Future low solar activity periods may cause extremely cold winters in North America, Europe and Russia.

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Summary.
The observed winter temperatures for Turku, Finland (and also generally for North America, Europe and Russia) for the past 60 winters have been strongly dependent on the Arctic Oscillation index (AO). When the Arctic Oscillation index is in "positive phase", high atmospheric pressure persists south of the North Pole, and lower pressures on the North Pole. In the positive phase, very cold winter air does not extend as far south into the middle of North America as it would during the negative phase. The AO positive phase is often called the "Warm" phase in North America. In this report I analyzed the statistical relation between the Quasi-Biennial Oscillation index (QBO is a measure of the direction and strength of the stratospheric wind in the Tropics), the solar activity, and the Arctic Oscillation index and obtained a statistically significant regression equation. According to this equation, during negative (easterly) values of the QBO, low solar activity causes a negative Arctic Oscillation index and cold winters in North America, Europe and Russia, but during positive (westerly) values of the QBO the relation reverses. However, the influence of the combination of an easterly value of the QBO and low solar activity on the AO is stronger and this combination is much more probable than the opposite. Therefore, prolonged low solar activity periods in the future may cause the domination of a strongly negative AO and extremely cold winters in North America, Europe and Russia.

Arctic oscillation index and Turku winter temperature.
Turku is located in the SW corner of Finland where the Arctic Oscillation Index for December-February almost completely controls the winter temperature for these months. See Figures 1 and 2.

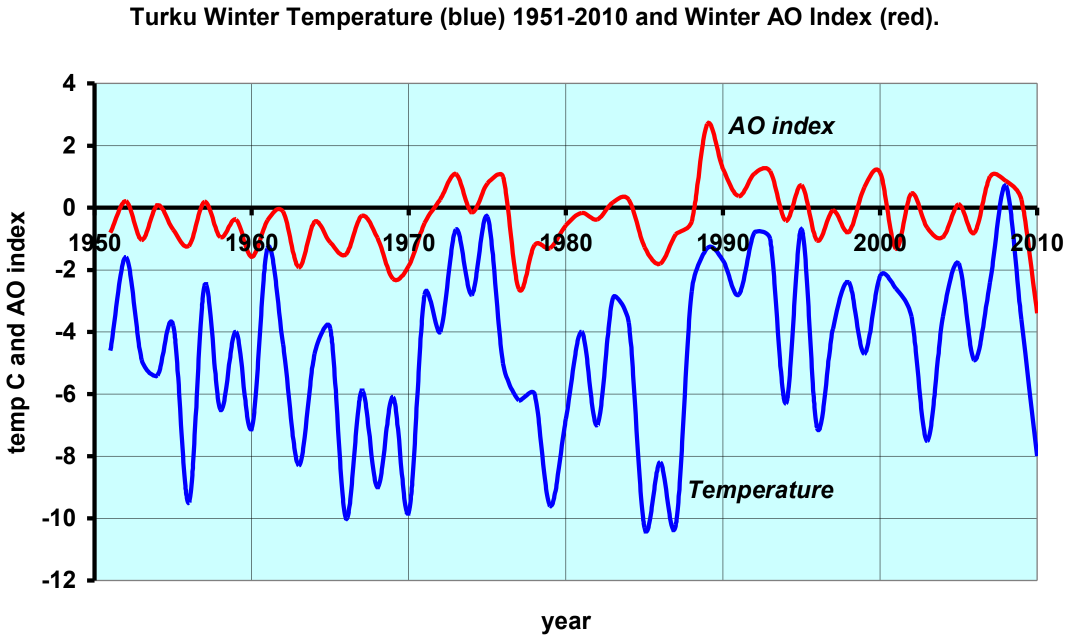

Figure 1. Turku Winter temperature December-February 1951-2010 and corresponding Arctic Oscillation index, data from NOAA (2010).

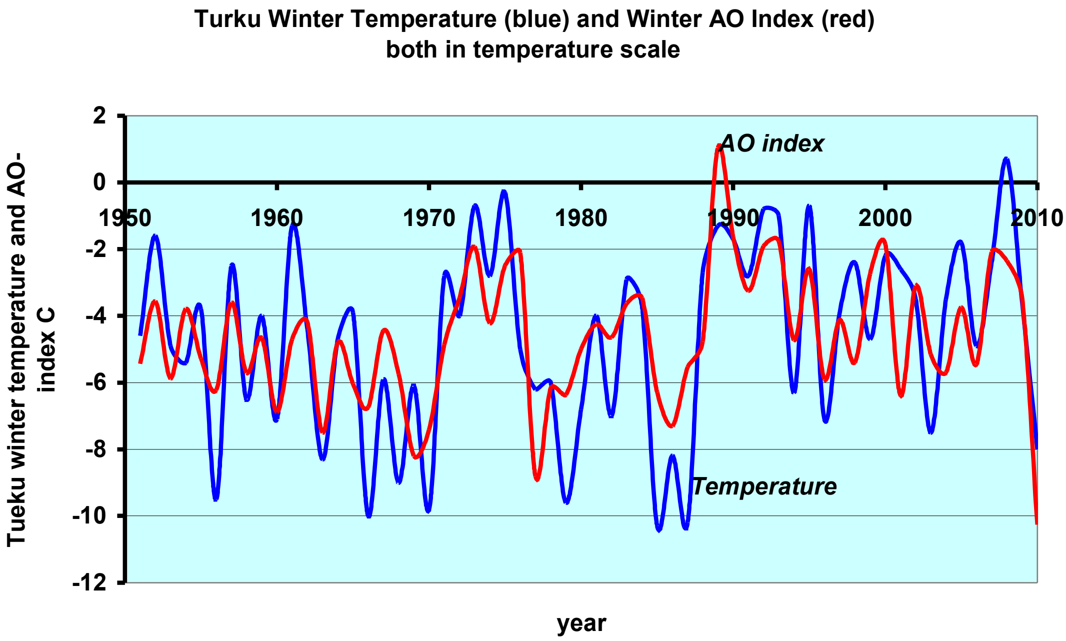

Figure 2. Same as Figure 1., but the Arctic Oscillation index is by means of regression analysis converted to the same scale as the Turku winter temperature.

In January and February 1989 the Arctic Oscillation index jumped up to a very high level causing a warm winter. The index stayed at a higher level, but collapsed back to a record low level in December 2009 - February

2010. This kind of behavior of a time series is very typical for 1-lag and 2-lag random walk mechanisms.

The data for the Arctic Oscillation index (*AO*) December-February 1951-2010 (NOAA 2010) are presented in Appendix 1., and the probability density diagram in Figure 3.

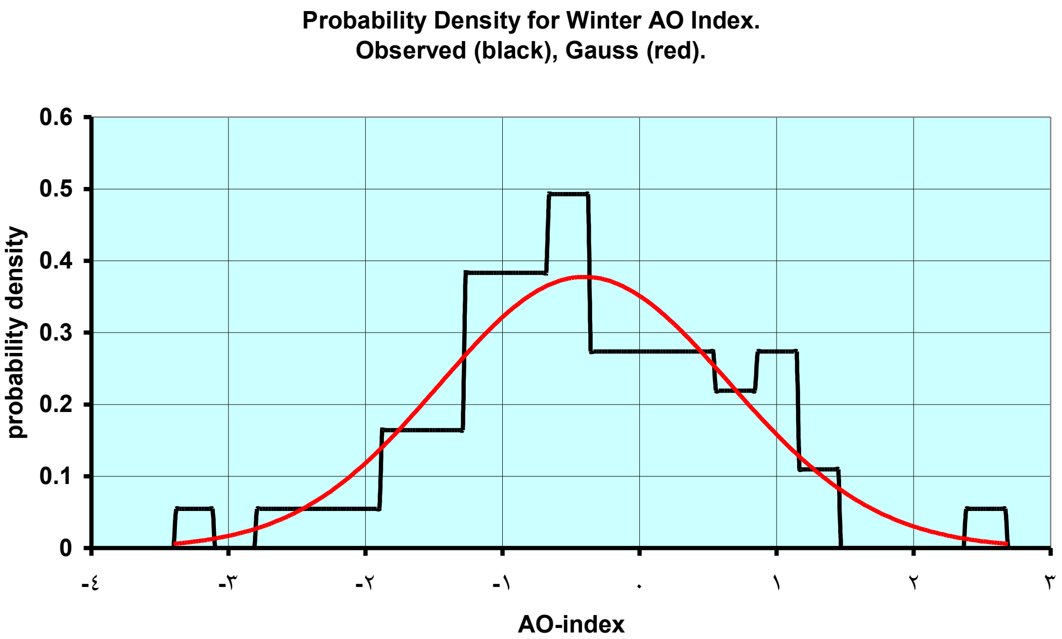

Figure 3. Probability density diagram for the Arctic Oscillation index for December-February 1951-2010.

The Arctic Oscillation index for the winter months 1951-2010 follows a Gaussian distribution with an arithmetic mean value of -0.375.

The random walk behavior of the Arctic Oscillation index points towards a mechanism whereby the index consists of white noise that is driven by two or more harmonic oscillations. Most probable candidates for these oscillations are the Quasi-Biennial Oscillation with a period length of about 28 months, and the solar activity cycle with a period length of about 138 months.

A clear influence of the solar activity and the Quasi-Biennial Oscillation index on the Arctic Oscillation index has been discovered by Labitzke (2005) and will here be verified by means of statistical methods.

Quasi-Biennial Oscillation index.

The Quasi-Biennial Oscillation index is a measure of the strength and direction of tropical stratospheric wind. A negative value corresponds to easterly wind, and a positive value to westerly wind. The data for the Quasi-Biennial oscillation index (*QBO*) December-February 1951-2010 (NOAA 2010) are presented in Appendix 1. and the probability density diagram in Figure 4.

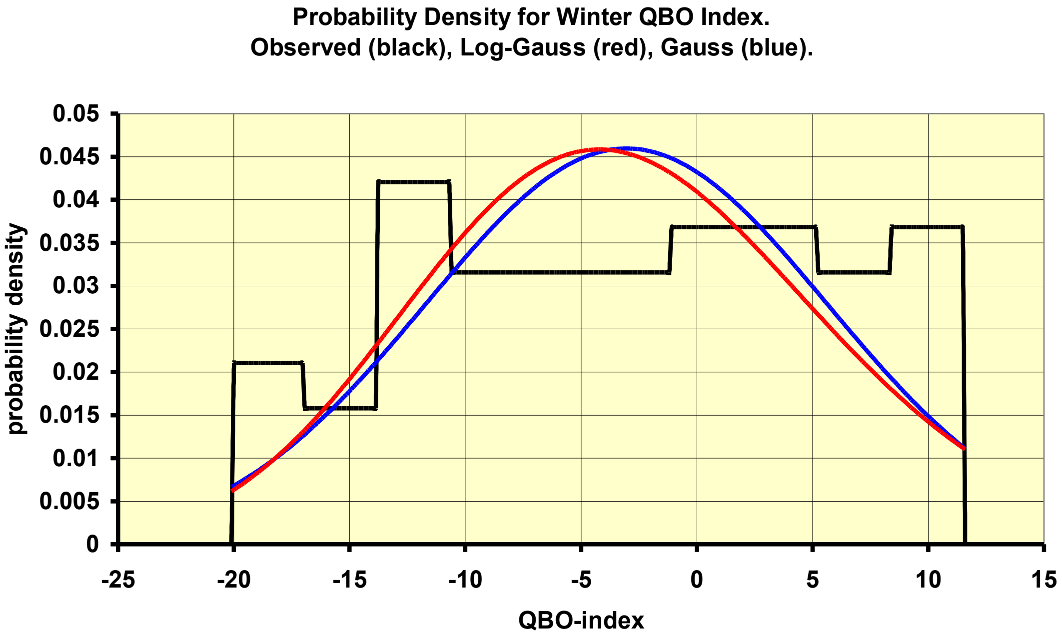

Figure 4. Probability density diagram for the Quasi-Biennial Oscillation index for December-February 1951-2010.

For the winter months 1951-2010 the distribution is almost rectangular with an arithmetic mean value of -2.9. Thus, negative or easterly values of the *QBO* have been predominant during the winter months.

The solar activity.

Labitzke (2005) used the 10.7 cm solar flux as a measure of solar activity. As the correlation coefficient between this measure and the sunspot number is 0.98, we may as well use the sunspot number directly.

The data for sunspot number (*SUN*) December-February 1951-2010 (NOAA 2010) is presented in Appendix 1. and the probability density diagram in Figure 5.

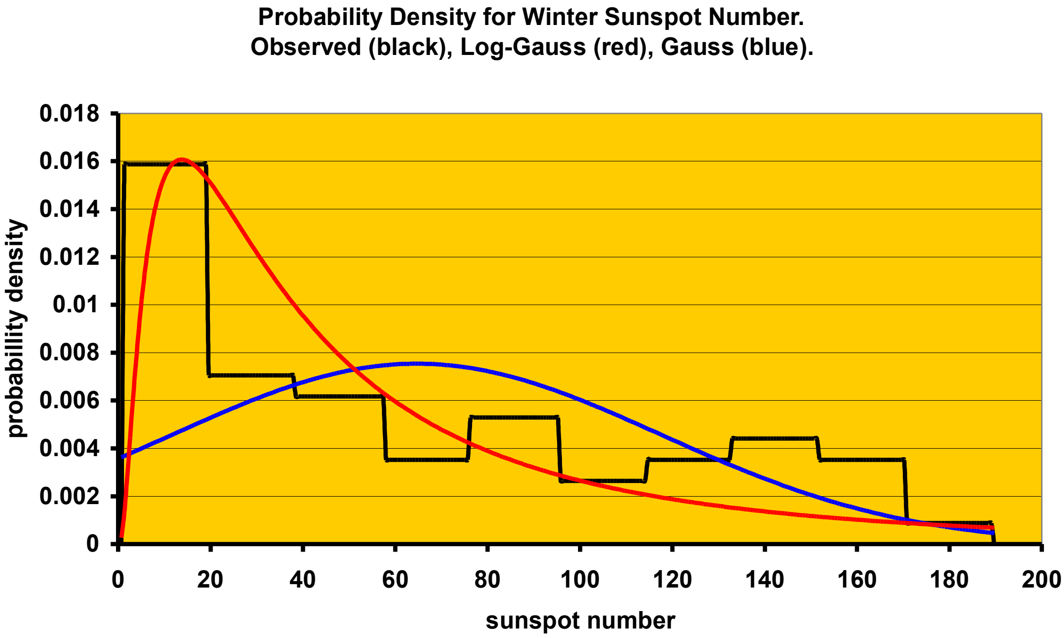

Figure 5. Probability density diagram for the sunspot numbers for December-February 1951-2010.

As the sunspot number can never be negative, a log-Gauss curve fit can describe the observations. We can see that low solar activity has been more common than high solar activity. Taken together with the *QBO*, the combination low *QBO* - low *SUN* has been much more common during the winters than the combination high *QBO* - high *SUN*.

***AO* as a function of *QBO* and *SUN*.**

By means of multiple regression analysis, the following equation was tested:

$$AO = b_0 + b_1*QBO+b_2*SUN+b_3*QBO*SUN+b_4*QBO^2+b_5*SUN^2 \quad (1)$$

where $b_0 - b_5$ are regression coefficients. The result is shown in Appendix 1. b_2 , b_4, and b_5 were eliminated as statistically insignificant.

The final statistically significant regression equation ($p < 0.05$) is:

$$AO = -0.2779 + 0.06096*QBO - 0.0005149*QBO*SUN \quad (2)$$

Graphical presentation of the regression equation.

On order to obtain a picture of the Equation (2), *AO* was plotted as a function of *SUN* for two values of *QBO* in Figure 6. These values were chosen as minimum and maximum values from the rectangular probability density in Figure 4.

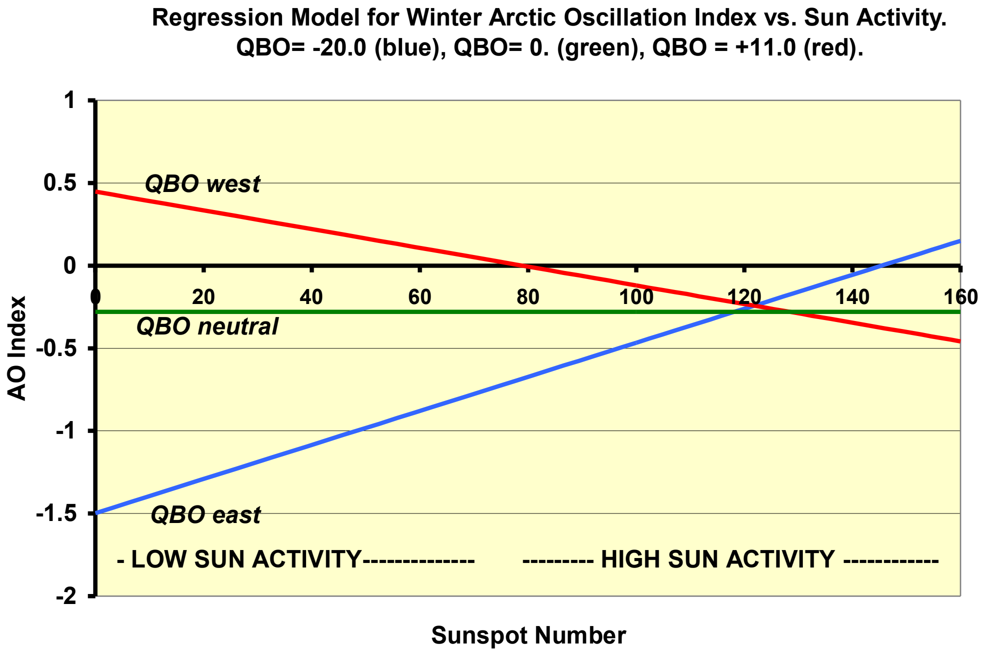

Figure 6. Statistically significant ($p < 0.05$) regression model for the Arctic Oscillation index as a function of Sunspot Number plotted for minimum (east), neutral, and maximum (west) values of the Quasi-Biennial Oscillation index.

It is very obvious that a predominantly low sunspot solar activity at negative (easterly) Quasi-Biennial oscillation index is able to decrease the Arctic Oscillation index much more than the other combinations are able to change the Arctic Oscillation index.

At high solar activity, the Arctic Oscillation index has not been very sensitive to the Quasi-Biennial oscillation.

Turku winter temperature.
The fact that the solar activity and the Quasi-Biennial Oscillation together with stochastic noise control the Arctic Oscillation means that the Turku winter temperature too is dependent on these two oscillating parameters.

Equation (2) together with the connection obtained from Figure 2. give the result shown in Figure 7. Despite considerably high variations between different winters, the combination low *QBO*-low *SUN* is more likely to correspond to colder winter temperatures in Turku than all other combinations.

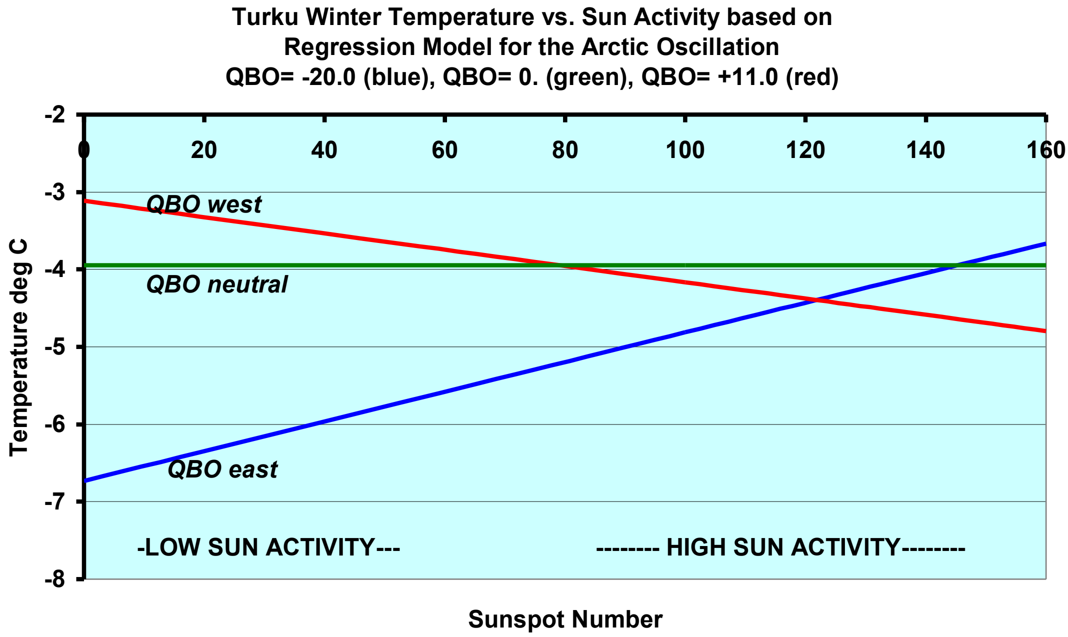

Figure 7. Turku winter temperature as a function of solar activity and Quasi-Biennial oscillation.

Conclusion.

Historically, low solar activity has been connected to cold winters in Europe. A definitive physical mechanism for this fact has not yet been presented. This analysis however shows that the influence of solar activity together with stratospheric mechanisms acting on the Arctic Oscillation is statistically significant. It also explains why the Arctic Oscillation seems to behave according to a random walk mechanism. If the solar activity in the future goes into a new Dalton or Maunder Minimum, the winters in North America, Europe and Russia may become very cold.

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Labitzke, K., 2005: On The Solar Cycle-QBO relationship, a summary. J. Atm. Sol-Terr. Phys., **67**, 45-54

Update on:
http://strat-www.met.fu-berlin.de/labitzke/moreqbo/MZ-Labitzke-et-al-2006.pdf

NOAA, 2010: AO-data on:

http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao.index.b50.current.ascii

NOAA, 2010: QBO-data on:
http://www.esrl.noaa.gov/psd/data/climateindices/

NOAA, 2010: Sunspot data on:
ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/MONTHLY

APPENDIX 1.

Data matrix1951-2010 Dec-Feb QBO-index, SUNspot Number, and AO-index

	QBO	SUN	QBO*SUN	sq(QBO)	sq(SUN)	AO-index (dependent)
1951	-4.8800	59.700	-291.34	23.814	3564.1	-.80400
	-6.1600	34.400	-211.90	37.946	1183.4	.20300
	-2.4200	21.400	-51.788	5.8564	457.96	-1.0370
	-4.7000	.70000	-3.2900	22.090	.49000	.82100E-01
	-8.4600	17.900	-151.43	71.572	320.41	-.71700
	-.14000	80.400	-11.256	.19600E-01	6464.2	-1.2250
	-13.320	132.00	-1758.2	177.42	17424.	.18600
	5.5700	189.70	1056.6	31.025	35986.	-.94600
	-18.750	163.60	-3067.5	351.56	26765.	-.38500
1960	5.4900	126.40	693.94	30.140	15977.	-1.5790
	-5.8200	52.500	-305.55	33.872	2756.3	-.40900
	4.2400	35.000	148.40	17.978	1225.0	-.13100
	-16.390	17.100	-280.27	268.63	292.41	-1.9140
	4.8900	11.400	55.746	23.912	129.96	-.45600
	-1.0800	14.100	-15.228	1.1664	198.81	-1.1250
	-20.100	19.300	-387.93	404.01	372.49	-1.5020
	11.590	83.800	971.24	134.33	7022.4	-.26600
	-8.6200	46.600	-401.69	74.304	2171.6	-.97000
	-8.1200	106.40	-863.97	65.934	11321.	-2.2880
1970	1.3000	117.50	152.75	1.6900	13806.	-1.8670
	-10.580	86.300	-913.05	111.94	7447.7	-.49500
	8.4200	76.700	645.81	70.896	5882.9	.26500
	-7.0300	40.500	-284.71	49.421	1640.3	1.0850
	.30000E-01	24.400	.73200	.90000E-03	595.36	-.14600
	-18.220	15.500	-282.41	331.97	240.25	.78200
	9.8900	6.2000	61.318	97.812	38.440	.99300
	-13.640	18.000	-245.52	186.05	324.00	-2.6170
	3.9300	60.800	238.94	15.445	3696.6	-1.2000
	2.5100	140.70	353.16	6.3001	19797.	-1.3030
1980	-10.920	145.10	-1584.5	119.25	21054.	-.56800
	8.3200	142.00	1181.4	69.222	20164.	-.16800
	-13.180	138.80	-1829.4	173.71	19265.	-.37500

	10.870	86.000	934.82	118.16	7396.0	.17300
	-11.140	56.100	-624.95	124.10	3147.2	.26300
	-1.4400	15.900	-22.896	2.0736	252.81	-1.2670
	9.4700	12.100	114.59	89.681	146.41	-1.8060
	-10.600	5.8000	-61.480	112.36	33.640	-.85400
	7.4600	40.900	305.11	55.652	1672.8	-.44700
	-2.9500	167.40	-493.83	8.7025	28023.	2.6880
1990	-9.6700	157.90	-1526.9	93.509	24932.	1.2530
	9.2500	152.80	1413.4	85.563	23348.	.37500
	-13.660	147.70	-2017.6	186.60	21815.	1.0950
	9.5400	78.900	752.71	91.012	6225.2	1.1790
	-7.8300	50.700	-396.98	61.309	2570.5	-.41800
	7.4400	26.900	200.14	55.354	723.61	.72300
	-5.7500	8.9000	-51.175	33.063	79.210	-1.0550
	-3.8300	8.5000	-32.555	14.669	72.250	-.96000E-01
	-1.0100	34.900	-35.249	1.0201	1218.0	-.77800
	1.6600	71.000	117.86	2.7556	5041.0	.64900
2000	5.1600	98.000	505.68	26.626	9604.0	1.1300
	-15.260	97.100	-1481.8	232.87	9428.4	-1.3120
	4.7100	128.50	605.23	22.184	16512.	.45400
	-1.1000	74.800	-82.280	1.2100	5595.0	-.64500
	-1.2000	45.700	-54.840	1.4400	2088.5	-.94300
	.31000	25.930	8.0383	.96100E-01	672.36	.10500
	-18.370	22.800	-418.84	337.46	519.84	-.81000
	3.7500	14.600	54.750	14.063	213.16	1.0030
	-12.200	4.8000	-58.560	148.84	23.040	.85900
	11.170	.80000	8.9360	124.77	.64000	.25800
2010	-15.000	4.5000	-67.500	225.00	20.250	-3.4220

Mean of Var.(1) = -2.9428 stdev. = 8.98
Mean of Var.(2) = 64.414 stdev. = 53.7
Mean of Var.(3) = -163.12 stdev. = 798.
Mean of Var.(4) = 87.990 stdev. = 98.1
Mean of Var.(5) = 6982.6 stdev. = .908E+04
Mean of Var.(6) = -.37535 stdev. = 1.08

Backward Elimination Multiple Regression Analysis:
Number 4 is insignificant and eliminated (square of QBO insignificant)
Number 2 is insignificant and eliminated (linear SUN insignificant)
Number 5 is insignificant and eliminated (square of SUN insignificant)

Statistically significant regression coefficients at 0.05 significance level:

b 0 ...	-.27994110			Intercept
b 1 ...	.60961730E-01	stdev. ...	.220E-01	Linear coefficient for QBO
b 3 ...	-.51492850E-03	stdev. ...	.247E-03	Coefficient for QBO*SUN

F(1) = ... 7.68
F(3) = ... 4.33