A Data–Adaptive Filter of the Tahiti–Darwin Southern Oscillation Index and the Associate Scheme of Filling Data Gaps

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ABSTRACT

The Tahiti–Darwin Southern Oscillation index provided by Climate Analysis Center of USA has been used in numerous studies. But, it has some deficiency. It contains noise mainly due to high month–to–month variability. In order to reduce the level of noise in the SO index, this paper introduces a fully data–adaptive filter based on singular spectrum analysis. Another interesting aspect of the filter is that it can be used to fill data gaps of the SO index by an iterative process. Eventually, a noiseless long–period data series without any gaps is obtained.

Key words: Southern Oscillation index, Data–adaptive filter, Scheme of filling data gaps, Iterative process

I. INTRODUCTION

As a dominant pattern of short–term climatic fluctuations with a characteristic period of 2–7 years, the Southern Oscillation (SO) and the related El Nino phenomenon are the main causes of climate anomalies in many regions (Chen, 1982; McBride and Nicholls, 1983). Therefore, the SO is of great importance to climate studies, and is paid so much attention by meteorologists and oceanographers. For many purposes, some indices which can indicate the long–period state of the SO are required.

Many indices have been formed from surface pressure, rainfall, and sea surface temperature at different places (e.g., Troup, 1965; Trenberth, 1976, 1984; Wright, 1975, 1989). The most commonly used indices are those based on Tahiti and Darwin pressures. Unfortunately, these indices contain high noise as a result of small–scale and transient meteorological phenomena not related to the SO. In addition, because of some missing values before 1933, the indices also have several gaps (Ropelewski and Jones, 1987).

In order to cull noise in these SO indices, we design a fully data–adaptive filter based on singular spectrum analysis (SSA). SSA is a statistical technique related to empirical orthogonal function (EOF) analysis, but applied in temporal domain rather than in spatial domain. It is widely used to detect and analyze signals in noisy systems (Broomhead and King, 1986; Fraedrich, 1986). SSA also can serve as a basis of designing a fully data–adaptive filter which is used to cull noise from the original time series and to retain significant signal (Ghil and Vantard, 1991). On the other hand, missing values of time series may be estimated by various schemes, e.g., of cubic splint interpolation and Gandin's optimum interpolation (Gandin, 1965; Yang, 1974). This paper is to introduce a new scheme for filling gaps in the SO indices, which is based on the fully data–adaptive filter in a sequence of iteration steps.

In practice, the Tahiti–Darwin index has been computed in several different ways. These various forms yield almost the same qualitative description of the state of the SO. Throughout this paper the Climate Analysis Center's operational monthly index is used to test the feasibility of the fully data–adaptive filter and the filling scheme, and to provide a noiseless Tahiti–Darwin SO index without any gaps.

In Section II, a fully data–adaptive filter based on SSA is introduced. A new iterative filling scheme associated with the filter is also presented in this section. Filtering of the post–1933 CAC's SO index is illustratively given in Section III. A lot of numerical experiments are presented in Section IV for the test of the feasibility of the filling scheme. Then, we compile a filtered and complete SO index over 1882–1992, and identify extreme low and high index years according to this index in Section V. Finally, conclusions are presented in Section VI.

II. FILTER AND FILLING SCHEME

Given a discretely–sampled time series x_i of length $1<i<N_T$, we construct an augmented matrix $\underset{\sim}{f}_{N\times M}$

$$\underset{\sim}{f}_{N\times M}=\begin{bmatrix} f_{1,1} & f_{1,2} & \cdots & f_{1,M-1} & f_{1,M} \\ f_{2,1} & f_{2,2} & \cdots & f_{2,M-1} & f_{2,M} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ f_{N,1} & f_{N,2} & \cdots & f_{N,M-1} & f_{N,M} \end{bmatrix}=\begin{bmatrix} x_1 & x_2 & \cdots & x_{M-1} & x_M \\ x_2 & x_3 & \cdots & x_M & x_{M+1} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_N & x_{N+1} & \cdots & x_{N_T-1} & x_{N_T} \end{bmatrix}, \quad (1)$$

where M is the dimension of embedding space, and $N=N_T-M+1$. By virtue of (1), we have

$$x_i=\begin{cases} \dfrac{1}{i}\sum\limits_{j=1}^{i} f_{i-j+1,j} & 1\leqslant i\leqslant M-1 \\ \dfrac{1}{M}\sum\limits_{j=1}^{M} f_{i-j+1,j} & M\leqslant i\leqslant N \\ \dfrac{1}{N_T-i+1}\sum\limits_{j=i+M-N_T}^{M} f_{i-j+1,j} & N+1\leqslant i\leqslant N_T. \end{cases} \quad (2)$$

From the covariance matrix $\underset{\sim}{c}_{M\times M}$ of $\underset{\sim}{f}_{N\times M}$ we calculate its eigenvalues λ_k arranged in decreasing order, and correspondent eigenvectors v_k, $k=1,\cdots,M$, which are also called empirical orthogonal functions. Then the EOF expansion is as follows:

$$f_{i,j}=\sum_{k=1}^{M} t_k(i)v_k(j), \quad (3)$$

$$t_k(i)=\sum_{j=1}^{M} f_{i,j}v_k(j), \quad (4)$$

where t_k is the principal component associated with the λ_k and v_k. Occasionally the magnitudes of the λ_k, after a certain M_θ, drop relatively abruptly and remain relatively small. By using some objective selection rules, we choose the truncation parameter M_θ, so that the first M_θ eigenvalue may be considered important in the representation of the total variance of $\underset{\sim}{f}_{N\times M}$. Then, (4) takes the resultant form

$$f_{i,j}=\sum_{k=1}^{M_\theta} t_k(i)v_k(j)+\sum_{k=M_\theta+1}^{M} t_k(i)v_k(j). \quad (5)$$

After retaining the first sum which is regarded as the signal of interest, and culling the second sum which is considered to be a non–significant noise, we have

$$\hat{f}_{i,j} = \sum_{k=1}^{M_\theta} t_k(i) v_k(j). \tag{6}$$

Further, with the help of (2), a new generated filtered noiseless time series $\underline{\hat{x}}$ is obtained by

$$\hat{x}_i = \begin{cases} \dfrac{1}{i}\sum\limits_{j=1}^{i} \hat{f}_{i-j+1,j} & 1 \leqslant i \leqslant M-1 \\ \dfrac{1}{M}\sum\limits_{j=1}^{M} \hat{f}_{i-j+1,j} & M \leqslant i \leqslant N \\ \dfrac{1}{N_T - i + 1}\sum\limits_{j=i+M-N_T}^{M} \hat{f}_{i-j+1,j} & N+1 \leqslant i \leqslant N_T . \end{cases} \tag{7}$$

In fact, $\underline{\hat{x}}$ gives least–square deviation from the original time series $\underline{x}$. From (7), (6), (4) and (1), we have

$$\hat{x}_i = \begin{cases} \dfrac{1}{i}\sum\limits_{j=1}^{i}\sum\limits_{l=1}^{M}\sum\limits_{k=1}^{M_\theta} v_k(l) v_k(j) x_{i-j+l} & 1 \leqslant i \leqslant M-1 \\ \dfrac{1}{M}\sum\limits_{j=1}^{M}\sum\limits_{l=1}^{M}\sum\limits_{k=1}^{M_\theta} v_k(l) v_k(j) x_{i-j+l} & M \leqslant i \leqslant N \\ \dfrac{1}{N_T - i + 1}\sum\limits_{j=i+M-N_T}^{M}\sum\limits_{l=1}^{M}\sum\limits_{k=1}^{M_\theta} v_k(l) v_k(j) x_{i-j+l} & N+1 \leqslant i \leqslant N_T . \end{cases} \tag{8}$$

It is just the new type of filter that can effectively cull noise of original time series $\underline{x}$.

If time series $\underline{x}$ had missing values, we should fill gaps with certain estimation. An iterative scheme associated with the filter (8) is given as follows. First, suppose that non–missing values and some sort of guess for the missing values in $\underline{x}$ form time series $\underline{x}^{(0)}$. By EOF expansion of the augmented matrix $\underline{f}^{(0)}$ of $\underline{x}^{(0)}$ and choice of truncation parameter $M_\theta^{(0)}$, we have

$$\hat{x}_i^{(1)} = \begin{cases} \dfrac{1}{i}\sum\limits_{j=1}^{i}\sum\limits_{l=1}^{M}\sum\limits_{k=1}^{M_\theta^{(0)}} v_k^{(0)}(l) v_k^{(0)}(j) x_{i-j+l}^{(0)} & 1 \leqslant i \leqslant M-1 \\ \dfrac{1}{M}\sum\limits_{j=1}^{M}\sum\limits_{l=1}^{M}\sum\limits_{k=1}^{M_\theta^{(0)}} v_k^{(0)}(l) v_k^{(0)}(j) x_{i-j+l}^{(0)} & M \leqslant i \leqslant N \\ \dfrac{1}{N_T - i + 1}\sum\limits_{j=i+M-N_T}^{M}\sum\limits_{l=1}^{M}\sum\limits_{k=1}^{M_\theta^{(0)}} v_k^{(0)}(l) v_k^{(0)}(j) x_{i-j+l}^{(0)} & N+1 \leqslant i \leqslant N_T , \end{cases} \tag{9}$$

where $\underline{v}_k^{(0)}$ is k^{th} EOF of $\underline{f}^{(0)}$. After substituting the missing values in $\underline{x}$ with counterparts in $\underline{\hat{x}}^{(1)}$, a new time series $\underline{x}^{(1)}$ is obtained. Because information may propagate from observation into gaps, the substituted values are in $\underline{x}^{(1)}$ generally better than the initial guess in $\underline{x}^{(0)}$. At the second iteration step, the EOF analysis of the augmented matrix $\underline{f}^{(1)}$ of $\underline{x}^{(1)}$ and again using (8) yield

$$\hat{x}_i^{(1)} = \begin{cases} \frac{1}{i} \sum_{j=1}^{i} \sum_{l=1}^{M} \sum_{k=1}^{M_0^{(1)}} v_k^{(1)}(l) v_k^{(1)}(j) x_{i-j+l}^{(1)} & 1 \leqslant i \leqslant M-1 \\ \frac{1}{M} \sum_{j=1}^{M} \sum_{l=1}^{M} \sum_{k=1}^{M_0^{(1)}} v_k^{(1)}(l) v_k^{(1)}(j) x_{i-j+l}^{(1)} & M \leqslant i \leqslant N \\ \frac{1}{N_T - i + 1} \sum_{j=i+M-N_T}^{M} \sum_{l=1}^{M} \sum_{k=1}^{M_0^{(1)}} v_k^{(1)}(l) v_k^{(1)}(j) x_{i-j+l}^{(1)} & N+1 \leqslant i \leqslant N_T. \end{cases} \quad (10)$$

Likewise, we repeat the procedure up to the n^{th} step with the general form

$$\hat{x}_i^{(n)} = \begin{cases} \frac{1}{i} \sum_{j=1}^{i} \sum_{l=1}^{M} \sum_{k=1}^{M_0^{(n-1)}} v_k^{(n-1)}(l) v_k^{(n-1)}(j) x_{i-j+l}^{(n-1)} & 1 \leqslant i \leqslant M-1 \\ \frac{1}{M} \sum_{j=1}^{M} \sum_{l=1}^{M} \sum_{k=1}^{M_0^{(n-1)}} v_k^{(n-1)}(l) v_k^{(n-1)}(j) x_{i-j+l}^{(n-1)} & M \leqslant i \leqslant N \\ \frac{1}{N_T - i + 1} \sum_{j=i+M-N_T}^{M} \sum_{l=1}^{M} \sum_{k=1}^{M_0^{(n-1)}} v_k^{(n-1)}(l) v_k^{(n-1)}(j) x_{i-j+l}^{(n-1)} & N+1 \leqslant i \leqslant N_T. \end{cases} \quad (11)$$

Consequently, the limit of the iterative process $\hat{\underline{x}}^{\infty}$ as $n \to \infty$ is just the desired time series in which the missing values are filled and the noise is filtered out. A lot of numerical experiments have shown that the scheme converges very rapidly.

III. FILTERING OF TIME SERIES

Because the Climate Analysis Center has complete observed operational SO indices from January 1933 to December 1992, we use the monthly index ($N_T = 720$) to demonstrate the filtering operation of the time series. Following the filtering scheme described in previous section, we use a reasonable embedding dimension $M = 60$resulting in $N = N_T - M + 1 = 661$. The normalized eigenvalues of the covariance matrix $\underline{c}_{M \times M}$ are given by defining

$$\rho_k = \lambda_k \Big/ \sum_{k=1}^{M} \lambda_k .$$

Notice that ρ_k has another interpretation: it gives the fractional amount of variance of $\underline{f}$ associated with the k^{th} mode v_k. The solid line in Fig. 1 is plotted by the first 20 normalized eigenvalues ρ_k in decreasing order. In order to choose M_0 significant EOF components, we employ the Monte Carlo selection scheme (Preisendorfer, 1988). First, when $\underline{x}$ is strongly autocorrelated, we determine an effective sample size N_T^* to be used in place of the sample size N_T of $\underline{x}$ by

$$N_T^* = \frac{1 - r^2}{1 + r^2} N_T .$$

Here $r = 0.635$ is calculated for autocorrelation coefficient at lag=1 month and $N_T^* \approx 310$. Then, we construct 100 independent realization of each of N_T^* variables from normal population $N(0,1)$, and also form the augmented matrix $\underline{g}_{N^* \times M}$ with $N^* = N_T^* - M + 1 = 251$. This is the random $N^* \times M$ counterpart $\underline{g}$ to the $N \times M$ matrix $\underline{f}$. The ω^{th} realization $\underline{g}(\omega)$ results in an ordered sequence of normalized eigenvalues:

$$\mu_1(\omega) > \cdots > \mu_j(\omega) > \cdots > \mu_M(\omega), \omega = 1, \cdots, 100.$$

For each j, order these (after relabeling) as

$$\mu_j(\omega_1) < \cdots < \mu_j(\omega_{100})$$

and set

$$\sigma_j(05) \equiv \mu_j(\omega_5), \quad \sigma_j(95) \equiv \mu_j(\omega_{95}).$$

These $\sigma_j(05)$ and $\sigma_j(95)$ values, which are plotted in Fig. 1, define the 5% and 95% points on the cumulative distribution for the j^{th} normalized random eigenvalues. Only those normalized eigenvalues from $\underline{x}$ greater than $\sigma_j(95)$ are considered to be statistically significant. From Fig. 1 we know that the number of the significant components is $M_\theta = 7$ and they account for 62.7% of the total variance.

After calculating $\underline{t}_k$, $\underline{v}_k$ and defining M_θ, we apply the filter (8) to CAC's operational SO index for the period 1933–1992. Consequently, a filtered version of the SO index is obtained. Fig. 2 gives the time series plots of the unfiltered and filtered SO index. This figure shows that the noisy short–term fluctuations have been successfully culled.

IV. NUMERICAL EXPERIMENTS OF FILLING DATA GAPS

By use of CAC SO index spanning from 1933 to 1992 we conduct a lot of numerical experiments to test the filling scheme described in Section II. Assume some observed data in the time series are not utilized. By using the filling scheme, correspondent estimates can be obtained. Thus, comparison of the estimate with original observation or filtered values may be used to evaluate the performance of the filling scheme. Two employed measures are correlation coefficient r_{eo} between estimates and observation, and r_{ef} between estimates and filtered values.

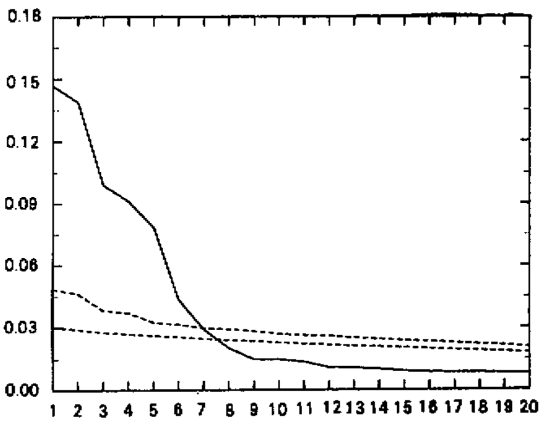

Fig. 1. The first 20 largest normalized eigenvalues λ_k in decreasing order (solid lines). The dashed lines are plotted by the 5% and 95% points on the cumulative distribution for the correspondent random eigenvalues obtained by Monte Carlo procedure.

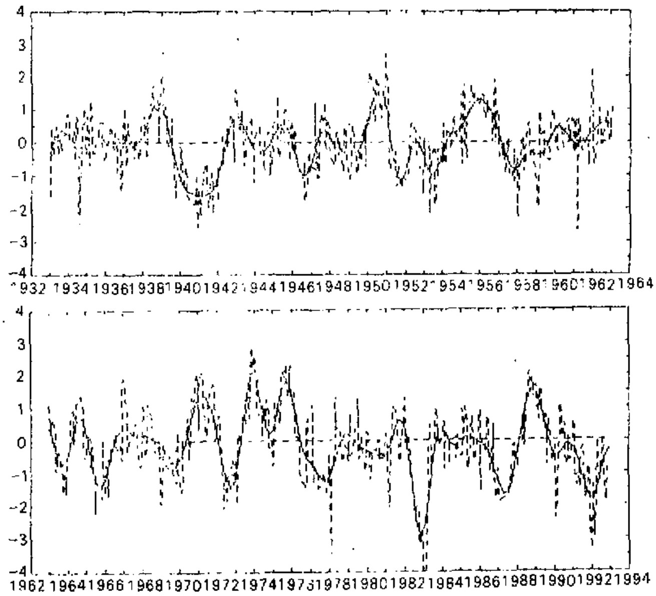

Fig. 2. The unfiltered (dashed) and filtered (solid) time series of Tahiti–Darwin Southern Oscillation index during 1933–1992.

Table 1. Performance of the Scheme of Filling Data Gaps

Class	A	B	C
r_{eo}	0.549	0.403	0.308
r_{ef}	0.795	0.581	0.445

Table 2. 12 Extreme Lowest Index Years and 12 Highest Index Years over 1882–1992. The Values in Parentheses Are Estimates

Year	1982	1905	1940	1991	1896	1888	1941	1965	1925	1977	1972	1987
Index	−2.18	−1.61	−1.53	−1.40	−1.38	−1.36	−1.31	−1.15	−1.10	−1.09	−1.08	−1.07
Year	1917	1907	1975	1973	1950	1988	1955	1895	1892	1906	1910	1938
Index	2.00	(1.46)	1.43	1.28	1.24	1.18	1.12	(1.08)	1.02	(1.02)	1.01	1.01

Table 3. Periods when Successive Years Are all Relatively Extreme, and Mean Values at Least 1.0 or at Most −1.0. The Values in Parentheses Are Estimates for Missing Values

Period	1982–83	1904–05	1991–92	1939–41	1916–17	1906–07	1974–75
Mean	−1.27	−1.12	−1.11	−1.11	1.48	(1.24)	1.02

Three classes of filling experiments are done. In class A, let 12 consecutive observations be not utilized and the initial guess be zero in 1942, ··· , 1982, respectively. The estimate, and correspondent observations and filtered values of some of the 41 filling experiments are given

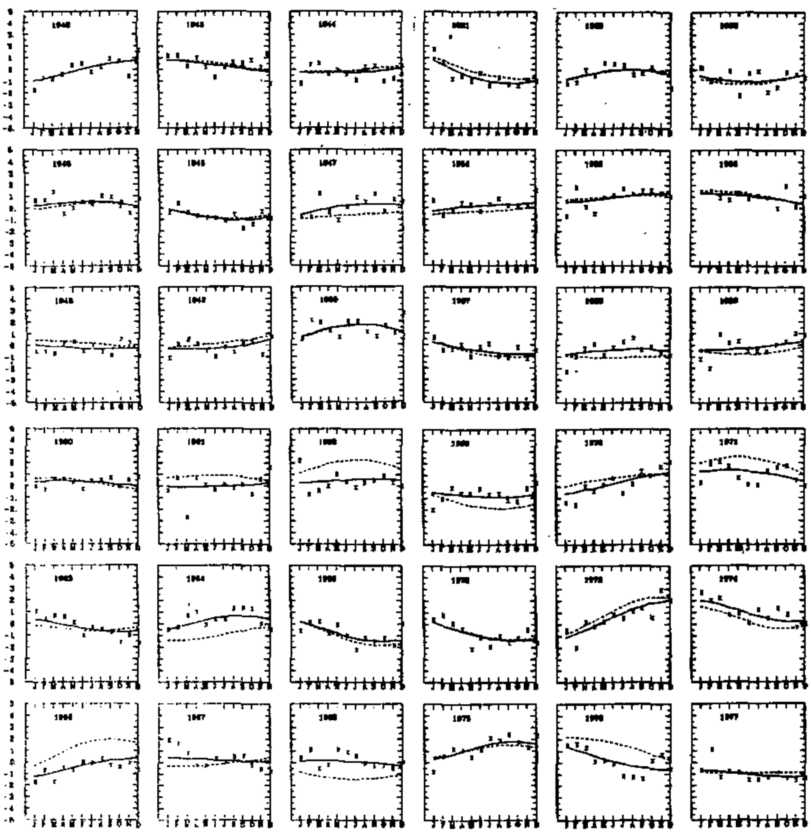

Fig. 3. Observation (indicated by × 's), filtered values (solid) and estimates (dashed). In these experiments of filling data gaps, 12 consecutive observations are not utilized, and the correspondent initial guess is zero.

in Fig. 3. In class *B*, let 24 consecutive observations be not utilized and the initial guess be zero in 1942–1943, ···, 1982–1983, respectively. Fig. 4 shows some results. In class *C*, we obtained Fig. 5 which shows estimate, observation and filtered values of the filling experiments with 36 consecutive utilized values and the zero initial guess. Table 1 summarizes the performance of the three classes of experiments. From Figs. 3, 4, 5 and Table 1 we know that more missing values result in lower filling skills, and up to 36 consecutive missing values in the SO index can be estimated very well.

V. COMPILATION OF THE NOISELESS AND COMPLETE LONG–PERIOD SO INDEX

By applying the filter and the filling scheme in Section II to Climate Analysis Center's SO index over the period 1882–1992, we obtained a noiseless and complete long–period SO index (in Appendix). Time series plots of the new compiled SO index and the original index for 1882–1941 are given in Fig. 6. From the figure we know that the several isolated gaps in the original SO index have been filled and fluctuations shorter than 1 year also have been almost completely eliminated while interannual variability is retained.

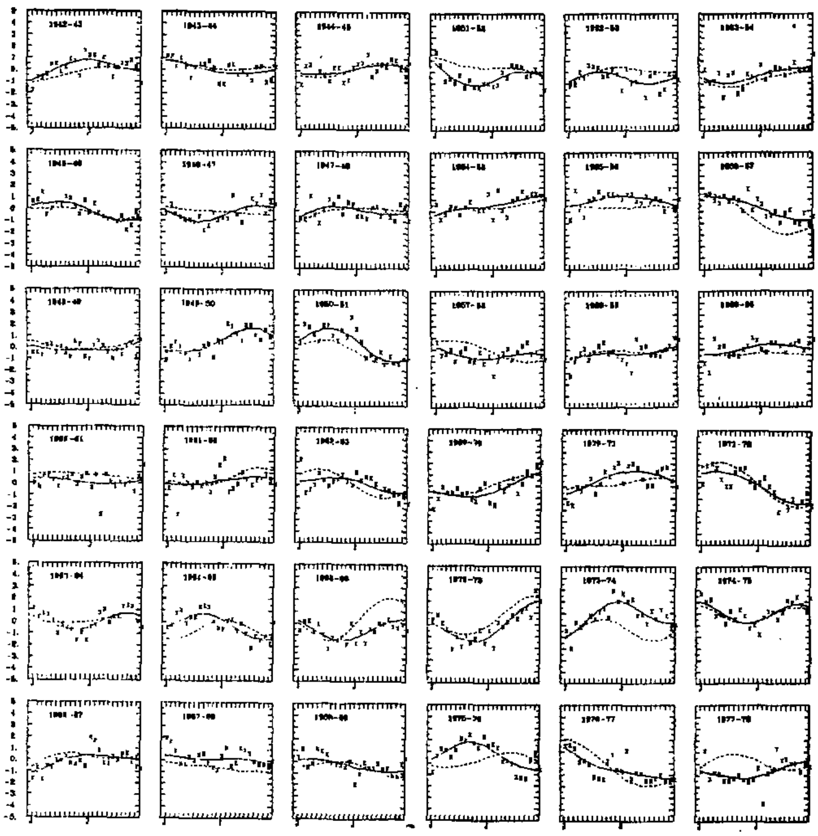

Fig. 4. The same as in Fig. 3, but for 24 consecutive observations not utilized.

We may use the new SO index for climate researches. As a simple application, it will be used to identify extreme low and high index years. We form annual values from the monthly index with years defined as April of the given year to March of the next year. Table 2 lists the 12 extreme lowest and 12 extreme highest years according to this annually series. There is a clear bias towards higher amplitude extremes in the low index events than in the high index events. Table 3 lists the spells in which successive years are all relatively extreme, and mean values were above 1.0 or below−1.0. Based on these two tables, we know that the 1982−1983 period was the lowest 2−year period in the record.

VI. CONCLUSIONS

We have introduced a fully data−adaptive filter. Based on the filter, a scheme of filling data gaps has been given as well. The results show that: (a) the shorter period fluctuations in the CAC's SO index may be effectively filtered out, while the interannual signal is retained by applying the filter; (b) the scheme of filling data gaps can substitute missing values of the SO index with good estimates. Clearly, methods demonstrated here can be applied to other atmospheric and oceanic indices.

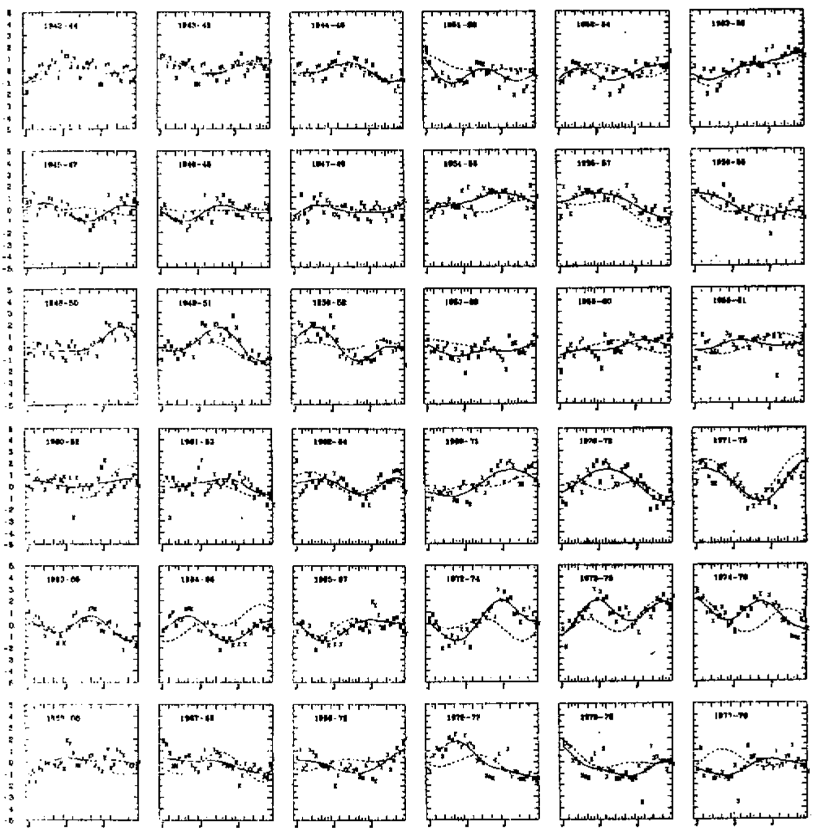

Fig. 5. The same as in Fig. 3, but for 36 consecutive observations not utilized.

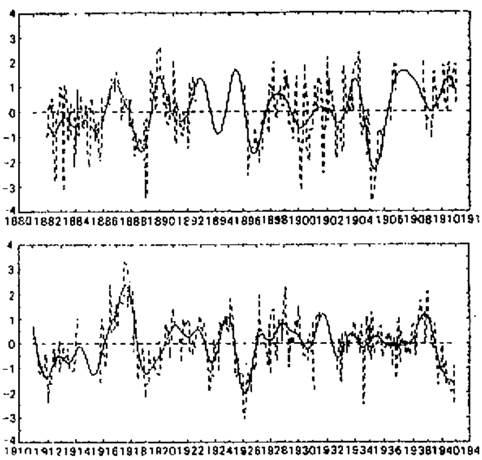

Fig. 6. The unfiltered CAC's Tahiti–Darwin Southern Oscillation index with several isolated gaps (dashed), and its filtered version with gaps filled by the iterative filling scheme described in this paper (solid).

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Appendix

Filtered Monthly SO index with any gaps. The figures in parenthese are substitutes for the missing values.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1882	-0.5	-0.5	-0.6	-0.7	-0.8	-0.9	-1.0	-0.9	-0.8	-0.6	-0.5	-0.4
1883	-0.3	-0.3	-0.3	-0.2	-0.2	-0.3	-0.3	-0.4	-0.5	-0.5	-0.6	-0.6
1884	-0.6	-0.6	-0.5	-0.5	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.4	-0.4
1885	-0.5	-0.5	-0.6	-0.7	-0.7	-0.8	-0.8	-0.9	-0.8	-0.8	-0.6	-0.5
1886	-0.3	-0.1	0.1	0.3	0.5	0.7	0.9	1.0	1.1	1.2	1.2	1.2
1887	1.1	1.0	0.9	0.8	0.7	0.6	0.4	0.3	0.2	0.1	-0.1	-0.3
1888	-0.4	-0.6	-0.8	-1.0	-1.2	-1.3	-1.5	-1.6	-1.6	-1.6	-1.6	-1.5
1889	-1.4	-1.1	-0.9	-0.6	-0.2	0.1	0.4	0.7	1.0	1.2	1.3	1.4
1890	1.4	1.4	1.3	1.1	0.9	0.8	0.6	0.4	0.3	0.1	0.0	-0.1
1891	-0.1	-0.2	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3
1892	-0.1	0.0	0.2	0.3	0.5	0.7	0.9	1.0	(1.1)	(1.3)	(1.3)	(1.4)
1893	(1.3)	(1.3)	(1.2)	(1.1)	(0.9)	(0.7)	(0.4)	(0.2)	(0.0)	(-0.2)	(-0.5)	(-0.6)
1894	(-0.8)	(-0.9)	(-0.9)	(-0.9)	(-0.9)	(-0.8)	(-0.6)	(-0.4)	(-0.2)	(0.0)	(0.3)	(0.6)
1895	(0.8)	(1.1)	(1.3)	(1.5)	(1.6)	(1.7)	(1.7)	(1.6)	(1.5)	(1.3)	(1.1)	(0.8)
1896	0.4	0.1	-0.3	-0.6	-0.9	-1.2	-1.4	-1.6	-1.7	-1.7	-1.7	-1.6
1897	-1.5	-1.4	-1.2	-1.0	-0.8	-0.6	-0.4	-0.2	0.0	0.2	0.3	0.4
1898	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6
1899	0.5	0.5	0.4	0.3	0.1	0.0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6
1900	-0.6	-0.7	-0.7	-0.7	-0.6	-0.6	-0.5	-0.5	-0.4	-0.3	-0.3	-0.2
1901	-0.1	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
1902	0.1	0.1	0.1	0.0	-0.1	-0.2	-0.3	-0.4	-0.4	-0.5	-0.5	-0.5
1903	-0.4	-0.3	-0.2	-0.1	0.1	0.3	0.5	0.7	0.9	1.1	1.2	1.3
1904	1.3	1.3	1.2	1.0	0.8	0.5	0.2	-0.1	-0.5	-0.8	-1.2	-1.5
1905	-1.8	-2.0	-2.2	-2.3	-2.4	-2.3	-2.2	-2.1	-1.9	-1.7	-1.4	-1.2
1906	-0.9	-0.6	(-0.3)	(0.0)	(0.2)	0.5	0.7	0.9	1.1	1.2	1.4	(1.5)
1907	(1.5)	(1.6)	(1.6)	(1.6)	(1.6)	(1.6)	(1.6)	(1.6)	(1.5)	(1.5)	(1.4)	(1.4)
1908	(1.3)	(1.2)	(1.2)	(1.1)	(1.0)	(0.9)	(0.7)	(0.6)	0.5	0.4	0.3	0.2
1909	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
1910	0.9	1.0	1.1	1.2	1.3	1.3	1.4	1.3	1.3	1.2	1.0	0.9
1911	0.7	0.4	0.1	-0.1	-0.4	-0.6	-0.9	-1.1	-1.2	-1.3	-1.4	-1.4
1912	-1.4	-1.4	-1.3	-1.1	-1.0	-0.9	-0.8	-0.6	-0.6	-0.5	-0.5	-0.5
1913	-0.5	-0.6	-0.6	-0.7	-0.7	-0.8	-0.8	-0.8	-0.8	-0.7	-0.6	-0.5
1914	-0.4	-0.3	-0.2	(-0.1)	(-0.1)	(-0.1)	(-0.2)	(-0.3)	(-0.4)	-0.5	(-0.7)	(-0.8)
1915	(-1.0)	(-1.1)	(-1.2)	(-1.3)	(-1.3)	(-1.3)	(-1.2)	(-1.1)	(-0.9)	(-0.7)	-0.6	-0.4
1916	-0.2	0.0	0.2	0.3	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.2
1917	1.4	1.5	1.7	1.9	2.1	2.2	2.3	2.4	2.4	2.3	2.2	2.0
1918	1.7	1.4	1.1	0.7	0.4	0.0	-0.3	-0.6	-0.8	-1.0	-1.1	-1.2
1919	-1.3	-1.3	-1.2	-1.2	-1.1	-1.0	-1.0	-0.9	-0.8	-0.7	-0.7	-0.6
1920	-0.5	-0.4	-0.4	-0.3	-0.1	0.0	0.1	0.2	0.3	0.4	0.5	0.6
1921	0.7	0.7	(0.8)	(0.7)	(0.7)	(0.6)	0.6	0.5	0.4	0.4	0.3	0.3
1922	0.3	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.5
1923	0.4	0.3	0.2	0.0	-0.2	-0.4	-0.5	-0.7	-0.8	-0.8	-0.8	-0.8
1924	-0.7	-0.5	-0.3	-0.1	0.1	0.4	0.6	0.8	1.0	1.1	1.1	1.1
1925	1.1	0.9	0.8	0.5	0.2	-0.1	-0.5	-0.8	-1.2	-1.5	-1.7	-1.9
1926	-2.0	-2.1	-2.1	-2.0	-1.9	-1.7	-1.4	-1.2	-0.9	-0.6	-0.4	-0.1
1927	0.1	0.2	0.3	0.4	0.4	(0.4)	(0.3)	(0.2)	0.2	0.1	0.1	0.1
1928	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.8	0.8
1929	0.8	0.8	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
1930	0.3	0.2	0.2	0.1	0.0	-0.1	-0.2	-0.2	-0.3	-0.3	-0.2	-0.1
1931	0.0	0.1	0.3	0.5	0.7	0.9	1.0	(1.1)	(1.2)	(1.2)	(1.2)	(1.1)
1932	(0.9)	(0.8)	(0.5)	(0.3)	(0.1)	(-0.1)	(-0.3)	(-0.5)	-0.6	-0.6	-0.6	-0.6
1933	-0.5	-0.4	-0.3	-0.1	0.0	0.2	0.3	0.3	0.4	0.4	0.4	0.3
1934	0.3	0.2	0.1	0.0	-0.1	-0.1	-0.2	-0.2	-0.2	-0.1	-0.1	0.0
1935	0.0	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.1

Appendix (*continued*)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1936	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
1937	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.1
1938	0.2	0.3	0.5	0.6	0.8	0.9	1.0	1.1	1.2	1.2	1.2	1.2
1939	1.1	1.0	0.8	0.6	0.4	0.2	0.0	-0.3	-0.5	-0.7	-0.9	-1.0
1940	-1.1	-1.2	-1.3	-1.4	-1.4	-1.5	-1.5	-1.5	-1.5	-1.6	-1.6	-1.6
1941	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.5	-1.5	-1.4	-1.3	-1.2
1942	-1.0	-0.8	-0.6	-0.4	-0.2	0.0	0.2	0.4	0.5	0.6	0.7	0.8
1943	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	-0.1	-0.2
1944	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.2	-0.1	0.0	0.1
1945	0.2	0.3	0.4	0.5	0.5	0.6	0.6	0.5	0.5	0.4	0.2	0.1
1946	-0.1	-0.3	-0.5	-0.6	-0.8	-0.9	-1.0	-1.0	-1.0	-1.0	-0.9	-0.7
1947	-0.6	-0.4	-0.2	-0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.2
1948	0.1	0.0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
1949	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.2	0.0	0.1	0.3	0.5
1950	0.7	1.0	1.2	1.4	1.5	1.7	1.7	1.7	1.7	1.5	1.3	1.1
1951	0.8	0.4	0.1	-0.3	-0.6	-0.8	-1.0	-1.1	-1.2	-1.2	-1.1	-1.0
1952	-0.8	-0.6	-0.4	-0.3	-0.1	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.4
1953	-0.5	-0.7	-0.8	-0.9	-1.0	-1.0	-1.0	-0.9	-0.8	-0.7	-0.6	-0.4
1954	-0.3	-0.2	-0.1	0.0	0.1	0.2	0.3	0.3	0.3	0.4	0.4	0.5
1955	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.2	1.3	1.3
1956	1.3	1.3	1.3	1.2	1.2	1.1	1.0	0.9	0.8	0.7	0.5	0.4
1957	0.2	0.0	-0.1	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.8	-0.8	-0.8
1958	-0.8	-0.7	-0.6	-0.5	-0.5	-0.4	-0.4	-0.3	-0.3	-0.3	-0.4	-0.4
1959	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3	-0.2	-0.1	0.0	0.1	0.2	0.3
1960	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.1	0.0
1961	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.1	0.1	0.2	0.2
1962	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5
1963	0.4	0.3	0.1	-0.1	-0.2	-0.4	-0.5	-0.6	-0.7	-0.7	-0.7	-0.6
1964	-0.4	-0.3	-0.1	0.1	0.3	0.5	0.6	0.7	0.7	0.7	0.6	0.4
1965	0.2	0.0	-0.3	-0.5	-0.8	-1.0	-1.2	-1.4	-1.4	-1.5	-1.4	-1.4
1966	-1.2	-1.1	-0.9	-0.7	-0.5	-0.3	-0.1	0.0	0.1	0.2	0.3	0.4
1967	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
1968	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.0	0.0	-0.1	-0.2	-0.3
1969	-0.5	-0.6	-0.6	-0.7	-0.8	-0.8	-0.9	-0.9	-0.9	-0.9	-0.8	-0.7
1970	-0.6	-0.5	-0.3	-0.2	0.0	0.2	0.4	0.6	0.8	0.9	1.1	1.2
1971	1.3	1.3	1.4	1.4	1.4	1.3	1.2	1.1	1.0	0.8	0.6	0.4
1972	0.2	-0.1	-0.3	-0.6	-0.8	-1.0	-1.2	-1.4	-1.4	-1.4	-1.4	-1.3
1973	-1.1	-0.8	-0.5	-0.2	0.2	0.6	0.9	1.3	1.5	1.8	1.9	2.0
1974	1.9	1.8	1.7	1.4	1.2	0.9	0.7	0.5	0.3	0.2	0.2	0.3
1975	0.4	0.5	0.7	1.0	1.2	1.4	1.6	1.7	1.8	1.8	1.7	1.6
1976	1.4	1.1	0.9	0.6	0.4	0.1	-0.1	-0.3	-0.4	-0.5	-0.6	-0.7
1977	-0.7	-0.8	-0.8	-0.9	-1.0	-1.1	-1.1	-1.2	-1.2	-1.2	-1.2	-1.2
1978	-1.1	-1.0	-0.9	-0.7	-0.6	-0.4	-0.2	-0.1	0.0	0.1	0.1	0.1
1979	0.2	0.1	0.1	0.1	0.0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3	-0.3
1980	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4	-0.5	-0.5	-0.5	-0.6	-0.6	-0.5
1981	-0.5	-0.4	-0.3	-0.1	0.1	0.2	0.4	0.5	0.6	0.6	0.6	0.5
1982	0.3	0.0	-0.3	-0.7	-1.1	-1.5	-1.9	-2.3	-2.6	-2.8	-2.9	-2.9
1983	-2.8	-2.5	-2.2	-1.9	-1.5	-1.1	-0.7	-0.4	-0.1	0.1	0.2	0.3
1984	0.3	0.3	0.2	0.1	0.0	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2
1985	-0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
1986	0.0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.4	-0.5	-0.7	-0.8	-1.0	-1.1
1987	-1.3	-1.4	-1.5	-1.6	-1.6	-1.6	-1.6	-1.5	-1.4	-1.2	-1.0	-0.7
1988	-0.5	-0.2	0.1	0.3	0.6	0.9	1.1	1.3	1.4	1.5	1.5	1.5
1989	1.5	1.4	1.2	1.1	0.9	0.6	0.4	0.2	0.0	-0.1	-0.3	-0.4
1990	-0.5	-0.5	-0.5	-0.5	-0.4	-0.3	-0.3	-0.2	-0.2	-0.1	-0.1	-0.2
1991	-0.2	-0.3	-0.5	-0.6	-0.8	-1.0	-1.1	-1.3	-1.5	-1.6	-1.7	-1.8
1992	-1.9	-1.8	-1.7	-1.6	-1.3	-1.1	-0.9	-0.7	-0.6	-0.5	-0.4	-0.3