THE WORK OF THE PERMANENT SERVICE FOR MEAN SEA LEVEL

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I imagine that a good proportion of my audience have had some contact or correspondence with the Permanent Service, and have perhaps wondered exactly what its functions are and how it works. To understand the situation as it exists today, it is first necessary to go back 29 years to the 5th General Assembly of the International Union of Geodesy and Geophysics at Lisbon in 1933.

At the meeting of the International Association of Physical Oceanography (IAPO) at that time it was decided to form a Mean Sea Level Committee, the initiative having been taken by the famous Finnish oceanographer, Professor R. WITTING, in a paper which set out the needs for international cooperation in this field. The reasons he gave for such cooperation are still valid today; in his own words :

"For the study of the tides and the tidal currents, of other movements of the sea surface and of currents of different origin, continual observations of sea level are the sole or a most valuable basis. For the solution of a complex of geophysical problems, data regarding sea level and its changes are of great importance ".

The collaboration of the International Hydrographic Bureau was readily obtained, and the invaluable assistance given by the IHB from that day to the present time cannot be emphasized too much.

At the meeting of the IAPO in 1936 it was decided that the collection of mean sea level data should be made as comprehensive as possible and should be published in a special volume. Through its hydrographic contacts the IHB had already commenced the collection of data from as many countries as possible throughout the world, and it placed them at the disposal of the Committee. The first volume to appear was Publication Scientifique No. 5 in 1940, a notable volume which contained monthly and annual mean values of sea level up to and including the year 1936. The first record we have of a monthly sea level average is for Swinemünde in the Baltic for 1811. Much of the work of compilation had fallen to Professor PROUDMAN of the Tidal Institute, as Secretary of the Mean Sea Level Committee. It was decided that similar volumes should be produced at intervals of 5 years,

but due to the war publications appeared in 1950 (No. 10), 1953 (No. 12) and 1958 (No. 19).

In 1951 the original terms of reference of the Committee were extended to include the compilation of a report on the secular variations of mean sea level and this appeared as Publication Scientifique No. 13. in 1954.

Dr. CORKAN and Dr. DOODSON, both of the Tidal Institute, in turn succeeded Professor PROUDMAN as Secretaries of the Mean Sea Level Committee. By this time it had become obvious that the labour and cost of the work would continue to increase, and it would be advantageous for the functions of the Committee to be transferred to a Permanent Service of the International Council of Scientific Unions. By this means it was hoped that the growing interest in the subject of mean sea level variations would be met on a more satisfactory financial basis as well as giving the organization some international authority.

The constitution and functions of the Committee were revised, and in addition to numerous modifications of the system of data collection, the liaison between the IHB, IAPO, and the Permanent Service was strengthened. Four new principles were adopted:

(1) The Service should make strong attempts to ensure a higher standard of accuracy in the data received for publication, with particular reference to the need for frequent levelling to check gauge zeros and tidal bench marks, and also to promote the use of reliable methods of computing monthly and annual means.

(2) The Service should encourage the permanent installation and maintenance of new gauges in those areas where present coverage is inadequate, with particular reference to oceanic islands.

(3) The Service should be empowered to commission the reduction of tidal observations in cases where the data would otherwise remain unused.

(4) The Service should engage in research work.

In effect, the Tidal Institute of the University of Liverpool, in view of its past association with the Committee for Mean Sea Level, was charged with the operation of the new Permanent Service and the present organization began to operate in 1958. It was fortunate that its inception coincided with the International Geophysical Year, for the Permanent Service was able in some small degree to smooth out some of the difficulties which occurred in connection with the new tide-gauge stations set up during the IGY. Virtually all the IGY mean sea level data that were observed were published by the Permanent Service in 1959 (No. 20) and at present we are engaged upon the task of publishing observations for the years 1959 to 1961 inclusive.

The average number of stations sending data to the Permanent Service during recent years is approximately 350. Whilst this is a considerable increase upon the early days, it is an unfortunate fact that the geographical distribution of these stations is still confined very largely to the northern hemisphere. Some of the geophysical questions which are still awaiting resolution require the knowledge of the eustatic changes in sea level that can only be obtained from a tide-gauge network which adequately covers the large oceans in the southern hemisphere.

The Permanent Service is endeavouring to improve this state of affairs

by a representation to the newly formed Intergovernmental Oceanographic Commission, but whatever help can be given by States Members of the IHB will be of great value. Ultimately, of course, responsibility for the installation and maintenance of gauges falls upon national and local authorities, and for their assistance the Permanent Service has published a schedule of the minimum requirements considered necessary for the adequate maintenance and operation of tide-gauges. This paper appeared in the form of IHB Special Publication No. 43 (1961) and stresses the points which, if neglected, may completely invalidate all the labour and expense put into the installation.

As mentioned above, one important item has been added to the original functions of the Mean Sea Level Committee — research. Due to many other commitments our research has been restricted, but some useful tasks have been completed or are in progress, of which the following gives a brief description :

(*a*) The compilation and publication of a comprehensive catalogue of all mean sea level data ever published by the Committee. This appeared as IUGG Monograph No. 23 in 1961 and we believe it will become a valuable reference work for those who wish to know what sea level data are available for any area and for any time.

(*b*) The compilation and publication of a Bibliography on Mean Sea Level. This work is still in the course of preparation but it is hoped it will appear in print towards the end of this year.

(*c*) Investigations into variations in mean sea level. These variations can be said to be either of a periodic or a secular nature. Monthly mean sea level data, if accurately prepared, will have been freed from the contributions of the astronomical tidal constituents with periods up to and including one month. Annual mean sea level values will have been freed from all the tides normally considered of importance, with the exception of the 19 yearly variation. Of course, perfect elimination of all the tidal constituents is impracticable, and it is therefore necessary to realize that monthly and annual means are only to be considered accurate to about 0.01 ft (3 mm) and 0.005 ft (1.5 mm) respectively. Having made this statement, what can then be said about the causes of variations in sea level ? Besides the very long period astronomical tides, mean sea level is affected by changes with time of the distribution of oceanographical and climatological factors, and of the distance of the earth's surface from the centre of the earth.

The most outstanding oceanographical factor affecting mean sea level arises from changes in the density of sea-water according to the season of the year. Such changes are known as steric changes and variations in sea level in the lower latitudes can be largely attributed to this cause. The further one travels from the equator, however, the more important do the climatological factors become, and foremost amongst these is the influence of the barometric distribution and its rate of change with time. Work performed by the Permanent Service during recent years has shown that most of the monthly and annual variations in mean sea level in European waters can be directly correlated with changes in the pressure system over these areas. It has been possible to formulate empirical relationships between observed barometric pressure distributions and observed sea level changes. Subsequently, by imposing a uniform barometric pressure over

the whole area an estimate of the *undisturbed* sea level can be obtained. The purpose of this investigation was to explain some of the differences of more than 0.5 metres in level between the Baltic and the Mediterranean as found from precise spirit levellings. This procedure, whilst appreciably reducing the standard deviation of the annual sea levels at all stations, mainly served the purpose of emphasizing that the time mean difference between the Baltic and the Mediterranean must be due to the time mean distribution of steric levels between the two areas.

Climatological factors can also have a marked effect upon secular changes in sea level. Much has been said during recent years of a trend toward a warmer climate throughout the world. Such a situation can have a two-fold effect upon sea level, first by melting some of the glaciated areas, thus increasing global sea level, and secondly by releasing the earth from the ice load, thus reducing sea level (relative to the land) in the deglaciated areas. Unfortunately, reliable mean sea level records do not exist for a sufficient length of time to indicate, more than approximately, what changes have occured. It is probably true that during recent decades mean sea level has risen throughout the world at the rate of something like 10 centimetres per century. Various geological estimates suggest that at the height of the fourth glacial age sea level was almost 100 metres lower than at the present time. At present, sea level around Great Britain appears to be rising at the rate of half a foot per century. This figure is small of course, but we have no guarantee that it will not increase; on the other hand, it may well decrease. It is of interest to remark that a rise of half a foot per century doubles the probability of the incidence of dangerous high water levels at British ports.

Changes in the distance of the tidal bench mark from the centre of the earth have been referred to, and may arise from glaciation or deglaciation. The earth's crust also responds directly to the tide-generating forces, to give what is known as the earth tide, and it also yields to the load imposed by the tidal bulge of the oceans and seas. This second effect is known as the loading tide, and earth tide measurements show it extends a remarkable distance inland from continental coasts.

It is perhaps worthwhile making a few remarks about the tidal cycle having a period of 18.6 years, that of the revolution of the moon's nodes. The theoretical existence of this tide is frequently used as an argument for taking 19 yearly averages or for taking a 19 yearly span of observations when examining variations of many kinds. The distribution and magnitude of this oscillation, however, have proved to be difficult to determine from observations because one is seeking an oscillation which is much smaller than the general noise level of the data. Attempts to remove the noise associated with winds and atmospheric pressure distributions have failed to give any more reliable results for the nodal tide than have analyses of the crude data. It now seems most probable that if the nodal tide can be observed it should be given by the expression $18.5\ (\sin^2 \lambda - \frac{1}{3})$ cos N in mm where λ is latitude and N the mean longtitude of the moon's ascending node. This theoretical expression includes a factor of 0.7 to allow for the yield of the earth referred to above. Many more years of

accurate observations than we now possess will be required before this can be verified.

If we had 100 years' accurate observations for 100 stations ideally distributed throughout the world how much better off would we be? Firstly we would have a better knowledge of the eustatic changes in sea level during that time, that is to say the changes in the average sea level of the global ocean. This would enable us to throw more light on such geophysical questions as the variation in the length of the day, which is dependent upon the angular momentum of the earth's rotation. If the eustatic changes are appreciable they must have come from glaciation or deglaciation, and according to the geographical location of the ice-caps so the instantaneous axis of the earth's rotation would be affected; this would throw more light upon the variations in latitude which have been observed. At present these geophysical phenomena are not satisfactorily explained by known changes in sea level, though of course, it must be understood that the variation of sea level is not the only factor that can affect the length of the day and the variation of latitude.

Oceanographical levelling, that is to say, the use of the sea surface as a check upon conventional methods of precise spirit levelling, has become of interest during recent years as a result of the Unified European Levelling Network, to which reference has already been made.

The Permanent Service is at present engaged on two tasks. It is attempting to determine the best values of the seasonal variations in sea level at selected stations around the world. Amongst other things it is hoped that this will be of some practical use for tide prediction purposes. It also proposes to provide a continuing analysis of data, as received, so as to give the most up-to-date estimates of secular changes in sea level. To do this it will be necessary to put all data received on to punched cards.

Many other aspects of mean sea level variations could be discussed in detail, were time available. The role played by the mean level of shallow seas in the dissipation of tidal energy is probably negligible, but the whole subject of tidal friction, bound up as it is with the rotation of the earth, is now so open to new theories that it is perhaps unwise to be too dogmatic. The abstraction of sea water as a coolant for many types of heavy industry demands a detailed knowledge not only of the tides but of the probability of abnormal sea levels, as does the construction of sea defences.

One common factor can be distinguished throughout all these varied topics. It is the need for more permanent gauges efficiently maintained, producing records which are accurately processed to give mean levels. As a personal ambition for the Permanent Service I shall be more than pleased, if during the next 25 years, we build up an adequate network of such stations so that our successors will have the data to work with which we at present are denied.