JIMAR CONTRIBUTION N0. 91-233
DATA REPORT NO. 008

Joint Institute for Marine and Atmospheric Research

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Honolulu, Hawaii 96822

TOGA SEA LEVEL CENTER:

DATA FROM THE INDIAN OCEAN

by

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National Oceanographic Data Center

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October 1990

Abstract

The TOGA Sea Level Center has collected sea level data in the Indian Ocean from a network of island-based and coastal tide gauges, most of which have been recording since 1985. This network consists of stations of the Indo-Pacific Sea Level Network, which is a cooperative between the University of Hawaii and the host countries, and stations operated by national agencies. A description of acquisition, quality control, assessment, and the present contents of the data archive is provided.

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Introduction

Over the past few decades, the scientific community has become increasingly interested in the predictability of climate. Consequently, the World Climate Research Programme (WCRP) was created by the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) with the objective to determine the extent of climate predictability and of man's influence on climate.

A key activity of the WCRP is the Tropical Ocean Global Atmosphere (TOGA) Project, which has been organized with the joint support of the ICSU's Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The TOGA project has several principal objectives: 1) to determine the predictability of the coupled atmosphere-ocean system on time scales of months to years and to understand the mechanisms and processes underlying its predictability, 2) to study the feasibility of modelling this system for the purpose of predicting its variations on the same time scales, and 3) to provide the scientific background for designing an observation and data transmission system for operational prediction if the coupled air-sea models prove to be reliable.

The TOGA International Implementation Plan was prepared to design the strategy for meeting these objectives. A major component of the plan is to monitor the global atmosphere and the upper layers of the three tropical oceans during the ten-year period of 1985-1994. Existing meteorological and oceanographic observation systems have been maintained and new networks have been installed. These observations along with available historical data will provide a description of the ocean-climate system and its variability from sub-seasonal to interannual scales and will serve as the basis for studies of oceanic and atmospheric dynamics and for model input and verification.

An important parameter of the ocean monitoring system is sea level. The TOGA program requires daily sea level values with an accuracy of 2 cm from the sites stated in the implementation plan (International TOGA Project Office, 1987). In order to concentrate the efforts of acquiring, processing, and archiving the sea level data, the TOGA Sea Level Center was established at the University of Hawaii under the direction of Dr. Klaus Wyrtki, who was chiefly responsible for the original Pacific Ocean network of sea level stations and more recently, the Indo-Pacific network. This center is supported by the National Oceanographic and Atmospheric Administration (NOAA).

The functions and responsibilities of the TOGA Sea Level Center include the collection of data from selected island-based and coastal tide gauges in the Pacific and Indian Ocean tropical belt between 30 N and 30 S starting January 1985 and the collection and archival of sea level data obtained before 1985 provided by the originators of the data. Data from the tropical Atlantic are not routinely collected; however, contributions are accepted. Hourly, daily, and monthly values are prepared and archived. Other activities are to analyze the data, to produce products, and to establish and operate an archive of sea level data which are stored digitally on magnetic tape and distributed yearly to other TOGA data centers, to the Permanent Service for Mean Sea Level (PSMSL), and to World Data Centers A and B for Oceanography. The TOGA Sea Level Center also contributes to the Global Sea Level Observing System (GLOSS).

As the quantity of data collected by the TOGA Sea Level Center increased, expertise in data management was provided by the National Oceanographic Data Center (NODC) with the establishment of the Joint Archive for Sea Level (JASL) at the University of Hawaii. The JASL is designated to assist the TOGA Sea Level Center with acquisition, quality assurance, and archival of sea level data. The proximity of JASL staff to the sea level experts insures a research data set of the highest quality, while the NODC lends its skills in data management to aid in timely turnaround of concise, standardized, well-documented data sets to the scientific community.

This report focuses on the sea level data collected in the Indian Ocean by the TOGA Sea Level Center. Similar information for the Pacific Ocean has been documented (Caldwell *et. al*, 1989). First, the TOGA Sea Level Network in the Indian Ocean is described. Secondly, methods of acquisition, quality control, and assessment are detailed, and finally, the permanent archive and data requests are discussed.

The TOGA Sea Level Network in the Indian Ocean

The TOGA Implementation Plan has designated 58 stations as sea level observation sites in the Indian Ocean network (Table 1A and Figure 1). At the beginning of the TOGA project in 1985 sea level stations existed only along the coasts of Australia, Thailand, India, Pakistan, and South Africa, and on a single island, Reunion. Since 1985, more than 30 stations have been newly established or re-activated by the University of Hawaii as well as by many national agencies.

The University of Hawaii, in cooperation with the host countries, established sea level stations at 20 sites (Table 2), of which 13 are island-based. Of these 20, Agalega Island has not delivered any data because the bubbler gauge was repeatedly destroyed by wave action. Data return from Praslin, Mogadishu, and Kismayo has been irregular due to lack of support from local authorities. With the exception of a bubbler gauge at Agalega, all stations consist of float and stilling well analog or analog-to-digital recorder (ADR) gauges. In contrast to most sites of the sea level network in the Pacific Ocean, redundant sensors at each site are not available and satellite transmitters have not yet been installed. Although the data return has not been as successful as in the Pacific, a return rate of 90% has been maintained for the other 14 stations, excluding the Maldives. The worst rates of return are in the Maldives with values of 53 and 70% for Male and Gan during 1987 - 1989, respectively. These poor rates are attributed to the difficulties of getting spare parts to these isolated sites as well as the insufficient support from the local authorities. On the other hand, rates of return greater than 97% have occurred at Diego Garcia, Port Louis, Port Victoria, Zanzibar, and Benoa.

Other national agencies participate as well. Australia has installed gauges on Christmas and Cocos Islands in addition to the existing 6 gauges along the west coast of their continent. Malaysia has installed a network of 5 stations on the western Malay Peninsula. Indonesia hosts several gauges not listed in the TOGA Implementation plan which are part of the ASEAN network, a cooperative with Australia. Historic data sets have been provided for Mozambique by Portugal and for Port Victoria, Diego Garcia, Port Louis, and Aldabra by England. A complete list of data originators is provided in Appendix 1. The length of the historic sets averages 5 years with the longest records from Durban (28 years), Colombo (13 years), and Port Victoria (10 years).

The TOGA network in the Indian Ocean is more than half complete; 38 of the 58 stations in the implementation plan exist. In addition, data from many stations not listed in the original plan are available (Figure 2 and Table 1B). Desirable missing island stations are Banda Acheh, Telukbetung, and Kupang in Indonesia, and Minicoy, Nicobar, and Port Blair in India. In the Indian Ocean, only India is withholding its data.

Acquisition, Quality Control, and Assessment

Acquisition

The University of Hawaii, in conjunction with participating agencies in the host countries (Appendix 1A), provides data for 19 stations. The data are routinely received by mail at the TOGA Sea Level Center on continuous paper rolls from the analog gauges and on punched paper tape rolls from the ADR gauges. These data are received in a delayed mode. Most monthly rolls are received with about a month lag; however, for remote stations, rolls are received in batches with up to a 4-month lag.

Many national agencies also contribute data to the TOGA Sea Level Center (Appendix 1B). Originally, daily data were requested; however, experience has shown that daily values cannot be properly quality controlled. Consequently, requests were made for hourly values. The response has been positive as over 150 station years from 14 countries or agencies have been received. Most requests are sent by mail, and data are typically received in digital form on floppy diskettes, magnetic tape, or hourly listings. If necessary, comparative readings from a tide staff and the levelling history for each station are also requested.

Quality Control

The quality control procedures applied to the data received by the TOGA Sea Level Center are performed at annual increments. There are several reasons for choosing this schedule. First, most of our stations report data via punch paper tapes that are received in a delayed-mode as mentioned above. Second, a fully quality-controlled sea level data set must be placed on a carefully maintained reference level. Possible level shifts are best detected and corrected on time series longer than one month. Finally, and most importantly, the effort required to process a year-long time series is not significantly greater than that required to process a month-long series. Since the TOGA project did not require data to be available operationally, support was not requested to create a more timely, and more expensive, data set. Where possible we have included data from 1989 and 1990 in the present catalog; however, the normal schedule is to make data available 18 months after the end of the calendar year in which it was collected. Requests for selected data on a shorter time scale can be accommodated, but must be considered on a case-by-case basis. Of course, an operational data set could be provided if additional funding were available.

The processing of the data at the TOGA Sea Level Center is thoroughly documented (Wyrtki *et al.*, 1988). Briefly, several techniques are employed to insure the integrity of the sea level data after they are received on analog paper strips and punched paper tape rolls, which are normally recorded at 15-minute intervals. The checks consist of replacing obviously wrong values, correcting timing drifts, and maintaining reference level stability. The basis for most quality control is the calculation and graphical display of residuals, which are the observed data minus the predicted tides. The predicted tides are formed using a least squares harmonic analysis technique (Foreman, 1977). The analysis is performed on a year of apparently good data with minimal gaps for the calculation of harmonic constituents which, in turn, can be used to predict the tides for other years.

Because redundant sensors are not available for the Indian Ocean sites, data gaps can not be easily replaced. If a gap less than or equal to 24 hours exists, the gap is filled by the predicted tide method. This method consists of statistically comparing the predicted tides to the observed data and shifting the predicted tides in time to correct for timing differences, then adding the linear interpolation between hourly values at the end points of the gap in the residual series to the corresponding corrected predicted tide data to obtain interpolated values over the span of the gap. Gaps longer than a day are left untouched and are documented.

Data from the ADR gauges are decimated into hourly values with a three-point Hanning filter centered on the hour. This filter was chosen to minimize aliasing from subsampling and to minimize the attenuation of the tides. The procedure was tested with actual tide data as well as random data. Data from the analog rolls are spot read on the hour.

The *hourly data sets* form the focal point for quality assurance and assessment for all data sources. The ADR data received on punched paper rolls at the University of Hawaii need less processing at the hourly level since they are checked at the 15-minute interval. However, data from the analog rolls and data received as hourly values from international sources require closer examination. Quality control involves the steps taken with the high-frequency data as mentioned above: replacement of obviously wrong data values and short gaps, correction of timing drifts, and maintenance of reference level stability. Checks begin with an examination of a plot of residuals. Obviously wrong data values and short gaps in a span less than or equal to 24 hours are replaced by the predicted tide method. Obviously wrong data in a span greater than 24 hours are removed from the record. Timing errors of exact increments of one hour are corrected by shifting the data. The reference levels are corrected at the TOGA Sea Level Center for all stations listed in Table 2. Reference levels of data from international sources are corrected by the responsible agencies. Daily values via a simple 25-hour average are computed and plotted to monitor the stability of the reference level. These daily values are not archived. Differences of daily values with neighboring stations are also helpful. If a shift is suspected, the responsible agencies are informed and requested to investigate. If the agencies cannot provide information, obvious shifts are corrected to the best of our ability and documented in the quality assessment. Unresolved shifts are also documented. The record for a station is broken into separate data sets if the reference levels on either side of a reference level shift are not linked by levelling to the same bench marks. Such segments of sea level records are distinguished by alphabetically placing letters behind the station name, for example, Port Louis-A and Port Louis-B. Upon completion of quality control for the hourly values, all data are relative to GMT and are in millimeters.

Daily values are obtained using a two-step filtering operation. First, the dominant diurnal and semi-diurnal tidal components are removed from the quality controlled hourly values. Secondly, a 119-point convolution filter (Bloomfield, 1976) centered on noon is applied to remove the remaining high-frequency energy and to prevent aliasing when the data are computed to daily values. The 95, 50, and 5% amplitude points are 124.0, 60.2, and 40.2 hours, respectively (Figure 3). The Nyquist frequency of the daily data is at a period of 48 hours which has a response of about 6% amplitude, thus, aliasing is minimal. The primary tidal periods have a response of less than 0.1% amplitude.

The filtering operation incorporates an objective procedure to handle gaps. This objective technique simply replaces the filter weight at any missing observation with a zero and renormalizes the sum of the modified weight function to unity. This technique is equivalent to interpolating the missing observation with an estimate of the local mean of the time series. The local mean is defined as the mean of a given segment of length equal to the length of the filter. The error associated with this technique can be estimated objectively and is used as a criterion for accepting or rejecting a daily value computed in an area of the time series which contains a gap or gaps. This error depends on the ratio of the standard deviations of the input (hourly) and the output (daily) data. Thus in order to keep the ratio low, it is essential to apply this technique to the residual series as defined above.

The *monthly values* are calculated from the daily data with a simple average of all the daily values in a month. If seven or fewer values are missing, the monthly value is calculated. The number of missing days for the calculation of each monthly value is also recorded.

Assessment

A quality assessment is formed for each station based on the residuals of the hourly data. This information accompanies each data file in the permanent archive (Appendix 2). The assessment includes general information such as station location, the contributor and originator, instrumentation, and processing notes, as well as the policy upon which the evaluation was made (Appendix 3). A Completeness Index (CI) is defined as the percentage of days with data for each year. If a data set ends on 30 June 1985, then the CI will be 50% for 1985. A Quality Index (QI) is defined as the percentage days in a year with available data that do not contain questionable fluctuations in the residuals. In general, fluctuations in the residuals are considered significant and are noted if the fluctuations are greater than 25 cm. However, each case is subjectively analyzed to determine if the fluctuation is a natural event, an indication of mechanical problems with the gauge or instrument setting, or a result of unreliable predicted tides. The predicted tides for locations with shallow water, river mouths, or complex coastal geometry and sea bottom topography can be unreliable if the harmonic analysis does not accurately compute all the necessary harmonic components. Such features are noted in the quality assessments.

Since the daily and monthly data are derived from the quality controlled hourly data, the assessment based on the hourly data is also given in the permanent archive of daily and monthly values. The CI of the hourly data may be biased low for the daily and monthly data because of the gap handling characteristics of the 119-point filter as noted above. A summary of the CI and QI for stations with quality assured data in the Indian TOGA domain (Figure 4 and Table 1) are given in Appendix 4.

The Permanent Archive and Data Requests

Hourly, daily, and monthly data constitute the permanent archive of sea level. For the Indian Ocean, the archive presently contains over 200 station years from 49 stations. For convenience, we have included stations on Sumatra, Java, and the Lesser Sunda Islands into the Indian Ocean files. The data and quality assessments are stored digitally on magnetic tape. When the data have passed quality control and the assessments contain all the necessary general information, they are submitted to the World Data Center-A for Oceanography. This submission occurs with about an 18-month time lag after the calendar year in which the data were collected.

Send requests for data to:

The World Data Center-A for Oceanography
c/o NOAA/NODC
User Services E/OC21
1825 Connecticut Avenue, N. W.
Universal Bldg. Rm. 412
Washington, D. C. 20235 USA
phone: 202-673-5549

Some stations may have unresolved problems. These data are retained at the TOGA Sea Level Center and may be obtained on a case-by-case basis. Send for these data and questions concerning data preparation to:

The Joint Archive for Sea Level
c/o The TOGA Sea Level Center
University of Hawaii
1000 Pope Rd. MSB 317
Honolulu, Hawaii 96822
phone: 808-956-6574

Acknowledgements

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Table 1A. List of TOGA Stations in the Indian Ocean.

TOGA	GLS	STATION	COUNTRY	LAT	LONG	E	QC-YEARS
I001	001	Suez	Egypt	29-55N	032-33E	-	0000-0000
I002	002	Djibouti	Djibouti	11-36N	043-09E	-	0000-0000
I003	006	Ras Hafun	Somalia	10-25N	051-16E	-	0000-0000
I004	007	Mogadishu	Somalia	02-02N	045-20E	+	1988-1989
I005	008	Mombasa	Kenya	04-04S	039-39E	+	1986-1988
I006	297	Zanzibar	Tanzania	06-09S	039-11E	+	1984-1989
I007	xxx	Dar Es Salaam	Tanzania	06-49S	039-17E	+	1986-1989
I008	011	Pemba	Mozambique	12-58S	040-30E	-	1971-1973
I009	xxx	Mozambique	Mozambique	15-00S	041-30E	-	0000-0000
I010	xxx	Beira	Mozambique	20-00S	035-00E	-	0000-0000
I011	xxx	Maputo	Mozambique	26-10S	032-42E	-	1974-1974
I012	013	Durban	South Africa	29-53S	031-00E	+	1970-1987
I013	003	Aden	P.D.R. Yemen	12-47N	044-59E	-	0000-0000
I014	009	Mtwara	Tanzania	10-08S	040-07E	-	0000-0000
I015	004	Salalah	Oman	17-00N	054-00E	+	0000-0000
I016	005	Muscat	Oman	23-38N	058-34E	+	1987-1989
I017	295	Gwadar	Pakistan	25-09N	061-33E	+	1987-1987
I018	030	Manoro (Karachi)	Pakistan	24-48N	066-58E	+	1985-1987
I019	031	Veraval	India	20-54N	070-22E	+	0000-0000
I020	281	Marmagao	India	15-25N	073-48E	+	0000-0000
I021	xxx	Lakshadweep	India	11-00N	073-00E	-	0000-0000
I022	032	Cochin	India	09-58N	076-16E	+	0000-0000
I023	029	Minicoy	India	08-17N	073-03E	-	0000-0000
I024	034	Madras	India	13-06N	080-10E	+	0000-0000
I025	035	Vishakhapatnam	India	17-41N	083-17E	+	0000-0000
I026	038	Port Blair	India	11-41N	092-46E	-	0000-0000
I027	041	Great Nicobar	India	07-00N	093-50E	-	0000-0000
I028	141	Moulmein	Burma	16-29N	097-37E	-	0000-0000
I029	037	Akyab	Burma	20-09N	092-54E	-	0000-0000
I031	042	Ko Taphao Noi (Phuket)	Thailand	07-50N	098-26E	+	1985-1987
I033	xxx	Kelang	Malaysia	03-03N	101-22E	+	1983-1987
I034	xxx	Lumut	Malaysia	04-14N	100-37E	+	1984-1987
I035	033	Colombo	Sri Lanka	06-56N	079-51E	+	1953-1965
I036	xxx	Banda Acheh	Indonesia	05-30N	095-30E	-	0000-0000
I037	045	Padang (Teluk Bayuk)	Indonesia	01-00S	100-22E	+	1986-1990
I038	xxx	Telukbetung	Indonesia	05-30S	105-00E	-	0000-0000
I039	048	Pelabuhan Ratu	Indonesia	07-00S	106-30E	-	0000-0000
I040	291	Cilacap	Indonesia	07-45S	109-01E	+	1987-1990
I042	049	Benoa	Indonesia	08-45S	115-13E	+	1988-1990
I043	050	Kupang	Indonesia	10-10S	123-35E	-	0000-0000
I044	062	Darwin	Australia	12-28S	130-51E	+	1984-1988
I045	040	Broome	Australia	18-00S	122-13E	+	1986-1987
I046	051	Port Hedland	Australia	20-19S	118-34E	+	1984-1987
I047	052	Carnarvon	Australia	24-53S	113-37E	+	1984-1986
I048	046	Cocos	Australia	12-07S	096-54E	+	1985-1989
I049	047	Christmas	Australia	10-25S	105-40E	+	1986-1987
I050	026	Diego Garcia-A	U.K.	07-14S	072-26E	-	1961-1963
I050	026	Diego Garcia-B	U.K.	07-14S	072-26E	-	1969-1969
I050	026	Diego Garcia-C	U.K.	07-14S	072-26E	+	1988-1989
I051	027	Gan	Maldives	00-41S	073-09E	+	1987-1989
I052	028	Male-A	Maldives	04-11N	073-31E	-	1987-1989
I052	028	Male-B	Maldives	04-11N	073-31E	+	0000-0000
I053	273	Port Victoria-A	Seychelles	04-37S	055-28E	-	1975-1984
I053	273	Port Victoria-B	Seychelles	04-37S	055-28E	+	1986-1989
I054	014	Aldabra	Seychelles	09-24S	046-13E	-	1975-1976

I055	016	Agalega Is.	Mauritius	10-26S	056-45E	+	0000-0000
I056	019	Rodrigues,Mathurin	Mauritius	19-40S	063-25E	+	1986-1990
I057	018	Port Louis-A	Mauritius	20-09S	057-29E	-	1942-1947
I057	018	Port Louis-B	Mauritius	20-09S	057-29E	-	1964-1965
I057	018	Port Louis-C	Mauritius	20-09S	057-30E	+	1986-1990
I058	017	Reunion	France	20-55S	055-18E	+	1982-1986
I059	015	Nosy Be	Madagascar	13-24S	048-17E	+	1987-1989
I060	271	Fort Dauphin	Madagascar	25-02S	047-00E	+	0000-0000
I061	096	Dzaoudzi (Mayotte)	France	12-47S	045-15E	+	0000-0000

Table 1B. List of Additional Stations in the Indian Ocean TOGA Domain

TOGA	GLS	STATION	COUNTRY	LAT	LONG	E	QC-YEARS
I070	xxx	Keling	Malaysia	02-13N	102-09E	+	1984-1987
I071	xxx	Langkawi	Malaysia	06-26N	099-46E	+	1985-1987
I072	xxx	Penang	Malaysia	05-25N	100-21E	+	1984-1987
I073	292	Surabaya	Indonesia	07-13S	112-44E	+	1988-1990
I074	xxx	Praslin	Seychelles	04-21S	055-46E	+	1987-1989
I075	xxx	Kismayo	Somalia	00-30S	042-30E	+	0000-0000
I076	xxx	Antonio Enes	Mozambique	16-14S	039-58E	-	1967-1967
I077	xxx	Nacala-A	Mozambique	14-34S	040-41E	-	1975-1975
I077	xxx	Nacala-B	Mozambique	14-34S	040-41E	-	1982-1983
I078	xxx	Wyndham	Australia	15-27S	128-06E	+	1984-1988
I079	053	Fremantle	Australia	32-03S	115-44E	+	1984-1988
I080	xxx	Meneng	Indonesia	08-07S	114-23E	+	1987-1990
I081	xxx	Pari	Indonesia	05-51S	106-37E	+	1987-1990
I082	xxx	Lamu	Kenya	02-16S	040-54E	+	1989-1989

GLS: GLOSS, E:EXISTING STATION (+ yes, - no), QC-YEARS: YEARS OF QUALITY CONTROL

Table 2. Sea Level Stations in the Indian Ocean that were installed by the University of Hawaii (UH) or have received equipment from UH.

STATION	COUNTRY	LAT	LONG	GAUGE	STS	START YY
Mombasa	Kenya	04-04S	039-39E	LS	G	1986
Dar Es Salaam	Tanzania	06-49S	039-17E	LS	G	1986
Port Louis	Mauritius	20-09S	057-30E	LS	G	1986
Diego Garcia	USA Trust	07-17S	072-24E	FP	G	1986
Rodrigues	Mauritius	19-40S	063-25E	LS	G	1986
Praslin	Seychelles	04-21S	055-46E	FP	P	1987
Teluk Bayur,Padang	Indonesia	00-58S	100-20E	FP	G	1986
Male	Maldives	04-11N	073-31E	FP	G	1987
Gan	Maldives	00-41S	073-09E	FP	G	1987
Muscat	Oman	23-38N	058-34E	LS	G	1987
Salalah	Oman	17-00N	054-00E	FP	G	1989
Port Victoria	Seychelles	04-37S	055-28E	FP	G	1987
Mogadishu	Somalia	02-01N	045-20E	FP	P	1987
Agalega Is.	Mauritius	10-26S	056-45E	BUB	D	1988
Colombo	Sri Lanka	06-56N	079-51E	FP	G	1989
Kismayo	Somalia	00-30S	042-30E	LS	P	1988
Zanzibar	Tanzania	06-09S	039-11E	FLT	G	1986
Surabaya	Indonesia	06-55S	112-14E	FP	G	1988
Cilacap	Indonesia	07-34S	108-59E	FP	G	1987
Benoa	Indonesia	08-46S	115-13E	FP	G	1988

GAUGE TYPES - LS: Leupold Stevens analog; FP: Fisher and Porter ADR; BUB: Bubbler; FLT: analog float

STATUS (STS) - G : good; P : Poor, various problems; D: temporarily discontinued

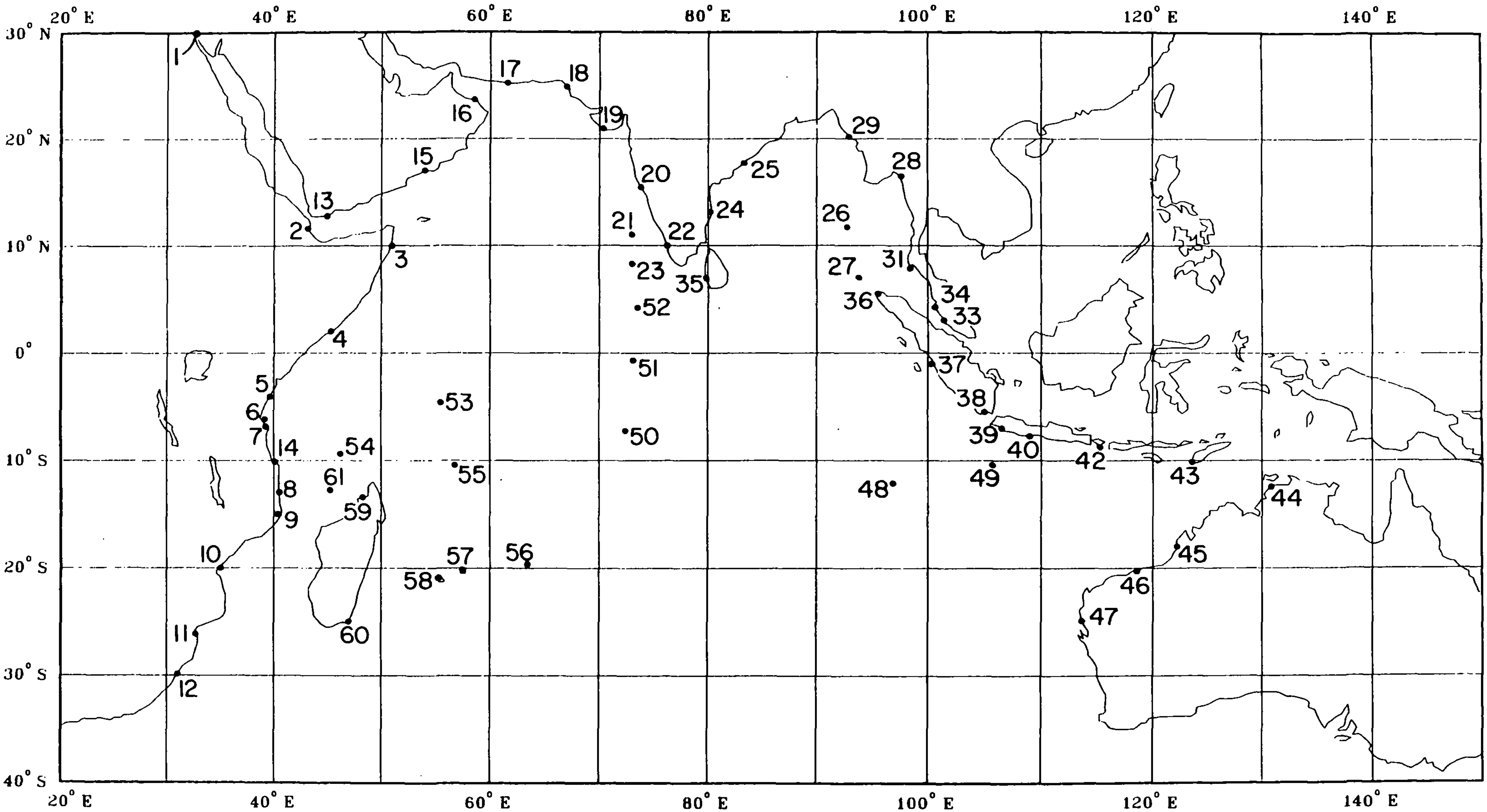

Figure 1. Stations of the TOGA Implemenatation Plan.

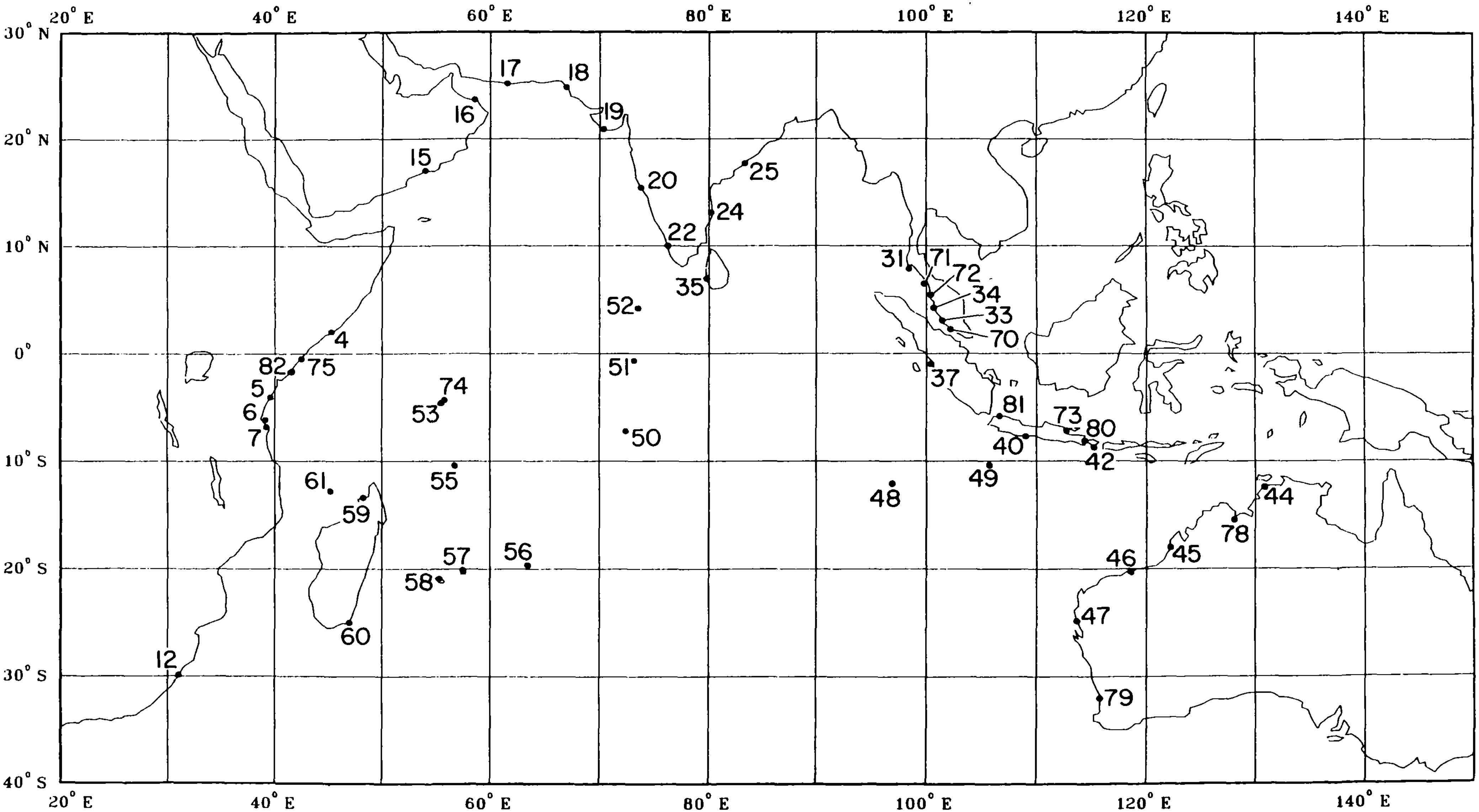

Figure 2. Existing stations; the stations with numbers 70 or greater are not part of the original TOGA Implementation Plan.

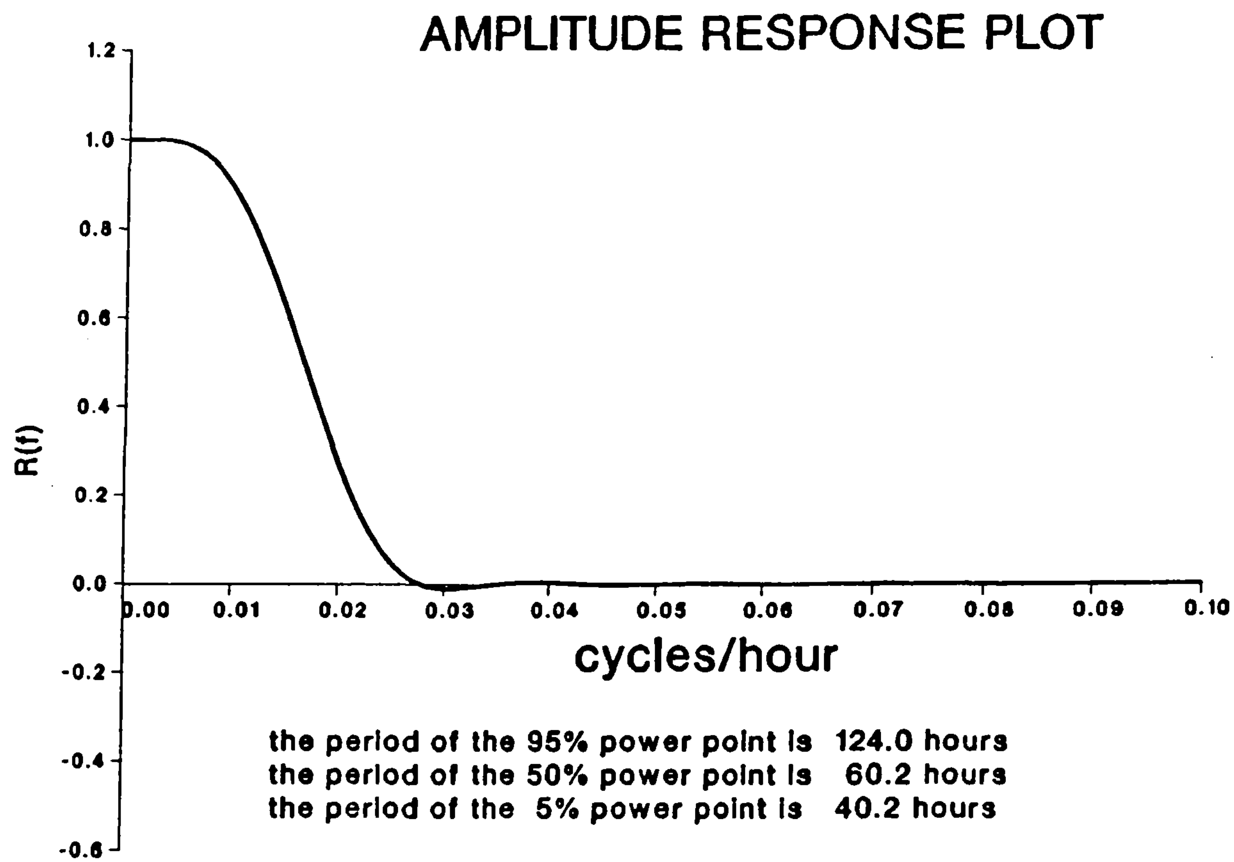

Figure 3. Response function of a 119-point convolution filter used to process hourly into daily values. The filter varies as sin(t)/t. Convergence factors have been applied to control the Gibbs phenomena.

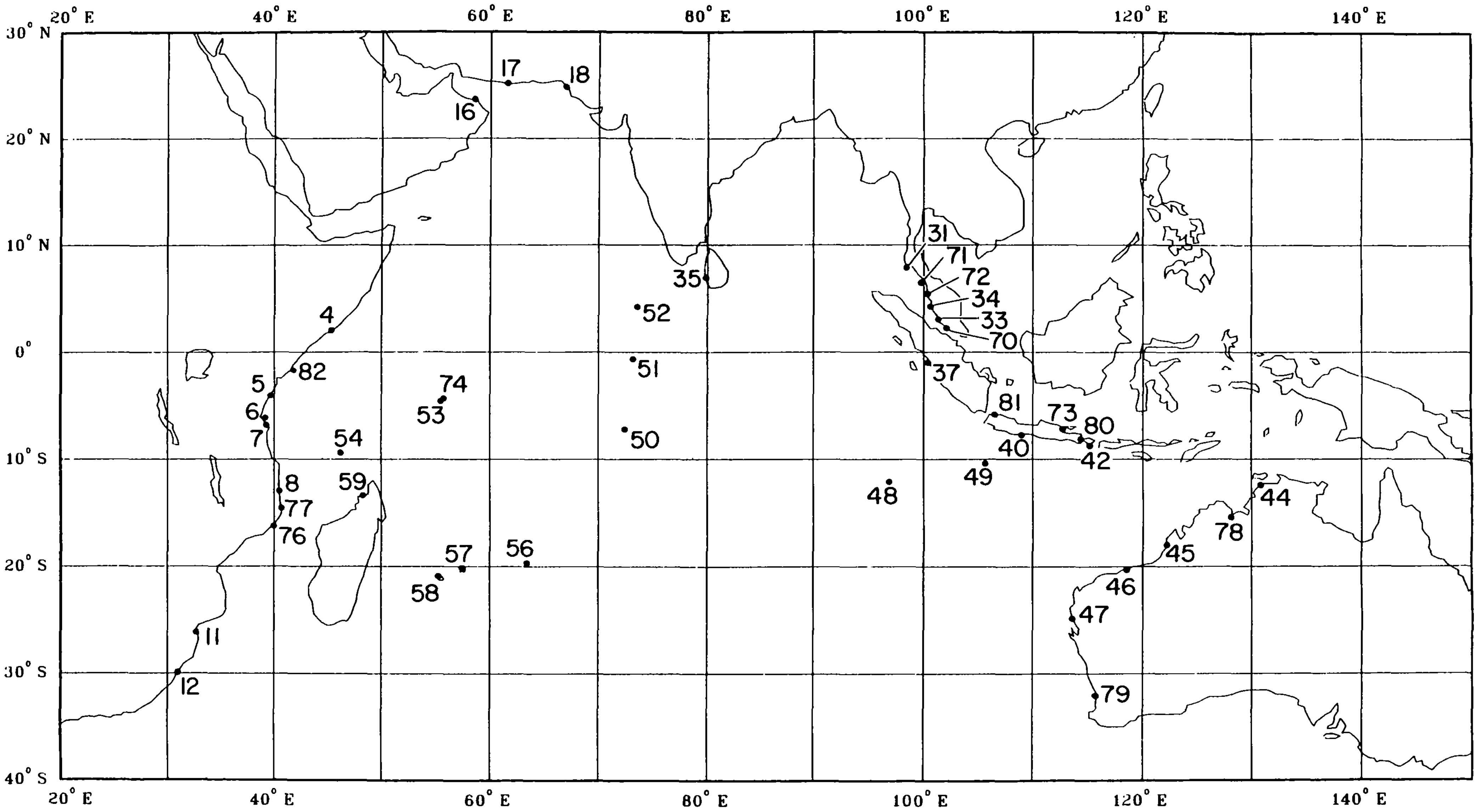

Figure 4. Stations with quality-controlled data in the JASL archive; the stations with numbers 70 or greater are not part of the original TOGA Implementation Plan.

Appendices

Appendix 1-A. Cooperating Agencies with the University of Hawaii: The Indian Ocean Sea Level Network

1) Kenya Marine and Fisheries Institute
P. O. Box 81651
Mombasa, Kenya

Stations: Mombasa and Lamu

2) Institute of Marine Sciences
University of Dar Es Salaam
P. O. Box 668
Zanzibar, Tanzania

Station: Dar Es Salaam

3) Meteorological Services
Vacoas, Mauritius
Indian Ocean

Stations: Port Louis-C and Rodrigues

4) Naval Oceanographic Command Detachment
F. P. O. San Fransisco, CA 96885-2905

Station: Diego Garcia-C

5) BAKOSURTANAL, Indonesia
Jl. Raya Jakarta Bogar Km 46
P. O. Box 46
Cibinong, Indonesia

Stations: Padang, Surabaya, Cilacap, and Benoa

6) Dept. of Meteorology
Male, Republic of Maldives

Stations: Male-A, Male-B, Gan

7) Director of Meteorology CIVAIR
SEEB International Airport
P. O. Box 204
Muscat, Sultanate of Oman

Stations: Muscat and Salalah

8) Directorate of Civil Avaition
P. O. Box 181
Seychelles International Airport
Republic of Seychelles

Stations: Praslin and Port Victoria-B

9) Somali Ports Authority
P. O. Box 935
Mogadishu, Somalia

Station: Mogadishu, Kismayo

10) National Aquatic Resources Agency
Commodore F. N. Q. Wickremaratne
Colombo, SRI LANKA

Station: Colombo

11) Commission of Lands and Environment
PO Box 811
Zanzibar, Tanzania

Station: Zanzibar

Appendix 1-B. National Agencies which contribute hourly sea level data from the Indian Ocean.

1) Institute of Oceanographic Sciences (IOS)
Bidston Observatory, Birkenhead
Merseyside L43 7RA

Stations: Port Louis-A, Port Louis-B, Port Victoria-A, and Aldabra

2) Scripps Institute of Oceanography
University of California at San Diego
La Jolla, California 92093

Stations: Diego Garcia-A, Diego Garcia-B

3) Dept. of Survey and Mapping
Jalan Gurney
50578 Kuala Lumpur, Malaysia

Stations: Kelang, Keling, Langkawi, Lumut, Penang

4) Pakistan National Institute of Oceanography
37 K. Block 6 P.E.C.H.S.
Karachi, 29 PAKISTAN

Stations: Gwadar and Karachi

5) Naval Hydrographic Dept.
Royal Thai Navy
Aroon-Amarin Road
Bangkok 10600 Thailand

Station: Ko Taphao Noi

6) Center for Oceanological Research and Development
J. Pasir Putih I. Ancol Timur
P. O. Box 580 DAK Jakarta 11001
Indonesia

Stations: Meneng and Pari

7) Service Hydrographique Et Oceanographique De La Marine
Establissement Principal
B.P. 426 -29275 Brest, Cedex, FRANCE

Station: Reunion

8) Flinders University of South Australia
School of Earth Sciences
Bedford Park, South Australia 5042

Stations: Wyndham, Broome, Carnarvon, Darwin, Port Hedland, and Fremantle

9) CSIRO
Division of Oceanography
GPO Box 1538
Hobart, Tasmania 7001

Stations: Christmas and Cocos

10) Directorate of Hydrography
Maritime Headquarters
Private Bag Retreat
7965 South Africa

Station: Durban

11) Instituto Hidrografico Marinha
Rua das Trinas
49-P-1296 Lisboa Codex
Lisbon, Portugal

Stations: Maputo, Antonio Enes, Pemba, Nacala-A, and Nacala-B

12) National Aquatic Resources Agency
Crow Island, Mattakkuliya
Colombo-15, SRI LANKA

Station: Colombo

13) Centre National De Recherches Oceanographique
BP: 68 (207) Nosy Be
MADAGASCAR

Station: Nosy Be

Appendix 2. Example: **QUALITY ASSESSMENT OF SEA LEVEL DATA by the TOGA SEA LEVEL CENTER/NATIONAL OCEANOGRAPHIC DATA CENTER JOINT ARCHIVE FOR SEA LEVEL**

```
Station  : Mombasa                  Latitude:  04 04.2S
Country  : Kenya                   Longitude: 039 39.4E
JASL #   : 101A               Time Meridian: 045E (GMT + 3 hr)
GLOSS #  : 008      TOGA #: I005      NODC #: 30034901
Contributor   : Kenya Marine and Fisheries Institute
                P. O. Box 81651
                Mombasa, Kenya
Originator    : same
Original Data: analog
Instrmnt Type: Leupold and Stevens, model A-71, float gauge
Digitzd Intvl: one hour spot reading
Present Data : Hourly, daily, and monthly values obtained by:
      Hourly : The original digitizing interval was hourly
      Daily  : 119-point convolution filter (Bloomfield, 1976)
               centered on noon applied to the hourly data
               with respective periods of the 95, 50, and 5%
               amplitude points at 124.0, 60.2, and 40.2 hours
      Monthly: Simple average of all daily values; calculated if
               7 or fewer days are missing
Span of data : 17 Jun 1986 - 31 Dec 1988
Gaps > 1 mon : 06 Nov 1987 - 29 Feb 1988
Time Refernce: GMT (hours 00-23)   Space-filler Flag   :-9999
Units        : millimeters         Missing Data Flag   : 9999
Refernce Levl: The sea level heights are referred to the zero
               point assigned to the tide staff. Bench mark
               information is available upon request.
Comment      : The daily and monthly means do not reveal any
               reference level shifts and agree well with an
               adjacent station, Zanzibar.  Occasionaly,
               timing errors were evident in the hourly data.
```

YEAR	CI (%)	QI (%)	MISSING DATA	REPLACED GAPS OR BAD DATA	QUESTIONABLE FLUCTUATIONS
1986	51	46	254-258,304-308, 333-335,355-357	(13)216-(00)217 (15)217-(23)217 (19)219-(06)220 (23)222-(08)223 (02)320-(19)320 (01)324-(19)324	175,214-215,231-233, 260-264,282,317-319, 358-360
1987	78	68	37-40,130-132, 147-159,215-222, 310-365	(13)048-(21)048 (17)050-(03)051 (20)052-(05)053 (12)136-(22)136 (00)137-(10)137 (18)160-(05)161 (14)161-(23)161 (04)171-(23)171	59-60,67,73-74,80-84,88-89,91,93,106, 134,142-147,168-169, 173,177-178,194-195, 214,222,224,227-228, 275-278,281
1988	93	85	1-59,94-96, 151-154,232-243, 245-252,332-335	none	79-81,83-84,93-94, 100-103,108-110,129-130,139-142,150-151, 245,268-270,319,337, 344-345

Appendix 3. QUALITY ASSESSMENT POLICY

The quality assessment is mostly based on the residuals (observed data minus predicted tides) of the hourly data. This assessment also applies to the daily and monthly data since they were derived from the quality-controlled hourly data.

The following abbreviations are used in the assessment: JASL - Joint Archive for Sea Level; GLOSS - Global Sea Level Observing System; TOGA - Tropical Ocean Global Atmosphere research program; NODC - National Oceanographic Data Center; Instrmnt - instrument; Digitzd Intvl - digitized interval; Gaps > 1 mon - missing data in a span greater than one month; Refernce - reference.

The following corrections are made to the hourly data prior to this assessment:
1) Gaps or obviously wrong data points in a span less than 25 hours are filled by the predicted tide method* or by diagonal linear interpolation**.
2) Timing errors of exact increments of an hour are corrected by shifting the data.
3) Reference level shifts are only corrected after information from tide staff readings or comparative readings with a fixed bench mark are checked to verify that the shift was not a natural event. If comparative readings are missing or incomplete, comparisons of the data with nearby stations may warrant the correction of some obvious shifts.

For each year, the following information is documented from the quality-controlled hourly data with dates given as the nth day of the year starting from 1 January:
1) a Completeness Index (CI) based on the percentage of hours with available data,
2) a Quality Index (QI) based on the percentage of days in the year with available data that do not contain questionable fluctuations in the residuals,
3) a list of gaps longer than a day,
4) a summary of days with consecutive missing or obviously wrong data in a time span longer than 6 but less than 25 hours that have been replaced, with hours in parentheses, and
5) a summary of days with questionable fluctuations in the residual series. Fluctuations within the residuals are considered significant and are noted if the fluctuations are greater than 25 cm. These questionable data can be described:

FAULT	FLUCTUATION CHARACTERISTICS
Glitch	Consecutive questionable values in a span less than one-half day.
Timing	Fluctuations have a regular pattern and are obviously offset in time.
Amplitude	Fluctuations have a regular pattern and are aligned with the observed data.
Noise	Fluctuations have a random pattern.

Note : If the predicted tides poorly model the observed heights due to non-linear effects of station location, then the above faults are not relevant and a general subjective comment on the quality of the data is given.

*The predicted tides are obtained with the use of a harmonic analysis program (Foreman, 1977) which is executed on a year of apparently good data for a given station. The Predicted Tide Method for filling gaps consists of statistically comparing the predicted tides to the observed data and shifting the predicted tides in time to correct for timing differences. Then the linear interpolation between hourly values at the end points of the gap in the residual series is added to the corresponding corrrected predicted tide data to obtain interpolated values over the span of the gap.

**A diagonal linear interpolation consists of averaging data exactly 25 hours before and after a point. This is only possible when the diurnal and semi-diurnal tidal components dominate the time segment in question. It is used for short gaps when the tidal analysis approximates the observed data insufficiently.

Bloomfield, P., 1976. Fourier Analysis of Time Series: An Introduction. New York: John Wiley and Sons. pp 129-137.

Foreman, M., 1977. Manual For Tidal Height Analysis and Prediction. Institute of Ocean Sciences, Patricia Bay, Victoria B.C. Pacific Marine Science Report 77-10.

Appendix 4. Indian Ocean Sea Level Data in the JASL Permanent Archive.

STATION	TOGA	SPAN	CI	QI
Mogadishu	I004	04 Sep 1988 - 31 Dec 1989	83	70
Mombasa	I005	17 Jun 1986 - 31 Dec 1988	87	78
Zanzibar	I006	01 Mar 1984 - 30 Jun 1989	100	97
Dar Es Salaam	I007	06 Jul 1986 - 31 Dec 1989	85	53
Pemba	I008	30 Sep 1971 - 31 Jan 1973	25	3
Maputo	I011	01 Jan 1974 - 31 Dec 1974	100	63
Durban	I012	30 Sep 1970 - 31 Dec 1987	86	76
Muscat	I016	03 Apr 1987 - 31 Dec 1989	90	70
Gwadar	I017	18 Jan 1987 - 31 Dec 1987	63	40
Karachi	I018	01 Jan 1985 - 31 Dec 1987	91	74
Ko Taphao Noi (Phuket)	I031	01 Jan 1985 - 30 Jun 1987	100	99
Kelang	I033	15 Dec 1983 - 20 Jan 1987	99	99
Lumut	I034	12 Dec 1984 - 08 Jan 1987	93	92
Colombo	I035	01 Jan 1953 - 31 Dec 1965	94	93
Padang (Teluk Bayur)	I037	16 Nov 1986 - 31 Mar 1990	88	87
Cilacap	I040	13 Oct 1987 - 31 Mar 1990	76	75
Benoa	I042	29 Apr 1988 - 28 Feb 1990	99	82
Darwin	I044	01 Jan 1984 - 31 Dec 1988	90	90
Broome	I045	12 Jul 1986 - 30 Sep 1987	100	100
Port Hedland	I046	01 Jan 1984 - 31 Dec 1987	88	81
Carnarvon	I047	07 Apr 1984 - 26 Aug 1986	62	54
Cocos	I048	11 Dec 1985 - 30 Sep 1989	88	88
Christmas	I049	28 Sep 1986 - 09 Oct 1987	79	79
Diego Garcia-A	I050	01 Apr 1961 - 31 Aug 1963	100	99
Diego Garcia-B	I050	31 Jan 1969 - 30 Jun 1969	41	39
Diego Garcia-C	I050	01 Mar 1988 - 31 Dec 1989	97	96
Gan	I051	04 Mar 1987 - 31 Dec 1989	70	70
Male-A	I052	22 Feb 1987 - 02 Mar 1989	53	45
Port Victoria-A	I053	17 Jun 1975 - 15 Oct 1984	84	83
Port Victoria-B	I053	28 May 1986 - 19 Jun 1989	97	95
Aldabra	I054	09 Jun 1975 - 20 Aug 1976	100	98
Rodrigues	I056	08 Nov 1986 - 31 Mar 1990	87	76
Port Louis-A	I057	01 Jan 1942 - 31 Dec 1947	90	87
Port Louis-B	I057	01 Mar 1964 - 31 Dec 1965	86	85
Port Louis-C	I057	01 Aug 1986 - 31 Mar 1990	97	95
Reunion	I058	01 Jan 1982 - 25 Nov 1986	93	91
Nosy Be	I059	27 Jul 1987 - 31 Dec 1989	94	51
Keling	I070	05 Nov 1984 - 21 Jan 1987	100	94
Langkawi	I071	29 Nov 1985 - 07 Jan 1987	100	100
Penang	I072	15 Nov 1984 - 07 Jan 1987	84	83
Surabaya	I073	12 Jan 1988 - 31 Mar 1990	90	83
Praslin	I074	05 Nov 1987 - 27 Jun 1989	89	89
Antonio Enes	I076	11 May 1967 - 31 Aug 1967	31	0
Nacala-A	I077	14 Jan 1975 - 21 Mar 1975	18	0
Nacala-B	I077	03 Oct 1982 - 01 Jan 1983	100	4
Wyndham	I078	08 Aug 1984 - 16 Dec 1988	98	98
Fremantle	I079	01 Jan 1984 - 31 Dec 1988	100	99
Meneng	I080	14 Jun 1987 - 11 Apr 1990	94	92
Pari	I081	30 May 1987 - 21 Jan 1990	84	56
Lamu	I082	01 Jan 1989 - 31 Dec 1989	90	66

JASL: Joint Archive for Sea Level
CI : Completeness Index or the percentage of available data for the given time span
QI : Quality Index or the percentage of available data that do not contain questionable fluctuations