RADAR SCATTEROMETER DATA ANALYSIS

NASA/MSC MISSION 73, SITE 130

Southern California

by

John W. Rouse Jr.

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I. INTRODUCTION

Mission 73 of the NASA/MSC earth resources aircraft program was flown over selected sites in Southern California to satisfy objectives within the disciplines of geology, geography, forestry, and hydrology. Included among the several remote sensors employed in this study was a Ryan Redop 2.25 cm wavelength radar scatterometer. Previous experiments with this sensor has confirmed its applicability to determination of sea state (Rouse, et.al., 1969) and differentiation of Arctic ice type (Rouse, 1969). Earlier NASA/MSC Missions have employed the Ryan system to record backscatter energy from terrain, however, these data have not been analyzed. The research described in this report essentially constitutes an engineering experiment, and, hence is presented from that viewpoint. The objective of the analysis was to determine the geoscience application areas of this sensor by evaluating its performance over specific, documented regions.

This work is the first detailed analysis of the NASA/MSC scatterometer data of agricultural sites, but radar measurements of soils, crops, natural vegetation, etc. have been recorded for many years. The programs of Ohio State University (Cosgriff, et.al., 1960), Waterways Experiment Station (Lundien, 1966), Naval Research Laboratory (Ament, et.al., 1959), and others have produced a "catalog" of backscatter characteristics (Earing, 1961). However, most of these measurements were produced as information for radar system design specifications, or were in other ways unsuitable for determination of general geoscience potential. Consequently, the Mission 73 radar measurements, due to the unique advantages of the particular scatterometer employed, offered the opportunity to considerably improve the "catalog" of backscatter data from natural terrain.

The analysis of the radar scatterometer data from Mission 73 site 130 was conducted at the Remote Sensing Center, Texas A & M University. It established that the radar returned was sufficiently well correlated to crop type or field conditions, and that sufficient samples were recorded within each field type to make possible the alignment of the return amplitudes from each individual field. The relative amplitude of the backscatter energy at each of several incidence angles exhibited field-type categorization potential. Unfortunately this potential could not be fully realized in this analysis program. The initial data contained several apparent processing errors that seriously effected their reliability. Although some corrected results were available just prior to the conclusion of this work, the data were incomplete. Consequently the full merits of the research cannot be fully determined, however, several significant features of the data were documented.

II. RADAR SCATTEROMETER

Radar Scatterometers measure variation of the scattering coefficient with incidence angle. Some instruments employ as additional variables the frequency and polarization of the transmitted energy. Scatterometer measurements permit a detailed observation of radar scattering behavior, although the resolution and areal coverage are generally poorer than radar images. The NASA scatterometer used for these measurements was a 2.25 cm wavelength Ryan Redop system. This radar transmits a vertical polarization, CW signal in a "fan-beam" antenna pattern. The illuminated area is 120^{o} ($\pm$ 60^{o}) fore-aft along the aircraft flight line and 3^{o} ($\pm$ 1.5^{o}) port-starboard.

The radar return was recorded on magnetic tape and subsequently processed through a set of Doppler filters. Each filter represented a discrete incidence angle within the 0^{o} to 60^{o} (fore and aft) beam, e.g. 5^{o}, 10^{o}, 15^{o}, 20^{o}, etc. The filter frequencies correspond to the incidence angle according to the relation:

$$f_d = \frac{2v\sin\theta}{\lambda}$$

where: f_d = Doppler frequency

v = relative velocity of radar

θ = incidence angle

λ = wavelength

Since the entire $120^{o} \times 3^{o}$ region is continuously illuminated, the scattering coefficient versus incidence angle curve fore and aft was recorded during a single overflight. By suitable processing of the return signal, a scattering coefficient versus incidence angle plot was obtained which shows the scattering coefficient variation for particular terrain "cells" along the flight line. This is done by delaying in time the signal outputs of each Doppler filter. By appropriate choice of each time delay, the effect of viewing one spot on the terrain from several angles simultaneously is obtained. The data shown in this report are the scattering coefficient for adjacent "cells" about 30m square. Since the radar return are recorded in quadrature, the fore and aft-beam data are separated. The results shown in this report are fore-beam measurements only.

III. MISSION 73 - SCATTEROMETER EXPERIMENT

Within a week of the aircraft flights during the spring of 1968 a preliminary analysis was conducted on radar scatterometer data from the geography test site in the Salton Sea area (site 130, line 2a). The preliminary analysis employed only the analog output of the Doppler filters. These data were uncorrected for aircraft parameters. This analysis resulted in determining that the radar return had sufficient character to allow correlation of the return with the terrain features. The resolution relative to the field sizes was sufficient to provide several samples of each crop or field type. The angle dependence of the uncorrected scattering coefficient appeared to be sufficiently distinct for cataloging of certain crop types or field conditions. The "signature" of date palms was quite different than that of any other crop type and identification of this crop could be made with a high degree of reliability. It was anticipated that subsequent n-dimensional analysis of these data would lead to disjoint categorization of many of the crop types.

Based on the preliminary analysis, a detailed study of the data from test site 130 line 1, 2, 2a, 5, 5a, and 5b was undertaken. In preparation for this study, NASA/MSC performed a data reduction and correction processing on the Mission 73, site 130 measurements.

IV. MEASUREMENTS

The Mission 73 results used in this analysis consisted of 9 x 9 inch black-and-white aerial photography and the processed radar measurements for six lines of site 130. The radar measurements were in three forms: (1) scattering coefficient versus incidence angle graphs for each "cell" along the flight, (2) uncorrected scattering coefficient versus time along the flight line for five incidence angles (approximately 5^o, 20^o, 50^o, 55^o, amd 60^o), and (3) tabulated scattering coefficient values for nine incidence angles in each "cell" along the flight line.

The photography was obtained with an approximate 10% overlap and was of good quality. The photos were examined to determine the conditions on the flight relative to the utility of the radar data. The specific findings of this review are detailed under Section VI. In general it was discovered that excessive drift angles (greater than 4^o) during parts of the overflight necessitated ellimination of several terrain segments. Excessive drift angle causes the subsequent scattering coefficient versus incidence angle plots to be in error since they do not represent a distinct "cell" on the terrain. In addition, several sections of the lines were flown so near roadways that the radar return was unrepresentative of field conditions but instead contained a composite of both the roads and the fields. Efforts to obtain "signatures" of urban regions were also hampered due to excessive drift or due to the unrepresentation natures of the few usable sites.

The majority of the lines selected were flown at 1500 or 2000 feet altitude. One run of line 2 was flown at 6000 feet and was found unusable since the increased resolution size reduced the number of samples per field to less than five and the alignment was poor.

The preliminary review of the radar data indicated some problems which are described in Sections V and VI. However, the format of the scattering coefficient versus time plots was excellent for obtaining data alignment with the 9 x 9 inch photos. In each case the alignment was obtained using only the 5° and 20° incidence angle readings. The other angles available were greater than 40° and were unusable for alignment due to excessive deviations. It was subsequently determined that the sampling rate of data obtained above approximately 40° was apparently too low to handle the Doppler frequencies in this region, and hence a low confidence level was placed on these data.

V. ANALYSIS APPROACH

Scatterometer data are optimally suited to defining the radar scattering coefficient. This parameter can be expressed as a function of several variables in the following form

$$\sigma^0 = f\ (\varepsilon, \Gamma, \lambda, \theta, P)$$

where: σ^0 = scattering coefficient

λ = wavelength of incident signal

θ = angle of incidence

P = polarization of incident signal

ε = dielectric property of the terrain

Γ denotes surface roughness

The complex dielectric constant, ε, and the surface roughness factor, Γ, are the fixed terrain parameters which are to be determined. The system parameters; λ, θ, and P, are the variables employed to define the terrain parameters.

The Mission 73 data consists of constant wavelength and polarization with a variable incidence angle. Therefore the analysis approach used with these data was to attempt to determine a terrain "signature" unique to each crop or field type using σ^0 versus θ curves. This approach was previously employed using backscatter from Arctic ice and distinct "signatures" were obtained for different ice types (Rouse, 1969). In the Arctic analysis an individual surface roughness parameter was obtained to describe each ice-type "signature" by fitting the data to a scattering theory based on the Kirchhoff-Huygens Principle. The Mission 73 analysis was established to follow the same procedure.

The procedure was to determine the segments of the flight line for which the flight conditions, instrument conditions, and terrain conditions were such to warrant analysis. The segments on the air photos were aligned with the uncorrected scattering coefficient versus time plots to establish the exact data time correspondence with the terrain features. This alignment was considered satisfactory when the data from at least two incidence angles showed correct feature correspondence. This procedure is critical since the corrected scattering coefficient tabulations are related exclusively to the time record. For example, the alignment procedure establishes that field A is illuminated from time 18:40:05 to time 18:40:32. The tabulated scattering coefficient values for all "cells" occuring between these time bounds are therefore representative of the backscatter from field A. The average of these values is then the scattering coefficient versus incidence angle curve identifying field A. These data are then further analyzed in an attempt to identify a "signature" for field A.

Several difficulties were encountered in employing this procedure for the Mission 73 measurements. The initial processed data released by NASA/MSC contained discrepancies which were not detectable prior to conducting relatively detailed analysis. The most serious of these apparent errors are the following: (1) time error in tabulated values of scattering coefficients, (2) absolute amplitude error for scattering coefficient values at θ_1 through θ_4 (5° to 20° incidence), and (3) sampling rate error for calculations of scattering coefficient at θ_7 through θ_9 (greater than 45° incidence). The exact cause and full extent of the latter two problems is still unknown. The third error did not seriously hamper the analysis. However, the second error was critical.

The time error in the tabulated values of the scattering coefficient was due to processing of fore-beam data as though it were aft-beam data and vice-versa. This problem was discovered during the data alignment stage of the analysis and was corrected by employing a procedure developed by Eppes (1969). In a second release of parts of the Mission 73 processed scatterometer data by NASA/MSC in late April 1969 the time error was corrected. The new results agreed with manually adjusted values, however, the new data disagreed with the previously released results in magnitude of the radar return.

The apparent error in the absolute values of the original tabulated scattering coefficients was discovered by comparing the resultant scattering coefficient plots to similar terrain return measured by Ohio State University and others. The scattering coefficient plots exhibit the characteristic that the value of the scattering coefficient monotonically increased as the incidence angle increased from 5° to 20°. This characteristic was previously noted in the uncorrected analog scattering coefficient plots, but was known to be unrepresentative of actual behavior due to the stage of the computer program at which these data are read out. The persistance of this characteristic is supposedly corrected data was unexplainable. The later processing of the data improved this characteristic as will be shown in Section VI.

The sampling rate error was apparently caused by failure to meet the required rate required by the Sampling Theorem in the high Doppler frequency range. Reprocessing of the data did effect the data values for incidence angles above 40°, but the significance of this change is unknown.

VI. ANALYSIS RESULTS:

The analysis results of primary interest are from lines 5, 5a, and 5b. Line 1 was barren terrain of little interest. Line 2 and 2a contained a wide range of terrain types, however, the field sizes were small and the alignment of the NASA/MSC digital filter output data was not accomplished with sufficient confidence to warrant advancing conclusions based upon these data. The alignment of the measurements of lines 5, 5a, and 5b was excellent.

Line 5

Line 5 extended from Niland, California to Brawley, California. The scatterometer data record was 3 minutes 25 seconds in length. The line was initiated in an arrid region crosses a sparsely settled residential section, and covers a well-defined agricultural segment. The aircraft experienced excessive drift during the first 1 minute 5 seconds of the flight. This restricted the analysis to the agricultural segment only.

The alignment of the time history plots with the fields was excellent. This alignment is shown in figure 1a and 1b. Throughout the line all fields were plowed perpendicular to the flight direction. Several roads located perpendicular to the line exhibited very distinctive radar return.

The only tabulated scattering coefficient values available for line 5 were those supplied during the initial NASA/MSC data processing. The reprocessing did not include line 5. The "signatures" of several fields are also shown in figure 1a and 1b. Although fields of similar crop type or condition are readily identifiable on the time history graphs, the average scattering coefficient plots show unexpected characteristics that do not confirm a crop categorization potential and raise doubt as to their validity.

<u>Line 5a</u>

Line 5a extended from Niland, California to Brawley, California parallel to line 5. The scatterometer data covered approximately 14 n.m. in a period of 5 minutes, 25 seconds. The region is predominately agricultural in nature with several large, well-defined fields.

The flight records show that for a 22 second interval at 1 minute 28 seconds into the line the aircraft drift angle was excessive, i.e. greater than 4°. Likewise the last 39 seconds of the run were recorded under excessive drift angle conditions. Reviewing the air photos revealed that during the first 1 minute 20 seconds of the run the aircraft was sufficiently close to a road paralleling the flight line that the radar return would be influenced by its presence. This problem also occured in the second of the two major agriculture segments of line 5a. In general it is questionable that the "signatures" of any specified field in the line would be completely free of the influence of the road return.

Although the presence of the road is believed to restrict the value of these data, it was noted that very distinctive field character was present in the radar data. That is, fields of one crop type were readily distinguished from fields of other crop types. This is evident in sigure 2a.

Three adjacent fields in the line were found to have been illuminated sufficiently far from the road that some confidence could be placed in these data points. Although the ground truth was not available for these particular fields, each field appears to be of a different crop type or field condition.

Field A-B in figure 2b is a homogenious crop type but half of the field is either under water or has recently been under water. The crop in this half is markly retarded relative to the other half of the field. The distinction between the two halves is clearly shown by scatterometer data as shown in the illustrations, although the validity of the field A data is questionable. The second two fields (field C and D) have remarkable similar backscatter characteristics, yet based solely on the photographic data they are dissimilar field types. The similarity in the "signatures" is shown in the illustrations. This characteristic is not unexpected for certain crops. A study of radar images of Western Kansas crops showed little distinction between certain crops such as grains (Simonett, et.al., 1967).

The average scattering coefficient plots obtained for line 5a from the initial NASA released scatterometer data suffered from the errors effecting the line 5 plots. The new data do not exhibit the pronounced uniform characteristic of the former results in which the return increased monotonically for the near vertical angles. (field A in figure 2b is an exception). The tendency of these data to remain nearly constant out to 20° incidence angle is in agreement with some of the Ohio State measurements, and is explainable due to the high frequency of incident signal and very rough nature of the illuminated crops.

Line 5b

Line 5b extends from Brawley, California to El Centro, California in the Imperial Valley. The data recording time was 4 minutes 36 seconds. The line initiated in an urban region, passes over a well-defined agricultural region, extends through broken terrain near the center of the line, continues over another region of well-defined agricultural sites, and concludes in an urban region.

The aircraft drift angle at the beginning of the run was in excess of +5°. This excessive drift angle existed over the urban area. The scatterometer results were considered of little value over this section. Excessive drift angles were again experienced near the center of the line over the region of poorly defined agriculture sites. The drift angle was again satisfactory after this region and was less than +2° for the remainder of the run. The agricultural section of the latter half of the run was recorded under good aircraft conditions, however, a road intersected the flight line in this region and degraded the scatterometer results. Consequently the analysis was restricted to the flight time interval 18:15:40 to 18:17:05. This time interval contained agricultural sites exclusively. The field sizes were sufficiently large that approximately 10 "cells" were available for averaging within each field.

The scatterometer data time histories for the analyzed segment showed excellent correlation with the ground photos. Since roads crossed the flight line at a rate of approximately 1 road per 10 seconds, the alignment of the time history was readily accomplished. The alignment is shown in figures 3a and 3b.

Within the segment were approximately 15 well defined fields. Four of these fields, denoted field type I, contain the same type crop at about the same stage of growth. The crop type was believed to be Alfalfa. Two fields denoted field type II appear to be recently planted, and were both at the same state. Two recently plowed fields, (plow direction approximately 20° to the flight line) adjacent to one another, were labeled field type III. Two other fields, also in a state of recent plowing, were denoted field type IV. These two fields differ from the category III type.

The classifications were made by visual inspection of the black and white aerial photography accompaning the mission. The scatterometer data time history information at θ_4 (approximately 25°) gives a clear indication of the category I fields. A return from these fields is approximately 5db higher than any other fields in the 15 field segment. The category II fields are distinct from the category III or IV fields. Return from the category II fields varies from 3-5 db lower than the latter categories. The category III and

IV fields are not distinguishable from each other on either the θ_1 or θ_4 time histories.

Figure 3a and 3b show the field type categorization from the time history graphs based on θ_1 (5°) and θ_4 (20°) returns. The subsequent transformation of these data to scattering coefficient plots does not support the expected unique "signature" classification. However, these data are from the initial data processing and are of questionable validity. Only a short segment of line 5b was included in the later reprocessing of the Mission 73 data.

Figure 4 is a comparison of the data from the first and second NASA data processing operations. The plots are from field B, line 5b (figure 3a). The new data appears to be free of many of the characteristics which caused the original data to be questionable.

VII CONCLUSION

The Mission 73 radar scatterometer experiment produced strong indications that backscatter from agricultural sections directly relates to the illuminated crop type or field condition, and that several types may be uniquely identified. However, the analysis was sufficiently hampered by poor data quality and/or by unsatisfactory flight parameters that complete confirmation of these indications was not possible. In general, the degree of crop type differentation capability of the radar scatterometer was not obtained from these data, however, evidence was found that supported the contention that such capability does exist.

The analysis established certain factors relative to proposed future use of radar scatterometry from earth orbit altitudes. The higher altitude flights conducted during Mission 73 showed that the consequential increase in radar resolution size degraded the use of these data for crop type identification. In addition the conglomerate terrain segments averaged at these altitudes obstructed possible conclusions about soil type or moisture content. However, the 2.25 cm wavelength system employed was not expected to produce results regarding these terrain parameters. The separation of urban and rural segments was clearly accomplished even at high altitudes, however classification of urban composition was not found to be feasible using these data.

The study should not be interpreted as conclusive regarding the applicability of radar scatterometry to the subject disciplines. The single-frequency, single-polarization sensor employed, the questionable and incomplete data, and other factors restrict any attempt at generalization based on these findings. The added NASA capability for multi-frequency, multi-polarization measurements and the improved understanding of the data processing procedure, gained in part through this analysis program, should soon enable more positive determination of the utility of radar scatterometry in rural and urban studies.

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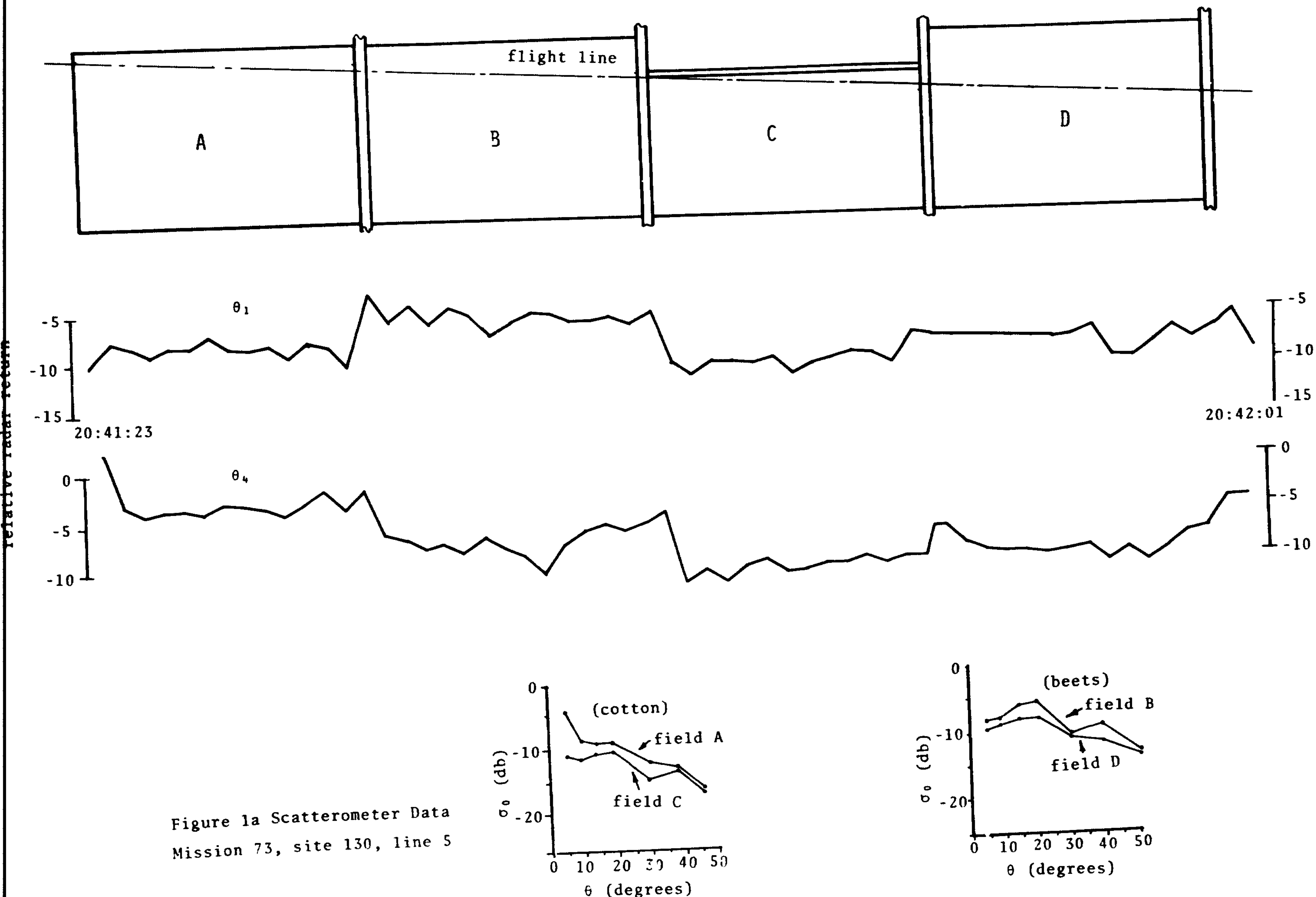


Figure 1a Scatterometer Data
Mission 73, site 130, line 5

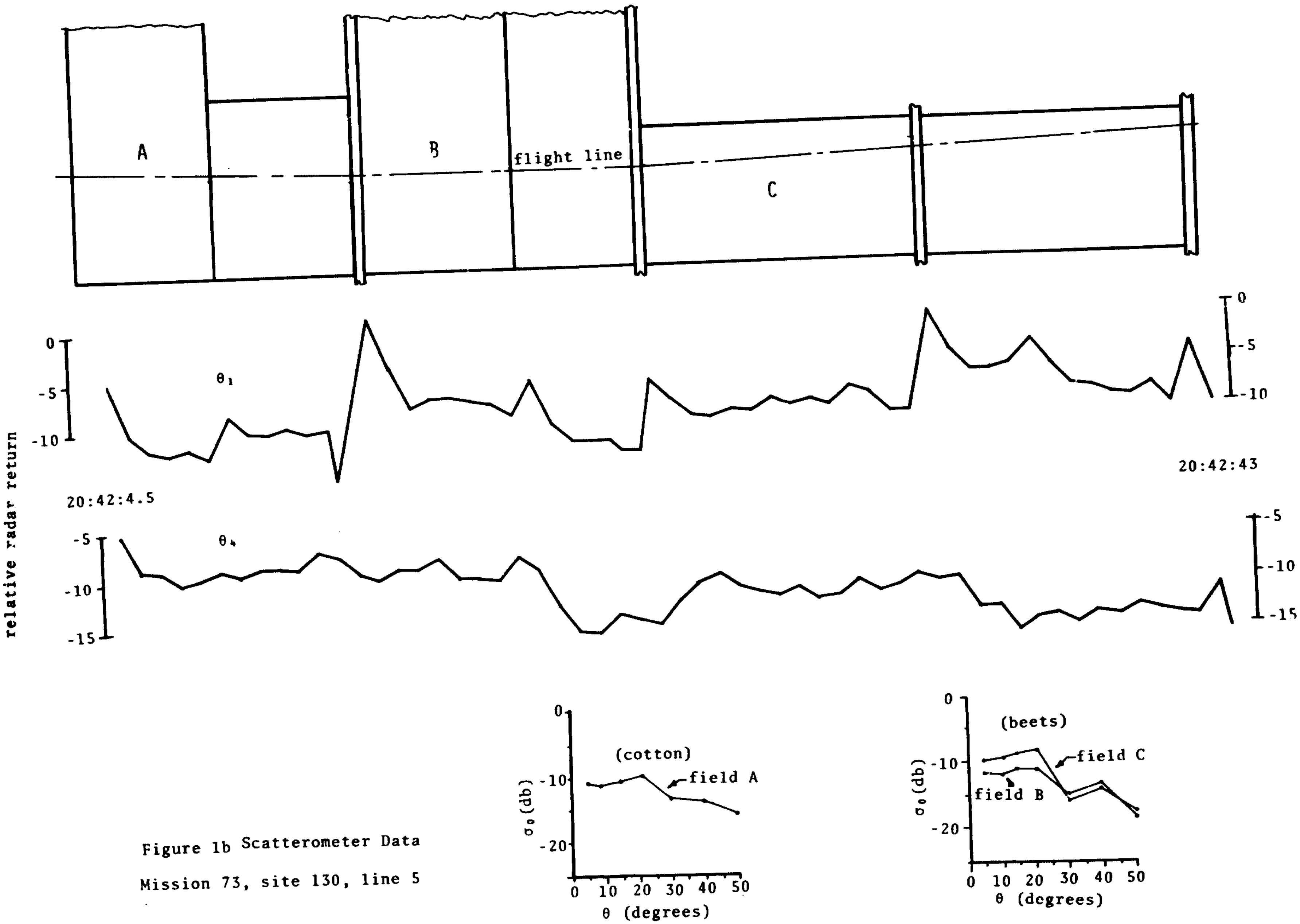


Figure 1b Scatterometer Data

Mission 73, site 130, line 5

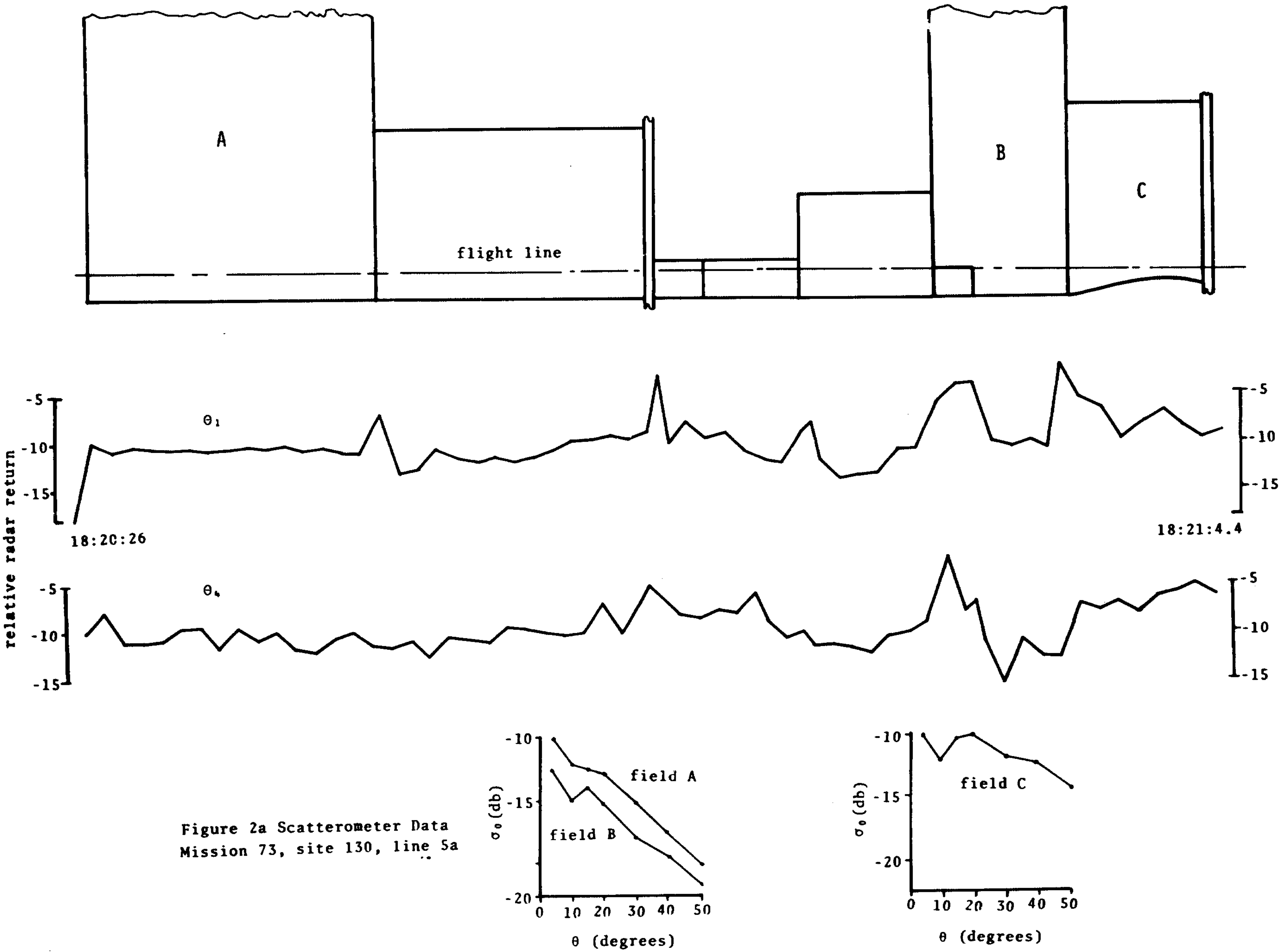
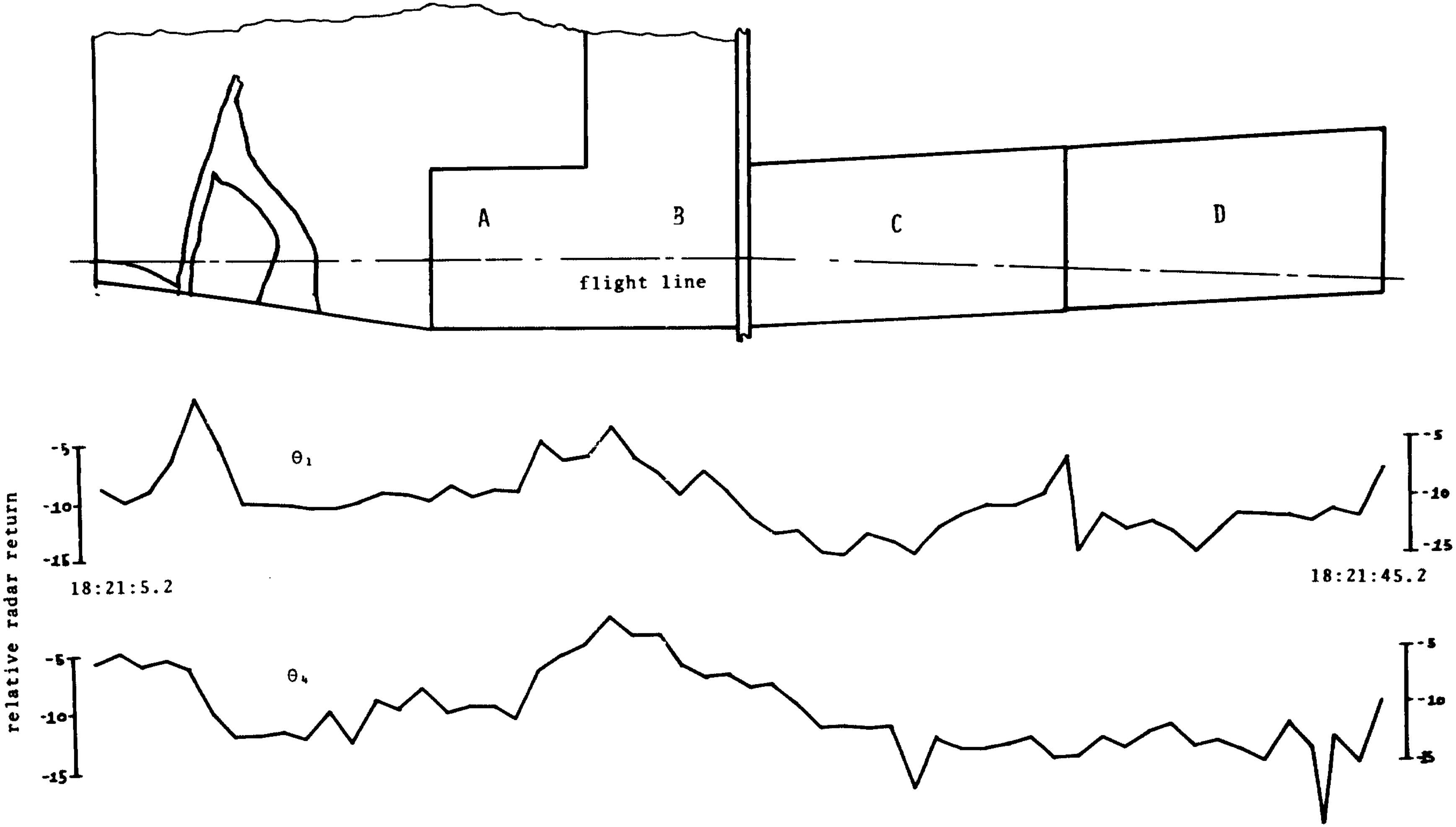


Figure 2a Scatterometer Data
Mission 73, site 130, line 5a



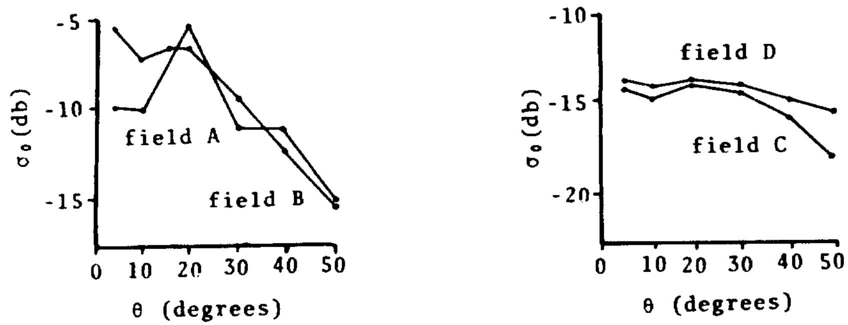


Figure 2b Scatterometer Data
Mission 73, site 130, line 5a

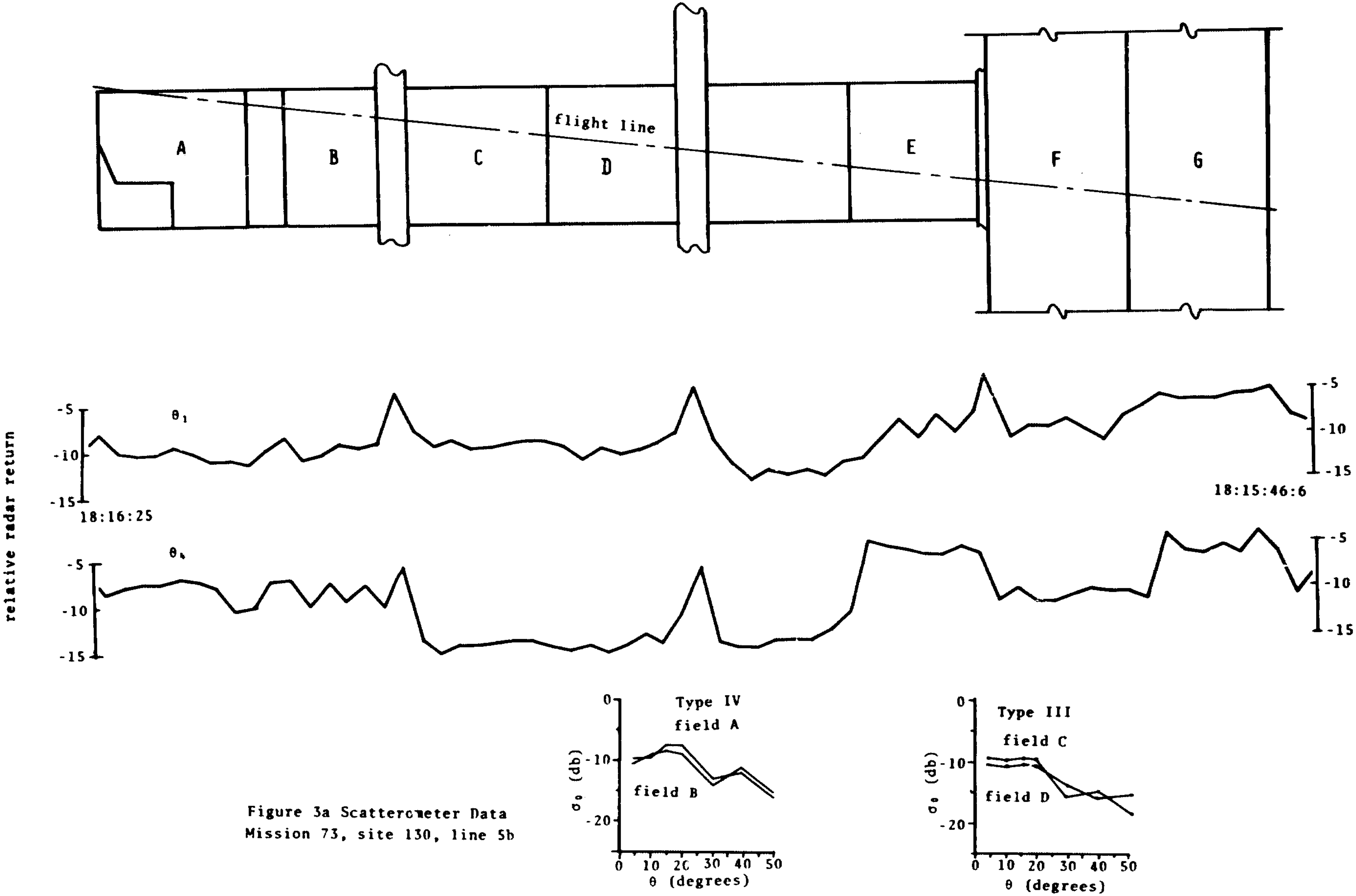
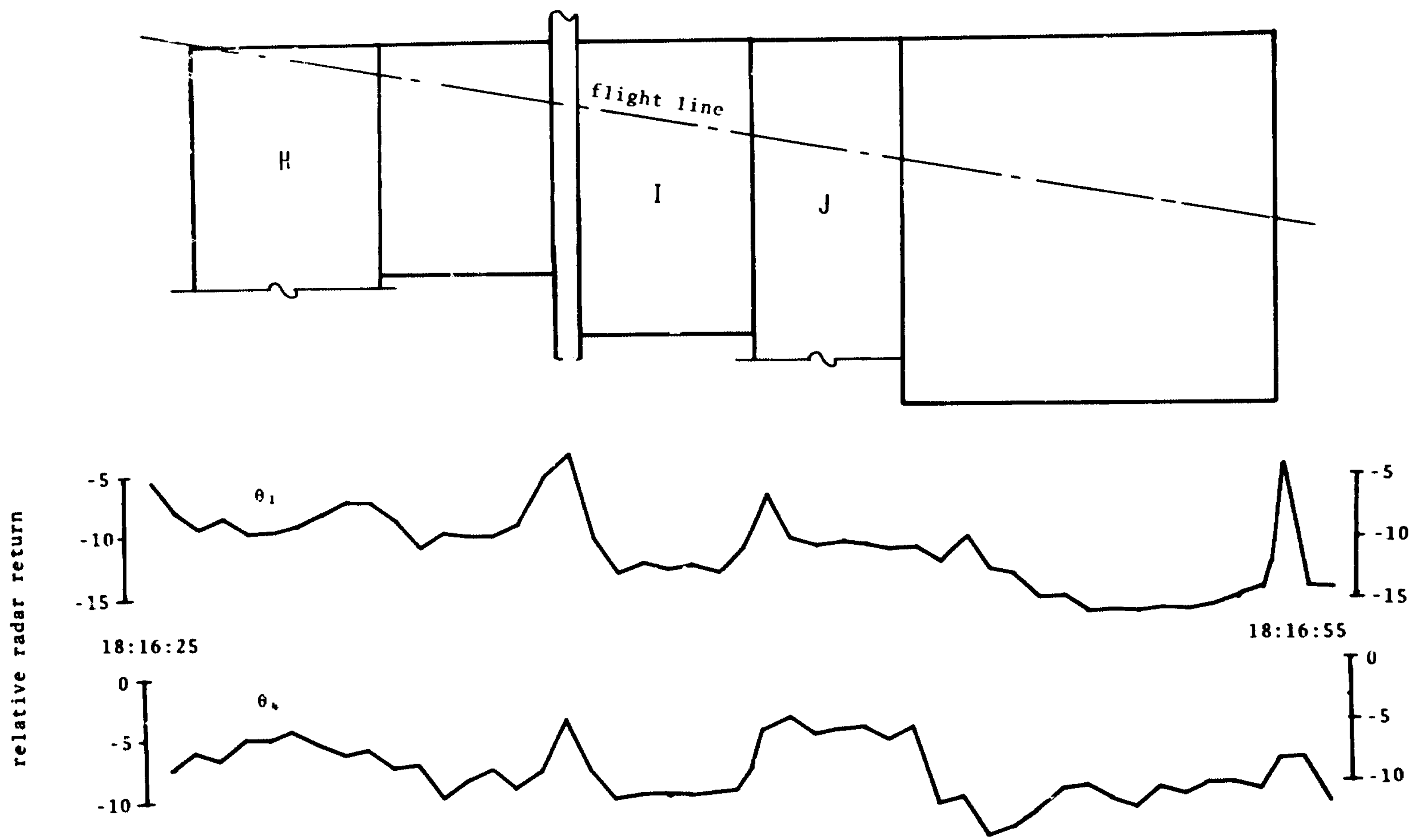


Figure 3a Scatterometer Data
Mission 73, site 130, line 5b



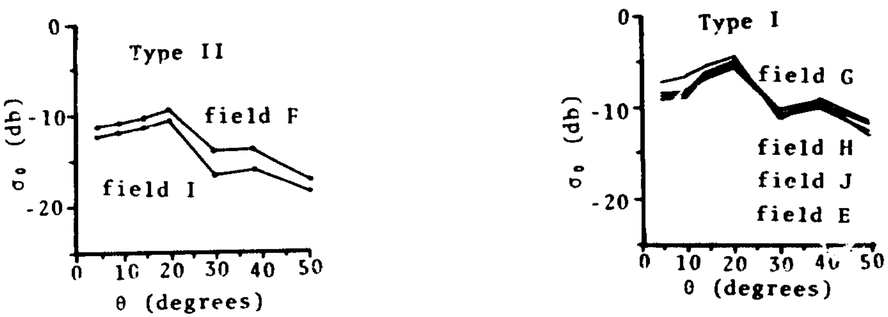


Figure 3b Scatterometer Data
Mission 73, site 130, line 5b

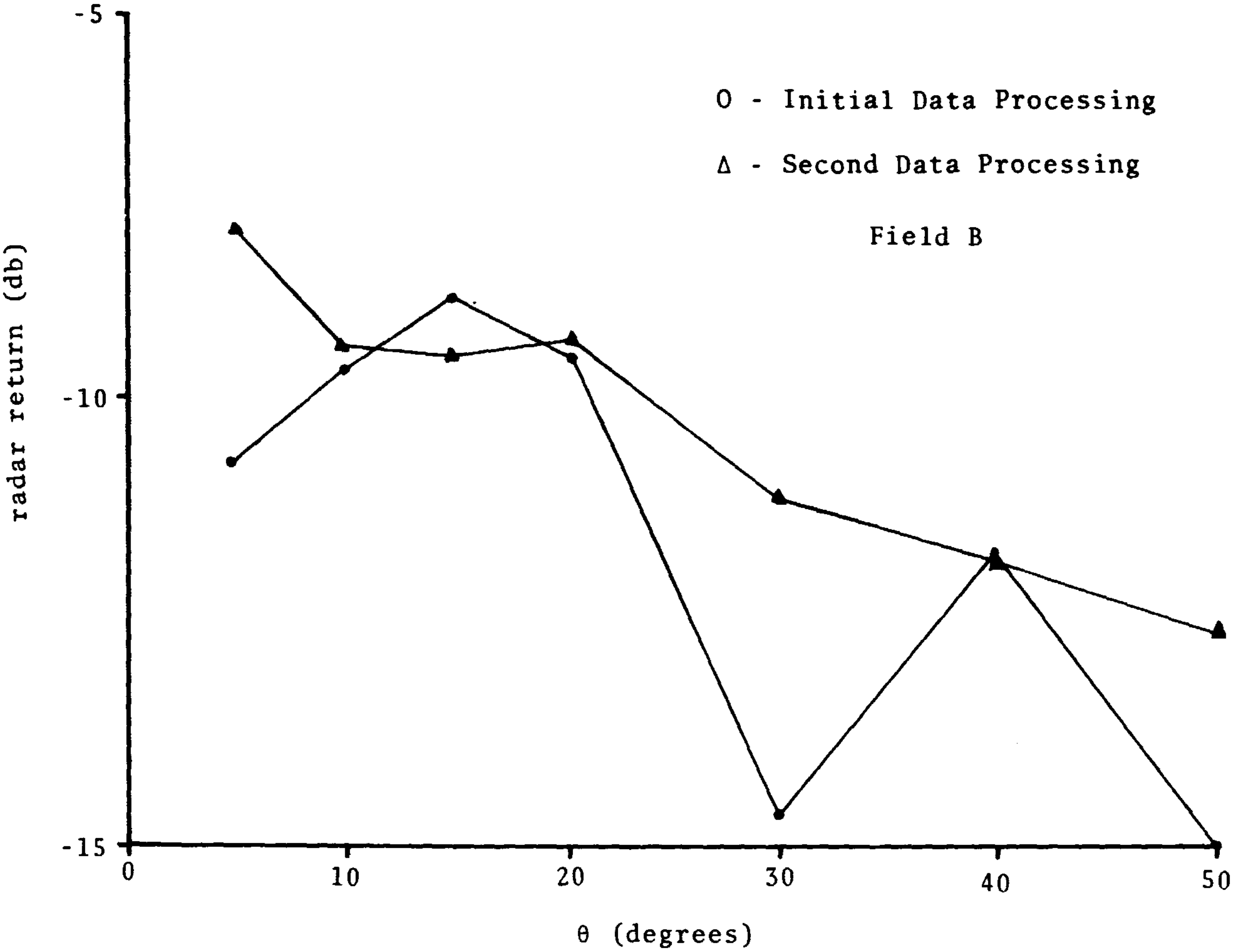


Figure 4 Scatterometer Data

Mission 73, Site 130, line 5b