ACTS PROPAGATION EXPERIMENT

Preprocessing Software User's Manual

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Overview for Experimenters

This manual includes by reference the earlier Radiometer Calibration Report of November, 1994, the Preprocessing Software Version 4 report of February 1995 and the README.TXT files provided with the software revisions made available since February 1995. The major changes to the preprocessing software since version 4 were 1) to make the preprocessing software more robust, 2) to make the preprocessing operation user friendly by including all the information required for radiometer system calibration in log files that are read whenever a day is processed or reprocessed, 3) to include a procedure for marking "bad" data, 4) to include modifications to the preprocessing software output (the .pv2 file to replace the .pv1 file - the .xxx notation is to identify the file type extensions used by the DOS operating system on an IBM compatible personal computer) that enables a user to recover the raw data (.rv0 data) from the output file (.pv2 file), and 5) to provide the minimum required output data for the experiment in the output files (.pv2, .edf, log, .srf, .rtn, and .dfc files). The histogram output (.edf file) contains the monthly histograms of attenuation, rain rate, fade duration and inter-fade interval that comprise the required output for each month for the ACTS Propagation Experiment. In addition, version 66 of the ACTS Preprocessing Program (Actspp) generates histograms of total attenuation averaged over a minute (i.e. attenuation relative to free space), attenuation relative to the clear sky averaged over a. minute, sky temperature averaged over one minute and the standard deviations of attenuation calculated for one minute.

'l'he contract between NASA Lewis and the experimenters specifies that the minimum output required from each experimenter includes the monthly and annual distributions of total attenuation at the 20 and 27 GHz frequencies employed in this experiment and the monthly and annual distributions of one minute averaged rain rate. This output is to be provided in two different formats, the digital data files to be archived at the University of Texas (the .pv2, .edf, .log, .srf, .rtn, .dfc, and .edf files), and a report containing plots and tables of the monthly and annual empirical distribution functions for attenuation and rain rate. To assist experimenters, the University of Oklahoma (OU) has provided Microsoft Excel 5 macros that compile the required empirical distribution functions (edf's - cumulative distributions of the observations) plots and tables from the .edf files. The macros are available via ftp from Dave Westenhaver's ftp server: anonymous@ftp.crl.com. Section 6 in this user's manual describes their use.

The ACTS propagation terminal provides simultaneous beacon receiver and radiometer output data at the two beacon frequencies, 20.185 and 27.5 GHz. These data are combined in the preprocessing program to provide estimates of the total path attenuation relative to free space between ACTS and the propagation terminal. **The beacon histogram output (.edf file) and the beacon attenuation time series (.pv2 files) are obtained from the combined beacon plus radiometer observations. The** radiometer data are used to establish the reference power level for the calculation of beacon attenuation; the beacon data are used to determine the change in power level from the reference value and effectively extend the dynamic range of the radiometer observations. **Output for the combined beacon plus radiometer observations (labeled beacon) are provided to satisfy the requirement to produce total path attenuation measurements. The** radiometer data are output separately (labeled radiometer) only for use in verifying radiometer system calibration.

The preprocessing program provides daily summaries of the significant observations on a minute-by-minute basis (one-minute averages and standard deviations). This output is the daily sum file. This output is for use by the experimenter and is not archived at the University of Texas (UT). For the beacon (plus radiometer) attenuation data, the standard deviation of the beacon signal levels (in dB), the maximum value in a minute, and the minimum value in a minute are also provided. These outputs can be used to separate scintillation effects from the more slowly varying processes that contribute to attenuation. The radiometer derived attenuation values are also reported as minute averages and standard deviations within a minute. The latter can be used to identify periods with rain and/or clouds.

The attenuation relative to clear-sky conditions (total attenuation minus gaseous absorption) cannot be obtained from the beacon and radiometer observations alone. To assist the experimenter, the sum files contain gaseous absorption estimates derived from surface meteorological data. These estimates are accurate to within 0.2 dB if the surface measurements are correct. The surface data input files (.srf) are used to provide surface data to the preprocessing program when the performance of the sensors provided with the propagation terminal is in doubt. Correct surface data are also needed to generate attenuation estimates from the radiometer observations because the preprocessing program uses the surface data to estimate the medium temperature required for the calculation of attenuation. Finally, the gaseous absorption estimates are used in radiometer system calibration because the radiometer derived attenuation values are required to match statistically the gaseous absorption estimates when the sky is clear. To assist the experimenter in verifying the radiometer calibration, the average difference between the gaseous absorption estimate and the radiometer attenuation estimate is output in the log file for clear-sky conditions.

1 Introduction

The preprocessing software (Actspp) reads the YYMMDDxx.RV0 files (or .rv0 fries) where YY is year, MM is month, DD is day and xx is site identifier) generated by the ACTS propagation terminals; performs radiometer calibrations, beacon reference level predictions, and beacon tone modulation corrections as needed to provide valid attenuation estimates at both beacon frequencies; tabulates attenuation histograms for further analysis; prepares one-minute averages or second-by-second output for further spreadsheet analysis; and generates YYMMDDxx.PV2 (or .pv2) files for archival ana further analysis. The program was originally developed to observe and diagnose ACTS propagation terminal receiver problems but has been quite useful for automating the preprocessing functions needed to convert the terminal output to useful attenuation estimates. As provided, the preprocessing software will generate .pv2 files automatically. Prior to having data acceptable for archival, the individual receiver systems must be calibrated and the power level shifts caused by ranging tone modulation must be removed.

Actspp provides three output files, the daylog (\DayLog xx\YYMMxx.LOG or log), the diurnal coefficient file (YYMMxx.DFC or .dfc) and the CALFILE.xxn file that contains calibrate information. All but the CALFILE.xxn file must be archived with the .pv2 files. The auxiliary files, the YYMMxx.SRF (or .srf) fiie containing corrected surface meteorological data if needed and the YYMMxx.RTN (or .rtn) file containing ranging tone times if different from the standard tone files provided by the University of Oklahoma (OU), must also be archived. hey provide sufficient data to verify that the system calibration was performed correctly and to complete] y recover the input .rv0 data from the archived files. The YYMMxx.EDF files must be archived to comply with the minimum reporting requirements of the experimenter's contracts.

The ranging tones must be removed from the 20 GHz beacon power level data to provide attenuation estimates valid at the low attenuations of interest for VSAT and other low margin communication system designs. The preprocessing software automatically removes most of the ranging tones if the statistical fluctuations in the received signal level are less than about 0.2 dB. During periods with stronger scintillation or rapid fluctuations in rain, the ranging tone detection algorithm may produce false detections and may miss some detections. This problem is critical for sites with observations at low elevation angles such as in Alaska. To circumvent the need for running the ranging tone detection segment of the program, a ranging tone time and level shift file (YYMM.RTN) should be used. OU has prepared these files and they are stored in the RToneTimes subdirectory on. Dave Westenhaver's ftp server: anonymous @ftp.crl.com. If you have a .rtn file with data for the day you are processing, the system will use the tone start and stop times from the file. It is strongly recommended that you use the prepared ranging tone files.

Actspp automatically marks data as "bad" when the receiver status flags indicate bad data, loss of lock, etc. The experimenter can also mark data as "bad' when some element of a receiver is malfunctioning, or the terminal is not operating correctly, or the antenna is not correctly pointed, or for any other reason. This is done by entering the times (in hours and minutes to begin and end a bad data section in the daylog (log file). All "bad" data are marked in the .pv2 files. The user defined "bad" periods are also archived in the log files. Data marked "bad" are considered bad for the entire minute in which a "bad" mark is detected. Data considered bad are not used in the compilation of the histograms or in estimating beacon reference levels.

The preprocessing program prepares an estimate of the undisturbed beacon power level at the receiver for use as a reference for the determination of beacon attenuation. The reference level is obtained from a fourth order harmonic curve fit to the attenuation corrected beacon power levels from the prior day. The attenuation correction is derived from the radiometer data. An additional diurnal variation correction is required to provide a correction to the fit to the data for the previous day to compensate for day-to-day variations in satellite radiated power, The additional diurnal correction is computed at the end of each hour and applied to predict the correction for the next hour. To provide some smoothing, the coefficients for the additional diurnal corrections are passed through a first order infinite impulse response (IIR) filter with a time constant of about 3 hours. The long time constant is needed to provide valid reference level predictions during periods with rain or times when the rms variation in the radiometer derived attenuation correction exceeds a preset threshold. The preset threshold is site dependent. It varies from 0.1 to 0.5 dB. The constants for the fourth order correction are stored in the daylog (log file); the constants for the hourly corrections are stored in YYMMxx.DFC (.dfc files). If the program is run a second time, the fourth order curve fit to the current day is used instead of the fit for the prior day unless the program is directed to use only the curve fit for the prior day.

Data with slow variations in signal level with radiometer attenuation corrections of less than 4 dB that also pass a rms variation test and are not marked as "bad" are included in the fourth order fit. If strong unmodeled attenuation events such as due to wet snow on the antenna are present or if bad attenuation adjusted beacon level estimates occur due to radiometer instability or ranging tone detection errors, the reference level for the next day will be in error. In this case run the program for the next day twice. If the data for the current day are in error, force the use of the curve fits for the prior day.

If no reference level predictions are available, the program assumes a constant reference level and computes the hourly diurnal adjustments relative to that constant level. The constant reference level is the received power level in the first second of valid observations. Note that the observations used to compute the fourth order harmonic fit for a day are not contaminated by the fit obtained from the prior day or the diurnal correction to that fit.

The beacon power reference level is obtained from a least squares fit of the diurnal variation model to the recorded beacon power levels after a correction for path attenuation using the attenuation value estimates obtained from the radiometer. This process is equivalent to performing a least squares fit of the beacon attenuation data to the radiometer attenuation data for attenuation values less than about 2 dB. The beacon observations are employed to obtain the signal level change from the reference level established using the radiometer data. The beacon observations extend the dynamic range of the radiometer measurements. The resulting attenuation estimates are for the total attenuation relative to "free space" or propagation in the absence of an atmosphere. The total attenuation is caused by gaseous absorption, extinction by clouds and rain, or by condensed water or wet snow on the antenna surface. In studies of attenuation by rain, only the rain component of the total attenuation is of interest. It is up to each experimenter to ascribe a physical cause to each attenuation event. The histograms produced by the program are for total attenuation not for attenuation due to rain. In Actspp version 66 and later, histograms of one-minute average estimates of attenuation relative to clear-sky conditions are also generated.

The reference level determination procedure produces a maximum reference level estimation error of less than 0.5 dB during an eclipse period at the satellite. The typical reference level estimation error is less than 0.1 dB. Comparisons between radiometer and beacon (plus radiometer) edf's show less than a 0.1 dB difference over a O to 2 dB attenuation value range. The main source of error in the estimation of attenuation is the approximately 0.2 dB day-to-day uncertainty in radiometer system calibration stability.

A valid estimate of total attenuation requires a well calibrated radiometer system. Periodic receiver calibrations are performed by the radiometer system to maintain radiometer calibration but independent system calibrations must be made by each experimenter throughout the entire measurement series. The preprocessing software provides the information necessary to perform a system calibration. An assumption in the design of the preprocessing system is that the surface meteorological measurements, pressure, temperature and relative humidity, are correct. If they are in error, data must be manually entered into the system via the YYMMxx.SRF file (or .srf file). Hourly averages of the three surface variables are needed.

2 Radiometer System Calibration

2.1 Background

The entire radiometer system must be calibrated and the possibility of a change in calibration constants must be monitored over the duration of the experiment. Two types of calibration are performed, a periodic receiver calibration and an aperiodic system calibration. The preprocessing program does the periodic receiver calibration every 15 minutes. Each experimenter must do an independent, aperiodic radiometer system calibration (once per month say) and whenever the receiver rf box is opened or moved. A theoretical description of the radiometer system calibration process was provided in the Radiometer Calibration Report (see also Sections 5.4 and 5.5). Recent changes to Actspp (version 66) make it easy to monitor the adequacy of the calibration constants over periods of a month or more for use in determining when a recalibration is required.

The radiometer system is of total power design and the components in the receiver system may drift in time (i.e. variable amplifier gains, offset voltages, transmission line matches) with a result that the output voltage from the square law power detector is not simply related to the power input to the low noise amplifier (LNA) connected to the antenna. To track and compensate for any possible component variations, standard, known power level signals are introduced into the LNA. They are periodically obtained from the reference load and the noise diode connected to the reference load by switching the LNA from the antenna to the reference diode and turning on then off the noise diode. Under ideal conditions, the noise diode always adds a known amount of power to the power from the thermal noise of the reference load. If, in addition, the match (fraction of power transferred from the reference load to the LNA) between the reference load and the LNA (through a coaxial line switch) is identical to the match between the antenna and the LNA, the response of the square law detector to power received by the LNA can be monitored. Using the automatic periodic calibrations and the two known power levels (the reference load and reference load plus noise diode noise power), the assumed linear relationship between input power and output voltage for each radiometer channel can be measured, monitored and maintained.

For a perfect receiver system with a known input power to output voltage relationship, the response of the system to a known power flux density incident on the antenna is still not known. A second (aperiodic) system calibration must be made to establish this relationship. Unfortunately we do not have a known signal to input to the antenna. The ACTS propagation terminals were supplied with hot and cold loads to supply known signals but these loads do not establish the fraction of the power received from the main lobe of the antenna pattern or the fraction of power received in the "spill-over" side lobes of the antenna pattern. They also do not maintain the same match to the receiver system as the antenna when not covered by the load. Use of the hot and cold load calibration procedure is not recommended. The noise diode calibration system has better stability.

The only signals available for overall system calibration are from the atmosphere and from the satellite. If the signal input from the satellite is constant in time (or changes in time as predicted by the beacon reference level), then attenuation events will change the satellite signal level and simultaneously produce changes in the input power to the radiometer from thermal emission from the atmospheric gases, clouds, or rain producing the attenuation. The attenuation observed using the beacon signals should match statistically the attenuation estimated from the change in sky brightness temperature observed by the radiometer. The beacon signal level change is measured precisely. The match between the beacon signal level change and the. observed change in the attenuation estimate obtained from the radiometer may be used to calibrate the radiometer system.

Two calibration constants are required, one that estimates the fraction of the power received from the antenna main lobe and the second that estimates the fraction of the power received from the antenna side lobes. The latter is not easil y found from the former because of the possible differences in the matches between the LNA and the antenna and the LNA and the reference load. Two independent calibration signals are necessary to determine the calibration constants. One signal is obtained from the change in power level (or attenuation) recorded for the beacon signal. For a second calibration signal we use the thermal emission from the atmosphere during periods without rain and clouds.

Ideally, we could tilt the antenna in elevation and measure the attenuation produced by a horizontally stratified cloud-free atmosphere to determine the value for thermal emission. For the ACTS propagation terminal this is not possible due to high antenna side lobe levels. The thermal emission can only be calculated theoretical] y using radiative transfer theory and a measured vertical profile of temperature, pressure, and humidity. In the absence of calculations using sounding data, the clear-sky thermal emission (sky temperature) and attenuation values can be estimated statistically from the surface observations alone. The coefficients for a linear statistical relationship between attenuation and surface temperature and water vapor density were obtained from a regression analysis on the full numerical calculations using a number of measured vertical profi les. The calculations were made at both observing frequencies using 108 soundings from the National Weather Service facility in Norman, Oklahoma. This relationship, adjusted for the elevation angle to the satellite and for the height of the ACTS propagation terminal above mean sea level (i.e. surface pressure), is used to generate the estimated absorption values output in columns BD and BE in the sum file spreadsheet.

A statistical regression analysis was also made to relate medium temperature to the surface meteorological conditions. This relationship is used in the estimation of attenuation from the sky temperature values observed by the radiometer. The one-minute averaged sky temperature values are also output in the sum file and histograms of sky temperature values are output to the .edf file (Actspp version 66 and later).

If all the system components were perfectly matched, the two calibration constants needed would be the antenna efficiency (fraction of power in the main lobe) and the spill-over power received via the side lobes. The latter would change from one day to the next as the atmospheric parameters and surface temperature and emi ssivity change. The spill-over power is characterized by a temperature (K) that must be obtained empirically. The spill-over contribution is also expected to change in proportion to changes in absolute outside air temperature (K).

Note that because the critical matches between system components are unknown, the antenna efficiency and spill-over temperature values that result from the radiometer system calibration are strictly empirical. They are intended for use with the reference level and noise diode power values for radiometer calibration. They are effective values that will not match values calculated for the antenna alone.

2.2 Calibration procedure

The calibration of the radiometer system is iterative. Initially, the software is supplied with the calibration constants used for November 1993 at the Oklahoma site. In Oklahoma the calibration "constants" have changed slowly in time due to noise diode malfunction (drift) and abruptly on occasion when we have disturbed the rf box. Anytime the rf box is moved relative to the antenna surface or removed for servicing or adjustment, the antenna efficiency will be changed unless the box is replaced in exactly the same location relative to the antenna surface. In practice exact replacement is not possible and a shift in the calibration constants must be assumed.

Calibration must be done over a long enough period of time to sample several cloud-free intervals of long duration and several intervals with rain. Because the underlying calibration procedure is statistical the larger the sample for calibration, the better.

The procedure used to determine the beacon reference power levels for the calculation of attenuation forces a statistical best match bet ween the radiometer and beacon attenuation values at radiometer derived attenuation levels below about 2 dB. Any scattergram of simultaneous observations of attenuation derived from the beacon and radiometer receivers will show agreement within about 0.2 dB between the two estimates of attenuation for attenuation values less than 2 dB (unless an undetected or falsely detected ranging tone is present). Figures 1 and 2 present results for October 18, 1994 obtained in Oklahoma. For both frequencies, the expected agreement is evident. This agreement should be observed even if the radiometer system is not calibrated correctly. It is forced by the preprocessing program.

Figures 1 and 2 show a progressively increasing difference between the attenuation values reported for the beacon and radiometer receivers. The beacon data show the correct change in attenuation from the values around 1 dB (forced by making the radiometer and beacon data agree). The radiometer observations are about 0.5 dB too low at a 5 dB attenuation at 20 GHz and about 0.3 dB too high at 5 dB at 27 GHz. The radiometer observations can be aligned more closely with the beacon receiver attenuation change observations by changing the two calibration constants for each frequency. Exact alignment is not necessary because the radiometer is used to set the reference level (~1dB) for the beacon measurements and the beacon receiver then measures precisely the change from that level. Exact alignment is not possible because the relationship between the radiometer observations of sky temperature and the calculated estimates of attenuation is not exact but depends upon the location of the rain or clouds causing the. attenuation relative to the receiving antenna, the physical temperature of the rain or cloud causing the attenuation, the microphysical properties of the rain or clouds (size, shape, orientation, etc.), the distribution of other attenuators along the path, and, for periods with intense rain, the uncertainty in the medium temperature value to be used in the estimation of attenuation because a significant fraction of the power lost by attenuation is redirected due to scattering and the full radiative transfer equation with multiple scattering must be used to determine the correct value for medium temperature. The relationship between attenuation and sky temperature is expected to change within a storm and from storm to storm. A statistical best fit relationship should be used that provides a good match over a number of storms with light to moderate rain intensity. A better fit will not change the beacon (plus radiometer) attenuation distribution that is the required output from this experiment.

The critical test for radiometer calibration is the match between the estimated attenuation due to gaseous absorption and the radiometer attenuation values reported for clear-sky conditions when the only attenuation to be observed is due to gaseous absorption. To perform this part of the calibration, periods without clouds or rain must be identified. This can be done by finding the days within a. month having the minimum attenuation observations. The .edf file histograms list the number of seconds (and for Actspp 66, the number of minutes) in the day an attenuation level is observed. Days with a significant number of relatively small attenuation observations should be used for this phase of the calibration process. Locate times without clouds or rain by plotting the radiometer estimated attenuation values vs. the gaseous absorption values (see Figures 3 and 4) and observing the lowest values for the radiometer. If the system is well calibrated, they should be within 0.2 dB of the gaseous absorption estimates (the 1:1 line on the plots). For Figure 3, good agreement is evident but in Figure 4 a disagreement of about 0.4 dB is evident. This comparison should be made for a number of days with a month. Calibration is achieved when agreement within 0.2 dB is obtained most of the time or when the number of days with a positive difference is equal to the number of clays with a negative difference.

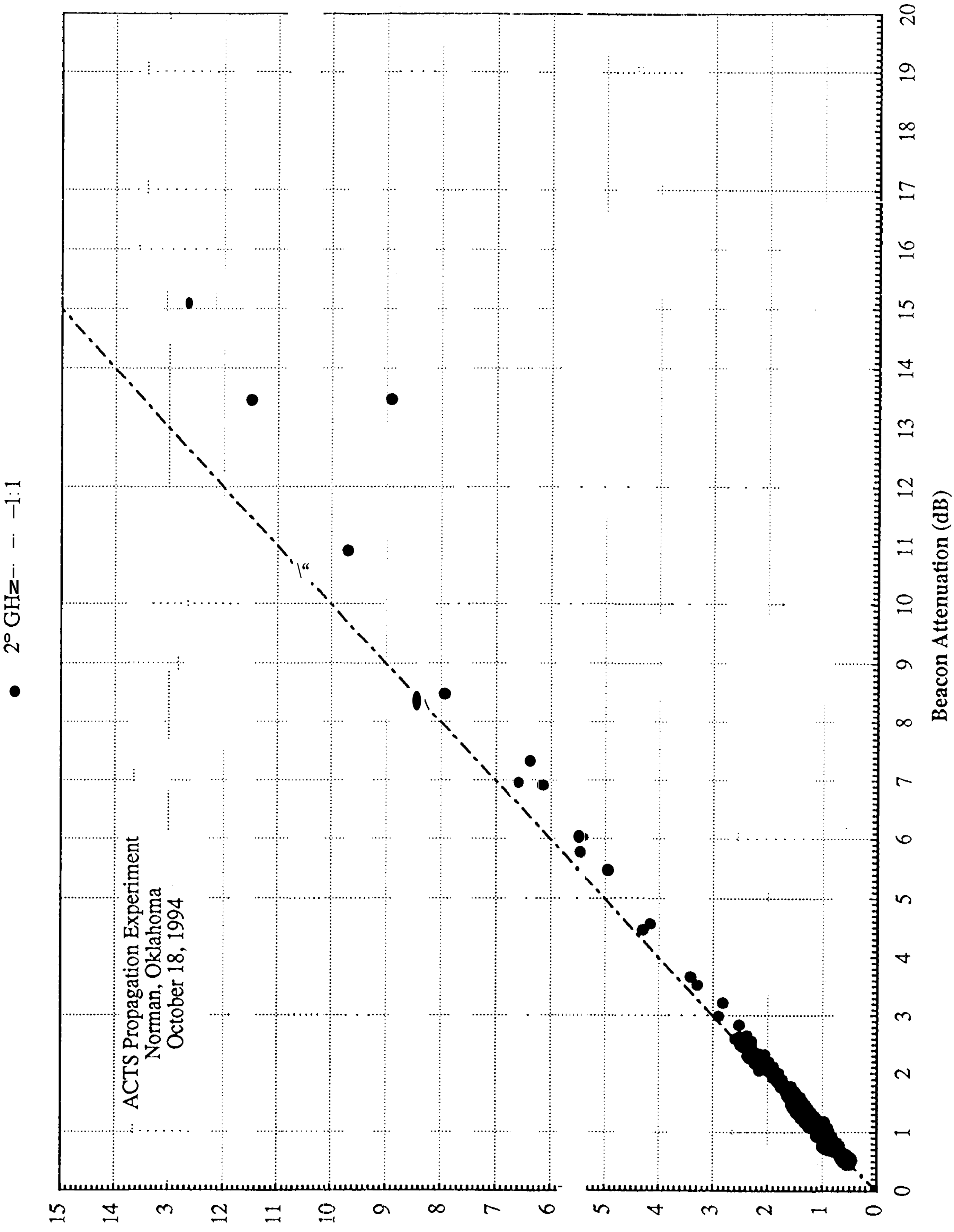
The calibration procedure is iterative. A change in effective antenna efficiency to make a better match between the radiometer and beacon observations will affect the radiometer estimate of attenuation during clear-sky conditions. A change in spill-over temperature will in turn affect the comparison of beacon vs. radiometer attenuation values. In practice it is more important to get a good match between the estimated gaseous absorption values and the radiometer values for periods with low attenuation (no clouds). The final adjustments to get a good match can be made using spill-over temperature alone because, in the end, the match between beacon and radiometer attenuation values is not important at attenuations above about 3 dB. Below 3 dB, the radiometer attenuation corrections to beacon received power used in determining the beacon reference power become important and the better the match, the better the reference level determination,

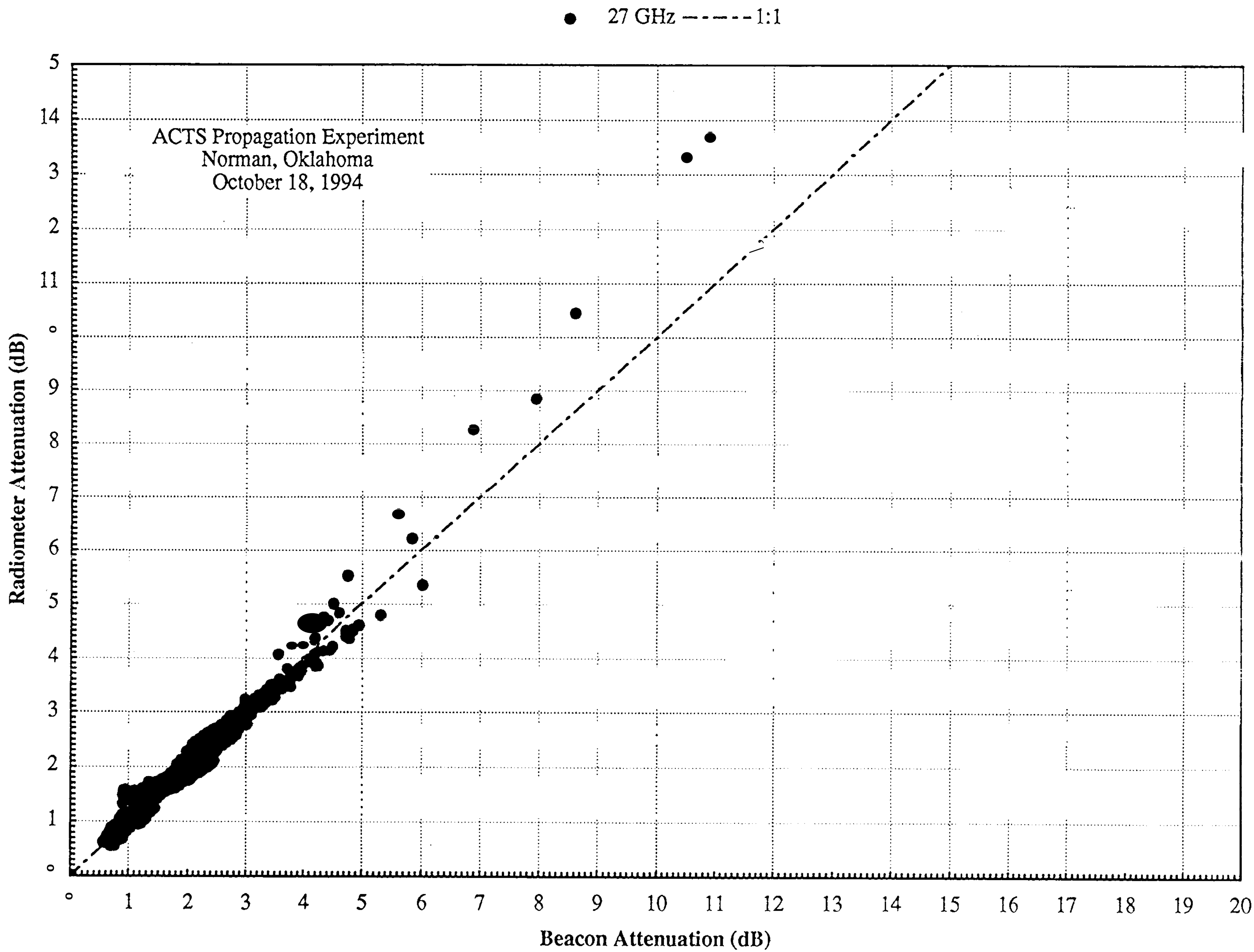
The differences between radiometer and beacon observations evident above 2 dB in Figures 1 and 2 will not affect the performance of the beacon (plus radiometer) estimates of attenuation. A look at the entire month of October shows some days with the radiometer attenuation estimates above the 1.:1 line and other days with the radiometer estimates below the line. Such variations are to be expected as the locations of the attenuating regions relative to the antenna, the relative effects of multiple scattering, and the microphysics of the rain process change from clay to day.

Any error made in the determination of the clear-sky radiometer attenuation values produces an error of the same magnitude in the attenuation distribution output at all attenuation levels.

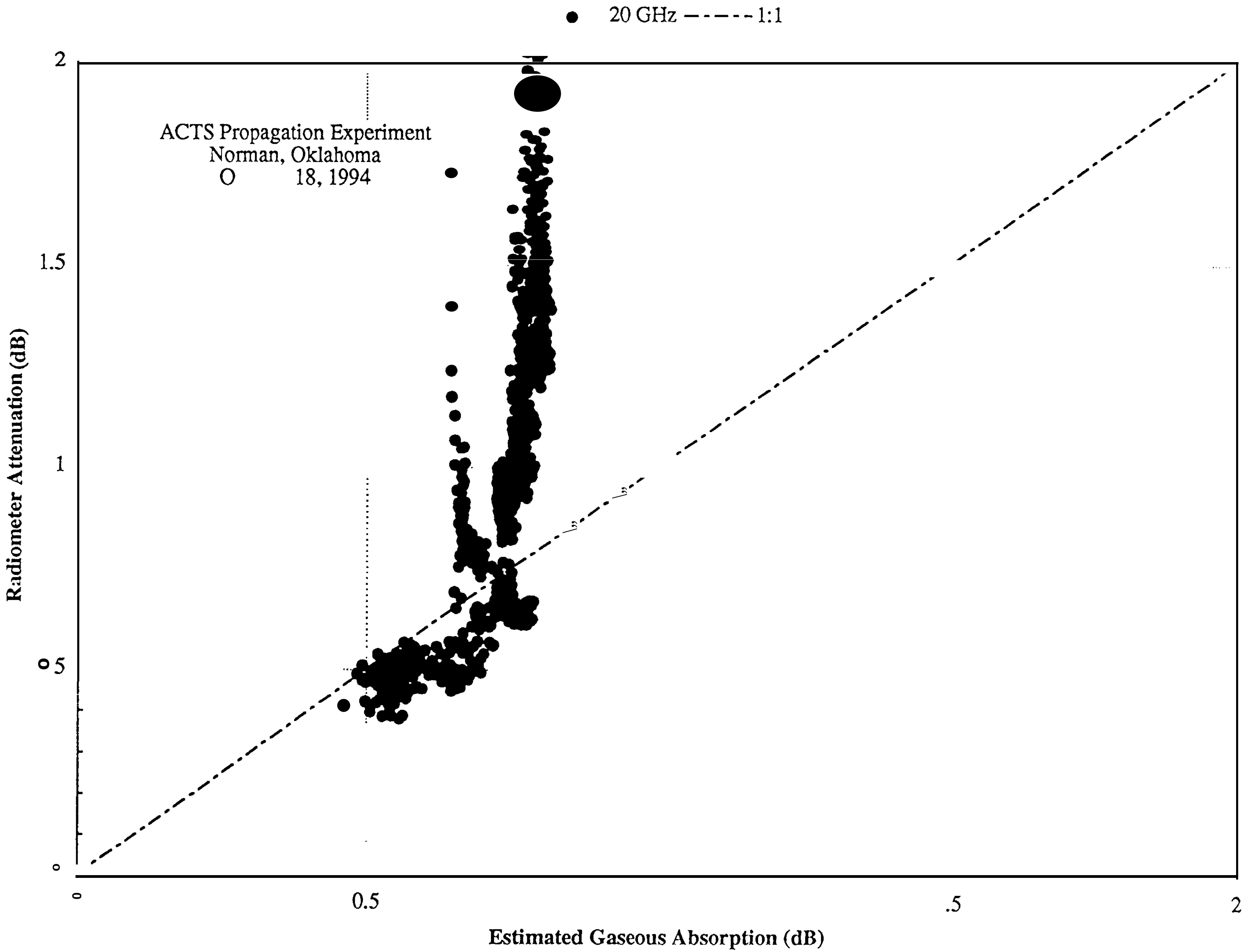
Version 66 of Actspp provides daily estimates of the average difference between the gaseous absorption estimates and the radiometer derived attenuation estimates for clear-sky conditions. These data are also listed in the revised .log file output. An easy way to verify system calibration is to plot the daily differences. They should be small except for days with no cloud-free times.

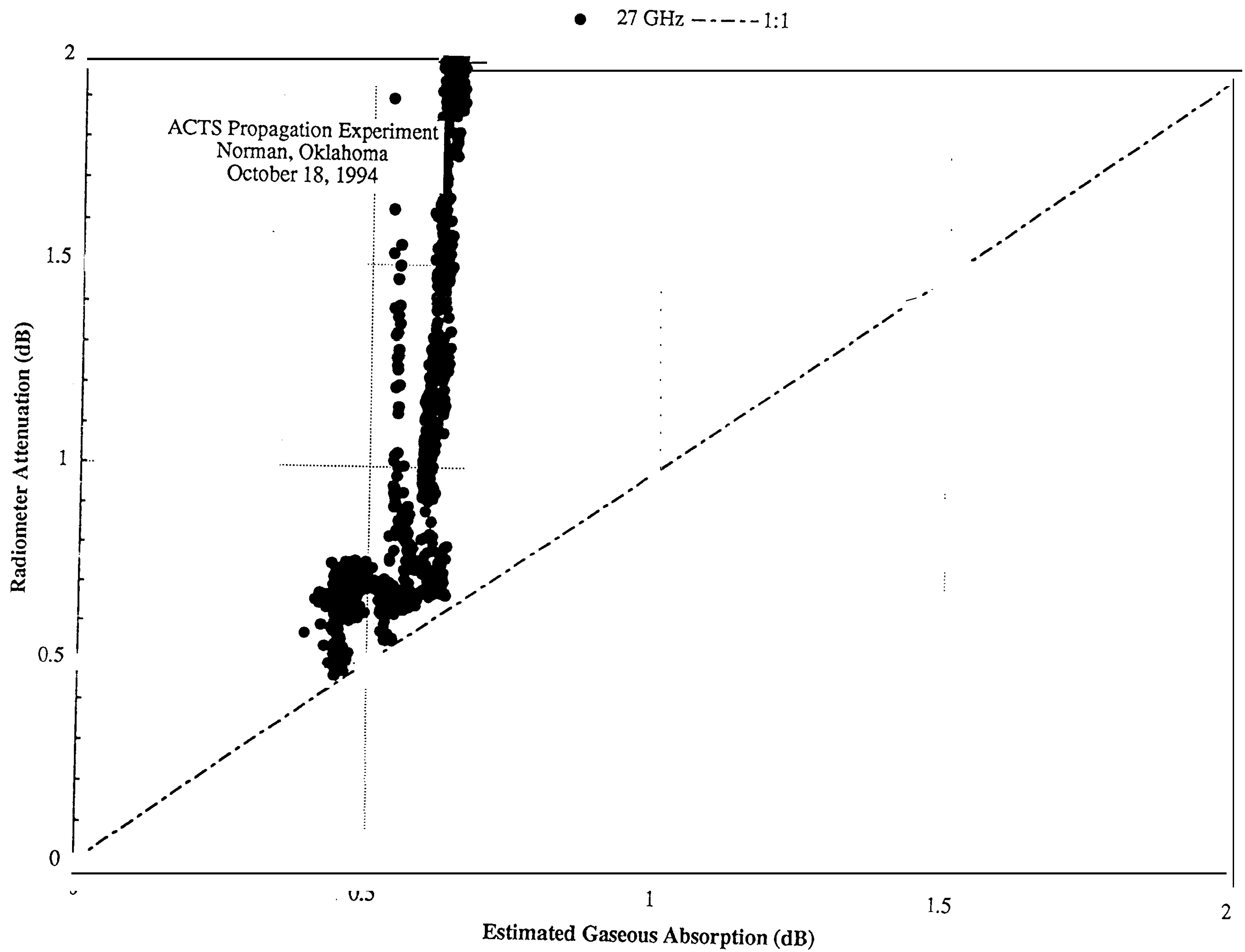
A macro to automatically produce an output from a daily sum file for calibration checking has been generated by OU and is included in macro set ACTS03.XLS available from Dave Westenhaver's ftp server: anonymous @ftp.crl.com. A sample output is shown in Figure 5 for a well calibrated system.


2° GHz
1:1
ACTS Propagation Experiment
Norman, Oklahoma
October 18, 1994
Beacon Attenuation (dB)
Radiometer Attenuation (dB)

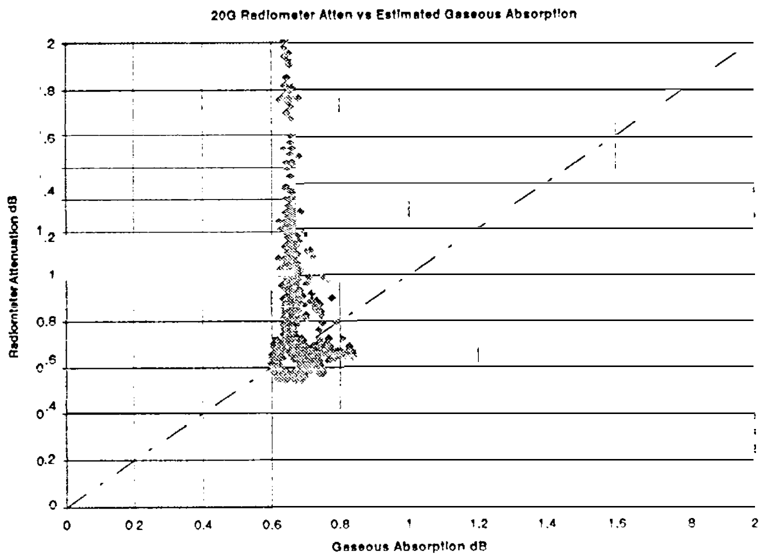


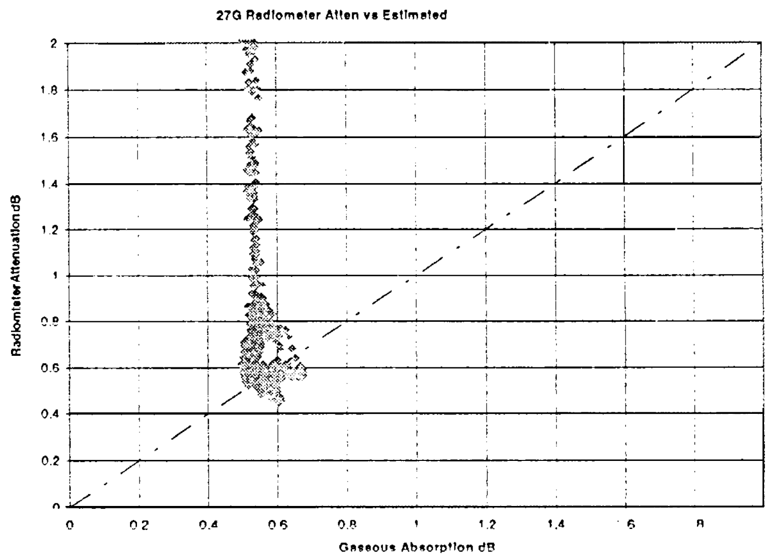
27 GHz ------ 1:1
ACTS Propagation Experiment
Norman, Oklahoma
October 18, 1994
Radiometer Attenuation (dB)
Beacon Attenuation (dB)

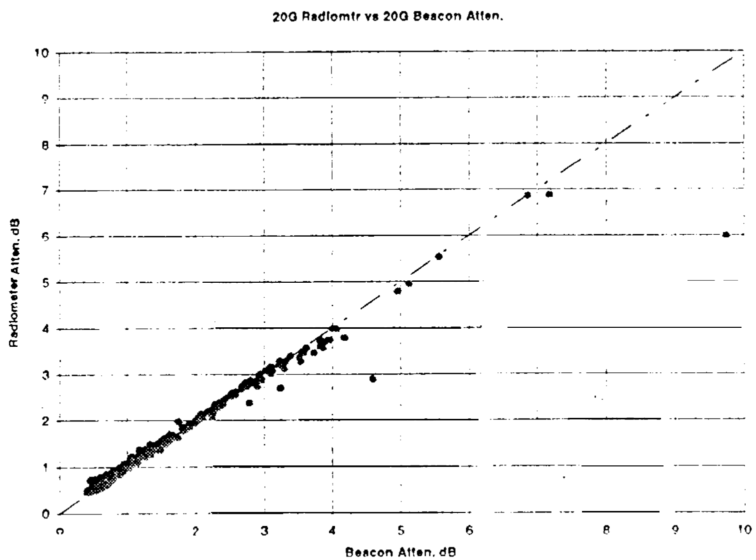

20 GHz
1:1
ACTS Propagation Experiment
Norman, Oklahoma
O 18, 1994
Radiometer Attenuation (dB)
Estimated Gaseous Absorption (dB)
2
1.5
1
0.5
.5
0

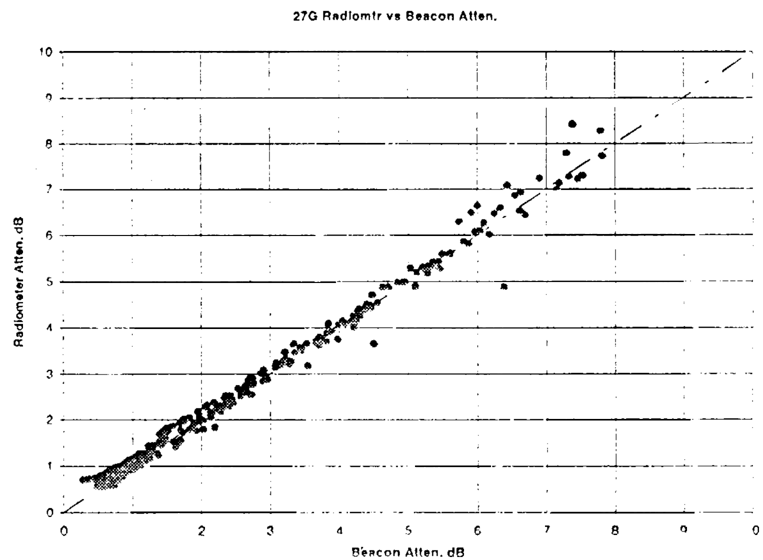

27 GHz
1:1
ACTS Propagation Experiment
Norman, Oklahoma
October 18, 1994
Radiometer Attenuation (dB)
0
0.5
1
1.5
2
Estimated Gaseous Absorption (dB)

940425OK Calibration Checking









3 Attenuation Relative to Clear Sky

The preprocessing program provides measurements of attenuation and estimates of gaseous absorption. The difference between these two outputs is the attenuation relative to clear-sky conditions. Distributions of attenuation relative to clear sky are compiled using the one-minute average data and output in the .edf files generated by Actspp version 66 (and higher). These outputs also have had any scintillation effects removed by averaging over a minute.

Time series of the one-minute average total attenuation values and the gaseous absorption estimates are listed in the sum files. The time series of attenuation relative to clear-sky conditions may be constructed by subtracting the gaseous absorption estimates from the total attenuation values obtained from the beacon receiver.

4 Empirical Distribution Functions

Actspp automatically generates all the statistical data needed to satisfy the minimum reporting requirements of the experimenter's contracts with NASA. Version 66 has added a number of one-minute average and standard deviation histograms of use to the propagation community. They maybe regenerated from the archived .pv2 fries if an earlier version of Actspp was used in preparing the .pv2 files. The Actspp version number is recorded in the .pv2 file.

The following histograms are recorded in the .edf files:

One-second average beacon (plus radiometer) total attenuation - the basic attenuation data.
One-second average radiometer total attenuation - for calibration only

One-minute rain rate

One-second average fade durations at 3,5,7 and 10 dB thresholds

One-second average inter-fade intervals at 3,5,7 and 10 dB thresholds

Versions 66 and later

One-minute average beacon (plus radiometer) total attenuation - the basic attenuation data.

One-minute average radiometer total attenuation - foı calibration only

one-minute average beacon (plus radiometer) attenuation relative to clear sky

One-minute sky temperature

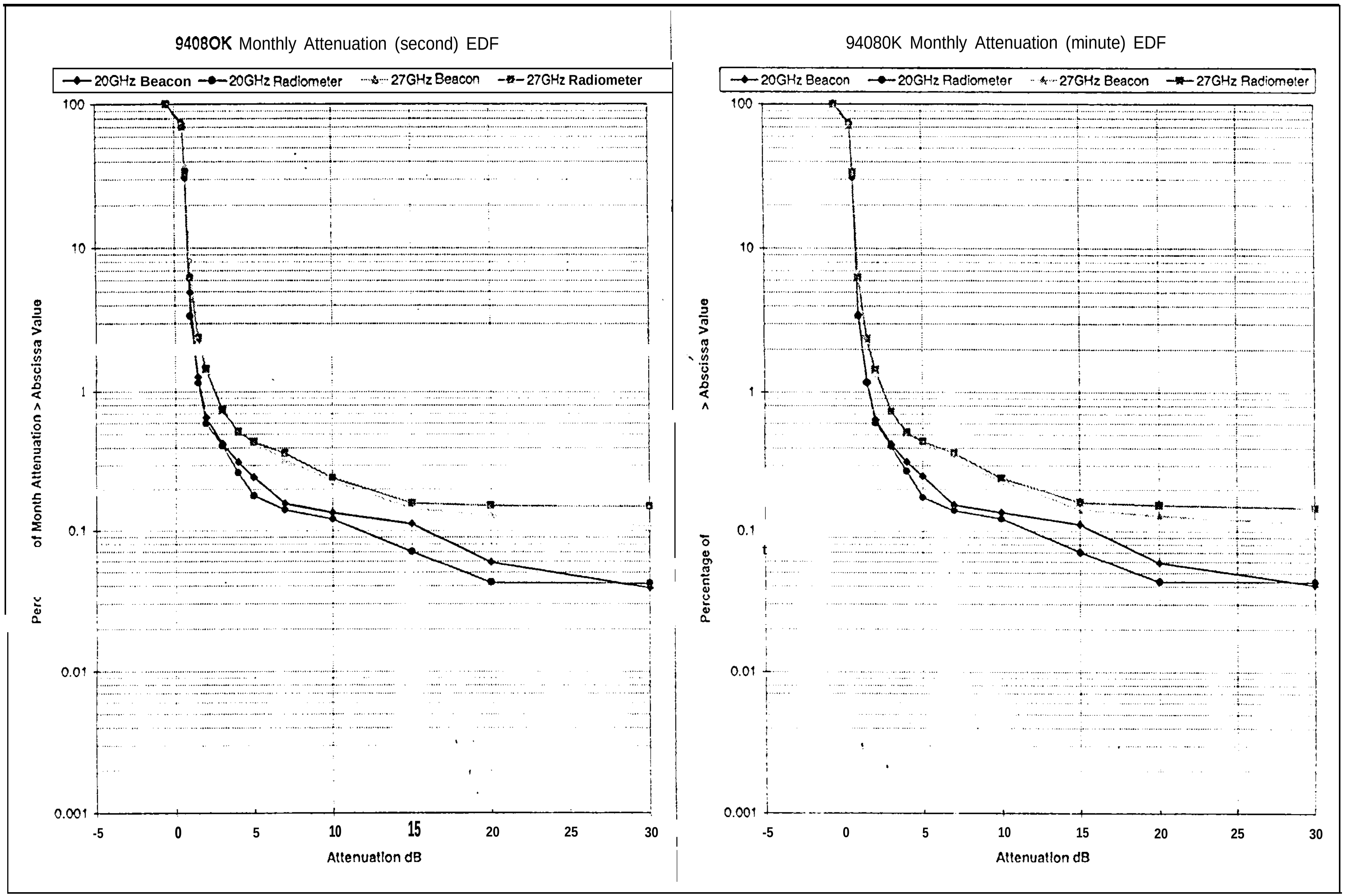
One-minute standard deviation of beacon received power

One-minute standard deviation of radiometer attenuation.

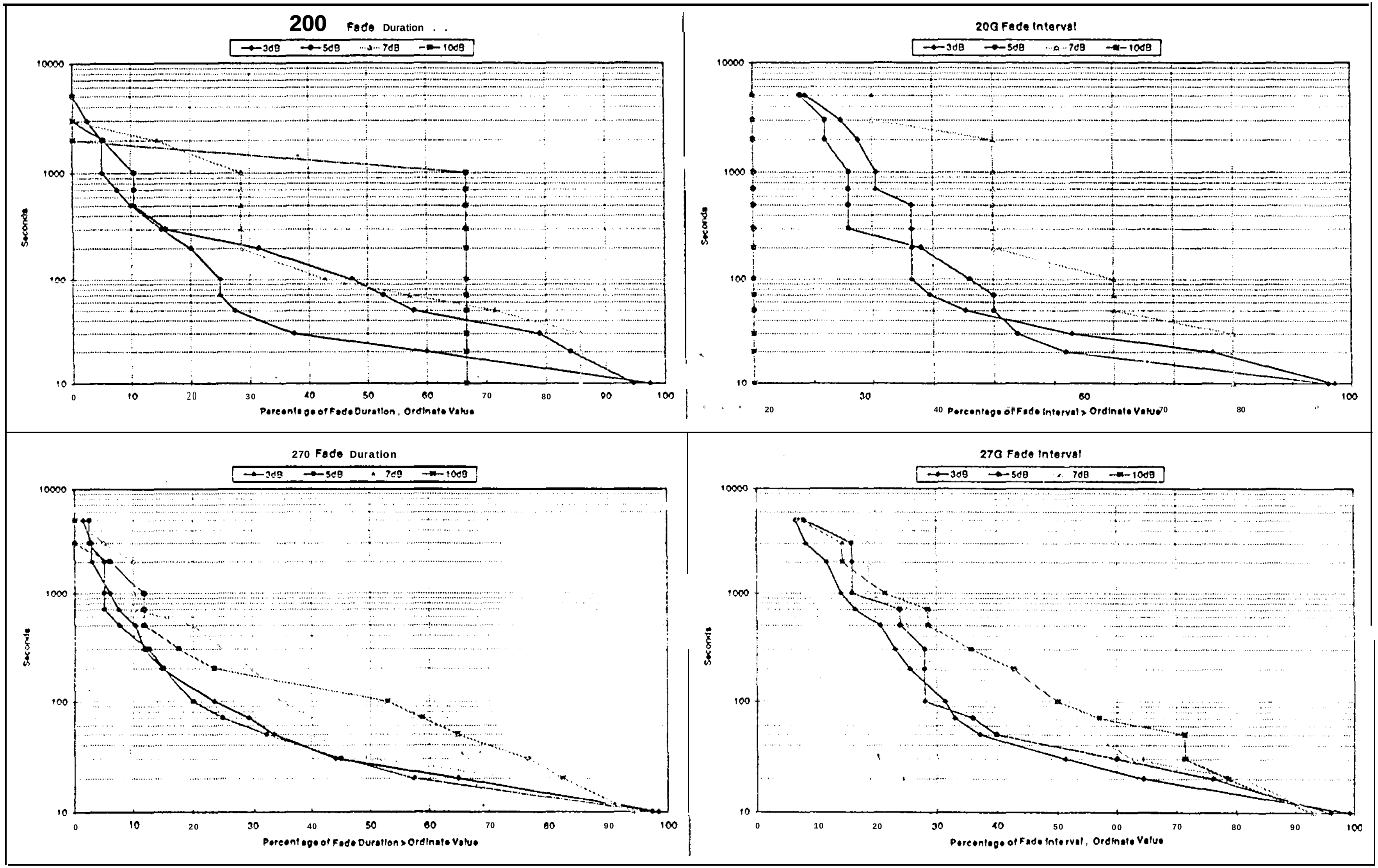
The histogram data are in logarithmically spaced attenuation, fade duration, inter-fade interval and standard deviation bin widths. The sky temperature data are reported in linearly spaced bin widths. The data may be readily summed and converted into cumulative distributions of the measurements - empirical distribution functions (edf' s). OU has developed a set of macros to do automatically the summations and generate the edf 's. They also produce standardized cumulative distribution plots. These plots are sufficient for the final report to NASA.

Sample plots for the required edf's are presented in Figures 6-8.

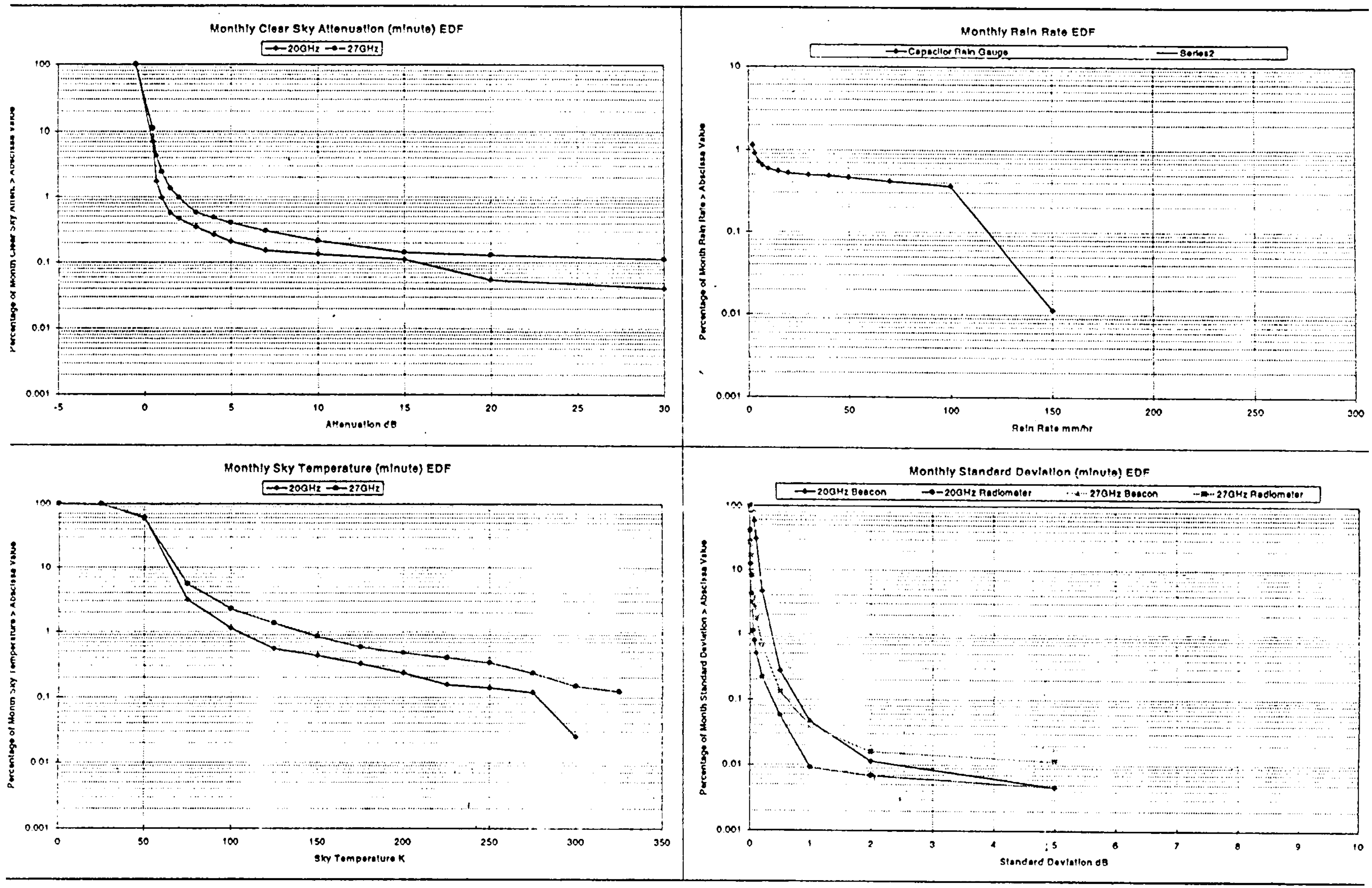
9408OK Monthly Total Attenuation Second and Minute EDFs



94080K Fade Duration and Fade Interval EDFs



94080K Monthly Clear Sky Atten., Sky Temp., Rain Rate, Std Deviation EDFs



5 Preprocessing Program (Actspp)

5.1 Overview

The information or data processing procedures used within Actspp are described in general terms in this section. At its most basic there is the initial setup, the calculations. and then the summary (conclusions) at the end. The Actspp program 'is organized with this "top-down" view, but the details are driven from a "bottom-up" view of the information or data. This manual describes some processes of Actspp from the "top-down" view and others from the "bottom-up" point of view. Both are needed to understand how the data is processed and how to use the program and its output files. The goal of Actspp is to remove the site differences and measurements system effects and to distill the one-per-second measurements into more concise measurements of propagation effects.

The lowest unit of information is the one-per-second data record. This 16 byte record contains a time stamp, amplitude and status of the beacon receivers, radiometer voltage readings and two time-multiplexed status words. The time-multiplexed status words have a repeat period of 60 seconds. Thus, it takes a minute of data to obtain a complete, normal set of information. However, the second time-multiplexed status word is used to report two additional asynchronous events when they occur. The highest priority of the two events is the "override" status word that reports specific collection system switch and logical changes. The override status is present several times during each radiometer calibration every 15 minutes. The second priority is the reporting of a tipping bucket rain gauge tip time.

Actspp processes each second of data. The one-minute multiplexed data frames provide the basis for the one-minute data averages. The bias removal (reference level determination) corrections are updated each hour because these corrections change slowly. At the end of the day, summary information is generated. Each day begins with reading the summary information for "yesterday" and "today" and the day ends with writing new summary information for 'today". This day "at a time" processing leads to the capability of processing months of data during one session. This process may be extended over many months.

A more detailed description of the processing steps within Actspp begins with an initial setup of the session variables. This is followed by the process of locating the directories and files for the input and output information. Then prior calibration information is retrieved for the day selected from the Jog files. Next the auxiliary files are read for surface weather data and ranging tones times. Then the processing begins for the day.

A second of data is read from the input file and decoded into several variables. The radiometer voltages are then converted to sky temperature and the radiometer derived attenuation is calculated. Then the time stamp is checked to determined if there has been a gap in the data. Next the status of this second's information is determined based on the override switch status, beacon receivers status and the beacon levels. This internal status is used to steer the remaining processes. Then Actspp checks for the radiometer calibration events and they are processed. Next the ranging tones are either detected or read from the file and their effect is removed. Then the bias is removed and more consistency checks are made on the beacon and radiometer attenuation to set the internal sample status and "bad data" is identified. This is followed by averaging the one second data for a minute. If the second is 59 then the process of calculating and writing the one-minute averages is called to write the data to the output summary file. Then the summation variables are set to zero and processing is started for the next minute. Next the internal status is converted to the beacon and radiometers attenuation status information for this second of data and written to the

.pv2 output file. Then the attenuation histograms are processed. This basic process is repeated for all the seconds in the input data file.

At the end of the day the summary process updates the calibration information, the empirical distributions, and the other files. If more days are to be processed in this session Actspp initializes internal variables and restarts with the reading of previously processed day's calibration information.

5.2 Actspp input options

Actspp has several input options that are described in order of appearance while running the program.

The first input option appears only if a script file has been found and asks if you want to use this script file or ignore it. If you select to use the script file then the answers to the file selection and input options question are read from the script file. When reading a script file the answers are read one line for each question and then parsed to remove the comments. Only the most used options are allowed. Specifically only .rv0 files are allowed as input and the system calibration parameters cannot be changed with a script file.

The default answers to each question are displayed when not using a script file. If this is the answer you wish to use then pressing the "enter" key will accept the default and move to the next question. An answer of" QUIT" is a valid answer for most questions and stops the program.

Choosing the desired input data file is the next question. The default preprocessing reads .rv0 raw data files but you can also choose to process .pvl or .pv2 data.

If the .pv2 file is input, the program does not rework the radiometer calibrations. It " starts with the attenuation data and works backwards through the calibration and reference level adjustment procedures to recover the input data. The required calibration information was stored *in the* .pv2 file. The additional hourly data needed to reverse the reference level estimation procedure are contained in the .dfc file. If the latter are mi ssing, the program will not provide input beacon level estimates.

Next the full **path** name of these files must be provided. The default path to the .rv0 or .pvn files is given and you can chose to enter a new path. Actspp then checks the directory for valid input file types and lists the files found before proceeding to the next question. The next question is whit}] input file do you wish to process? The file number or the file name are valid answers. If the file is not found the question is repeated. When a valid input file is found the file name is displayed in the screen.

The default **paths to the** output subdirectories are displayed and you are allowed to change them. Actspp then checks for the existence of the required subdirectories. The question is repeated if the subdirectories are not found. The drive and path names are saved in the "actspp.ini" file located in the same directory as the Actspp program and this becomes the default path for the next usage.

The program prompts for the desired processing options. Several options are available:

N - the Normal or "Next" in sequence of days which is used for multi-day processing with little output to the screen and selected output to the spreadsheet, B - Brief that does an entire day (or multiple days) but writes one-minute average data to the screen and selected output to the spreadsheet,

F - Full that does an entire day (or multiple days), writes one-minute average data to the screen and writes the full set of output data to the spreadsheet (all receiver voltages, etc. - this mode is recommended only for use in troubleshooti rig),

S - a short segment of Second-by-second output, both to the screen and to the spreadsheet file,

M - a short segment of one-Minute average output, both to the screen and to the spreadsheet file.

The additional options that may appended to the selection are:

A - for noise diode calibrate factor Adjust,
C - for change Calibrate *constants*,
D - to force ranging tone Detection,
N - to select multiple days (use if the N processing, option was not selected above)
U - to Use prior day bias reference coefficients if already calculated,
B - to change radiometer for Bias reference when radiometer fails,
R - for maintaining the Radiometer and beacon time bases the same for the cdf but different as a function of frequency,
I - for Independent time bases for each calf,
T - for special Testing outputs.

Please note that when processing a .pv1 or .pv2 input file the only valid additional options are "N", "R' or "I".

The options "A" and "C" will cause the calibration menus to be presented where you can change the calibration constants. The "C" option allows you to change the system calibration constants. The current values are displayed and you can change them. The constants are the antenna efficiencies for 20 and 27 GHz, the spill-over temperature for 20 and 27 GHz and the humidity sensor calibration adjustment factor. The "A" option allows you to change the noise diode temperature adjustment multiplier factor. This option provides a convenient way to adjust the parameters and keep a reasonable balance between adjusting antenna efficiency and spill-over temperature. It should be used after the system is initially calibrated to provide the incremental changes needed to keep up with system component drift.

The "B" option presents a menu to allow you to select which radiometer channel is in error when one of the radiometers is not working properly or is suffering interference. You are asked to enter 1 for 20 GHz, 2 for 27 GHz to force the use of the other radiometer.

If the "N" option was entered the next question is how many days you wish to process in this session. Because we have already selected the data paths all these files must be in the same sub-directory.

If the processing option was either "N" or "F" or "B" the full day will be processed and you have the option of generating or regenerating the cdf's. The default answer is "Yes".

If the option was either "S" or "M" the processing start and stop times are needed from you. The "S" option is for use for processing a limited data set (in time). With this option, bias removal is not attempted.

5.3 Actspp files and directories:

Actspp uses three file types. They are binary files, tab-delimited text files and a text file. The primary input and output files are one-second data records that are binary file types. The tab-delimited text files are used for data input and output. This format is based on one that Microsoft's Excel can read fen- easy viewing and plotting. In general, the file naming convention is based on the date, site and file type is the extension. In the file name YY is the year, MM is the month, DD is the day and xx is the site identification. The file extension identifies the data. type.

The input data file for Actspp is either a YYMMDDxx.RV0 raw binary data file or a YYMMDDxx.PV1 or YYMMDDxx.PV2 preprocessed binary data file. These input files can be located on any logical drive and directory that can be accessed by the PC. This includes a second hard disk, a CD ROM drive or a drive on a network. The drive and path names are saved in the "actspp.ini" file located in the same directory as the Actspp program and this becomes the default path for the next usage.

The output and auxiliary files are located in separate subdirectories. Again there are no restrictions on the drive and path to these subdirectories. The three required subdirectories are "dataout", "dataSum" and "daylogxx".

The parent directory for these three sub-directories is where the "screen" file is placed. The file name for this file is "sfMMDDxx.Tss". The last letters in the extension is the PC's clock seconds when the file is opened. This was done so that separate runs of the same day do not automatically overwrite the older data. The screen file is a text file of the messages and data that appear on the screen while the program is running. Many messages flash too fast to be read on the CRT. Also an unattended running of the program leaves a list of the events and the end of day summaries in this text file to be reviewed by the experimenter later.

The subdirectory "dataout" is the directory for the YYMMDDxx.PV2 preprocessed binary data files. The format of this file is similar to the .rv0 file.

The subdirectory "datasum" is the directory for the YYMMDDxx.sum or YYMMDDxx.unk tab-delimited output data files. If the input option is "M", "B", "F" or "S", the .unk file is generated; otherwise, the "N" or normal option generates the sum file. The input option "S" generates a second-by-second output of a small number of items and is useful in testing by looking at a few minutes of data. The other options place the one-minute averages of various items in the output file.

The "daylogxx" subdirectory contains several monthly summary files. These files are readied and updated for each day processed. If the file does not exist then Actspp will generate it. The first file, calfile.xxn, was originally used for the calibration constants derived from the system calibration and the every-1 5-minute radiometer calibration. This file is still used but its major function now is to provide default values.

The YYMM.RTN or YYMMxx.RTN is the ranging tone time file with one line for each day in the month. Standard files are provided but are inadequate sometimes because of data collection clock errors. Thus the site specific form YYMMxx.RTN is the first file name in the search list. If site specific ranging tone times are needed then the standard should be copied or renamed to the site specific name format before using the "D" detect option. If there are no entries in the row for the current day then Actspp automatically switches to the ranging tone detection mode.

The YYMMxx.SRF file is the fiie to allow experimenters to enter surface weather data for use in place of the collection systems' gauges. To use the external data the experimenter should enter the local barometric pressure, temperature and relative humidity for each hour -24 triple inputs. If the pressure is zero or there is no entry for the hour then the program uses the site instrument measurements. This file is always present and checked for surface weather data.

The YYMMxx.DFC file is written by Actspp with one line for each day in the month. The diurnal bias removal fit coefficients are listed in this file by hour. This file allows a .pv2 file to be read and regenerates the collected data, creating new one-minute average files and updating the attenuation histograms.

The YYMMxx.EDF file is written by Actspp with one line for each day in the month in each of six data blocks. The first data block is the histogram of the one-second average attenuation and one-minute average rain rates. The second block contains the Fade Duration histograms and the third block has the Inter-Fade Interval histogram information. The fourth and fifth data blocks contain one-minute average total attenuation, attenuation relative to clear sky and sky temperature histogram information. Block 6 contains the standard deviation histogram data. These files are updated by Actspp unless the operator selects the option not to update these files.

The YYMMxx.LOG file is written by Actspp with one line for each day in the month. Additional lines are possible for each day to enter Good and Bad time limits for marking "bad" data or for entering time-tagged comments or weather conditions. The date and times are entered in column 1-4 (A - D in the spreadsheet), the "B" or "G" status indicator is entered in column 5 (E) and the channel (20, 27 or Both) in column 6(F). This file may be edited by the experimenter to change the system calibration, mark the times of known "bad data" or times to "ignore" the data in calculating the histograms (all but rain rate), and add relevant information about the day's collection or weather state. The file contains specific information about the last radiometer calibration in the day and bias removal coefficients derived during the processing. Carrying forward this data allows smooth day to day transitions. Actspp first reads the data from "yesterday" to retrieve the last radiometer calibration in the day, bias removal coefficients and the system calibration values. Actspp then reads data from "today" to update the bias removal coefficients - if the option "U" was not selected - and the system calibration values if they are present.

5.4 Actspp data calculation and calibration

Calibration is necessary because both the beacon and radiometer measurements are needed and they must be forced to agree over the limited dynamic range where they both should agree. The beacon receiver is very linear and has a large dynamic range but there is no way to know the zero dB point and the power from ACTS does slowly change. The radiometer can predict the attenuation during clear sky and for very low attenuation events but it has a very limited dynamic range.

The total power radiometer measures the noise power of the receiver. The major contributors to this power are the LNA (low noise amplifier), the thermal noise from the sky and the thermal noise of the ground received from the side and back lobes of the antenna. The radiometer is a very high gain and wide bandwidth noise power measurement device. To counteract the system gain changes over time and operating temperatures, the radiometer is "calibrated" every 15 minutes.

This calibration consists of switching the LNA from the antenna to a resistive 20 dB attenuator load - whose temperature is measured - that is in series with a noise source. During the "calibrate" time the noise diode is switched on and off. This gives the power reading for two stable noise temperatures. From this, the "system temperature" can be measured over long periods of time relative to the load and noise diode "temperatures". The "temperature" of the load and noise diode as measured by the radiometer are not known and thus must be inferred through other measurements to get to the sky temperature we want. Also we don't know how to partition this noise between the LNA's large temperature, the side lobe temperature and the sky temperature.

Direct inference of the load and noise diode temperature by using "known temperatures" at the antenna feed has failed, most probably because of the system VSWR matching problems.

Actspp does use an indirect, "total operational system approach" calibration to remove these uncertainties by using the predicted sky temperatures and the variation in these temperatures to derive the system calibration. In fact the approach Actspp uses is much more direct. The downside is that the calibration is driven by weather events and not the operator and has a statistical nature.

While this may be upsetting to some, please remember that the "bottom line" of all of the propagation measurements is statistical.

5.5 Sky temperature estimation

The system noise temperature is calculated from the radiometer voltage by:

$$Ti = a + b * V$$

V is radiometer voltage and is reported to the sum file in the column "Avg Rad V . ..". Ti is the system noise temperature and it is in the column "Avg Trad . ..". The calibration constants "a" and "b" are reported to the .sum file when you use the "T" option. The constants are derived during the every 15 minute radiometer calibration. During this calibration the radiometer voltage is collected for both when noise diode is on and off. The temperature for the case when the noise diode is off is the measured temperature of the load. It is about 323 K. The temperature when the noise diode is on is about 613 K when the "Cal Adjust multiplier" is set to 1.

It is not important that we don't know these temperatures because we must perform a system calibration to convert the system temperature to a sky temperature and this system calibration will remove any effect of not knowing the true temperatures. The "Cal Adjust multiplier" is available to remove the effect of the slow drift in the noise diode's noise temperature.

The system calibration is used to convert system temperatures to sky brightness temperatures. The simplified form of this conversion is:

$$Tb = c * Ti - f * ((273+TZ) / (273+TZo))$$

where "c" is 1/ "antenna efficiency" and "f' is what we call "spill-over temperature." TZ is the current outside ambient temperature and TZo is a constant = -3 C. With this, the "spill-over" temperature is scaled to the current ambient temperature. Tb is reported in the column "Avg Sky Temp... " of the . sum file. Ti is the system temperature and we get it from the radiometer's voltage after applying the every- 15-minutes radiometer calibration.

Actspp calculates the radiometer attenuation by using the equation:

Atten = -4.343 * LN((Tm-Tb) /(Tm-2.74))

where Tm is the medium temperature and Tb is the sky brightness temperature.

As the sky temperature approaches the medium temperature, the attenuation increases very fast. Thus, a slight error in the sky temperature or in the medium temperature can cause a many dB change in the attenuation for attenuation values above about 10 dB. Actspp estimates the medium temperature from ground based measurements in an effort to extend the range of useful radiometer attenuation estimates.

The goal of the system calibration is to find the two constants "antenna efficiency" and "spill-over temperature". This is done by 1) using a light rain intensity event to match the beacon and radiometer attenuation and 2) using clear sky days to match the radiometer attenuation to the attenuation predicted based on the ground based weather measurements. Matching the predicted sky temperatures to the observed sky temperature values is redly the same thing.

A change in the antenna efficiency has little effect at low radiometer voltage reading compared to high readings. Thus you can change antenna efficiency to make a better match at the high attenuation. But remember, we don't know the "sky temperature" during an event. With two constants we could force the beacon to match the radiometer at low attenuation values and we could force the radiometer to match the beacon at high attenuation values (above 10 dB). An exact value for the medium temperature is required to make a match at high attenuation values and have a valid calibration for intermediate attenuation levels. The medium temperature changes during a rain event and between rain events. An exact match that holds for a period of time is not possible. The critical part of the calibration process is the statistical match between the. radiometer attenuation values and gaseous absorption values under clear sky conditions.

6 Macro Library for use with Actspp

6.1 Introduction:

The macros in ACTS03.XLS are written in Visual Basic and can only run in Microsoft Excel 5.0 or higher version.

There are 5 macros in ACTS03.XLS. They are written for use with the output files (sum, .unk, .edf) from Actspp.

Here is a brief description of the function of each macro:

Beacon:

This macro reads sum files of successive days in a month and automatically prints out the time series of radiometer adjusted beacon power level for the chosen days. User is prompted to give the site ID, the path of the sum files, the begin and end day he wishes to process, the position of the bad marker on the chart, the number of plots for each day and if he wants to save all the work in Excel files for later checking.

Cal_adjust:

This macro is written to assist experimenters checking their APT system calibration. It gives users radiometer attenuation vs. gaseous absorption and radiometer attenuation vs. beacon attenuation charts for both frequencies. A well calibrated system should show that the lowest dots in the radiometer attenuation vs. gaseous absorption chart are less than 0.2 dB apart from the 1:1 line, and the dots in the radiometer attenuation vs. beacon attenuation chart for a "good" rain day are clustered around the 1:1 line.
For details about how to adjust your system calibration please refer to Radiometer System Calibration in ACTS Propagation Experiment Preprocessing Software User's Manual.

DailySummary

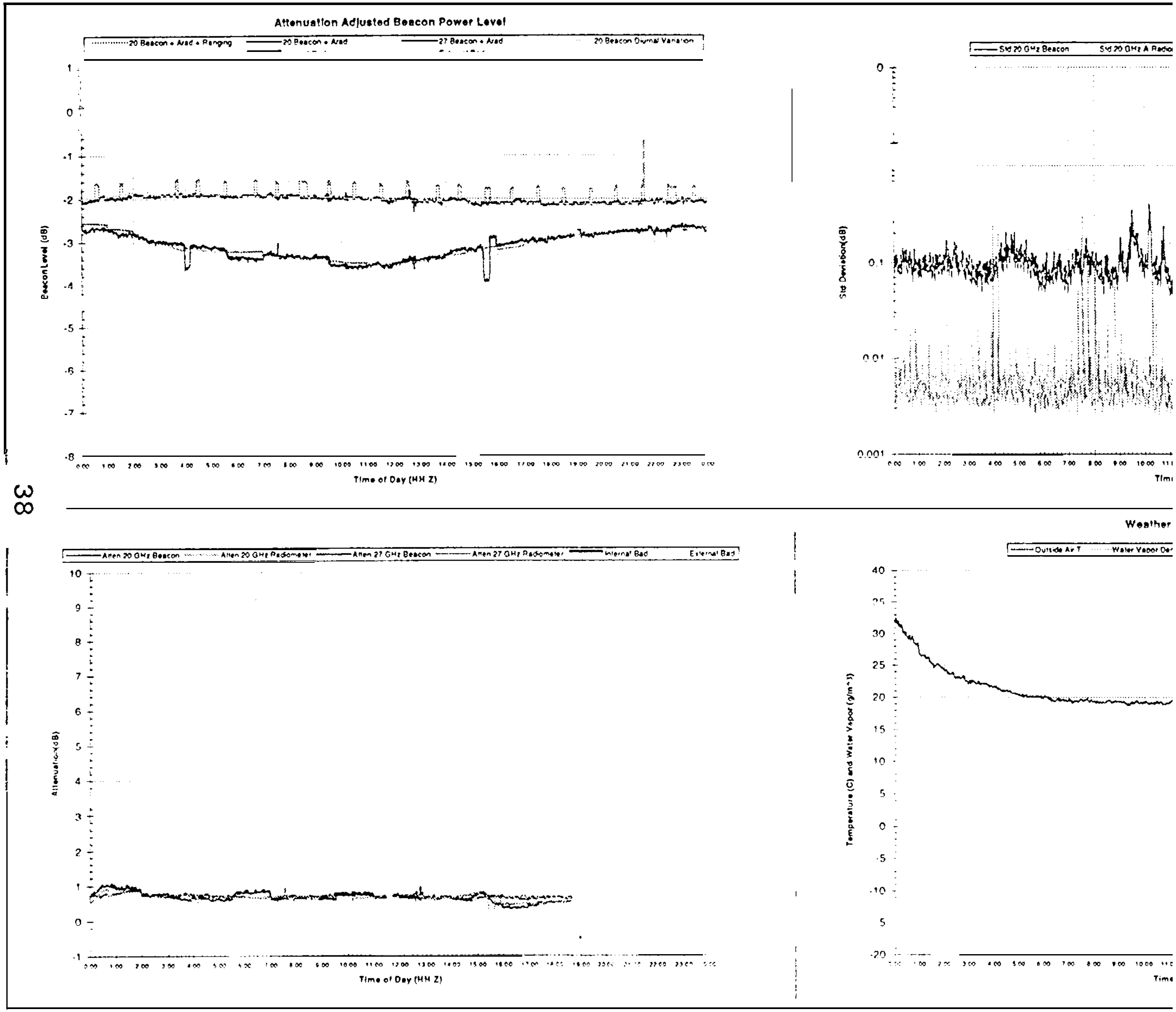
This macro is an extension of Beacon. Besides the time seri es of the beaeon power level, it also generates time series of total attenuation, standard deviation and weather information and also can automatically print out sheets which include all these four time series for the user-chosen days. It will ask the user the same questions as Beacon before it runs. A sample output using this macro is shown in Figure 9.

Edf0

This macro reads the .edf file for a month and calculates all the edfs in that file, namely monthly total attenuation by second distribution, monthly total attenuation by minute distribution (these two attenuation edf's are in one sheet), monthly fade duration and fade interval edfs (these two fade statistics are in one sheet), monthly free space attenuation, sky temperature, rain rate and standard deviation edfs (these four edfs are in one sheet). (Note: for .edf file generated by Actspp65 or earlier, only monthly total attenuation edf, fade duration and fade interval edf's are generated.)

ViewUNK

This macro can only work with a short (See) segment file (a second by second .unk file generated by choosing option S when you run Actspp). It generates a second by second time series of 20G beacon power level for that short time period and can be used to assist the experimenter in checking ranging tone removal.



Attenuation Adjusted Beacon Power Level
20 Beacon + Arad + Ranging
20 Beacon + Arad
27 Beacon + Arad
20 Beacon Diurnal Variation
Beacon Level (dB)
Time of Day (HH Z)
Std 20 GHz Beacon
Std Deviation(dB)
Atten 20 GHz Beacon
Atten 20 GHz Radiometer
Atten 27 GHz Beacon
Atten 27 GHz Radiometer
Internal Bad
External Bad
Attenuation(dB)
Time of Day (HH Z)
Weather
Outside Air T
Temperature (C) and Water Vapor (g/m^3)

6.2 Installing and Running the Macros:

> To install the macros:

Two files ACTS03.XLS and XL5GALRY.XLS are needed for installation. You can get them from Dave Westenhaver's ftp server: anonymous@ftp.crl.com (use binary transfer mode).

Before you install the macros, please back up the original xl5galry.xls in your c:\excel\xlstart directory (in case you want to restore your original Excel working environment).

EDF template (for Edf0)
skyattenedf - monthly clear sky attenuation EDF template (for Edf0)
Atten - attenuation time series template (for Daily Summary)
Beacon+Arad+(RangTone) - radiometer adjusted beacon power level time series (for Daily Summary and Beacon)
RvsEst - radiometer attenuation vs estimated gaseous absorption (for Cal_adjust)
RvsB atten20G - radiometer attenuation vs beacon attenuation (for Cal_adjust)
fade1 - fade duration EDF (for Edf0)
fade - fade interval EDF (for Edf0)
Weather - time series of on site weather instrument records (for Daily Summary)
UNKchart - second by second time series of 20G beacon level (for ViewUNK)
Note: XL5GALRY.XLS is the Microsoft Excel 5.0 template file, which includes all the chart templates needed for running macros in ACTS03.XLS.

Put the new XL5GALRY.XLS and ACTS03 .XLS in your c:\excel\xlstart directory. The installation is finished.

> To run the macros:

1) Start Excel from the Windows Program Manager.

2) Since ACTS03 .XLS is put in xlstart directory, it is opened every time Excel starts but it is in hidden mode. You may see an empty window of Excel with only File and Help on the menu bar, or you may see other menus in the menu bar if a file has been already opened in the window. For the first case from File menu, choose Macro... while for the second case from Tools, choose Macro . . . . A Macro window will pop up, in which available macros are listed. Choose the macro you want to run (e.g., ACTS03 .XLS!Edf0) and click Run. Follow the prompts of the macro, then watch the macro finish the operation.

> Adjusting the scales of some charts:

The chart templates for ACTS03.XLS are suitable for the OK site. You may need to adjust the scales of some charts for your site, especially the ordinate scale for Beacon Power Level chart. Here are the steps:

From the File menu choose Open: an Open window will pop up. Change the directory to c:\excel\xlstart (you may also need to change the drive if Excel is in the other hard drive.) Then select xl5galry.xls and click OK. You will see all the chart templates for **ACTS03.XLS:**

cdf - monthly attenuation EDF template (for chart in Edf0 macro)
rain - monthly rain rate EDF template (for chart in Edf0 macro)
stdedf - monthly standard deviation EDF template (for Edf0)
skytempedf - monthly sky temperature skybrightT - not used by ACTS03.XLS
std - time series of standard deviation (for Dail ySummary)

If you want to change the ordinate scale for Beacon+Arad+(RangTone), select the tab of Beacon+Arad+(RangTone) from the bottom of the Excel window. The Beacon+Arad+(RangTone) template will show in the window. Now double click on the Y axis; a Format Axis window will pop up. Choose the Scale tab from the top of the Format Axis window. Now you can enter the suitable. scale values for your site (e.g., set minimum -14; maximum -2; . . .). When you are done, click OK and check the scale of the axis you have just changed; if it is OK, from File choose Save. The next time you run the macro Daily Summary or Beacon (these two will use Beacon+ Arad+ (RangTone) template), changes in the Y axis of the beacon power level time series will show up.

If the beacon level does not drift out of scale over time, you only need to edit this template once.

Changing the other template is much the same as above. For editing other parts of a chart please refer to Excel User's Guide.

> To see the source code of the macros:

Either from File (when only two menus appear in the menu bar) choose Unhide, or from Window choose Unhide. An Unhide window will pop up. Select ACTS03 .XLS and click OK. The source codes for all the macros will show up. You can modify the code of a macro to suit your special purpose.