REASONS AND POSSIBILITIES FOR AN EXTENDED USE OF THE TRANSIT SYSTEM

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SUMMARY

Observations of Earth rotation and polar motion are now performed on a routine basis by classical astronomical methods and by the satellite Doppler technique.

In the near future the laser is likely to realize its old objective of determining ER and PM with an accuracy of a few milliseconds of arc through ranging to Lageos. VLBI is still in development.

To permit investigation of possible systematic differences, all these techniques should be used simultaneously for a period whose length should not be set in advance.

The Doppler method can still be improved and could be easily introduced at many observatories in support of the Medoc campaign. We present here two possible methods of data condensation which, if implemented, would permit much of the data analysis to be done at the tracking stations and would reduce to a very few the number of parameters required by the central computing agency.

1. NON A PRIORI SELECTION OF A SPECIFIC METHOD OF OBSERVATION

During the UGGI General Assembly of Grenoble (1975) Prof. P. Melchior, considering the availability of satellite techniques and their good results, initiated a free discussion centered on the use of these new methods and their impact on the future evolution of International Services devoted to Polar Motion (PM) and Earth Rotation (ER) studies. At the next IAU General Assembly Prof. Robbins (1976) gave a review of the various proposals given by many geodesists and astronomers. The main conclusions were that it was at present impossible:

- to answer the question "which techniques must be maintained or selected?"

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- to define the length of the period during which the coexistence of classical (PZT, astrolabe..) and new instruments (Doppler, laser, interferometer..) should be maintained.

Since that time the reasons and needs for more precise measurement of the Earth's angular position have been often considered, and summarized by P.Melchoir (1976), J. Popelar (1976), A.C. Schulteis (1977), P. Paquet (1978). From many discussions it comes out that a 5 cm precision in the pole positioning and 0^{s}0001 for the Earth rotation velocity are requested over time intervals extended from few hours to one day. These constraints are the proposed objectives to be reached within the next 10 years. Precise polar coordinates are of immediate use for space research and geodesy but not necessarily on a continuous basis. However, in the longer term, for humanitarian and economic reasons, programmes considering earthquake predictions (plate deformation control) and climatic variations could require continuous knowledge of the parameters fixing the observers' positions.

It is important to know if a high accuracy is continuously necessary or if very sophisticated techniques will be requested only for particular circumstances. In the meantime less accurate methods could perhaps monitor the Earth rotation and polar motion.

The fascination of space research and the possibilities for increasing the accuracy with which ER and PM could be measured have produced a competition between scientists, each defending his preferred technology: astronomical, Doppler, Laser or interferometry. In practice all these techniques are complementary and may be considered as developments in the evolution of the best system (?) of observation whose use would be just to check if Earth motions are those to be expected from theory.

What is the present state of the techniques for Earth rotation and polar motion measurements?

For several years an accuracy of 0$''$01 has been obtained by classical astronomy and, as improvements are in progress, an accuracy between one hundredth and few thousandths of a second of arc can be expected during the next decade. What is desirable is to reduce progressively the observer functions by installation of more automated instruments like the PZT and the Chinese astrolabe.

For the Laser, confronted by the difficulties of ranging to the Moon on a continuous basis, a new solution is now possible with ranging to the Lageos satellite. To check the expected performance on Lageos, a request for a several years campaign has been expressed at the Workshop on Space Oceanography, Navigation and Geodynamics (SONG, 1978) organised by the European Space Agency.

Long baseline radio interferometry (VLBI) is in a similar situation to that of the Moon laser at the beginning of the 1970's A few experiments have been realized, some capabilities have been demonstrated and during the next years it remains to improve the technology (Schilizzi, 1978). Several years ago short baseline interferometry (SBI) was able to measure the angular Earth position with similar precision to that obtained with a PZT (Ryle and Elsmore, 1973). Besides these systems the radio Doppler method is well established and is the only new technique producing pole coordinates on a routine basis. The Doppler low cost instrumentation is already used in many disciplines such as astronomy, geodesy, navigation, and geology, and the Workshop SONG (1978) requested experiments using the Doppler method with a third frequency near 2 GHz.

Considering the state of art of these methods, no selection of a specific technique can be made at present and we must consider that their coexistence is fortunate. It is an excellent arrangement for detecting systematic deviations. From the same point of view it is not realistic to predetermine an overlapping period during which the different methods are to be used. This overlapping must be long enough to compare the results and reach conclusions we may trust. However, considering the urgent request for higher precision in determination of the Earth's position, we think that Commission 19 should encourage and recommend the use of new techniques during the next few years.

Having this in mind we will propose here some methods for which trials are in process for a possible extension of the Doppler system. By extension we mean to allow for many observatories to be easily introduced in a tracking network, to perform their own preprocessing and so reduce the amount of data transmission and the task of the Central Computing Agency. This is indeed the usual procedure in classical astronomy: each station reduces its own set of observations and only the final results are transmitted to BIH and IPMS.

2. REASON FOR AN EXTENDED USE OF THE DOPPLER METHOD

If the technical performance of the Transit satellites remains in the present state is it possible to improve the Doppler results? There are several reasons for believing that the theory and modelling of perturbations acting on the satellite motion and signal propagation could still be improved:

- B. Bowman and C. Leroy (1976) estimated at 40 cm the possible error on pole positions deduced from their analysis. These authors also showed that occasionally separate solutions deduced from different Transit satellites can give pole positions differing by between 50 cm and 1 m. This inhomogeneity was not explained, but they attribute it to resonance effects, and to a different number and distribution of stations for the data collected on each satellite.

- if external errors are here understood as those deduced from comparisons of several similar experiments, and not from results obtained by two different methods, then for Doppler results the ratio between external and internal errors was estimated by Paquet (1973, 1977) to be about 2.5.

- the technology of tracking stations could be improved.

- the present results obtained by DMA are based on the observations performed by 17 TRANET stations acquiring data from only two of the five available Transit satellites. A lot of data which are not used, and generally not even collected, could be included in the computations.

- GRGS has restricted the MEDOC experiment to only one Transit satellite.

All this demonstrates that the models used for the data analysis could be improved with the support of a great amount of data which remains available. However, to use all the data acquired at each station, the central computing center has to solve two main difficulties:

- To produce results without unreasonable delay the data collection must be performed by telex or some other fast way.

For a tranet station the number of useful bits collected during each pass is about 2 000. For JMR or Marconi receivers one pass is composed of about 10 000 bits of Doppler data. The transmission of all the bits is a first important limitation in cost and volume.

- the work of data preprocessing is very important.

To support Doppler programmes it should be necessary to reduce to a minimum of parameters the data acquired during one pass or a set of passes. These condensed data will have to be deduced by pass preprocessing performed at each station, on the basis of a unified theoretical model of reduction. This unified model must contain:

- the modelling of perturbations to be immediately removed from observations;

- the gravity model used to integrate the approximate orbit, whose initial conditions are to be regularly renewed by the central computing center;

The Computer programmes must be delivered by the same agency.

Advantages of such a solution are that it

- considerably reduces the quantity of data to be transmitted;

- shares the preprocessing tasks between observers;

- increases the number of satellites that can be included in the solution for Earth rotation and polar motion determinations.

Moreover, as suggested by M.Lefebvre and F.Nouel (CNES), if the pass can be reduced to a few parameters, the transmission facilities of the ARGOS satellite will be available; this is being developed as a joint Franco-American (CNES, NOAA, NASA) project for a location and data-collection system. Information is available from the CNES center at Toulouse.

3. POSSIBLE SOLUTIONS

Observatories generally have good computing facilities, which would allow calculation of a satellite orbit with the best available methods of numerical integration and using one extended gravity model taking account of solar pressure, atmospheric drag, Earth tidal effects, Sun and Moon attraction ... The availability of the best predicted orbit makes it possible to perform efficient preprocessing at each station on a pass-by-pass basis. This preprocessing consists of the comparison of the observed quantities with the theoretical ones as deduced from the predicted orbit.

In the Doppler system the data selection generally results from a least squares solution, fitting the pass observations by adjustment of frequency offset ΔF, tropospheric scaling factor, range (R_o, R_2) and along track (L_o, L_2) parameters as defined by Guier (1963) in a reference system with its origin at the satellite position at the time of closest approach (TCA). The axes are:

- R, the range axis from station to satellite

- L, the along-track axis positively oriented with the satellite motion

- Z, the third axis perpendicular to the plane (R, L).

The along-track and range unknowns are called the navigation errors related to the errors on the station and the satellite coordinates. The equations of observations fitting the Doppler residuals ℓ_j are of the form:

(1) $\ell_j = \Delta F + L_o\, u_{s,o} + L_2\, u_{s,2} + \dots + R_o\, u_{a,o} + R_2\, u_{a,2} + \dots$

where the coefficients $\underline{u}$ are given in Guier (1963).

The values of these parameters associated with

- the errors, on each parameter, resulting from the solution of the normal equations,

- the number of accepted data after filtering,

- the balance between data acquired before and after TCA,

were used to define the constraints of pass rejection during the European Geodetic Campaigns EDOC-1 and EDOC-2 (Pâquet 1977). With appropriate upper limits they define a set of very selective filters, efficient enough to eliminate all doubtful passes and allowing the surviving passes to be introduced definitively in the matrix developed to determine station coordinates. Anderle (1973) was using similar parameters.

For data condensation this preprocessing is the first necessary task to be done in situ. Two methods of condensation can be employed:-

a) Condensation of a set of passes

After the preprocessing the usual procedure to improve the satellite orbit is to fit the accepted data in a least squares solution which includes as unknowns the 6 constants of orbital integration, the two coordinates of the pole, one drag scaling factor and some complementary station parameters. In the Doppler system, for each station and for each pass, these complementary unknowns are the frequency offset and a tropospheric refraction scaling factor. The final system of normal equations results from adding the individual systems deduced from each accepted pass of the tracking network.

Having a large experience in such an analysis R. Anderle (1973) wrote: "The least squares solution is not iterated under normal circumstances since the prediction errors from the preceding orbital fit rarely exceed 100 m during the 48 hours prediction interval". At present, at the end of the same interval of time, the prediction error seems to be lower than 50 meters; this strengthens Anderle's remark.

From these remarks it becomes clear that a first method of condensation is for each station to perform its own preprocessing and compute, for orbit improvement, its own set of normal equations including all accepted passes during the agreed periods. Even this simplest solution yields a substantial reduction in the number of unknowns. Indeed, if the preprocessing is performed with the best predicted orbit the instrumental and local parameters may be determined by each station.

With the number of unknowns thus reduced to 9, and with one orbit improvement every two days, 54 parameters have to be transmitted to the Central Computing Agency every two days. This corresponds to a maximum of 3000 bits, less than two satellite passes recorded by Tranet equipments.

With this procedure the task of the CCA would be to combine the matrices received from all the stations, solve the system, and return the solution to the observers for the next prediction.

b) Pass by pass condensation

During the preprocessing step the along-track and range parameters determined by separate pass analysis reflect station-position errors and also errors of the predicted satellite orbit. The relations between station-satellite errors and fitted parameters were derived by Guier (1963). The quantities (L, R) of equation (1) are given as linear functions of the station displacement and satellite position errors and their derivatives, evaluated at TCA and expressed in a reference system whose origin is the satellite position at TCA.

These relations have been extensively used with success in geodesy for two main purposes:

- to improve the coordinates of ground stations. The orbit is assumed fixed and the total position errors are attributed to the erroneous initial station position. The European Doppler Campaigns, EDOC-1 and EDOC-2 were treated by this procedure (Pâquet, 1976, 1977) and the results are of the same quality as those obtained by more classical methods.

- W.H. Guier and R.R. Newton (1965) and S.M. Yionoulis et al. (1972) used the relations to improve the Earth gravity field. For this analysis Guier and Newton developed a linear perturbation theory allowing computation of (L, R) in terms of changes of the gravity harmonics, the orbit parameters and the station positions.

The success of these relations suggests their experimental use as a second possibility for data condensation. The linear approximation must be limited to variation of the orbital elements, coordinates of the pole position and Earth rotation velocity, while the gravity field and the station coordinates are fixed. This process, if correctly conducted, allows reduction of the data to be transmitted to less than 300 bits per pass.

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