several years at a time by the use of punched card equipment. The noon and midnight values of the Moon's longitude, latitude and parallax have been computed from Brown's *Tables of the Motion of the Moon*, and the main stage of the conversion of these values to corresponding values of the right ascension and declination has been completed for the years 1951–60. For the same years, midnight values of the heliocentric equatorial rectangular co-ordinates of Mercury and Venus have been obtained from the heliocentric latitude, longitude and radius vector which were already available from Newcomb's *Tables*. Apart from the final stages of conversion to apparent position, which is done year by year as required, the whole of the fundamental work on the Sun, Moon and planets is thus complete to 1960. It is hoped shortly to complete all punched card processes for the Moon's longitude, latitude and parallax to the year 2000.

No changes have been made in the *Nautical Almanac*, which is still much reduced in size in comparison with the edition for 1941. Preparation of the *Supplement* is in progress, and a general revision of the *Almanac* is under consideration.

For the years 1944, 1945 and 1946, the apparent places of the 426 10-day stars normally received from the Office of the *Connaissance des Temps* for inclusion in the volume of *Apparent Places of Fundamental Stars* were computed in the Office, while the 32 circumpolar stars for the years 1945 and 1946 were received from the Office of the *American Ephemeris*. The French, German and Spanish introductions to this volume are being reinserted in the 1946 edition.

The reopening of communications will enable France to supply once again the calculations allotted under international agreement, which have during the war been jointly undertaken by Britain and America.

The scope of the occultation prediction programme has been increased as enemy-occupied countries have been liberated. Predictions of occultations for 1945 and 1946 have been dispatched to all observatories so far liberated. Partially reduced observations have been received for 1943 and 1944, somewhat irregularly due to war-time difficulties of communication. Reductions received for 1943 have mostly been completed, but further observations are expected. Plans for centralised publication have been delayed and no definite scheme is yet in operation.

By agreement with Professor Brouwer, the annual discussion of the motion of the Moon derived from observations of occultations will, as from 1943, be undertaken by the Royal Observatory; it is hoped to continue a preliminary investigation, started before the war, into the practicability of taking account of the irregularities in the limb of the Moon.

Although little change has been made in the form or presentation of the navigational publications issued by the Office, much investigatory work has been undertaken, particularly for the Air Ministry, into various instrumental, tabular and graphical methods for astronomical navigation. In several cases sufficient calculations have been made to allow of a full-scale test of the methods. The annual visits to the Office of the R.A.F. Specialist Navigation Course have provided many opportunities for the interchange of practical and theoretical view-points.

Royal Observatory, Edinburgh
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This report covers the period 1940 December to 1945 April.

In the autumn of 1940, as a result of representations made by the Astronomer Royal, it was decided that the Observatory should be equipped for the purpose of duplicating the various time signals normally originating from Greenwich. (Provision had previously been made for transmitting the B.B.C. "six-pips" signals only.) The work of installation was to a large extent carried through in 1940 December, the equipment sent from Green-

wich including the Free Pendulum Clocks Shortt Nos. 11 and 16. By the end of December the work of installation had fortunately been carried to a point which allowed the transmission of rhythmic signals to Rugby, and as a result the Observatory was able to operate the Rugby signals, although under difficult conditions, in 1941 January when, in consequence of enemy action, it was impossible to operate this service from the Greenwich station at Abinger. At the same time the work of installation proceeded. From 1941 May to 1943 March 29 and from 1943 October 27 to the present date the rhythmic signals radiated from Rugby at 10^h U.T. were normally operated from Edinburgh, but originated from Abinger on a few occasions when, owing to technical faults, transmissions from Edinburgh were not possible or advisable. A large number of the Rugby transmissions at 18^h U.T. and of the transmissions from British short-wave stations (which were commenced in 1942 July) have also been operated from Edinburgh. On a few occasions the Observatory has been called upon to operate the B.B.C. "six-pips" signals. Hourly signals to the Post Office have been supplied and have been available for the control of the "speaking clock".

In 1943 February a direct line link was installed between Abinger and Edinburgh whereby the clocks at each station were made available at the other. Early in 1944 a quartz clock of the Post Office Group IV type, the first of a set of such clocks constructed for the Royal Observatory, Greenwich, by the Post Office Radio Branch Laboratories, was installed at Edinburgh, and commencing 1944 February 26 the Rugby signals both at 10^h and 18^h U.T. (at the time the 18^h signals were being operated from Edinburgh) originated from this clock, the phonic motor of which was constructed so as to provide for the transmission of rhythmic vernier signals. A similar clock was installed at Abinger shortly afterwards (together with another Group IV clock, the phonic motor of which delivers mean time second impulses).

Throughout the whole period transit observations were secured at Edinburgh on all possible occasions, and were combined with observations obtained at Abinger for the purpose of deriving clock errors.

Considerable developments have been made in the general technique of the Time Service during these war years. In the following paragraphs reference will be made only to development work carried out at Edinburgh with the object of improving the service. This report is thus to be regarded as supplementary to the Greenwich reports, to which reference must be made for a complete account of the various changes that have been made in the pre-war technique. In addition to the requirement of providing signals giving absolute time to an accuracy adequate for navigational and surveying purposes, the signals radiated from Rugby at 10^h U.T. are now intended to provide a standard of frequency, the desideratum being that consecutive 10^h signals should define an interval of 24 hours with an accuracy of the order of a millisecond. The development work which has been carried out at the Edinburgh end has been concentrated on this aspect of the service.

Throughout the years 1941 to 1943 the operation of the service was based on Shortt free pendulum clocks. During this period the performance was improved. The original circuit arrangements were modified, and in addition to the development (to which reference is made below) of line transmission, radio reception and chronographic measurement, a technique was developed for using a "mean clock" for signal transmission purposes, the effect of clock erratics being reduced by averaging as many clocks as were available. The process developed was similar in principle to the process previously developed at Greenwich for the purpose of basing definitive corrections to the signals on a "mean clock", but there were differences in detail which arose from the circumstance that for signal transmission purposes clock errors have to be extrapolated. During 1942 a fundamental change was made in that the service was ultimately based on quartz controlled clocks situated at other institutions, and the process of extrapolation of the errors of the pendulum clocks at the Observatory was reduced to extrapolations, for periods of

24 hours only, of the relative errors of the pendulum clocks and the quartz controlled standards, these relative errors being obtained *via* a radio link which employed the 10^h Rugby signals themselves. It had become apparent at this stage that the performance of quartz controlled clocks was of an altogether higher order than that of the best pendulum clocks. During 1942 and 1943 some investigations were carried out on the erratics of free-pendulum and quartz clocks, the results being published in a paper by Greaves and Symms (*M.N.*, **103**, 196—the free-pendulum clocks designated X, Y and Z in this paper are respectively Shortt 4, Shortt 11 and Shortt 16). The conclusion reached that the P.O. type quartz controlled clocks are very superior in performance has been more than confirmed by subsequent experience. As regards their erratics of rate (designated in the paper by types B and C) the mean absolute scatter in daily rates has been found (from an analysis, made at the Observatory, of the results of beat frequency comparisons supplied by the Post Office Radio Branch Laboratories) to be of the order of $\pm 0{\cdot}05$ milliseconds per day. This figure represents a combination of erratics of types B and C, and the performance indicated thereby contrasts strikingly with that of the Shortt clocks for which the mean absolute scatter of daily rate due to type C erratics alone seems to be of the order of ± 1 to ± 2 milliseconds per day. The "wanderings" of pendulum clocks are in fact much greater than those of quartz controlled clocks of the Post Office Group IV type. As regards erratics of type A, an investigation, using an electronic chronometer, at the Post Office Radio Branch Laboratories has shown that the phonic motors of the quartz clocks introduce random errors with a standard deviation of the order of $\pm 0{\cdot}1$ milliseconds. The Observatory is indebted to the Radio Branch, Engineer-in-Chief's Office, General Post Office, for permission to quote this result and the result of the analysis of the beat frequency comparisons.

It was clear that the state of affairs in which the signals were operated by pendulum clocks was unsatisfactory, even though the service was ultimately based on quartz controlled clocks. But in some respects the experience gained with pendulum clocks was of permanent value. The performance of the "mean" pendulum clock was good enough to justify efforts being made to reduce the errors of radio reception and chronographic measurement and to secure a greater degree of constancy of the transmission time over the line system connecting the Observatory to Rugby. The technique of radio reception and of chronographic measurement were developed and, largely owing to the very valuable co-operation given by the Post Office Engineering Department (Scottish Region), considerable reductions were effected in the errors introduced by variable line lag. The result was that when the quartz clock was installed in 1944 it was possible to take advantage of its superiority and to reduce materially the errors of individual 24-hour intervals defined by consecutive G.B.R. signals at 10^h. But it became clear that the full superiority of the clock was not being utilised. More improvements were made in the chronographic technique, and in the later months of 1944 efforts were successfully made to secure a further reduction of errors due to line transmission. A series of experiments, which included oscillographic investigations of build-up, were carried out with a view to improving the method whereby the signals are fed on to the line, and the previous circuit arrangements were modified. The Post Office contributed to this by supplying relays of a greatly improved type, and they took the important step of discarding the arrangement whereby a traffic line channel was switched over to signal use for a short period only, and provided a permanent channel, with a loop at Rugby feeding a return channel, and available for test at any time. This channel became available in 1945 January; an arrangement was made whereby the stability of the line system was kept under observation at the Observatory, and on receipt of a message that re-adjustment of the system was necessary the Post Office engineering staffs have promptly taken the necessary steps. In addition they have themselves made regular tests of line stability, employing the same method of testing as has been applied at the Observatory. This method is an adaptation of the "chaser" method devised at Greenwich for measuring the total lag of a looped