CARTEL: A METHOD TO CALIBRATE S-BAND RANGES WITH GEOSTATIONARY SATELLITES

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ABSTRACT

An intensite tracking campaign - named CARTEL - has been organized, with four S-band stations, for a period of one week, the relative geometry of the network with respect to the satellites was an opportunity to show how the most precise orbit can be computed with the operational software.

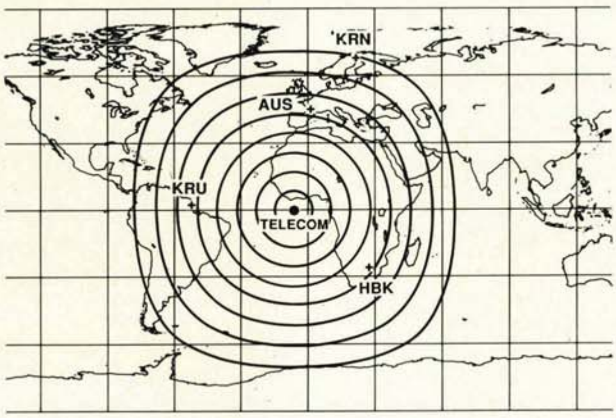
This precise orbit served as a reference in order to evaluate what can be achieved with one single station with range and angular measurements : a typical configuration used for station keeping of geostationary satellites.

Orbit computation implied numerical integration with gravitational (Earth, Moon and Sun) and solar radiation pressure as forces acting on the satellite.

Arc lengths of two days gave initial state vectors which were compared every day. One can conclude that a precision of ten meters has been achieved.

However, an analysis of the influence of several parameters entering the orbit computations reveals that the absolute accuracy is of the order of an hundred meters. It comes from the fact that some modelling perturbations have been neglected in the operational software (such as polar motion for example). In a relative sense, this reference orbit allowed estimation of systematic errors for other tracking antennas.

Keywords : Antenna calibration, geostationary orbit computation.



LONGITUDE 8° W
10° GROUND ELEVATION GRID

Telecom visibility

1. INTRODUCTION

The french telecommunication satellites TC1A and TC1B were launched by Ariane III respectively on August 4, 1984 and on May 8, 1985. They reached their location points at 5° and 8° west longitude.

They both have 2 GHz and 4.6 GHz onboard transponders. A ten days intensive tracking campaing called CARTEL - has been organized with the four S-band stations of the CNES network on the two satellites TC1A and TC1B (Ref. 1).

For this campaign, 2 GHz antennas were used at the following stations :

Aussaguel (AUS), France,
Kourou (KRU), French Guyana,
Kiruna (KRN), Sweden,
which allow range measurements.

Hartebeestock (HBK), South Africa,
which allows both range and angular measurements.

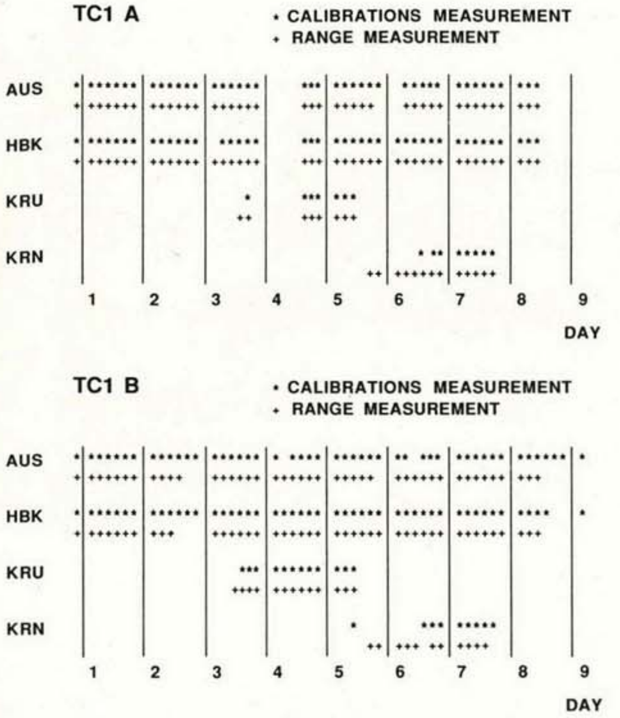
2. THE TRACKING CAMPAIGN

The objective of this campaign is to calibrate the CNES 2 GHz network, that means use the range measurements to identify systematic errors in equipment and software.

For each satellite and each ground station, the range measurement is 256 fixes in 64 seconds intervals every four hours.

Before each range measurement session, each ground station carried out calibration measurements (delays in station equipment) and weather report (pressure, temperature, humidity).

Figures 1a, 1b, 1c, show the range and calibration measurement chronology.



Figures 1a - 1b . Calibration and range measurement chronology during the complete campaign.

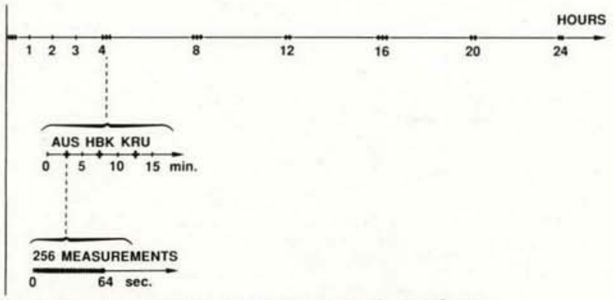


Figure 1c . Daily measurement chronology.

3. MEASUREMENT PROCESSING

Reference orbits have been computed through the range measurements of many ground stations on two days arcs with a one day recovered period.

The orbit computation software uses numerical integration of the satellite motion laws and takes into account the following perturbational forces acting on the satellites :

- earth gravity field (with the GEM10 model to the order 20),

- solar and lunar gravity fields,

- direct solar radiation pressure.

The computation uses parameters adapted to the geostationary satellites :

a : semi major axis,
ex : $e\cos(w+\Omega)$
ex : $e\sin(w+\Omega)$
ix : $i\cos\Omega$
iy : $i\sin\Omega$
l : $w+\Omega+M$

where a, e, i, w, Ω, M are the classical Keplerian parameters.

The results of the orbit computation consist in values for those parameters and an estimation of a multiplicating factor of the solar radiation pressure.

4. RESULTS

4.1 Measurement accuracy

When examining the residuals (ie theoretical measurements - real measurements) we can reach some information on the measurement accuracy.

On picture 2 you can see residuals obtained through orbit computation for one station on a two days arc.

The residual amplitude for each measurement session is about 4 meters. On a particular session bigger residuals (about 30 m) are observed. You can see that session in figure 3.

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On the residuals for one session, there's no significant signal coming from eventual modelization errors. The residuals consist in a point cloud traducting the measurement noise.

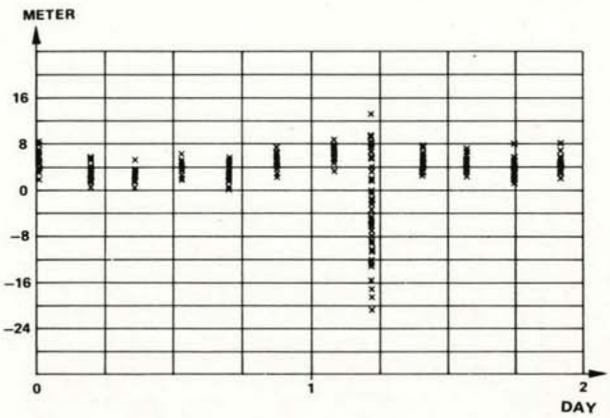

Figure 2 . Range residual for a station on a two days orbit arc.

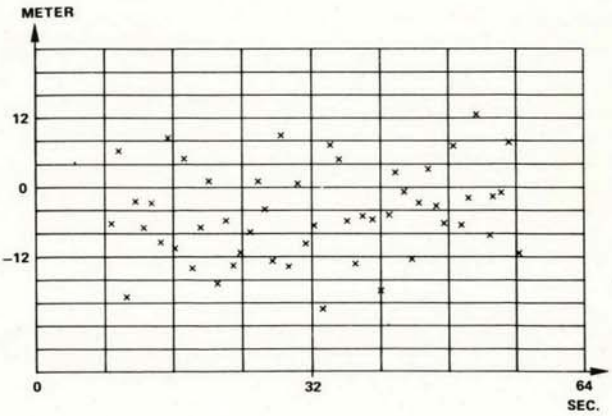

Figure 3 . Range residual for a station and a measurement session with a 1 meas/s rate.

On the residuals for measurement session on a two days arc (Fig. 2), it appears a caracteristic periodic signal coming from either the instrument itself or errors in range modelisations using the satellite orbit and the station position.

By comparing the averages per session of the residuals and of the calibrations we see that the part of the calibration errors is negligible in regard to the part of the model errors.

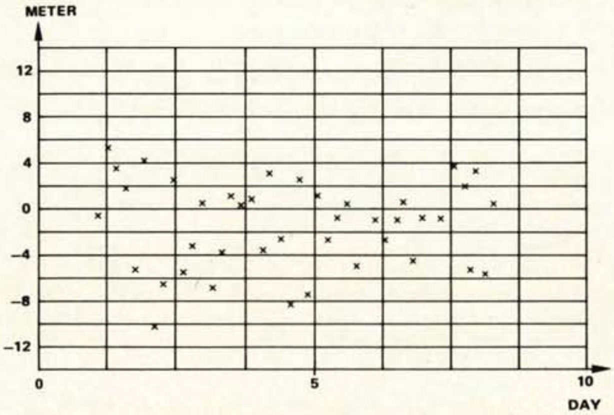

Figure 4a . Average residuals for a station on a eight days period.

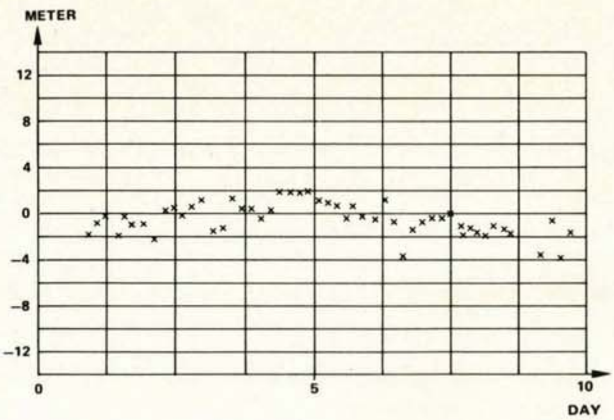

Figure 4b . Calibrations for the same station on a eight days period.

In conclusion, it seems that the periodic signal in the residuals should come from the errors in the satellite or station motions.

4.2 Orbit accuracy

The reference orbit arcs comparison on one day common period shows along track differences about 25 m, with computations realized in the same observation conditions (see an example on Fig. 5).

When using only two stations (instead of three) for computations, the differences grow and can reach 100 m along track.

But the quality of the computed orbit is not much better when adding a fourth station to the basis network.

The results are nearly the same for both satellites which have nearby location points.

As a result you can say that the relative geometry of the three basis stations (KRU, HBK, AUS) is nearly an ideal conception and acts an important role despite the dynamic orbit computation process.

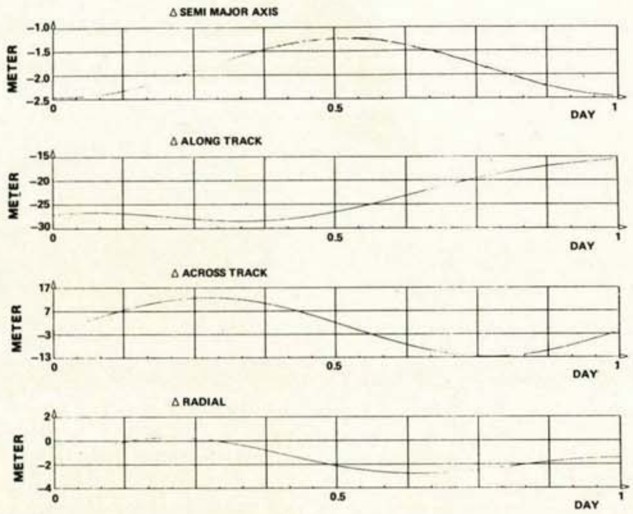

Figure 5 . Comparison of the TC1B computations on one day.

4.3 Angular measurement calibration

During all the campaign the HBK station made angular measurements with the rate of 2 points at 30 seconds interval every hour.

The previous orbit computed through the range measurements only is used as reference.

When examining the angular residuals in relation to this orbit, you can estimate the systematic errors on those measurements.

However you must notice that it's impossible to determine their causes (instrument or computation) if you don't consider in detail every error source.

If not correcting the angular measurements with their biases and using them in an orbit computation, you observe, what was forseeable, that these biases act particularly on the orbit plan orientation estimation.

On the computed orbit you can observe modelisation errors which appear in residual with 12 or 24 hours period signatures. But the residual amplitude is less than 100 meters.

Then you can then say that a signal with a bigger amplitude appearing in the residuals of other kind of measurement comes from the instrumentation. With the same method, the CARTEL campaign was used to calibrate the new 12 GHz TDF1 antenna in Aussaguel.

5. ORBIT SENSITIVITY

5.1 Earth Gravity Field Model

Two days orbit arcs were computed with GEM10, GEM6, GEML2 models in the same conditions on the same period. The residuals thus obtained are summarized in the following picture.

Residual	GEML2	GEM10	GEM6
overall	4,32	4,33	9,8
AUS	4,65	4,67	6,63
HBK	4,43	4,48	11,38
KRU	3,71	3,6	11,16

The GEM12 and GEM10 models allow a better modelisation of the earth gravity field. This is confirmed by the results obtained on the arcs comparison.

5.2 Direct solar radiation pressure Kp

A solar radiation pressure coefficient is estimated at each orbit computation, which stay about one.

The variation of the estimated Kp on two days orbit arcs is weak in front of the estimated value on an eight days computation.

On the comparisons of the arc common parts you observe that the error on the satellite position grows with the Kp variations.

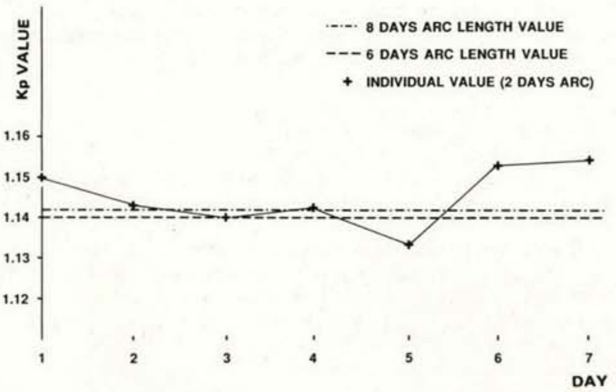

Figure 6 . Solar radiation pressure coefficient.

6. SIMULATION RESULTS

6.1 Description

A simulation was realized with the following plan :

- TC1B reference orbit initialization.

- Measurement simulation on a two days period at the rate of one measurement per second during one minut every four hours with the four stations (HBK, AUS, KRN, KRU).

- The error model of the earth gravity field is 2 % of the GEM8 model.

- The uncertainty on the X and Y pole coordinates is 50 %.

- The measurement bias is 10 m.

- The errors on the X, Y and Z station coordinates are 20 m.

6.2. Comparative studies on different error sources influences

On the satellite orbit, we consider each error source and the main effects can be studied separately :

- on the semi-major axis : earth gravity field and X pole coordinate.

- on the excentricity : earth gravity field.

- on inclination : X pole coordinate

  Range bias of the AUS station

  Y AUS station coordinate

- on angular location : X pole coordinate

  X KRU and HBK station coordinates

  Range bias of the KRU station,

On the satellite location in spherical coordinates, the effects can be divided as following :

- on the radius vector earth center to satellite :

  the X pole coordinate has the main effect (11 m)

- on the velocity : earth gravity field (0,1 cm/s)

- on the latitude : X pole coordinate / Range bias of the AUS station } 0.6"

- on the longitude : earth gravity field

  X pole coordinate

  Station coordinates.

To have a better satellite location, the pole location (earth rotation axis) should be taken into account in the computations.

We can see on the simulations that this effect is important, but in the real computations this influence is unobservable, because the computation is made in a comparative way.

7. USE OF A LEO (LOW EARTH ORBIT) SATELLITE FOR THE CALIBRATION

A geostationary satellite essentially allows to calibrate angular measurements of a station in a single direction.

Now the manufacturers often require a three dimensional evaluation of the systematic errors, by example to determine radome effects.

The SPOT satellite (at an altitude of 800 km) is equipped with S-band and C-band transponders. On the figure 7, we can see the track distribution on a five days period.

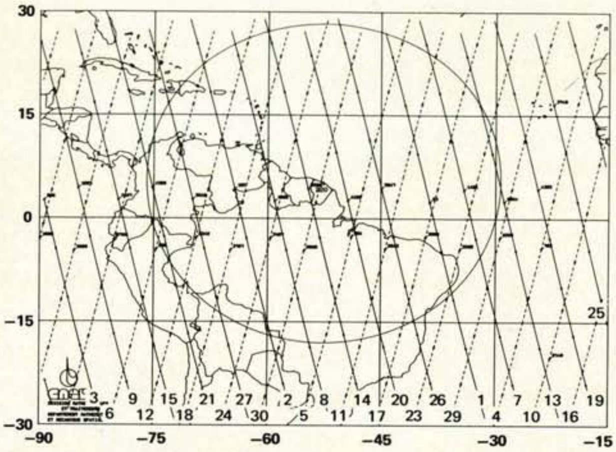

Figure 7 . Coverage for a station with the SPOT satellite.

Considering the tracking means used for SPOT, for a satellite at this altitude, orbit computations can't reach satellite location accuracy better than 100 m on a five days period.

The idea is then to use the crossing points, ie when the satellite is located twice on the same geographical location (figure 8).

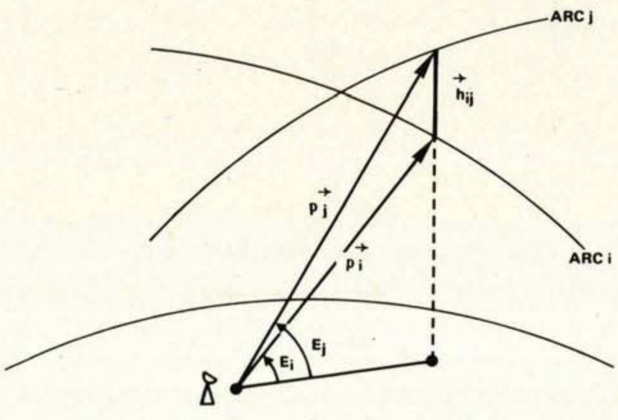

Figure 8 . Crossing arc geometry.

The equation $h_{ij}^2 = p_i^2 + p_j^2 - 2\ p_i\ p_j \cos\ (E_j - E_i)$

where p_i and p_j are the range measurements at the E_i and E_j elevations respectively for the i and j arcs,

allows the computation of the h_{ij} height at the crossing point.

The orientation effects influence the range measurement, but they are second order comparing to the angular measurements.

In case there's a systematic error on the elevation, you can consider the effect second order too, because the E_i and E_j elevations are very close and taken into account through their difference. The h_{ij} height will then be considered as the observation.

From orbital aspect, the short periods (2, 3 or more times per revolution) will be eliminated by using the Kaula formulation on the i and j arcs, so computed more often separately.

The theoretical h_{ij} quantities will be compared to the h_{ij} quantities observed on all the crossing points above a station.

We will consider that each i arc is modified with a bias and a slope, and we'll estimate their values through the least squares method.

Such a technique is used in altimetry to eliminate uncertainty effects on the orbit.

In conclusion we'll have a set of orbit arc, which accuracy is about the range measurement accuracy (less than 10 m for S-band and C-band).

This method will be tested and evaluated on the Kourou site with the S-band station and the ARIANE tracking radars (C-band).

8. CONCLUSION

The telecom satellites offer the opportunity to compute a reference orbit with an accuracy better than 100 m, subject to a few conditions :

- Orbit time coverage
- Suitable stations network.

Any other tracking method (S-band range, angular) can be calibrated in relation to this reference.

This only limitation proceeds from the geostationary satellites, particularly when studying the spatial distribution of the angular measurement errors. The use of the SPOT satellite will perhaps allow to eliminate this limitation.

9. REFERENCES

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