THE INFLUENCE OF CLIMATIC CONDITIONS OF THE NORTH ATLANTIC ON RECRUITMENT TO THE ICELANDIC COD STOCK

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Abstract

The economy of Iceland depends heavily on the fishing industry, which provides more than 60% of export earnings and employs 8% of the work force. The economy, therefore, remains sensitive to declining fish stocks.

In the mid-1980s, a complete collapse of the Icelandic cod stock appeared imminent and it has remained at historically low levels since. During the last three decades, the weather conditions off the coast of Iceland have been changing. It is difficult, if not impossible to enumerate all the factors that influence the bio-equilibrium of the North Atlantic waters. Nevertheless, it is known that the climate has some considerable influence in the behavior of cod stocks. In this study, the focus is on trying to assess the relative importance of the external oceanic climate to other factors that have an impact on cod stocks. Weather covariates from the North-Atlantic air pressure field are derived. These seem to give additional information to that provided by the North Atlantic Oscillation Index. A state space model for recruitment to the cod stock, which takes into account these climate related covariates, as well as other factors, is proposed and tested using available data. Results indicate that, although the ocean climate has a significant effect on cod recruitment, it is possible, through adequate management of fisheries, drive cod stocks to more sustainable levels.

1 Introduction

The cod stocks in the North Atlantic have undergone a dramatic decline in recent decades. The Icelandic cod stock is no exception, and over the decades there has been growing concern about the possible depletion of such an important natural resource. The single most important industry in Iceland is fishing which makes this small country, of fewer than 300,000 inhabitants, specially vulnerable to sudden changes in its external environment. Iceland's per capita earnings from fisheries remain by far the highest in the OECD region and in the world. According to the OECD, in 2001, the per capita earnings from fisheries in Iceland was 2970 US Dollars, compared to 282 of Norway, 85 of Japan, 73 of Korea, 58 of Australia, 38 of Canada, 16 of the EU, 13 of the USA, and 10 of Mexico. However, due to declining fish stocks, the participation of fisheries in the economy of Iceland has been diminishing. Since 1980, the share of fisheries income in GDP has declined from 17 to 10 per cent, its shares in total exports is declining, and its share in labour force has decreased from 14 to 8 per cent.

It is accepted that overfishing may have been the cause of the declining fish stocks. In the early years, before 1976, fishing practices often led to exceeding, by far, recommendations on total catch. In 1976, marine scientists warned that fishing mortality in the cod fisheries was excessively high, that the spawning stock was threatened, and that prevailing levels of catch could not be sustained. This led the Icelandic government to adopt a series of fisheries management strategies. A total allowable catch (TAC) was advised but the catch for that year clearly exceeded the TAC. Effort restrictions were then imposed: trawlers were allowed to fish for 323 days a year, and later only 215 days. By 1983 the spawning stock of cod was estimated at an all-time low, just over 200,000 tonnes, fishing mortality was high and catch was 100,000 tonnes in excess of recommendations. In 1984 TACs and individual vessel quotas were imposed for cod and other fish species, with great disagreement about the necessity and fairness of such system. Until 1990, catch was still far beyond recommended levels and in excess of TACs, which were set beyond scientific advice. In 1990, the Fisheries management Act was established, which regulates fisheries activities, following closely scientific recommendations, and making provision for the strict compliance of the act by fishermen.

During these same decades, the weather conditions off the coast of Iceland have also been changing. It is difficult to determine which of the factors, mismanaged fisheries or medium-term changes in the ocean climate, has had the stronger influence in the decline of the cod stock.

The weather variables considered in this study will be derived from sea-level air pressure measurements. Sea-level air pressure dominates the superficial climatic conditions of the North Atlantic in the summer, which will have a crucial influence mainly in the early stages of the life of cod. Hence, we will analise data on recruitment to the cod stocks and the relationship in its variation to weather related variables.

In order to understand the potential influence of the weather on the amount of newly recruited fish to the Icelandic cod stock, it is important to note a few facts about the reproduction and initial life cycle of the species.

Background on Icelandic cod initial life-cycle

According to Jensen (1972) and Malmberg et al (1994), Icelandic cod spawn at an age of around seven years. Spawning takes place in the warm waters along the south and southwest coast of Iceland during the spring. These waters are warmed in the spring by an influx of water from the low to middle latitudes of the Atlantic via the Irminger current. The fish spawn deep in the water, however, the eggs gradually rise and float on the surface and are thus susceptible to any dramatic changes in either the weather or currents. The eggs and resultant larvae float with the Irminger current and most end up on the North, Northwest and Northeast Icelandic shelf. Some eggs and larvae do however get carried west toward Greenland as the Irminger current splits just south of Iceland and travels eastward as well as clockwise around the island. A diagram of seasonal averages of the Irminger current, corresponding to April-May-June and July-August-September, appears in Figure 1.

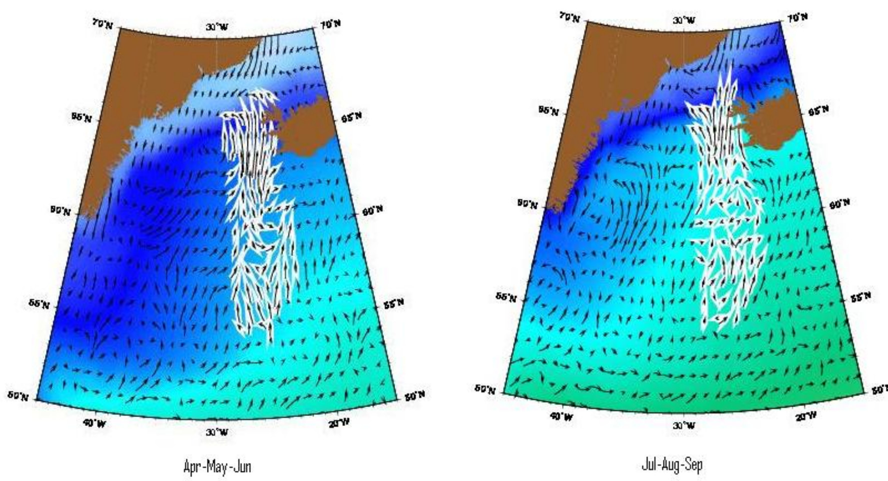

Figure 1: The Irminger current is the northward flowing component of the N. Atlantic subpolar gyre. It transports relatively warm water that mixes with colder water transported by the E. Greeland current from the Arctic Ocean.

This time during which the eggs and larvae float on the surface is crucial to the number of fish who will develop into adults. Due to the fact that most of the cod will spawn in mid spring, with a few being either a little early or a little late, the majority of the eggs and larvae are at their most vulnerable from early June through late July. The eggs can be destroyed by either dramatic temperature changes or wind which agitates the water. The larvae are heavily dependent upon availability of plankton and capelin at the surface which is also influenced by the weather.

By August most of the cod have hatched and are in the nursery area on the northern coast of Iceland. Here the water is still warmed by the Irminger current, however, a second current, the East Icelandic current brings cold water from the north. It has been suggested that the influence of this colder current has been increasing over the past three decades with a seemingly negative effect on the cod stock. Schopka (1994) suggests that the colder water is associated with lower levels of plankton and capelin, the major sources of food for Icelandic cod. It is also noted that the lower levels of salinity that generally accompany colder water temperatures may also have a negative impact on cod. The larvae continue to float on the surface until about two months after hatching, at which time they become fry and make a journey down into deeper water. Cod are generally found at depths of 120 to 900 feet, and water temperatures between 32 and 52 degrees Fahrenheit, see Jensen (1972). Once the fish go deeper, they must adjust to surviving on different sources of food, but the weather has a lesser effect on their survival.

The rest of the work is organised as follows. In Section 2 data on Recruitment is described, in Section 3 a stochastic model for Recruitment, involving weather covariates is proposed, In Section 4 a summer weather index is derived, and in Section 5 results of model estimation and model selection are shown. Section 6 carries conclusions of the study.

2 Recruitment to the Icelandic cod stock

The yearly figures referred to as recruitment to the stock are assessments of the year-class strength at the age of three years. The values are lagged such that they are entered in the years when the year classes were spawned. For example, the estimated recruitment for the year 1955 represents the number of cod hatched in 1955 that survived to an age of three years. The data was extracted from the web pages of the Marine Research Institute of Iceland (http://www.hafro.is). These data are retrospectively updated every year.

A time series plot of the current assessment of recruitment to the cod stock is shown in Figure 2. The time span is from 1955 to 2003.

Upon inspection of Figure 2, it appears that Recruitment undergoes some drastic changes over time. It appears that from 1955 until 1970 Recruitment stayed relatively constant, with the exception of some random fluctuations. From 1970 to 1973 there seems to have been an unusually large jump in the stock. It has been mentioned in the literature (see, Schopka, 1994) that those were unusually warm years in the ocean near Iceland, and that this may partly explain the high value of Recruitment. After 1973, the Recruitment goes into a gradual decline with the exception of some high values from 1983 to 1984, which may be partly explained by a short warming trend in these waters beginning around 1983. In particular, there seems to have been a large drop in 1986 that is thus far unexplained. Although the weather certainly has some impact on the cod stocks, there are many other processes that influence cod stocks, e.g. salinity, water temperature, human intervention, etc.

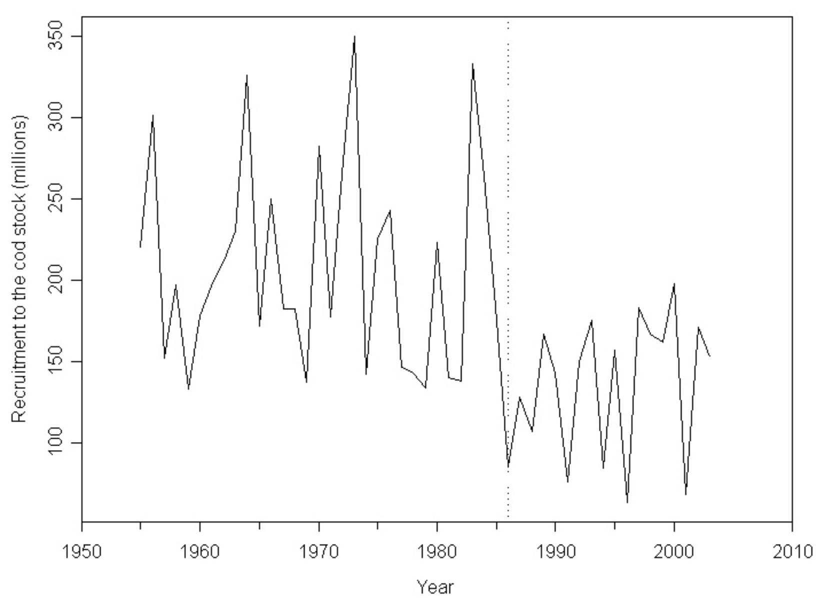

Figure 2: Recruitment to the Icelandic cod stocks, 1955-2003. Source: Marine Research Institute of Iceland.

3 A stochastic model for recruitment to the cod stocks off Iceland

Although a stochastic model is a mere approximation and simplification of a complex real life process, it should try to mimic the real life process in question in a simple but thorough way.

Taking into account the considerations made in the Introduction, our stochastic model relating Recruitment with climate related variables as predictors should also take into account the unobserved underlying processes that influence Recruitment. To ignore these factors in a stochastic model would be a gross error and would lead to wrong conclusions or results not quite interpretable. On the other hand, it is important to be able to assess the relative impact of the weather to the impact of the numerous underlying unobserved processes influencing Recruitment levels.

A general model for Recruitment is the following

$$\begin{aligned} R_t &= \mu_t + WI_t + \epsilon_t \\ \mu_{t+1} &= \rho\,\mu_t + u_t, \end{aligned} \tag{1}$$

where R_t, μ_t, WI_t denote the level of Recruitment to the cod stock at year t, the level of the unobserved process influencing Recruitment at year t, and the value of a summer weather index, yet to be constructed, at year t, respectively. The terms ϵ_t and u_t are random variables both with mean zero and variance σ^2 and τ^2 respectively. They denote noise or disturbances at time t. The parameter ρ is such that $|\rho| \leq 1$.

What equations (1) mean is that we think of Recruitment as the sum of two processes, one of them deterministic (the summer weather index, WI) and the other one stochastic (the unobserved process, μ), plus white noise. The unobserved process is thought of as an autoregressive process (if $|\rho| < 1$) or could also be a random walk process (ρ=1).

This kind of model is a special type of a state-space model, usually referred to in the literature as a structural time series model with predictor variables. See Harvey, 1989.

Inference using the proposed model can be carried out using algorithms based on the Kalman filter and Smoothing filter techniques. See e.g. Harvey (1989) and de Jong (1991).

Next the development of a weather index will be dealt with in order to be able to test Model (1).

4 The North Atlantic climate

Climate conditions in the North-Atlantic are mostly governed by the air pressure distribution over the area.

The data available consists of air pressure measurements at 221 sites over the North Atlantic for the years 1955 through 2004. A diagram of the locations of the 221 points is provided in Figure 3, which is a 5-degree-distance-of-latitude/longitude grid, 20N-80N/0W-80W, over the North Atlantic. The source of the data is The Data Support Section of the Scientific Computing Division at the National Center for Atmospheric Research in Boulder, Colorado, NCAR. See http://dss.ucar.edu/datasets/ds010.1/

To try to investigate the relationship between cod recruitment and 50 years of average air pressure values at each of 221 points presents quite a unmanageable task. As such, some sort of data reduction technique is desired. It is desired to describe the air pressure

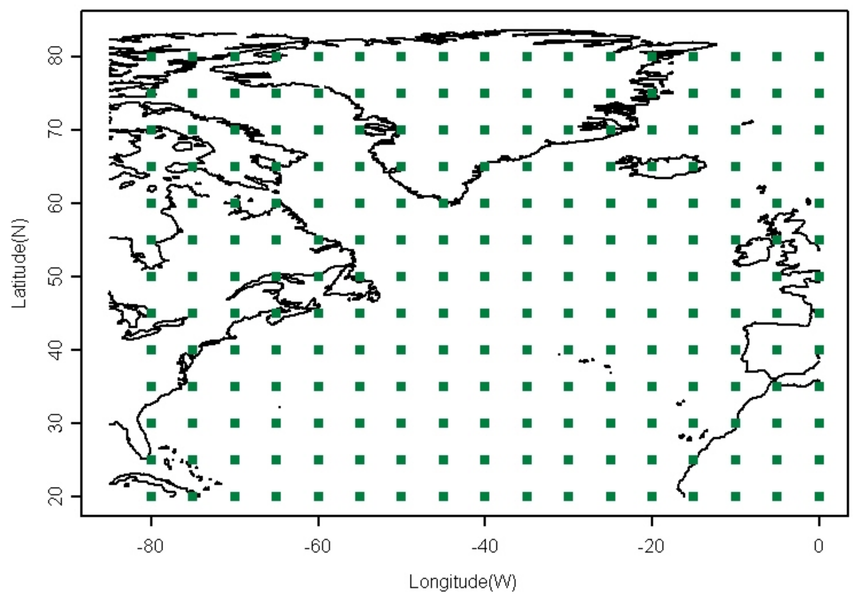

Figure 3: Grid over which air pressure measurements were taken.

field in terms of a few quantities that capture the main features of the weather over this section of ocean. A simple investigation into the climatology of this region reveals that the air pressure over the North Atlantic has consistent seasonal patterns.

Geophysical features

According to Van Loon (1984) and Isemer et al (1985), the air pressure field over the North Atlantic during late spring and early summer is dominated by two features. In most years, there is a cyclonic low pressure zone that develops by July that is generally situated at a latitude of about 65 degrees North. Low pressure zones are associated with cold, stormy weather and winds that circulate in a counter clockwise direction. The second dominating feature is a subtropical high pressure anticyclonic zone, sometimes referred to as the Azores high. This feature is present in all years recorded thus far. High pressure zones are associated with warm, calm weather and winds that circulate in a clockwise direction. See either Lehr et al (1965) or Lutgens et al (1989) for a more thorough explanation of cyclonic low pressure zones and anticyclonic high pressure zones.

When low pressure zones move close to high pressure zones a front is formed which leads to strong winds and relatively violent storms. These violent storms would certainly cause the water and thus the floating cod eggs to be agitated resulting in many of them dying. A diagram of how the high and low pressure zones interact to create storm fronts is provided in Figure 4. For a more thorough explanation we refer the reader to either Lehr et al (1965) or Lutgens et al (1989).

Although, the relationship is not yet well understood (see Van Loon, 1984), there is

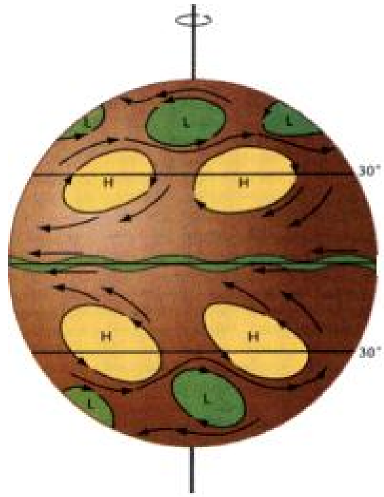

Figure 4: Semi-permanent features of atmospheric circulation. Sub-tropical highs: Descending air at 30^o produces clockwise circulating cells, strongest in summer; e.g., Pacific and Bermuda - Azores High,. Sub-polar lows: at 60^o circulate counterclockwise, and are strongest in winter. e.g., Aleutian Low, Greenland Low. The westerlies: a belt of strong westerly winds at ca. 40^o. Between the sub-tropical highs and sub-polar lows.

evidence that cyclonic low pressure zones are associated with the currents in the oceans beneath them (see Jonsson, 1994 and Dickson et al, 1994). There has also been some suggestion that when the prevailing westerly winds (these winds travel from the west to the east) , which are generated by the anticyclonic Azores high pressure zone, move north that the Irminger current is affected. This means that when the Azores high gets larger and thus its northern edge moves northward the waters carried in the warm Irminger current may have a stronger influence on the water in the spawning grounds and nursery areas near Iceland and Greenland (see Dickson et al, 1994).

Weather covariates

Based on the above information, the data was summarised in the following way.

The air pressure field is a weighted average of the monthly mean air pressure corresponding to the four months, May, June, July and August, with twice the weight on June and July, when the eggs and larvae are at their most vulnerable. This average air pressure field is described in terms of six quantities chosen to reflect as simply as possible the dominating features, as well as certain quantities we believe to have an important influence on the ocean currents and temperatures. The six quantities are:

- the area of the Azores high pressure zone, as defined by the area enclosed by the 1020 hPa isobar, south of 60^o of latitude north;
- the intensity of the high pressure area;
- the centroid of the Azores high pressure zone, defined by the 1020 hPa Isobar;
- the intensity of the low pressure area;

- the centroid of the Icelandic low pressure zone, defined by the 1012 hPa isobar (north of 50^o of latitude north);
- the distance between the centroids of the high and low pressure zones.

These six measures should give us some representation of the size of the warming influence of the Azores high as well as the positions of the two features. It was not possible to determine the area of the 1012 hPa Isobar in all years as the boundary was not always well defined.

The centroids and intensities of the low and high pressure areas

The centroids of the low pressure area for the years 1955 to 2003 were calculated as follows. The coordinates of the centroids of the low and high pressure areas, in longitude and latitude are defined, respectively, as,

$$c_{x,low} = \frac{\sum_A p_i \times long_i}{\sum_A p_i} \quad , c_{y,low} = \frac{\sum_A p_i \times lat_i}{\sum_A p_i} \quad ,$$

and

$$c_{x,high} = \frac{\sum_B p_i \times long_i}{\sum_B p_i} \quad , c_{y,high} = \frac{\sum_B p_i \times lat_i}{\sum_B p_i} \quad .$$

where $A = \{i : lat_i > 40 \ \ and \ \ p_i \leq 1012\}$, $B = \{i : p_i \geq 1020\}$, p_i represents the air pressure at point i, and $long_i$ and lat_i represent the longitude and latitude of point i, respectively. The index, i represents the data point and runs from 1 to 221. Essentially, the centroids are "centers of mass" of low and high pressure.

In Figure 5, the locations of these two centroids, from 1955 until 2004, are shown. It appears that the centroid of the high pressure area remains fairly fixed, while the centroid of the low pressure area shows more movement in time.

Our background knowledge of how low pressure zones and high pressure zones interact suggests that we also consider the relative positions of these two dominant features. For this reason we calculate the distance, in kilometers, between the two centroids.

A time series plot of the distances, in Km, is displayed in Figure 6. It appears that there is a tendency for the centroids to be further apart as time evolves. Note that, when the distance between the centroids is larger, this would imply less intense westerlies and hence more favourable survival conditions for newly born cod.

The intensities of the Azores High and Icelandic low pressure areas and the North Atlantic Oscillation Index

As suggested in the background on the air pressure field, the size of the Azores high pressure zone may have an impact on the warmth of the water in both the spawning and nursery areas of the Icelandic cod. The area of the region enclosed by the 1020 hPa isobar was estimated as a possible representation of the intensity of the Azores high pressure area. A time series plot of the areas is shown in Figure 7. As can be seen, since 1981 the size of the high pressure area has diminished and showed a less regular variation.

The intensities of the Azores high and Icelandic low pressure areas are defined as the corresponding averages of the air pressures used to determine the corresponding centroids. As could be expected, the area of the Azores high pressure area is related to the measure of intensity just described. See Table 1.

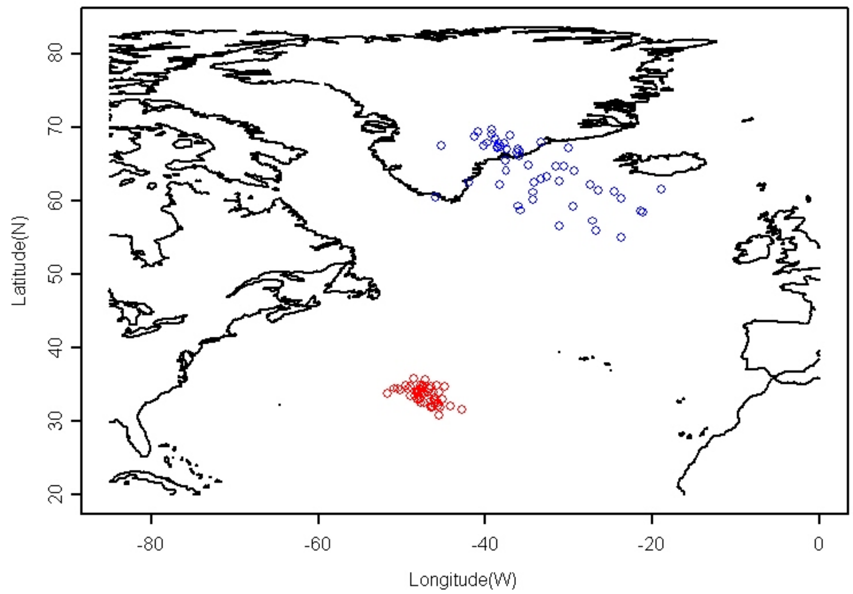

Figure 5: Position of the centroids of the high and low pressure zones, in red and blue, respectively, 1955-2004.

A time plot of these intensities is found in Figure 9 and 8. Looking at Figure 9, it is possible to note that since about 1986, the intensity of the low pressure area has started to show increased variation with a tendency to have very low intensity values, which are associated with negative conditions for the survival of cod larvae.

In all the studies that were made where these two intensity variables were included, the corresponding parameters were of similar magnitude but opposite sign. Hence the difference of the intensities will be considered. This prompts us to consider a well known measure of the difference in intensities namely the North Atlantic Oscillation index, or NAO for short.

Seasonal indices of the NAO are three-month running averages of normalised sea level pressure. They are based on the difference of normalized sea level pressure (SLP) between Ponta Delgada, Azores and Stykkisholmur/Reykjavik, Iceland. The SLP anomalies at each station were normalized by division of each seasonal mean pressure by the long-term mean (1865-1984) standard deviation. Normalization is used to avoid the series being dominated by the greater variability of the northern station. Positive values of the index indicate stronger-than-average westerlies over the middle latitudes. Source: http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html#naostatseas A plot of the average of the May-June-July and June-July-August seasonal indeces is shown in Figure 10. This average will be referred to as the Summer seasonal NAO index.

As expected, the differences in intensities derived here and the Spring-Summer NAO index are related. Note, however, that the Spring-Summer NAO index is based on two measurements of the field, taken at the same geographical location year after year. The difference in intensities is based on a set of measurement taken at locations that vary

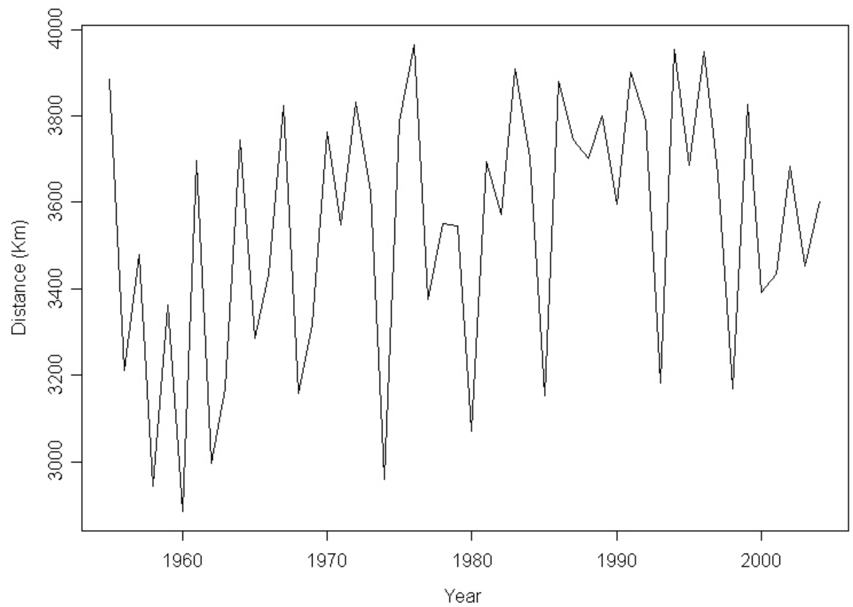

Figure 6: Distance between the centroids of the high and low pressure zones, 1955-2004.

every year. The distance between the centroids, and the difference of intensities, and the NAO as well. See Table 1. As can be seen, it is indeed the intensity of the low pressure area and the distance between the centroids that are correlated. Since the high pressure area seems to have a more or less fixed position, relative to the low pressure area, as the distance between centroids becomes larger, the low pressure area moves north implying lower intensity values. Also, the area of the high pressure area seems to be in direct relation to the intensity of the high pressure area. These are all important considerations to take into account when building a weather index.

	Dist.Centr.	Int.high	Int.low	Surf.high	Diff.Int.
NAO	0.34	0.65	-0.45	0.65	0.76
Dist.Centr.		0.08	-0.52	0.25	0.47
Int.high			0.03	0.74	0.58
Int.low				-0.09	-0.80
Surf.high					0.52

Table 1: Correlations between weather covariates.

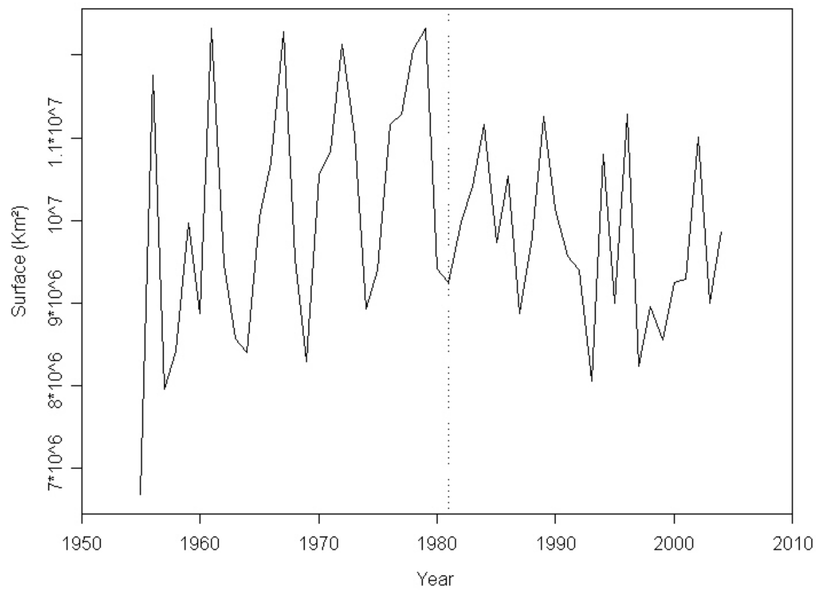

Figure 7: Area enclosed by the 1020 hPa isobar, 1955-2004.

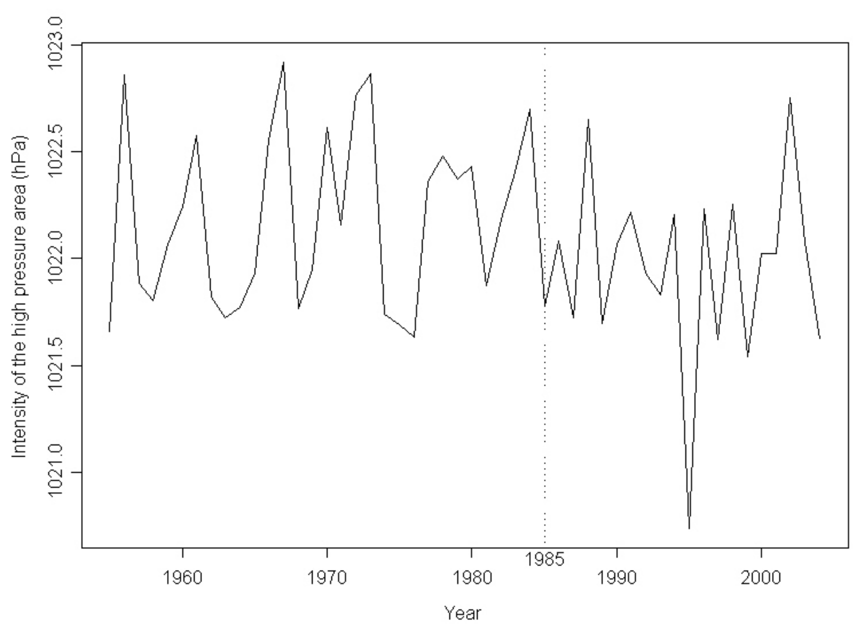

Figure 8: Time plot of the intensities of the high pressure area, 1955-2004.

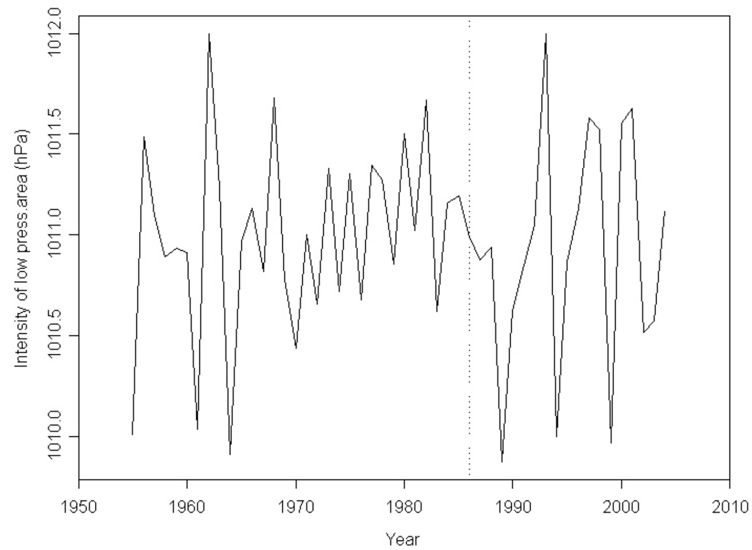

Figure 9: Time plot of the intensities of the low pressure area, 1955-2004.

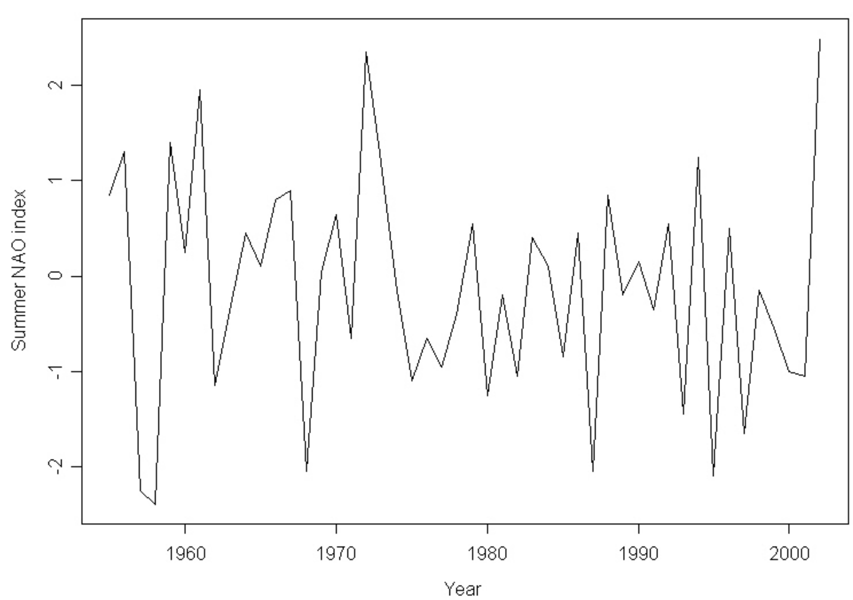

Figure 10: Summer seasonal NAO index, 1955-2004.

A weather index

A weather index, WI, should include features from both, the low and high pressure areas. A weather index is a linear combination of the six quantities described above which summarise the main features of the sea-level air pressure on the North-Atlantic during the summer. However, due to the correlations between the variables shown in Table 1, a weather index cannot include the distances between centroids and the low pressure area intensity, or the distance between centroids and the NAO index. These leaves us with very few combinations.

One possibility is a <u>univariate index</u> consisting of one of:

- the distance between the centroids;
- the summer NAO;
- the difference in intensities;

or a <u>multivariate index</u> consisting of the linear combination of one of:

- the NAO and the distance between the centroids;
- the area of the high pressure zone and the distance between the centroids;
- the intensity of the high pressure zone and the distance between the centroids;
- the intensities of the high and low pressure areas.

5 Estimation of the model parameters

The model fitted is a slight, but important, modification of Model (1), namely

$$\begin{aligned} R_t &= \mu_t + WI_t + \epsilon_t, \\ \mu_t &= \rho\mu_{t-1} + \lambda\delta_{t-1} + u_t, \end{aligned} \tag{2}$$

for $t = 1955, \ldots, 2003$, where $\delta_t = 1$ if and only if $t = 1986$ and $\delta_t = 0$ otherwise. The parameter λ measures the drop in recruitment occurred in 1986, unaccounted for by weather factors. Without the parameter λ the fits to model 2 result inadequate, in that the residual analysis indicates the need for the introduction of such a parameter. This indicates that the weather index alone cannot explain the collapse in recruitment occurred in 1986.

The parameters are estimated via maximum likelihood. To evaluate the joint likelihood of the y's we use the Diffuse Kalman Filter (DKF) and the results and algorithms stated in de Jong (1991).

Note also that it is not possible to find significance of the model if $\tau = 0$, where $\tau^2 = var(u_t)$, and the other parameters are estimated via least squares, even if λ is left in the model.

Model parameters were estimated assuming a univariate weather index and a bivariate weather index. The results of the model estimation are displayed in Tables 2 and 3.

The conclusion that can be drawn from Tables 2 and 3 is that a univariate weather index seems to be more significant than a bivariate index, besides from being more parsimonious, for the data. The bivariate indeces which were possible to be constructed, fail to show significance of one of the terms, except for distance between the high and low pressure area centroids. For this reason, a univariate weather index, which is a constant times the distance between the centroids, should be preferred. Note that a weather index proportional to the difference in intensities (intensity of the high pressure area minus intensity of the low pressure area) provides approximately the same fit. However, the fit using the distances between the centroids seems to be slightly better. Figure 11 shows the standard errors of prediction for the model with the distance between the centroids and the difference in intensities in black and red, respectively. As can be seen the standard errors of prediction of the model with the difference in intensities are consistently larger than the standard errors of prediction for the model with the distance between the centroids.

	X		
Parameter	Dist.centr.	NAO	Diff.intens.
β	0.56	8.81	18.14
(Std.error)	(0.03)	(6.88)	(1.14)
λ	-111.88	-74.69	-100.42
ρ	0.94	1.00	0.94
τ	0.0001	0.0695	0.0001
σ	54.52	55.58	54.42

Table 2: Parameter estimates of Model (2) with a univariate weather index $WI = \beta X$.

X_1	NAO	Area high($\times 3 \times 10^{-4}$)	Int.high($\times 10^{-1}$)	Int.high($\times 10^{-1}$)
X_2	dist.centr($\times 10^{-1}$)	dist.centr($\times 10^{-1}$)	dist.centr($\times 10^{-1}$)	Int.low($\times 10^{-1}$)
β_1	2.89	-0.02	-0.02	95.74
(Std.error)	(6.79)	(0.16)	(0.16)	(109.34)
β_2	0.55	0.58	0.58	-94.77
(Std.error)	(0.04)	(0.15)	(0.15)	(110.54)
λ	-103.09	-112.77	-109.78	-100.70
ρ	0.95	0.94	0.94	0.95
τ	0.00004	0.0001	0.0002	0.0002
σ	54.92	54.51	54.52	55.09

Table 3: Parameter estimates of Model (2) with a bivariate weather index $WI = \beta_1 X_1 + \beta_2 X_2$.

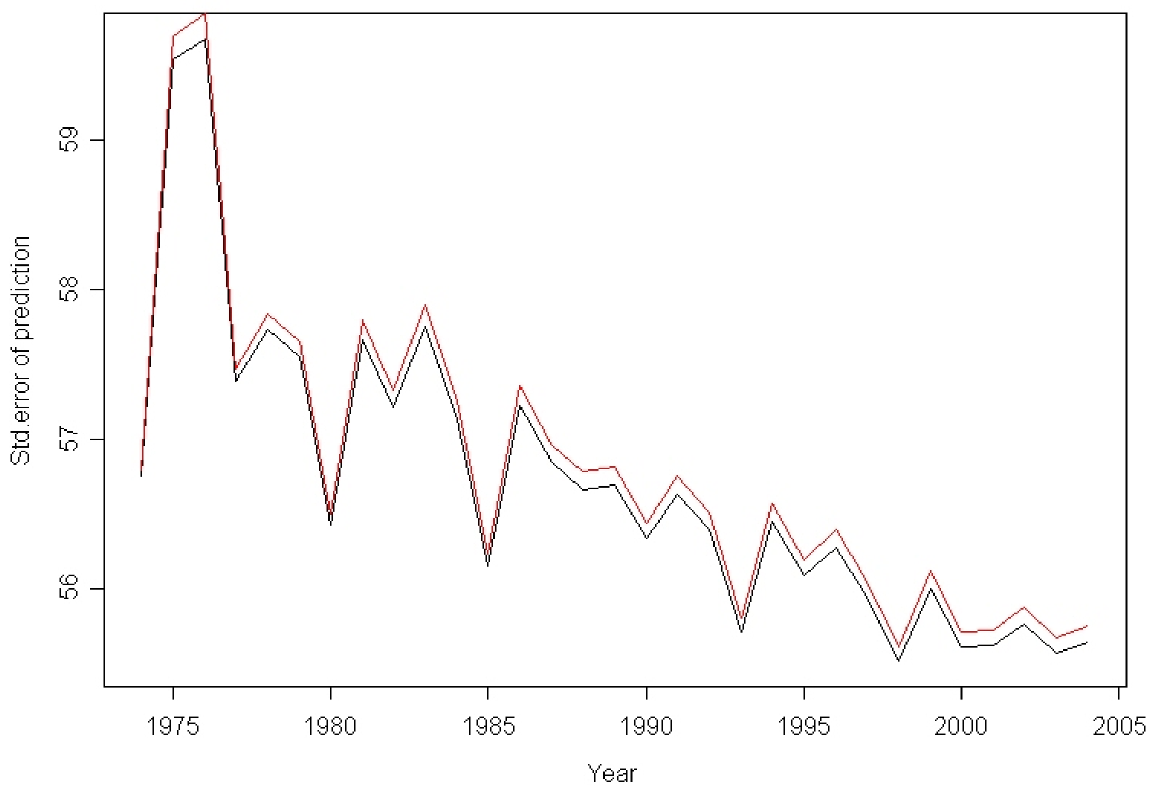

Figure 11: Standard errors of prediction for model 2 with "$WI = \beta$ Dist.centroids" in black and "$WI = \beta$ Diff.intensities" in red.

6 Conclusions

It has been shown that, although Recruitment to the Icelandic cod stocks is a complex process, possibly influenced by an innumerable amount of processes, it is possible, through adequate modeling, to isolate the effect of one of these processes, in this case the summer ocean climate. The process μ, representing the unobserved processes influencing recruitment, can be predicted, and its values are shown in Figure 12. As can be seen, before 1986 it seems to be the weather mainly driving variation in Recruitment, as μ is essentially not significant. After 1986, the unobserved process shows more variation becoming highly significant, indicating a recovery in recruitment levels. Although the weather conditions in the North Atlantic seem to have changed after 1986, in detriment to Recruitment, the predicted values of the unobserved process show that these conditions were offset by μ. I have included in Figure 12 the different Icelandic fisheries management strategies over time, as described in the Introduction. One may infer that the introduction of the Fisheries Management Act has, in any case, worked towards building up a more sustainable cod stock.

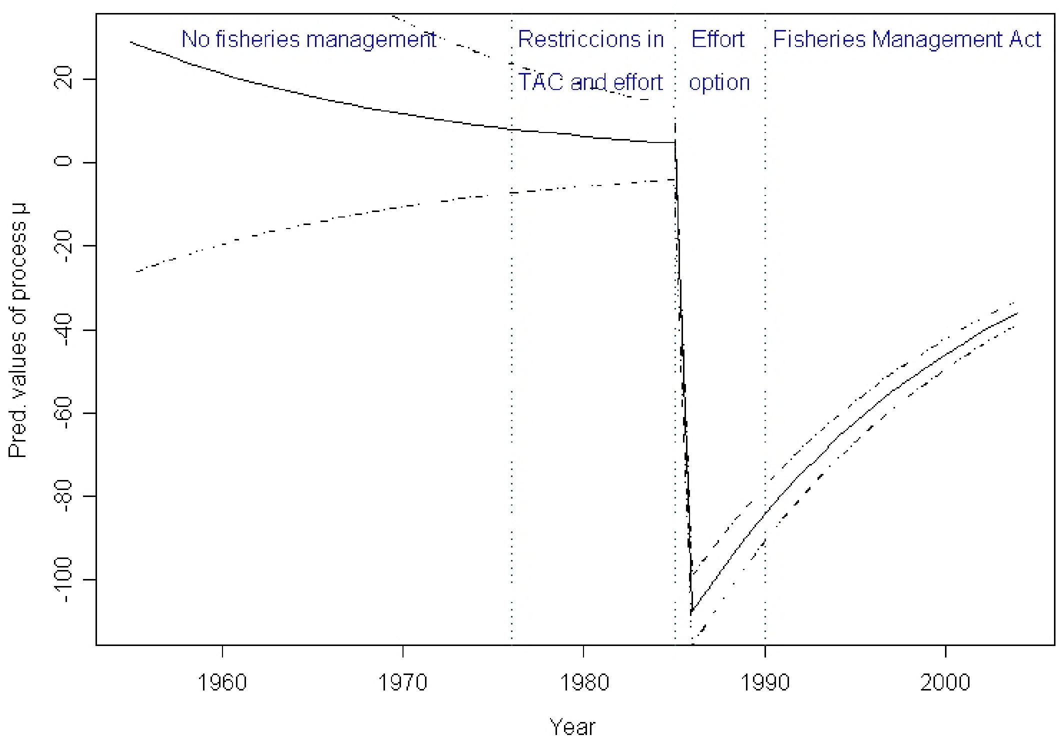

Figure 12: Predicted values of the unobserved process μ (solid line) with approximate 95%confidence bands, and changes in Icelandic fisheries management.

7 Bibliography

COLBOURNE, S., NARAYANAN, S., PRINSENBERG.(1994). “Climatic changes and environmental conditions in the Northwest Atlantic, 1970-1993”, *ICES mar. Science Symposium*, 198, pp 311-322.

DE JONG, P. (1991). “The diffuse Kalman filter”, *The Annals of Statistics*, vol.19, pp. 1073-1083.

DICKSON, R.R., BRANDER, K.M. (1994) “Effects of a changing windfield on cod stocks of the North Atlantic (extended abstract)” *ICES Mar. Science Symposium*, 198, pp 271-279.

HARVEY, A.C. (1989). *Forecasting Structural Time Series Models and The Kalman Filter*. Cambridge University Press.

HARVEY, A.C.(1993). *Time Series Models*, second edition. Harvester Wheatsheaf.

ISEMER, J.H., BUNKER, A.F., HASSE, L. (1985). *The Bunker Climate Atlas of the North Atlantic Ocean* New York: Springer Verlag.

JENSEN, A.C. (1972). *The Cod*. New York: Thomas Y. Crowel Co.

JONSSON, S. (1994). “Cyclonic gyres in the North Atlantic” *ICES mar. Science Symposium*, 198, pp 287-291.

LEHR, P.E., BURNETT, R.W., ZIM, H.S. (1965). *Weather*. New York: Golden Press.

LUTGENS, F.K., TARBUCK, E.J. (1989). *The Atmosphere*. New Jersey: Prentice Hall.

MALMBERG, S., BLINDHEIM, J. (1994). “Climate, cod, and capelin in northern waters” *ICES mar. Science Symposium*, 198, pp. 297-310.

McILVEEN, R. (1992). *Fundamentals of Weather and Climate*. London: Chapman and Hall.

SCHOPKA, S.A. (1994). “Fluctuations in the cod stock off Iceland during the twentieth century in relation to changes in the fisheries and environment” *ICES mar. Science Symposium*, 198, pp. 175-193.

VAN LOON, H. (1984). *World Survey of Climatology, Volume 15, Climates of the Oceans*. Amsterdam: Elsevier.