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THE LARGE-SCALE ENSO EVENT, THE EL NIÑO AND OTHER IMPORTANT REGIONAL FEATURES

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Abstract

Information has been and is continuing to be gathered, coordinated and improved on this activity. However, the rather tenuous year-to-year data on the Southern Oscillation (SO)-related climatic changes are primarily limited to the period AD 622 to the present. The recurring large-scale ocean-atmosphere fluctuation, the El Niño/Southern Oscillation (ENSO), which is noted over the lower latitudes from East Africa eastward to the Americas manifests itself roughly as a «see-saw» in ocean-atmosphere conditions between the area in and surrounding the tropical Indian Ocean and the area in and surrounding most of the tropical Pacific Ocean. The ENSO relates to a low index phase of the SO and is associated on the west side of the «see-saw» with an eastern and northern Australian drought, an east monsoon drought over Indonesia, deficient summer monsoon rainfall over India, and deficient summer monsoon rainfall over the highlands of Ethiopia (resulting in a weak contribution to the Nile River system). In contrast, on the east side of the «see-saw» it relates to an El Niño, anomalously high sea surface temperatures (SSTs) and above normal rainfall over the central and eastern equatorial Pacific, and anomalously heavy subtropical Chilean rainfall. The high index (anti-ENSO phase) of the SO relates on the west side of the «see-saw» to anomalously heavy rainfall over eastern and northern Australia, anomalously heavy east monsoon rainfall over Indonesia, above normal summer monsoon rainfall over India, and an abnormally large supply of water entering the Nile River system as a result of abnormally heavy summer monsoon rainfall over the highlands of Ethiopia. In contrast, on the east side of the «see-saw» it relates to cool anti-El Niño conditions over the northwestern South American coastal region with its cool upwelling waters, an equatorial Pacific dry zone extending far to the west as a result of the underlying cool upwelling sea water caused by strong easterly winds, and anomalously low subtropical Chilean rainfall. Although each individual large-scale ENSO and anti-ENSO phase pattern will display its own unique characteristics, the above-stated generalities will frequently occur, particularly when the events are in the strong and very strong intensity categories.

At times the initial onset of these large-scale developments can be noted earlier on the western side of the «see-saw» than they can on the eastern side. There is no better example of this than the very strong 1982-1983 ENSO development. An ultimate goal of all research on the large-scale ENSO, the El Niño, and other associated regional climatic features is to eventually develop the capability to provide reasonably reliable long-range outlooks as to the time of onset, areal extent, duration, and intensity of these recurring SO-related ocean-atmosphere climatic fluctuations. Here some of the background information, data, and records obtained over the historical past are presented and discussed.

Key words: *ENSO, El Niño, rainfall, Australia, Indonesia, India, Ethiopia, South America, subtropical Chile.*

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EL EVENTO ENSO DE GRAN ESCALA, EL NIÑO Y OTRAS IMPORTANTES CARACTERÍSTICAS REGIONALES

Resumen

En esta actividad, se ha colectado -y continua colectándose- información coordinada y mejorada. Sin embargo, los datos año a año sobre cambios climáticos relacionados con la Oscilación del Sur (SO) están primariamente limitados al período entre el año 622 d.C. y el presente. La fluctuación oceano atmosférica recurrente y de gran escala, El Niño/Oscilación del Sur (ENSO), que se nota en las bajas latitudes desde el África oriental hacia el este hasta las Américas, se manifiesta groseramente como un «sube-y-baja» en las condiciones oceano atmosféricas entre el área del Océano Índico tropical y el Área del Océano Pacífico tropical. El ENSO se relaciona con una fase de bajo índice de la SO y está asociado, en el lado occidental del «sube-y-baja», con una sequía en Australia oriental y septentrional, una sequía este-monzónica en Indonesia, deficiente lluvia este-monzónica de verano en India y deficiente lluvia monzónica de verano en las alturas de Etiopía (resultando en una débil contribución al sistema del río Nilo). En contraste, en el lado oriental del «sube-y-baja», él se relaciona con El Niño, temperaturas superficiales del mar (TSM) anormalmente altas y lluvias encima de lo normal en el Pacífico central y oriental, y lluvias anormalmente fuertes en Chile subtropical. El alto índice (fase anti-ENSO) de la SO se relaciona, en el lado occidental del «sube-y baja», con lluvia anormalmente fuerte en Australia oriental y septentrional, lluvia este-monzónica anormalmente fuerte en Indonesia, lluvia monzónica de verano sobre lo normal en la India, y un suministro de agua anormalmente grande al sistema Río Nilo como resultado de lluvia monzónica de verano anormalmente fuerte en las alturas de Etiopía. En contraste, en el lado oriental del «sube-y-baja», él se relaciona con condiciones frías anti-El Niño en la región noreste de la costa Sudamericana con sus aguas frías de afloramiento, una zona seca en el Pacífico ecuatorial que se extiende lejos hacia el oeste como resultado del agua marina subyacente causada por fuertes vientos del este, y lluvia anormalmente escasa en Chile subtropical. A pesar que el patrón de cada fase individual ENSO o anti-ENSO de gran escala mostrará sus características propias únicas, las generalidades antes establecidas ocurrirán frecuentemente, particularmente cuando los eventos pertenecen a las categorías de intensidad fuerte y muy fuerte.

A veces, el inicio de estos desarrollos de gran escala se notan en el ladio occidental del «sube-y-baja» antes que en el lado oriental. No hay mejor ejemplo de esto que el desarrollo del ENSO muy fuerte de 1982-1983.

Una meta última de toda la investigación sobre los ENSO de gran escala, el Niño y otros rasgos climáticos regionales asociados es la de eventualmente desarrollar la capacidad de proveer razonablemente perspectivas de largo plazo y fiables como el tiempo de inicio, extensión areal, duración e intensidad de estas fluctuaciones climáticas oceano-atmosféricas recurrentes asociadas a la SO. Aquí, se presentan y discuten algunas informaciones de base, datos y registros obtenidos en el pasado histórico.

Palabras claves: *ENSO, El Niño, lluvia, Australia, Indonesia, India, Etiopía, Sudamérica, Chile subtropical.*

L'ÉVÉNEMENT ENSO À GRANDE ÉCHELLE, EL NIÑO ET AUTRES CARACTÉRISTIQUES RÉGIONALES IMPORTANTES

Résumé

En ce qui concerne cette activité, on a ramassé - et on continue de le faire - une information coordonnée et améliorée. Cependant, les informations année après année sur les changements climatiques en lien avec l'Oscillation du Sud (SO) sont limitées de façon primaire à la période comprise entre l'année 622 et nos jours. La fluctuation océano-atmosphérique récurrente et à grande échelle, El Niño/Oscillation du Sud (ENSO), qui se présente sous les basses latitudes depuis l'Afrique orientale vers l'est jusqu'aux Amériques, se manifeste en gros comme une «balançoire» dans les conditions océano-atmosphériques entre la zone de l'Océan Indien tropical et celles de l'Océan Pacifique tropical. L'ENSO est en lien avec une phase de bas indice de la SO et est associé, du côté occidental de la «balançoire», à une sècheresse en Australie occidentale et septentrionale, une sècheresse par l'est de la mousson en Indonésie, une pluie déficiente de la mousson-est d'été en Inde et une pluie déficiente de la mousson d'été dans la montagne Éthiopienne (qui débouche sur une faible contribution au système du Nil). Par opposition, du côté oriental de la «balançoire», celle-ci est en lien avec El Niño, avec des températures superficielles de la mer (TSM) anormallement hautes, des pluies au-dessus de la normale dans le Pacifique équatorial central et oriental et des pluies anormalement fortes dans le Chili sub-tropical. Le haut indice (phase anti-Niño) de la SO est en lien, du côté occidental de la «balançoire», avec des pluies anormalement fortes en Australe orientale et septentrionale, des pluies de mousson de l'est anormalement fortes en Indonésie, des pluies de mousson d'été au-dessus de la normale en Inde, et une quantité d'eau anormalement grande qui se déverse dans le Nil, suite aux pluies de mousson d'été trop fortes dans les montagnes éthiopiennes. Par contre, du côté oriental de la «balançoire», celle-ci est en relation avec un anti-Niño froid dans la région nord-est de la côte sud-américaine avec ses eaux froides d'affleurement, une zone sèche dans le Pacifique équatorial qui s'étend au loin vers l'ouest, causée par de l'eau marine froide sous-jacente due à de forts vents d'est, et une pluie anormalement rare dans le Chili sub-tropical. Bien que le modèle de chaque phase individuelle ENSO ou anti-ENSO à grande échelle ait ses propres caractéristiques, les généralités établies auparavent ont lieu fréquemment, particulièrement quand les événements appartiennent aux catégories de forte et très forte intensité.

Parfois, ces développements sur grande échelle sont d'abord visibles du côté occidental de la «balançoire». Il n'y a pas de meilleur exemple que le développement du ENSO très fort de 1982-1983.

Un dernier but de toute la recherche sur les ENSO de grande échelle, El Niño et autres événements climatiques associés est de développer éventuellement la capacité de proposer raisonablement des perspectives à long terme et fiables comme le temps de démarrage, l'espace couvert, la durée et l'intensité de ces fluctuations climatiques océano-atmosphériques récurrentes associées à la SO. Ce travail présente et discute quelques informations de base, des données et des enregistrements obtenus dans le passé historique.

Mots clés : *ENSO, El Niño, pluie, Australie, Indonésie, Éthiopie, Amérique du Sud, Chili sub-tropical.*

1. INTRODUCTION

Over the past 3 years an attempt has been made to prepare a record of the recurring large-scale ocean-atmosphere climatic fluctuations which are particularly prominent over the lower latitude area extending from east Africa eastward to the Americas. This large scale feature is usually referred to as the El Niño/Southern Oscillation or ENSO. Our earlier work was primarily focused on the regional El Niño which more directly affects the coastal regions of southwestern Ecuador, northwestern Peru, and their offshore waters (Quinn *et al.*, 1978; 1987; Quinn & Neal, 1992). However, in order to extend the record of low Southern Oscillation Index (SOI)-related climatic activity (the ENSO) farther back in time, and to bring in additional supportive data and information, it was necessary to extend this investigation to the western extremity of the area primarily affected by the ENSO. (Information over western South America and its offshore waters was limited to the period since the early 16th century when the Spanish first arrived on the scene.) Information over many centuries is available on droughts, floods, plagues, famines, and Nile River levels for that sector (East Africa, the Middle East, and India). The yearly flood of the Nile River has been the basis of Egyptian agriculture for thousands of years; and prior to the installation of upstream regulatory facilities several decades ago, its maximum flow level at Cairo registered the effects of the summer monsoon (June-September) rainfall over the highlands of Ethiopia, with a low SOI in general relating to a below average flood level at Cairo and a high SOI relating to an above average maximum flood level at Cairo. Yearly maximum and minimum Nile River levels at Cairo were obtained, with a few breaks along the way, back to A.D. 622.

2. THE ENSO AND THE EL NIÑO

The ENSO, the El Niño, and Equatorial Pacific warm event, are often terms that are used synonymously. And although the El Niño and many other regional features are integral parts of the large-scale ENSO, for the purposes of this paper the ENSO will be considered the parent ocean-atmosphere fluctuation encompassing the many regional climatic changes that are brought about primarily over the tropics and subtropics of the area extending eastward from East Africa to the Americas. In this context, the El Niño represents the resulting regional climatic changes brought about in particular over southwestern Ecuador, northwestern Peru and their coastal ocean waters. Tables 1 and 2, pertaining to revised ENSO and El Niño listings which will be referred to in this report were taken from Quinn (in press). It must be realized that the ENSOs and their related regional features can vary greatly in areal extent, duration and intensity. Long-term global changes may significantly affect the ENSO (Quinn, in press; Quinn, 1971; Markgraf *et al.*, 1992).

3. ENSO AND NILE RIVER FLOOD LEVELS

Sir John Lyons (1906) found a correspondence between good Nile floods July-October and low pressure conditions June-September over the Middle East, as well as between poor Nile floods and high pressure conditions June-September over that area. Of course, the low pressures over this area were but a part of the very large low pressure system that extends over India and the Arabian Sea and brings strong persistent southwesterlies and heavy rainfall over the highlands of Ethiopia during the summer monsoon under a high SOI condition. The Imperial Gazetteer of India (vol. 1, 1908) noted that years of drought in western/northwestern India were usually years of low Nile flood and that years of heavier rains than usual over that region were years of high Nile flood. Although the inherent variability in individual large-scale weather patterns would not guarantee an inevitable area to area conformability, the statements of Griffiths (1972), indications in Figure 1.8 of Lockwood (1985), and Figure 1 of Quinn (in press) would tend, in general, to support the Gazetteer statement.

It is primarily the Blue Nile and secondarily the Atbara Rivers, that originate in Ethiopia, which supply waters of the annual Nile River flood; the White Nile plays very little part in the flood that is caused by the summer monsoon rainfall over the highlands of Ethiopia. When the SOI is high, it indicates the large low pressure system extending over India and the Arabian Sea is well developed and the summer monsoon rainfall is likely to be heavy; when the SOI is low it indicates that the low pressure system is not as deep and/or displaced to the east and the summer monsoon rainfall is likely to be deficient.

To relate the annual July-October discharge at Aswan to the maximum annual Nile River flood height at Cairo and to relate the changes of both to the SO-related climatic activity, the contents of Table 4 from Quinn (in press) are provided as Table 3. In retrospect the relationships were derived from the large drop in July-October discharge at Aswan and the related large drop in maximum height of the Nile River at Cairo between the periods 1869-1898 and 1900-1929. In this relationship a minimal drop in height of 27 cm at Cairo is equivalent to a discharge drop of 546 x 107m^3 at Aswan. For further discussion of this unusual change that took place near the turn of the century and its cause, reference is made to Quinn (in press).

The Nile River flood as related to the summer monsoon rainfall contribution over the highlands of Ethiopia is represented in Figure 1. In an attempt to reduce effects of regulatory features to some extent, the July-October discharge data for Dongola (19o10′N, 30°29′E) on the main Nile was used for 1912-1973 (data taken from Table 15 in Shahin, 1985). Dongola is

Table 1 - *Years (Yrs) in which large-scale El Niño/Southern Oscillation (ENSO) events occurred, with some years modified by E (early), M (mid), or L (late). Strengths (Str) are moderate (M), strong (S), or very strong (VS) with a + or - added for intermediate values. Confidence (Conf) ratings (1-5) are estimates based on the quantity and quality of information afforded, ranging from minimal (1) to complete (5).*

Yrs	Str	Conf	Yrs	Str	Conf	Yrs	Str	Conf
1525-E26	M	2	1713-14	M+	3	1852-E53	M	4
1531-E32	M	2	1715-16	S+	3	1854-55	S	5
1535	M+	2	1718	M	2	1857-E59	M+	5
1539-41	S	2	1720	M+	3	1860	M	3
1544	M+	3	1723	S	4	1862	M-	2
1546-47	S	2	1725	M	2	1864	S+	5
1552-53	S	3	1728	M	3	L1865-E66	M+	4
1558-E61	S	3	1731	M+	2	L1867-E69	S+	5
1565	M+	2	1734	M	2	1871	M	3
1567-68	S+	3	1737	S	3	1873-74	M+	5
1574	S	2	1744	M+	3	L1876-78	VS	5
1578-E79	S	3	1747-48	S	3	1880-81	M+	5
1581-82	M+	3	1751	M+	2	1884-85	M+	4
1585	M	2	1754-55	S	2	L1887-E89	S	5
1589-91	S	3	1758	M	1	1891	M	5
1596	M	2	1761-62	S	3	1896-97	M+	5
1600-01	S	3	1765-66	M+	2	1899-M1900	VS	5
1604	S	3	1768-69	M+	4	L1901-02	S+	5
1607-08	S	3	1772-73	M	3	1904-05	S	5
1614	S	3	1776-E78	M+	3	1907	M+	5
1618-19	M	3	1782-84	VS	5	1911-12	M+	5
1621	S	3	1785-86	M+	3	M1913-M15	S+	5
1624	M+	2	1790-93	VS	5	1918-E20	S+	5
1630-31	S+	3	1794-97	M+	3	1923	M	5
1635	M	3	1799	M	2	1925-26	S	5
1640-41	S+	3	1802-04	S+	5	L1929-E31	M+	5
1647	M	2	1806-07	M	3	1932	M+	5
1650	S+	3	1810	M	2	1939	M	4
1652	M	2	1812	M+	3	1940-41	VS	5
1655	M	2	1814	S	3	1943-44	M	5
1661	VS	3	1817	M+	3	1951-E52	M+	5
1671	M+	2	1819	M+	3	1953	M	5
1681	S	2	1821	M	3	1957-58	S	5
1683-84	M+	2	1824-25	S	5	1965-66	S	5
1687-88	S	3	1827-28	S+	5	M1968-69	M-	3
1692	M+	2	1830	M	3	1972-73	S+	5
1694-95	VS	2	1832-33	S+	5	1976-77	M	5
1697	M	2	1835-36	M	3	1979-80	M-	3
1701	M	3	1837-39	S	5	1982-M83	VS	5
1703-04	S	3	1844-E46	VS	5	M1986-87	M	5
1707-09	M	2	1850	S	5	M1991-92	S	3

Table 2. Years (Yrs) in which regional El Niño events occurred, with some years modified by E (early), M (mid), or L (late). Strengths (Str) are moderate (M), strong (S), or very strong (VS) with a + or - added for intermediate values. Confidence (Conf) ratings (1-5) are based on the number of information sources with 5 indicating 5 or more. (See text for details.)

Yrs	Str	Conf	Yrs	Str	Conf	Yrs	Str	Conf
1525-E26	M	2	1704	M	2	1857-58	M	5
1531-E32	M	2	1707-09	M/S	3	1860	M	4
1535	M+	2	1713	M	2	1862	M-	2
1539-41	M/S	3	1715-16	S	3	1864	S	5
1544	M+	4	1718	M+	2	E1866	M+	4
1546-47	S	4	1720	VS	5	L1867-68	M+	5
1552	S	3	1723	M+	4	1871	S+	5
1558-E61	M/S	4	1728	VS	5	1874	M	4
1565	M+	2	1734	M	2	1877-78	VS	5
1567-68	S+	5	1737	S	3	1880	M	3
1574	S	3	1744	M+	3	1884	S+	5
1578-E79	VS	5	1747	S+	5	L1887-E89	M	4
1581-82	M+	3	1751	M+	3	1891	VS	5
1585	M+	2	1754-55	M	2	1897	M+	4
1589-91	M/S	3	1758	M	1	1899-E1900	S	5
1596	M+	2	1761	S	5	1902	M+	5
1600	S	3	1765	M	2	1904-05	M-	5
1604	M+	3	1768	M	3	1907	M+	4
1607-08	S	5	1772	M	2	1910	M+	4
1614	S	5	1776-E78	S	3	1911-12	M	5
1618-19	S	4	1782-83	S	3	1914-E15	M+	5
1621	M+	2	1785-86	M+	2	1917	M+	5
1624	S+	4	1791	VS	5	1918-19	M	5
1630	M	2	1803-04	S+	5	1923	M	5
1635	S	3	1806-07	M	3	1925-26	VS	5
1640-41	M	2	1810	M	2	L1930-E31	M	5
1647	M+	3	1812	M+	2	1932	S	5
1650	M	3	1814	S	3	1939	M+	5
1652	S+	3	1817	M+	4	L1940-41	S	5
1655	M	2	1819	M+	3	1943	M+	5
1661	S	2	1821	M	4	1951	M-	5
1671	S	3	1824	M+	4	1953	M+	5
1681	S	2	1828	VS	5	1957-58	S	5
1684	M+	3	1830	M	2	1965	M+	5
1687	S+	4	1832	M+	5	1969	M-	3
1692	S	3	1837	M+	4	1972-E73	S	5
1695	M	2	1844-E46	S	5	1976	M	5
1697	M+	3	1850	M	4	L1982-M83	VS	5
1701	S+	5	1852	M	3	1987	M	4
			1854	M	3	1992	S	3

down-river from the critical inputs of the Blue Nile and Atbara Rivers and up-river from the High Aswan Dam and Lake Nasser controls. The average amount for July-October for 1912-1964 was 6138 x 10^7m^{3}yr^{-1} and after reducing that by 546 x 10^7m^{3}yr^{-1} (to arrive at the minimal level for a degree 1 event), we have a departure line at 5592 x 10^7m^{3}yr^{-1} (about 55.9 x 10^9m^{3}yr^{-1} on Figure 1) to separate out event years with their lower discharge values. Values for 1964-1966 are fairly representative but values continue to diverge more and more from reality as the reservoir formed by the High Aswan Dam fills. Figure 9.12 of Shahin (1985) shows this year to year filling. Figure 1 also shows a graph of the combined annual discharge values for July-October for the Blue Nile and Atbara rivers at 15o37'N, 32°32'E and 17°42'N, 33°58'E, respectively. These data were obtained from Tables 11 (Blue Nile) and 14 (Atbara) in Shahin (1985). The average combined discharge amount for these rivers for July-October of 1912-64 was 5657 x 107m^{3}yr^{-1} and after reducing that by 546 x 10^7m^{3}yr^{-1}, we have a departure line at 5111 x 10^7m^{3}yr^{-1} (about 51.1 x 10^9m^{3}yr^{-1} on Figure 1) to separate out event years. It is interesting that the combined annual average for the Blue Nile and Atbara rivers for July-October (5657 x 107m^{3}yr^{-1}) when compared to the average discharge for the main Nile at Dongola over the same months and years (1912-64) of 6138 x 10^7m^{3}yr^{-1} is about 92.2% of the discharge for the average July-October period. The average Blue Nile contribution is about 3.7 times that of the Atbara River for the July-October period.

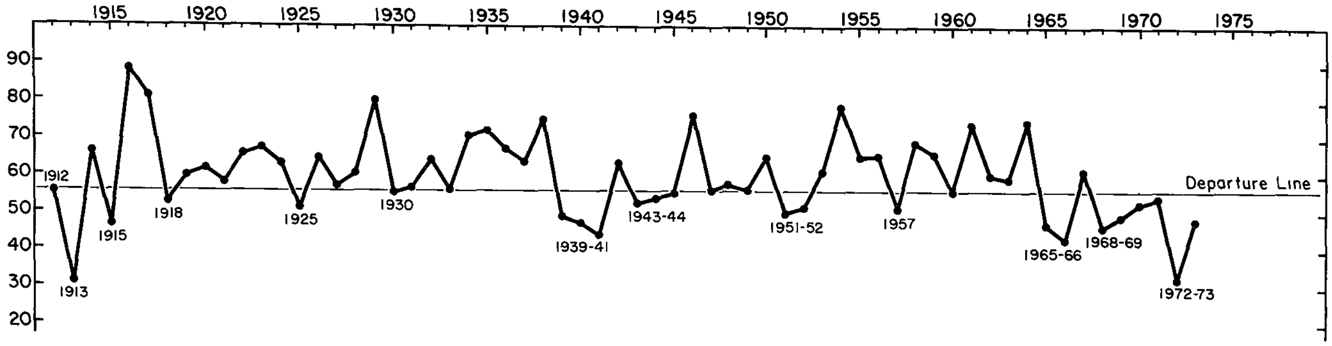
Table 3 - Relationship between decrease in annual maximum height of the Nile River flood at Cairo below applicable long-term average maximum height and departure of annual cumulative discharge amount for July-October below applicable annual average amount for July-October at Aswan Dam (23°45'N, 32°°50'E), Dongola (19°10'N, 30°29'E), and the combined Blue Nile/Atbara river discharges at respectively 15°37'N, 32°30'E/17°42'N, 33°58'E, with degrees of decrease/ reduction (1-5) indicated. (Holds up to about 1964; see text for details.) (Taken from Quinn, in press.)

Departure of annual maximum height below a specified average annual maximum height for the Nile River at Cairo in meters above Mediterranean Sea level at Alexandria	Degree of reduction in maximum flood height or discharge amount from long-term averages	Departure of annual cumulative discharge amount for July-October below a specified annual average amount for July-October for the indicated river discharge sites
.27-.53 m	1	546-1091 x 107m3
.54-.80 m	2	1092-1637 x 107m3
.81-1.07 m	3	1638-2183 x 107m3
1.08-1.34 m	4	2184-2729 x 107m3
1.35- m	5	2730- x 107m3

4. THE ENSO AND SEVERAL REGIONAL FEATURES

In constructing Table 4 the ENSO and El Niño entries were taken from Tables 1 and 2 (originally from Quinn, in press). The northeast Brazil drought (Seca) data are included in the chart since Secas often occur near the time of the El Niño, as noted by Caviedes (1973, 1985). Although the frequency of occurrence for Secas is less than that for El Niño, in most cases when there was a Seca there was also an El Niño. However, considering the global

Annual discharge of the Main Nile River for July-October at Dongola in $10^9m^3yr^{-1}$



Combined annual discharge of the Blue Nile and Atbara Rivers for July-October in $10^9m^3yr^{-1}$

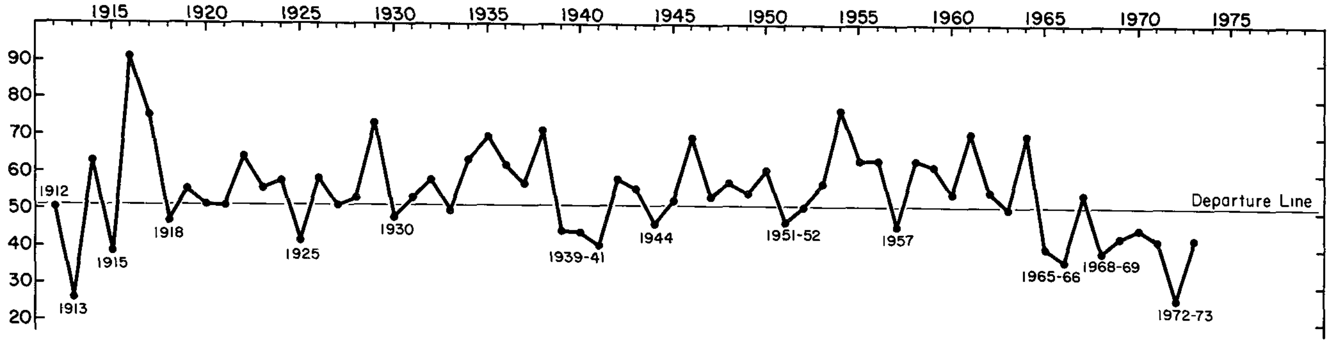


Fig. 1 - Annual discharge of the Main Nile River for July-October at
Upper Panel: Dongola (19°10'N, 30°29'E) in $10^9m^3yr^{-1}$, with the departure line at 55.92 x $10^9m^3yr^{-1}$ to signify the discharge level for the minimal degree 1 reduction from the long-term average discharge value. (See text and accompanying Table 3 for details.)
Lower Panel: Combined annual discharge of the Blue Nile and Atbara rivers for July-October at respectively 15o37'N, 32°E and 17°42'N, 33°58'E, in $10^9m^3yr^{-1}$, with the departure line at 51.11 x $10^9m^3yr^{-1}$ to signify the combined minimal degree 1 reduction from the long-term combined average discharge value. (See text and accompanying Table 3 for details.) (From Quinn, in press.)

zonal-vertical cells of Flohn (1971), this activity over Brazil would be primarily associated with the Atlantic cell in which the air of the southeast trades rises on the east side of the Andes and sinks off the west coast of Africa. References and more discussion on the Secas are contained in Quinn & Neal (1992). Data on the anomalously heavy rainfall over subtropical Chile are contained in Mackenna (1877), Taulis (1934), Quinn & Neal (1983a), and recent-year news reports. Data on anomalously heavy equatorial Pacific precipitation were obtained from Dixon (1877), Quinn & Burt (1970; 1972), Taylor (1973), Junk (1984), and Monthly Climatic Data for the World (1948-1991). Data on the east monsoon drought over Indonesia were obtained from Van Bemmelen (1916), Berlage (1957), and Flohn (1986). Australian droughts are as reported by Nichols (1988; in press). Records of deficient summer monsoon rainfall over India between 1769 and 1870 are based on information in Martin (1858-1861), Walford (1879), Hunter (1882), Hurst (1891), The Imperial Gazetteer of India (1908), Bhatia (1967), Mooley & Parthasarathy (1979), and Mooley & Pant (1981). Here we are interested in the deficient summer monsoon rainfall periods (June-September) which generally relate to a low SOI; however, many of the drought periods in various publications include the following dry season conditions that can persist through May of the following year. From 1871 on, deficient summer monsoon rainfall years were as noted in Mooley and Parthasarathy (1984). However, in Table 4 I have also listed those years that fell below their mean summer rainfall level, but which did not meet their deficiency criteria, and designated them as SBM (slightly below mean) since they were in the correct direction for the developments being evaluated. For the maximum levels of the annual Nile River flood and/or monthly and annual river discharge levels for various locations, I had the following information available for consideration over the period 1768-1991:

(1) Lyons (1906) data and graphic plots for 1768-1800 and 1825-1905;

(2) Toussoun's (1925) tabular data and some anecdotal information for 1768-1921;

(3) World Weather Records for 1931-1940 which include maximum annual height readings from the Roda gauge at Cairo for 1918-1943;

(4) World Weather Records for 1941-1950 which include height data at Roda for 1943-1954, and monthly and annual Nile River discharge data at Aswan for 1869-1954;

(5) Popper (1951) for data on flood levels for 1768-1889.

(6) Shahin (1985) which provides monthly and annual discharges for various locations along the White Nile, the Main Nile, Blue Nile and Atbara rivers for 1912-1973.

(7) Monthly Climatic Data for the World (1948-1991);

(8) Le Comte's world weather summaries (1980-1992).

Using Table 4 data for 1768-1868 when only the Nile River height data were available for determining maximum levels, but eliminating reference to the 1821 event since no Nile data were available for that year, there were 31 ENSO occurrences and 25 periods of related low annual Nile River flood maximums, for an 80.6% level of agreement. For the period 1871-1991, there were 33 ENSO occurrences and 27 periods of related low Nile River July-October discharge levels for an 81.8% level of agreement. There was an extremely dry period in subtropical Chile from 1770 through the early 19th century, most likely in association with Little Ice Age activity; and over that period only 1783 responded which was during the

Table 4 - Years with ENSO events and regional features relating to them for 1768-1992. For the east side of the «see-saw» it shows years with the El Niño, the northeast Brazil drought, anomalously heavy subtropical Chilean rainfall, and anomalously heavy equatorial Pacific rainfall; for the west side it shows years with Indonesian east monsoon drought, eastern/northern Australian drought, deficient summer monsoon rainfall over India, and weak Nile River floods due to deficient summer monsoon rainfall over the highlands of Ethiopia. Strengths (Str) are included for ENSOs and El Niños; and at times years are modified by E (early), M (mid), or L (late). Weak Nile floods are rated by degree (1-5) of reduction below average in height or discharge amount as indicated in Table 3, with confidence ratings (1-5) based on number of confirmation sources. The notation * indicates no data available.

ENSO		El Niño		NE Brazil Drought	St Chile Anm (+)	Eq. Pac. Anm (+)Pcpn	E. Mons. Drought	Australian Drought	Defic.India Sum. Mons.	Weak Nile Flood		
Yr	Str	Yr	Str							Yr	Deg	Conf
1768-69	M+	1768	M	-	1768	*	*	*	1769	1769	1	2
1772-73	M	1772	M	1772	-	*	*	*	-	1772	3	2
										1773	1	2
1776-E78	M+	1776-E78	S	1777-78	-	*	*	*	-	1776	2	2
1782-84	VS	1782-83	S	1784	1783	*	*	*	1782-84	1782	4	4
										1783	5	4
										1784	4	4
1785-86	M+	1785-86	M+	1786	-	*	*	*	-	1785	3	3
1790-93	VS	1791	VS	1790-93	-	*	*	1790-91	1790-92	1790	1	3
										1791	3	4
										1792	3	3
										1793	3	3
1794-97	M+	-	-	-	-	*	*	1796-97	-	1794	3	4
										1795	2	3
										1796	2	3
										1797	2	3
1799	M	-	-	-	-	*	*	1798-99	1799	1799	2	2
1802-04	S+	1803-04	S+	1804	-	*	*	1803-04	1802-04	1803	3	2
1806-07	M	1806-07	M	-	-	*	*	-	1806-07	1806	2	2
										1807	2	2
1810	M	1810	M	1809-10	-	*	*	1810	-	-		
1812	M+	1812	M+	-	-	*	*	-	1812-13	1812	1	2
1814	S	1814	S	1814	-	*	*	1814	-	1814	1	2
1817	M+	1817	M+	1816-17	1817	*	*	1817	-	-		
1819	M+	1819	M+	-	1819-20	*	*	1819	1819-20	-		
1821	M	1821	M	-	1821	*	*	1821	-	*		
1824-25	S	1824	M+	1824-25	-	*	*	1824	1824-25	1824	4	2
										1825	4	3
1827-28	S+	1828	VS	1827	1827-28	*	*	1828	1827-28	1828	2	2
1830	M	1830	M	1830	1829	*	*	-	-	1830	2	2
1832-33	S+	1832	M+	1833	1833	*	1833	1832	1832-33	1832	1	3
										1833	4	4
1835-36	M	-		-	-	*	1835	-	-	1835	4	2
										1836	3	2
1837-39	S	1837	M+	1837	1837	*	1838	1837	1837-38	1837	4	3
										1838	2	2
										1839	3	2
1844-E46	VS	1844-E46	M/ S+	1844-45	1843 & 1845	*	1844-45	1845	1844	1844	1	2
										1845	3	2
1850	S	1850	M	1850	1850-51	*	1850	1850	1850	1850	2	2
1852-E53	M	1852	M	-	-	*	1853	-	1853	1852	2	2

ENSO		El Niño		NE Brazil Drought	St Chile Anm (+)	Eq. Pac. Anm (+)Pcpn	E. Mons. Drought	Australian Drought	Defic.India Sum. Mons.	Weak Nile Flood		
Yr	Str	Yr	Str							Yr	Deg	Conf
1854-55	S	1854	M	-	1855-56	*	1855	1854	1855	1855	3	3
1857-E59	M+	1857-58	M	-	1858	*	1857	1857	-	1857 1858 1859	1 2 2	2 3 2
1860	M	1860	M	-	1860	*	-	-	1860	-		
1862	M-	1862	M-	-	-	*	-	1861-63	-	-		
1864	S+	1864	S	-	1864	*	1864	1864	1864	1864	4	4
L1865-E66	M+	E1866	M+	-	-	*	1866	1866	1865-66	-		
L1867-E69	S+	L1867-68	M+	1867	1868	M1868-E69	1868	1868	1868-69	1867 1868	1 4	2 4
1871	M	1871	S+	-	-	*	-	1871	-	-		
1873-74	M+	1874	M	-	-	*	1873	1874	1873SBM	1873	2	3
L1876-78	VS	1877-78	VS	1877-79	1877	*	1877	1877	1876SBM, 1877	1877	4	4
1880-81	M+	1880	M	-	1880	*	1881	1880	1880SBM	1881 1882	1 2	2 2
1884-85	M+	1884	S+	-	-	*	1884-85	1884	1885	1884 1886	2 1	3 2
L1887-E89	S	L1887-E89	M-/ M+	1888-89	1887-88	*	1888	1888	1888 SBM	1888	4	3
1891	M	1891	VS	1891	1891	*	1891	-	1891SBM	-		
1896-97	M+	1897	M+	1898	-	1896	1896-97	1896	1896SBM	1897	1	3
1899-M1900	VS	1899-E1900	S	1900	1899-1900	M1899-1900	1899	1899	1899	1899	5	4
L1901-02	S+	1902	M+	1902-03	1902	M1902-E03	1902	1902	1901, 1902SBM	1902	2	4
1904-05	S	1904-05	M-	1904	1904-05	M1904-	1905	1905	1904SBM, 1905	1905 1905	1 1	3 3
1907	M+	1907	M+	1907	-	-	-	1907	1907SBM	1907	2	2
1911-12	M+	1911-12	M	-	-	1911-12	1911	1912	1911,1912 SBM	1912	1	3
M1913-M15	S+	1914-E15	M+	1915	1914	L1913-M15	1913-15	1914	1913SBM, 1915SBM	1913 1915	5 2	4 3
1918-E20	S+	1918-19	M	1919-20	1919	M1918-E20	1918-19	1918	1819,1920	1918	1	4
1923	M	1923	M	-	-	1923-E24	1923	1923	1923SBM	-		
1925-26	S	1925-26	VS	-	1926	M1925-M26	1925-26	1925	1925SBM	1925	2	3
L1929-E31	M+	L1930-E31	M	1930-31	1930	L1929-E31	1929-30	1930	1929SBM, 1930SBM	1930	1	3
1932	M+	1932	S	1932	-	E1932	1932	1932	1932SBM	-		
1939	M	1939	M+	1939	-	L1939	-	-	1939SBM	1939	2	4
1940-41	VS	L1940-41	S	1941-42	1941	1940-41	1940-41	1940	1941	1940 1941	2 3	4 4
1943-44	M	1943	M+	-	1944	-	1944	1943	-	1943 1944	1 1	2 2
1951-E52	M+	1951	M-	1951-52	-	M1951-L51	1951	1951	1951,1952 SBM	1951 1952	2 1	3 2

ENSO		El Niño		NE Brazil Drought	St Chile Anm	Eq Pac. Anm	E. Mons. Drought (+)	Australian Drought (+)	Defic.India Sum. Mons.	Weak Nile Flood		
Yr	Str	Yr	Str							Yr	Deg	Conf
1953	M	1953	M+	1953	1953	E1953-L53	1953	1953	-	-		
1957-58	S	1957-58	S	1958-59	-	M1957-M58	1957SBM	1957	1957SBM	1957	2	3
1965-66	S	1965	M+	1966	1965	M1965-E66	1965	1965	1965-66	1965	3	2
										1966	3	2
M1968-69	M-	1969	M-	1970	-	E1969	-	-	1968SBM	1968	2	2
										1969	2	2
1972-73	S+	1972-E73	S	1972	1972	M1972-M73	1972	1972	1972	1972	5	2
										1973	2	2
1976-77	M	1976	M	-	-	M1976-E78	1976	1976	-	-		
1979-80	M-	-		1979-80	-	L1979-80	1979	1980	1979	1980	1	2
1982-83	VS	L1982-M83	VS	1982	1982	M1982-M83	1982	1982	1982	1982	3	2
M1986-87	M	1987	M	-	1987	M1986-87	1987	1987	1987	1987	2	2
M1991-92	S	1992	S	*	1991	M1991-92	1991	1991	1991(Nw India)	1991	2	2

exceptionally strong 1782-84 ENSO (See Wood, 1984, concerning the unusual year of 1783.). The contents of Figure 1 and Table 4 provide verification for the relationship between the ENSO and the Nile River years of flood deficiency. In fact, the years of S, S+, and VS intensity ENSO's in Table 4 agree to the 100% level.

5. EARLY NILE RIVER RECORDS

History of the Nile River dates back to about 5000 B.C. and the record of Nile levels dates back to about 3000 to 3500 B.C. (Bell, 1970; 1971; Shahin, 1985). An historical overview covering nilometer development and information sources is provided in Quinn (in press). Problematic aspects such as variations with time in flood levels attributable to sedimentation, original source data in cubits and fingers, scales of measurement used, variations with time in the minimal level required for irrigation (plenitude) in Egypt, use by the Mohammedan chroniclers of the Mohammedan lunar calendar which rotates through all months of the solar year once in each cycle of about 33 of its years, and use of the skip year in the Mohammedan calendar which is the 33rd year of a cycle when equated with a cycle of 32 solar years, are discussed in Quinn (in press). Records on events (weak or excessive Nile flood years) as reported by the different chroniclers, may often differ by a year in the older records due to the recognition of different skip years. The following empirical formula which was obtained from Albert Galloway, a professional numismatist, was found to be very useful for converting the A.H. (anno Hegirae) dates of the Mohammedan era to A.D. dates:

A.H. date — (0.0303 x A.H. date) + 622 = A.D. date.

6. YEARS WITH LOW NILE MAXIMUM LEVEL FLOODS A.D. 622-1991

Table 5 was constructed after considering tabulated data and textual information in Toussoun (1925) as modified by tabulated data, graphic plots, and corrections from Popper (1951). Popper's tables included data on the stronger developments from Ibn Taghri Birdi, Ibn al-Hijazi and Ibn Aibak. Table 5 lists the years of poor Nile floods, their degree of weakness (1-5) and a confidence rating (1-5). For about the first 460 years, the smallest flood deficiency level (1) was just below 16 cubits (cu), the original plenitude level [16 cu = 17.35 m above Mediterranean Sea Level at Alexandria in Toussoun's (1925) data, which is a little below normal for the period]. For the other degrees of weakness (2-5), the reduction values, based on 50-year averages for the annual Nile River maximum levels at Cairo, are as indicated in Table 3. After A.D. 1080, the degree of reduction, using the applicable 50-year average, pertains to all degrees as it did for Table 4 data. Also, the confidence level (1-5) is based on the number of sources of evidence [e.g., Toussoun, Popper, Popper's Arab sources (Ibn Taghri Birdi, Ibn al-Hijazi, Ibn Aibak)].

Table 5 shows a total of 179 weak Nile flood years with varying degrees of deficiency (1-5); during this 901-year period (622-1522) the figures on the average would indicate a weak Nile flood occurrence about every 5 years. However, the distribution of these weak Nile flood years makes it difficult to relate them to ENSO events during periods of extended weakness. Considering what we see in Table 4 and between applicable parts of Table 1 and Table 5, it appears possible that those extended weak Nile flood periods of 4-7 years in a row, that occur in the first part (based on the A.D. 622-999 record) of Table 5, may be associated with 2 or more ENSOs, with one setting in at the onset of the period and another 2 or 3 years later. There will be further discussion of these extended periods of activity in the following section. Out of the 901-year record with 179 years of weak Nile floods, there were 97 in degree 1, 33 in degree 2, 25 in degree 3, 13 in degree 4, and 11 in degree 5. Over the period A.D. 622-999 there were 105 years of weak Nile floods, occurring in approximately 27.8% of the years. Over the period A.D. 1000-1290 there were 24 years of weak Nile floods, occurring in about 8.2% of the years. For the period A.D. 1291-1522 there were 50 years of weak Nile floods, occurring in about 21.6% of the years. There were several cases of extended records during the earliest period but none in the other 2 periods of Table 5. It was now essential to tie in these earlier findings with the later records on the Nile; and although there were several breaks in the record between 1523 and 1823, it was possible to construct Table 6, despite breaks in the record, through the use of diagnostic interpretation as applied to data and anecdotal information obtained from Walford (1879), Lyons (1906), Toussoun (1925), Jarvis (1935), Hurst (1957), Popper (1951), Bell (1971), Shahin (1985), Le Comte (1980-1991), and many other authorities.

The available information for the years A.D. 622-1991 is broken down into 5 periods for considering the occurrence of those years with weak Nile River flood maximums, as shown in Table 7. Over the period 1523-1899 weak Nile floods occurred about 28.1% of the years. Also, several cases of extended weak Nile floods occurred over this period. During the recent period 1900-1991 weak Nile floods occurred about 29.3% of the years, but there were no periods of extended activity. Over the period 1525-1991 about 80.3% of the ENSOs were accompanied by weak Nile floods.

Table 5 - Years (Yrs), over the period A.D. 622-1522, with weak Nile floods (those below plenitude and/or specified average annual maximum flood levels) at Cairo, rated by degree (Deg) of deficiency (1-5) as noted in Table 3, with confidence (Conf) ratings based on the number of confirmation sources. (See text for details.)

Yrs	Deg	Conf	Yrs	Deg	Conf	Yrs	Deg	Conf	Yrs	Deg	Conf
629	4	2	759	1	2	828	1	2	941	1	1
									942	1	1
632	2	2	761	1	5	830	4	5			
			762	1	2				945	1	5
642	2	2	763	1	2	832	3	5	946	1	5
			764	2	2	833	2	2	947	1	5
650	5	3	765	1	2	834	1	2	948	3	5
									949	3	4
662	1	4	767	1	2	836	1	2	950	1	3
						837	2	2	951	1	3
678	1	2	769	2	2						
			770	2	2	841	4	5	963	1	2
683	1	2	771	1	2	842	5	4	964	2	2
			772	1	2				965	1	2
687	3	2	773	1	2	847	1	2	966	3	2
688	4	5				848	2	2	967	5+	5
689	5	5	776	2	2						
						850	1	2	977	1	2
691	1	4	779	1	2	851	3	2			
			780	1	2	852	1	5	981	2	3
693	3	5	781	1	2				982	2	5
694	5	5	782	3	5	860	1	2			
695	3	3							989	1	2
696	4	3	785	1	2	881	3	4			
									996	1	2
702	3	5	788	1	5	885	1	2			
			789	1	5				1007	3	5
705	4	5				887	1	5	1008	4	5
			791	2	2	888	1	5			
713	4	5	792	1	2				1023	3	5
						894	1	2			
721	1	4	794	1	5	895	3	5	1036	2	2
									1037	1	2
723	1	3	796	1	2	897	1	2			
			797	2	2				1057	1	2
726	1	4				903	5	5			
			799	2	2				1066	2	2
733	2	2				907	1	2			
			802	3	3				1072	1	2
735	3	3	803	4	5	917	1	4			
									1085	3	5
737	1	2	811	1	2	927	3	4			
			812	4	3				1096	5	1
740	1	2				931	2	2			
			817	2	2				1122	1	2
756	2	5	818	1	2	939	2	2			
									1124	1	2
1144	5	2	1313	1	3	1385	2	3	1459	1	3
1159	4	5	1321	1	3	1389	3	3	1461	2	3
									1462	1	3
1200	5+	5	1326	1	3	1393	2	3			
1201	1	2				1394	2	3	1466	1	2
1202	1	2	1334	1	3						
						1399	1	3	1468	1	2
1210	3	4	1337	1	3						
			1338	1	3	1401	2	3	1474	2	2
1219	3	4				1402	1	3			
			1340	1	3	1403	4	4	1484	1	2
1230	5	3									
1231	1	2	1348	1	2	1408	3	4	1490	1	2
1234	1	2	1350	1	2	1418	1	2	1492	1	2
			1351	1	2						

1244	4	4	1362	1	2	1420	1	3	1497	3	3
1290	1	2	1369	1	2	1424	2	3	1504	1	2
1294	3	4	1370	1	2	1427	3	3	1510	1	3
1297	1	2	1373	2	3	1433	2	3	1518	2	3
1298	2	2	1380	1	2	1449	1	3	1520	1	2
1309	1	3				1450	5	4			
						1451	1	3			

Table 6 - Years (Yrs) with deficient annual maximum Nile River heights at Cairo/deficient July-October Discharge levels into the Nile River system of Blue Nile and Atbara River water, resulting from deficient summer monsoon rainfall over the highlands of Ethiopia during the period 1523-1991; and ratings by degree (Deg) of deficienty (1-5) as noted in Table 3, with confidence (Conf) ratings (1-5) based on the number of confirmation sources.

Yrs	Deg.	Conf	Yrs	Deg.	Conf	Yrs	Deg.	Conf.	Yrs	Deg.	Conf
1525	1	2	1650	5	3	1762	2	2	1832	1	3
1531	1	2	1655	1	1	1765	3	2	1833	4	4
1540	2	2	1661	3	2	1766	4	3	1835	4	2
1541	1	2	1671	1	1	1769	1	2	1836	3	2
1544	2	2	1683	1	1	1772	3	2	1837	4	3
1553	5	2	1687	1	1	1773	1	2	1838	2	2
1559	1	1	1694	5	2	1776	2	2	1839	3	2
1567	3	1	1695	2	1	1782	4	4	1844	1	2
1578	3	2	1697	1	2	1783	5	4	1845	3	2
1582	1	2	1703	1	2	1784	4	4	1850	2	2
1589	2	2	1709	1	2	1785	3	3	1852	2	2
1596	1	2	1713	3	3	1790	1	3	1855	3	3
1600	4	2	1714	1	2	1791	3	4	1857	1	2
1604	4	2	1715	5	2	1792	3	3	1858	2	3
1607	3	2	1716	5	2	1793	3	3	1859	2	2
1614	1	2	1720	1	2	1794	3	4	1864	4	4
1618	2	2	1723	2	3	1795	2	3	1867	1	2
1621	3	2	1725	3	2	1796	2	3	1868	4	4
1624	1	2	1731	2	2	1797	2	3	1873	2	3
1630	4	2	1734	1	2	1799	2	2	1877	4	4
1631	3	2	1737	2	3	1803	3	2	1881	1	2
1635	2	2	1744	1	1	1806	2	2	1882	2	2
1640	4	3	1748	1	2	1807	2	2	1884	2	3
1641	5	3	1754	1	1	1812	1	2	1886	1	2
1647	1	1	1758	3	2	1814	1	2	1888	4	3
1905	1	3	1925	2	3	1824	4	2	1897	1	3
1907	2	2	1930	1	3	1825	4	3	1899	5	4
1912	1	3	1939	2	4	1828	2	2	1902	2	4
1913	5	4	1940	2	4	1830	2	2	1972	5	2
1915	2	3	1941	3	4	1951	2	3	1973	2	2
1918	1	4	1943	1	2	1952	1	2	1980	1	2
			1944	1	2	1957	2	3	1982	3	2
						1965	3	2	1987	2	2
						1966	3	2	1991	2	2
						1968	2	2			
						1969	2	2			

7. DISCUSSION

All available information and data have been carefully reevaluated and coordinated prior to entry into the various tables of this report. In addition to the sources referred to here and in prior work on this subject, the high index (anti-ENSO) features, that occurred between the 7th century and the present, were referred to as a further control on the ENSO event occurrences. In the studies of various portions of the record from 1523 up to the present, it was noted that about 80-81% of the ENSOs were accompanied by years with low Nile maximum levels. However, this percentage of agreement increased for ENSO events in the S, S+, and VS categories. Information of this nature can be useful when relating event occurrence dates of this historical sequence to those estimated in the various proxy records. Based on the contents of Tables 1 and 5 there is a continuous record of low SOI-related climatic activity available for A.D. 622-1992. Considering the degree 5 Nile reductions (prior to 1523)/very strong ENSO activity (1523-1992), the years of extreme low SOI-related climatic conditions would appear to be A.D. 650, 689, 694, 842, 903, 967, 1096, 1144, 1200, 1230, 1450, 1661, 1694-95, 1782-84, 1791-93, 1844-45, 1877-78, 1899-M1900, 1940-41, and 1982-M83.

I have often been queried about using rainfall data to quantify the river data over northeast Africa. One must realize that it would take several thousand rainfall and evaporation stations to attempt to provide the excellently integrated data available through the river discharge systems.

I agree with Popper (1951) on his views concerning the sedimentary buildup of the Nile River bottom. There appeared to be very little buildup over the first 4 centuries. It is expected that average rainfall was less over this early cool period. And, of course, a cooler atmosphere would contain less precipitable water. It is expected that the rainfall amount was a little higher and less variable, in general, during the Little Climatic Optimum.

The extended periods of low Nile flood also appear to be a feature of the cooler ages. The 7-year period of plenty and 7-year period of famine, as referenced in the Bible no longer appears unusual when reviewing these long records. In fact, the low Nile flood period of 1790-1797 can be verified by 3 separate sets of data, Lyons (1906), Toussoun (1925), and Popper (1951). This extended weak Nile flood condition has been studied in more detail. Since the Ethiopian highlands are at the westernmost periphery of the summer monsoon system, a significant lag in the shifts in location, depth, and areal extent of the equatorial low from its low index (ENSO) phase position in the east over to its high index (anti-ENSO) phase position to the west could very well lead to an extension of the associated weak Nile flood (low summer monsoon rainfall over the Ethiopian highlands) condition; and, this in conjunction with successive ENSO's could bring about extended low Nile flood periods such as we see in 1790-1797.

A.D. 1525-1899, which would, in general, be considered the Little Ice Age (LIA), shows frequent occurrences of weak Nile floods and also shows several extended periods of weak Nile floods (Table 7); whereas, A.D. 1000-1290 which would be considered to represent the Little Climatic Optimum (LCO) shows a very low percentage of weak Nile floods and no extended periods for such floods. A.D. 1291-1522 was considered to be an interim period between the LCO and LIA. Based on the above findings it would appear that activity over A.D. 622-999 would be more representative of a cool period. This would be in agreement with Maejima & Tagami (1986) who noted a cool age during the 7th-9th centuries in Japan.

Moreover, the findings here would indicate that Joseph lived during a cool period (prior to and after 1700 B.C.), with his 7 years of famine setting in about 1708 B.C. (Walford, 1879; Biswas, 1970; Encyclopaedia Judaica, 1971).

Increasing SSTs, along with decreasing sea level atmospheric pressure were noted over the southeast Pacific in Quinn (1979). The temperature increases since mid-1976 over the tropics and lower subtropics were further discussed in Quinn & Neal (1984) and the extended effects can be seen in the generally lowered SOI values of Figure 2. Over the period April 1976-March 1988 the SOI anomalies averaged out to 1.5 mb below the mean. All other pressure indices showed a similar drop over this 12-yr period. It is interesting that one of the strongest recorded ENSOs (1982-1983) occurred in the midst of this significantly below-normal SOI period (Quinn & Zopf, 1984). Also, when we came out of that 12-yr period of below average SOIs, the plot moved up rapidly into the high SOI feature of 1988 (Fig. 2) and this was accompanied by a period of extremely heavy rainfall and flooding in the western sector of the SO. Le Comte (1989) reported that:

«Heavy rainfall in the Blue Nile's catchment basin in the Ethiopian highlands during late July and early August contributed to major flooding along the Nile in Sudan.»

An Egyptian newspaper *al-Ahram* in its 13 August 1988 edition stated that the two Nile tributaries the day before spilled across a region south of Khartoum «until only tree tops remained visible.» This was the first such period of flooding rains over this region in more than a decade. Since mid-1989 it appears that we have slipped back into the generally below normal index mode, and this continued indication of increased sea temperatures forewarns us of serious marine ecological consequences that may continue to arise in the global coastal zones of the tropics and lower subtropics. Over the past 12 years many of the global coral reef regions have been seriously threatened (Bunkley-Williams and Williams, Jr., 1990); and, in particular, the very strong 1982-1983 ENSO was disastrous to several coral reef areas (Glynn, 1990).

One of the interesting findings from this study is the fact that the large-scale ENSO developments often show up many months earlier in the regional features on the western side of the «see-saw» than they do on the eastern side. This was of course very clearly shown in the case of the very strong 1982-1983 ENSO.

Based on this study, it appears that the LCO and LIA may have caused some significant changes in the SO-related activity. In Quinn and Neal (1992) it was noted that the LIA caused an increase in the length and strength of subtropical Chilean droughts during the 17th, 18th, and early 19th centuries. In fact, during the peak drought period, 1770-1814, there was only one ENSO strong enough to bring about an above normal subtropical Chilean rainfall; this was the very strong ENSO of 1782-1784 that caused the heavy Chilean rainfall and floods of 1783 (1783 was a very unusual year for atmospheric phenomena, as reported by C.A. Wood in the 24 June 1984 EOS. The Laki volcanic eruption occurred in Iceland in 1783 along with other unusual phenomena.). I have often been questioned concerning the effects of volcanic eruptions on ENSOs and whether the El Chichon eruption caused the onset of the very strong 1982-1983 El Niño. As pointed out in Quinn & Neal (1983b) El Chichon occurred in April 1982, and by that time several of the ENSO-related developments were already underway, particularly those on the western side of the «see-saw.» In looking over past records I find as many or more cases where strong ENSO activity led volcanic activity. For

Table 7 - The years A.D. 622-1991 are broken into 5 periods for considering the occurrence of weak Nile River floods (WNRFs): 622-999, a relatively cool period; 1000-1290, representing the Little Climatic Optimum (LCO); 1291-1522, considered to be an interim period between the LCO and Little Ice Age (LIA); 1523-1899, representing the LIA; and 1900-1991, covering the recent period. The number of WNRFs by degree (as specified in Table 5) and total number are listed for each period, as are cases where extended (4 or more years in a row) of WNRFs occurred.

Period	Feature	Number of WNRFs by degree					Total number	Cases where WNRFS occur 4 or more years in a row
		1	2	3	4	5		
622-999	Cool period	55	20	15	9	6	105	693-696, 761-765, 769-773, 779-782, 945-951, 963-967
1000-1290	LCO	10	2	5	3	4	24	None
1291-1522	Interim period	32	11	5	1	1	50	None
1523-1899	LIA	34	27	21	16	8	106	1713-1716, 1782-1785, 1790-1797, 1835-1839,
1900-1991	Recent period	8	13	4	0	2	27	None

example there was no ENSO in 1815 or 1816 following the larger 1815 Tambora eruption, although there was a strong El Niño in 1814. However, after thinking about the reports of years without a summer over the New England states in 1816 and 1884 following the large Tambora and Krakatoa eruptions, I began to realize that when the two types of event occur near the same time, it might be the simultaneous occurrence of atmospheric warming over the tropical Pacific due to the ENSO and the cooling in higher latitudes as the optical depth of volcanic aerosols increased there, that caused the extreme weather activity of 1982-1983. I had checked with Dr. Kirby Hanson (then at ERL NOAA) and he reported that there were high turbidities in the polar atmosphere in spring 1983 and that it could also be assumed to be high there in the winter of 1982-1983. As an analogue, there was the great volcanic explosion of Krakatoa in August 1883 and the ENSO that set in early 1884; and it was in early 1884 that we had extremely heavy rainfall over the southwestern U.S. In fact, Los Angeles and San Diego received their greatest rainfalls in 1884.

For climatic trends Table 7 may be quite useful. Lamb (1977) indicates a warm dry time around 300 to 400 A.D. and a colder climate phase between A.D. 500 and 900 in Europe. The latter information like that from the Japanese (Maejima & Tagami, 1986) would tie in closely with our findings for East Africa. This study indicates that the most disastrous Nile flood failure occurred in A.D. 1200, and it is quite likely that the related large-scale ENSO was similarly unusual and may have caused the exceptionally strong El Niño that led to the cataclysmic «Chimu flood» in coastal Peru, which was reported in Nials *et al.* (1979).

The deficient summer monsoon rainfall over the highlands of Ethiopia and the El Niño along the coast of southwest Ecuador and northwest Peru are at opposite ends of the «see-saw» of ocean-atmosphere conditions, yet they are both integral features of the large-scale ENSO. However, as indicated by Griffiths (1972), the summer monsoon rainfall is primarily affected by the development and location of the equatorial low core of the SO; whereas, the winds, currents, SST conditions, coastal sea levels and weather conditions over the eastern tropical Pacific side of the ENSO depend greatly on the changes that take place in the southeast Pacific subtropical high.

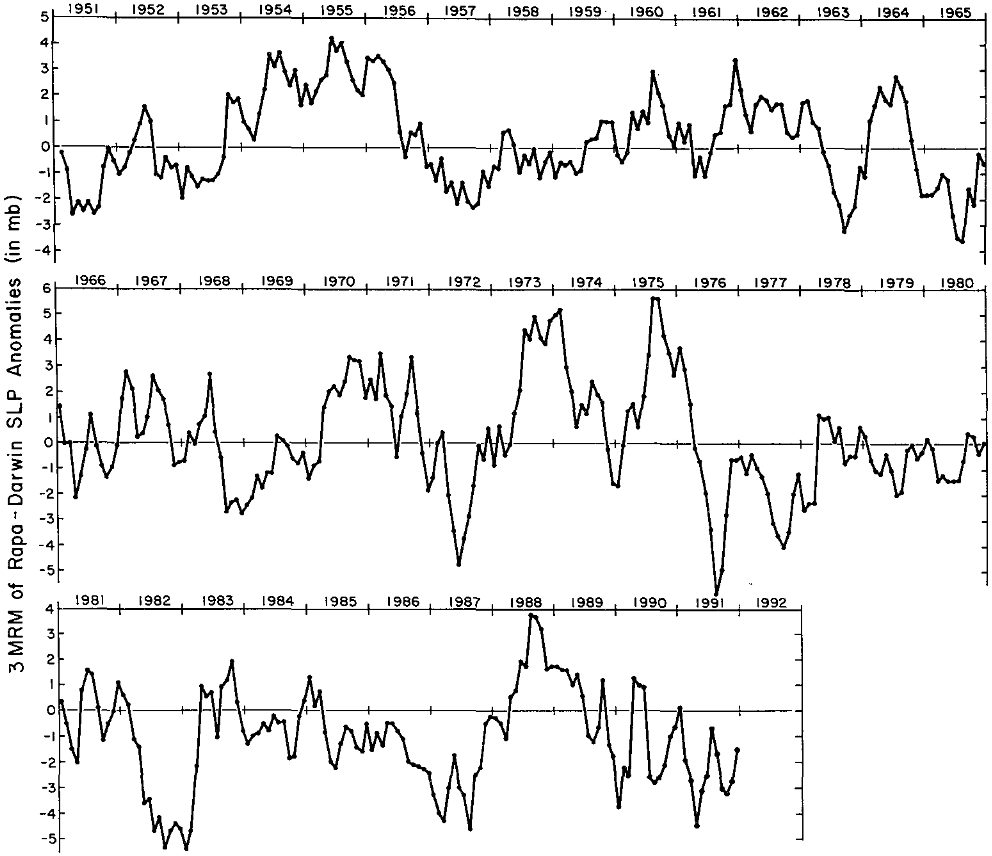


Fig. 2 -Three-month running mean plot of anomalies of the difference in sea level atmospheric pressure (mb) between Rapa Island (27o37'S, 144°20'W) and Darwin, Australia (12°26'S, 130°52'E). (Anomalies are based on data for 1951-1988.) (From Quinn, in press.)

Much more study is required to determine the cause of the significant differences between the SO-related climatic activity (as indicated herein) for the cool periods and the Little Climatic Optimum.

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