INTRODUCTION

THE FUTURE OF THE RESEARCHES ABOUT THE EARTH'S ROTATION

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It is well known that futurology, the science of forecasting the future, is a very difficult science. It also depends on the intervals of time for which we pretend to forecast the evolution of the physical system under consideration. Aldous Huxley thought that futurology might be a very good thing.

We are concerned about the future of the researches dealing with the Earth's rotation and I shall try a few guesses, considering suitable time intervals.

The astronomical and geological evolution of our planet can be conveniently expressed in units of a million years, but this time interval is very long from the point of view of the researches of the human civilisations dealing with the dynamics of the Earth around its centre of mass. Even a thousand years is already too long to attempt any forecast of our researches, because we cannot guess if our present type of civilisation will last as long as that; but we know that human civilisations have observed the luni-solar precession for about 2,000 years. If we consider one hundred years we are already in a better position to guess the future of our researches, but we must not forget that futurology is a very hazardous science. Actually the first systematic observations of the phenomena that concern us were made about a hundred years ago; that is, we are at the end of the first century of observations dealing with the Earth's rotation.

Another way to look into the future of our researches, for the next hundred years, is to study the history of science dealing with this subject during the last hundred years. The consideration of the main fields of advance in the researches concerned with the latitude and longitude variations depends, sometimes, on the viewpoint of the person who is looking into the subject.

About a hundred years ago, a large section of the astronomical community was sceptical about the possibility of measuring the small variations of latitude that were predicted when the dynamical theory

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of the motion of a rigid body around its centre of mass was applied to the case of the Earth. But patient and determined observers, employing the best instruments available at the time, suceeded in determining some variations of latitude.

This pioneer work was followed by the remarkable studies of Chandler that finally convinced everybody of the possibility of determining latitude variations. The so-called Chandler period corresponds to the period of the free nutation of the Earth. This observed value refers to the real Earth, and the theoretical values computed from mathematical models should therefore be in agreement with these observations. At that time the knowledge about the internal structure of our planet was very scanty and geophysics was beginning to appear as a science.

The successful demonstration of the possibility of determining variations of latitude led to the setting up of a remarkable programme of astronomical international cooperation called the International Latitude Service. The first observations were made in December 1899 and have continued, without interruptions, till the present day.

Another aspect of the motion of the Earth around its centre of mass corresponds to the study of the diurnal rotation and its irregularities; that is, the time problems. The theory we have mentioned forecasts the constancy of the 24 hours period to such a degree of precision that observation of irregularities of the daily rotation was not technically feasible until much later.

While latitude variations were already regularly observed at the beginning of the century, thanks to the development of adequate techniques, the corresponding time variations had to wait for further development of timekeeping devices. We must remember that pendulum clocks were still the main timekeeping instruments till about 40 years later. The researches of N. Stoyko, based on pendulum clocks, first detected the irregularities in the length of the day.

The organisation of another important programme of international cooperation, called the Bureau International de l'Heure, has been of fundamental importance not only in the adoption and improvement of new timekeeping devices but also in theoretical researches dealing with time problems.

These facts show the great importance that technological developments have on further improvements of our researches.

As we try to guess the future by looking into the past, let us define which were the main developments. The most important one, I think, was the establishment of international cooperation on a regular and permanent basis. Another important milestone was the adoption of the same type of instrument, and the same computing technique, for the reduction of latitude observations. When we remember that logarithms were the main computing technique and we see, nowadays, our electronic computers, we can guess that our colleagues, in a hundred years' time, will probably consider our computing techniques as primitive as we consider logarithms at the present time.

The theory employed in those days to forecast latitude and time variations can be considered as simple in comparison with the present day standards. The main difficulties were lack of adequate knowledge about the structure of the Earth, and lack of computing techniques that facilitated the integration of the equations of motion describing the dynamics of the Earth.

The advances in internal and external geophysics, specially during the last 50 years, gave us a good insight about the Earth. The progress of seismology and the publication of the seismological tables of Jeffreys and Bullen, based on proper statistical analysis, permitted the definition of the main layers of the Earth's interior. The knowledge about our atmosphere and hydrosphere also contributes to a better understanding of polar motion and time irregularities.

What will happen in the next century? It is known that some branches of science, after rapid strides in a fairly short time interval, tend to slow down for a time till new technological and theoretical advances are possible. So the answer to this question depends on the optimistic or pessimistic outlook of the person who tries to guess the future. My guess is that internal geophysics will not advance in a way that will modify substantially the important influence it has on time and polar motion problems, but external geophysics might show appreciable improvements in the next hundred years.

The present-day computing techniques have allowed us to set up theoretical models that take account of the actual knowledge about the structure of the Earth. But, precisely because of the easy access to computers, there is such a proliferation of theoretical models that it is extremely difficult to compare results; this applies not only for the structure but also for the geopotential, which is so important for the computation of orbits of the Earth satellites.

I hope that this problem will be solved in the near future by the setting up of reference models for the different regions, from the centre to the outer layers of the atmosphere, that make up our planet. The application of Rayleigh's principle, to calculate generally adopted first order perturbations of the reference models, will increase the usefulness of such models.

We are forgetting one of the main lessons of the past that I have already mentioned, namely, the need for adopting the same computing procedures. This is still more important nowadays than at the beginning of the century, because our computer programmes are so complex that it is not easy for an outsider to check the computations; that was an advantage of our colleagues of a hundred years ago, thanks to their primitive computing techniques. I hope that our colleagues in a hundred years' time will have adopted more streamlined and sophisticated computing techniques that will allow anybody to check their computations more easily.

I have already mentioned that latitude variations were observed far earlier than time variations; but technological advances, made around the middle of the present century, led to the construction of quartz and atomic clocks of such precision that the daily rotation of the Earth, our fundamental clock since the first human beings appeared on our planet, is no longer employed in many branches of physics. As, however, most of us are bound to the surface of this planet, we are still obliged to compare these timekeeping devices - the atomic clock and the diurnal motion of the Earth. There are a number of irregularities in time observations that we are beginning to study, thanks to the high precision attained by the atomic clocks, and these observations will oblige theoreticians to set up models trying to explain the irregularities.

What will the future reserve for us in this field of research? We had a rapid technological development of timekeeping devices for about 20 years, and what will happen in the next hundred years? I leave the questions without answer, but I think the explanation of these small irregularities will keep scientists busy for quite a time.

We are at present experiencing another technological revolution in the field of studies related to the motion of the Earth around its centre of mass. This is based on the utilization of Doppler and laser techniques with artificial satellites, laser techniques with the Moon, and very long base line interferometry with radio telescopes. These are the so-called modern techniques, which should be called the present-day techniques in the context of the viewpoint we are considering because they will probably be superseded in a hundred years.

We are debating, at the moment, the merits of these modern techniques in comparison with the classical techniques employing visual zenith telescopes (VZT), photographic zenith telescopes (PZT) and astrolabes. There are also discussions about the advantages and disadvantages of the above mentioned techniques for polar motion and universal time determinations.

We are at an important turning point in the researches about the Earth's rotation, thanks to this technological revolution. We can see that the classical techniques will be superseded, in due time, by modern techniques but one important matter, under discussion at present, is to know the right moment when the classical techniques might be discontinued, or if some of these techniques (for instance, the PZT) will still be useful in the next decades.

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Our colleagues, in the middle of next century, will know if we have taken the right decision at the appropriate time, or if we made a mistake, discontinuing long and regular series of observations without due care for a proper correlation with the modern techniques.

We must remember that if we go on with the classical observations longer than would be necessary, judging by the standards of the mid-twenty-first century, we do not lose anything of the valuable series of data accumulated till now. But if we discontinue our classical observations too soon, we shall introduce a big discontinuity in our records that cannot be recovered anymore, and our future colleagues will strongly critize us for taking this decision.

Our colleagues of about a hundred years ago were employing the first beginnings of what was later called statistics, and they had no idea about what are now described as correlation functions. Unfortunately, the word correlation is employed, even nowadays, in a loose sense and some scientists tend to forget that it has a precise statistical definition. Many observations are still presented in such a way that they do not conform with the theory of errors.

It is interesting to think that we are in the middle of a period of two hundred years at a time when new techniques are revolutionizing the acquisition of information about the Earth's rotation.

If the lessons of the past are applied to present circumstances, we should endeavour to set up central bureaus taking care of the observing programmes and adopting, as far as possible, the same type of instruments and the same observing techniques. The reduction of the observations should also be performed at the same computing centre in order to assure uniformity of the computations. The precisions obtained by these techniques are at least one order of magnitude greater than the classical techniques and, therefore, the problems of getting homogeneous series of observations are still more difficult than with the classical methods.

The debate, at the moment, is about which technique will be more useful or will give us more information at a lower cost. The adoption of one or more of the techniques mentioned will depend, to a great extent, on the amount of finance available for developing this type of research.

The possible experiments that might discriminate among the competing techniques have to be carefully planned, and we must not forget that the surface of our planet is subject to many forces, and that a more general model of the Earth should consider, for instance, its change of shape due to elasticity and the transference of heat. It is even pertinent to ask if there is such a thing as a fixed point on the Earth. The answer to this question depends, of course, on the definition of a fixed point and that, again, is related to the definitions of precision and accuracy of our measurements.

A good way to avoid all these difficulties is to set up, side by side, different techniques so we have no doubts about possible local displacements. The future will show us if we have adopted the right techniques and procedures.

The great advantages we have had with the functioning of the Central Bureau of the IPMS and the B.I.H. are widely recognised. In spite of the achievements obtained by these international organisations, we still suspect that some irregularities, in the pole path and in time determination, are due to some errors in the observing and computing programs.

We should forecast for the next decades the setting up of similar programmes of international cooperation dealing with observations made with Doppler, lasers to artificial satellites and the Moon, and VLBI. The results obtained by different techniques should be consistent, and that is another goal for the future.

Another colleague, speaking to a gathering dealing with Earth's rotation problems in a hundred years' time, will probably worry about new observational and computing techniques as we are doing today. Let us hope that our work will facilitate the job of our future colleagues of the next century.