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HF RADAR MEASUREMENTS OF PEAK ELECTRON DENSITY DURING TESTS CANUTO AND DARDABASI OF OPERATION BARBIZON

Raytheon Company, Sudbury Labs.

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13. ABSTRACT Tests Canuto and Dardabasi of Operation BARBIZON tested two new payload chemistries for producing ionized clouds in the upper atmosphere. Two 16 kg releases were made during each test, a standard chemistry release on the up-leg and a new chemistry release at the same altitude on the down-leg. The new chemistries were developed for test Canuto by Thiokol and for test Dardabasi by Space Data. Raytheon provided HF radar measurements of the peak electron density in each cloud as a function of time.

It was found that the peak electron densities produced by the new Thiokol mix (Canuto) was 46% higher and the new Space Data mix (Dardabasi) 34% lower than that produced by their respective standard mix releases on the same flights. A 12% difference between the standard releases is attributed to small but significant differences in release height and in geophysical conditions on the days the two tests were run. The uncertainty in the absolute peak electron density measurements is estimated to be ±10% and the relative measurement from release to release ±5% during the time intervals of interest (15 to 400 seconds after release).

From a radar propagation viewpoint the Canuto and Dardabasi tests were notable because other-user interference was unusually low and because anomalous cloud-related returns were observed at late-times (an hour or more after release). The low interference level made it possible for the first time to detect separate negative-going doppler "tails" for the ordinary and extraordinary ray as the cloud became underdense verifying an important facet of the theory used to interpret the data. The late-time echoes are discussed and some speculations offered as to their cause

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HF RADAR MEASUREMENTS OF PEAK ELECTRON DENSITY DURING TESTS CANUTO AND DARDABASI OF OPERATION BARBIZON

G. D. Thome
D. W. Blood

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PUBLICATION REVIEW

This technical report has been reviewed and is approved.

Joseph J Simons
For Vincent J Coyne
RADC Project Engineer

Joseph J Simons
RADC CONTRACT Engineer

LIST OF CONTENTS

LIST OF FIGURES

ABSTRACT

Tests Canuto and Dardabasi of Operation Barbizon tested two new payload chemistries for producing ionized clouds in the upper atmosphere. Two 16kg releases were made during each test, a standard chemistry release on the up-leg and a new chemistry release at the same altitude on the down-leg. The new chemistry for test Canuto was developed by Thiokol; the new chemistry for test Dardabasi was developed by Space Data. Raytheon provided HF radar measurements of the peak electron density in each cloud as a function of time.

It was found that the peak electron density produced by the new Thiokol mix was 46% higher than that produced by the standard mix on the same flight (Canuto). The peak electron density produced by the new Space Data mix was 34% lower than that produced by the standard mix on the same flight (Dardabasi). The peak electron density produced by the standard release on test Canuto was 12% lower than that produced by the standard release on test Dardabasi. This difference is attributed to small but significant differences in release height and in geophysical conditions on the days the two tests were run.

The uncertainty in the absolute peak electron density measurements is estimated to be ±10% during the time intervals of interest (15 to 400 seconds after release). The uncertainty in the relative measurement of peak electron density from release to release is estimated to be ±5% during the same time interval.

From a radar propagation viewpoint the Canuto and Dardabasi tests were notable because other-user interference was unusually low and because anomalous

cloud-related returns were observed at late-times (an hour or more after release). The unusually low interference level made it possible for the first time to detect separate negative-going doppler "tails" for the ordinary and extraordinary ray as the cloud became under dense. This observation verifies an important facet of the theory used to interpret the data and hence adds to our confidence in the electron density estimates derived by this technique. The late-time echoes are discussed and some speculations offered as to their cause but the phenomena is not satisfactorily understood.

1. INTRODUCTION

Raytheon participated in Operation Barbizon by fielding 8 HF radars at a site near the Barking Sands launch complex on the island of Kauai, Hawaii. Observations were made during the two LASL shaped charge releases (tests Alco and Bubia) and during the two ARPA barium chemistry tests (Canuto and Dardabasi). No returns were seen during either shaped charge release and it is concluded that either the electron density produced was too low (less than 10^6 e/cm^3) or the target cross-section too small (less than 10^4 m^2) to be detected. Returns were easily detected during the barium chemistry tests and the remainder of this report deals with the interpretation of these data in terms of the peak electron density produced by each release.

2. BACKGROUND

Tests Canuto and Dardabasi were designed to field-test two new payload chemistries, one developed by Thiokol and one developed by Space Data. The goal was to produce a cloud of the highest possible peak electron density for a given payload mass. A payload chemistry of 2.5 moles of barium to 1.0 mole of cupric oxide with 1.8% (by weight) of barium azide has been extensively used in past programs and was adopted as the "standard" against which the new payload chemistries were compared. The peak electron density achieved in a particular release is known to be a function of release height and of ambient geophysical conditions. In view of this, the test plan was to make two releases from each rocket: a standard chemistry 16kg release on the up-leg at 200 km and a new chemistry 16kg release on the down-leg at the same height. The two rockets were fired on different days and the peak electron density of each release was measured by means of HF radar. In this way the performance of each new mix could be compared directly against a standard mix under the same conditions. The two mixes could be compared against each other indirectly by referencing the peak electron density to the standard for each test.

3. PEAK ELECTRON DENSITY DIAGNOSTIC TECHNIQUE

The peak electron density in the cloud is measured as a function of time by illuminating the cloud on a number of fixed radar frequencies and measuring the duration of the return. At radar frequency f, the cloud will support ordinary ray reflections if the peak electron density in the cloud is greater than N_o, where

$$N_o = 1.24 \times 10^4 (f)^2$$

and will support extraordinary ray reflections if the peak electron density is greater than N_x, where

$$N_x = 1.24 \times 10^4 (f^2 - f f_h).$$

In these formulas f_h is the electron gyrofrequency (.96 MHz for Barbizon). The calculated electron densities are in units of electrons per cm^3 when the radar and gyrofrequencies are in units of MHz.

The Raytheon radars are phase coherent systems and the sensitivity of the measurements can be improved by measuring signal drop-out times in the doppler frequency domain after the returns have been spectrum analyzed. The sort of doppler signature expected theoretically from a barium release is shown in Figure 1. This particular doppler signature was generated by ray-tracing through a model cloud having a gaussian spatial density distribution.[1] The details of the signature will differ if the distribution differs from gaussian but the character will remain the same. That is, the signature will begin with a high positive doppler shift (Δf, solid curves) and end with two negative-going "tails", one corresponding to the ordinary ray and one to the extraordinary ray. Figure 1 also shows that the scattering cross-section (σ, dashed curves) drops rapidly towards the end of the doppler signature. In practice this makes it difficult to detect the negative-going tails because it is only during the last few tens of seconds of the echo that the ordinary and extraordinary traces are separated by enough in doppler shift to be resolved by the filter in the spectrum analyzer. During the Barbizon series, however, other-user interference was unusually low and it was possible to resolve the ordinary and extraordinary components. An example is shown in Figure 2. The importance of this is that signal drop-out can be read separately for the two components giving two points on the electron density versus time curve instead of one.

4. RESULTS

The conditions required to unambiguously interpret the radar measurements in terms of peak electron density within the cloud were met for at least a thousand seconds after release. That is, during this time the cloud remained unstriated, the line-of-sight from the radar to the cloud met the earth's magnetic field well off perpendicularity, and the cloud remained high enough in altitude to avoid E-region wind shear systems. After roughly a

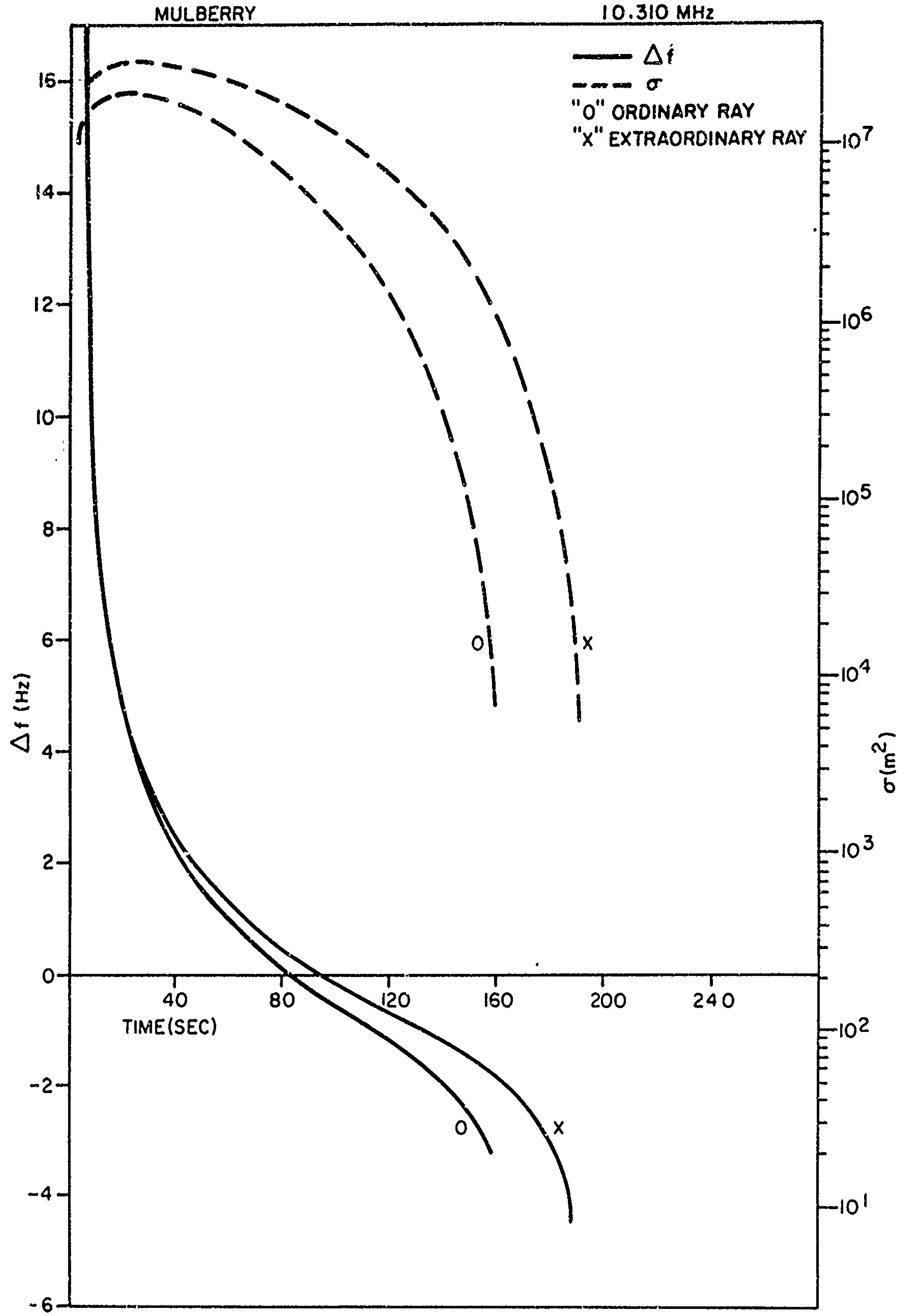

Figure 1. Theoretical doppler shift (Δf) and scattering cross-section (σ) signatures for a typical 16 kg barium release at 200 km altitude.

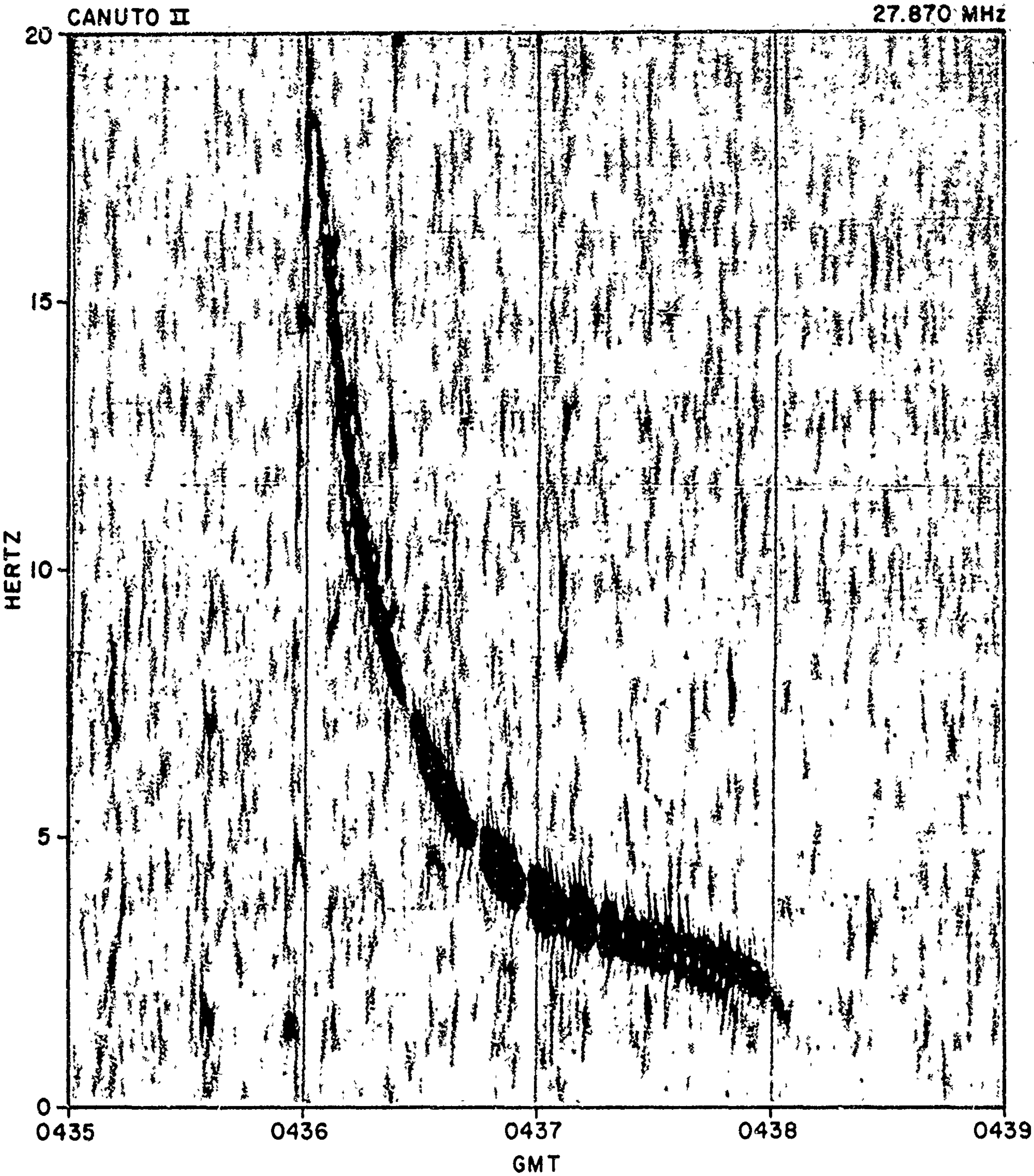

Figure 2. An example of a Barbizon doppler signature illustrating that ordinary and extraordinary modes can be identified separately.

thousand seconds optical coverage ends and it is no longer clear that all or any of these requirements are met. However, the clouds attain their peak electron density within a few tens of seconds after release and by a thousand seconds the important part of the experiment has long past. Thus for the primary purpose of this experiment, data collected after a thousand seconds could be ignored. These data are of interest from a propagation viewpoint, however, and may eventually prove to be useful in understanding the late-time development of barium clouds. For these reasons the radar observations are presented in two parts, the "early time" results which cover the first thousand seconds of development and the "late time" results which cover data collected after a thousand seconds. The early time results are interpreted in terms of the peak electron density in each cloud and form the primary output of this experiment. The late-time results are described and some speculations offered as to their meaning but no attempt is made to interpret them in terms of electron density.

4.1 Early Time Results

The peak electron density time history for each release is shown in Figure 3. Points derived from the ordinary ray are shown with circles, points derived from the extraordinary ray are shown with crosses. During the first 30 seconds the doppler separation between the two modes is too small to be resolved and consequently the echo onset is interpreted as meaning the cloud has gone overdense to the extraordinary ray. The solid curves through the measured points are drawn by eye. The peak values for each release are the following: 8.0×10^6 e/cm^3 for Canuto I, 1.2×10^7 e/cm^3 for Canuto II, 9.0×10^6 e/cm^3 for Dardabasi I, and 5.9×10^6 e/cm^3 for Dardabasi II. These values are believed accurate to within

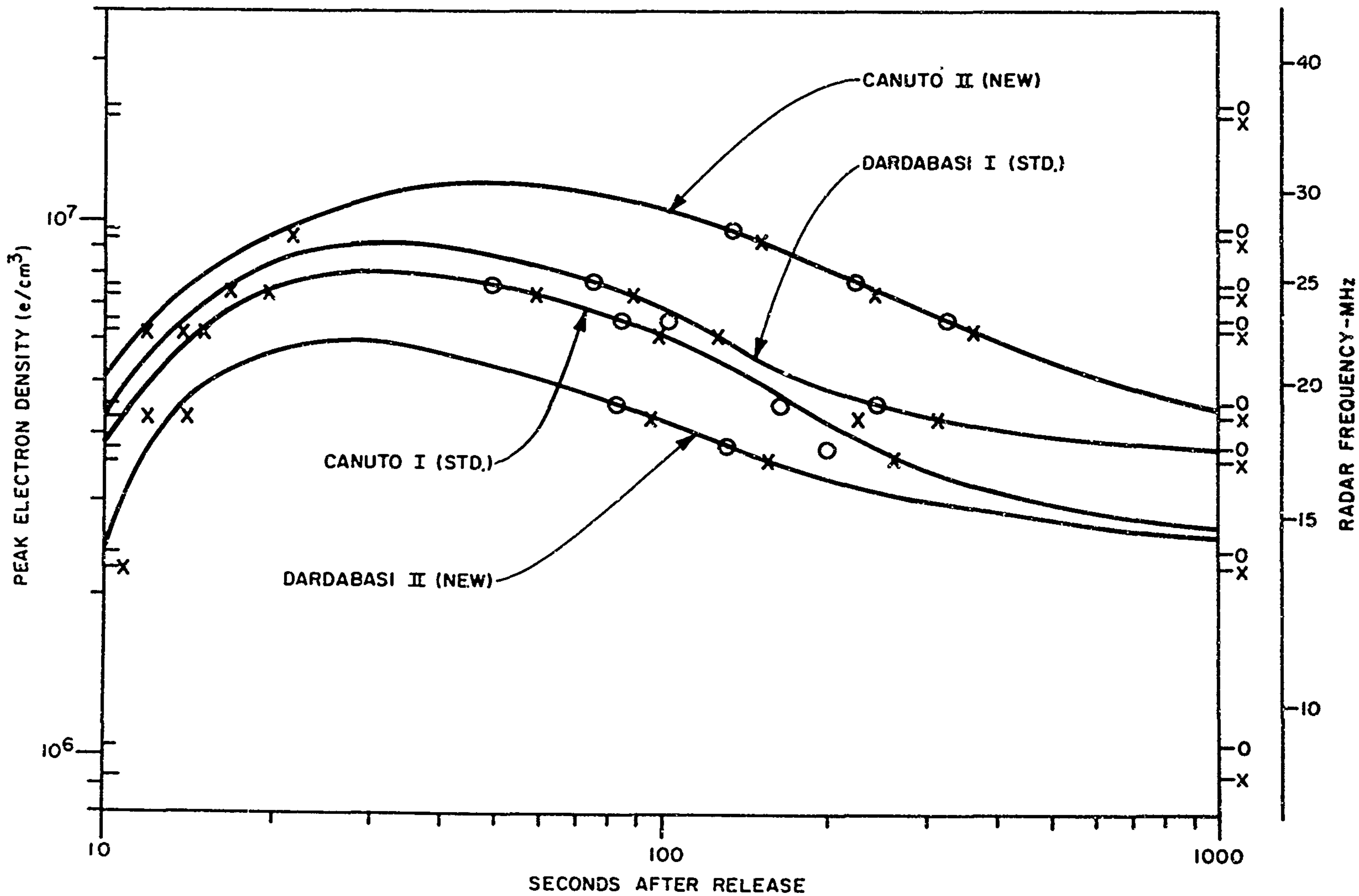

Figure 3. Measured peak electron density as a function time for events Canuto I & II and Dardabasi I & II.

$\pm$10% on an absolute basis and to within $\pm$5% on a relative basis.

Tests Canuto and Dardabasi took place on different days, at somewhat different heights (202 and 198 km respectively), and drifted with significantly different velocities (69 m/s at 44^{o} and 42 m/s at 14^{o} respectively). The standard release on Dardabasi produced a cloud of peak electron density about 12% greater than that produced by the standard release on Canuto and it is probable that this difference is due to the differences in geophysical conditions on the two days rather than due to differences between the two standard mixes. Assuming this to be the case, Figure 4 has been prepared showing how the 4 releases compare on a percentage basis referenced to the standard release on the same test, rather than in absolute terms. The objective is to compensate for geophysical differences between tests. The result is that the peak electron density of the new Thiokol mix was 46% higher than the standard and the new Space Data mix was 34% lower than the standard.

The shape of the curves for the two standard mixes is similar and the peak is reached at about the same time. The curves for the two new mixes, however, differ significantly in shape and thus the percentage difference between the new mixes and their standards will vary with time. Figure 5 shows this variation. Dardabasi II is initially about 30% below standard, reaches a maximum of about 40% below at release plus 70 seconds, and levels off to about 30% below thereafter. Canuto II begins about 30% above standard, reaches a maximum of 100% above at release plus 300 seconds then drops slowly thereafter.

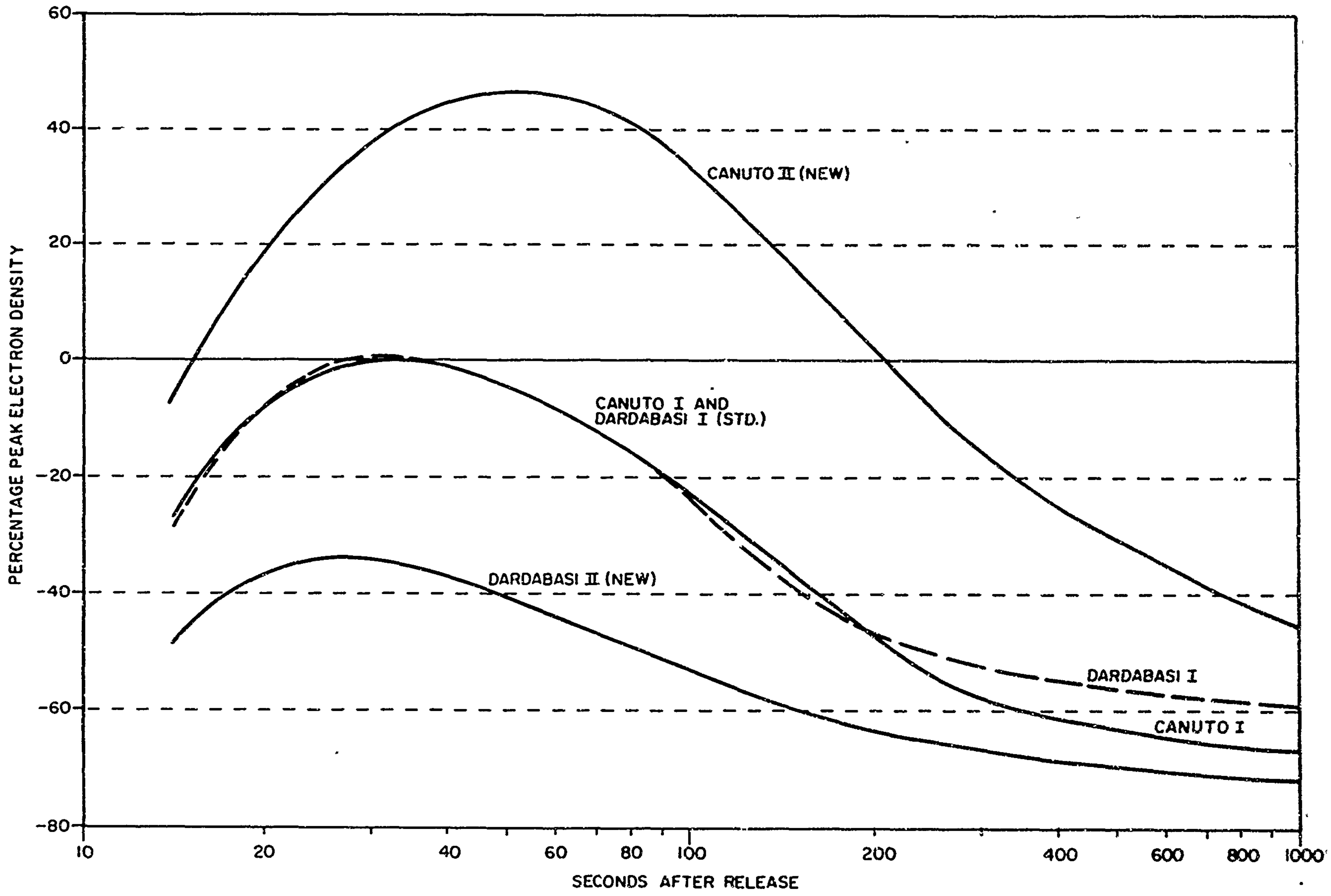

Figure 4. Peak electron densitites versus time for each release in terms of percentage referenced to the maximum density achieved by the standard release. The "zero" level corresponds to 8.0 x 10^6 e/cm^3 for the Canuto I & II curves and 9.0 x 10^6 e/cm^3 for the Dardabasi I & II curves.

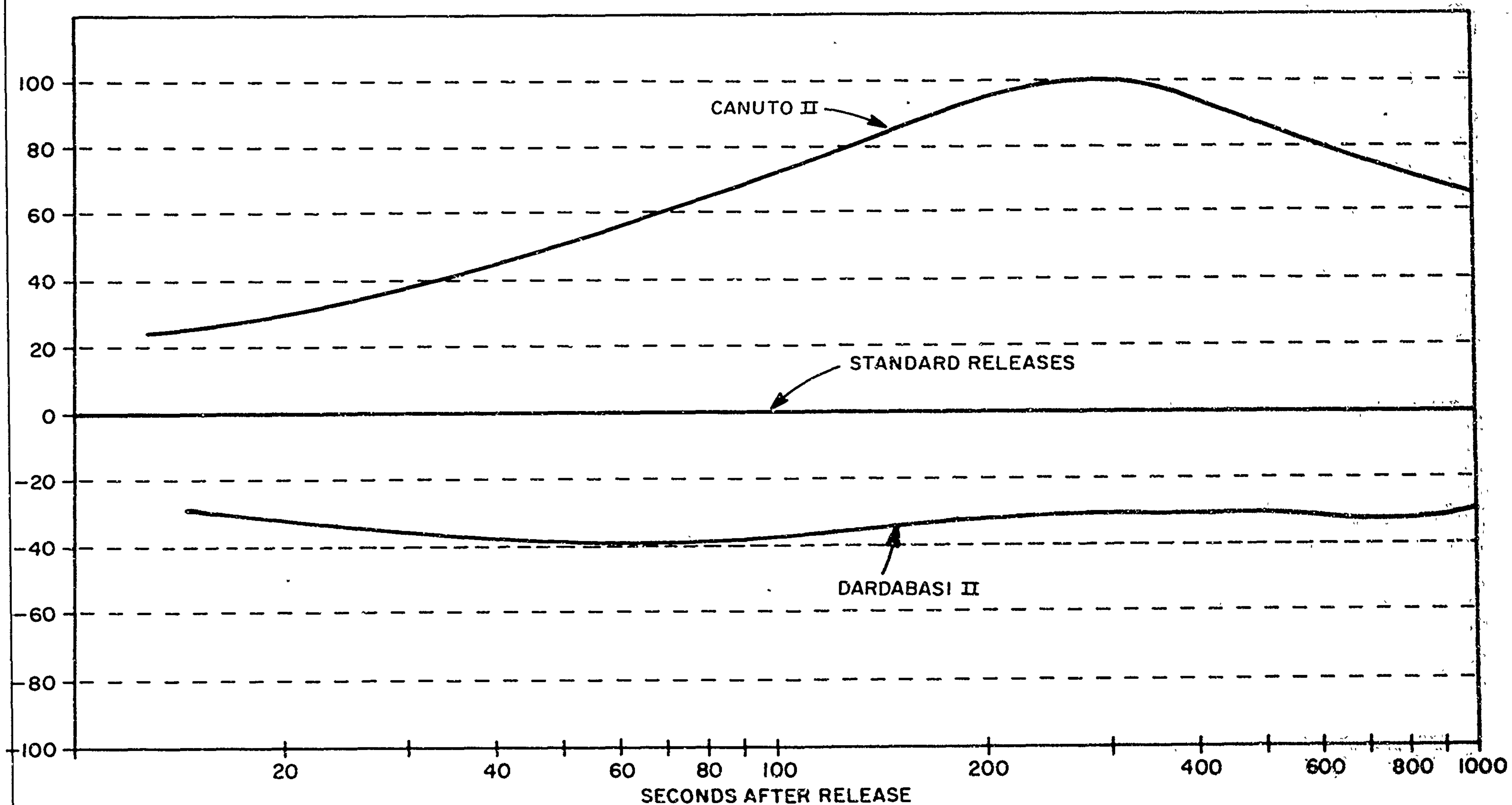

Figure 5. Peak electron density of Canuto II and Dardabasi II in terms of percentage above or below the peak electron density at the same time of the corresponding standard release.

4.2 Late Time Results

Figures 6, 7, 8, and 9 show the complete time history of the radar returns for Canuto I, Canuto II, Dardabasi I, and Dardabasi II respectively. The solid horizontal lines show when echoes were observed on each radar frequency. Care has been taken to insure that the echoes shown on these figures are definitely related to the release indicated. That is, range-time-intensity records for each frequency on each test have been examined to make sure that there is continuity in range-time between the various returns attributed to the same cloud. Eventually (usually about 2 hours after the release) the returns become distinguishable from E-region returns that are seen occassionally from the normal ionosphere and these echoes are indicated by cross-hatching and call-outs on the figures.

The late-time echoes are not well understood but it is speculated that they represent scattering from field aligned irregularities in the barium cloud when the cloud has drifted far enough from its release position so that the radar line-of-sight meets the magnetic field through the cloud at normal incidence. Figure 10 shows how the magnetic aspect angle for a radar at Barking Sands varies with cloud position, assuming the cloud is at a fixed height of 200 km. The cloud release positions are indicated on the figure (CI for Canuto I, etc.). Anomalous echoes can be expected if the clouds reach the 90^0 contour. Unfortunately the available cloud tracking data is very limited. No data at all exists for the down-leg releases and that which does exist for the up-leg releases lasts only for about 15 minutes and indicates a non-uniform

CANUTO I (STANDARD)

TIME HISTORY OF CLOUD PRODUCED RETURNS

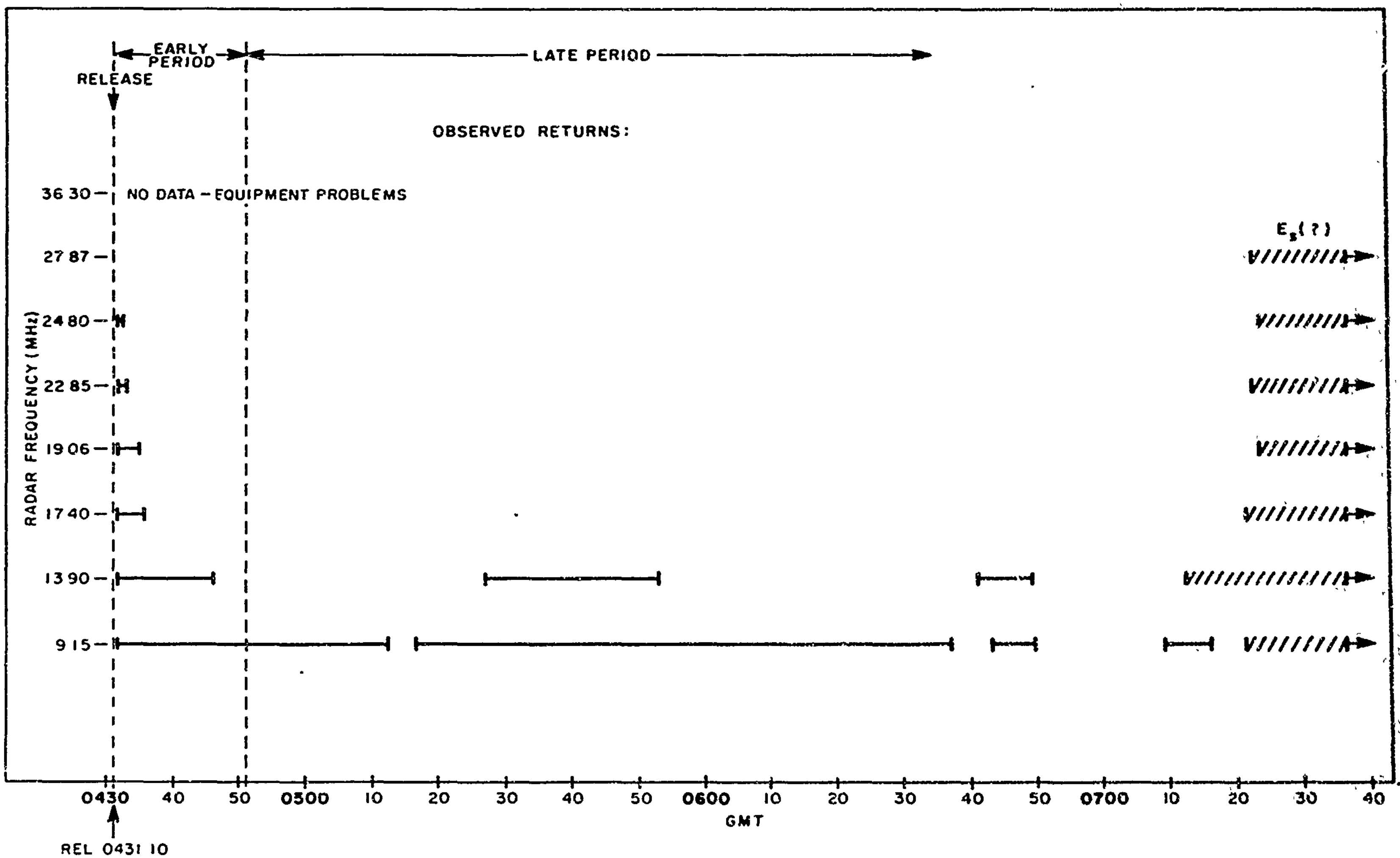

Figure 6. Time history of radar returns from Canuto I.

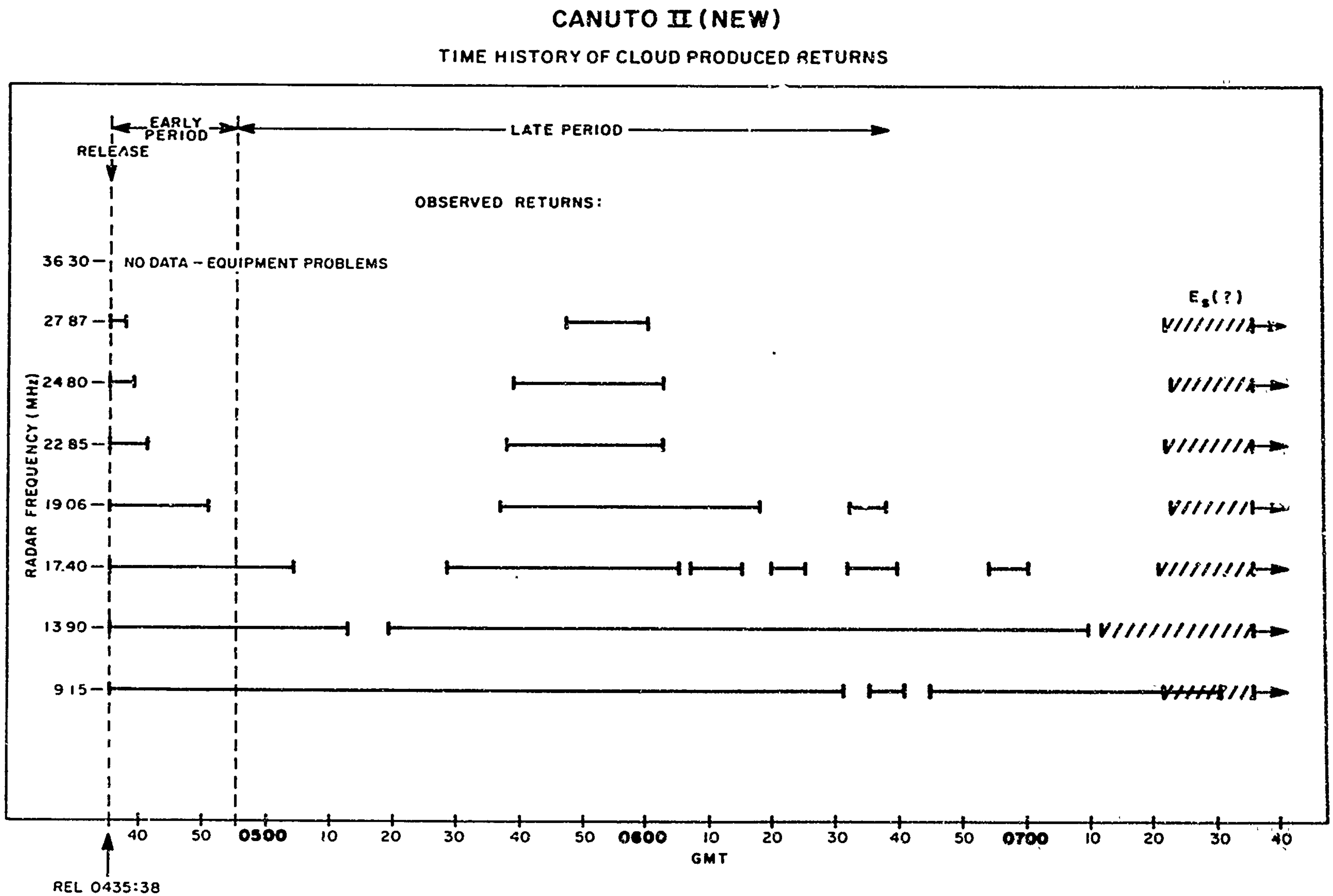

Figure 7. Time history of radar returns from Canuto II.

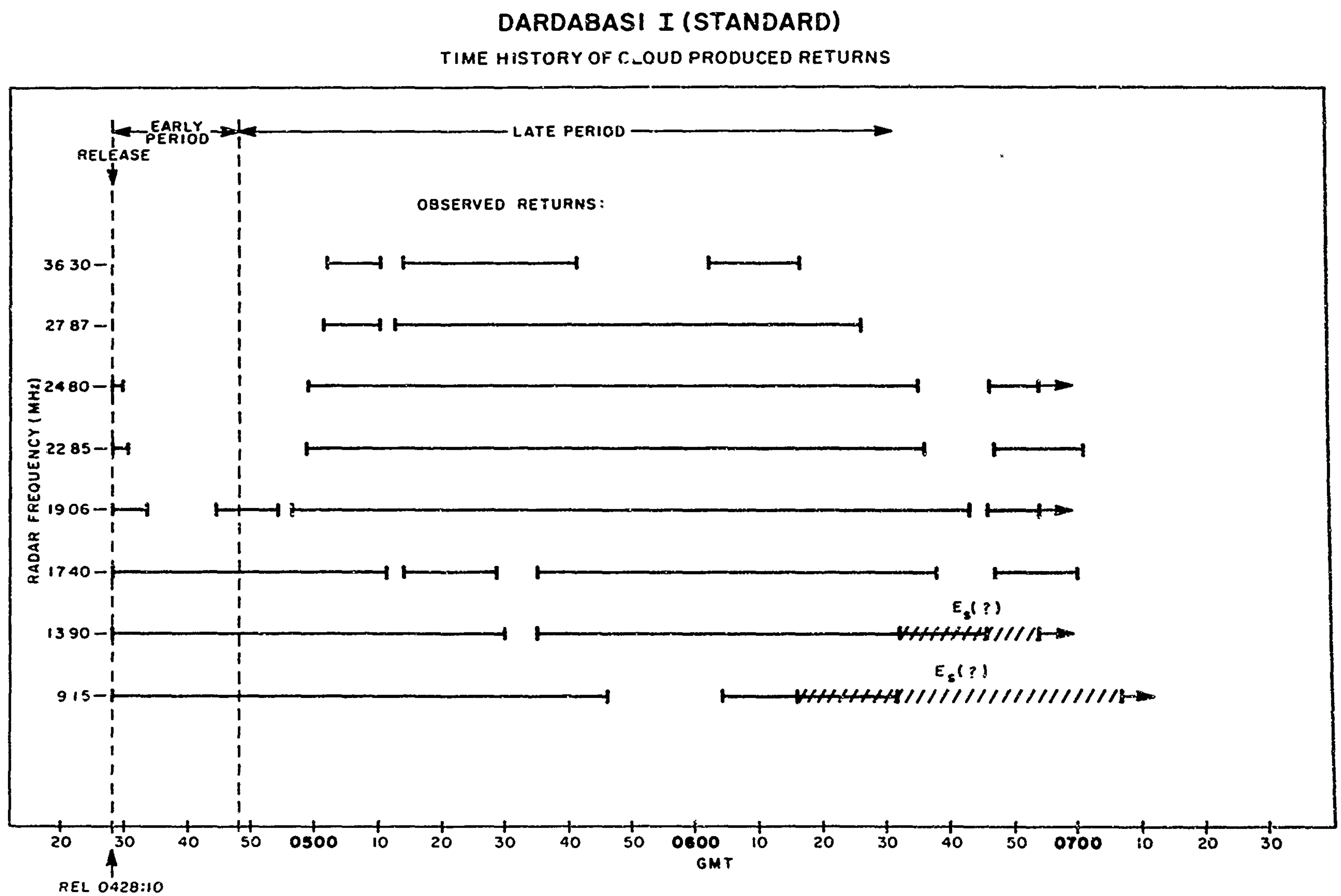

Figure 8. Time history of radar returns from Dardabasi I.

DARDABASI II (NEW)

TIME HISTORY OF CLOUD PRODUCED RETURNS

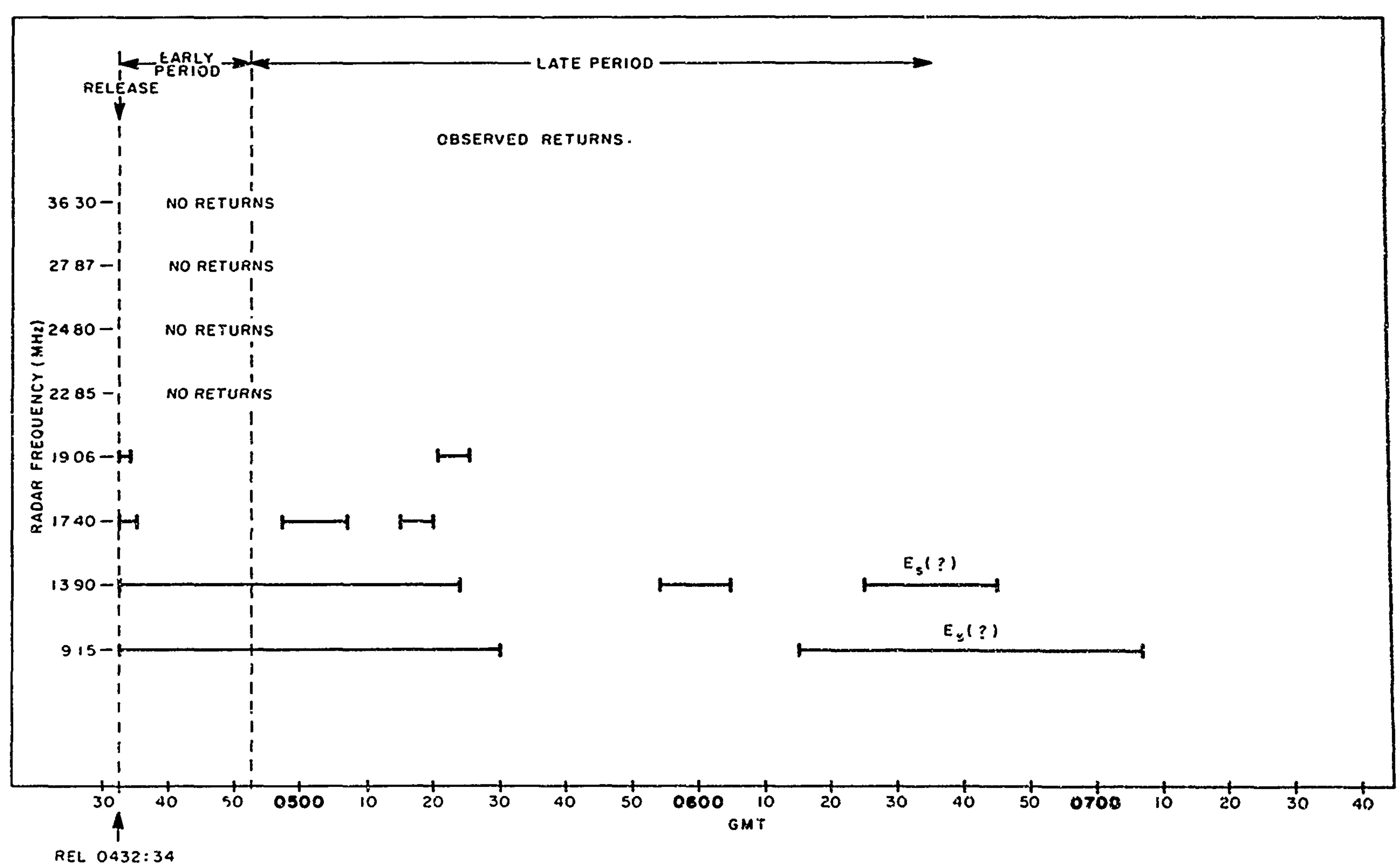

Figure 9. Time history of radar returns from Dardabasi II.

MAGNETIC ASPECT ANGLE FOR BARBIZON

RADAR AT BARKING SANDS

RELEASES AT 200km

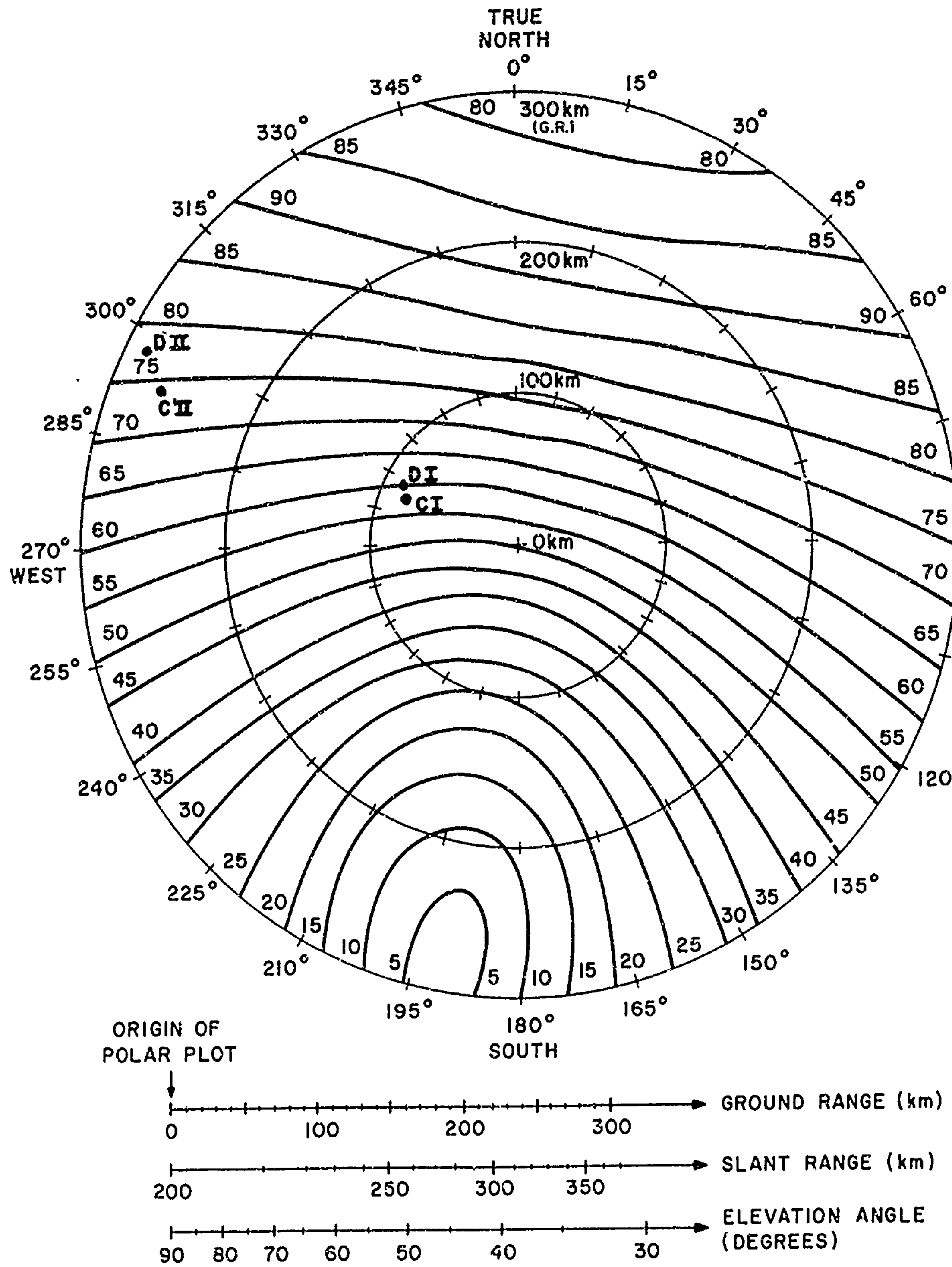

Figure 10. The magnetic aspect angle for a target at 200 km and a radar at Barking Sands, Kauai. Refraction is ignored.

track. In order to make at least an order-of-magnitude calculation of when anomalous echoes would be expected to onset according to this mechanism, we take the release point and the last track point[2] as defining the velocity vector for the up-leg releases. Under this assumption, Canuto I is found to drift at 69 m/s along an azimuth of 44° and Dardabasi I is found to drift at 42 m/s along an azimuth of 14°. At these velocities, Canuto I would reach the 90° contour at 0517 GMT and Dardabasi I would reach the 90° contour at 0529 GMT. If the down-leg releases are taken to drift with the same velocity as the respective up-leg releases, Canuto II would reach the 90° contour at 0512 GMT and Dardabasi II would reach the 90° contour at 0517 GMT. These times are of the right order but there is no agreement in detail. The test of this explanation for the late time echoes is considered inconclusive.

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1. P. B. Rao, E. M. Allen, and G. D. Thome, "Ray Tracing Synthesis of HF Radar Signatures from Gaussian Plasma Clouds", RADC-TR-71-313, March 1971.

2. Information furnished by W. Barton of the Sandia Corporation.