tained, and may result in agitated, unnatural movements, giving a totally false impression of the true natural characteristics of the animal.

This has been demonstrated on several occasions in making records of some of the shyer animals in the collection of the Zoological Society of London. In obtaining successful records of the rare and interesting maned wolf of South America, the kinematograph apparatus had to be set up again and again and the mechanism run without any film, before the animal could be induced to tolerate its presence or move about in a natural manner. On the other hand, the anthropoid apes, like children of the human race, are so intensely curious and interested in what is going on, that they will cease playing about in their normal fashion until they have been permitted thoroughly to examine the apparatus and satiate their curiosity.

We are indebted for the accompanying illustrations to the directors of British Instructional Films Ltd., 26-27 D'Arblay Street, Wardour Street, London, W.1.

Meteorological Perturbations of Sea-Level.

By Dr. A. T. DOODSON.

IT is always understood that the predicted heights of high and low tidal water do not take into account the variations in the height of the sea due to wind and to air-pressure, and that the errors due to these causes may be of considerable magnitude. With the large ships that are now in common use the margin between sea-bottom and ship-bottom is small, and since many of the largest ports in the world are situated in comparatively shallow water, navigation, both in channels and into dock, is carried on only with constant reference to the state of the tide. A particular example of the problem is that of loading a vessel in dock: how much cargo must be left on the quay-side so as to leave sufficient clearance for the vessel to get safely out of dock? The cargo so left has afterwards to be transported by lighter, with consequent increase of expense. If the tide is lower than was expected there is increased risk to the vessel, and if the tide is higher than was expected needless expense has been caused through leaving cargo to be transported by lighter. It is therefore obvious that a forecast of the effects of wind and air-pressure on sea-level and tides would be of very great advantage to navigators in and near a port, and for this reason much attention has recently been given to the subject.

The effects of wind and air-pressure on sea-level are also important factors for engineers engaged in the construction of harbour works. Again, they are of importance in connexion with geodetic surveys, since sea-level is an obvious datum from which to take measurements; but it has been shown by the Ordnance Survey ("Second Geodetic Levelling of England and Wales," p. 34) that measurements by levelling gave mean sea-level at Dunbar and Liverpool respectively 0·8 ft. and 0·4 ft. higher than at Newlyn. These discrepancies cannot be attributed wholly to errors of levelling, and there is reason to believe that part of the explanation is connected with climatic causes. Investigations as to the variation of sea-level with wind and pressure have been made by Mr. H. L. P. Jolly, of the Ordnance Survey, and are referred to below.

Most investigations on this subject have been concerned with air-pressure and not with wind, the sea being regarded as a negative water barometer; the "constant" for the barometer, however, varies much from place to place, and even according to the numerical method used in obtaining it. A British Association Committee in 1896 reported that the effects of wind and pressure were real, but no law could be established; the methods of investigation, however, were faulty. A successful reduction to law for both wind and pressure in connexion with tides at Ymuiden was published by Ortt in 1897, his method being to collect together observations for given ranges of values of pressure, wind direction, and strength. This method has been used, in essence, by other continental workers. Prof. R. Witting (Bulletin de la Société de Géographie de Finlande, Fennia, 39, No. 5, 1918) has elaborated a method of comparing the gradients of the sea-level in the Baltic Sea with the gradients of the pressure-system over the sea; this method is strictly in accordance with theoretical considerations, but it requires a large number of observing stations, and is most confidently applied to narrow seas. His use of pressure gradients instead of wind-strength and direction of wind is very commendable, and was utilised by Mr. Jolly in his investigations, leading to the simple formula

$$\zeta = \kappa(B - \bar{B}) + \lambda(E - \bar{E}) + \mu(N - \bar{N}),$$

where ζ is the meteorological disturbance of sea-level; B, E, N are the values of the local barometric pressure and its gradients to the east and north respectively; bars denote means in the interval of time considered, and κ, λ, μ are constants determined from observation.

This formula is valuable because it lends itself very easily to numerical methods, and fairly accurate values of the constants may be obtained from observations extending over only a month, whereas an elaborate method like Ortt's requires far more observations and much more labour. It represents the perturbations of mean sea-level with a fair degree of accuracy.

The formula has been used extensively at the Tidal Institute at Liverpool, and has yielded some very interesting results. It is easy to deduce from it the direction of the most effective wind for raising sea-level at the place considered, and this has been evaluated from a month's observations at various places on the British coast, the results being illustrated in Fig. 1. The arrows give the direction from which the most effective winds blow, and the lengths of the arrows are proportional to the effects for a given strength of gradient in the most appropriate direction. Many previous investigators dealing with the perturbations of mean sea-level on the Continental coast of the North Sea have found that the most effective winds for raising sea-level there are those which blow towards the shore, and conclusions have been formulated that the effect is due to the local wind blowing the water towards the shore. This conclusion is not substantiated by Fig. 1, for the winds which raise sea-level on the east coast of Britain are those which blow away from the shore. A westerly wind therefore raises the water of the whole of the North Sea in some degree or other, and this effect must therefore be due to wind blowing over a large area to the north of Scotland. The direction of the most effective wind at Felixstowe has a much larger northerly component than is present at Dunbar. In other words, a northerly wind would have little effect at Dunbar as compared with Felixstowe, the reason probably being that the sea becomes shallower towards the south, agreeing with theoretical conclusions that, apart from the effects of rotation, wind operates more effectively in shallow water than in deep water.

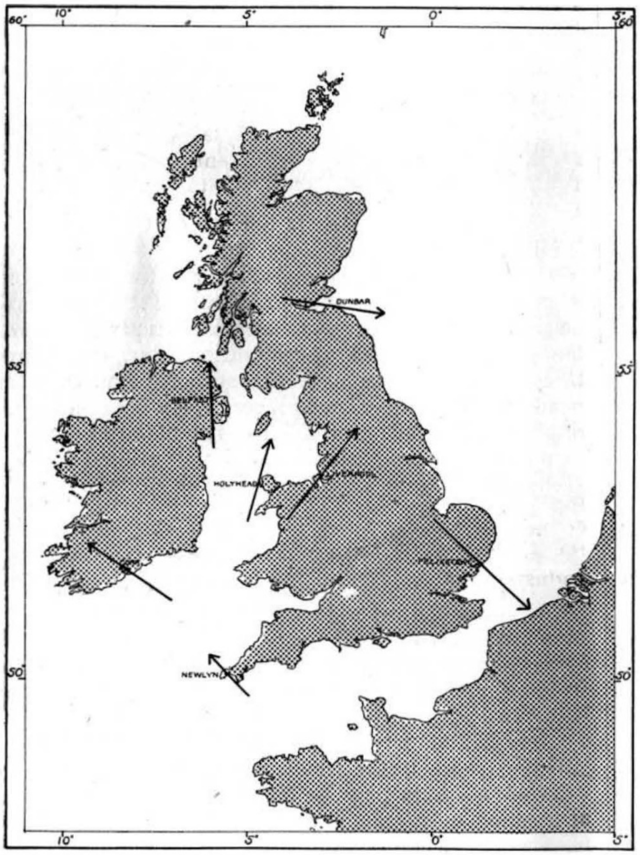

FIG. 1.—The most effective winds for raising sea-level round the British Isles.

The Irish Sea gives some interesting results. It would appear that from Newlyn northwards the most effective wind has a large southerly component. Local influences are far more marked at Newlyn and Cork than at Holyhead and Belfast, while the effect of the broadening out of the Irish Sea is shown slightly at Holyhead and still more at Liverpool, where the westerly component of the wind shows its influence, and again the shallower water of the upper part of the Irish Sea helps the effect.

Some of these conclusions could have been formulated roughly from qualitative statements in seamen's almanacs, but what gives value to the results dealt with above is that they are expressed quantitatively. Further, qualitative statements are liable to give not the most effective wind for a given wind-strength, but that wind which has happened to give a storm-effect.

The predominating factor in the above results is the southerly wind operating on the Atlantic water south of Ireland. This conclusion has been verified for Liverpool by applying an extension of the formula so as to include Atlantic winds (south of Ireland) as well as local winds. The results show that, for a given wind-strength operating in the most favourable direction in each case, the Atlantic wind has 50 per cent. more effect than a local wind, in spite of the deeper Atlantic water being less favourable to wind effects. Further, the most effective Atlantic wind blows from the south and the most effective local wind from almost due west.

When we correlate the pressure system at a fixed time with the mean sea-level at a variable time we find that the correlation between the sea-level at Liverpool and an easterly gradient of pressure, corresponding roughly to a south wind, is greatest when the mean sea-level is taken about fifteen hours later than the corresponding pressure gradient. The corresponding time for Newlyn is nine hours. For a northerly gradient, however, the time difference for maximum correlation with mean level at Liverpool is practically zero. These results are in conformity with those just discussed, for we should expect a large time-interval for setting up the circulation of water from the Atlantic and a small time interval for effects generated in the Irish Sea.

It can be deduced, therefore, that the most favourable conditions for giving exceptional effects on sea-level are those in which a south wind blows for some hours, filling the Irish Sea as a whole, and then changes to the west—the rapidity with which the west wind operates is apparently favourable to storm-effects.

The correlation between mean level at Liverpool and the fluctuation of the local atmospheric pressure is greatest when the sea-level is taken about three hours earlier than the pressure. For Newlyn the time-advance is five hours. These results are of very great interest: the anticipation in mean sea-level of changes in barometric pressure is probably due to the different rates of travel of disturbances through air and through water. Ferrel (U.S. Coast Survey, Report, 1871, p. 93) in 1871 noted that the changes in sea-level in Boston Harbour, U.S.A., appeared to anticipate the barometric pressure. Anticipation of coming storms, according to Dr. Bell Dawson (Trans. Roy. Soc., Canada, 1909, pp. 186-188), is also shown in the currents off Newfoundland; a change in magnitude and direction is noticeable some twelve hours before the onset of a storm, and generally (with some exceptions) the current sets more strongly towards the direction from which the wind is about to blow. This phenomenon is regarded by the local fishermen as an unfailing indication of bad weather. These anticipatory effects are worthy of fuller investigations.