Comparison of Faraday Rotation Measurements of the Ionosphere

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An evaluation of the mapping techniques employed to provide ionospheric charged particle calibration for post-flight analysis and for Mariner Mars 1971 tracking system analytical calibration operations was performed. Comparisons based on Faraday rotation data from geostationary satellites were made between various satellites as recorded at the Venus Deep Space Station and by Stanford Center for radar astronomy.

I. Introduction

Continual efforts are being made as part of the tracking system analytic calibration (TSAC) effort to improve the accuracy of the ionospheric calibration. One approach to this calibration is the use of Faraday rotation measurements, principally from geostationary satellites. A description of the technique for employing a stationary measurement as a calibration for a moving line of sight can be found in Ref. 1. To evaluate these mapping techniques, a computer program ICARIS (Ionispheric CompARISon), with the capacity to compare charged particle measurements over two different lines of sight, has been written. ICARIS can compare measurements made to stationary satellites or to space probes and can use various types of charged particle measurements, i.e., Faraday rotation, differenced range versus integrated doppler, dual frequency, or ionosonde.

This article describes several comparisons which have been made using ICARIS, concentrating on a comparison of Faraday rotation measurements made from Goldstone DSCC to ATS-1[1] and to ATS-5 (two geostationary satellites) during the period December 1970 to February 1971.

These comparisons were to evaluate the mapping of measurements from one line of sight to another and thereby establish the quality of calibrations calculated from data. The comparisons indicate that the mapping is generally better than 0.5 m of radio path change at S-band. The comparisons were made by mapping (adjusting in time and space) the ATS-1 data to the ATS-5 line of sight and comparing the mapped ATS-1 data to the unmapped ATS-5 data. The process was then reversed. A successful mapping is one for which the mapped and unmapped data are nearly identical. If the mapping is good, space probe data may be calibrated

[1]ATS = *Applications Technology Satellite.*

for charged particles by a measurement to zenith (in the case of ionosonde data) or to some arbitrary fixed position (in the case of Faraday rotation measurements to a geostationary satellite). The mapping used in ICARIS is not always expected to be good over the range of all possible elevation angles and longitude differences between mapped and unmapped data. The assumption of spherical symmetry of the ionosphere (at a given sun–earth–probe angle) can be expected to fail at low elevation angles, and may fail elsewhere as well. The comparisons described in this article indicate some of these limitations.

II. ATS-1 and ATS-5 Faraday Rotation Comparison

A. Background

Faraday rotation measurements were available for 26 days during the period December 1970 to February 1971 for the geostationary satellites ATS-1 and ATS-5. The days of comparison were chosen under the criterion that sufficient data were available to provide a significant test.

The data was originally recorded at DSS 13 on a paper tape or on a strip chart recorder. The ATS satellites transmit a beacon at 137-MHz for which the Faraday rotation of an electromagnetic wave may be as great as 900 deg or as little as 90 deg at zenith during a typical day. It is necessary to "refasten" the data, which has been recorded modulo 180 deg. The technique for refastening the data has been described in Ref. 1.

Two problems accompanied the reduction of data. They were revealed only upon comparison of the ATS-1 and ATS-5 data sets. First, the ATS-5 data still had several ambiguities which had not been detected. If the data record was quite smooth at that point, the ambiguities were prominent, and identifiable by the fact that they left a vertical gap in the data of 180 deg. If the record was jogged or there were only a few time points in the area, repeated attempts were necessary to get a best fit to the ATS-1 data.

The second problem was the determination of the magnitude of the conversion factor. Calculations of the geomagnetic field suggested that 180 deg of Faraday rotation corresponded to an electron content of 0.479×10^{17} electrons/m^2. This value introduced two characteristic irregularities into the ATS-5 data: the ATS-5 peak-to-trough amplitude was always larger (by fixed factor) than the ATS-1 data; and at each point where a modulo was inserted a small discontinuity ($\sim 0.05 \times 10^{17}$ electrons/m^2) was introduced into the ATS-5 trace. After considerable experimentation with five days worth of data (2/1/71 to 2/6/71), it developed that a conversion factor for 180 deg of 0.430×10^{17} electrons/m^2 eliminated these errors. The fact that these systematic anomalies did not recur when the complete data set was compared gives one some confidence in the *a posteriori* experimental value for the conversion factor. The cause of this descrepancy between the computed and empirical values for the conversion should be explored further.

B. Results

The average standard deviation of the difference between ATS-1 and ATS-5 was 0.11×10^{17} electrons/m^2 ($\sim$ 0.1 m of radio path change at S-band). ICARIS was reciprocal. That is, the results obtained did not depend on which satellite data was mapped. There was a very small systematic difference between the two sets of measurements: $\langle \text{ATS-5} - \text{ATS-1} \rangle = 0.02 \times 10^{17}$ electron/m^2. This could be due to a small error in the conversion factor, but the absence of any of the small discontinuities produced by an inaccurate conversion constant weighs against this explanation. More likely, it is caused by an error in the mapping technique. Figure 1 shows a day on which the comparison was very good—February 3, 1971. Notice that the deviation between mapped (ATS-1) and (ATS-5) averages 0.056×10^{17} electrons/m^2 ($\sim$ 6-cm range error). Careful examination of the figure shows that the ATS-5 data may lag the ATS-1 data during the day–night and night–day transitions by $\sim$10 min. This has yet to be explained. It may be an error in recording or reading the strip chart, a mapping error, software error, or a reflection of actual conditions.

Figure 2 (12/24/70) shows that same lagging tendency, greatly magnified, which is believed to be an error in strip chart recording or reading. ATS-5 is located at 105°W (Table 1) on the celestial equator, while ATS-1 is located at 150°W. Thus, ATS-5 is in the sun about 3 h earlier than ATS-1. The ICARIS mapping corrects for this by comparing measurements made at the same sidereal time, not at the same clock time. Perhaps this is too simple a correction, and the earth's polar inclination or the differing elevation angles of the probes (ATS-1 $\sim$ 36 deg; ATS-5 $\sim$ 48 deg) modify this time translation slightly. Other speculations are possible. Stricter tests of ICARIS mapping would be low elevation angle comparisons and data over a much greater longitude range (useful for multiple-station tracking calibration).

III. Other Comparisons Using ICARIS

For July 2 and 3, 1971, a comparison of Stanford to ATS-1 and ATS-3 Faraday rotation data has been made. This data (Fig. 3) is somewhat more erratic than the DSS 13 to ATS-1–ATS-5 comparison. It is tempting to ascribe this irregularity to the summer season, since the summer ionosphere is much more irregular than at other seasons and nothing else has changed significantly. (ATS-3 is at 47°W). More data is required to make any firmer statement.

A comparison of Stanford ATS-1 data measured in 1967 and Goldstone DSCC ATS-1 data taken in 1969. with Spanish ionosonde data for the same period was also done. This data exists for 23 days in 1967 and 17 days in 1969 from August through November. The data is quite sparse. Often the mutual pass period consists of as few as 10 points (see Fig. 4). The ionosonde data, probably because only the content up to the F2 layer is measured while the portion above F2 is estimated, is systematically less than the Faraday rotation measurement. In some cases, the nighttime ionosonde reading is equal to the nighttime Faraday rotation measurement, but this is not consistent. To draw meaningful conclusions about the longitude mapping ability of ICARIS, Faraday rotation data from Spain is required.

Acknowledgment

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Reference

1. Mulhall, B. D., et al., *Tracking System Analytic Calibration Activities for the Mariner Mars 1969 Mission,* Technical Report 32-1499. Jet Propulsion Laboratory, Pasadena, Calif., Nov. 15, 1970.

Table 1. Geostationary satellite view angles

Satellite	Longitude	Elevation, deg	Azimuth, deg
ATS-1	150°W	36	230 (from DSS-13)
		37	222 (from Stanford)
ATS-3	47°W	28	122 (from Stanford)
ATS-5	105°W	48	160 (from DSS-13)

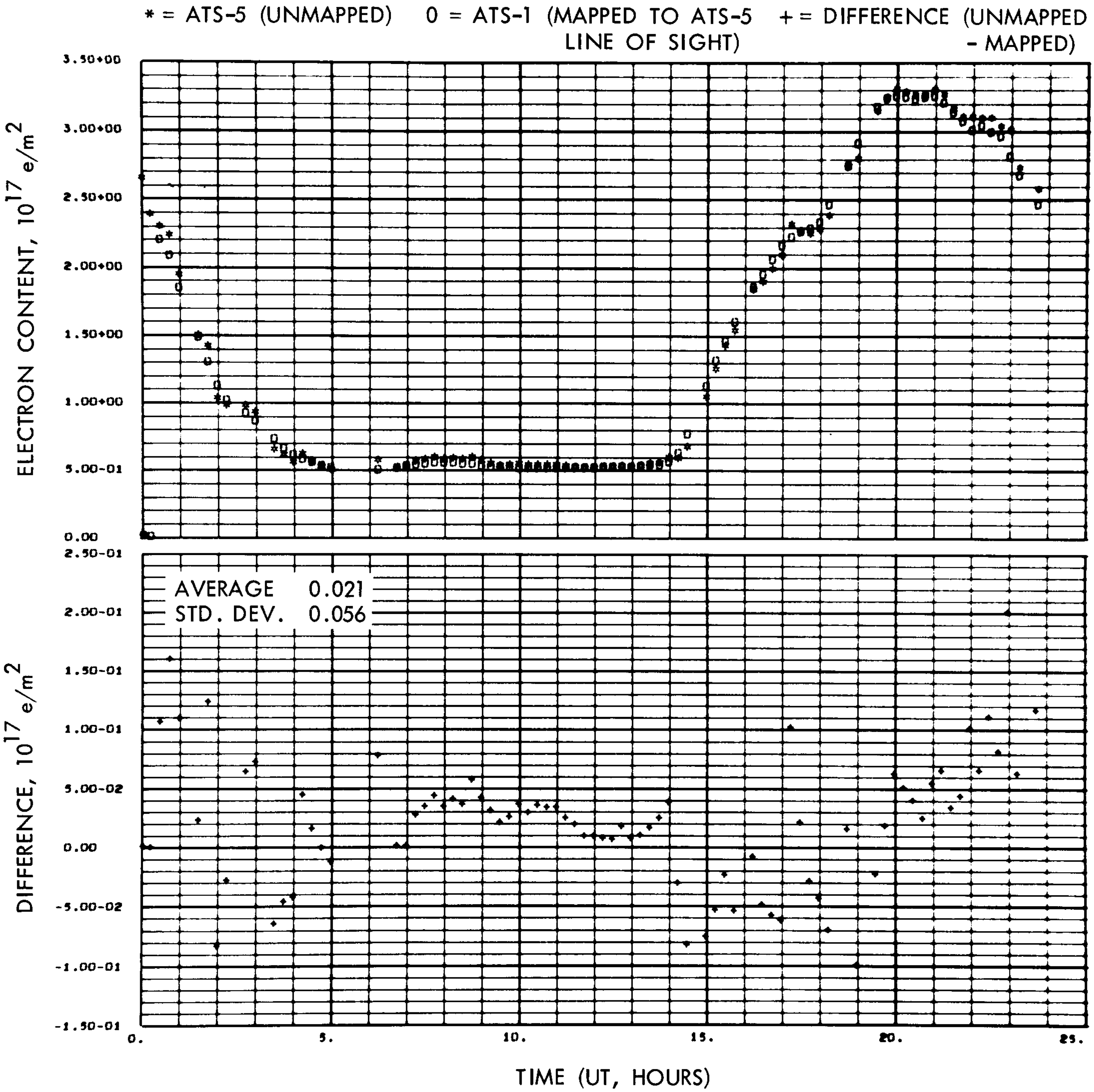

Fig. 1. Comparison of ATS-5 and ATS-1 Faraday rotation measurements of 2-3-71

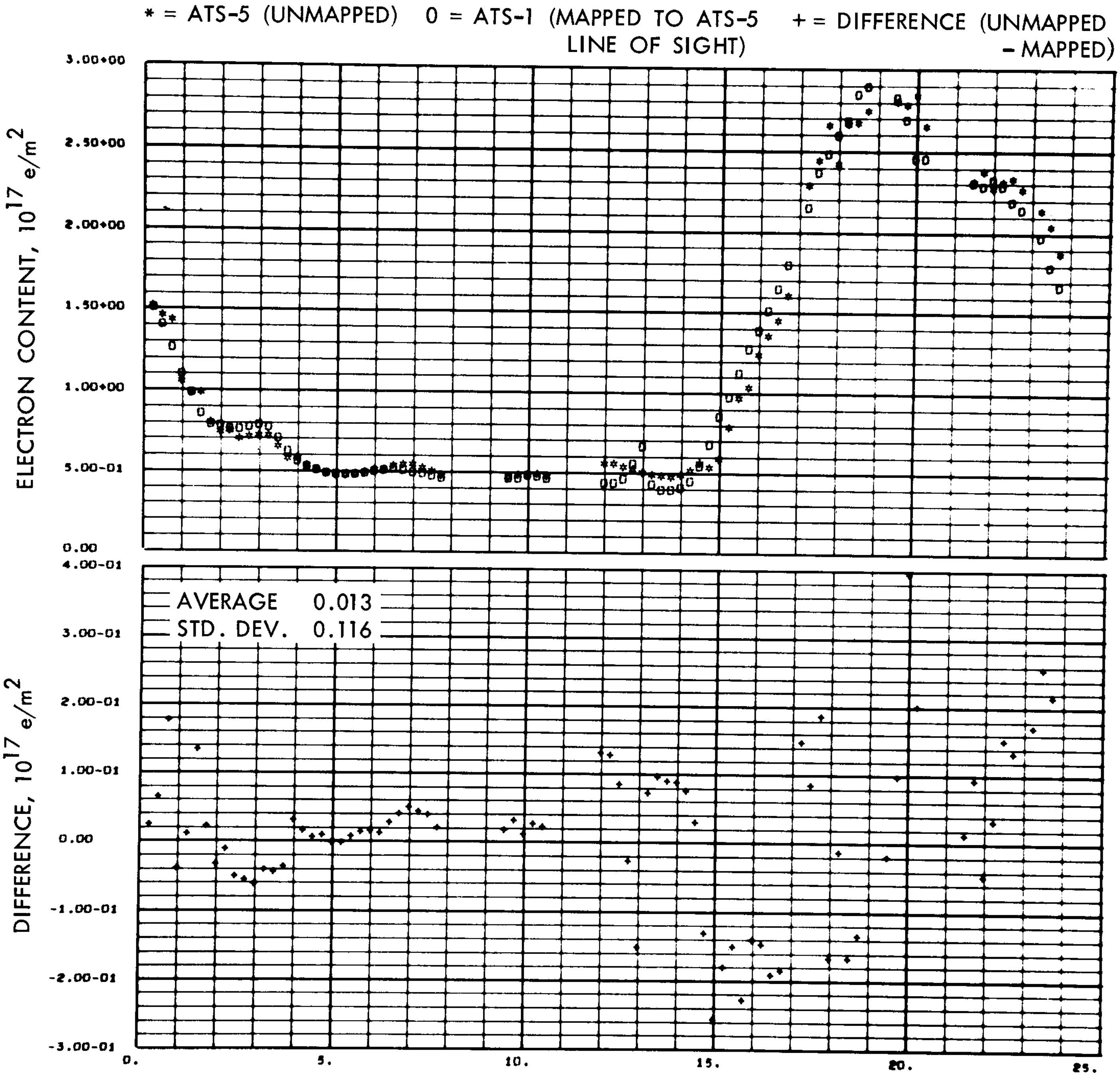

Fig. 2. Comparison of ATS-5 and ATS-1 Faraday rotation measurements of 12-24-70

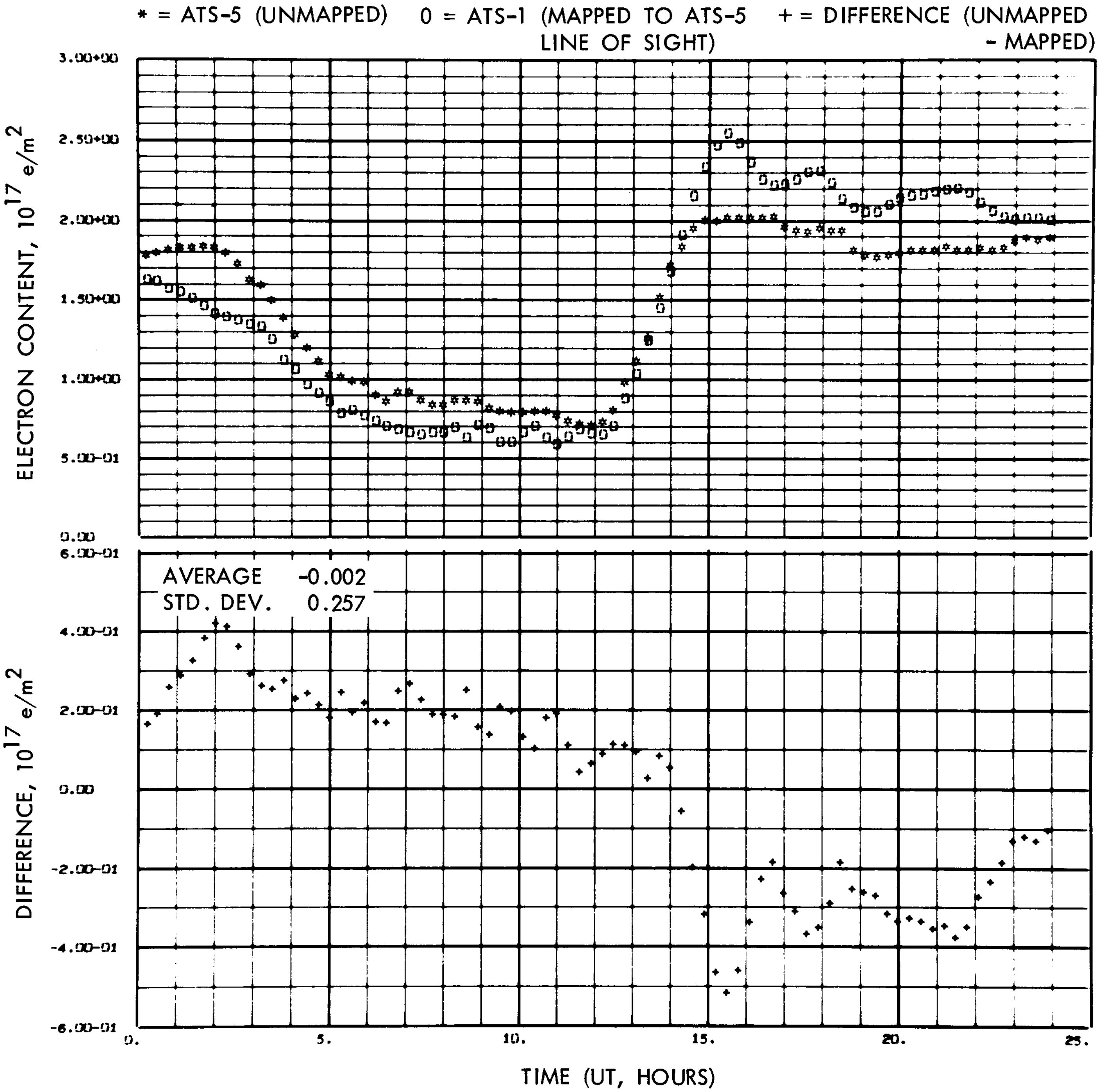

Fig. 3. Comparison of ATS-3 and ATS-1 Faraday rotation measurements of 7-3-71

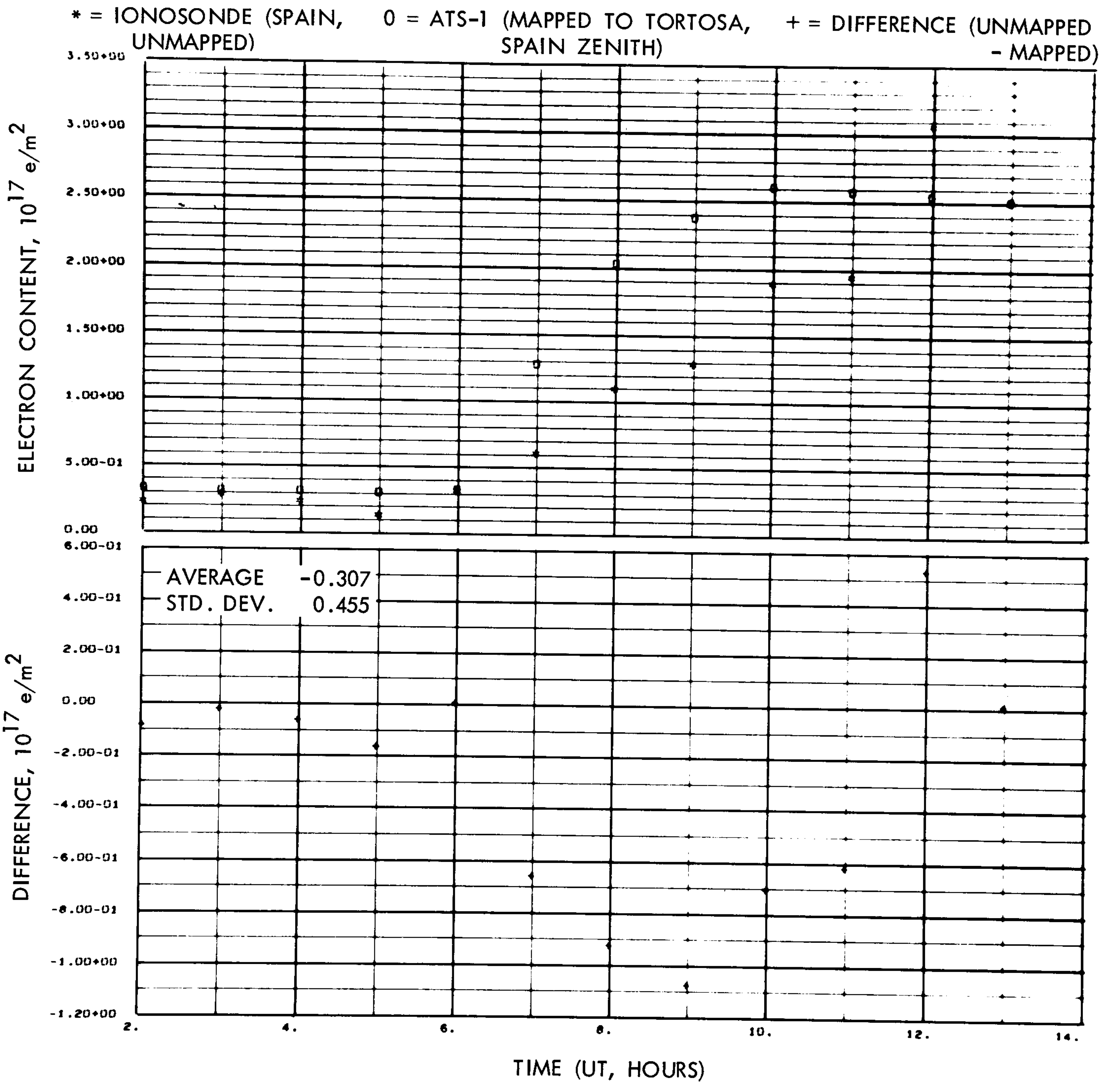

Fig. 4. Comparison of ionosonde (Observatorio de Ebro, Tortosa, Spain) and ATS-1 Faraday rotation (California) 11-7-67