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CLASSIFICATION OF PACIFIC OCEAN WATERS ACCORDING TO TRANSPARENC--ETC(U)
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# CLASSIFICATION OF PACIFIC OCEAN WATERS ACCORDING TO TRANSPARENCY

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In the course of correlating massive geophysical data, there inevitably arises /181*
the need for their objective classification according to stable indices reflecting the specific behavior of the quantities studied or the dependence of these quantities on the environmental factors determining them. This fully applies to the optical characteristics of World Ocean waters, and primarily to the physical transparency of water, on which a considerable amount of data has recently been collected.

The optical structure of World Ocean waters is formed as the result of the simultaneous action, on the one hand, of dynamic processes (flow, turbulence, processes in vergence zones), and on the other hand, biological and geological processes affecting the formation and arrival of particles of organic and inorganic origin. The action of these processes promotes an increase in the field gradients of the suspension and correspondingly, field gradients of the optical characteristics, whereas the role of advection and turbulent diffusion is manifested in the equalization of the concentration of suspended matter, and hence, in the smoothing of optical field gradients.

In each specific region of the ocean, the interaction of geophysical and biological factors leads to the formation of an optical structure of waters that is typical of a given season, and creates a very definite pattern of distribution of optical properties.


Fig. 1. Frequency of values of the light attenuation index ε in surface waters of the Pacific Ocean.

Water transparency: I - maximum, II - high, III - normal, IV - reduced.

Indeed, as was shown by an analysis of the spatial distribution of the values /182
of the most massive hydrooptical characteristic - the attenuation index ε (or physical transparency θ) in the Pacific Ocean during the winter season of the northern hemisphere, the ε values for $\lambda = 546$ nm are grouped in such a way that vast water areas are observed in which these values fluctuate over comparatively narrow ranges. This is clearly evident in Fig. 1, which shows a graph of the frequency of attenuation index values, plotted by allowing for the entire file of ε values at our disposal for Pacific surface waters. ε values are laid off along the abscissa axis, and the number of ocean surface points N at which the measurements were made are laid off along the ordinate axis.

On the basis of the shape and character of the graph, one can distinguish four arbitrary types of ocean waters differing in transparency: maximum, high, normal,

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*Numbers in the right margin indicate pagination in the original text.

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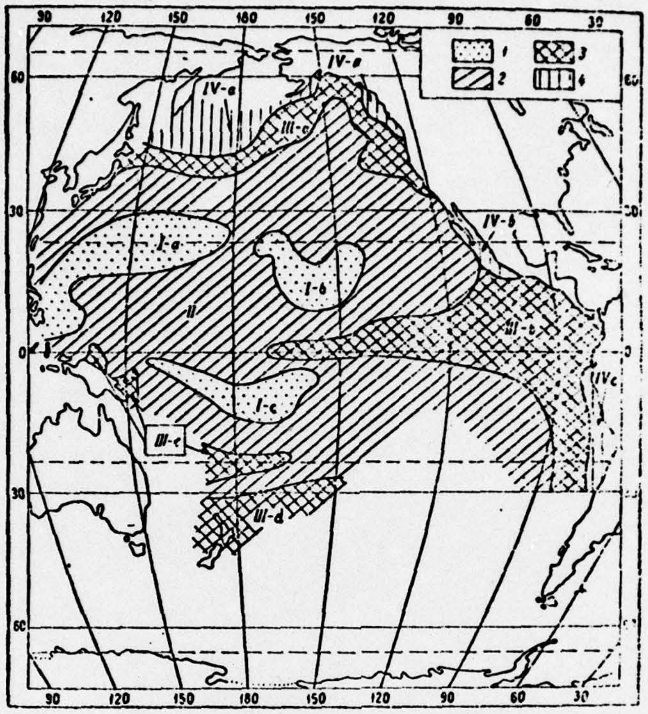




Fig. 2. Hydrooptical classification of Pacific Ocean waters according to transparency. Water transparency: 1 - maximum (type 1), 2 - high (type 2), 3 - normal (type 3), 4 - reduced (type 4). Roman numerals - hydrooptical regions (see Table 1).

and reduced. Let us note that one could also speak of waters of low transparency, but they are not characteristic of the open ocean, and are found only in a very narrow zone near the shore, so that this type of waters will not be discussed here.

The map (Fig. 2) shows the distribution of these water types over the area of the Pacific Ocean. A comparison of this map with similar maps of the plankton, suspension, primary production, and also with the pattern of surface circulation of Pacific Ocean waters[1-4] shows a clear similarity in the spatial distribution of all these elements.

On the largest scale, this similarity consists in the presence of features of latitudinal and circumcontinental zonality in the distribution of these elements, including transparency.

The circumcontinental zonality is manifested in a regular change in transparency with increasing distance from the shore; two water zones are observed in this case: coastal, and waters of the open ocean. In the Pacific Ocean, the coastal zone with waters of reduced transparency has the shape of a fairly narrow band, which is natural, since no large rivers empty into the Pacific Ocean, there are no vast areas of aeolian suspension, and rocky shores predominate, i.e., there are no large sources /18
of continental suspension. 3

In the open ocean, the transparency distribution is characterized by a latitudinal zonality, related to the latitudinal structure of the horizontal circulation of Pacific Ocean waters.

An important feature of the macroscale distribution of the transparency of Pacific surface waters is the coincidence of ranges of individual types of waters (according to transparency) with the location of the main ocean currents and ver- /184 gences. Thus, ranges of waters of maximum transparency are "superimposed" on the subtropical convergences of the northern and southern hemispheres. At the same time, the spaces occupied by the main currents comprising the tropical and subtropical circulations are essentially occupied by waters of high transparency, which are found over most of the water area of the Pacific Ocean, so that their transparency may be considered most characteristic of ocean waters as a whole (for the winter season of the northern hemisphere). This is confirmed by the graph of Fig. 1, which shows that these waters account for the majority of the data, despite their fairly uniform distribution over the water area of the ocean.

The part of the Pacific Ocean occupied by waters of the other two types of transparency consists of separate ranges whose location exhibits features of both latitudinal and circumcontinental zonality. It is of interest that ranges of waters of reduced transparency differ in the dependence on the character of the sources of suspended matter. Thus, these waters are observed at the equator and near the coasts of Peru and California, i.e., they belong to upwellings - zones of pronounced rise of deep waters rich in biogenic elements and therefore marked by a high plankton productivity. Completely different, i.e., terrigenous, sources of suspension "feed" waters of reduced transparency off the Canadian coast, abundant in sea cliffs, and in the zone of the Aleutian and Kurile Islands, where an intensive mixing takes place in the channels that encompass the entire water mass and hence makes the waters rich in mineral suspension.

Thus, an oceanic water area occupied by waters of one type of transparency can scarcely be regarded as an optically homogeneous region, since its individual parts may contain (and indeed exhibit, as indicated above) a different combination of dynamic elements and suspension sources, i.e., of the basic factors forming the field of optical properties in the ocean. However, it is well known that it is precisely a stable combination of these factors that promotes the creation of a stable optical water structure characterized by a definite homogeneity of optical properties.

It is therefore natural to try to continue the subdivision of the water areas considered (or their ranges), occupied by waters of the same type of transparency, into regions possessing a definite combination of the indicated factors. An arrangement of such regions, which we identified in the Pacific Ocean, is shown in Fig. 2, and their names are given in Table 1.

It is obvious that in these regions, which may be arbitrarily called quasi-homogeneous hydrooptical regions, the variability of optical properties should be less than within the confines of the entire water area as a whole. The validity of /185 separation of the hydrooptical regions may be estimated very objectively by comparing and analyzing the statistical parameters of the optical fields, calculated for each type of water area as a whole and for the individual hydrooptical regions.

For this purpose, we obtained the values of the mean transparency $\overline{\theta}$ ($\lambda$ = 546 nm) and standard deviation $\sigma_{\theta}$ for each water area as a whole and for the individual regions. The relationships between these parameters and the values of the variation coefficient $\frac{\sigma_{\theta}}{\overline{\theta}}$ are given in Table 2.

Table 1

| Index of region (Fig. 2) | Name of region |
|---|---|
| Ia | Western part of subtropical convergence of northern hemisphere |
| Ib | Eastern part of subtropical convergence of northern hemisphere |
| Ic | Subtropical convergence of southern hemisphere |
| IIIa | Transition zone between subpolar and subtropical waters of northern hemisphere |
| IIIb | Equatorial-tropical region of eastern hemisphere |
| IIIc | Southwestern region of island waters |
| IIId | Region of temperate waters of southern hemisphere |
| IVa | Subpolar region of northern hemisphere |
| IVb | Region of California current |
| IVc | Region of Peruvian current |

Table 2

| Optical type of waters or region | Number of stations | Ratio of the given type to type 1 | | Ratio of the region to the type as a whole | | Variation coefficient |
|---|---|---|---|---|---|---|
| | | $\frac{\bar{\theta}\text{ type}}{\bar{\theta}\text{ type 1}}$ | $\frac{\sigma_\theta\text{ type}}{\sigma_\theta\text{ type 1}}$ | $\frac{\bar{\theta}\text{ region}}{\bar{\theta}\text{ type}}$ | $\frac{\sigma_\theta\text{ region}}{\sigma_\theta\text{ type}}$ | $\frac{\sigma_\theta}{\bar{\theta}}$ |
| | 3 | 4 | 5 | 6 | 7 | 8 |
| Type 1 | 58 | 1.00 | - | - | - | 0.034 |
| Region Ia | 35 | - | - | 1.01 | 1.00 | 0.034 |
| " Ib | 11 | - | - | 0.99 | 0.69 | 0.024 |
| " Ic | 12 | - | - | 1.00 | 1.24 | 0.042 |
| Type 2 | 150 | 0.90 | 1.38 | - | - | 0.052 |
| Type 3 | 35 | 0.75 | 1.00 | - | - | 0.045 |
| Region IIIa | 14 | - | - | 1.03 | 0.90 | 0.039 |
| " IIIb | 11 | - | - | 1.01 | 1.34 | 0.060 |
| " IIIc | 7 | - | - | 1.00 | 0.72 | 0.033 |
| Type 4 | 7 | 0.54 | 2.28 | - | - | 0.143 |

Analyzing the tabulated data, one must first of all note the general increase in the variation coefficient from more to less transparent waters, indicating an increase in the inhomogeneity of the transparency field in more turbid waters. This may be assumed to be due to an increase in the role of cloudlike distribution of suspended matter in more turbid waters, manifested in an increase in transparency gradients

Interesting conclusions are obtained by comparing the data for the entire water area of a given type with values pertaining to individual regions inside it. In this case, while the value of $\overline{\theta}$ remains practically unchanged (Table 2, column 6), significant fluctuations of $\sigma_\theta$ (column 7) and of the variation coefficient are observed. Changes in the latter are particularly important, since they make it possible to estimate the inhomogeneity of the transparency fields of individual regions relative to the optical type as a whole.

In the majority of cases (4 out of 6), the transparency variance and transparency variation coefficients for the regions turned out to be equal to or much smaller than /18
the corresponding values for the overall type. Thus, the purpose of classification, consisting in identifying water spaces with a more homogeneous transparency field over a water area occupied by waters of a definite optical type, was achieved in this case.

However, for two regions (Ic and IIIb), the transparency variances and variation coefficients considerably surpass the analogous values for the type, i.e., the optical inhomogeneity of the transparency field of these regions is greater than the mean inhomogeneity of the field over the entire area of waters of a given type. In region Ic, occupying the area of subtropical convergence of the southern hemisphere, this is due to the fact that the boundaries of the range of type 1 were not drawn accurately enough and include portions of the water area occupied by waters of other optical types.

Indeed, in the western part of this region (west of 180°), the subtropical convergence shows up rather faintly, so that there is observed a complex dynamic system with flows of different directions. This leads to the injection into this region, occupied by waters of type 1, of relatively more turbid waters belonging to optical type 2, and in the extreme west of the region, even to optical type 3 (suspension-rich waters of the island zone). Under these conditions, it is very difficult to draw an exact boundary of the range type (and correspondingly, region), and this requires a large quantity of data that is not available to us at the present time.

The situation in region IIIb, located in the equatorial-tropical area of the /187
eastern hemisphere, is somewhat different. Here the increase in transparency variance and variation coefficient indicate the necessity of subdividing the region into several smaller and optically more homogeneous regions. Analysis of the dynamic processes and character of the suspension sources shows that such a finer subdivision is possible. Thus, the only obstacle to a more correct identification of the optical regions in this area of the ocean is the small quantity of available transparency measurements.

On the whole, the data shown in Table 2 support the validity of the proposed method of hydrooptical classification of the Pacific Ocean according to transparency, a classification which in our view can already be used in its present form in solving various types of problems. Increasing the volume of measured data and the number of optical characteristics directly determinable in the sea will help to supplement this classification system so that the latter will meet the scientific objectives as well as the steadily growing requirements of practical harnessing of the ocean.

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