Secchi Depth Atlas Of The World Coastlines

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ABSTRACT

A seasonal Secchi depth atlas has been developed for the world's coastlines. Optical data have been compiled from the National Oceanographic Data Center and open literature for water depths less than 500 meters. These data have been averaged by one-degree squares and sorted by season and placed in a category of 6 classes of Secchi depth ranges. Four charts were used to cover the world at a scale of 1:12,233,000, and four seasons were selected to encompass 3-month intervals. Additionally, annual mean Secchi depths have been compiled in 4 charts. Secchi depth data were found for approximately 50% of the world's coastlines. In the areas where no optical data were available other oceanographic, meteorologic and geomorphic data sources were used to estimate the expected Secchi depth ranges.

Secchi depth values show high temporal and spacial variability in certain coastal regions, even though the amount of data was highly limited. This variability suggests that improved techniques of compiling coastal optical properties, such as through use of satellites be examined both to aid in understanding historical ship data, and to obtain additional optical data.

Introduction

Recent developments within the oceanographic community which have improved data collection and handling procedures have shown that spatial and temporal variability of oceanographic parameters are much higher than previously surmised. Attempts to compile oceanographic data into an atlas format have been somewhat successful such as for ocean temperature, salinity, and currents. Ocean optical data has been quite restrictive since major problems exist in which data techniques and lack of the basic optical relationships with physical or biochemical properties is not well understood. For these reasons the development of a seasonal optics atlas has not been well established.

The objective of this report is to quantify the variability of coastal optical properties by using historical measurements of coastal optical properties, or by inferring the optical properties from non-optical coastal/oceanographic processes and meteorological conditions.

The coastal regions have extremely variable oceanographic parameters, since these areas are responsive to local meteorological and coastal processes. Water optical properties in particular have an extremely high variability in coastal areas since they respond to changes in biological, chemical, and geological processes. The optical properties may be strong indicators of the biological, physical and geological processes occurring within a region and provide improved understanding of the oceanography when coupled with non-optical parameters. The establishment of an optical data base for global conditions required selection of an optical property for which numerous measurements have been made. Also, this property should be standardized so that various investigators' data can be jointly utilized. Although the Secchi depth measurement is not the most quantitative optical property, it did meet our criteria and was selected as the basis for this global coastal atlas.

The necessity for coastal optics atlas arose from the Defense Mapping Agency (DMA) which is developing coastal hydrographic charting systems whose performance is constrained by water optical properties. The seasonal distribution of the coastal optical properties provides a method by which water clarity may be taken into account during the planning of operational surveys and thereby increase system performance and accuracy.

The atlas (in response to DMA) extends to all coastlines from 40°N to 40°S latitude with the exception of United States coastal waters. (An extensive literature of coastal water optics exists for U. S. Coastal Waters)[1,2]

Methods

Figure 1 represents the flow chart by which the coastal Secchi depth atlas was developed. The steps in this process will be described in some detail. The optical data base was established primarily from the National Oceanographic Data Base (NODC). These estimated 96,000 Secchi depths for worldwide waters were screened for coastal values by eliminating all Secchi depths in waters greater than 500 meters. The remaining 23,000 worldwide data points were used in this coastal atlas study. It is recognized that waters at 500 meters depth may have considerable different optical properties than those waters in shallower coastal waters. This problem is inherent in the atlas development and should be taken into consideration in examination of the final atlas.

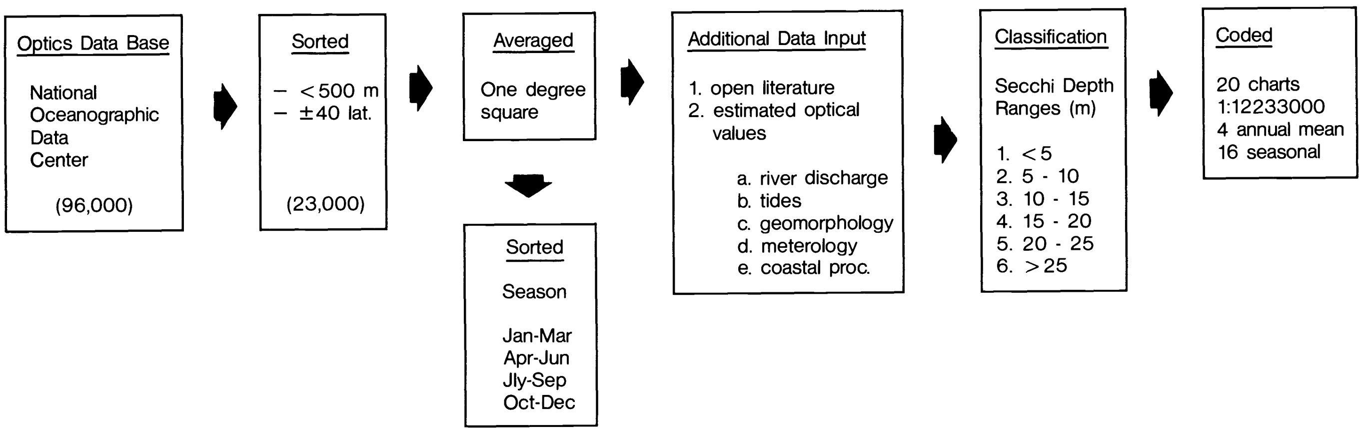

Figure 1: Flowchart of Secchi depth atlas development.

These 23,000 data points were next sorted into one-degree squares such that the horizontal coastal variability could be averaged. This has the affect of smoothing the large horizontal variation that could occur if values were obtained from various distances offshore. Examination of the variability of the data within each one degree square suggests the estimate of the averaging process . However, the statistical analysis of this variance is misleading if only a few data point exist within a one-degree square. The high variance could indicate extremely high horizontal variability , or an insufficient number of data points. The values for each one-degree squares were next sorted into four seasons. The seasonal and annual mean for each square was computed. The oceanographic climate of various regions around the world has substantially different seasons. In order to avoid the development of several seasonal atlases for various regions, four seasons were selected for the entire atlas development. They are:

Season
1. January - March
2. April - June
3. July - September
4. October - December

Regions which do not necessarily reflect these oceanographic seasons (e.g., the monsoon season in the Indian Ocean) should be taken into consideration upon examination of the atlas. As will be described later, other types of oceanographic and meteorologic conditions were also utilized in compiling the seasonal variability of coastal optical properties.

The seasonal optical data for each one-degree square were next classified into one of six Secchi depth ranges. This provided a mechanism to permit rapid screening of the data for regional trends and allowed for a color coded method of placing the data on the charts. The Secchi depth ranges used:

Range code	Range (m)	Color
1.	< 5	Brown
2.	5 - 10	Yellow
3.	10 - 15	Orange
4.	15 - 20	Green
5.	20 - 25	Blue
6.	>25	Purple

A series of 4 base charts obtained from DMA (compiled from hydrographic chart numbers 6004, 6005, 6006, 6007, 6008, 6009, 6010, 6011) were used to compile the worldwide optics data base. The charts were at a scale of 1:12,233,000 and were divided in one degree squares. They are labeled in the following fashion:

Chart	Geographical Area	Longitude
1	Atlantic Ocean North & South America	5°E- 95°W
2	Western Indian Ocean, Africa Coasts	5°E - 70°E
3	Western Pacific, Indonesia, Australia, Eastern Indian Ocean	70°E - 165°W
4	East and Central Pacific	165°E - 95°W

The coverage of each of these charts is shown in figure 2. Therefore, a total of sixteen charts representing the four seasons on four charts of the world have been developed. In addition, the annual mean coastal Secchi depth values are represented on the four world charts. This results in a total of 20 charts.

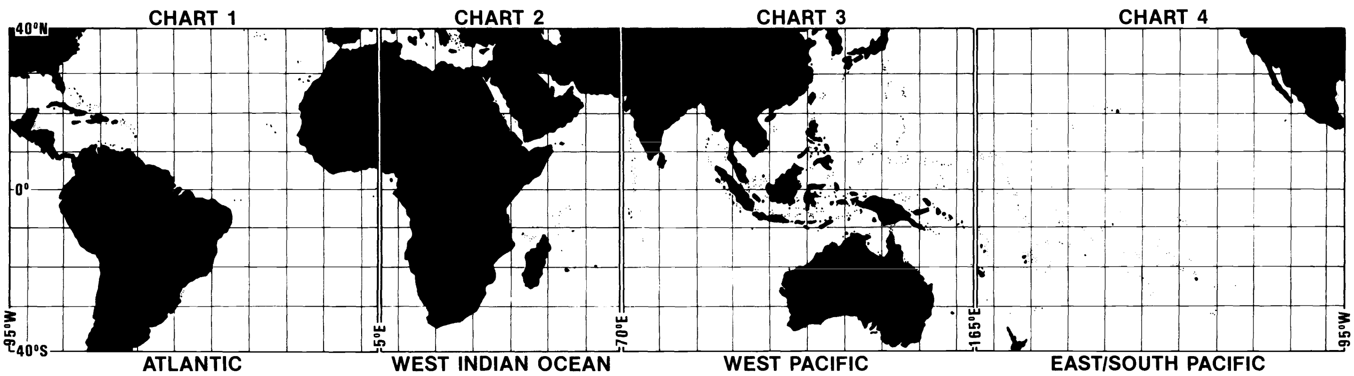

Figure 2: Geographic coverage for charts 1-4.

The NODC data base which provided the framework on which the atlas was developed, has insufficient Secchi depth data available for complete world coastal coverage. For these reasons it was necessary to supplement the data base with optical data reported in open literature. This optical data was also limited, and in many cases the data had to be converted to Secchi depth values. Several regional studies[3] in which greater resolution than the one-degree were also incorporated into the Atlas. The literature of ocean optics is covered in several bibliographies[1,4,5,6] and the reader is directed to these for regional studies if a more detailed requirement is necessary.

Results of the extensive open literature search still left large gaps with regard to the seasonal variation of coastal optical properties needed to complete the atlas. Based on additional sources of oceanographic, meterological and coastal information water optical properties were inferred. The data base was extended at first by examination of the Secchi depths values. For example, if a one-degree square was surrounded by a specific range of Secchi depths, then the same range was assigned to it. The color-code was striped in this one-degree square rather than colored in solidly to signify that the data had been inferred. Additional inferences were based on a knowledge of coastal and geomorphic processes; such as those related to proximity to major river mouths, major offshore currents, upwelling zones, etc.

Difficulties and Problems

The foremost problem encountered in generating a coastal atlas is the presently insufficient amount of data. The inference techiques implemented are limited and actual in-situ measurements are required to validate the procedures used.

In obtaining data for coastal regions, the spatial variability is difficult to characterize from ship collected data. Averaging of optical properties within one-degree square leads to a bias toward the deeper water optical values. Measurements in shallow water are quite restrictive due to ship handling problems, and navigational hazards within several miles from the coast. Collection of shallow water data are further compounded by political problems, especially in foreign areas. The optical ranges presented for each square will most likely be slightly more turbid closer to the coast. It is extremely difficult to represent near shore properties, since the local conditions, (land/sea breeze, surf conditions, etc.) will strongly influence the optical climate.

The Secchi depth measurement is restrictive in clear water where the bottom is able to be seen. In areas where the bottom is readily visible (eg. Bahamas, Pacific Atolls) a Secchi range-6 (> 25 meters; purple) was used on the charts. The present use of the Secchi depth measurement has this distinctive problem which suggest utilization of a different optical property for future work.

Results

An example of the coastal Secchi depth atlas is illustrated in figure 3. This figure represents the annual mean Secchi depth ranges for the South East Asia area, taken from the western one third portion of chart 3. Notice that the extent of available optical data is rapidly discerned by the solid colorations and that inferred values are color striped. The annual mean chart contains the largest amount of available data for a region, whereas the amounts of seasonal data are less. Figure 3 shows that values were inferred in the areas surrounding the Phillipines and the Austrailian coasts.

The spatial variability characterized by this figure illustrates the rapidly changing coastal optics. Notice that the Malacca Strait is quite turbid and approximately 200 nautical miles to the northeast clear waters are extremely clear. Similar coastal variability is observed near the Gulf of Tonkin. This high variability is perhaps more striking might be estimated, since the data has been averaged over one-degree squares and overall seasons. This should tend to filter out the high frequency variability. The remaining variability suggests that more data are required to determine whether the temporal or spatial variability is more prevelent.

Presently the Defense Mapping Agency is publishing the coastal optical charts and a NORDA reprint will be available this summer '84 which should include color-coded charts. We are attempting to correlate general oceanographic climatic parameters with results from the coastal charts. The positions of the equitorial oceanic and coastal currents are observed to affect the coastal optical properties in such areas as the West African and West South American coasts. Discharge of major rivers is also observed to control the seasonal coastal turbidity along long coastlines.

In order to characterize the general water turbidity ranges for global coverage and to estimate the seasonal trends, the number of one-degree squares for each Secchi depth range for each chart was counted to establish the seasonal variability for the coastlines.

The results of this analyses are illustrated in figure 4. It should be noted that the four charts have unequal numbers of one-degree squares bordering on coastlines. The percentage of coastline (water depths less than 500m) for each chart is: Chart 1: 25%; Chart 2: 19%; Chart 3: 45%; Chart 4: 13%.

Figure 4a illustrates coastal coverage for each season for chart 1 for each Secchi depth range. Chart 1 contains mostly the waters bordering the Atlantic Ocean. Range-1 (<5m) is observed to have slightly higher percentage in October-March than in the other months. The variability in this percentage can be attributed to the seasonal outflow of the Amazon River, whose discharge affects a large coastal area along northern South America. Although this percentage range is quite small, approximately 6%, it is slightly higher than for the world wide average as is shown below. Range-2 shows a seasonal distribution similar to that for range-1. Range-4 is observed to contain the highest percentage of this chart; with a mean percentage of 31%. Ranges-5 and -6 do not indicate high seasonal variability. The percentage of very clear waters (range-6) is 21% which is quite high compared to all continental coastal areas covered by this chart.

Figure 4b illustrates the percentage estimates for chart 2. This chart covers the Western Indian Ocean, Southern African coast and Red Sea areas. A significant change is observed by comparision with the previous chart in that the percentages of range 1 water is reduced to approximately 1%. The clear water range is observed to occur in the July-September period, where as the range-6 water comprise about 39%. Elevated coastal turbidity is shown in the October-December period most likely because of southerly flow of the Somali current along the African coast as a result of the monsoon.

Figure 4c illustrates percentage estimates for chart 3. This chart includes the largest coastal borders in the world (45%). A relatively high percentage of range-1 waters is found along the coasts (5%). The seasonal distribution indicates that the July-September period has the highest percentage of clear waters. A similar seasonal distribution is observed for range-2 waters. Ranges-3 and -4 waters show very little seasonal variability. A relatively even distribution is observed between ranges-5 and -6.

Figure 4d illustrates percentage estimates for the East and South Pacific in chart 4. This area of coastal coverage is composed of numerous atolls, yet it represents only 13% of the total world coastlines. The percentage of turbid range-1 or -2 waters is considerably lower in this area, and range-6 water occupies about 66% of the coastal water in this area.

Figure 4e illustrates the global coastal percentage taken from a composite of all four charts. The seasonal distribution for the coastal areas indicates that the July-September time period has slightly clearer water conditions than for the other time periods. This is mostly due to the effects of the monsoon seasons which were indicated on the previous chart 2 and 3 estimates where more turbid conditions were observed during the October-March time period.

Summary and Conclusion

A seasonal Secchi depth atlas of global conditions (± 40° latitude) has been compiled on 20 charts from a limited amount of available data. Six ranges of values have been assigned to coastal areas that are 60nm square and less than 500m in depth. This limited data base illustrates a high coastal spatial and temporal variability. Probable mechanisms for the variability are suggested, though detailed modeling the optical variability with coastal processes requires additional investigation and high resolution data.

The global distribution of coastal Secchi depths indicates a high percentage of relatively clear waters. Less than 5% of the coastlines are shown to have less than 5 m Secchi depth values. Little seasonal changes in the percentage of each range was observed. The highest percentage of coastal waters occured in ranges-4 (15-20m) and -6 (<25m).

Insufficient spatial and temporal data in coastal areas was considered the most significant problem with atlas development. Improvements of the data base require that synoptic and improved spatial coverage be considered. Since field programs are man and cost intensive, the applications of visible remote sensing systems should be investigated for data collection. Only in this way can the spatial and temporal variability of the coastal optical properties be established for modeling purposes.

Application of remote sensing technology for generating an optical data base has significant advantages in addition to providing temporal coverage. Presently a regional study using the Coastal Zone Color Scanner aboard the Nimbus 7 satellite for computing an optical data base is nearing completion, and the results are very encouraging.

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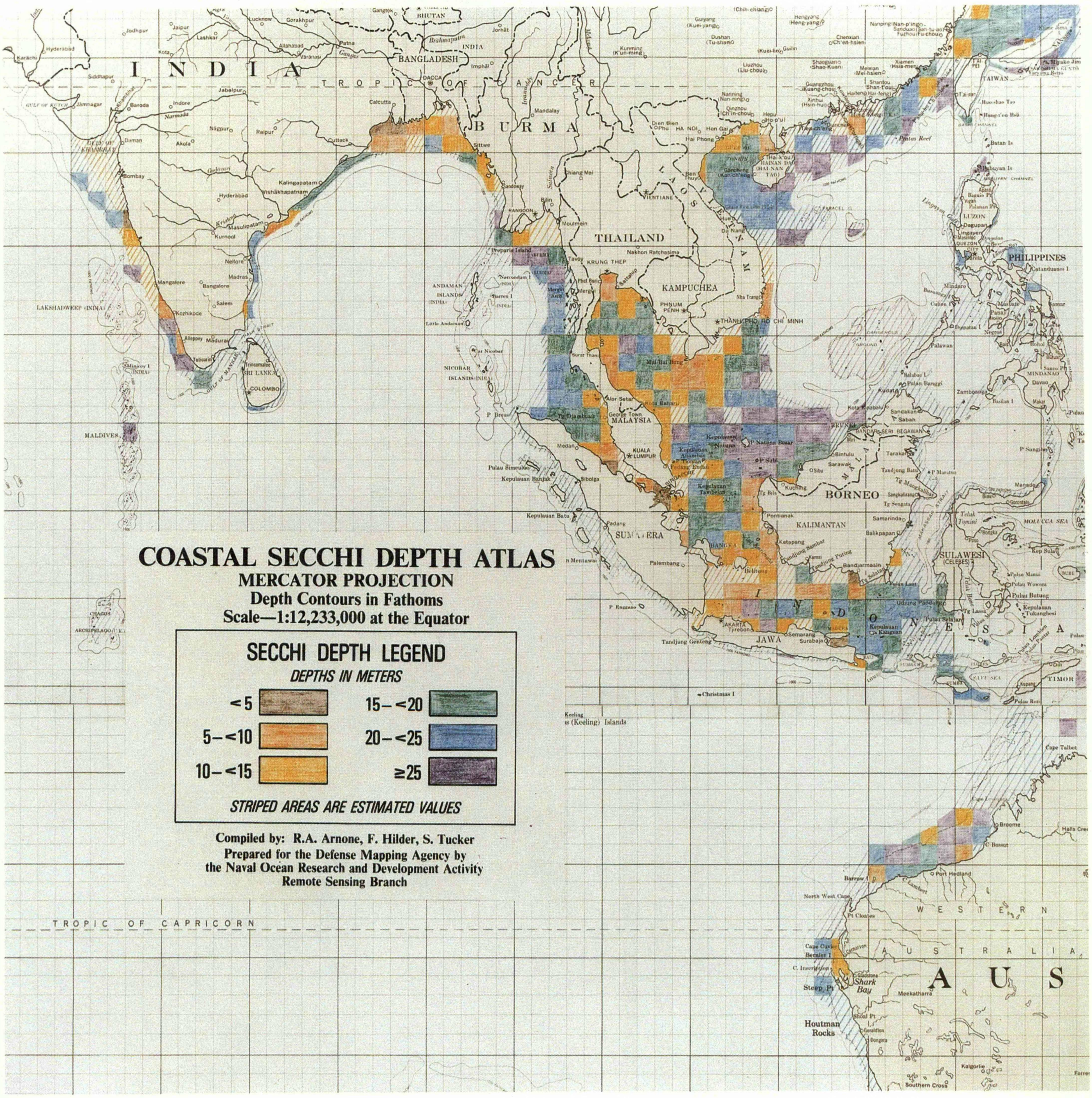

Figure 3: Example of Secchi depth atlas in South East Asia (region within chart 3).

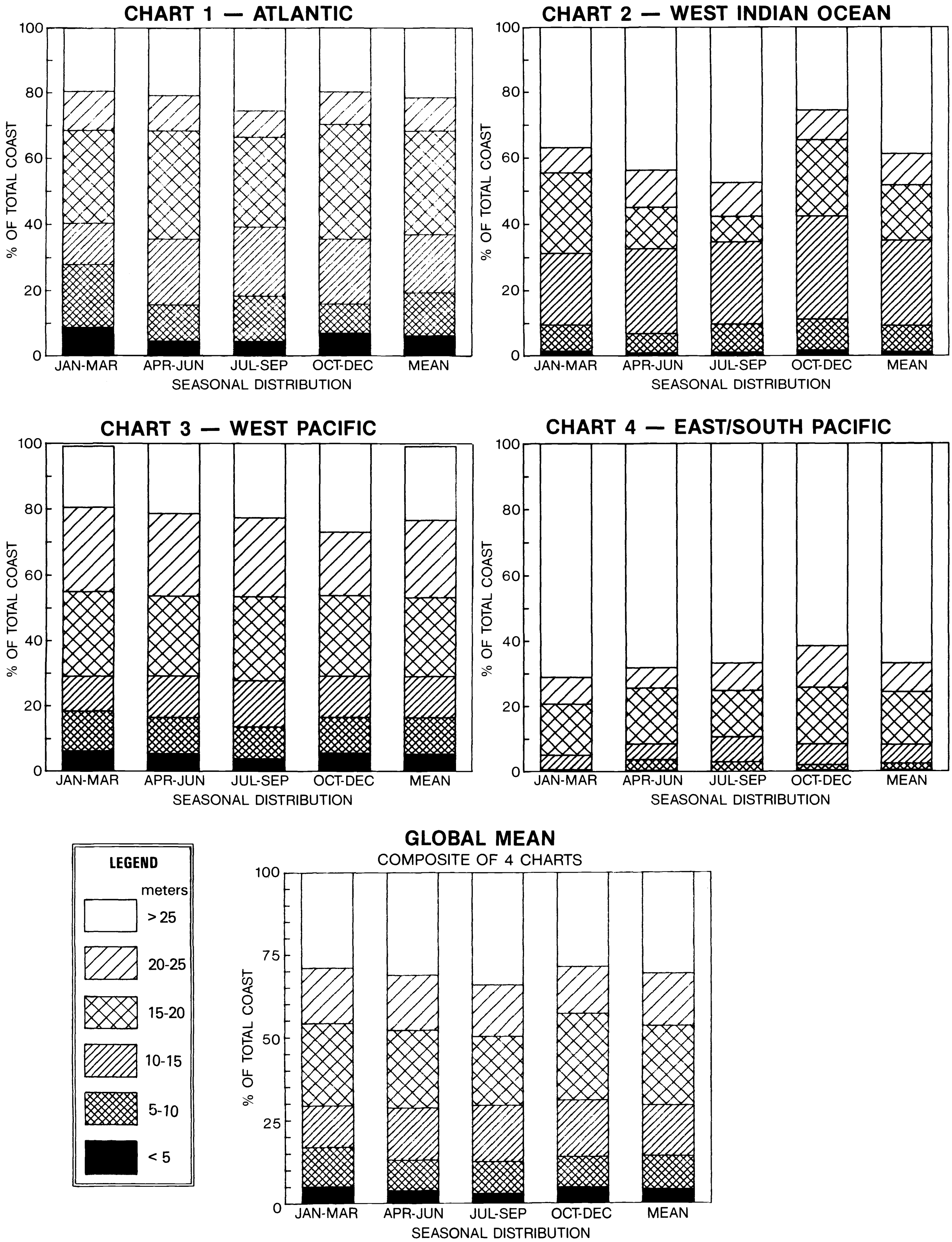

Figure 4: Seasonal and annual mean percentages of Secchi depth ranges for chart and global coastlines.