21  19  .876
     8    5.88   8  .661          20   12.42  20  .901
     9    5.88   9  .752          21   14.34  21  .854
    10    5.98  10  .817          22   15.77  22  .827
    11    8.43  11  .675          23   15.77  23  .865
    12    8.44  12  .750          24   17.35  24  .833

   LAGS                PARTIAL AUTOCORRELATIONS                      STD ERR
   1 -12    0.21 0.03 0.06 0.05 -.03 0.04 0.12 -.11 0.02 0.02 -.22 0.09   0.13
  13 -20    -.02 -.07 0.14 0.08 -.15 -.01 -.10 -.03                       0.13
```

SACF AND SPACF FOR ANNUAL AVERAGE SEA WATER TEMPERATURE OFF SKROVA 1936-2003

```
   NET NUMBER OF OBSERVATIONS =   68
 MEAN=    5.8152       VARIANCE=   0.19009       STANDARD DEV.=   0.43599

   LAGS                    AUTOCORRELATIONS                          STD ERR
   1 -12    0.45 0.24 0.11 -.01 -.08 -.11 -.09 0.05 0.08 0.08 0.01 0.04   0.12
  13 -24    0.06 -.05 -.04 -.09 -.11 -.14 -.16 -.09 -.07 0.00 -.01 0.03   0.15

  MODIFIED BOX-PIERCE (LJUNG-BOX-PIERCE) STATISTICS  (CHI-SQUARE)
     LAG    Q    DF  P-VALUE       LAG    Q    DF  P-VALUE
      1   14.57   1  .000          13   23.24  13  .039
      2   18.68   2  .000          14   23.48  14  .053
      3   19.50   3  .000          15   23.62  15  .072
      4   19.52   4  .001          16   24.37  16  .082
      5   19.98   5  .001          17   25.47  17  .085
      6   20.83   6  .002          18   27.23  18  .075
      7   21.53   7  .003          19   29.59  19  .057
      8   21.75   8  .005          20   30.48  20  .062
      9   22.24   9  .008          21   30.91  21  .075
     10   22.76  10  .012          22   30.91  22  .098
     11   22.77  11  .019          23   30.91  23  .125
     12   22.89  12  .029          24   31.00  24  .154

LAGS                    PARTIAL AUTOCORRELATIONS                     STD ERR
   1 -12    0.45 0.04 -.02 -.08 -.06 -.04 -.01 0.15 0.02 0.00 -.08 0.05   0.12
  13 -20    0.06 -.11 0.04 -.09 -.05 -.09 -.05 0.02                       0.12
```

SACF AND SPACF FOR ANNUAL AVERAGE SEA TEMPERATURE OFF LISTA 1943-2003

```
NET NUMBER OF OBSERVATIONS =   61
 MEAN=    8.5053       VARIANCE=   0.36226       STANDARD DEV.=   0.60188

   LAGS                    AUTOCORRELATIONS                          STD ERR
   1 -12    0.66 0.52 0.39 0.19 0.10 0.12 0.18 0.15 0.20 0.18 0.10 0.09   0.13
  13 -24    0.03 -.01 0.05 -.05 -.09 -.15 -.23 -.35 -.36 -.32 -.37 -.28   0.23

  MODIFIED BOX-PIERCE (LJUNG-BOX-PIERCE) STATISTICS  (CHI-SQUARE)
     LAG    Q    DF  P-VALUE       LAG    Q    DF  P-VALUE
      1   27.87   1  .000          13   69.97  13  .000
      2   45.27   2  .000          14   69.98  14  .000
      3   55.32   3  .000          15   70.18  15  .000
      4   57.75   4  .000          16   70.36  16  .000
      5   58.45   5  .000          17   71.10  17  .000
      6   59.44   6  .000          18   73.07  18  .000
      7   61.77   7  .000          19   77.98  19  .000
      8   63.36   8  .000          20   89.41  20  .000
      9   66.25   9  .000          21  102.14  21  .000
     10   68.59  10  .000          22  112.47  22  .000
     11   69.29  11  .000          23  126.03  23  .000
     12   69.88  12  .000          24  134.40  24  .000

   LAGS                PARTIAL AUTOCORRELATIONS                      STD ERR
   1 -12    0.66 0.14 0.00 -.19 -.01 0.17 0.20 -.09 0.03 -.03 -.04 0.05   0.13
  13 -20    -.04 -.04 0.13 -.23 -.09 -.11 -.09 -.18                       0.13
```