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"THE MEAN SEA LEVEL AND ITS CHANGES IN TIME AND SPACE IN THE NORTH ATLANTIC OCEAN"

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The considerable differences in mean sea level heights at different places in the oceans and seas are due to meteorological factors: the atmospheric pressure and winds, to the deviations in the distribution of water temperature and salinity, and to currents. The range of these deviations is not negligible, even for practical purposes. A height difference in mean sea level amounting to approximately 270 cm has been computed for the western parts of the Pacific Ocean to the south-east of Japan, on the one hand, and the South Atlantic Ocean off the Antarctic coast, on the other hand.

In order to determine the variability of these differences for a more restricted area the sea level records for the 10 years period 1955 - 1964 were studied on the basis of the monthly and annual average data for 24 recording stations in the northern part of the Atlantic Ocean and for the research region as a whole. The results show that the variability of the monthly data is characteristic not only of the seasonal cycle in mean sea level. The position of the recording stations is also a significant factor. For instance, the difference between the European and the American coasts of the North Atlantic Ocean is striking. In addition, pronounced features may be noted concerning the variability of the annual mean sea level data in the research region.

As well known, the considerable differences in mean sea level heights at different places are due to the meteorological effects and to the deviations in the distributions of water density as a consequence of changes in temperature and salinity, and to currents. Several significant attempts have been made to determine the dynamic topography of the physical water surface and thus approximately the mean sea level, in the high sea parts of the particular oceans and in the area covered by water as a whole. In this connection reference must be made at least to the study by DEFANT concerning the Atlantic Ocean [1], to REID's paper on the Pacific Ocean [6], and to LACOMBE's survey of the Indian Ocean [2]. Some years ago a few studies were published in which the important results of the oceanographers named above were not only combined, but also extended [4,8]. It may be appropriate to mention in this connection some of the results of these studies.

If considering only the water covered area situated between 60°N and 60°S it may be noted that the lowest mean sea level appears in the South Atlantic Ocean off the Antarctic coast, the highest mean sea level in the western parts of the Pacific Ocean to the south-east of Japan. The difference between these extreme average sea level heights amounts approximately to 270 cm. The mean sea level in the northern hemisphere is about 25 cm higher than in the southern hemisphere. As a whole the Pacific Ocean stands some 35 cm higher than the Indian Ocean and approximately 70 cm higher than the Atlantic Ocean. The average sea level in the eastern parts of the Atlantic Ocean off the coast of Portugal is about 40 cm lower

than the mean sea level outside the coast of the United States at the same latitude in the western parts of the ocean. The extreme mean sea level heights in the North Atlantic Ocean as a whole differ by more than one meter.

A few data may also be given for some of the adjacent and mediterranean seas. For instance, the Mediterranean stands, on an average, roundly 30 cm lower than the Atlantic Ocean, the Black Sea approximately 20 cm lower than the Mediterranean. There is a difference of about 60 cm between the western and the eastern parts of the Mediterranean. In the Baltic Sea the northern parts of the Gulf of Bothnia stand 30 cm higher than the southern parts of the sea basin at the approaches to the Danish Sounds.

The examples mentioned above may suffice to show that we possess at the time being an approximate picture of the distribution of the average sea level heights not only along the coast of a continent. Also for places which are situated on opposite sides of an ocean and which can not be connected by geodetic levelling and directly compared with the help of recorded sea level data such a comparison is possible. The principal disadvantage in this connection is that a steady and continuous improvement of our knowledge of mean sea level heights is by no means an easy problem. The most important factors on which this statement is based are the following:

- A. The total coastline of all continents and islands is of considerable length and natural conditions necessary for the erection and maintaining of sea level recorders are so far practically missing in numerous regions.
- B. The area covered by water is extremely extensive. The research work at sea is expensive requiring especially equipped research vessels. In addition, the work at sea is frequently subject to considerable difficulties owing to unfavourable weather conditions.
- C. The greatest difficulty consists, however, doubtless in the fact, that all water masses in the oceans and seas are continuously in movement primarily as a consequence of the effect of different meteorological factors. These factors may also cause secondary changes in the inner structure of the water masses. Observations made over a more or less extensive sea area are, as a rule, not quite simultaneous and the results based on these observations thus not strictly comparable. In addition, it must be taken into account that the determination of the mean sea level must always be based on a very large number of data, as only in this manner the disturbing contribution of more or less extreme data may be reduced. The work must therefore cover a considerable span of time.

In order to get a conception of the occurrence of these extreme and exceptional data and the variability of the mean sea level, recorded values may be of great importance. As research area was selected the northern part of the Atlantic Ocean. This area is insofar the most adequate for our purpose as the number of sea level recording stations is here comparatively larger than in other oceanic regions and the distribution of these stations along the eastern and western coasts is sufficiently even. Unfortunately the number of islands with sea level recording stations in operation is in the North Atlantic Ocean rather limited. The results mentioned in the following are based on the data for

24 stations. All the concerned data were recorded during the 10-year period 1955-1964.

The monthly and annual mean sea level data were for each of the selected stations reduced to the zero level for the whole research period, and the corresponding deviations computed for every month and year during this period. In this connection it must be kept in mind that the zero level differs considerably in height for the particular stations. A difference of approximately one meter was already mentioned above for the North Atlantic Ocean.

The results showed quite distinctly that the monthly mean sea level variations in the research area are characterised by a seasonal cycle with low, that is negative values during the former part of the year and high, or positive values during the later part. The problem of the seasonal variation in sea level has already been studied by different oceanographers for the total world ocean, and it may therefore be left out of consideration in this connection [3,5]. The next step is the question of the variability of the mean sea level during the particular months and in different years.

To begin with it may be interesting to point out a characteristic feature in the data which is connected with the annual cycle of wind frequency and wind velocity. Determining the amplitude between the extreme sea level data recorded during each particular month it may easily be noted that this amplitude is approximately 50 per cent larger during the stormy winter months than in the calmer summer time. It may be mentioned that, on an average, the amplitude for the 24 selected stations was 14 cm in summer and 21 cm in winter. For the separate stations the variability is still more pronounced. For instance, for Hoek van Holland we may note in January an amplitude amounting to 50 cm, while in April it is only 10 cm.

Passing over to the annual mean sea level data the amplitudes of the variations, as may be expected, decrease to some degree. Nevertheless, they are also in this case by no means negligible. A remarkable feature in this connection is the pronounced deviation between the European and the American coast of the North Atlantic Ocean. Concerning the stations selected for this research the amplitude amounted, on an average, to 13 cm in the former case and to 8 cm in the later case. For the seven stations situated on islands in different parts of the research area the amplitude was 9 cm, or slightly higher than for the American coast. Concerning the causes of the inequality of the two opposite coasts it is, of course, not excluded that their configuration is to some degree responsible for this fact. However, the effect of the meteorological factors must also be taken into consideration. In this connection it must be accentuated that the influence of these considerable deviations on the final result diminish with the increasing length of the recording period.

However, for the determination of a more or less precise value of the mean sea level these data as such are not adequate. Different types of filters have to be applied in order to diminish the contribution of the disturbing factors. A number of different studies, especially those performed by ROSSITER have, however, shown that also after the elimination of the perturbations there always remains in the

data a certain inexactness [7]. This inexactness is probably due to the specific position of the different stations and to the local conditions typical of these stations. There is, in addition, the possibility that some of the recorded data may be inexact owing to a functional deficiency in the recording apparatus, but this possibility can not be proved and it does, probably, not occur too frequently.

The North Atlantic Ocean is an extensive area and the correspondence in sea level behavior between two adjacent stations is not always marked, especially concerning the monthly means. For instance, positive and negative deviations may in some months vary from station to station. On the other hand, there are also numerous months during which similar deviations are characteristic of a comparatively large area. For the annual mean sea level data the coincidence seems to be more pronounced. Thus it may be mentioned that in the year 1956 all stations, except three, showed a negative deviation, while in the year 1961 only two stations were characterised by negative values, all the rest of them by positive values. The two years named form the extreme cases concerning the mean sea level in the North Atlantic Ocean as a whole. In 1956 this level was -2 cm, in 1961 it was +2 cm. For the remaining years under consideration there is a marked trend to be noted in the data. Frequently the mean sea level was either high or low in the northern part of the research region, while the southern part showed the opposite sign. The position of the line separating the northern and the southern parts is, however, by no means always the same. A pronounced locomotion in each direction may be easily noted.

This short survey of the present results of mean sea level studies illustrated by the few data for the North Atlantic Ocean distinctly shows the multilateral difficulties connected with this problem.

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D i s c u s s i o n

WEMELSFELDER:

"Is it right that the Coriolis forces (or slopes) must be added to the figures given in your paper.

The oceans currents really exist, so the Coriolis slopes must really exist as well. One can calculate that there must be height differences in the order of magnitude of 1 1/2, 2 or even 3 m."

LISITZIN:

"The Coriolis force is included in the paper."

