Project Report
ATC-239

Beacon Radar and TCAS Interrogation Rates: Airborne Measurements in the 1030 MHz Band

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16. Abstract

Airborne measurements were made of the rates of beacon-radar interrogations and suppressions in the 1030 MHz band. These measurements were undertaken in order to provide a basis for interference analysis of the proposed system of GPS-Squitter. The measurements were made during a flight along the East Coast, including New York, Philadelphia, Baltimore, and Washington. Measurements were also made at Atlanta and in the Dallas Fort Worth area. Results are given in a form that shows the rates of interrogations and suppressions as a function of time and location of the aircraft. Interrogations are also separated into those that were transmitted by ground-based interrogators and those that were transmitted by airborne TCAS equipment. Mode S interrogations were also separated from the other modes. The number of TCAS aircraft in the vicinity was also measured during the flights. The results indicate that the rates of interrogations and suppressions were consistent in most respects from location to location. The rates Mode A and C interrogations from the ground were consistently less than 100 per second with two brief exceptions. Previous measurements had indicated a trend of decreasing interrogation rates with time since the early 1970's. The new measurements support this observation and indicate that the trend has continued.

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EXECUTIVE SUMMARY

The FAA is in the process of developing GPS-Squitter techniques for surveillance of aircraft based on satellite technology. In this system, each aircraft would periodically transmit position, trend, and identification messages, called "squitters". The squitters are broadcast in a frequency channel of the existing air traffic control beacon radar system, using data obtained from the Global Positioning System (GPS). Reception of squitters can be used for several purposes, including surveillance of airborne aircraft by a ground station, surveillance of aircraft on the airport surface, and air-to-air surveillance.

In developing the new system, it is necessary to know the rates of existing signal transmissions in the 1030 and 1090 MHz radio frequency channels, which are the interrogation and reply bands for beacon radar and TCAS. The GPS-Squitter would be transmitted in the 1090 MHz channel, like a reply. Two important issues concern the possibility of interference to squitter reception from existing signals in the 1090 MHz band and the possibility of interference to existing systems from the new GPS-Squitter transmissions.

To confirm GPS-Squitter capacity and interference calculations, airborne measurements were undertaken by Lincoln Laboratory. The results are reported here. An instrumented aircraft flew from Boston to New York, Philadelphia, Baltimore, Washington, and Norfolk. Measurements were also made in Atlanta and Dallas Fort Worth. Receptions were recorded during the flight, and subsequently analyzed to determine the interrogation rates in the 1030 MHz band.

The results indicate that the rate of Mode A and C interrogations received from ground-based radars was less than 100/sec consistently during the flights, with two brief exceptions at Baltimore and Atlanta. These results indicate that the interrogation rate environment has diminished substantially over the past two decades, presumably due to efforts that have been made to improve the operating conditions of interrogators using this band. Another significant result was that the rate of Mode C interrogations from TCAS aircraft was consistently less than 40/sec, which was the value used in standardizing TCAS transmissions.

Prior to these airborne measurements, interference analyses had been made by Lincoln Laboratory based on environment models to characterize the current activity in these frequency bands. The airborne measurements were undertaken to complement those analyses. The measured rates have now served to validate the models that were used. For example, the analysis model for Mode A and C interrogations from the ground was a rate of 100 per sec; the airborne measurements indicate that this model was reasonable and somewhat conservative (higher than the actual rate). Also, the analysis model for Mode C interrogations from TCAS aircraft was a rate of 40 per sec; the airborne measurements indicate that this model too was reasonable and actually somewhat conservative.

In summary, after making airborne measurements at 1030 MHz in a number of locations and examining the data in some detail, we can report that the results appear to be reasonable and not substantially different from the expectations based on prior measurements and a general trend toward diminished interrogation rates. Also, the models used for assessing GPS-Squitter capacity and interference effects are found to be reasonable and somewhat conservative.

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1. INTRODUCTION

1.1 BACKGROUND

The Federal Aviation Administration (FAA) is in the process of developing GPS-Squitter techniques for surveillance of aircraft based on satellite technology. In this system, each aircraft would periodically transmit position, trend, and identification messages, called "squitters". The squitters contain aircraft identification and position reports, using data that was obtained from the Global Positioning System (GPS). Reception of squitters can be used for several purposes, including surveillance of airborne aircraft by a ground station, surveillance of aircraft on the airport surface, and air-to-air surveillance. Reference [1] provides a more detailed description of the GPS-Squitter concept.

In developing the new system, it is necessary to know the rates of existing signal transmissions in the 1030 and 1090 MHz frequency bands. These are the beacon-radar and TCAS interrogation and reply channels. The GPS-Squitter would be transmitted in the 1090 MHz band, like a reply. A key issue is the possibility of interference to squitter reception from existing signals in the 1090 MHz band. Reference [1] documents the initial calculations of the magnitude of these interference effects, and Reference [2] provides more detailed calculations.

To validate these initial calculations, Lincoln Laboratory is making direct measurements of the rates of existing transmissions in both bands. These signals consist mainly of interrogations in the 1030 MHz band and replies in the 1090 MHz band. While the GPS-Squitters would experience interference from the 1090 MHz replies, signals in the 1030 MHz band, the subject of this report, are of interest because these interrogations are responsible for triggering replies at 1090. Knowing the interrogation-rate environment provides a basis for projecting the reply-rate environment into the future when numbers of aircraft may be expected to increase.

1.2 EXPECTATIONS

Before beginning the current airborne measurements, there were some indications that the 1030 MHz interrogation rates have been diminishing over time. Measurements in 1973 indicated that interrogation rates reached several hundred per second in the vicinity of major metropolitan areas [3, 4]. By comparison, rates measured in 1978 and 1979 seemed to indicate that rates did not exceed about 150 interrogations per second, suggesting a significant decrease with time [5, 6].

It may seem counter-intuitive during a period of growth in aircraft traffic to see a decrease in the interrogation environment, but such a trend might be explained as the result of the FAA's efforts to improve the operating practices of radars that use these bands. During the 1970's, the FAA conducted a substantial program to monitor and improve the operation of beacon-radar interrogators. Many interrogators were found to be transmitting higher power levels and at higher rates than needed. This was particularly true for "ramp testers" which are interrogators used to test aircraft transponders prior to takeoff. Also some military interrogators were found to be operating without sidelobe suppression, which greatly increased the interrogation rate for aircraft at short ranges.

These factors could explain a decrease in interrogation rate and therefore in reply rate. Airborne measurements have now been made by Lincoln Laboratory (during 1994) of the interrogation rates along the East Coast, including Boston, New York, Philadelphia, Washington, and Norfolk, Virginia. Measurements have also been made in Atlanta and Dallas Fort Worth. This report documents the results, along with a description of the measurement equipment and procedures.

2. MEASUREMENT EQUIPMENT AND TECHNIQUES

During the Mode S development program, MIT Lincoln Laboratory designed and built an "Airborne Measurement Facility" (AMF) for measuring beacon radar signals in the 1030 and 1090 MHz bands. When used at 1030 MHz in the normal mode, the AMF digitizes each received pulse and records it on tape as one pulse word, containing the received power level, the pulse width, and the time of reception. Subsequently, analysts play back the recorded data, and apply computer analysis to recognize pulse combinations that constitute interrogations. The analysis then counts interrogations to determine interrogation rates. Figure 1 illustrates the equipment configuration. Reference [7] documents the functions of the AMF in more detail. Lincoln Laboratory upgraded the data recording subsystem of the AMF in 1993, as documented in [8].

Because the AMF records data in a detailed form, it is possible to conduct diverse and comprehensive analyses. In some cases in the past, more detailed analyses have been applied to single-out a particular interrogator from all of the rest. This makes it possible to determine the interrogator's scan rate, received power level, and antenna patterns [5, 6, 9]. The results reported here do not focus on individual interrogators, but do separate the interrogation modes for separate counting. For example, Mode C interrogations from TCAS[1] include a P4 pulse (Figure 2), which can distinguish TCAS signals from other signals. In this analysis, we have made use of the P4 pulse reception to distinguish TCAS signals and count them separately from the signals that were transmitted by ground-based radars. Figure 2 summarizes the formats of TCAS signals and signals from ground stations as now in use in the 1030 MHz band.

The software that recognizes interrogations uses a technique intended to identify all interrogations, even when received overlapped. If two interrogations are overlapped, this software will recognize and count both. In such situations, a transponder would reply to only the first interrogation, and therefore, the transponder reply rate is somewhat lower than the total interrogation rate. It is also possible, and more common, that a suppression will precede an interrogation, causing the transponder to not reply. We expect that the difference between the total interrogation rate and the reply rate is relatively small in most cases.

Some of the receptions in the 1030 MHz band are Mode S interrogations, which can be from TCAS or from ground-based Mode S radars. In AMF data, the analysis recognizes Mode S interrogations by their pulse pattern, which consists of two preamble pulses, 2 microseconds apart, followed by a data block beginning 1.5 µs later. The AMF equipment does not have the capability to decode the data in the Mode S message. Therefore, it is not possible at this time to distinguish between Mode S interrogations from TCAS and those from the ground. Given that almost no Mode S ground-based radars were operating at the time of these measurements (August 1994), nearly all of the Mode S interrogations are presumably from TCAS aircraft.

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1 The Traffic Alert and Collision Avoidance System (TCAS) is airborne equipment that uses air-to-air signaling for collision avoidance.

The AMF also records data from several peripheral units as illustrated in Figure 1. These include an altimeter, a GPS receiver (to record the position of the aircraft as a function of time), and a Mode S transponder (to provide a count of the TCAS aircraft in the vicinity). The AMF and this peripheral equipment have been installed in a Cessna 421 twin engine aircraft. The aircraft is equipped with both a top antenna and a bottom antenna. They are both short monopoles, typical of the antennas used for aircraft transponders.

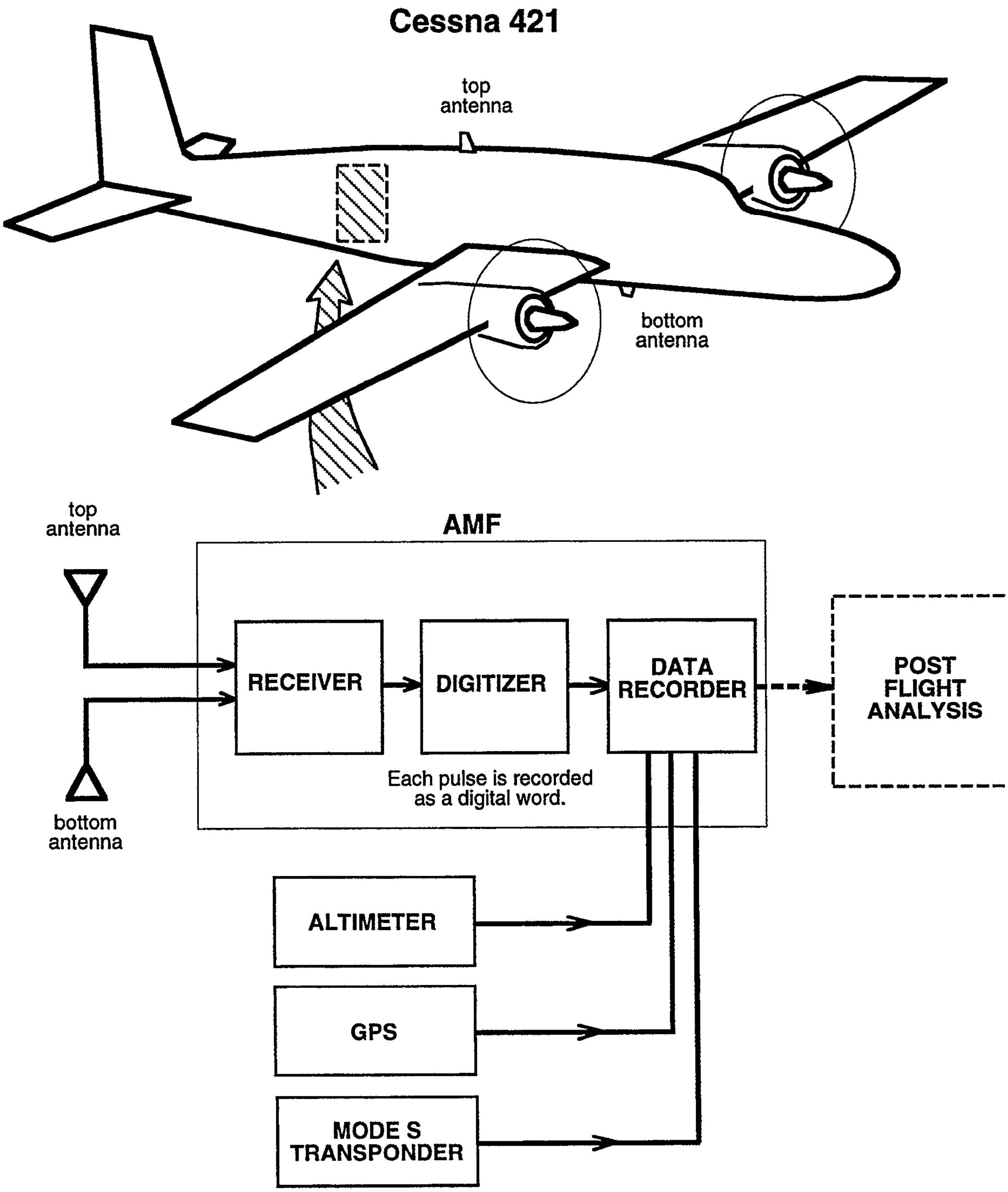

Figure 1. The Airborne Measurement Facility.

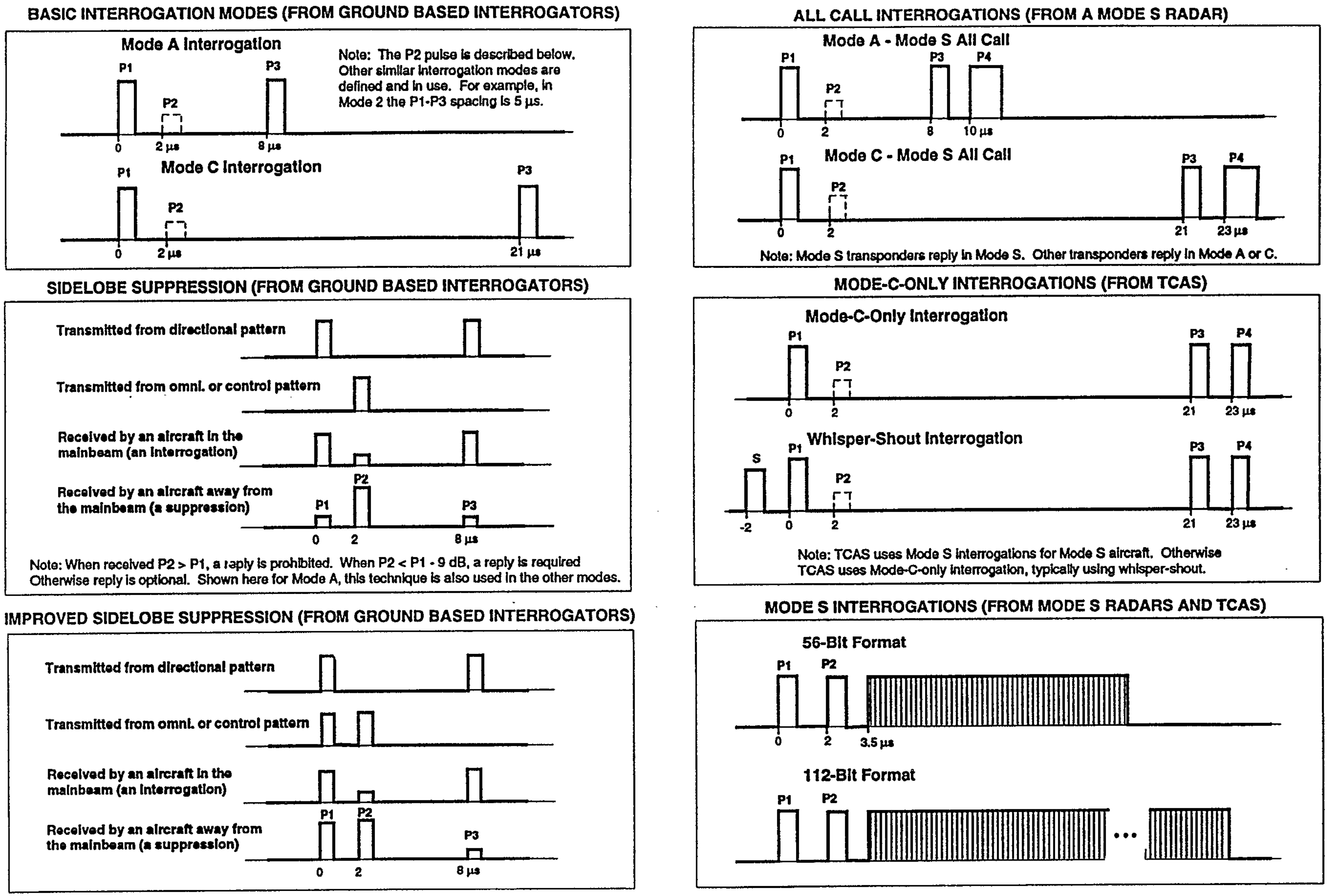

Figure 2. Transmissions in the 1030 MHz band.

3. AIRBORNE MEASUREMENTS, BEDFORD—NEW YORK—PHILADELPHIA

3.1 MEASURED RATES

On 1 August 1994, the Cessna 421 equipped with the AMF flew along the East Coast, beginning in Bedford, Massachusetts, and passing over New York and Philadelphia. Figure 3 shows the flight path. Altitude was constant at 6000 ft as is plotted in the figure. Figure 4 shows the interrogation and suppression rates that were measured along this flight path. The interrogation rates are also plotted in Figure 5 showing several interrogation modes. These plotting formats are described in more detail below.

Interrogations and Suppressions

The distinction between interrogations and suppressions is illustrated in Figure 2. For the simple case of a Mode C interrogation, the distinction depends on the presence and the strength of a P2 pulse reception. According to the standards for beacon radar, if the received P2 pulse is stronger than or equal to the preceding P1, then the reception is a suppression, and the transponder is prohibited from replying. If the P2 is weaker than or equal to P1 - 9 dB, then the reception is an interrogation and the transponder is required to reply. Between these two limits, the transponder reply is optional. The analysis leading to the data shown in Figures 3 and 4 used the midpoint of this tolerance band. That is, a P1/P2 threshold of 4.5 dB was used to distinguish between interrogations and suppressions.

Plot Formats

Figure 4 shows the total interrogation rate and total suppression rate, together on a log scale. Each point is the average rate over a 1-minute period. Figure 5 shows the interrogation rate and its major subsets in more detail on a linear scale. The lowest curve includes Mode A and Mode C interrogations from the ground. These are distinguishable from TCAS interrogations by the absence of the P4 pulse (Figure 2). The next highest curve shows the Modes A and C interrogations from the ground plus the Mode C interrogations from TCAS. By looking at the increment between this curve and the lowest one, one can see the rate of TCAS Mode C interrogations. This is the reason for using a linear scale in Figure 5. The highest of the three curves shows the total interrogation rate, which includes the middle curve plus Mode S interrogations, and is the same as the interrogations curve in Figure 4.

Data in the 1030 MHz band were recorded continuously during most of this flight, with two exceptions when the AMF was used in a different mode. This caused a gap in the data (Figure 3) after the aircraft passed New York, and also was the event that marked the end of the plotted data near Philadelphia.

Receiver Threshold

The rates in Figures 4 and 5 apply for a receiver threshold of -74 dBm, referred to the antenna end of the antenna-to-transponder cable. This is a nominal value for a Mode S transponder, as specified in the National Standard. The receiver threshold, sometimes called

Minimum Triggering Level, or MTL, is defined as the point of 90% detection. For flexibility in data analysis, the AMF pulse measurements were made with a more sensitive receiver setting[2], namely -80 dBm. Then in the post-flight analysis that yielded Figures 4 and 5, the receptions lower than -74 dBm were deleted.

This deletion of low-power receptions was done separately for top-antenna receptions and bottom-antenna receptions. It was important to perform the analysis in this manner because the deletion of low-power pulses affects the distinction between interrogations and suppression for TCAS receptions. This detailed point is illustrated in Figure 6.

TCAS Effects

The interrogations and suppressions received during this flight are shown in Figure 7 in a TCAS context. Here the TCAS Mode C interrogations and suppressions and Mode S interrogations are combined into a total rate. As mentioned in Section 2, the AMF does not have the capability to demodulate the Mode S data block and so cannot distinguish between TCAS and other interrogators. So it is based on an assumption that essentially all of the received Mode S interrogations came from TCAS aircraft that this total is combined with the other TCAS Mode C interrogations to get the total TCAS effect. This total can be of interest in assessing the total effect of TCAS in the environment, by combining the effects of interrogations and suppressions.

Figure 7 also shows the number of TCAS aircraft, based on transponder receptions on the AMF aircraft. This is the count used for interference limiting in TCAS, and equals the number of TCAS aircraft within approximately 30 nmi. Each TCAS aircraft transmits self-identifying broadcasts in the form of Mode S interrogations (at 1030 MHz). The Mode S transponder on the AMF aircraft receives these signals, recognizes them as being TCAS identifications, and passes them to the AMF for recording and subsequent counting.

Rate vs. Threshold

It is to be expected that raising the receiver threshold will reduce the rate of interrogations received, and vice versa. Figure 8 shows, for New York and Philadelphia, the results obtained when the receiver threshold was varied by ±6 dB above and below the nominal value. Each point plotted is the average rate over 3 minutes.

3.2 DISCUSSION OF RESULTS

The interrogation rate in Modes A and C from the ground, plotted in Figure 5, varies with aircraft location, rising as the aircraft came near New York and Philadelphia. At no time did the rate exceed 100 per sec, and most of the time it was substantially lower. This confirms the expectation that these rates have decreased with time since the 1970's.

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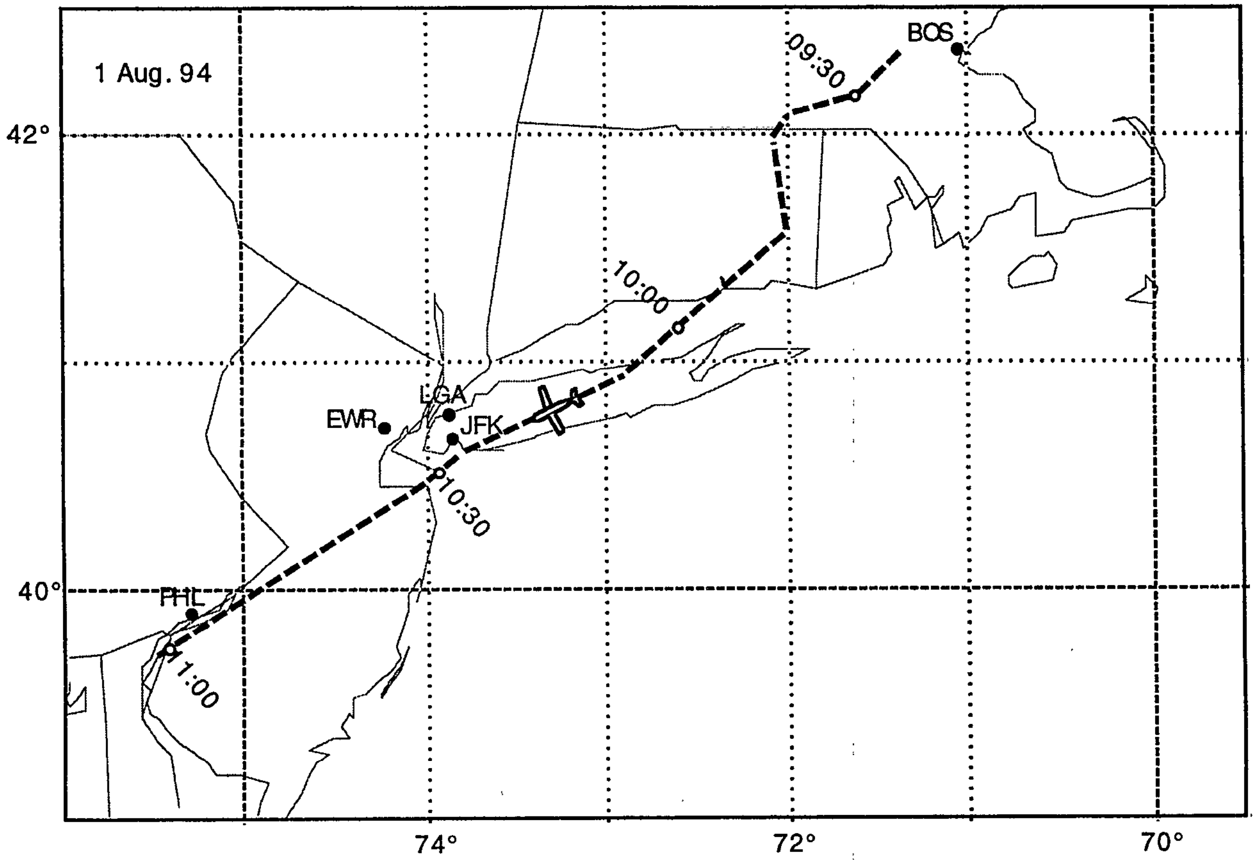
2 The AMF was calibrated in power levels to approximately ±0.5 dB. This was done for both the receiver threshold (which was constant at -80 dBm) and the power level measurement for each pulse.

The overall decrease since the measurements in 1973 has been dramatic. Figure 9 shows similar measurements that were made in the Connecticut–New York–New Jersey area in 1973 [3]. Note that the interrogation rate in Modes A and C was consistently over 100 per sec much of the time, and rose to over 300 per sec in several different periods. Comparable measurements were obtained from flights in the Los Angeles–San Diego area in the same year.



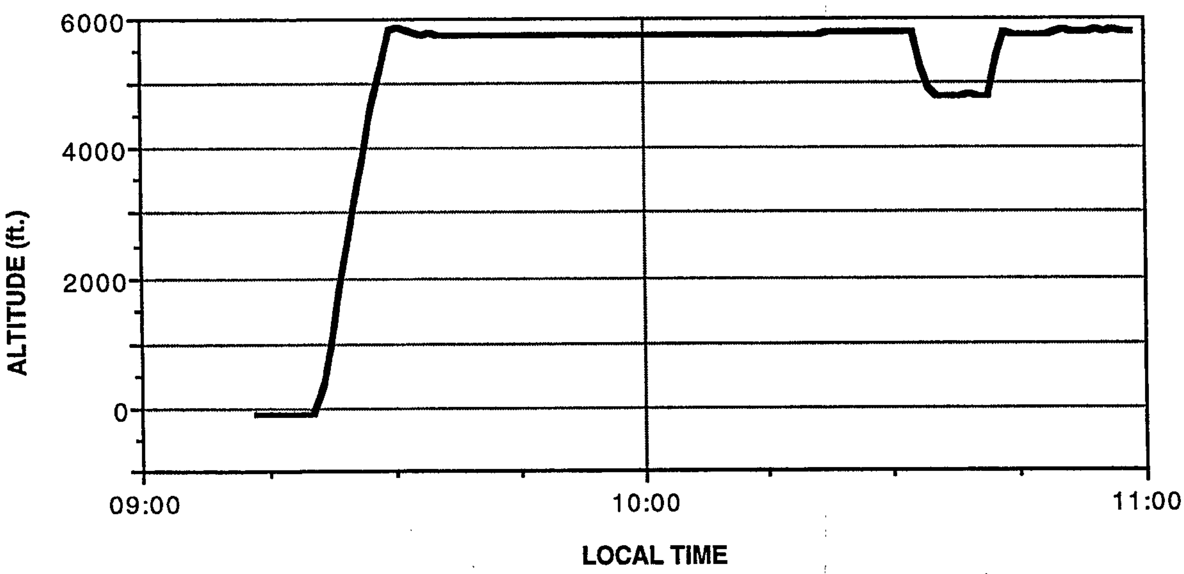


Figure 3. Flight path.

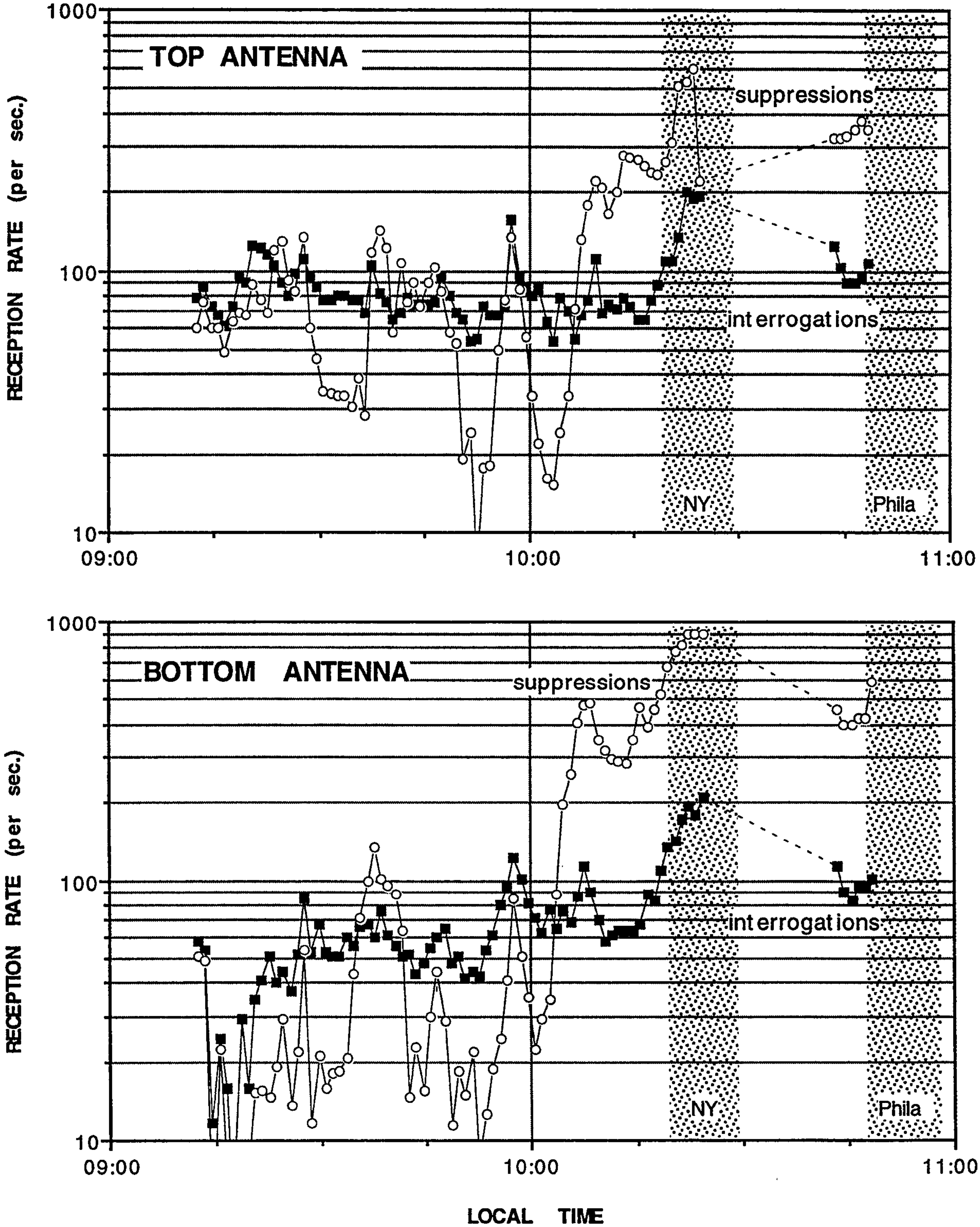
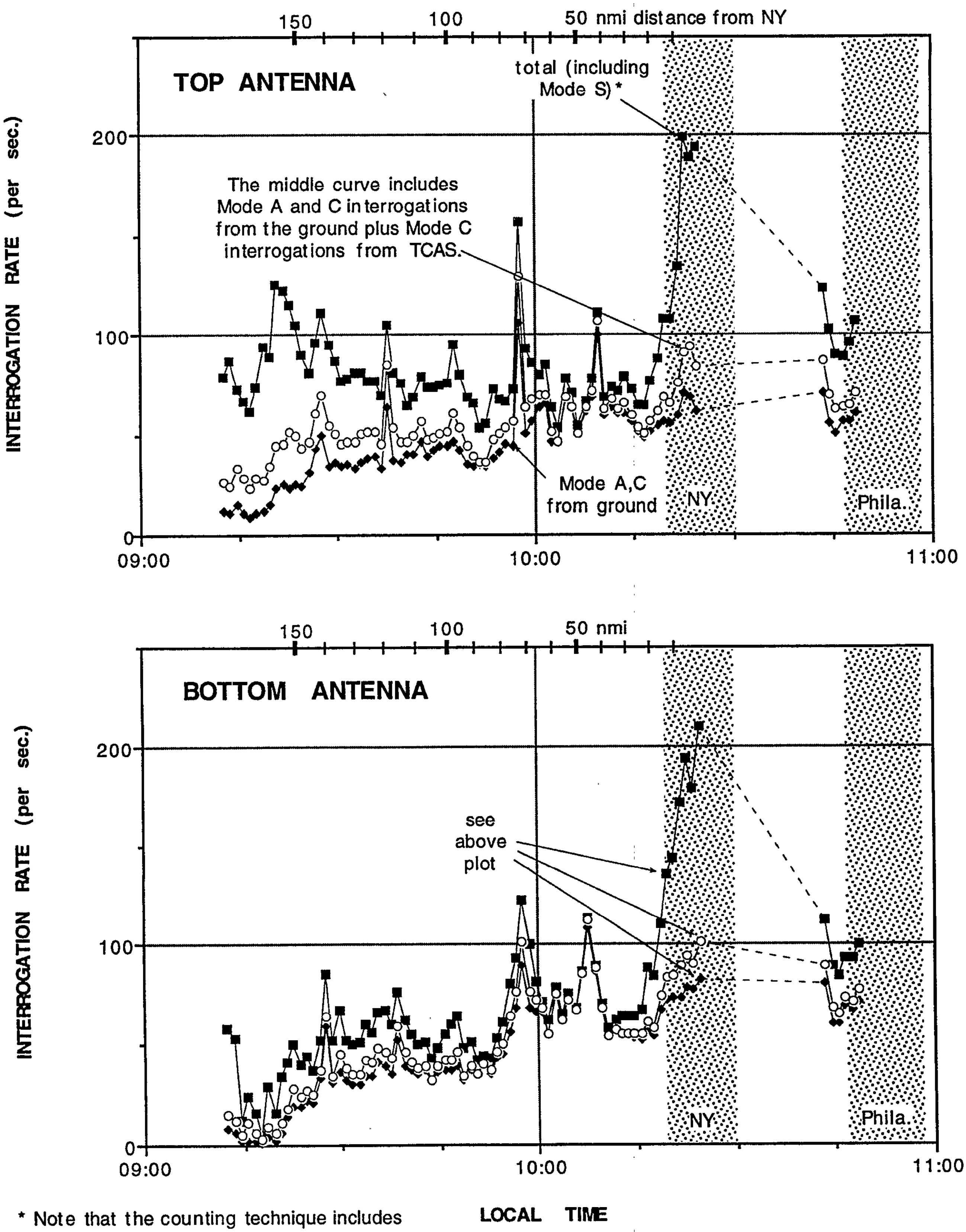


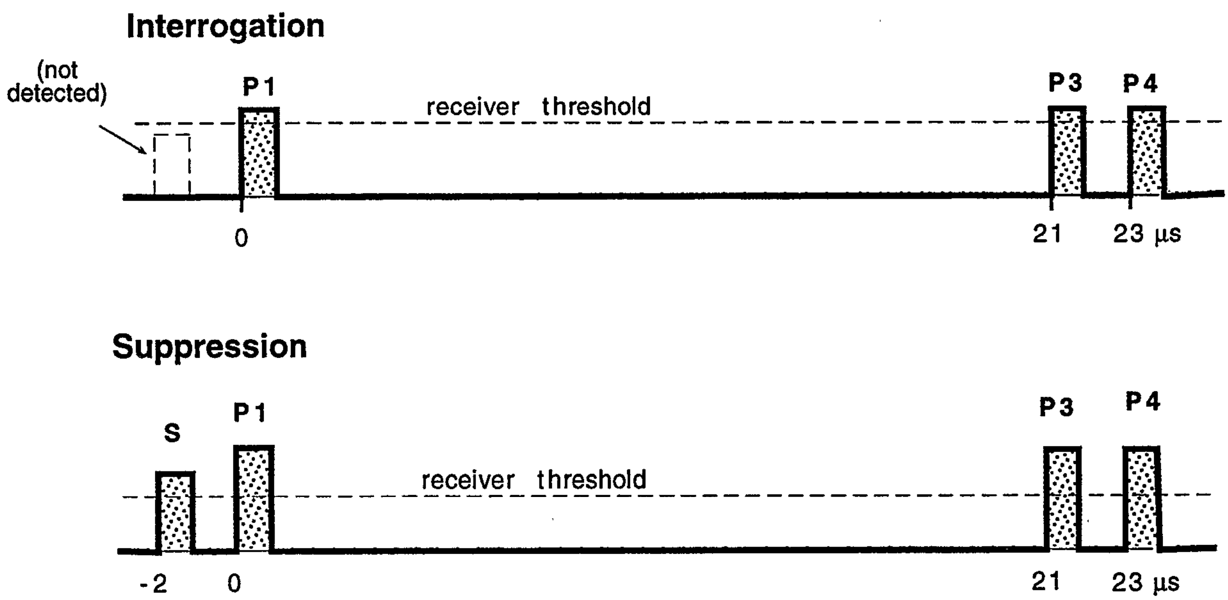
Figure 4. Total interrogations and suppressions received by the AMF.



* Note that the counting technique includes all interrogations, some of which would not elicit a reply (see page 3).

Figure 5. Interrogations of several types.

TCAS INTERROGATIONS AND SUPPRESSIONS



TCAS interrogations embody a technique called whisper-shout, which is the reason for including the S pulse. This technique is intended to reduce the number of replies to a single interrogation. TCAS transmits a sequence of interrogations, of increasing power levels. Each interrogation, other than the first, includes an S pulse whose purpose is to suppress all transnponders that have already replied to a weaker interrogation. To accomplish this, the S pulse is several dB weaker than the pulses that follow. When a transponder receives the S pulse above threshold, the pulse pair S and P1 are interpreted as a suppression pair (Ref. 11).

Note that the receiver threshold level affects the distinction between TCAS interrogations and suppressions. This reception would be an interrogation (upper plot) or suppression (lower plot) depending on whether the threshold is higher or lower.

Figure 6. Interrogations vs. suppressions.

This includes TCAS Mode C interrogations and suppressions and Mode S interrogations (assumed to be all from TCAS).

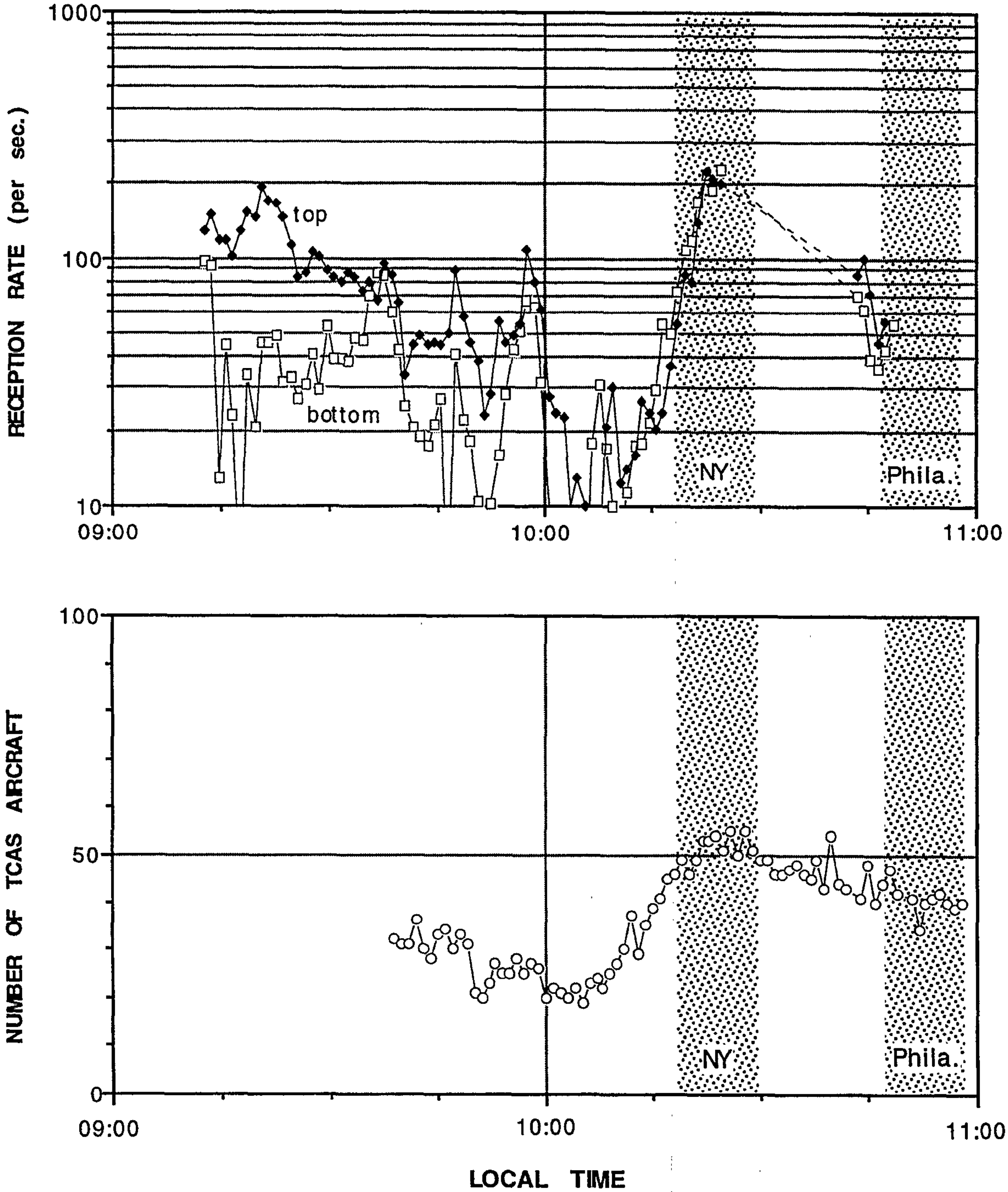
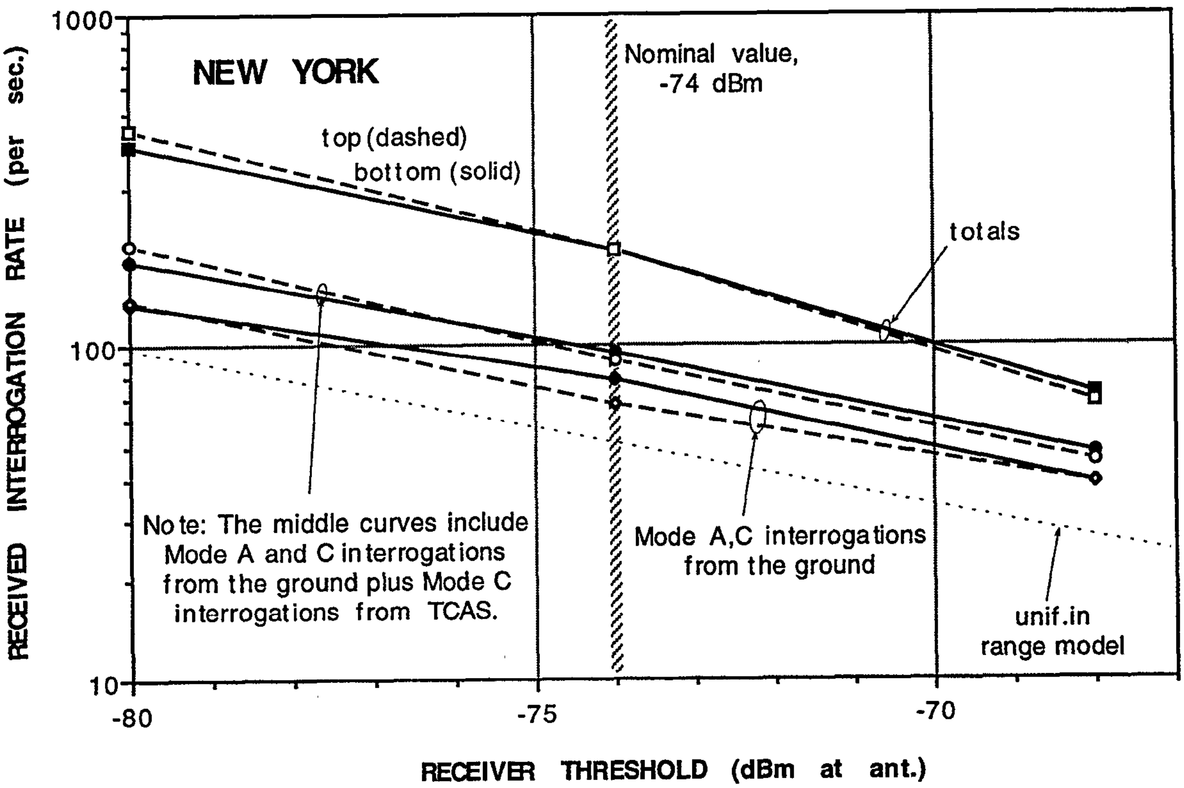


Figure 7. Total TCAS interrogations and suppressions received by the AMF.



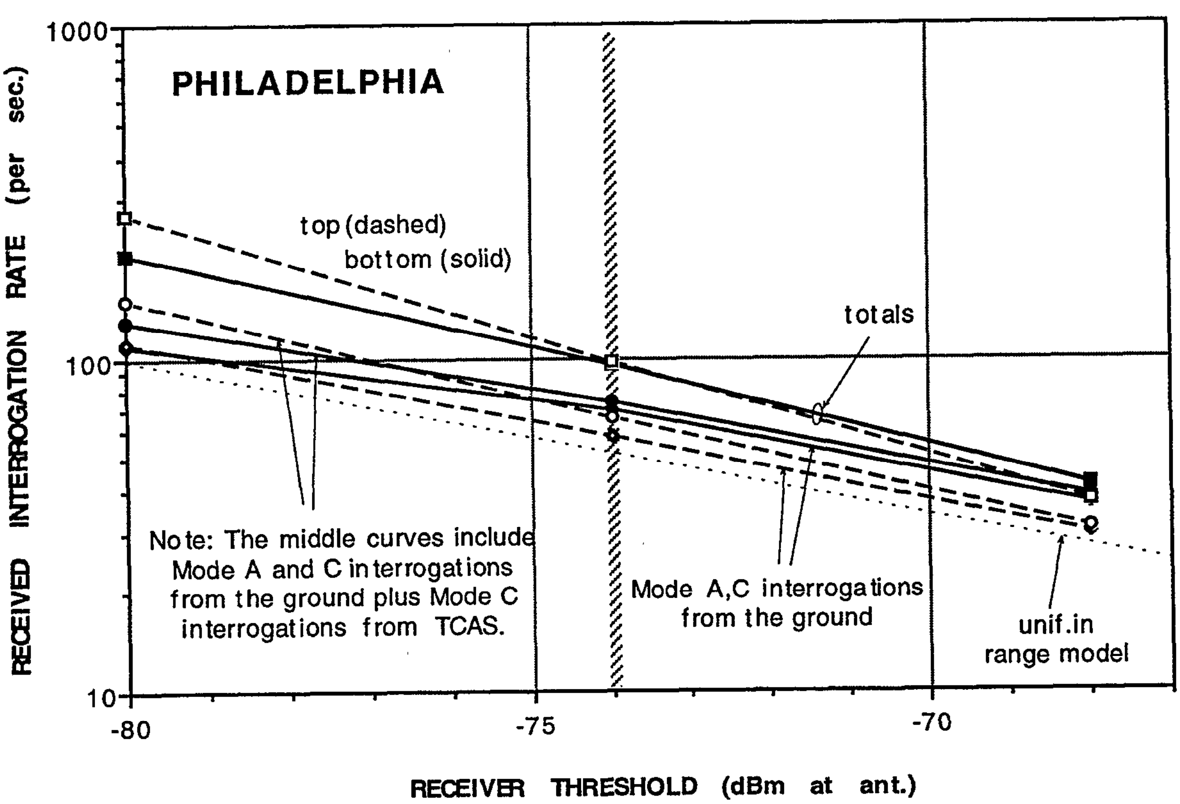
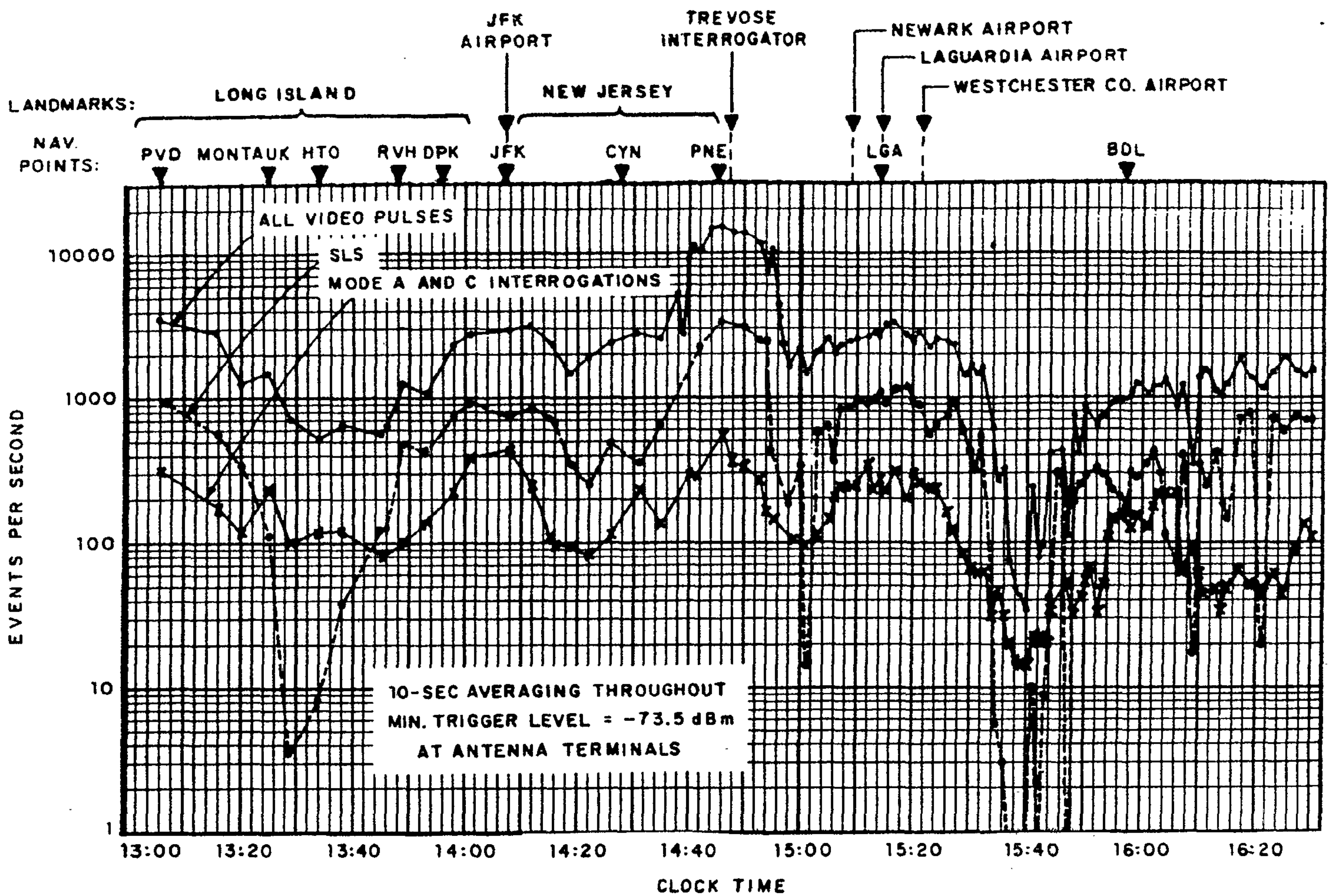


Figure 8. Power distributions.



Bottom antenna,
Minimum triggering level = -73.5 dBm at antenna,
Altitude, 6500 to 7500 ft.

Figure 9. Airborne measurements made in 1973.

Given that typical Mode A,C interrogators transmit at a rate of about 350 interrogations per sec. and that the mainbeam width is about 1 percent of 360 degrees, we would expect to receive an average of about 3.5 interrogations per sec from any one interrogator. Multiplying this by 20 interrogators, which is a reasonable number considering the line-of-sight visibility of an aircraft on the East Coast at an altitude of about 6000 ft, yields a total of 70 interrogations per sec. This is a rough estimate of the average interrogation rate a transponder would receive under nominal conditions. The fact that the 1973 measurements were so much higher than this rough estimate seems to indicate that unwanted sidelobe effects were predominating, and/or that some interrogators were operating with power levels much higher than necessary. These were the issues that the FAA addressed during the intervening years to try to improve the conditions in this band. The current measurements reported here are much more consistent with the rough estimate of interrogation rate. This comparison of past measurements with current measurements and a rough estimate of what rate to expect provides a good indication that the FAA's efforts have been very successful.

In the preliminary GPS-Squitter analysis given in [2], the model for present-day Mode A,C interrogations from the ground was 100 interrogations per sec. (See Reference [2], page 7). The AMF measurements plotted in Figure 5 indicate that was a valid and somewhat conservative model. The average interrogation rate is significantly less than 100 per sec.

3.2.1 Variation with Location

The data in Figures 4 and 5 indicate that both interrogation rate and suppression rate vary as a function of aircraft location, with suppression rate varying more widely. Presumably this is due to the fact that the suppressions are being received from shorter ranges, and therefore are dependent on the local density of interrogators, which is higher around major cities. The data also indicate that the suppression rate is higher on the bottom antenna. This also is consistent with the notion of suppressions coming from ground-based transmitters that are relatively near.

3.2.2 TCAS

TCAS Mode C interrogations are of interest in the GPS-Squitter development because they trigger replies which are a source of interference in the 1090 MHz band. In these measurements, the aircraft received TCAS Mode C interrogations at a rate of about 10 to 20 per second throughout the flight (Figure 5). TCAS standards for Mode C interrogations are intended to limit the total interrogation rate from all TCAS aircraft to approximately 40 per sec. (See Reference [10], Section 5.1.1.3). The AMF measurements are generally consistent with that rate and usually were somewhat less. The preliminary GPS-Squitter analysis was based on the TCAS standard of 40 per sec. See Reference [2], page 7.). The new measurements indicate that this is a valid and somewhat conservative model.

Note that the number of TCAS aircraft (Figure 7) varied mildly during the flight, reaching a peak of about 55 in New York. This appears to be a reasonable value.

3.2.3 Top and Bottom Antennas

Figure 5 indicates that Mode A and C interrogations from the ground were received over the top and bottom antennas at approximately the same rates. Both varied from low rates in Connecticut to higher rates around New York. This behavior seems consistent with the notion that the interrogations are transmitted from high-gain, narrow-beam antennas; therefore, they can be received over a long range; long range receptions arrive from a nearly horizontal direction, in which geometry the top and bottom antennas have approximately the same antenna gain.

On the other hand, the top and bottom antennas received different rates of Mode S interrogations, with the top antenna receiving a higher rate of interrogations than the bottom antenna when the aircraft was flying in low-density areas. This behavior seems consistent with the notion that the TCAS aircraft transmitting these interrogations were mostly flying higher than the AMF aircraft (which was at 6000 ft). When the AMF aircraft reached the high-density areas of New York and Philadelphia, the Mode S interrogation rate increased, and was approximately equal on top and bottom. This seems consistent with the lower altitudes of TCAS aircraft in the terminal areas. Looking more closely at the TCAS Mode C interrogations, note that for these, too, the bottom-antenna rate was lower than the top-antenna rate when flying in low-density areas and the top and bottom rates were approximately equal when flying in the terminal areas. The plot in Figure 7 shows similar behavior in the TCAS rates. All of these observations support our understanding of the mechanisms that control receptions of these various signal types.

3.2.4 Receiver Threshold

Figure 8 indicates that, as expected, received interrogation rates decrease as receiver threshold is raised. Following are two simple models that can be used for comparison with the measured rates.

Suppose receiver threshold were reduced by 6 dB. This would increase the reception range by a factor of 2, which would increase the reception area by a factor of 4. If the signals were originating from a large number of transmitters uniformly distributed in area, then the total number of transmitters within reception range would increase by a factor of 4, and the reception rate would also increase by that factor. An alternative model that is more appropriate for a location like New York or Philadelphia is that the transmitters are concentrated near the center, having a uniform-in-range distribution. For this model, the reduced threshold would increase the number of transmitters by a factor of 2. Generalizing this behavior for any amount of change in receiver threshold, the two models can be summarized as follows.

Uniform-in-area distribution:	Rate changes by 4:1 for each 6 dB change.
Uniform-in-range distribution:	Rate changes by 2:1 for each 6 dB change.

Both models would appear as straight lines in Figure 8, which is a log-log plot. Comparing the measured data with these models, notice that the measurements generally agree with the uniform-in-range model. The plotted rates vary approximately linearly with threshold (in the log-log plot) and with a slope that is approximately 2:1 per 6 dB. This seems reasonable, in view of the fact that the data in this figure apply to the high-density areas of New York and Philadelphia.

4. AIRBORNE MEASUREMENTS IN OTHER LOCATIONS

4.1 PHILADELPHIA—NORFOLK

Data recorded by the AMF while the Cessna 421 was flying between Philadelphia and Norfolk (1 August 1994) is plotted in Figures 10 through 13. These plots are in the same form as the data described above. It can be seen that rates rose to a peak in the Baltimore-Washington area, and that most of the features and trends noted in the earlier data were evident here too.

4.2 ATLANTA

Figures 14 through 17 show the flight path in the Atlanta area and the interrogation and suppression rates measured there. As shown in Figure 14, the AMF aircraft flew a landing approach to Atlanta International Airport, passing over the airport at very low altitude, and then climbed and departed toward the northwest. A zoomed-in plot of the aircraft path in Figure 14 shows that the aircraft passed directly over the north runway. The measured rates are plotted in Figures 14 - 17 in the same formats as discussed above.

In many respects, these results are consistent with the New York, Philadelphia, Washington data given above. The rate of Mode A,C interrogations from the ground was less than 100 per sec most of the time, but did exceed this briefly right at the airport.

Note that the rate of Mode A,C interrogations from ground-based interrogators exhibited a pronounced peak at the airport in Atlanta (Figure 16) and also in Baltimore (Figure 12). The shapes of the curves indicate that these increases were caused by interrogators located at or near the airports. Conceivably, this peaking could be caused by sidelobe punch-through, that is, distortions in the sidelobe suppression pulse patterns causing conversions of sidelobe suppressions into interrogations. Bearing in mind that an interrogator mainbeam is typically about 1 percent of the 360-degree scan, we see that when an aircraft is near enough to receive the sidelobes, it is being exposed to suppressions at a rate of about 100 times the average rate of interrogations. If even a small percentage of these suppressions are converted to interrogations, this can cause a significant increase in the interrogation rate. If a given peak in interrogation rate is arising from a single Mode A,C interrogator, then we would expect that conversion of that ground station to a Mode S interrogator would cause the interrogation rate to be reduced by a factor of about 3 or 4 (the factor by which the repetition rate is reduced). Another possible cause of the interrogation peak might be ramp testers at the airport. These are lower power interrogators used for checking transponder performance on the ground. Although these are supposed to be operated at very low power level, and would not reach airborne aircraft, it is worth considering the possibility that these may in some cases have an effect. A third possible cause might be experimental equipment.

4.3 DALLAS FORT WORTH

Figures 18 through 21 show the interrogation and suppression rates measured by the AMF in the vicinity of Dallas Fort Worth. As shown in Figure 18, the AMF flew at a constant altitude of 11,000 feet, while approaching the DFW airport from the northeast, flew nearly directly over the airport, and then flew away to the northwest. The plots that follow are in the same format as used above.

These results are generally consistent with the results from New York, Philadelphia, Washington, and Atlanta. In particular, the Mode A,C interrogations from the ground do not exceed 100 per sec, and the rate is substantially lower everywhere except very near the airport. Also, the TCAS Mode C interrogations (the source of TCAS Mode C fruit) are consistently less than the nominal value, 40 per sec.

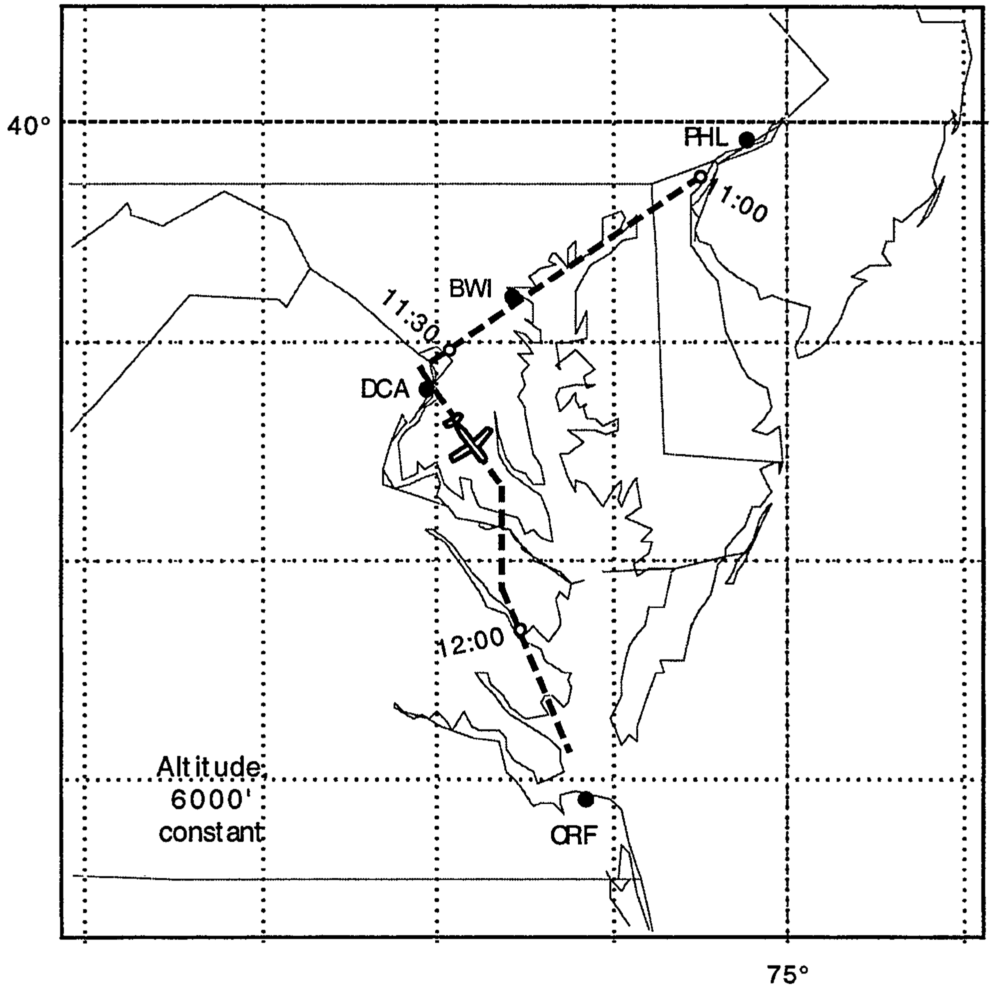


Figure 10. Flight path (Washington).

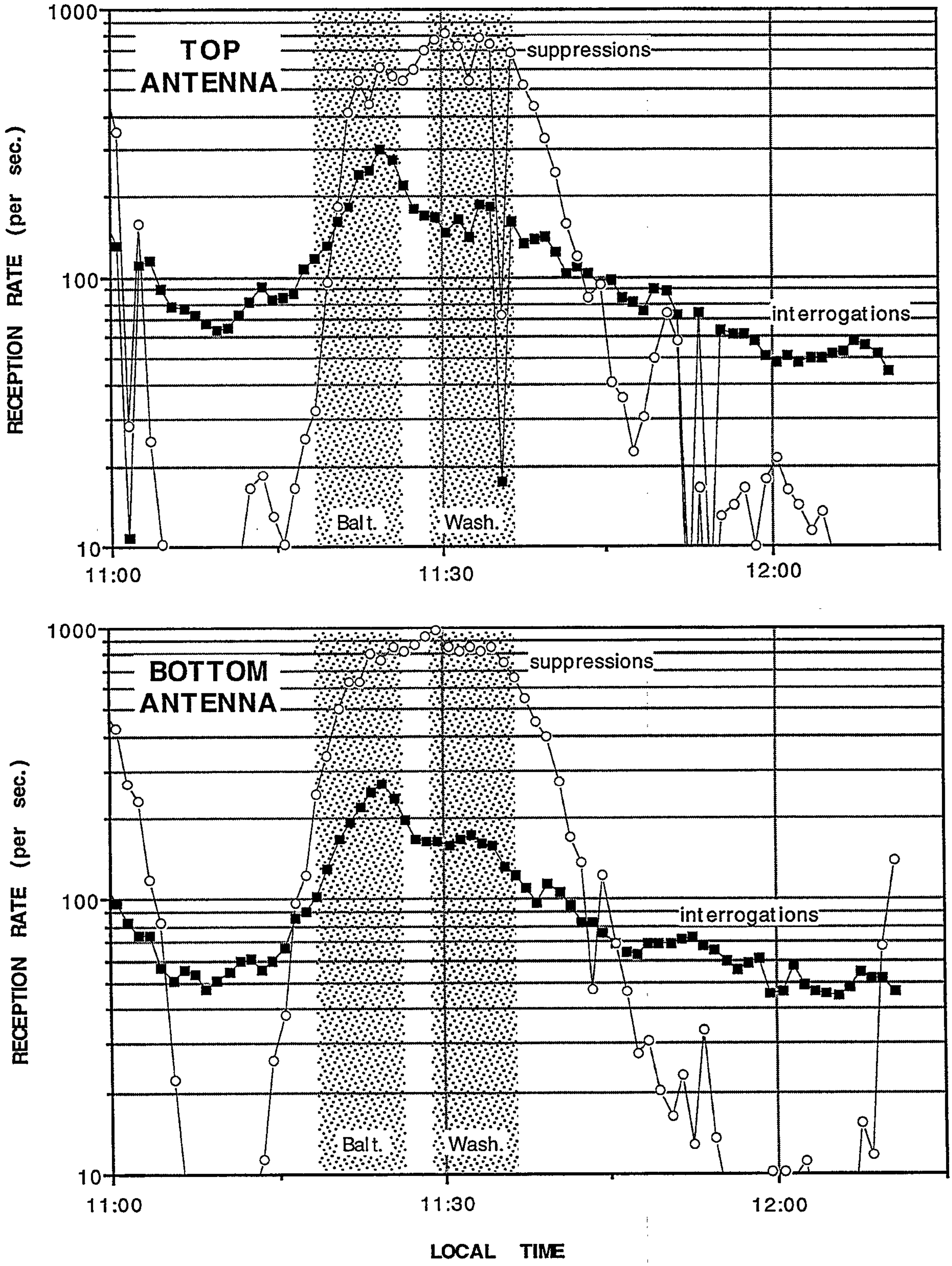
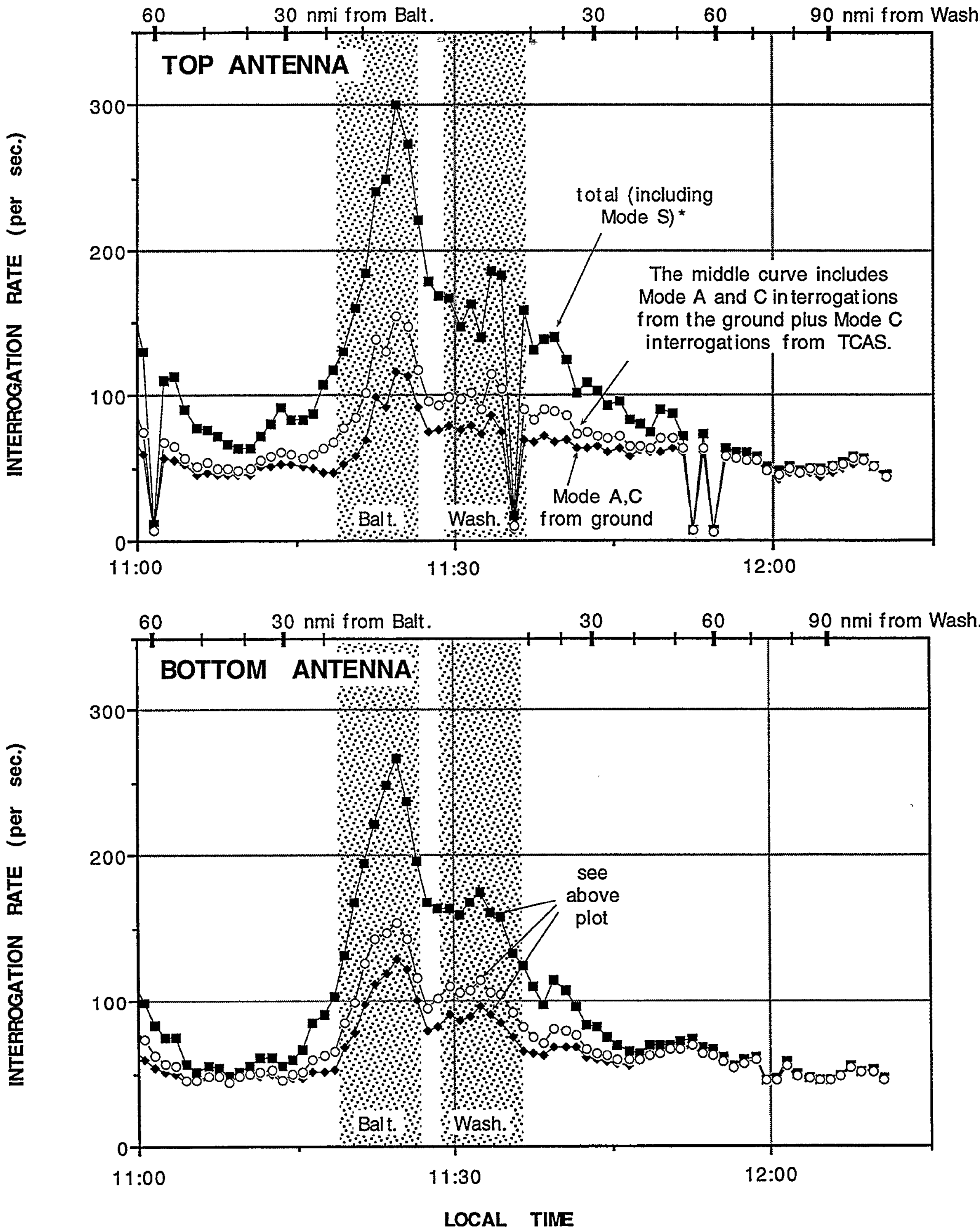


Figure 11. Total interrogations and suppressions received by the AMF (Washington).



*Note that the counting technique includes all interrogations, some of which would not elicit a reply (see page 3).

Figure 12. Interrogations of several types, Washington.

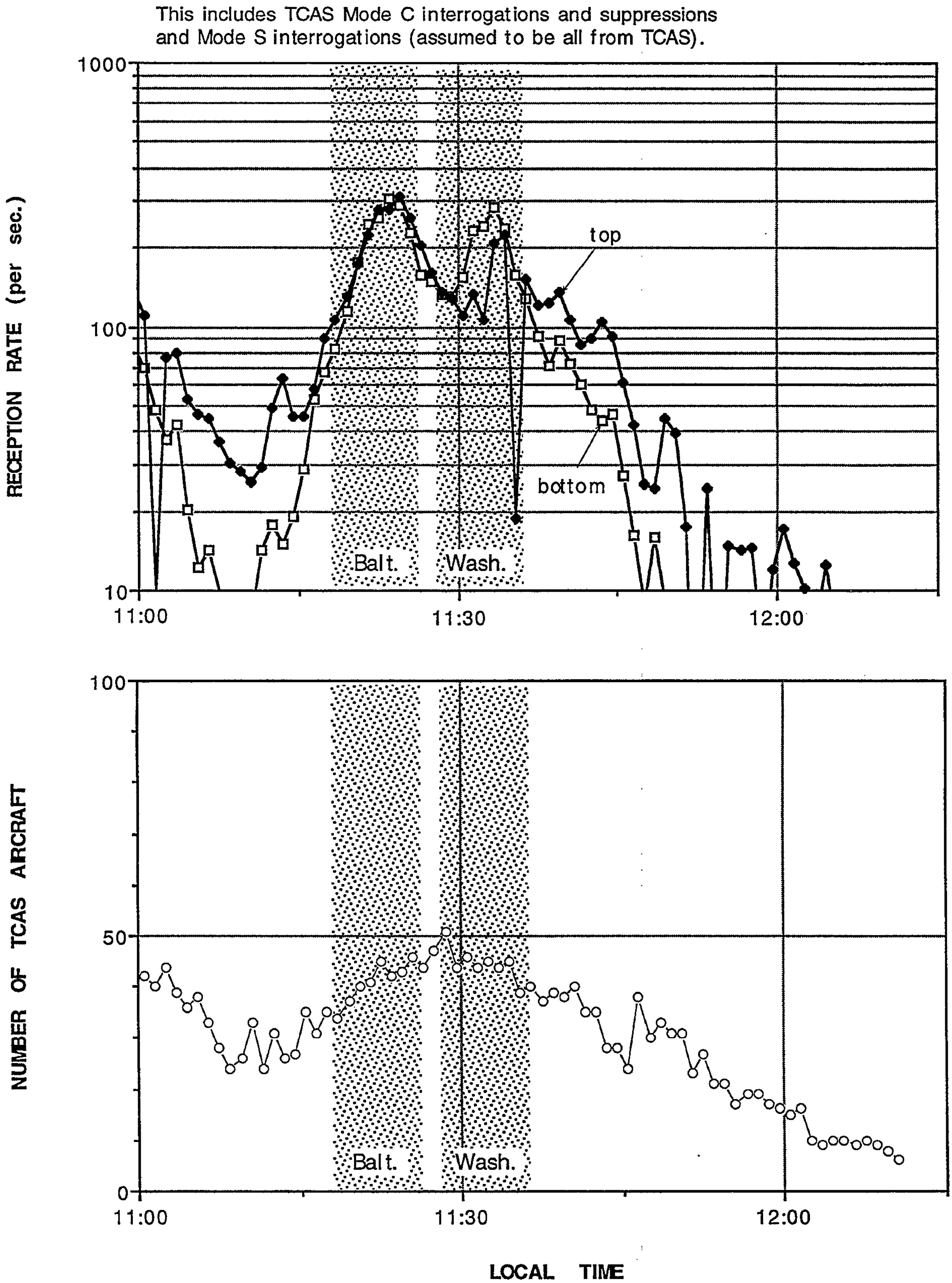


Figure 13. Total TCAS interrogations and suppressions received by the AMF, Washington.

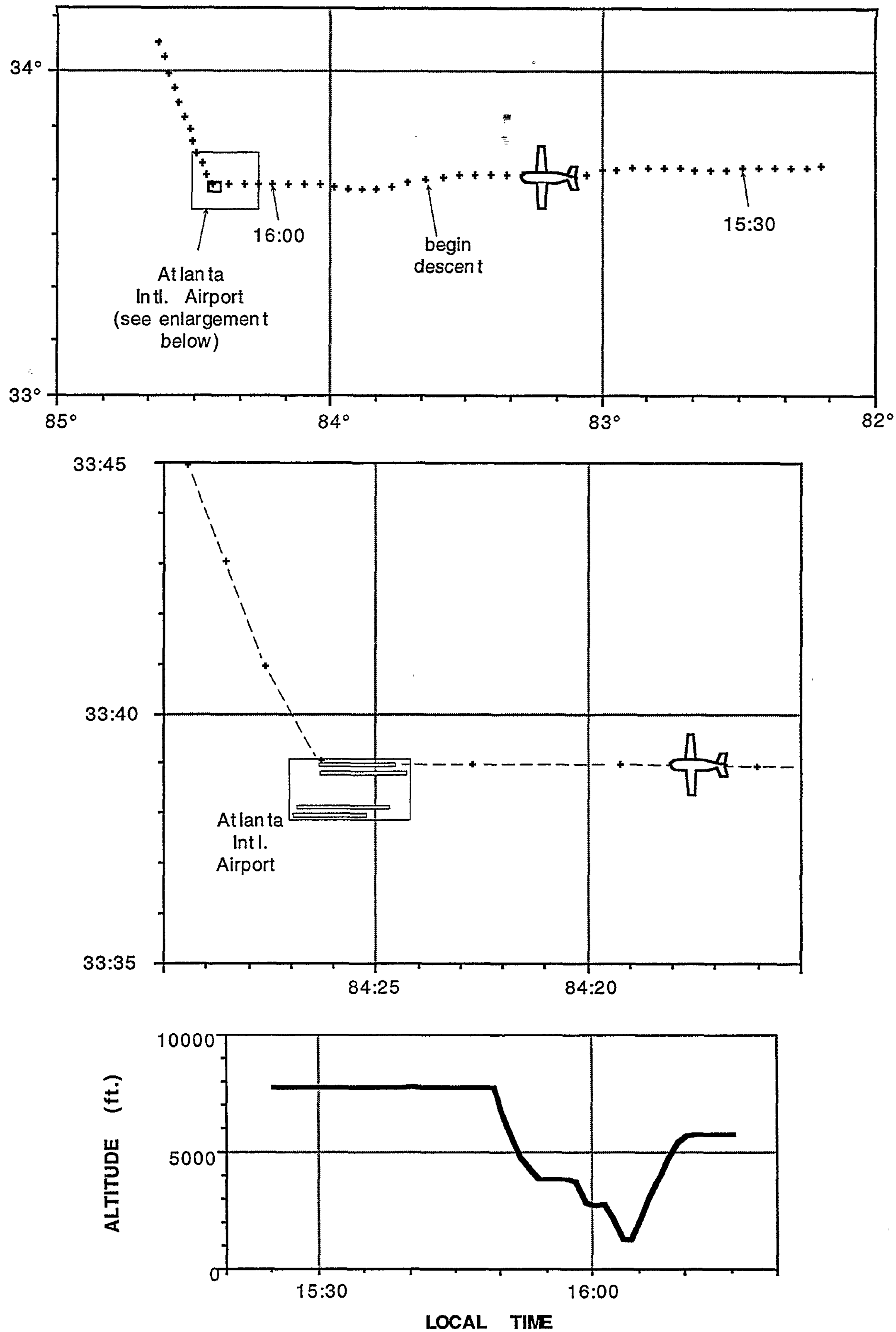
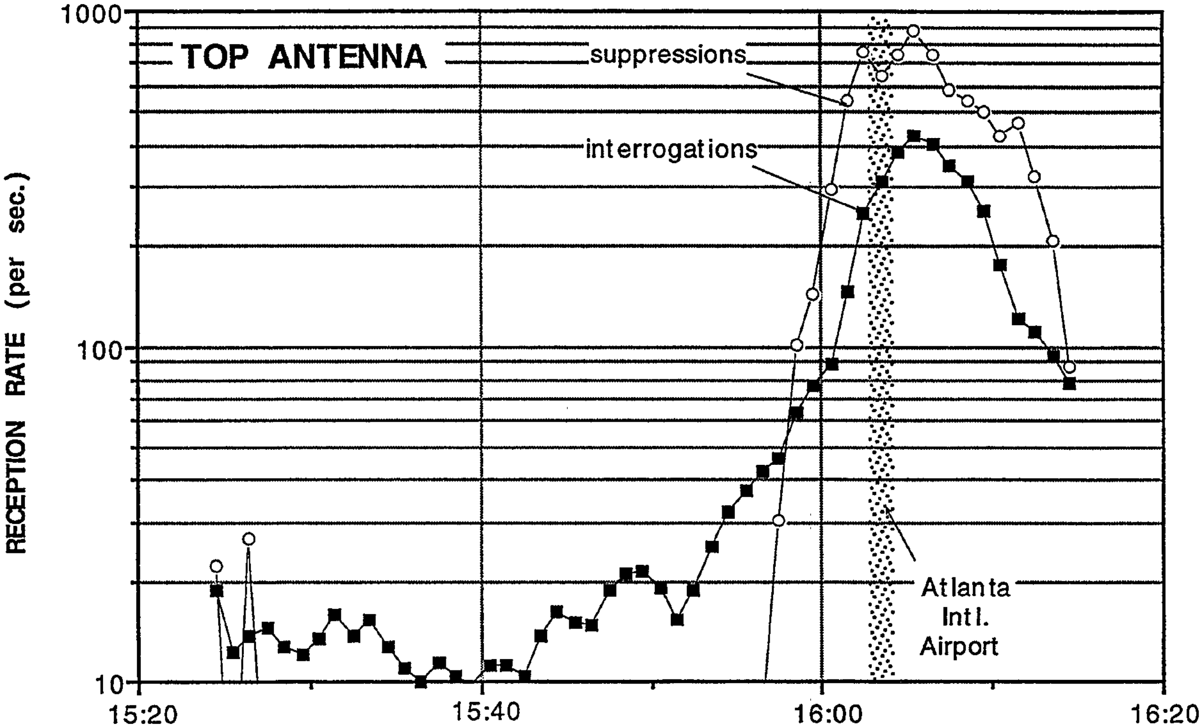


Figure 14. Flight path (Atlanta).



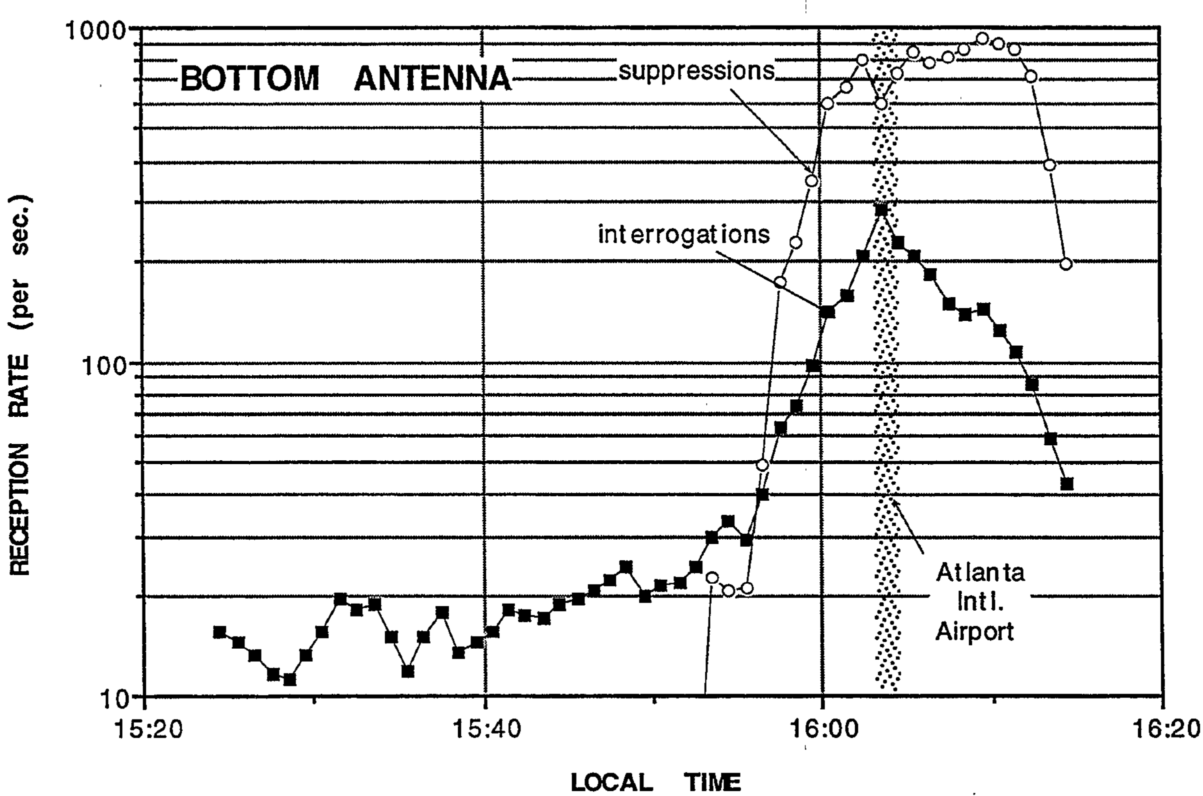
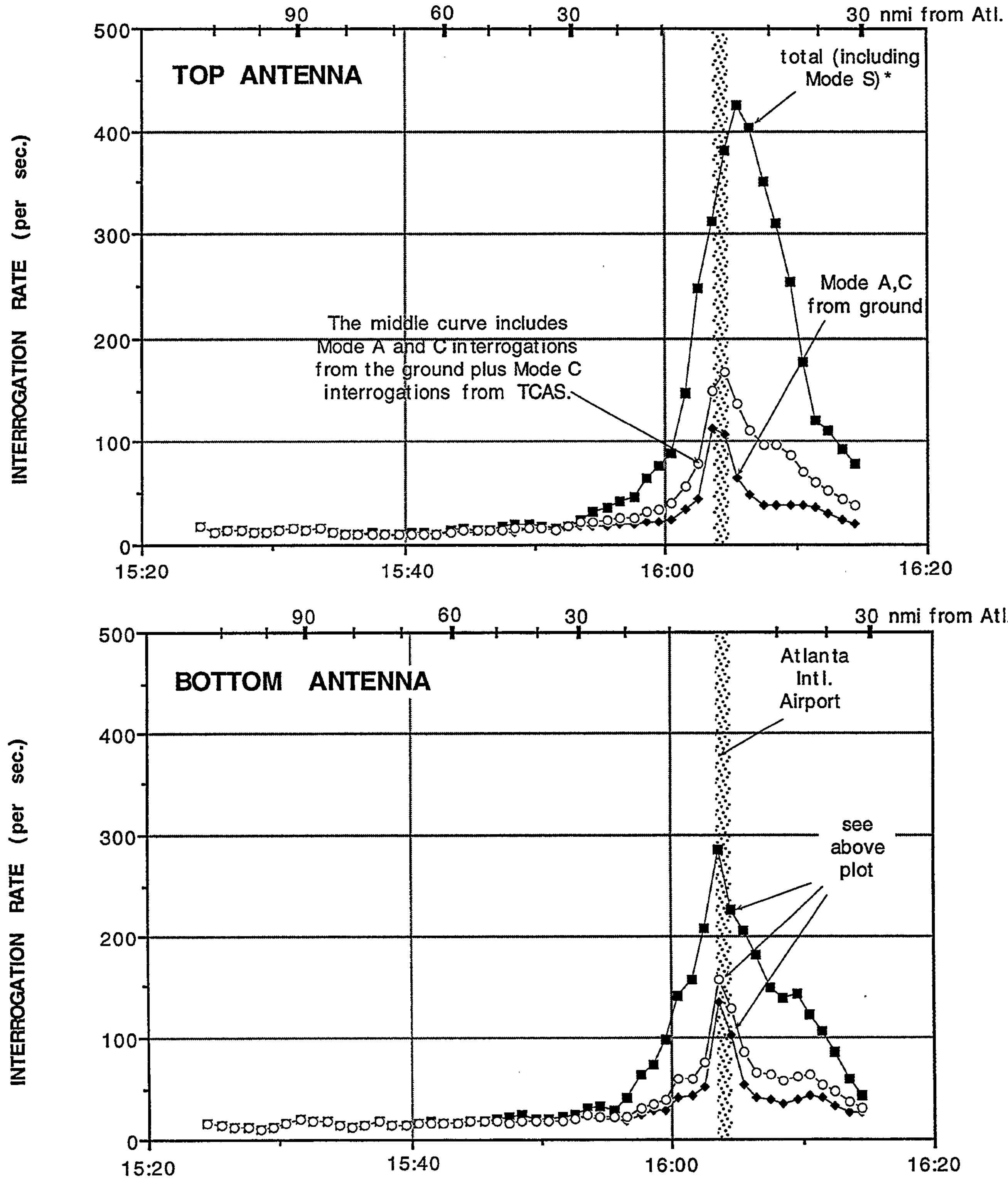


Figure 15. Total interrogations and suppressions received by the AMF (Atlanta).



LOCAL TIME

*Note that the counting technique includes all interrogations, some of which would not elicit a reply (see page 3).

Figure 16. Interrogations of several types, Atlanta.

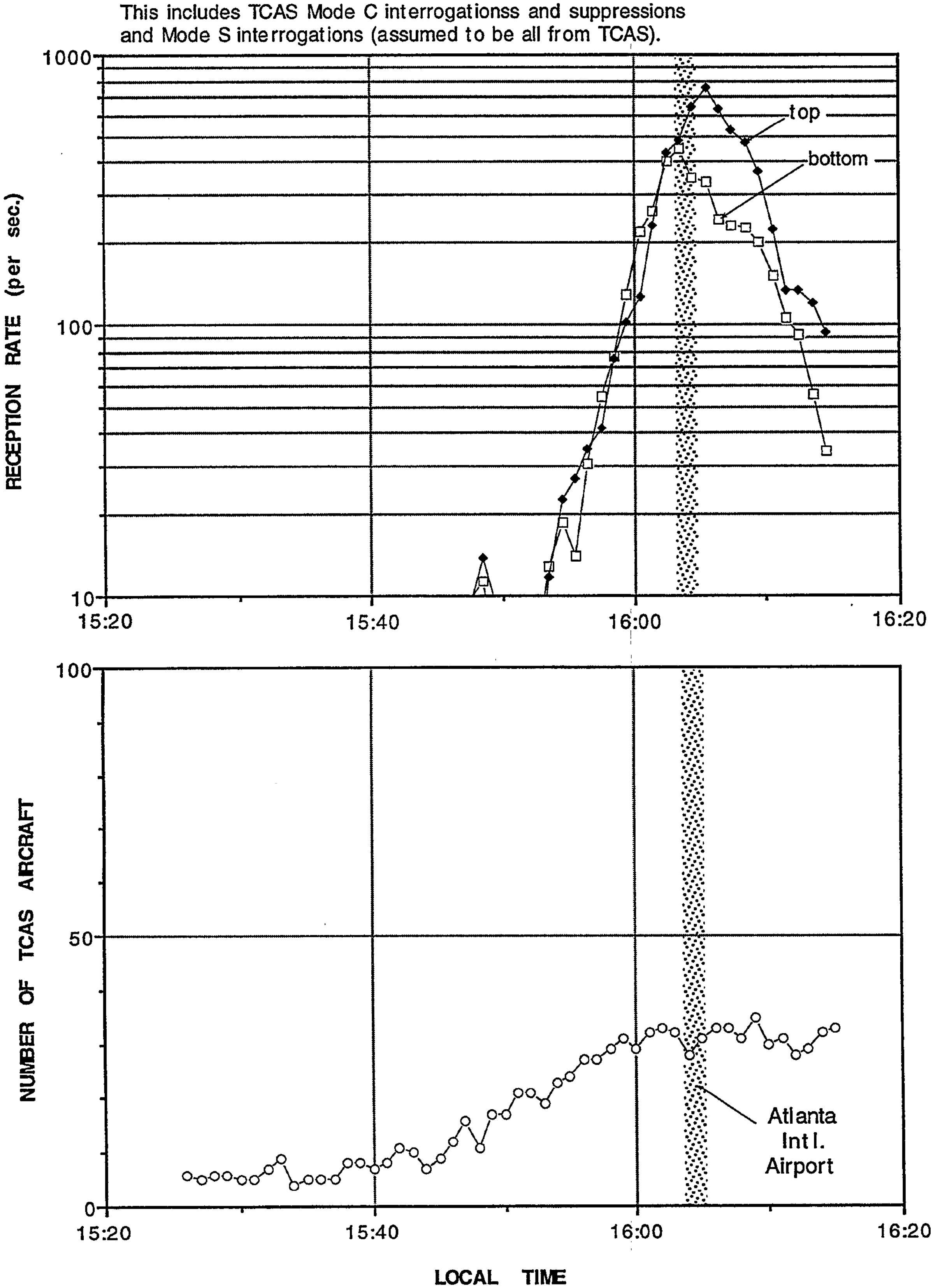


Figure 17. Total TCAS interrogations and suppressions received by the AMF (Atlanta).

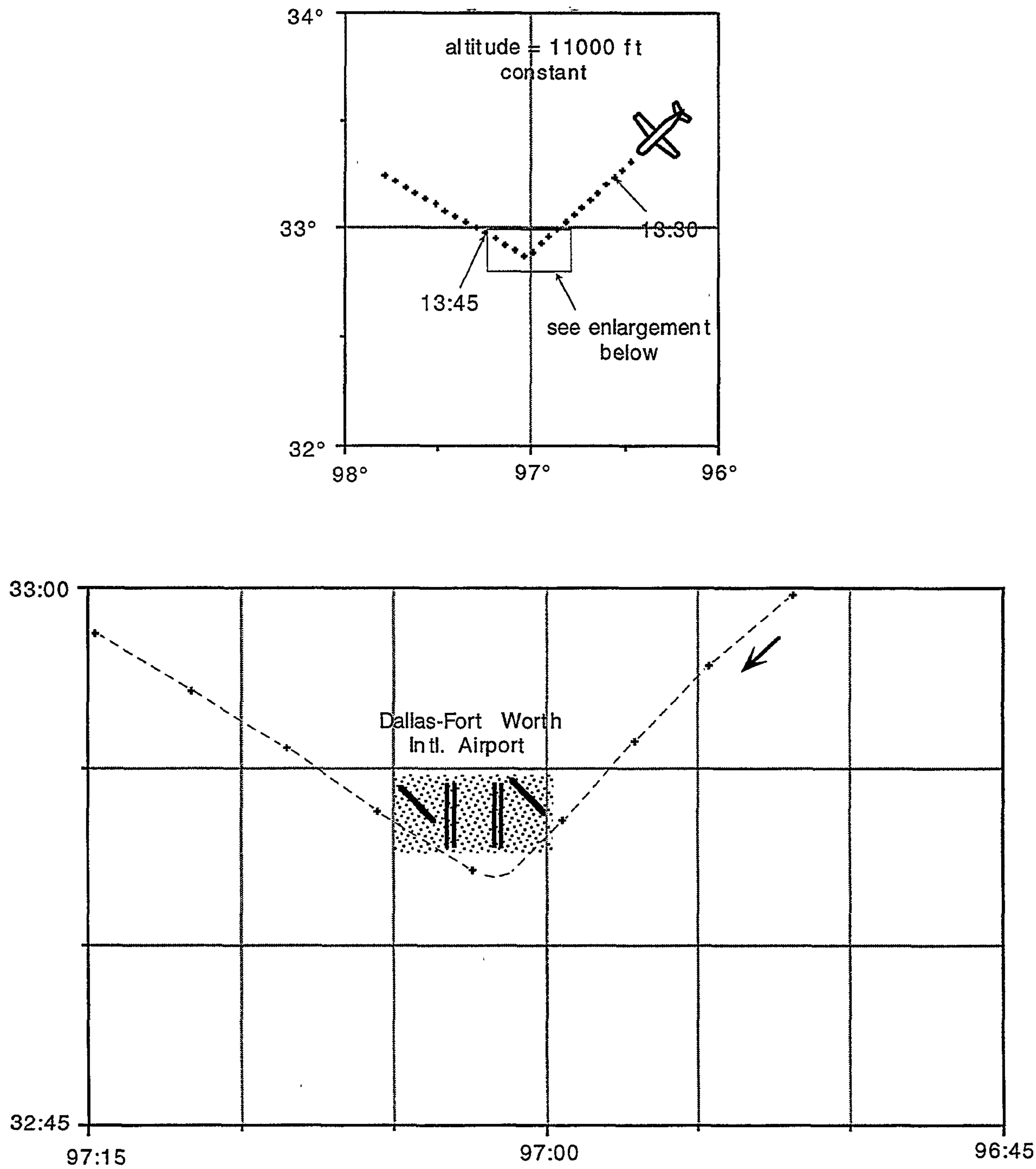


Figure 18. Flight path (Dallas).

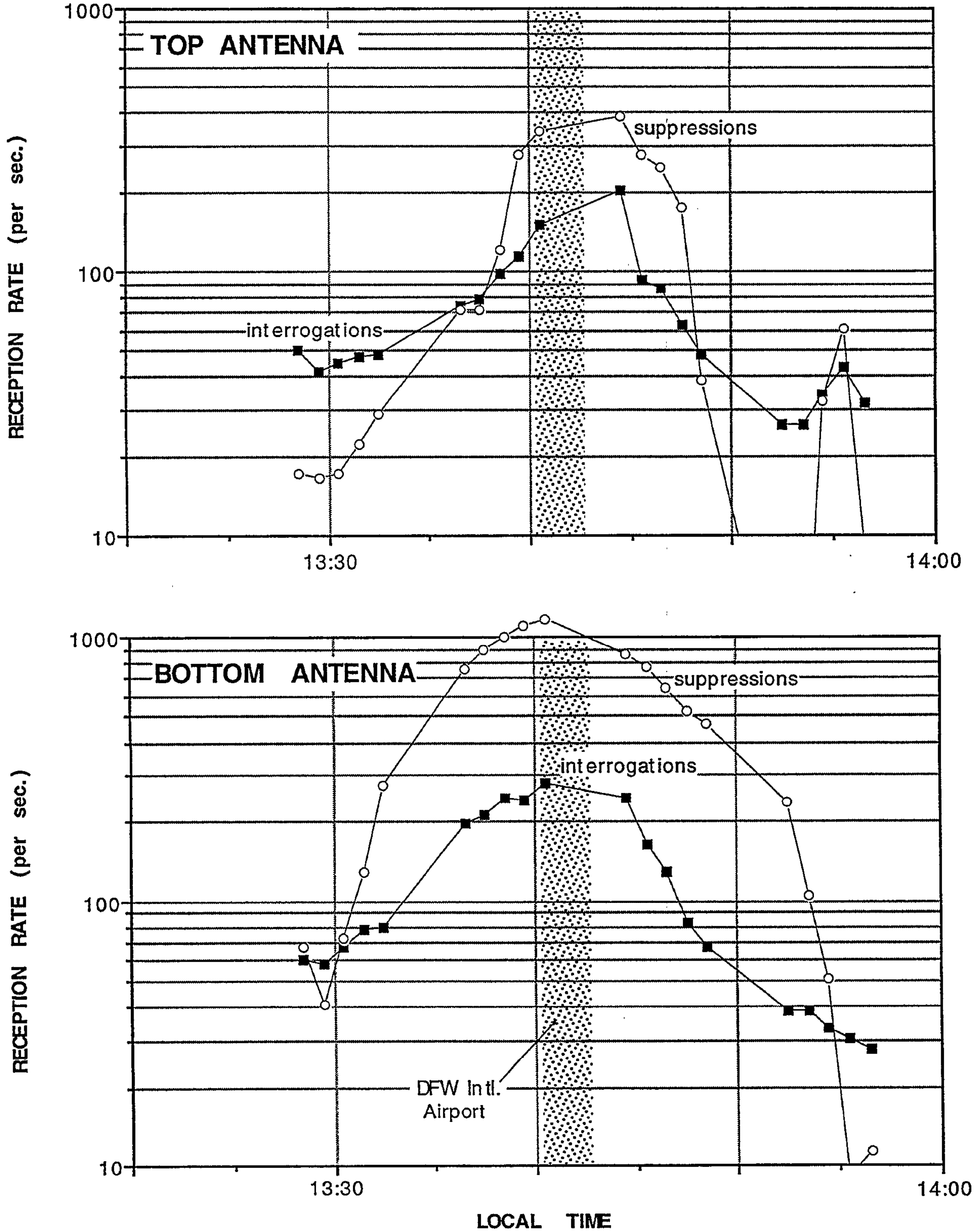
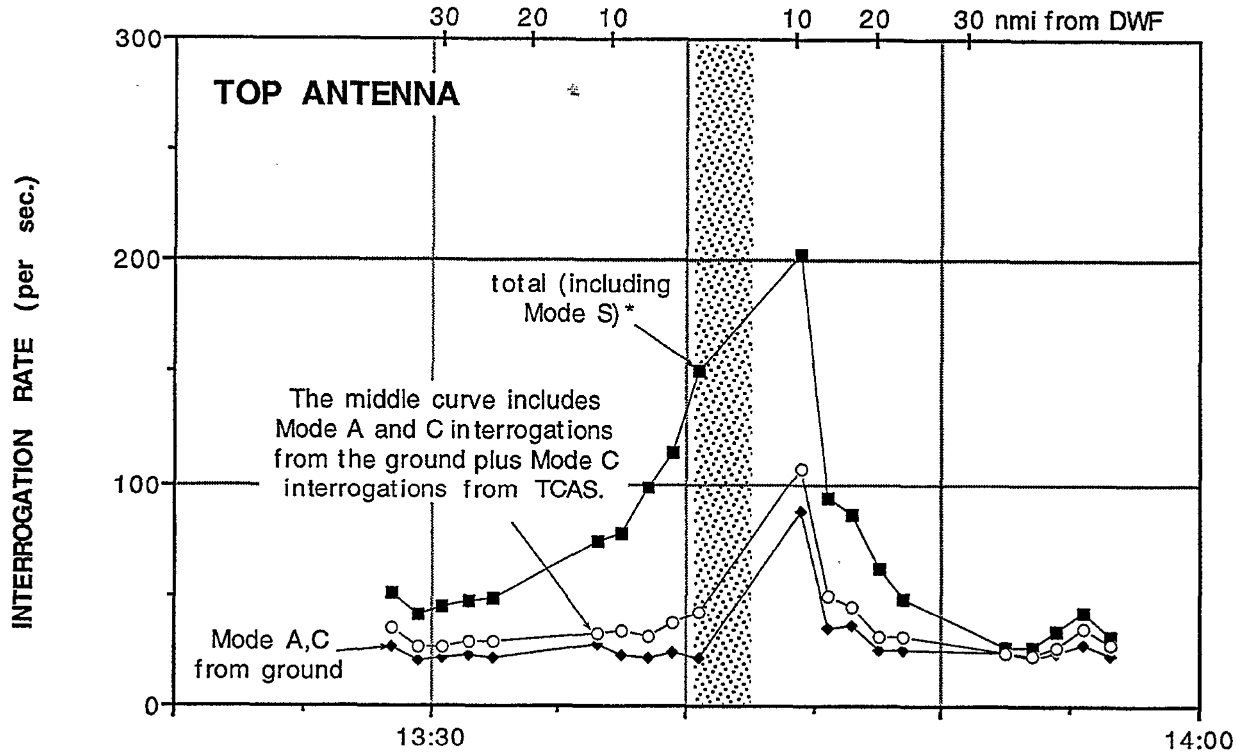
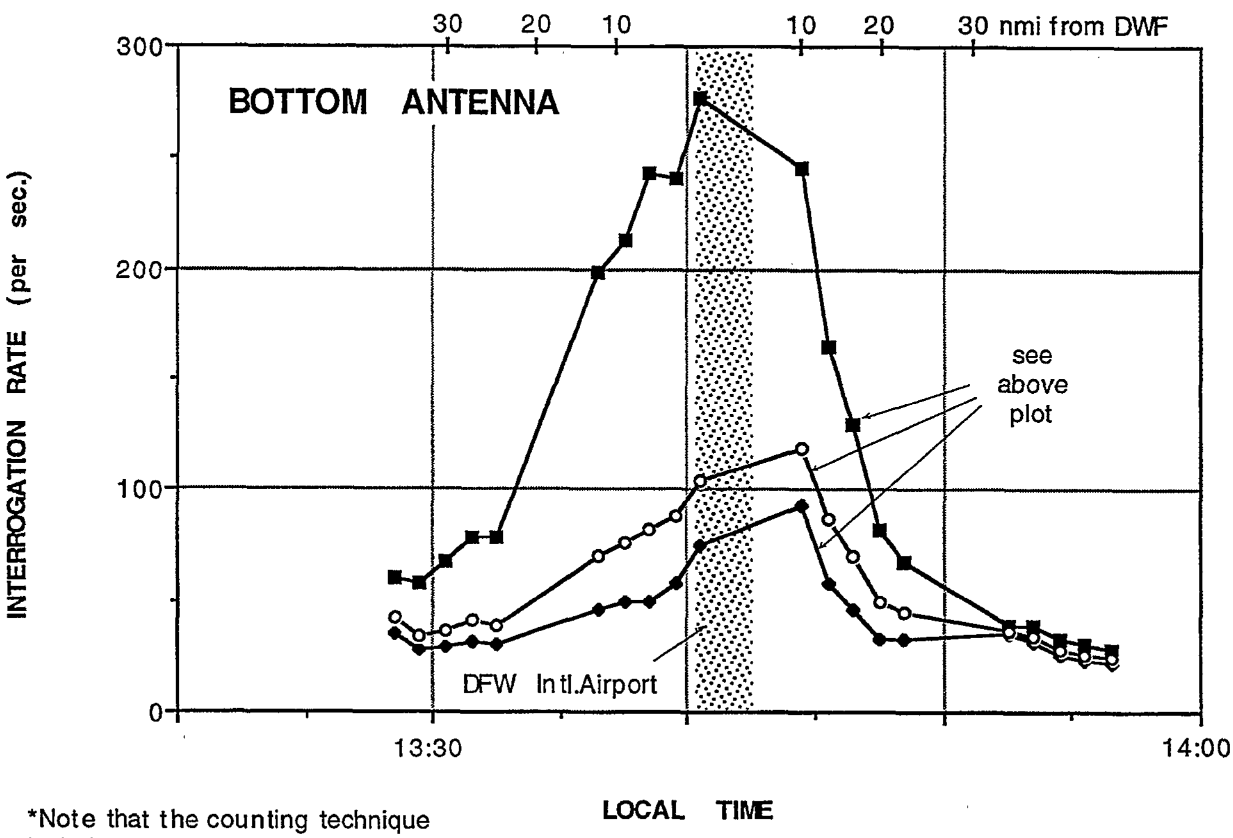


Figure 19. Total interrogations and suppressions received by the AMF (Dallas).





*Note that the counting technique includes all interrogations, some of which would not elicit a reply (see page 3).

Figure 20. Interrogations of several types, Dallas.

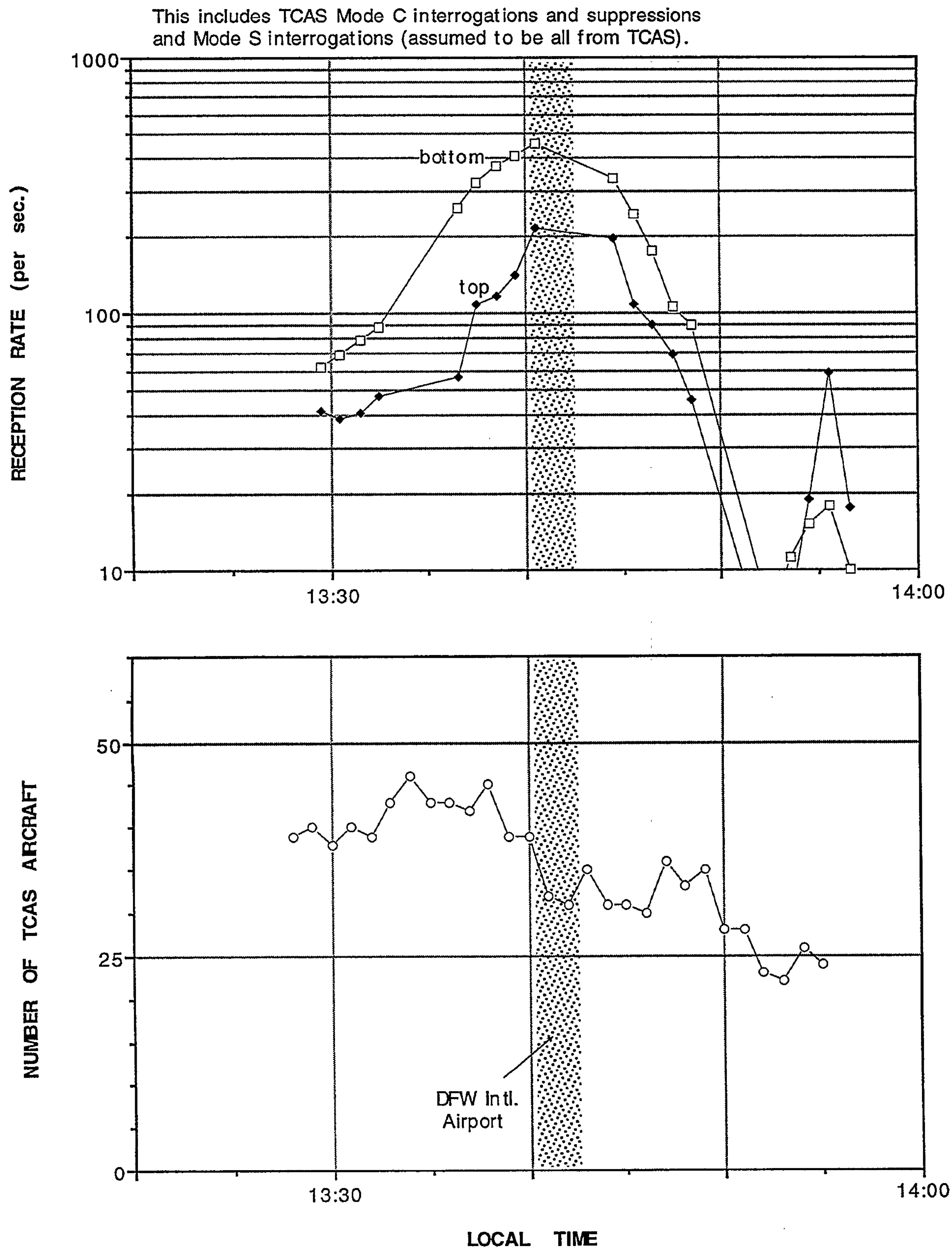


Figure 21. Total TCAS interrogations and suppressions received by the AMF (Dallas).

5. CONCLUSIONS

The measured rates of interrogations and suppressions are consistent from location to location in most respects. The rates of Mode A,C interrogations from the ground were consistently less than 100 per sec, except for brief periods near Baltimore and Atlanta. These results confirm the expectation, mentioned in Section 1, that these rates have decreased with time since the early 1970's. It seems likely that we are seeing the benefits of the efforts that have been made by the FAA and others to improve the operating practices of radars that use the 1030 MHz band.

In the preliminary GPS-Squitter performance analysis [2], the model for calculating Mode A,C interrogations from the ground is a constant 100 per sec. For surveillance of airborne aircraft in either a terminal area or enroute, performance depends on the interrogation-rate average over a large area. The AMF measurements indicate that the average is consistently less than 100 per sec. Therefore, the measurements validate the model that was used, and indicate that it is somewhat conservative.

Essentially all of the observations made in connection with the Bedford to Philadelphia data (Section 3.2) also apply to the measurements in the other locations. Interrogation rates are more constant as a function of location than suppression rates, presumably because interrogation is a long-range phenomenon. Suppression on the other hand is a short-range phenomenon that varies, therefore, according to the number of interrogators in the near vicinity. Suppression rates also tend to be higher on the bottom antenna than the top, and presumably for the same reason.

The Mode C interrogation rate from TCAS aircraft has been found to be consistently less than 40 per sec in all of the locations. This value, 40 per sec, was used as the model for this effect in the GPS-Squitter performance analysis [2]. The measurements validate this model, and indicate that it is somewhat conservative.

The number of TCAS aircraft (Figures 7, 13, 17, and 21) rose to approximately 50 in each of the high-density areas tested. The overall maximum value seen was 55 TCAS aircraft, which occurred at New York.

The overall conclusion, after having examined 1030 MHz interrogation and suppression rate measurements in a number of locations, is that the measurements appear to be reasonable and not substantially different from the expectations. These expectations were based on prior measurements, and a general trend of diminishing interrogation rates. Finally, the models used for assessing GPS-Squitter interference effects are found to be reasonable and somewhat conservative.

GLOSSARY

AMF	Airborne Measurement Facility
DWI	Dallas, Fort Worth International Airport
FAA	Federal Aviation Administration
GPS	Global Positioning System
MHz	MegaHertz
MIT	Massachusetts Institute of Technology
MTL	Minimum Triggering Level
P1, P2,...	Pulses in an interrogation (see Figure 2)
TCAS	Traffic Alert and Collision Avoidance System

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