Proceedings of the Eleventh Advanced Communications Technology Satellite Propagation Studies Workshop (APSW XI)

Held in Oklahoma City, Oklahoma October, 22–23, 1998

Nasser Golshan
Editor

Christian Ho
Co-Editor

December 10, 1998

National Aeronautics and Space Administration
Jet Propulsion Laboratory
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ABSTRACT

The Advanced Communications Technology Satellite Propagation Studies Workshop (APSW) is convened each year to present the results of the Advanced Communications Technology Satellite (ACTS) Ka-band propagation campaign. Representatives from the space community including industry, academia, and government who are interested in radiowave propagation at Ka-band are invited to APSW for discussions and exchange of information. The ACTS Propagation campaign will complete five years of Ka-Band data collection at seven sites in North America by December 31, 1998. Through this effort, NASA is making a major contribution to the effective utilization of this band by providing timely propagation data and models for predicting the performance of Ka-band links between space and ground.
PREFACE

The ACTS Propagation campaign will complete the planned five years of Ka-band data collection at seven sites by December 31, 1998. Through this effort, NASA is making a major contribution to the effective utilization of this band by providing timely propagation data and models for predicting the performance of Ka-band links between space and ground. The Eleventh ACTS Propagation Studies Workshop (APSW XI) was held in Oklahoma City, OK, at the Embassy Suites. This set of proceedings contains the presentations from that workshop.

This year the ACTS workshop focused on four areas:

1) Latest results and findings from ACTS propagation experimenters.
2) Theoretical and empirical considerations for propagation prediction models including interaction of precipitation with the antenna for design of satellite systems at Ka band.
3) Plans for dissemination of the findings of the ACTS Propagation Campaign.
4) Consideration of NASA’s ACTS blue ribbon panel findings regarding the ACTS propagation campaign.

Session 1, Spacecraft and Program Updates, chaired by R. Acosta, provided an overview of ACTS spacecraft and program status as well as an update on NASA propagation studies by N. Golshan.

Session 2, Status Reports, chaired by L. Ippolito, provided status reports from ACTS propagation experimenters at seven Ka-band measurement sites, a summary of attenuation observations for all seven sites, and a status report from the ACTS Propagation Data Center.

Session 3, Special Topics, chaired by J. Goldhirsh, included reports on propagation effects modeling and revision of NASA’s propagation handbooks.

Session 4, Propagation Campaign With ACTS in Inclined Orbit, chaired by R. Acosta, included a report by R. Bauer on the findings of NASA’s ACTS Blue Ribbon Panel regarding propagation experiments during ACTS inclined orbit, and a report by D. Westenhaver on propagation terminals tracking ACTS in inclined orbits. Session 5, Plenary, was chaired by R. Crane and D. Rogers.

The success of the meeting owes a lot to the speakers and session chairs and the active participation of all attendees. We would like to express our thanks to Ms. M. Wilkins of JPL and to Ms. C. Jones of the University of Oklahoma for meticulously caring for many administrative details of the meetings. Last but not least, we would like to thank Roger Carlson of the JPL technical information section for coordinating the publication of this document.

The next ACTS Propagation Studies Workshop will take place in conjunction with NASA Propagation Experimenters (NAPEX) Meeting in the greater Washington DC area in early June 1999; the exact date and location will be announced by January 1999.
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SESSION 1. SPACECRAFT & PROGRAM UPDATES

Chair: R. Acosta

(NASA/LeRC)
Spacecraft and ACTS Program Updates

R. Acosta

NASA/LeRC

APSW XI

October 22-23, 1998

Oklahoma City, OK 73108
• Original goal to maintain US pre-emminence in communications satellite technology
• Experiments began December 6, 1993.
• Initial 2 year mission extended (4 yr. design life) - sixth year now underway!
• Over 150 organizations involved in 92 experiments; 81 demonstrations to various audiences.

Launched September 12, 1993 aboard STS 51 - Discovery.
KEY ACTS TECHNOLOGIES

Ka-Band
- 30/20 GHz RF spacecraft & earth station components
- Adaptive rain fade compensation
- Propagation measurements to characterize band
- Only currently available 30/20 GHz satellite testbed in U.S.

High Gain, Fast Hopping Spot Beams
- EIRP > 64 dB
- G/T > 20 dB/K
- Frequency Reuse > 4

Onboard Processing & Switching
- Baseband Switching at 64 kbps circuit level
- Max throughput of 220 Mbps
- Full mesh, single hop connectivity
- Wideband Switch Matrix of 3 channels at 900 MHz each
EXPERIMENT AREAS

- Transition to commercial assets
- Networking and interoperability
- Inclined orbit operations
- Ka-band technology
NASA PROPAGATION STUDIES
STATUS
Nasser Golshan

Jet Propulsion Laboratory
California Institute of Technology
CURRENT FOCUS: ACTS PROPAGATION CAMPAIGN

OBJECTIVE OF ACTS PROPAGATION CAMPAIGN:

- To leverage NASA's Advanced Communications Technology Satellite (ACTS) to characterize radiowave propagation at Ka-band for utilization by U.S. industry and the space community

EXPECTED RESULTS & OUTPUTS OF THE ACTS PROPAGATION CAMPAIGN:

- Ka-band propagation data
- Prediction models of rain and atmospheric attenuation and scintillation
- Fade and nonfade distributions
- Frequency scaling models
- Diversity models
- Mitigation schemes for signal impairments due to propagation
- Wet antenna effect model
- Rain climate region map revision
- Revised propagation handbooks for design of satellite communications systems
- Contributions to regulatory organizations
# ACTS PROPAGATION CAMPAIGN MILESTONES

<table>
<thead>
<tr>
<th>MILESTONE</th>
<th>CALENDER YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>First planning workshop held in Santa Monica, Ca</td>
<td>1987</td>
</tr>
<tr>
<td>Announcement of Opportunity released</td>
<td>1989</td>
</tr>
<tr>
<td>Virginia Polytechnic Institute commissioned to develop the ACTS</td>
<td></td>
</tr>
<tr>
<td>Propagation Terminal</td>
<td></td>
</tr>
<tr>
<td>Terminals delivered and ACTS launched</td>
<td>1989</td>
</tr>
<tr>
<td>Two years (14 station-years) of ACTS propagation data distributed on CD-ROM</td>
<td>1993</td>
</tr>
<tr>
<td>Work started to use ACTS propagation data to revise propagation models</td>
<td>1996</td>
</tr>
<tr>
<td>and handbooks</td>
<td></td>
</tr>
<tr>
<td>Three years (20 station-years) of ACTS propagation data distributed on CD-ROM</td>
<td>1996</td>
</tr>
<tr>
<td>Revised propagation models and handbooks to be distributed</td>
<td>1997</td>
</tr>
<tr>
<td>Four years (27 station-years) of ACTS propagation data to be distributed</td>
<td>1998</td>
</tr>
<tr>
<td>on CD-ROM</td>
<td></td>
</tr>
<tr>
<td>Contributions to regulatory organizations to be made</td>
<td>1998-1999</td>
</tr>
<tr>
<td>Five years (34 station-years) of ACTS propagation data to be distributed</td>
<td>1999</td>
</tr>
<tr>
<td>on CD-ROM</td>
<td></td>
</tr>
<tr>
<td>ACTS transitions into inclined orbit</td>
<td>1999</td>
</tr>
</tbody>
</table>
NEW FOCUS FOR NASA PROPAGATION STUDIES

- Source of Funding for NASA Propagation Studies: NASA’s Cross Cutting Technology UPN 632-50
  - Entire 632 program managed through a GSFC Formulator (Gary Martin) and a JPL Implementor (Steve Prusha), with high level HQ oversight by Code SM
  - NASA Enterprises are the main customers for NASA’s Cross Cutting Technology
  - 632 program segregated into major “Thrust Areas”
  - Communications is part of “High Rate Knowledge Delivery” Thrust Area with manager at LeRC (TBD)
  - JPL Propagation Studies is part of Communications
- JPL Propagation Studies will focus on priorities of “High Rate Knowledge Delivery” as they are defined.
SESSION 2. EXPERIMENTS STATUS REPORTS

Chair: L. Ippolito

(Stanford Telecom)
MODEL COMPARISON AND VERIFICATION FOR SCINTILLATION, FADE DURATION, AND CLOUD EFFECTS

BRADLEY E. JAEGER, DONALD L. HOPKINS, DAE HONG KIM, AND CHARLES E. MAYER

I. Scintillations

Scintillation model predictions were compared to four years of the Fairbanks ACTS data at 20.2 and 27.5 GHz. Models used in the comparison are Karasawa et al. [1], ITU-R [2], Ortgies-N [3], Ortgies-T [3], DPSP (Direct Physical Statistical Prediction) [3], MPSP (Modeled Physical Statistical Prediction) [3], and Tervonen et al. [4]. Dependencies of these seven models are shown in Table 1. The monthly average for scintillation standard deviation, along with all the model predictions using the local meteorological parameter input, is plotted in Figs. 1 and 2 for 20.2 and 27.5 GHz respectively.

### Table 1. Scintillation Model Comparison

<table>
<thead>
<tr>
<th>Scintillation Model</th>
<th>Year</th>
<th>freq. dep.</th>
<th>sin θ dep.</th>
<th>Par.</th>
<th>H (m)</th>
<th>Data source</th>
<th>Regression</th>
<th>Model Restrictions</th>
<th>Fade/Enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karasawa, Yamada, Allnutt</td>
<td>1988</td>
<td>0.45</td>
<td>-1.3</td>
<td>N_wet</td>
<td>2000</td>
<td>Yamaguchi, Japan (11.45 GHz, 4,6,5,9°)</td>
<td>m vs. N_wet</td>
<td>7 - 14 GHz</td>
<td>Regres. m vs. variance</td>
</tr>
<tr>
<td>ITU - R</td>
<td>1990</td>
<td>0.583 (7/12)</td>
<td>-1.2</td>
<td>N_wet</td>
<td>1000</td>
<td>Darmstadt, Ger. (Oly)</td>
<td>ln(σ_e^2) vs. N_wet</td>
<td>6 - 20 GHz</td>
<td>Regres.</td>
</tr>
<tr>
<td>Ortgies-N</td>
<td>1993</td>
<td>0.605</td>
<td>-1.2</td>
<td>N_wet</td>
<td>1000</td>
<td>Darmstadt, Ger. (Oly)</td>
<td>ln(σ_e^2) vs. T</td>
<td>6.5 &lt; θ &lt; 30°</td>
<td>J Gauss. (sym.)</td>
</tr>
<tr>
<td>Ortgies-T</td>
<td>1993</td>
<td>0.605</td>
<td>-1.2</td>
<td>T</td>
<td>1000</td>
<td>Darmstadt, Ger. (Oly)</td>
<td>ln(σ_e^2) vs. T</td>
<td>6.5 &lt; θ &lt; 30°</td>
<td>J Gauss. (sym.)</td>
</tr>
<tr>
<td>DPSP- Direct Physical Statistical Prediction</td>
<td>1997</td>
<td>0.583</td>
<td>-1.2</td>
<td>T</td>
<td>2058 + 94.5 T</td>
<td>Louvain-la-Neuve, Bel. (12.5, 29.7) and Milan, Italy (19.8)</td>
<td>Ver. Refrac. gradient (radiosonde) to give ln(σ_e^2) vs. T</td>
<td>T &gt; -5 °C</td>
<td>J Gauss. (sym.)</td>
</tr>
<tr>
<td>MPSP- Modeled Physical Statistical Prediction</td>
<td>1997</td>
<td>0.583</td>
<td>-0.917</td>
<td>T</td>
<td>2058 + 94.5 T</td>
<td>Louvain-la-Neuve, Bel. (12.5, 29.7) and Milan, Italy (19.8)</td>
<td>Ver. Refrac. gradient (radiosonde) to give ln(σ_e^2) vs. T</td>
<td>T &gt; -5 °C</td>
<td>J Gauss. (sym.)</td>
</tr>
<tr>
<td>Tervonen, van de Kamp, Salonen</td>
<td>1998</td>
<td>0.45</td>
<td>-1.3</td>
<td>N_wet</td>
<td>P(Cu)</td>
<td>Kirkkonummi, Finland (19.8, 29.7)</td>
<td>σ_e vs. N_wet &amp; P(Cu)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mean hourly rms (dry)  
TU-R rms  
Karasawa rms  
Mean hourly rms (wet)  
Ortgies -N  
Ortgies -T  
Salonen  
DPSP  
MPSP

**Fig. 1.** 4 Year Comparison of Monthly Average 20 GHz RMS Deviation With Model Predictions

**Fig. 2.** 4 Year Comparison of Monthly Average 27 GHz RMS Deviation With Model Predictions

### II. Matricciani Fade Model

Table 2 indicates the place of the Matricciani fade model among other models of fade durations. The data used in the development of each model are listed along with the basic modeling technique. The Matricciani model is not an engineering model since it requires the user to have a rain rate time series but it may provide better prediction accuracy than other models. It is mostly a mathematical construction with only storm translation speed, v, obtained from radar measurements in northern Italy. Compared to other fade duration models it also has the advantage of being able to predict fade times. At present, the only other model to do this is the Paraboni and Riva model.
### Table 2. Fade Duration Model Comparison

<table>
<thead>
<tr>
<th>Model</th>
<th>Data Frequency</th>
<th>Data Location</th>
<th>Model Type</th>
<th>Engineering Model</th>
<th>Accounts for short fades</th>
<th>Predicts Fade Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matricciani [6], [7]</td>
<td></td>
<td>Po River Valley</td>
<td>Simulation with Synthetic Storm Technique</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Paraboni &amp; Riva [10]</td>
<td>11.6 GHz ITU Database</td>
<td>Fucino, Gera Lario, Spino d'Adda</td>
<td>Log-normal Long Durations</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ACTS Rain Prediction Model [11], [12]</td>
<td>NA</td>
<td>NA</td>
<td>Log-normal Attenuation Spatial Correlation of Rain Cells Probability of Rain on the Path</td>
<td>Yes</td>
<td>Yes (Rain)</td>
<td>No</td>
</tr>
</tbody>
</table>

![Fig. 3 Matricciani Rain Cell](image)

Fig. 3 shows the precipitation pattern used in the Matricciani fade model. The cell is rectangular with a layer of rain at 20° C and a melting layer at 0° C. The variation in attenuation with time is simulated by the convolution of a function of rectangular shape with specific attenuation from a rain rate time series. In the Matricciani model, this convolution is done using a product in the frequency domain.
\[ \hat{S}_A(f) = S_{r,A}(f) \cdot L_A \cdot \sin(f \cdot L_A / \nu(\theta)) \cdot \exp(-j \cdot 2 \cdot \pi \cdot f \cdot \Delta x_0 / \nu(\theta)) \]
\[ + r_{\alpha}^a \cdot S_{\Delta L}(f) \cdot \Delta L \cdot \sin(f \cdot \Delta L / \nu(\theta)) \]

(1)

The sinc functions result from the rectangular cell and the exponential is a shift due to the difference in path lengths, \( \Delta x \). There is an extra term \( r_{\alpha}^b \) to account for the extra attenuation due to the melting layer. The simulated attenuation time series is then the inverse Fourier transform of (1). Fade durations greater than 60 seconds were then calculated from this attenuation time series. Statistics were recorded for the number of fades and the fade time. Since the Matricciani model attempts to account for fades from rain only, the statistics from the model were compared to statistics from measured ACA. Errors were measured for percentage of fade time and percentage of fades. The error at a given percentage and attenuation threshold was taken as

\[ \varepsilon = \ln \left( \frac{FD_{ACA}}{FD_{Matricciani}} \right) \]

(2)

Table 3 gives a summary of these errors for four years of Fairbanks data.

**TABLE 3. MATRICCIANI MODEL ERRORS (DECEMBER, 1993-NOVEMBER, 1997)**

<table>
<thead>
<tr>
<th>Number of Fades</th>
<th>Fade Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 dB ACA</td>
<td>3 dB ACA</td>
</tr>
<tr>
<td>20 GHz avg</td>
<td>0.022558</td>
</tr>
<tr>
<td>20 GHz rms</td>
<td>0.071022</td>
</tr>
<tr>
<td>27 GHz avg</td>
<td>0.037327</td>
</tr>
<tr>
<td>27 GHz rms</td>
<td>0.143645</td>
</tr>
</tbody>
</table>

The positive signs in front of errors in table 3 indicate that in all but one case the Matricciani model underpredicts both the number of fades and the fade time. Fig. 4 and 5 show graphically how well the Matricciani model predicts number of fades and fade time at 27.505 GHz for a representative year in Fairbanks, December 1996-November 1997.

![Fig. 4 - Number of 27 GHz ACA Fades Compared to the Matricciani Model.](image-url)
Fig. 5 - 27 GHz ACA Fade Time Compared to the Matriccianni Model.

Fig. 6 shows attenuation cumulative distribution function for the Matriccianni model compared to an ACA cdf at 27.505 GHz for a representative month at Fairbanks. The two dashed curves are model curves. There is one for optical gauge rain rate, ORR, and one for capacitive gauge rain rate, CRR. The ACA curves fall above the model curve for low attenuations. It may be that if the Matricciani model had a development accounting for antenna wetting this discrepancy would be resolved.

Fig. 6 - (June, 1997) 27.505 GHz ACA Compared to the Matricciani Model.
III. ACTS Data Correlated to Gaseous, Rain, and Cloud Attenuation Models

This section explores correlation of received ACTS beacon values to atmospheric attenuation by adapting National Climatological Data Center (NCDC) data used in clear sky (gaseous), rain, and cloud attenuation models. Attenuation due to clear sky and rain utilize ITU-R semi-empirical attenuation models, however cloud attenuation is more difficult to model due to highly variable cloud structures. Prior to July 1996, NCDC cloud cover data is recorded in tenths of total cover, with 10/10 = total cover. After June 96 NCDC recorded cloud data format changed, listing only five cloud cover increments: 0 (SKC or CLR), 1/8-1/4 (FEW), 3/8-1/2 (SCT), 5/8-7/8 (BKN), and 8/8 (OVC), and up to four distinct cloud ceilings. Cloud attenuation models are investigated, but require knowledge of the density of water (g/m$^3$) along the propagation path, which is generally not known. A SkyCam (modified digital camera) is used to help correlate viewed cloud conditions to NCDC published values. This section will show how recorded ACTS propagation data compares to the sum of attenuation from the three propagation models.

A. ACTS Data Collection Procedure

The first step in the analysis is to collect ACTS data in a form, which will allow comparisons over a long period. To accomplish this, a special program (Donext3.exe) was developed by Dave Westenhaver of Westenhaver Wizard Works to take preprocessed ACTS data and extract only the first minute of data (60 samples) from each hour selected. After this data is extracted, the next step is to limit the range of data to values greater than a threshold of -19 dB. This threshold is chosen since any values lower than this are considered below the noise floor of the equipment. After these erroneous values are eliminated, the remaining values for the minute are manipulated, where the average, maximum, and minimum values are saved for use in attenuation and scintillation studies. Finally the values (one per hour from hh:00:00 to hh:00:59) are collected and placed into a set of yearly ACTS averaged data for use in EXCEL. Averaging, saving maximum/minimum values, and compiling the data is done via an EXCEL macro specially developed for this purpose. Fig. 7 shows pictorially the data collection process and a sample of the collected data.

![Conversion of Processed ACTS Beacon Data to EXCEL Data](image-url)
B. Compiling NCDC Weather Data Used In The Analysis

Once the data is collected, the next step is to compile a set of weather data for the Fairbanks area. Required weather data used in the attenuation models includes: temperature (°C), relative humidity (%), rain rate (mm/hr), cloud cover (10ths), and cloud ceiling (m). NCDC weather data is published monthly (with about a one-month delay) and is available to users from any local National Weather Service office in print form and is also available on a fee basis via the Internet. One exception to the fee based data requires an educational (.edu) address on the requester's internet server. Of course other sources of local weather data exist. For this analysis much of the data is collected from a CD published by NOAA and available at the UAF's Rasmussen library. A variety of weather data is available in hourly readings/summaries (including many of the required types) for years up to 1995. Data is recorded using local standard time and correlation to ACTS data requires an appropriate time shift. The only weather parameter required for the attenuation models not included is rain rate, however the total accumulation is included for the preceding hour in the data. In this analysis rain rate is estimated as (total accumulation for the hour)/(one-hour), giving an estimated rain rate for each sample period.

C. Modeling of Gaseous Attenuation

The first element of the analysis is to model the gaseous attenuation for the ACTS to Fairbanks slant path. The gaseous (clear-sky) attenuation model is by the CCIR (1990) in Report 719 [14], which is a semi-empirical model used to estimate the amount of gaseous attenuation. This model takes into account atmospheric gases attenuating effects due to oxygen and water vapor (not including water vapor in cloud structures). This commonly referenced attenuation model utilizes signal and weather data including:

\[
\begin{align*}
\text{f} &= \text{Frequency (GHz)} \\
\text{T} &= \text{Temperature (°C)} \\
\theta &= \text{Elevation angle (°)} \\
\rho &= \text{Water Vapor Density (g/m}^3\text{)} \\
\text{RH} &= \text{Relative Humidity (％)} \\
\text{Rain} &= \text{yes/no (relates to scale height of ρ)}
\end{align*}
\]

Calculations used in the gaseous attenuation analysis are included in Appendix B. Once the attenuation values are calculated, they are placed into a spreadsheet and correlated to the averaged ACTS beacon values. Fig. 8 shows the results of the comparison. Note the seasonal trends show nicely on the plots, but deep fades are not tracked since they are due to rain attenuation, studied next. Also note the correlation coefficients shown in the plots where the 20 GHz (89.1%) is better correlated than the 27 GHz (76.7%). This difference is mainly due to the higher variability of the 27 GHz signal.

![Fig 8 - Gaseous Attenuation vs. Averaged ACTS Beacon Values](image)

D. Modeling of Rain Attenuation
Rain is the most severe attenuating factors in radiowave propagation, especially at higher frequencies. Even though this is the case, accurate measurement of rain rate (usually measured in mm/hr) during a rain event are not easily obtained. Errors exist from many sources including spatial diversity where the rain is falling in the propagation path, but not at the measurement site. Fig. 9 [15] shows sources of error for horizontal (LH) and vertical (Lv). In addition most conductive rain cells have widely varying amounts of rain rates throughout the cell and the rain gauge is usually at one position. In this instance there are errors induced, since NCDC data is used as the source of rain rate data and the Fairbanks weather station is approximately 3 km from the ACTS terminal.

![Fig 9 - Spatial Errors in Measuring Path Rainfall Rate](image)

Now given a rain rate (approximated as total rain for the hour per hour) the only missing variable in the equation is the effective path length. For this approximation another piece of information is necessary, rain elevation within the cloud layer. Initially it was hoped that NCDC cloud ceiling represented the bottom of the rain, however published values did not seem to relate to the heights of rain-bearing clouds. Also values for cloud ceiling are not consistently available, so ITU recommendation RPN.618-4, 1996 gives a method to estimate the effective slant path length of the rain layer below the freezing height. Calculations required to estimate rain attenuation are shown in Appendix C, where only knowledge of station latitude is required to estimate the effective rain path [16].

One approximation made is there will be no rain, although there may be snow, for ground temperatures less than −1°C. Liquid water in the form of rain is a strong attenuator of radio waves at ACTS frequencies, whereas snow mainly attributes to depolarization, which is not easily extracted from the ACTS data. NCDC data shows equivalent precipitation and does not differentiate this rain from snow. Luckily the transition of rain to snow occurs over a short period of the year in Fairbanks and should not skew the approximation significantly. Also to help account for the estimated rain rate experienced during the sampled period a value of 1.3 times the hourly rain accumulation from the NCDC data adjusts the hourly rate to an empirically defined rate (mm/hr) for the sample period. This 1.3 factor is determined from looking at the differences between the modeled gaseous + rain attenuation values, where the correlation of the two data sets is minimized for attenuation greater than 3 dB. Without more accurate radiosonde or real time rain rate data available, this approximation will certainly include errors, but the goal is to determine if NCDC data is usable to estimate rain attenuation with any degree of accuracy. Fig. 10 shows the results of the comparison, including modeled gaseous and rain attenuation.
It is interesting to note in Fig. 10 the deep fades, although not exactly correlated to the ACTS data, provide a better estimate of the actual performance of the satellite link based on the two models. One surprising result is the correlation of the two data sets did not improve with the added attenuating factor; in fact the correlation is slightly worse, 20 GHz from 89.1% to 88.9% and 27 GHz from 76.7% to 76.1%. This is probably due to an assumed "mismatch" of the estimated rain data and the ACTS beacon data. An analysis of the differences between the modeled attenuation and the actual ACTS data is performed using an absolute difference between the two values and calculating the differences in percent of total. This comparison is shown in Fig. 11. Note a difference of only 2 dB excludes all but 0.78% at 20 GHz and all but 1.81% at 27 GHz.

Fig 10 – Gaseous + Rain Attenuation vs. Averaged ACTS Beacon Values

The overall trends in Fig. 10 show a slight discrepancy between the ACTS beacon values and the gaseous + rain attenuation models (like a dc offset) for the summer months, thus in the next section a cloud attenuation model is defined to help counteract this.
E. Modeling of Cloud Attenuation

The attenuating effects of clouds on a satellite link may not have as dramatic effect as the gaseous or rain attenuation, but clouds may be present for a significant amount of time in the propagation path. Rain on the other hand is usually limited to short-term duration events. Clouds contain a combination of suspended water droplets and if conditions allow ice crystals. The suspended water droplets change the dielectric properties of the propagation path and effect via absorption/scattering the propagating radiowave. To begin with an analysis of various types of clouds generally observed and their inherent properties is appropriate.

Haroules and Brown measured cloud attenuation in 1969 [17] at frequencies of 8, 15, 19, and 35 GHz also at frequencies of 15 and 35 GHz by Alshuler. Using these studies and others, water density of many cloud types has been estimated. Slobin [17] lists typical parameters of clouds in mid-latitude conditions. This approximation is not truly suited for Alaska conditions, however during the summer in Fairbanks many of the cloud structures present are similar to those described. The next element in any model are the equations necessary to predict cloud attenuation. E. Salonen and S. Uppala [18] formed a model to predict the specific attenuation of clouds for frequencies above 20 GHz. Their model is based on Liebe’s MPM model [19]. The evaluation of this model uses the parameters shown in Appendix D.

Next Fig. 12 shows Slobin’s results and lists 15 different cloud types at mid-latitudes, their specific water density (g/m³), and typical heights above the ground (m) for top and bottom of each type of the 15 types of cloud structures. These 15 cloud types are grouped and adjusted such that the parameters for each cloud type (specific water density (g/m³) and effective depth) when evaluated using the equations in Appendix D, represent attenuation values observed by correlating ACTS data and SkyCam views, discussed in the next section. Note in Fig. 12, effective path is only an estimate using estimated top and bottom as a guide.

**Slobin’s Cloud Types**

<table>
<thead>
<tr>
<th>Cloud Type</th>
<th>Density (g/m³)</th>
<th>Height Above Ground (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Fog 1</td>
<td>0.15</td>
<td>Bottom: 100, Top: 150</td>
</tr>
<tr>
<td>Heavy Fog 2</td>
<td>0.10</td>
<td>Bottom: 0, Top: 75</td>
</tr>
<tr>
<td>Moderate Fog 1</td>
<td>0.06</td>
<td>Bottom: 0, Top: 25</td>
</tr>
<tr>
<td>Moderate Fog 2</td>
<td>0.02</td>
<td>Bottom: 0, Top: 5</td>
</tr>
<tr>
<td>Cumulus</td>
<td>0.50</td>
<td>Bottom: 600, Top: 2300</td>
</tr>
<tr>
<td>Altocumulus</td>
<td>0.45</td>
<td>Bottom: 600, Top: 2000</td>
</tr>
<tr>
<td>Nimbostratus</td>
<td>0.60</td>
<td>Bottom: 600, Top: 1000</td>
</tr>
<tr>
<td>Stratus</td>
<td>0.42</td>
<td>Bottom: 600, Top: 600</td>
</tr>
<tr>
<td>Stratus</td>
<td>0.29</td>
<td>Bottom: 350, Top: 1000</td>
</tr>
<tr>
<td>Stratus-stratocumulus</td>
<td>0.13</td>
<td>Bottom: 600, Top: 2000</td>
</tr>
<tr>
<td>Stratus-stratocumulus</td>
<td>0.09</td>
<td>Bottom: 150, Top: 600</td>
</tr>
<tr>
<td>Nimbostratus</td>
<td>0.06</td>
<td>Bottom: 600, Top: 2700</td>
</tr>
<tr>
<td>Stratus-stratocumulus</td>
<td>0.07</td>
<td>Bottom: 600, Top: 3400</td>
</tr>
</tbody>
</table>

**New Cloud Models**

<table>
<thead>
<tr>
<th>Cloud Type</th>
<th>% Coverage</th>
<th>Density (g/m³)</th>
<th>Estimated Cloud Thickness</th>
<th>Estimated Cloud Top</th>
<th>Effective Path (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nimbostratus</td>
<td>0.8</td>
<td>0.10</td>
<td>350</td>
<td>1820</td>
<td>1900</td>
</tr>
<tr>
<td>Altocumulus</td>
<td>0.6</td>
<td>0.15</td>
<td>355</td>
<td>1975</td>
<td>1900</td>
</tr>
<tr>
<td>Cumulus</td>
<td>0.2</td>
<td>0.35</td>
<td>600</td>
<td>2500</td>
<td>2700</td>
</tr>
<tr>
<td>Cirrus</td>
<td>0.2</td>
<td>0.21</td>
<td>2400</td>
<td>2500</td>
<td>2400</td>
</tr>
<tr>
<td>Stratus</td>
<td>0.2</td>
<td>0.35</td>
<td>600</td>
<td>3700</td>
<td>3500</td>
</tr>
</tbody>
</table>

Fig 12 – Conversion of Slobin’s 15 Cloud Types to New Model Cloud Types

Next the NCDC data is adapted to convert specific cloud coverage and ceiling data to these newly defined cloud types and then the calculations for cloud attenuation are performed. Fig. 13 shows a flowchart of how the clouds are classified and the parameters used in the model.

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The next step is to calculate the attenuation due to clouds, then add this attenuation to gaseous and rain attenuation values, calculated earlier. Fig. 14 shows the results of this comparison. Note in this figure the dc offset noted earlier is not observed.

Again an analysis of the differences between the modeled attenuation and actual ACTS data is performed using an absolute difference between the two values and calculating the differences in percent of total. This comparison is shown in Fig. 15. Note a difference of only 2 dB excludes all but 0.62% at 20 GHz and all but 1.32% at 27 GHz, an improvement over the model with only gaseous and rain attenuation values. The final comparison is when smaller time frames (one day) of three-part attenuation is correlated with the ACTS data. This comparison is shown next.
Fig 15 – Compare Gaseous + Rain Attenuation vs. Averaged ACTS Beacon Values

F. Comparison of One-Day Cloud Attenuation for Various Cloud Types

To ensure an accurate evaluation of cloud attenuation, a SkyCam is used to capture sky views and these views are used to coordinate cloud structures with observed ACTS attenuation. A sample of the SkyCam views and a schematic of the SkyCam apparatus are shown in Fig. 16.

![SkyCam Schematic](image)

FIELD OF VIEW - 6.1°

Fig 16 – SkyCam & Sample Views

The first type of cloud structure examined is that of cumulus clouds at/above cloud ceiling of 1500 meters. Fig. 17 shows the correlation of the ACTS beacons with the modeled attenuation. Also shown is the differences of the models with and without cloud attenuation and whether the models under or over predict the actual averaged ACTS attenuation. The curves on the right portion of the plot are when rain occurred in the signal path; otherwise where the cloud is noted the modeled attenuation tracks well with the actual data.

![Comparison of Cumulus Clouds At/Above 1500 m vs. Averaged ACTS Beacon Values](image)

Fig 17 – Compare Cumulus Clouds At/Above 1500 m vs. Averaged ACTS Beacon Values
Another type of cloud is that of a cumulus at a lower elevation, however this time about the cloud is at a ceiling of 500 meters and there is no rain present in the path. The comparison for this type of NCDC defined cloud type is shown in Fig. 18. Note in this case addition of cloud attenuation alters the difference and provides a better fit to the ACTS data.

![Fig. 18 - Compare Cumulus Clouds At ~ 500 m W/o Rain vs. Averaged ACTS Beacon Values](image)

Another type of cloud examined is that of a stratocumulus. Fig. 19 shows the comparisons for this type of cloud structure. Again the addition of the cloud attenuation improves the fit to the recorded ACTS data.

![Fig. 19 - Compare Stratocumulus Clouds At < 2000 m vs. Averaged ACTS Beacon Values](image)

The final type of cloud examined is that of an altostratus. This comparison is shown in Fig. 20. In this case the cloud attenuation is not of significant effect and does not significantly improve the fit.

![Fig. 20 - Compare Altostratus Clouds 2000 < h < 2900 m vs. Averaged ACTS Beacon Values](image)
G. Statistical Analysis of the Models

Up until now the values of attenuation have been evaluated relative to the ACTS averaged beacons, however many systems designers like to see statistics on the data. To compile a statistical analysis the Averaged ACTS beacon values are divided into 'bins' where values greater than a set attenuation value are collected and then a percentage is taken over the data set total, this is commonly known as a CDF. Fig. 21 shows the set of CDF data collected for the three types of modeled attenuation and the of the averaged ACTS data. As is shown in the figure, the 27 GHz models indeed do a very good job of predicting the attenuation of the ACTS-to-Fairbanks although the 20 GHz comparison is not as good, still represents a fair estimate of the link propagation statistics.

![20 ACTS Average Beacon vs. Attenuation Models](image1)
![27 ACTS Average Beacon vs. Attenuation Models](image2)

Fig. 21 -- CDF of ACTS Averaged Beacons vs. Modeled Attenuation

IV. Conclusions

The Ortgies-N scintillation prediction model best matches the ACTS data at Fairbanks, out of the seven models that we examined.

The Matricciani fade model was shown to underpredict both the number of fades and fade time for clear air attenuation. Subjectively, the magnitudes of the prediction errors are smaller for this model than for other fade prediction models.

In this study it is shown how NCDC weather data may be used with accepted CCIR gaseous and rain attenuation models and do a good job of estimating the actual ACTS performance for the ACTS-to-Fairbanks link. However with the addition of an empirically defined cloud attenuation model, the data fit is even better. Individual cloud types are examined and attenuation during specific cloud occurrences is determined. An interesting conclusion is that while the additional cloud attenuation by itself is not significant (when compared to gaseous and rain attenuation), it provides enough adjustment to improve the overall CDF. The end result is that given easily available NCDC weather data (with slight alterations), and CCIR gaseous and rain attenuation models along with an empirically defined cloud attenuation model, a reasonable prediction of the performance of satellite to ground propagation characteristics at ACTS frequencies can be made.
**APPENDIX A - Calculation of Power Law Parameters for Matricciani Fade Duration Model at Fairbanks**

\[ \theta = 64.86 \]
\[ h = 0.4 \]
\[ H_f (\phi) = 5.0 - 0.075 \cdot (\phi - 23.0) \]
\[ H_f (\phi) = H_f (\phi) - h \]
\[ H_f = 0.13716 \]
\[ \beta = \frac{7.92 \cdot 2 \cdot \pi}{360} \]
\[ L_x = \frac{H_f (\phi) - H_f}{\sin(\theta)} \]
\[ L_y = \frac{H_f (\phi) - H_f}{\sin(\theta)} \]
\[ r = 3.134 \]
\[ \Delta x = \frac{h}{\tan(\theta)} \]
\[ \alpha = \frac{64.86 \cdot 2 \cdot \pi}{360} \]
\[ \beta = \frac{(260 - (360 - 147.82)) \cdot 2 \cdot \pi}{360} \]
\[ \tau = \alpha \tan \left( \frac{\tan(\alpha)}{\tan(\beta)} \right) \]

Using Maggiori [9] power law parameters for 20 °C at 20, 25, and 30 GHz the interpolations for 20.185 and 27.505 GHz are:

\[
\begin{align*}
  k_h &= 10 \times \log \left( \frac{20.185}{25} \right) + \log(0.0751) \\
  k_v &= 10 \times \log \left( \frac{20.185}{25} \right) + \log(0.0691) \\
  a_h &= (1.061 - 1.099) \cdot \log \left( \frac{20.185}{20} \right) + 1.099 \\
  a_v &= (1.03 - 1.065) \cdot \log \left( \frac{20.185}{20} \right) + 1.065 \\
  k &= \frac{(k_h - k_v) + (k_h - k_v) \cdot \cos(\phi)^2 \cdot \cos(\tau)}{2} \\
  k_20 &= 0.07126363 \\
  a_20 &= \frac{k_h + k_v + a_h + a_v + (k_h - k_v + a_h - a_v) \cdot \cos(\phi)^2 \cdot \cos(2 \cdot \tau)}{2 \cdot k_20} \\
  a_20 &= 1.0677614815
\end{align*}
\]
Using Maggiori [9] power law parameters for 0 °C at 20, 25, and 30 GHz the interpolations for 20.185 and 27.505 GHz are:

\[
\begin{align*}
k_{20} &= (k_{20} - k_{27}) + (k_{20} - k_{27}) \cdot \cos(\theta) \cdot \cos(\tau - 2) \\
k_{20} &= 0.0630989053 \\
\alpha_{20} &= \frac{(k_{20} \cdot a_{20} + k_{20} \cdot \alpha_{20} + (k_{20} \cdot k_{20} - k_{20} \cdot \alpha_{20}) \cdot \cos(\theta)^2 \cdot \cos(2 \cdot \tau))}{2 \cdot k_{20}} \\
\alpha_{20} &= 1.0710708332
\end{align*}
\]
\[
\begin{align*}
\log(\frac{1.811}{1.159}) + \log(\frac{27.505}{25}) + \log(0.1159) \\
kh_{27} &= 10 \\
\left(\log(\frac{1.59}{1.128}) + \log(\frac{27.505}{25}) + \log(0.1028)\right) \\
kv_{27} &= 10 \\
\log(\frac{27.505}{25}) + \log(0.30) + \log(0.25) \\
\alpha_{h_{27}} &= (1.035 - 1.081) + 1.035 \\
\log(\frac{27.505}{25}) + \log(0.30) + \log(0.25) \\
\alpha_{v_{27}} &= (1.018 - 1.054) + 1.018 \\
k_{27} &= \frac{(kh_{27} - kv_{27}) + (kh_{27} - kv_{27}) \cdot \cos(\theta)^2 \cdot \cos(\theta - 2)}{2} \\
k_{27} &= 0.1311683662 \\
\alpha_{27} &= \frac{(kh_{27} - kv_{27}) + (kh_{27} - kv_{27}) \cdot \cos(\theta)^2 \cdot \cos(\theta - 2)}{2} \cdot k_{27} \\
\alpha_{27} &= 1.0006591497
\end{align*}
\]

**APPENDIX B - Calculation of CCIR-Defined Gaseous Attenuation**

CCIR Gaseous (Oxygen & Water Vapor) Attenuation Model Equations for \( f < 57 \) GHz:

\[
\begin{align*}
\alpha_{10} &= \alpha_{10} + \frac{6.09}{r^2 + 0.227 (f - 59)^2 + 1.5} \ [\text{dB/km}] \\
\alpha_{20} &= \alpha_{20} + \frac{6.09}{r^2 + 0.227 (f - 59)^2 + 1.5} \ [\text{dB/km}] \\
h_{56} \text{ km} &= \frac{1}{3} \left[ \frac{1}{r^2 + 0.227 (f - 59)^2 + 1.5} + \frac{8.9}{r^2 + 0.227 (f - 59)^2 + 1.5} \right] \ [\text{km}] \\
\text{where:} \\
h_{56} \text{ km} &= \text{clear, weather} = 2.1 \text{ km [rain]} \\
p &= \frac{\text{RH}}{R_u (T + 273)} \ [\text{millibars}] \\
\text{RH} &= \text{Relative Humidity [\%]} \\
\text{Correction Factors for Temperature Variances (Stated Range of Accuracy -20 °C to 40 °C):} \\
\alpha_{20, a_{h_{o}}} &= 0.01 \alpha_{20, a} \ [T - 15 °C] \\
\alpha_{20, a_{w}} &= 0.01 \alpha_{20, a} \ [T - 15 °C] \\
h_{20, b_{v_{o}}} &= 0.01 h_{56} \ [T - 15 °C] \\
h_{20, b_{w}} &= 0.01 h_{56} \ [T - 15 °C] \\
\text{Zenith Attenuation:} \\
A_{\theta} &= \frac{\sqrt{\alpha_{20, a_{h_{o}}} + \alpha_{20, a_{w}} + \alpha_{20, b_{v_{o}}} + \alpha_{20, b_{w}}}}{\sqrt{\cos(\theta)}} \ [\text{dB}] \\
\text{Correction for Non-Zenith Propagation Paths With Elevation Angles} \\
\theta < 10^\circ: \\
A_{\theta} &= \frac{\sqrt{\alpha_{20, a_{h_{o}}} + \alpha_{20, a_{w}} + \alpha_{20, b_{v_{o}}} + \alpha_{20, b_{w}}}}{\sqrt{\cos(\theta)}} \ [\text{dB}] \\
\text{where:} \\
f(x) &= \frac{1}{0.661 x + 0.339 \sqrt{x^2 + 5.31}}
\end{align*}
\]
APPENDIX C - Calculation of CCIR-Defined Rain Attenuation

CCIR Rain Attenuation Model Equations For ACTS Beacons (20.185 GHz Shown):

Evaluation of Site Tilt Angle:

\[ \tau = \arctan \left( \frac{\tan(\alpha)}{\sin(\beta)} \right) \]

(a = Earth_Station_Latitude  \beta = Satellite_Longitude - Earth_Station_Longitude

\[ \alpha = 64.7 \text{ deg} \]

\[ \beta = [360 - 100] \text{ deg} - (360 - 147.8) \text{ deg} \]

\[ (+ \text{ Northern Hemisphere}) \]

\[ (\text{Measured in Degrees East}) \]

\[ \theta = 8 \text{ deg} \] (Elevation Angle)

Calculate the Regression Coefficients Used in The Calculations, \( k \) and \( \alpha \):

\[ k_{1H} = 0.0751 \]

\[ k_{2H} = 0.124 \]

\[ f_1 = 20 \]

\[ f_2 = 25 \]

\[ \alpha_{1H} = 1.099 \]

\[ \alpha_{2H} = 1.061 \]

\[ k_{1V} = 0.0691 \]

\[ k_{2V} = 0.113 \]

\[ f_1 = 20 \]

\[ f_2 = 25 \]

\[ \alpha_{1V} = 1.065 \]

\[ \alpha_{2V} = 1.030 \]

\[ k_H := 10 \]

\[ k_V := 10 \]

\[ k_H = 0.07667 \]

\[ k_V = 0.07052 \]

\[ \alpha_H := \left( \alpha_{2H} - \alpha_{1H} \right) \]

\[ + \alpha_{1H} \]

\[ \alpha_V := \left( \alpha_{2V} - \alpha_{1V} \right) \]

\[ + \alpha_{1V} \]

\[ k_{20.185} := \frac{k_H + k_V + (k_H - k_V) \cos(\theta \text{ deg})^2 \cos(2 \tau)}{2} \]

\[ \alpha_{20.185} := \frac{k_H \alpha_H + k_V \alpha_V + (k_H \alpha_H - k_V \alpha_V) \cos(\theta \text{ deg})^2 \cos(2 \tau)}{2 k_{20.185}} \]

Values of \( \alpha \) & \( k \):

\[ k_{20.185} = 0.07119 \]

\[ \alpha_{20.185} = 1.06754 \]

Site Information:

\[ \phi = 64.7 \] (Station Latitude)

\[ \theta = 8 \text{ deg} \] (Elevation Angle)

\[ h_s = 580 \text{ ft} \] (Station Elevation)

Calculations:

Find the freezing height during rain (hfr):

\[ h_{fr} := \left[ 5.0 - 0.075 \cdot (\phi - 23) \right] \text{ km} \]

(For Latitudes > 23°)

Find the effective path length (Ls):\n
\[ h_{fr} - h_s = 1.696 \cdot \text{km} \]

\[ L_s := \frac{(h_{fr} - h_s)}{\sin(\theta)} \]

\[ L_s = 12.184 \cdot \text{km} \]
APPENDIX D - Calculation of Cloud Attenuation

Specific attenuation due to clouds is of the form:

$$\gamma_c(f) = 0.182 \cdot f \cdot \text{N}_w$$

Where:

- $f = \text{frequency in G}\text{Hz}$
- $\text{N}_w = \text{the imaginary part of the complex refractivity in ppm (10}^{-4})$
- $\text{w} = \text{the liquid water density in g/m}^3$
- $\eta = \frac{(2 + \varepsilon)}{\varepsilon'}$

Where $\varepsilon'$ and $\varepsilon''$ are the real and imaginary parts of the permittivity of water.

(The double Debye relaxation model gives the dielectric spectra for water as below)

$$\varepsilon'(f) = \frac{\varepsilon_0 - \varepsilon_1}{1 + \left(\frac{f}{f_p}\right)^2} + \frac{\varepsilon_1 - \varepsilon_2}{1 + \left(\frac{f}{f_s}\right)^2}$$

$$\varepsilon''(f) = \frac{f\cdot(\varepsilon_0 - \varepsilon_1)}{1 + \left(\frac{f}{f_p}\right)^2} + \frac{f\cdot(\varepsilon_1 - \varepsilon_2)}{1 + \left(\frac{f}{f_s}\right)^2}$$

Where:

- $f = \text{frequency (G}\text{Hz)}$
- $\varepsilon_0 = 77.66 + 103.3\cdot(0 - 1)$
- $\varepsilon_1 = 5.48$
- $\varepsilon_2 = 3.51$
- $f_p = 20.09 - 142\cdot(0 - 1) + 294\cdot(0 - 1)^2$ (G}\text{Hz})$
- $f_s = 590 - 1500\cdot(0 - 1)$ (G}\text{Hz})$

Liquid water content is found from:

$$w = w_o \cdot (1 + \frac{h}{h_r})$$

Where:

- $w_o = \text{the liquid water content of the cloud}$
- $h = \text{height from cloud base (m)}$
- $h_r = \text{reference height (m)}$

$$p_w = \begin{cases} \frac{g}{m^3} & \text{for } -20 \text{°C < t < 0 °C} \\ \frac{1}{m^3} & \text{for } t < -20 \text{°C} \\ 0 & \text{for } t > 0 \text{°C} \end{cases}$$

Distance (km) = \frac{\text{Effective Path(km)}}{\sin(\theta)}

Attenuation (dB) = Distance (km) \cdot \gamma_c(f) (\frac{\text{dB}}{\text{km}})

REFERENCES


UBC ACTS Terminal Operation and Maintenance

Bruce Dow,
Scientific Engineer,
UBC Electrical and Computer Engineering

ACTS Propagation Studies Workshop, Oklahoma City, 22-23 October, 1998
UBC ACTS Terminal Operation and Maintenance


- Preprocessing and Calibration Issues.

- Summary
Terminal Operation and Maintenance Summary

- The Collection Computer and associated ACTS laboratory setup were moved from the Fourth Floor to the Penthouse of the Electrical Engineering Building.

- This was accomplished with less than one half-hour of total downtime.
Terminal Operation and Maintenance Summary

- The Young capacitive rain gauge was received back from being repaired and calibrated, and was re-installed on the roof. Correct operation and calibration were verified.

- The amplifier enclosure of the CTS-10 Coordinated Time Link antenna was opened, inspected, cleaned out, and sealed with silicone seal before being put back into service. This preventative maintenance was suggested by Mr. Westenhaver.
Terminal Operation and Maintenance Summary

- A 48-hour power outage was scheduled for the Electrical Engineering Building. In order to maintain data collection during this time, a long extension cord was run from an adjacent building to power the terminal. This solution was suggested by Mr. Westenhaver.
Preprocessing and Calibration Issues

- Weather data for the first three years was obtained from Vancouver International Airport in electronic form. We now have Airport data for the first four years.

- Mr. Westenhaver converted the weather data into *.SRF files for use with ACTPP.
Preprocessing and Calibration Issues

- CRC decided to have the entire first four years of data from UBC preprocessed again by Xuhe Wang of the University of Oklahoma.

- Electronic copies of the site logs were sent to Xuhe Wang along with the *.SRF files.
Preprocessing and Calibration Issues

- Collaboration between the University of Oklahoma and UBC ensured a consistent treatment of past and future data. This included reaching an agreement on the proper calibration levels for all data.

- After looking at the first four years of data, Dr. Crane and Mr. Westenhaver provided recommendations on how to handle the problem of moisture in the feed horn.
Summary

- The terminal is in good condition. No problems are foreseen in collecting the remainder of the five years of data.

- Preprocessing of the fifth year of data is underway. Purchasing Airport weather data for the fifth year is being considered.
Young Capacitive Rain Gauge Calibration at UBC Site 980721

ACTS Propagation Studies Workshop, Oklahoma City, 22-23 October, 1998
ACTS Propagation Measurements in Vancouver

- Climatic characteristics at Vancouver
- Comparison of Measured Statistics with Prediction Models
- Summary
Climatic characteristics at Vancouver

- Pacific maritime climate. Little heavy rain but a great deal of widespread drizzle and lower-rate rainfall.
- Long-term annual average rainfall at the Vancouver Int. Airport: about 1020 mm. Average annual snowfall: 60 cm.
- Average daily temperature: from 0°C to 24°C over the year.
- Vancouver falls in rain zone D in the ITU-R classification and in rain zone B1 in the Crane's Global classification.
- Measured rain rate level for 0.01% of time: 13 mm/hr.
  (Measurements over a ten-year period at the Vancouver International Airport*).

* The Vancouver International Airport is located some 8 km south of the UBC site.
Rain Accumulation at Vancouver 1994-1997

Precipitation Departures from Normal (above/below the average of last 50 Years)

Source: Environment Canada
- Average precipitation and temperature were above normal in 1997 along much of the Pacific Coast
- 1997 averaged about 17% wetter than normal along the Pacific Coast, representing the 2nd wettest year in the last half century
- Temperature was close to two degrees warmer than normal over the course of the year
- 1997 was drier than normal in eastern Canada

### Seasonal and Annual Average Freezing Level Heights
(km above ground level)

<table>
<thead>
<tr>
<th>Station</th>
<th>Lat. N (deg.)</th>
<th>Long. W (deg.)</th>
<th>Height (m.a.s.l.)</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
<th>Annual average</th>
<th>ITU-R formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vernon B.C.</td>
<td>50.14</td>
<td>119.17</td>
<td>555</td>
<td>0.89</td>
<td>1.42</td>
<td>2.71</td>
<td>1.78</td>
<td>1.70</td>
<td>2.96</td>
</tr>
<tr>
<td>Port Hardy B.C.</td>
<td>50.41</td>
<td>127.22</td>
<td>22</td>
<td>1.25</td>
<td>1.43</td>
<td>2.83</td>
<td>2.18</td>
<td>1.92</td>
<td>2.92</td>
</tr>
<tr>
<td>Vancouver B.C.</td>
<td>49.15</td>
<td>123.15</td>
<td>164</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.0</td>
</tr>
</tbody>
</table>

Freezing level heights obtained from radiosonde data for the period 1979-1990. The values obtained utilizing the ITU-R formula agree fairly well with the observed summer heights, otherwise the heights tend to be overestimated.
Effect of Topography on Precipitation Across Southern British Columbia

Rain Rate Statistics at Vancouver
Statistics of Attenuation Using Reprocessed Data
1994-1997

Reprocessed Data
Attenuation wrt Clear Sky - 20 GHz

[Graph showing attenuation data for 1994 before and after reprocessing, 1997, and 1994 after reprocessing.]
Seasonal Statistics
Attenuation wrt Clear Sky - 20 GHz

SPRING

SUMMER

FALL

WINTER

% time abscissa exceeded

Attenuation (dB)

% time abscissa exceeded

Attenuation (dB)

% time abscissa exceeded

Attenuation (dB)

% time abscissa exceeded

Attenuation (dB)


Statistics of Attenuation

- 1997 clearly dominates the annual and seasonal statistics of attenuation for the period 1994-1997
- Attenuation distributions for 1994, 1995 and 1996 show little interannual variability
- Winter season (December-February) statistics show many small attenuation events of long duration, especially below 5 dB
- The effect of antenna wetting can have an important influence on the measured statistics, especially on statistics for the Winter season
Comparison of Measured Statistics with Prediction Models

Comparison of Models and Measurements
Vancouver - 20 GHz

% line abscissa exceeded

Average Year ('94-'97)

ITU-R (Loc. RR) Global Mod (Z B1)

Attenuation(dB)

0 4 8 12 16

CRC Communications Research Centre
Comparison of Models with Measurements

Vancouver - 30 GHz

Comparison of Models and Measurements

Vancouver - 20 GHz

Average Year ('94-'97)

Global Mod (Z B1)

ITU-R (Loc. RR)
Comparison of Models and Measurements
Vancouver - 30 GHz

Comparison of models with measurements

- Comparison of models with data measured for an average year (period 1994-1997):
  - The ITU-R model clearly underpredicts the attenuation measured at both frequencies
  - The Global model underpredicts the measured data in the region of small attenuation values but measured and model curves agree rather well above about 7 dB (at 20 GHz) and 12 dB (at 30 GHz)

- When models are compared with statistics of an average year for the period 1994-1996, the ITU-R model gives better results than the Global model

- In the region of low attenuation values the measured statistics can be affected by the combined effects of antenna wetting and moisture penetration into the receive antenna feed
Summary

- Four years of data (1994-1997) recorded at the ACTS-Vancouver site were re-processed by the U. of Oklahoma, improving their quality.

- Annual and seasonal attenuation statistics measured at Vancouver during the period 1994-1997 are strongly dominated by the year 1997 when rainfall reached record levels along the South-Pacific coast of Canada.

- Comparisons of measured statistics with the ITU-R and the Global rain attenuation prediction models indicates mixed results, with the Global model giving better results when compared with statistics of an average year (period 1994-1997).

- Correction for antenna wetting effects was not yet implemented.
Ka-Band Propagation Studies Using the ACTS Propagation Terminal and the CSU-CHILL Multiparameter Radar

Experimenters
Colorado State University
Department of Electrical Engineering
Fort Collins, CO 80523

Investigators
John Beaver, Research Assoc.
V.N. Bringi, Professor

ACTS Propagation Studies Workshop
October 22-23, 1998
Oklahoma City, OK
CSU-APT Site Location

- CSU-APT is located about 30 km southeast of Fort Collins near LaSalle, Colorado (approx. 13 km south of the CSU-CHILL radar)
- APT elevation angle - 43 deg
- APT azimuth angle - 173 deg
- Altitude 1.52 km
Outline

- CSU-APT Status Report
  - Terminal Update
  - Processing Update

- CSU-APT Attenuation Data
  - Comparison of data using APT weather files and external weather files
  - 1998 Data
  - Comparisons using local rain data for 1994

- Preliminary Melting Layer Studies
CSU-APT Status Report

- Terminal Status
  - replacement of WWV time card solved rebooting problems (re-seating the card was solution)
  - no major problems with collection system

- Processing Status
  - Data through August 1998 have been processed
  - Data from October 1994 through May 1996 have been reprocessed using external weather
May 1995 Data Comparison Using Various Weather Stations

APT Surface Data
CoAg Surface Data (Greeley)
CoAg Surface Data (Kersey)

Percentage Time Attenuation Exceeded (%) for Attenuation Level at 20 GHz (AFS, dB)
April 1996 Data Comparison Using Various Weather Stations

- APT Surface Data
- CoAg Surface Data (Ault)
- CoAg Surface Data (Kersey)

Percentage Time Attenuation Exceeded (%) vs. Attenuation Level at 20 GHz (AFS, dB)
April 1996 Data Comparison Using Various Weather Stations

- APT Surface Data
- CoAg Surface Data (Ault)
- CoAg Surface Data (Kersey)

Percentage Time Attenuation Exceeded (%) vs. Attenuation Level at 20 GHz (AFS, dB)
April 1996 Data Comparison Using Various Weather Stations

- Attenuation Level at 20 GHz (AFS, dB)
- Attenuation Level at 27 GHz (AFS, dB)

- Percentage Difference (%)

Legend:
- APT/Ault
- APT/Kersey
- Ault/Kersey
1995 Data Comparison Using Kersey/APT Weather Stations

APT/Kersey 1995

Percentage Difference (%)

Attenuation Level at 20 GHz (AFS, dB)

1995 Data Comparison Using Kersey/APT Weather Stations

APT/Kersey 1995

Percentage Difference (%)

Attenuation Level at 27 GHz (AFS, dB)
1995 Data Adjusted to Account for Moisture in Feed Horn

Percentage Time Attenuation Exceeded (%)

Attenuation Level at 20 GHz (AFS, dB)

Original Data
Data Adjusted for Moisture Effects

1995 Data Adjusted to Account for Moisture in Feed Horn

Percentage Time Attenuation Exceeded (%)

Attenuation Level at 27 GHz (AFS, dB)
1994, 95, 96, 97, 98 (through August) CDF Data (20 GHz ACA)

Percent of Time Attenuation Exceeded

Attenuation (dB)

1994, 95, 96, 97, 98 (through August) CDF Data (27 GHz ACA)

Percent of Time Attenuation Exceeded

Attenuation (dB)
December 1993 - August 1998 CDF Data (20 GHz ACA)

December 1993 - August 1998 CDF Data (27 GHz ACA)
July 7, 1996 Vertical Profile Plot

Date: 70796
Start RAY#: 36
Total: 100 rays
Time: 20449
from 14. to 16. km
Azim: 167.99
CSU-CHILL

Zdr

Zh

Rhv (IIR5)

LDR

Phdp.T = 3 deg
Dfr.T = 0 dB
Ldr.T = 0 dB
Ro.T = 0.90
Zh.T = 0 dB
Madfit = 2
Zslope = 40 dB
RCcf = 0.00 dB
DfrC = 0.00 dB
ACTS Propagation Measurements

Asoka Dissanayake, K. T. Lin, and Jorge Sosa

22 October 1998
Introduction

- ACTS propagation measurements conducted at three sites in Washington DC area and a tropical location in Mexico.

- Main objectives of the measurements are:
  - collect long-term propagation data
  - investigate multiple site diversity
  - characterize propagation conditions in tropical areas
  - development of propagation models
  - investigation of fade mitigation techniques

22 October 1998
Measurement Site Configuration: Washington DC Area

Clarksburg, MD 33 km Laurel, MD

66°

30 km

44 km

Reston, VA

25°

To ACTS Satellite

22 October 1998
Program Status

- Data collection:
  Clarksburg: 52 months completed
  Reston: 55 months completed
  Laurel: 33 months completed

- Data analysis:
  Clarksburg: 52 months completed
  Reston: 52 months completed

22 October 1998
Attenuation Statistics

- Single site attenuation statistics for the four years from November 1993 through October 1997 have been generated.

- For the same 12 month period, distribution of attenuation for the two sites are very similar.

- Considerable year-to-year variability observed in the data.

- Model predictions fall within the annual variation.
Cumulative Distribution of Attenuation at 20.2 GHz: Clarksburg

Percent Time Abscissa Exceeded

22 October 1998

Attenuation (dB)
Cumulative Distribution of Attenuation at 27.5 GHz: Clarksburg

Percent Time Abscissa Exceeded

Attenuation (dB)

22 October 1998
Diversity Analysis

- Diversity statistics derived for the two site configuration Clarksburg and Reston.
- Very little variation between joint statistics for the first two measurement years.
- ITU Diversity prediction model appears to underestimate diversity gain for percentage times greater than about 99.8%.

22 October 1998
Joint Attenuation Statistics at 20.2 GHz

22 October 1998
Joint Attenuation Statistics at 27.5 GHz

Percent Time Abscissa Exceeded

Attenuation (dB)

Year 1
Year 2
NU Model

22 October 1998
Joint Attenuation Between Two Paths

• Modeling of joint attenuation between two paths required in diversity and interference calculations.
• Models based on lognormal statistics are commonly used. The joint probability density function can be expressed as:

\[ f(A_a, A_b) = \frac{1}{2\pi\sigma_\alpha\sigma_b\sqrt{1-c^2}} \exp \left( -\frac{1}{2(1-c^2)} \left( \frac{(\ln A_a - \mu_\alpha)^2}{\sigma_\alpha^2} + \frac{(\ln A_b - \mu_b)^2}{\sigma_b^2} + 2c \frac{(\ln A_a - \mu_\alpha)(\ln A_b - \mu_b)}{\sigma_\alpha\sigma_b} \right) \right) \]

where \( \mu \) and \( \sigma \) are the mean and the standard deviation of the lognormal distribution, \( c \) is the correlation coefficient that depends on the spatial correlation function of rain intensity.
• The correlation function for rain intensity has an exponential form given by: \( e^{-\alpha \sqrt{d}} \), where \( \alpha = 0.25 \) and \( d \) is distance km.
Lognormal Diversity Model: 20.2 GHz

Joint Statistics at 20.2 GHz

- Year 1
- Year 2
- Lognormal Model

Percent Time Abscissa Exceeded

Attenuation (dB)

22 October 1998
Lognormal Diversity Model: 27.5 GHz

Joint Statistics at 27.5 GHz

- ■ Year 1
- ○ Year 2
- ▲ Lognormal Model

Percent Time Abscissa Exceeded

Attenuation (dB)

22 October 1998
Tropical Propagation Measurements

- Sponsored by INTELSAT
- Measurements conducted in collaboration with IPN, Mexico City.
- Objectives:
  - Collect long-term Ka-band propagation data from a tropical location using ACTS beacon signals.
  - Measurement site: Villahermosa in southern Mexico (latitude: 18° N; annual rain accumulation > 2000 mm)
  - Use of a weather radar to monitor precipitation cells influencing the beacon signals and characterize path attenuation at several elevation angles that are representative inter-continental satellite links.
  - Evaluate and refine propagation models for tropical climates.
  - Investigate frequency scaling within Ka-band and between Ka- and Ku-band.

22 October 1998
Measurement Site

• City: Villa Hermosa (17° 59’N, 92° 55’ W, altitude: 10 m)

• Facility owned by Mexican Telecommunications Authority; houses the regional telecommunication monitoring center.

• Annual average rainfall ~ 2000 mm

• Thunderstorm factor ~0.7

• Average temperature 28°C
Tropical Propagation Measurement System

- 2.4m tracking antenna used to monitor 20.2 and 27.5 GHz beacon signals to accommodate inclined orbit operation of ACTS.

- Radiometers at the beacon frequencies are used to remove equipment and satellite induced variations in the beacon signal level.

- Use of a co-located dual polarized X-band weather radar to estimate path attenuation at elevation angles other than the ACTS elevation.

- Ku-band radiometer to investigate frequency scaling from Ku- to Ka-band.

- Ancillary weather instruments to support data analysis and interpretation (rain gauge, distrometer, humidity gauge, temperature sensor).

22 October 1998
Measurement System

2.4 m antenna

1.8 m antenna

1.8 m antenna

Ka-band Beacon/radiometer Receiver

Ku-band Radiometer

X-band Radar

Temperature Gauge

Humidity Gauge

Rain Gauge

Disdrometer

Data Acquisition System

22 October 1998
Beacon/Radiometer Receivers

Specifications:
- RF head temperature stabilization $< 2^\circ$ C
- Measurement accuracy -
  - beacon signals: $< 0.25$ dB
  - sky noise: $< 2$ K
- Beacon measurement dynamic range: $\sim 30$ dB for 20 GHz
  $\sim 22$ dB for 27 GHz
- Signal acquisition after loss of lock: $< 20$ s
- Antenna pointing -
  - Step size: $\sim 0.01^\circ$
  - Update rate: once every 15 minutes

22 October 1998
Predicted Attenuation Distribution at Villahermosa
Rain Event on October 10, 1998

22 October 1998
Fade Ratio Between 27 and 20 GHz
Conclusions

- ACTS beacon data from Maryland and Virginia used to derive long-term statistics of attenuation.

- Fifth year of data collection in progress in Virginia

- Propagation measurements in Mexico to help characterize tropical conditions.

- Weather radar used to investigate elevation angle scaling of rain attenuation in tropics.

- Data analysis in progress to validate/improve propagation models.

22 October 1998
Space Communications Technology Center
(SCTC)

PROPAGATION MEASUREMENTS IN FLORIDA

HENRY HELMKEN
FLORIDA ATLANTIC UNIVERSITY (FAU)

&

RUDY HENNING
UNIVERSITY OF SOUTH FLORIDA (USF)

October 22, 1998
OUTLINE

- Florida Program Overview
- Site Operations
- AGA Model Comparisons
- Diversity Program
- Conclusions
FLORIDA PROGRAM GOALS

- Generate CDF's For Sub-tropical Regions
- Sub-tropical Fade Duration Statistics
- Seasonal and Diurnal Statistics
- Diversity Gain
- Sub-tropical Propagation Models
Total for time period: 169 mm

Intense Rain Event (09/20/98)
Intense Rain Event (09/20/98)

Total for time period: 137 mm
ACTS Propagation Studies in Florida

Intense Rain Event (09/20/98)
FLORIDA SUMMER/WINTER PROBABILITIES

Florida Summer/Winter Probabilities

- 20 GHz - Summer
- 27 GHz - Summer
- 20 GHz - Winter
- 27 GHz - Winter

Percentage of Time Exceeding or Equalling Abscissa

Fade Level (dB)

0
10
100
1000
102
20 GHz Model Comparison - 12Z

<table>
<thead>
<tr>
<th></th>
<th>Florida Statistics</th>
<th>MPM</th>
<th>Mean MPM</th>
<th>Crane</th>
<th>Mean Crane</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 GHz</td>
<td>MEAN 20 GHz 0.16736</td>
<td>0.16736</td>
<td>0.04094</td>
<td>SD 20 GHz 0.04094</td>
<td></td>
</tr>
<tr>
<td>27 GHz</td>
<td>MEAN 27 GHz 0.16736</td>
<td>0.16736</td>
<td>0.04094</td>
<td>SD 27 GHz 0.04094</td>
<td></td>
</tr>
</tbody>
</table>
DIVERSITY PROGRAM

- Diversity Improvement in Tropical Regions
  - 20 GHz Transportable Terminal
    - 1.2 m Prodelin Antenna
    - APT Digital Receiver

- Short Baseline Improvement
  - < 5km Separations

- Spatial Diversity Improvement
  - GBS Satellite 20.7 GHz Beacon at 17W
INCLINED ORBIT OPERATIONS

- Tracking Mount Requirements
  - VSAT Antenna Experience

- Replacement/Refurbished Antenna
  - Mitigate Wet Antenna Effects
  - Validate Florida APT Data Base

- Faculty and Student Support
CONCLUSIONS

- Normal APT Terminal Operations
- Validation of Crane Model for Florida
- Rain Shower Dependence of Diversity Gain
- Recommend Inclined Orbit Operations
New Mexico ACTS Propagation Terminal Status

Stephen Horan, Atle Borsholm and Xueyuan Tang
New Mexico State University
October 1998
Topics

- Changes
- Availability
- Analysis
Changes

- Thermal cutout switch failed in the receiver enclosure at the end of May; replaced it during July
- WWW just stopped receiving; still diagnosing the problem
Availability

- Lost data in June due to thermal switch failure
- Lost some data in October - cause unknown but probably due to someone laying an object on the keyboard
- No rain events lost
## Availability

<table>
<thead>
<tr>
<th>Month</th>
<th>Data Seconds</th>
<th>Gap Seconds</th>
<th>Availability</th>
</tr>
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<tbody>
<tr>
<td>June</td>
<td>1999492</td>
<td>592508</td>
<td>77.1%</td>
</tr>
<tr>
<td>July</td>
<td>2675824</td>
<td>2576</td>
<td>99.9%</td>
</tr>
<tr>
<td>August</td>
<td>2768400</td>
<td>0</td>
<td>100.0%</td>
</tr>
<tr>
<td>September</td>
<td>2591758</td>
<td>242</td>
<td>100.0%</td>
</tr>
<tr>
<td>Total</td>
<td>10035474</td>
<td>595326</td>
<td>94.4%</td>
</tr>
</tbody>
</table>

October 1998

NM APT Status
Analysis

- Detailed examination of the rain rates derived from the Capacitive Rain Gauge and the Tipping Bucket Rain Gauge
  - Total accumulations show the same general values (usually to within $\pm 1$ mm on all but trace events)
  - Instantaneous rain rates can be very different with the TBRG looking more realistic
Analysis

CRG and TBRG 2 minute average

Time (hours GMT)

Rain rate (mm/hr)

October 1998
Analysis

CRG and TBRG 2 minute average (Continued)

October 1998
NM APT Status
Project: Overall Statistical Modeling of Space-to-Ground Links

1. Define for each user population
   a. Longitude and latitude
   b. ITU and Crane rain region
   c. Population density database

2. Define for each satellite system
   a. Orbital dynamics
   b. Number of satellites in the constellation
   c. Satellite constraints e.g., minimum elevation angle

3. Define propagation time-varying effects
   a. For each user location, each satellite system will have a Probability Density Function (PDF) that describes the percent of time the satellite has a given elevation angle
   b. Use the elevation PDF to generate the PDF for propagation effects
   c. Estimate overall propagation effects weighted by
      i. Satellite elevation PDF
      ii. Rain, scintillation, gas, etc. by frequency
      iii. Number of satellites available to a user
   d. Weight results by population density to optimize service needs
ACTS Propagation Measurements Program

Data Analysis Summary

Cynthia Grinder
Jennifer Pinder
Louis J. Ippolito
Stephen Horan
Atle Borsholm

APSW XXIII
October 22-23, 1998
Norman, OK
Agenda

☐ Introduction
  ➢ Experiment objectives and configuration

☐ NM ACTS $K_A$ band measurements and analysis
  ➢ Four years (12/93-11/97) of propagation statistics
  ➢ Annual model comparisons
  ➢ Seasonal statistics
  ➢ Almost five years (12/93-8/98) of propagation statistics

☐ Summary and future activities
STel ACTS Propagation Experiment

Objectives

- Measure and evaluate $K_A$ band propagation effects and link performance for New Mexico

- Develop long-term statistics and prediction modeling techniques for the New Mexico climate region to be used for advanced satellite system planning and design
New Mexico APT

- Measured parameters
  - Beacons: 20.185 GHz and 27.505 GHz
  - Radiometers: 20 GHz and 27.505 GHz
  - Rain rate (CRG, TBG)
  - Temperature, Relative Humidity, Wind Vector, Barometric Pressure

- Rain Region:
  - Crane Region: F
  - ITU Region: E

- Site Specific Geometrical Parameters:
  - Elevation Angle: 51°
  - Polarization Tilt: 79°
  - Altitude: 1.459 km
  - Latitude: 32° 32' 40" N & Longitude: 106° 36' 48" W
Definition of Attenuation Terms

☐ AFS: Attenuation wrt Free Space
Difference between the received beacon level and the received level if in a vacuum. AFS includes attenuation due to atmospheric absorption, rain, clouds, and scintillation.

☐ ARD: Radiometrical Derived Attenuation
Attenuation measurements from radiometers. Comparable to AFS.

☐ ACA: Attenuation wrt Clear Air
The difference between the received beacon level and the expected level due to atmospheric absorption (AGA). ACA includes rain, clouds, and scintillation. ACA=AFS-AGA.

☐ ARS: Statistical Attenuation Ratio
Ratio of equiprobable attenuation levels at two frequencies of interest.
Cumulative Surface Temperature

Cumulative Temperature
December 1, 1993 through November 30, 1997

- Historical weather data shows the average annual temperature for the New Mexico site to be 17°C.
Historical weather data shows the average annual relative humidity for the New Mexico site to be 47%.
Cumulative Water Vapor Density

Water Vapor Density
December 1993 - November 1997

Location: Las Cruces, NM
Elevation Angle: 51°

Average is 4.64 g/m³.

*Calculated from hourly temperature averages and Jornada Relative Humidity data
Attenuation wrt Free Space (AFS)

Cumulative AFS
December 1, 1993 through November 30, 1997

Location: Las Cruces, NM
Elevation Angle: 51°

- 20 GHz
- 27 GHz

From *.pv2 files
Attenuation wrt Free Space (AFS)

Cumulative AFS 1998
(December 1997 - August 1998)

Location: Las Cruces, NM
Elevation Angle: 51°

— 20 GHz
— 27 GHz

Percent of Time Attenuation Is Exceeded or Equaled

From *p*2 files
New Mexico ACTS Statistics
Summary (Cont.)

- Measured Link Performance for 12/93-8/98 (*.pv2)

<table>
<thead>
<tr>
<th></th>
<th>20.2 GHz</th>
<th></th>
<th>27.5 GHz</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Availability</td>
<td>99.9</td>
<td>99.99</td>
<td>99.9</td>
<td>99.99</td>
</tr>
<tr>
<td>% Outage Time</td>
<td>0.1</td>
<td>0.01</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Attenuation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>5.4 dB</td>
<td>17.2 dB</td>
<td>8.5 dB</td>
<td>&gt;25.0 dB</td>
</tr>
<tr>
<td>1995</td>
<td>3.7 dB</td>
<td>19.4 dB</td>
<td>6.0 dB</td>
<td>&gt;25.0 dB</td>
</tr>
<tr>
<td>1996</td>
<td>6.3 dB</td>
<td>&gt;25.0 dB</td>
<td>10.0 dB</td>
<td>&gt;25.0 dB</td>
</tr>
<tr>
<td>1997</td>
<td>5.3 dB</td>
<td>18.2 dB</td>
<td>9.3 dB</td>
<td>&gt;25.0 dB</td>
</tr>
<tr>
<td><strong>4 Year</strong></td>
<td>5.4 dB</td>
<td>20.0 dB</td>
<td>8.4 dB</td>
<td>&gt;25.0 dB</td>
</tr>
<tr>
<td>1998</td>
<td>5.2 dB</td>
<td>16.0 dB</td>
<td>8.6 dB</td>
<td>&gt;25.0 dB</td>
</tr>
</tbody>
</table>
Annual ACA Empirical Distributions
(20 GHz)

ACA for December 1993- August 1998
(20GHz)

Location: Las Cruces, NM
Elevation Angle: 51°

Graph: Percent of Time Attenuation is Equalled or Exceeded vs. Attenuation (dB)

Legend:
- 1994
- 1995
- 1996
- 1997
- 4 year
- 1998 (thru August)

From .edf files.
Annual ACA Empirical Distributions
(27 GHz)

ACA for December 1993 - August 1998
(27 GHz)

Location: Las Cruces, NM
Elevation Angle: 51°

Percent of Time Attenuation is Equal to or Exceeded

Attenuation (dB)

From .edf files.
Annual Rain Rate Empirical Distributions from the Tipping Bucket

Annual Rain Rates for December 1993 - August 1998

Location: Las Cruces, NM
Elevation Angle: 51°

94 (thru August)
95
96
97
98 (thru August)

ITU (Reg E)
Crane (Reg. F)

Percent Time Rain Rate is Equal or Exceeded

Rain Rate (mm/hr)

From test files using tipping bucket.
Annual Rain Rate Empirical Distributions from CRG

Annual Rain Rates for
December 1993 - August 1998

Location: Las Cruces, NM
Elevation Angle: 51°

Percent Time Rain Rate is Equalled or Exceeded

Rain Rate (mm/hr)

From *.edf files using CRG data.
Model Comparison:
ACA 4yr Distribution (20 GHz)

Model Comparison:
20 GHz December 1993 - November 1997 ACA Annual Distribution

- ITU-R
- DAH
- ExCell
- Crane Global
- ACA from Beacon

Las Cruces, NM
Elevation Angle: 51°

Percent of Time Attenuation is Equaled or Exceeded

Attenuation (dB)

Rain rates used come from tipping bucket data.
Model Comparison: ACA 4yr Distribution (27 GHz)

Model Comparison:
27 GHz December 1993 - November 1997 ACA Annual Distribution

- ITU-R
- DAH
- ExCell
- Crane Global
- ACA from Beacon

Las Cruces, NM
Elevation Angle: 51°

Rain rates used come from tipping bucket data.
Model Comparison + Wet Surface Effects (20 GHz)

Comparison of Rain Attenuation Models + Wet Surface Effects to 20.2 GHz NM Data:
December 1993 - November 1997 ACA Annual Distribution

Rain rates used come from tipping bucket data.
Model Comparison + Wet Surface Effects (27 GHz)

Comparison of Rain Attenuation Models + Wet Surface Effects to 27.5 GHz NM Data:
December 1993 - November 1997 ACA Annual Distribution

- ITU-R
- DAH
- ExCell
- Crane Global
- ACA from Beacon

Las Cruces, NM
Elevation Angle: 51°

Rain rates used come from tipping bucket data.
**Five Year Winter AFS Statistics**

AFS for Winter (December, January, February) 1993-1997

Location: Las Cruces, NM
Elevation Angle: 51°

Winter Averages:
- Temperature = 8°C
- Relative Humidity = 44.4%
- Water Vapor Density = 3.4 g/m³

From *pv2 files

- Historical weather data for the New Mexico site: For Winter, the average temperature is 7.7°C and the average relative humidity is 40.6%.
Historical weather data for the New Mexico site: For Spring, the average temperature is 16.9°C and the average relative humidity is 26.3%.
Five Year Summer AFS Statistics

AFS for Summer (June, July, August) 1994-1998

- Historical weather data for the New Mexico site: For Summer, the average temperature is 27°C and the average relative humidity is 41.3%.
Four Year Fall AFS Statistics

AFS for Fall (September, October, November) 1994 - 1997

Location: Las Cruces, NM
Elevation Angle: 51°

Fall Averages:
Temperature = 18°C
Relative Humidity = 43 %
Water Vapor Density = 4.3 g/m²

Historical weather data for the New Mexico site: For Fall, the average temperature is 17.7°C and the average relative humidity is 42.3%.
## Summary of Seasonal Statistics

- **Measured Link Performance for 12/93-8/98 (*.pv2):**

<table>
<thead>
<tr>
<th>Attenuation</th>
<th>20.2 GHz</th>
<th>27.5 GHz</th>
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<tbody>
<tr>
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<tr>
<td>% Availability</td>
<td>99.9</td>
<td>99.99</td>
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<tr>
<td>% Outage Time</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Winter (5-yr)</td>
<td>3.0 dB</td>
<td>5.5 dB</td>
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<tr>
<td>Spring (5-yr)</td>
<td>2.4 dB</td>
<td>8.0 dB</td>
</tr>
<tr>
<td>Summer (5-Yr)</td>
<td>10.0 dB</td>
<td>&gt;25.0 dB</td>
</tr>
<tr>
<td>Fall (4-yr)</td>
<td>3.9 dB</td>
<td>11.2 dB</td>
</tr>
</tbody>
</table>

|                   |          |          |
|                   | 4.4 dB   | 7.3 dB   |
|                   | 3.3 dB   | 13.3 dB  |
|                   | 17.3 dB  | >25.0 dB |
|                   | 6.4 dB   | 20.0 dB  |
57 Month Cumulative Attenuation wrt Free Space (AFS)

Cumulative AFS Distribution
(December 1993 - August 1998)

Location: Las Cruces, NM
Elevation Angle: 51°

- 20 GHz
- 27 GHz

Percent of Time Attenuation is Equaled or Exceeded

Attenuation (dB)

From *.pv2 files
Actual Worst Month: July 1997
Attenuation wrt Free Space (AFS)

Location: Las Cruces, NM
Elevation Angle: 51°

Percent of Time Attenuation is Exceeded

20 GHz
27 GHz

From *.pv2 files
New Mexico ACTS Statistics

Summary

- **Seasonal Statistics**
  - Majority of Large Fades occur in summer months.

- **Rain attenuation model prediction comparisons**
  - All the rain models match the empirical data fairly well
  - Adding wet surface effects to the rain attenuation models improves the models significantly.

- **Worst actual month (in 57 months): July 1997**
STel Future ACTS Activities

- Complete 5 year cumulative distributions from *.pv0 preprocessing
- Complete 5 year cumulative distributions from *.pv2 preprocessing
- Complete the 5 year final report
ACTS Propagation Studies in Oklahoma

Xuhe Wang
Robert K. Crane

School of Meteorology, University of Oklahoma

APSW XI
Oklahoma City, OK
October 22-23, 1998
Outline

- OK APT Status - Terminal Update
- Reprocessing 4-year OK, MD, BC data
- ACTS04.XLS Excel Macros
- OK ACTS Home Page Update
- HDR File Archives Status
OK APT Status - Terminal Update

- Replaced ethernet card with ZIP (parallel port) drive on 11/14/97, but failed. Ethernet card was re-installed on 11/30/97. Since then lots of 1-2 seconds gaps in every day data. The problem was fixed by replacing the PC’s motherboard and all the cards on March 24, 1998. ZIP drive was also installed.
- “Lost default drive” bug in dacs.exe (TSR) was found during testing ZIP drive.
- Fiber optics modem power failed on 6/17/98 - 7/16/98. Many system crashes and data lost during that time period.
- APT system is now working smoothly except WWV card clock jumping problem still remains.
Reprocessing 4-year OK, MD, BC Data

- A new 333MHz PentiumII PC was used in reprocessing, which led to find that ACTSPP need updated to run on a fast PC.
- Weather events, system and operational faults were inserted into .LOG files, and marked bad if necessary. Snow events and rain gauge noises were marked bad in .LOG files.
- Calibration constants were re-adjusted for each site. For BC data calibration was done on a daily basis.
- A radiometer swapping problem were found in ACTSPP program during reprocessing MD data. MD data were then reprocessed second time with the new updated ACTSPP.
- NCDC surface data were used in reprocessing BC and MD data. Oklahoma Mesonet surface data were used in reprocessing OK data.
Reprocessing 4-year OK, MD, BC Data

12/1/93 - 12/31/97 BC 20 GHz Calibration

- 20 Clear Sky Delta
- 20 Ratio Beacon to Radiometer Attenuation
Reprocessing 4-year OK, MD, BC Data

12/1/93 - 12/31/97 BC 27 GHz Calibration

- 27 Clear Sky Delta
- 27 Ratio Beacon to Radiometer Attenuation
Reprocessing 4-year OK, MD, BC Data

3/16/94 - 5/31/98 MD 20 GHz Calibration

- 20 Clear Sky Delta
- 20 Ratio Beacon to Radiometer Attenuation

db or Ratio

1.6  1.4  1.2  1  0.8  0.6  0.4  0.2  0  -0.2  -0.4  -0.6
3/16/94  3/15/96  3/16/97  3/16/98
Reprocessing 4-year OK, MD, BC Data

3/16/94 - 5/31/98 MD 27 GHz Calibration

- 27 Clear Sky Delta
- 27 Ratio Beacon to Radiometer Attenuation
Reprocessing 4-year OK, MD, BC Data

12/1/93 - 6/30/98 OK 20 GHz Calibration

- 20 Clear Sky Delta
- 20 Ratio Beacon to Radiometer Attenuation
Reprocessing 4-year OK, MD, BC Data

12/1/93 - 6/30/98 OK 27 GHz Calibration

- 27 Clear Sky Delta
- 27 Ratio Beacon to Radiometer Attenuation

db or Ratio
ACTS04.XLS Excel Macros

- New user interface and more error prevention codes.
- Two new macros added.
  - ChangeConstMM
  - Marking
- Annual_edf macros now can compare the calculated edfs with attenuation models (need first install Attenuation Model Excel Add-in, which can be found at our web site).
- Current version can not run in Excel 97. Still working on new version.
- Testing version can be found in our ftp address or web page. Comments and suggestions are welcome.
<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
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<tbody>
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<tr>
<td>Data 7</td>
<td>Data 8</td>
<td>Data 9</td>
</tr>
</tbody>
</table>
ACTS04.XLS Excel Macros

9603-9702md EDF

- 20GHz Beacon
- 27GHz Beacon
- 20GHz T_CAtenF
- 27GHz T_CAtenF

Percentage of a Year Attenuation > Abscissa Value

Attenuation dB

0 5 10 15 20
Oklahoma ACTS Home Page Update
- http://rossby.metr.ou.edu/~actsrain/

- The page now has a new look, and many useful links about Ka-band SatCom.
- A text readme file has been added to Attenuation Model Excel Add-in page, which explains how to use the add-in in more detail.
- A new page - Excel Macros acts04.xls was added. User can get the test version of the macros from there.
- The reprocessed 4-year ACTS propagation data from 7 sites will soon replace the old data and graphs currently kept in the page.
Oklahoma ACTS Home Page Update

TO THE ACTS PROPAGATION EXPERIMENT PAGE

At School of Meteorology, University of Oklahoma, Norman, OK

Project Leader: Dr. Robert Crane

Research Associate: Nadeem Mone

ACTS Beacon Propagation Data  Graphs from Data  Ongoing Projects at OU  Useful Links  Feedback  Attenuation models  Excel add-ons  Excel Macros graphs.xls  Home
HDR File Archives Status

- Current HDR files list
  - AK: 960624-960816, 970607-980630 (16 months)
  - BC: 961021-961023, 980312-980625 (5 months)
  - CO: 960801-960930, 980105-980630 (8 months)
  - FL: 960618-960930 (4 months)
  - MD: 960627-980620 (25 months)
  - NM: 960828-970630, 970801-current (25 months)
  - OK: 960217-current (32 months)

- Experimenters please send your HDR files to Univ. of OK.
- HDR files can be made available on CDs.
Summary of Attenuation Observations for all 7 Sites and Comparison to the Updated Model Predictions

Robert K. Crane
Xuhe Wang
School of Meteorology, University of Oklahoma

APSW XI
Oklahoma City, OK
October 22-23, 1998
LOCAL MODEL IMPROVEMENTS

- Model for cell contributions to the rain-rate distribution is now consistent with the model for the cell contribution to attenuation.

- Rain-rate distribution model is revised so local hourly accumulation data can be combined with the cell component from the local model to produce adjusted debris component parameters - used for BC, CO and NM.

- The variability model has been improved using hourly rain accumulation data form each site in the local data base.

- ACTS empirical rain-rain rate distributions are consistent with the updated model predictions (lie within the 90% bounds).

- Corrected ACTS empirical attenuation distributions are consistent with earlier COMSTAR observations at sites where data are available - the corrections are for gaseous absorption and water on the antenna.

- Local or adjusted local attenuation model predictions are consistent with the corrected ACTS empirical attenuation distributions.
Rain Rate

- 94_01
- 95_01
- 96_01
- 97_01

U Bound
Model
L Bound

Model - Blaine, WA (closest site - 992 mm/yr)

Rain Rate (mm/h)

Percentage of a Year Rain Rate is Exceeded (%)
Rain Rate

| 95 01 | U Bound | Model | L Bound |

Percentage of a Year Rain Rate is Exceeded (%)
Rain Rate

Percentage of a Year Rain Rate is Exceeded (%)
Rain Rate

- 94 01
- 95 01
- 96 01
- 97 01
- U Bound
- Model
- L Bound

Percentage of a Year Rain Rate is Exceeded (%)
Norman, OK (2)

Rain Rate

- Solid Markers - Airport
- Open Markers - On Roof

Percentage of a Year Rain Rate is Exceeded (%)
Rain Rate (mm/h)

Percentage of a Year Rain Rate is Exceeded (%)

Wallops Island, VA (2)

1987 1988
U Bound
Model

1990

L Bound

1991

1992

1993

Gauge 1
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting

27.5 GHz, Alaska

ACTS Propagation Experiment
Attenuation Relative to Clear Sky Corrected for Antenna Wetting

ACTS Propagation Experiment

20.2 GHz, British Columbia

---

Percentage of Year Attenuation is Exceeded (%)

Attenuation (dB)
Attenuation Relative to Clear Sky Corrected for Antenna Wetting

27.5 GHz, Colorado

ACTS Propagation Experiment

Attenuation (dB)

Percentage of Year Attenuation is Exceeded (%)
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting

20.2 GHz, Florida

ACTS Propagation Experiment

- 94.01
- 97.01
- 95.01
- COMSTAR_79
- 96.01

T-C Expected

T-C Upper Bound

T-C Lower Bound

DAH Expected

Percentage of Year Attenuation is Exceeded (%)
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting

20.2 GHz, New Mexico

ACTS Propagation Experiment

- 94_01
- 95_01
- 96_01
- 97_01

- T-C Upper Bound
- T-C Expected
- T-C Lower Bound
- DAH Expected

Attenuation (dB)

Percentage of Year Attenuation is Exceeded (%)
27.5 GHz, New Mexico

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

ACTS Propagation Experiment

- 94_01
- 95_01
- 96_01
- 97_01

- T-C Upper Bound
- T-C Expected
- T-C Lower Bound
- DAH Expected

Percentage of Year Attenuation is Exceeded (%)
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting

20.2 GHz, Oklahoma

ACTS Propagation Experiment

Attenuation (dB)

Percentage of Year Attenuation is Exceeded (%)
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting

27.5 GHz, Oklahoma

ACTS Propagation Experiment

- 94_01
- 95_01
- 96_01
- 97_01

T-C Upper Bound
T-C Expected
T-C Lower Bound
DAH Expected

Attenuation (dB)
Percentage of Year Attenuation is Exceeded (%)
Attenuation Relative to Clear Sky Corrected for Antenna Wetting

ACTS Propagation Experiment

20.2 GHz, Virginia

Percentage of Year Attenuation is Exceeded (%)
Attenuation Relative to Clear Sky

19.0 GHz, Austin, TX

- COMSTAR_78
- T-C Upper Bound
- T-C Expected
- T-C Lower Bound
- DAH Expected
Attenuation Relative to Clear Sky

28.5 GHz, Austin, TX

- T-C Expected
- T-C Upper Bound
- COMSTAR_78
- T-C Lower Bound
- DAH Expected

Percentage of Year Attenuation is Exceeded (%)
Attenuation Relative to Clear Sky

28.5 GHz, Wallops Island

+ COMSTAR_77    × COMSTAR_78    □ COMSTAR_79    ——— T-C Upper Bound

——— T-C Expected    ——— T-C Lower Bound    ——— DAH Expected

Y-axis: Attenuation (dB)
X-axis: Percentage of Year Attenuation is Exceeded (%)
28.6 GHz, Waltham, MA

Attenuation Relative to Clear Sky

- X COMSTAR_78
- □ COMSTAR_79
- -- T-C Upper Bound
- --- T-C Lower Bound
- ---- DAH Expected

Percentage of Year Attenuation is Exceeded (%)
ACTS Propagation System Status
and
ACTS Propagation Data Base

David B. Westenhaver
Westenhaver Wizard Works, Inc.
746 Lioness Ct SW
Stone Mountain, GA 30087-2855
770-925-1091, wwwinc@crl.com

Presented at ACTS Propagation Studies Workshop XI
Oklahoma City, OK
October 22, 1998
Engineering Support and Systems Upgrades Status

Software Status / Deficiencies and Known Problems

DRX software status:
  Need to open beacon acquisition constraints.

DACS software status:
  Current version 10 of 4/01/96.
  Need to add force beacon reacquisition.
  Need to prevent repeating radiometer setups.

TSR software status:
  Current version 14 of 6/18/98.
  Some Traps added for DOS Critical-Errors.
  Works with Zip Drive except when operator error.
  Complete Drive:\Path Information added.
  Data missing from RV0; May be fixed.
  Changed to keep 61 days of *.rv0 data on disc.
  High Data Rate files are not automatically removed.
  Works with new GPS receivers for Timing.

ActsView software status:
  Current version 4.5 of 8/6/97.

Actspp PreProcessing software status:
  Current version 7.4 of 8/19/98.
### ACTS Data Center RAW Data Files as of 10-15-1998

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Total Daily RVO Files: 11,894
Total Compressed MegaBytes: 4,091
# ACTS Data Center Processed Data Files as of 10-15-1998

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Total Daily PV2 Files: 11,388
Total Compressed MegaBytes: 3,086
ACTS Propagation Data Base Procedures Review

- The detailed Data Base Procedures described in June 98 have worked very well.
- The logs indicate over 60 archive input sessions - over 10,000 days of data since June 98.
- The primary archives are on 2 each 6.4 GB disk (D:\ for processed data and E:\ for raw data).
- All processed and new raw data are copied to an "Image" 8.5GB disk on another PC.
- The new processed and raw files are transferred to a CD when we have >550 MB.
- The Archived RAW data CDs for 9312 - 9808 are in the vault.
- The Archived Processed CDs for 9312 - 9712 are in the vault.
- Several sites have requested CDs of the "current as of this date" archived raw data.
- Are new "current as of this date" archived raw data CDs needed? Send me an email request.

Archived data on CDs is the primary data source for the Experimenters.
4 Year ACTS Propagation Data Quality Checking is still in Progress.
• The current checking programs are Rd_log6 and Rd_edf3.
• The new updates have been improved to detect more "questionable data" - data that needs another review.
• The yymmxx.log files are scanned using the Rd_log program.
• The yymmxx.edf files are scanned using the Rd_edf program.
• The most common "questionable data" are a result of:
  • "Clear Sky Delta" is higher than expected.
  • "High Bias Coeff" which is an indication of a higher than expected system gain change or wet snow on the antenna or antenna pointing errors.
  • "Ratio errors" which is an indication that the length of time for the Beacon to Radiometer ratio is higher than expected due to calibration error or water in the wave guide or feed horn.
  • "Stray Sec" which may be an indication that data should be marked "bad" due to a step change in system gain.
• The "questionable data" have been reviewed with the experimenters.
• When water is known to be in the feed horn the calibration should be done daily.
• Many sites have reprocessed all data and it has been entered into the Archives.
• There are still days with "questionable data" in the Archives after the Quality Checking of the PreProcessed data. Further review of these days data is needed to resolve these "questions" in our data archives.
ACTS Propagation Data CD-ROM Distribution

- The 4 year Peer Review Copies were distributed Sept. 25 to the Experimenters.

- Request for comments from the ACTS Experimenters of the Peer Review data on the CDs.

- By site: AK, BC, CO, FL, MD, NM, OK

- We have more copies for distribution. The Data Request form must be filled out, signed and reviewed before distribution.

- Please read the Readme.txt file first.
SESSION 3. SPECIAL TOPICS

Chair: J. Goldhirsh

(JHU/APL)
Rain Attenuation Modeling

Asoka Dissanayake

23 October 1998
Background

* Rain attenuation is a key limiting factor in the introduction of higher frequency bands into satellite and terrestrial microwave systems.

* Limited knowledge of the rain process makes it difficult to come up with accurate predictions of rain attenuation.

* An average prediction accuracy better than 25% appears difficult to achieve; higher accuracies are desirable for communication system design purposes.

23 October 1998
DAH Model

* A need for an improved propagation model was identified to facilitate:
  - introduction of higher frequency services into tropical areas
  - reliable attenuation prediction for low elevation angle links
  - design of low availability services.

* This resulted in the development of the DAH model.

23 October 1998
DAH Model

* DAH model contains methodologies to predict
  - rain attenuation,
  - cloud attenuation,
  - melting layer attenuation, and
  - low angle fading.

* These are combined with the ITU prediction methods for
  - gaseous absorption and
  - tropospheric scintillations

to predict combined attenuation along satellite paths.

23 October 1998
Model Components

* Rain attenuation: empirical approach based on statistical models and available measured path attenuation data.

* Cloud attenuation: makes use of long term observations of cloud cover data with average cloud properties

* Low angle fading: extension to the ITU tropospheric scintillation model based on low-elevation angle measurements on satellite links.

23 October 1998
Rain Attenuation Prediction

* Input parameters:
  System related - frequency, polarization, elevation angle
  Rain related - rain rate distribution or rain rate at a given probability, rain height, drop size distribution, temperature, spatial correlation of rain intensity, year to year variability of rainfall.

* Output: attenuation exceeded for a given percentage of time

* Requirements: easy access of input parameters, applicability across a wide range of inputs

23 October 1998
Log-normal Model

* Both rain rate and path attenuation can be adequately described in terms of log-normal statistics (three parameter distribution)

\[
P (r > R) = P_o /2 \text{erfc}[(\ln r - \ln \mu_R) / (\sqrt{2} \sigma_R)]
\]
\[
P (a > A) = P_L /2 \text{erfc}[(\ln a - \ln \mu_A) / (\sqrt{2} \sigma_A)]
\]

\(P_o\) - probability of rain falling at a point;
\(P_L\) - probability of rain falling on the path

* \(P_L\) is a function of \(P_o\), path length, and rain climate

\[P_L = f(P_o, L, R)\]

23 October 1998
Path Averaged Rain Rate

* Path averaged rain rate is a useful concept in developing rain attenuation prediction methods.

* Conversion of point rain rate statistics to path averaged statistics through spatial correlation function: $\rho(L)$.

* $\rho(L)$ can be established using radar or rain gauge network data

* Spatial correlation modeled as a function of distance and rain climate using:
  \[ \rho(L) = \exp(-\alpha \sqrt{L}) \]
  \[ \alpha = 0.007 \times R_{0.01} \]

23 October 1998
Simplified Prediction Model

* Log-normal model requires full rain rate distribution including the probability of rain falling at a point.
* To simplify the attenuation prediction, a model centered around the 0.01% rain rate (similar to the ITU model) was devised by introducing:
  - a horizontal path adjustment factor to account for horizontal inhomogeneity of rain and
  - a vertical adjustment factor to account for vertical inhomogeneity
* Both factors applicable at the probability level of 0.01%.
* Attenuation distribution approximated by a power-law model.

23 October 1998
Horizontal Path Adjustment Factor

* Horizontal path adjustment factor best described as a function of specific attenuation, frequency, and the horizontal projection of the rainy path length.

* Shape of the path adjustment factor derived using the statistical model and the parameters describing the shape derived from the terrestrial attenuation database.

* Horizontal projection of the path is multiplied by the adjustment factor to obtain the effective horizontal path length.

23 October 1998
Horizontal path adjustment factor at 20 GHz

23 October 1998
Vertical Path Adjustment Factor

* Vertical adjustment factor applied to 0° C isotherm height; based on measured slant path attenuation data.

* Vertical adjustment factor is a function of frequency, specific attenuation, elevation angle, latitude, and the horizontally adjusted path length.

* After applying the two adjustment factors, effective path length is the distance across the box defined by the adjusted horizontal and vertical path lengths. A constant specific attenuation along the effective path length assumed.

23 October 1998
Vertical path adjustment factor
Rain Model

* For satellite link design a rain model based on local rain data is preferred.

* Zonal descriptions are appropriate for planning and coordination purposes.

* DAH model appears to provide reasonable predictions when used with the Rice-Holmberg rain model.

* Parameters for the Rice-Holmberg model (annual rain accumulation and thunderstorm factor) can be easily obtained from climatological data archives.

23 October 1998
Rain Model Comparisons

Austin, TX

- Measured
- R-H Model
- ITU
- Crane

Rain Rate (mm/hr)

Percent Time Ordinate Exceeded

23 October 1998
Goonhilly, UK

- Measured
- R-H Model
- ITU
- Crane

Percent Time Ordinate Exceeded

Rain Rate (mm/hr)

23 October 1998
Surabaya, Indonesia

- Measured
- R-H Model
- ITU
- Crane

23 October 1998
Attenuation Model Comparisons

- Combined attenuation for Clarksburg, MD

23 October 1998
- Combined attenuation for Reston, VA
Conclusions

* A simple rain attenuation prediction model based on the log-normal hypothesis developed.

* Slant-path case is treated as an extension to the terrestrial path prediction.

* Prediction accuracy depends on the availability of representative rain intensity data.

* DAH model provides a method of combining different propagation impairments.

23 October 1998
Basic Goals for Revised NASA Propagation Handbook

- Combine Scope of the Previous Two NASA Handbooks into a Single Comprehensive Document
- Eliminate Duplication
- Provide a More Cohesive Structure for the Reader
  - Offer Several Levels of “Entrance” into Handbook
- Include Tailored Propagation Analysis Procedures For Specific Types of Satellite Applications
Prior Editions
Above 10 GHz Handbooks

R. Kaul, R. Wallace, G. Kinal
March 1980

➢ Second Edition NASA Reference Publication 1082
L. Ippolito, R. Kaul, R. Wallace
December 1981

➢ Third Edition NASA Reference Publication 1082(03)
L. Ippolito, R. Kaul, R. Wallace
June 1983

➢ Fourth Edition NASA Reference Publication 1082(04)
L. Ippolito
February 1989
Prior Editions
Below 10 GHz Handbooks

➤ First Edition  NASA Reference Publication 1108
W. Flock
December 1983

➤ Second Edition  NASA Reference Publication 1108(02)
W. Flock
December 1987
Basic Structure of Handbook

Three Sections

SECTION 1 BACKGROUND
Provide Overview of Propagation Effects, including Theory and Basic Concepts, Propagation Measurements, Available Data Bases.

SECTION 2 PREDICTION

SECTION 3 APPLICATIONS
Three Section Structure

Section 1
Background

Section 2
Prediction

Section 3
Applications

Researcher, General Interest
Enters Here

Link Analyst
Enters Here

Systems Designer
Enters Here
Fifth Edition Handbooks

- Section 1 Background
  - Six Major Subsections 118 pages

- Section 2 Prediction
  - Six Major Subsections 226 pages

- Section 3 Applications
  - Eight Major Subsections 43 pages
  - 387 pages
Handbook Highlights
Section 1
Background

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Exhibit 1.3.3.2-2
Total path rain attenuation as a function of frequency and elevation angle
Location: Washington, DC
Availability: 99%
Prediction Model: Crane Global Model (see Section 2.2.4.2)
For most rain depolarization prediction models, semi-empirical relations can be used for the U and V coefficients. An example of the application of a rain depolarization prediction model is shown in Exhibit 1.3.3.4-3. The exhibit shows cross polarization discrimination, XPD, as a function of frequency and elevation angle. The curves are for a ground terminal in Washington, DC, and the link availability was set at 99%. The Chu Model (Section 2.2.5.1.1) was used for the calculations.

Exhibit 1.3.3.4-3
Rain Depolarization XPD as a function of frequency and elevation angle
Location: Washington, DC
Availability: 99%
Prediction Model: Chu Semi-Empirical Model (see Section 2.2.5.1.1)

Several models and procedures for the prediction of rain depolarization are provided in Section 2.2.5 of this handbook.
# Section 2
## Prediction

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2.3.4 Sky Noise Due to Clouds
2.2.4.1 ITU-R Rain Model

The ITU-R rain attenuation model is the most widely accepted model by the international propagation community. The model was first accepted globally in 1982 and is continuously updated as rain attenuation modeling is better understood. The current model has been deliberately kept simple for ease of use. This section describes the ITU-R model as described in the latest version of Recommendation ITU-R P.618-5, (1997).

The input parameters required for the ITU-R Rain Model are:
- \( f \): the frequency of operation, in GHz
- \( \theta \): the elevation angle to the satellite, in degrees
- \( \phi \): the latitude of the ground station, in degrees N or S.
- \( h_s \): the altitude of the ground station above sea level, in km.

The step by step procedure follows:

1) Calculate the effective rain height \( h_R \) from the latitude of the ground receiver site using the ITU-R rain height procedure.

The freezing rain height (or 0 °C isotherm) is the upper atmosphere altitude at which rain is in the transition state between rain and ice. The rain height is defined in km above sea level. Rain height is calculated as a function of ground station latitude (\( \phi \)). The rain height, latitude and elevation angle are then used to calculate the slant path \( L_s \) through a rain cell and the horizontal component of the slant path \( L_0 \).

The ITU-R rain height assumes that the rain height, is a function of latitude (\( \phi \)). The rain height \( h_R \) is found as follows:

\[
h_R(\phi) = \begin{cases} 
5 - 0.075(\phi - 23) & \text{for } \phi > 23^\circ \\
5 & \text{for } -21^\circ \leq \phi \leq 23^\circ \\
5 + 0.1(\phi + 21) & \text{for } -71^\circ \leq \phi \leq -21^\circ \\
0 & \text{for } \phi < -71^\circ 
\end{cases} \tag{2.2.4.1-1}
\]

where \( \phi \) is the latitude of the ground station receiver. Positive \( \phi \) corresponds to the Northern Hemisphere, and negative \( \phi \) corresponds to the Southern Hemisphere. The rain height is expressed in km and is expected to be a value greater than zero. The model is only valid for latitudes (\( \phi \)) less than 89.6° (or greater than -89.6°).

2) Calculate the slant-path length, \( L_s \), and horizontal projection, \( L_0 \), from the rain height and the altitude of the ground receiver site.
Rain attenuation is directly proportional to the slant path length. The slant path length $L_s$ is defined as the length of the satellite-to-ground path that is affected by a rain cell (see Exhibit 2.2.4.1-1).

\[
L_s(\theta) = \begin{cases} 
\frac{(h_R - h_S)}{\sin \theta} & \text{for } \theta \geq 5^\circ \\
\frac{2(h_R - h_S)}{[\sin^2 \theta + \frac{2(h_R - h_S)}{R_E}]^{1/2} + \sin \theta} & \text{for } \theta < 5^\circ
\end{cases}
\]

where,

- $h_R$ = the height of the rain (km), from Step 1
- $h_S$ = the altitude of the ground receiver site from sea level (km),
- $\theta$ = the elevation angle,
- $R_E$ = 8500 km (effective earth radius).

For angles greater than or equal to $5^\circ$, the slant path length is derived from the geometry from Exhibit 2.2.4.1-1. This equation for $L_s$ can result in negative values when the rain height is smaller than the altitude of the ground receiver site. If a negative value occurs, $L_s$ is set to zero.

The horizontal projection is calculated as

\[L_G = L_s \cos \theta\]
Exhibit 2.2.4.1-3. ITU-R North & South America Rain Regions
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2.2.7.2.2 Attenuation Due to Water on the Feed

The principles applied for the smooth conductor case, can also be applied to predict attenuation due to a wet feed. Crane and Ramachandran are currently working to apply these principles to the ACTS feed, the boundary conditions are determined by a four medium interface, illustrated in Exhibit 2.2.7.2-6.

Exhibit 2.2.7.2-6: Boundary Conditions for Water on the Antenna Feed.

Since the derivation and output equations from this method are extremely complicated, the derivation will not be described here. However, Crane and Ramachandran have conducted some simulations using this method. The results are illustrated in Exhibit 2.2.7-7.

Exhibit 2.2.7.2-7: Attenuation Due to Water on the Feed. (Rain Angle $\alpha = 20^\circ$)
2.2.8.1.3 Scintillation Dynamics

For many low elevation angle systems, the majority of fades below a desired threshold are scintillation induced. Exhibit 2.2.8.1-1 illustrates a scenario in which the mean fade level caused by gas and clouds is above the given threshold, but the strongest scintillations cause short outages.

![27.5 GHz Beacon Levels](image)

Exhibit 2.2.8.1-1
Beacon Data from Alaska ACTS Terminal (Elevation Angle 8°)

The cdf’s for signal fade levels due to combined atmospheric effects are used to estimate the percentage of time a signal will fall below a given threshold, but static cdf’s alone do not provide information on the frequency of fade/scintillation occurrence.

The frequency of fade and mean fade duration can be estimated using the static cdf and the well known “level crossing formula” where the expected fade rate of a normal random process is computed from the pdf and the power spectral density function of the process.

The model for estimating frequency of fade, which will be described in this section, was developed at Stanford Telecommunications and presented at the 1996 IEEE / URSI conference in Baltimore, Maryland (Weinfield, J. and T. Russell, 1996).
2.5.1.5 ITU-R Diversity Improvement – Sample Calculation

Considering the theoretical system in section 2.5.1.2 where:
- frequency: 20 GHz,
- elevation angle: 20°,
- availability: 99.9%,
- latitude: 38.4°N,
- rain region: K, and
- attenuation: 11.31 dB

with a second, identical site located at:

\[ D = 10 \text{ km} \]
\[ \Phi = 85^\circ, \]

the diversity improvement factor, \( I \), may be calculated.

Step 1: Calculate the empirical coefficient, \( \beta^2 \)

\[ \beta^2 = 10^{-4} \cdot D^{1.33} = 10^{-4} \cdot 10^{1.33} = 2.14 \cdot 10^{-3} \]

Step 2: Calculate the diversity improvement factor, \( I \)

where \( P_1 = 100\text{-Availability} = 0.1. \)

Therefore, for a system with an overall attenuation threshold of 11.31 dB the addition of the second site improved system availability from 99.90% to:

Plots of diversity improvement factor, \( I \), for various separation distances are presented in Exhibit 2.5.1.5-1.
Propagation Effects Handbook
for Satellite Systems Design

Section 3
Applications

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Exhibit 3.1.1-1
System Design Process
The comparisons and rankings are not by any means conclusive, since the range of RMS errors from the highest to the lowest rankings were in the range of 20 to 30%. There does appear to be a tendency, however, for the DAH, ITU-R, ExCell models to be well performing for all frequency bands.

The recommendations which follow in Section 3 of the handbook will be based for the most part on the results from the comparative studies above. The DAH Rain Attenuation Model (sometimes referred to as the USA Model) is recommended for application to the general link and for a general location. If the reader is interested in specialized conditions, such as low elevation angle, or specific region or frequency of operation, referral to the ITU-R and ACTS studies is highly recommended, where further qualitative breakdowns of the comparisons are provided in great detail.

This recommendation is subject to revision and update as further data and studies become available.
Determine Total Electron Content (TEC) for path of interest from local data or use TEC = $1 \times 10^{18}$ electrons/m$^2$ for typical maximum value [see Section 2.1.1 for guidance]

Determine Faraday Rotation from Exhibit (2.1.2-1)

Calculate Time Delay from Equation (2.1.3-1) or Estimate from Exhibit (2.1.3-1)

Calculate Time Delay Dispersion from Equation (2.1.4-1)

Calculate Phase Dispersion from Equation (2.1.4-3)

Are Conditions for Ionospheric Scintillation Expected?*

Calculate P-to-P Amplitude Fluctuation from ITU-R Ionospheric Scintillation Model [Section 2.1.5]

If Frequency $\leq 200$ MHz Estimate Auroral Absorption from discussion of Section 2.1.6

If Ground Station Latitude $\geq 64^\circ$ Estimate Polar Cap Absorption from discussion of Section 2.1.7

Yes

End

* See Section 1.2.3.2 for guidance.

Exhibit 3.2.1-1
Propagation Analysis Procedure for Satellite Links Operating Below About 3 GHz

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3.2.2 Mobile Satellite System Service Links

Propagation effects and modeling procedures for the service links of mobile satellite systems are described in companion NASA Handbooks published by Goldhirsh and Vogel (1992, 1998). The reader is referred to those documents for a complete compilation of propagation considerations for vehicular and personal mobile satellite systems operating in the frequency bands from UHF through K-band. This section provides a brief overview of the two documents and the subject areas covered.


The first edition of the Handbook describes a systematic set of studies of propagation effects for land mobile satellite system (LMSS) for rural and suburban conditions in the United States. UHF and L-band links are included. Measurements were accomplished with a variety of signal sources, including balloons, remotely piloted aircraft, helicopters, and satellites (MARECS-B2, ETS-V, and INMARSAT). The contents of the handbook are:

Chapter
1 Introduction
2 Attenuation Due to Individual Trees: Static Case
3 Attenuation Due to Roadside Trees: Mobile Case
4 Signal Degradation for Line-of-Sight Communications
5 Fade and Non-Fade Durations and Phase Spreads
6 Propagation Effects Due to Cross Polarization, Gain, and Space Diversity
7 Investigations from Different Countries
8 Modeling for LMSS Scenarios

LMSS models are described for roadside shadowing, diversity operation, probability distributions, and object scattering. Extensive references are provided.

The complete handbook can be found on-line at the NASA JPL propagation home page; http://propagation.jpl.nasa.gov/TOC.html


This document provides updated measurements since the first edition and broadens the scope to additional frequency bands and to other mobile service geometries. Measurements at UHF, L-band and K-band are described. Propagation effects for personal communications systems (PCS),
Exhibit 3.3.1-1
Propagation Analysis Procedure for Ku-Band FSS Links
Exhibit 3.3.1-2
Procedure for Evaluation of Link Restoration Techniques

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Exhibit 3.4.2-1
Propagation Analysis Procedure for Low Margin Ka-Band Links

Start

Calculate Atmospheric Gaseous Attenuation from ITU-R Method [Sec. 2.2.1.2.2]

Is Calculation for International Coordination?

No

Calculate Rain Attenuation from DAH Model [Sec 2.2.4.4]

Yes

Calculate Rain Attenuation from ITU-R Model [Sec. 2.2.4.1]

Calculate Cloud Attenuation from ITU-R Model [Sec. 2.2.2.1]

Calculate Tropospheric Scintillation Loss from ITU-R Model [Sec. 2.2.8.1.2]

Calculate Fog Attenuation from Altshuler Model [Sec. 2.2.3.1]

Calculate Cloud Scintillation Loss from Vanhoenacker Model [Sec. 2.2.8.2]

Calculate Wet Surface Effects Loss from [Sec. 2.2.7.2]

Is Frequency Reuse Employed?

No

Yes

Calculate Rain Depolarization from ITU-R Model [Sec. 2.2.5.2]

Calculate Ice Depolarization from ITU-R Model [Sec. 2.2.6.2]

Compare Results with Combined Effects Procedures [Sec. 2.2.11]

End

Will Link Restoration Techniques Be Employed?

No

Yes

Proceed to Exhibit 3.3.1-2

End
Exhibit 3.5-1
Propagation Analysis Procedure for Q/V-Band Links

Start

Calculate Atmospheric Gaseous Attenuation from ITU-R Method [Sec. 2.2.1.2.2]

Calculate Cloud Attenuation from ITU-R Model [Sec. 2.2.2.1]

Calculate Tropospheric Scintillation Loss from ITU-R Model [Sec. 2.2.8.1.2]

Calculate Rain Attenuation from the DAH Model [Sec 2.2.4.4]

Calculate Rain Attenuation from the ExCall Model [Sec 2.2.4.5]

Calculate Rain Attenuation from the ITU-R Model [Sec. 2.2.4.1]

Select Appropriate Rain Attenuation Values from Q/V-Band Evaluation Procedure [Sec 3.5.1]

Is Frequency Reuse Employed?

Is Elevation Angle ≤ 20°?

No

Yes

Calculate Rain Depolarization from ITU-R Model [Sec. 2.2.5.2]

Calculate Ice Depolarization from ITU-R Model [Sec. 2.2.6.2]

Calculate Fog Attenuation from Altshuler Model [Sec. 2.2.3.1]

Calculate Cloud Scintillation Loss from Vanhoenacker Model [Sec. 2.2.8.2]

End
Consider a low earth orbit (LEO) satellite in a circular polar orbit at an altitude of 765 km, with an ascending node at 100°W. This is a typical orbit for a MSS Big LEO satellite. Let us assume the satellite has a feeder link operating in the Ka-band, with a feeder link terminal located at 106.6°W and 32.5°N latitude (White Sands, NM). Assume that the 20 GHz downlink has a fixed power margin of 74 dB available for free space path loss and propagation losses.

Exhibit 3.7-1 shows a plot of elevation angle and path loss with time for a single pass of the satellite over the ground terminal. The elevation angle (heavy solid line) reaches a maximum of about 60 degrees. The free space path loss (long dashed line) ranges from 70 dB at the horizon points to a minimum of 59 dB at the center of the pass, where the elevation angle is at the maximum. The light solid line shows the available power margin of 74 dB. The difference between the available margin and the path loss, (shown by the double arrow line), is the margin available for propagation losses. The propagation margin ranges from 4 dB at the horizon points to 15 dB at the midpoint of the pass.
validates the comment made earlier that the system will have less margin at low elevation angles, where it is most needed.

The next step in the procedure is to determine expected rain attenuation outage statistics for the single pass, from the time variation of the rain margin. The rain attenuation prediction models in Section 2.2.4 of the handbook provide annual statistics of rain attenuation at a fixed elevation angle. The relative reliability at various portions of the LEO pass can be evaluated by applying the rain statistics from a prediction model to the time variable rain margin to determine an equivalent annualized outage probability for the link.

Exhibit 3.7-3 shows the annualized outage probability for the single LEO pass by application of the Global Model [Section 2.2.4.2] to the time varying Rain Margin shown in the previous plot. The ground station location is in Global Model Climate Region F (see Exhibit 2.2.4.2-1).

The result shows that the link has less than 0.01\% annual probability of outage (99.99\% link availability) for three minutes in the midpoint of the pass. However, the link availability drops to 99\% at ±2 minutes into the pass. The link will not close for about 1 minute at the horizon points.
Status and Future Plans

- Handbook Delivered to JPL October 23 1998
- Electronic Versions on-line
  - JPL
  - Stel
- On-going Peer Review
- Plan for Modifications and Enhancements
  - Revise current Edition
    - Corrections, Minor Changes
  - Develop Sixth Edition
    - Enhancements, Updated Models, New Areas
Highlights of:
“Propagation Effects for Vehicular and Personal Mobile Satellite Systems: Overview of Experimental and Modeling Results”

Julius Goldhirsh
Applied Physics Laboratory
The Johns Hopkins University
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Wolfhard J. Vogel
Electrical Engineering Research Laboratory
The University of Texas at Austin
wolf_vogel@mail.utexas.edu
Overview of Handbook

1. Revision of NASA Reference Publication 1274 Previously Entitled:
   (a) Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results
   (b) February 1992

2. New Title:
   Propagation Effects for Vehicular and Personal Mobile Satellite Systems: Overview of Experimental and Modeling Results

3. Comprised of 12 Chapters
   (a) Four are new
   (b) Other chapters updated and enhanced
Overview of Handbook (Continued)

4. Nine chapters have been completed and are on the Web
   (a) Address is:

   http://www.utexas.edu/research/mopro/

   (b) Chapters may be downloaded as Adobe files

5. Two chapters have been written and are being edited.

6. Final chapter is being written.

7. Hard copies to be available December 31, 1998
   (a) Disseminated to Workshop and other interested investigators
Overview of Handbook (Continued)

8. Handbook will subsequently undergo review process
   (a) Ernie Smith, Warren Flock, Ken Davies, other volunteers
9. Revised edition will subsequently be published
   (a) Reviewers' comments addressed
   (b) Other readers' comments addressed
Chapter 1: Introduction
   (Being edited)

Chapter 2: Attenuation Due to Trees: Static Case
   (On the Web)

Chapter 3: Attenuation Due to Roadside Trees: Mobile Case
   (On the Web)

Chapter 4: Signal Degradation for Line of Sight Communications
   (On the Web)

Chapter 5: Fade and Non-Fade Durations and Phase Spreads
   (On the Web)

Chapter 6: Polarization, Antenna Gain and Diversity Considerations
   (On the Web)
Status of Handbook (Continued)

Chapter 7: Investigations from Different Countries
(On the Web)

Chapter 8: Earth-Satellite Propagation Effects
Inside Buildings
(New: On the Web)

Chapter 9: Maritime-Mobile Satellite Propagation
Effects
(New: On the Web)

Chapter 10: Optical Methods for Assessing Fade
Margins
(New: On the Web)

Chapter 11: Theoretical Modeling Considerations
(Being written)

Chapter 12: Summary and Recommendations
(Being edited)
### Mobile Satellite Handbook Statistics

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<td>351</td>
<td>6,270</td>
<td>114</td>
</tr>
</tbody>
</table>
Anil V. Kantak
James Rucker
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109
October 23, 1998.
PROPAGATION MODELS DATABASE

➢ A database of various propagation phenomena models which can be used by the telecommunications systems engineers to obtain the desired parameter values for systems design.

➢ Propagation research
  ➢ Ease of using the models
  ➢ Passing the experimental data through the models
  ➢ Comparison and checking of experimental data.

➢ An easy to use convenient tool, implemented on a PC to analyze the user propagation data.
Salient features of the software:

- Microsoft Excel 5.0-based software, utilizing Excel’s excellent spreadsheet features and charting functions.
- Every model is written as Excel subroutine / Excel User-Defined Function.
- The program produces output for the user in its own spreadsheet or the user may use the subroutines / functions in their own Excel program and transport the result to their program.
- Every care is taken to avoid user-made errors in running the program models.
PROPAGATION MODELS DATABASE

- Every model of the database has the same overall instructions set and same operating procedure, making the user capable of using any model once the procedure is learned.

- Extensive charting procedures are available to the user and, where feasible, the charting procedures and workings are made transparent to the user. The program allows the user to vary any desired variable of the model and see its effects on the user-selected output variable via a chart. The user is allowed to loop back to obtain other combinations of outputs and independent variables without running the model again.

- Every chart produced may be saved or printed out.
The database is divided into six major categories:

- Ionospheric propagation models.
- Tropospheric propagation models.
- Land-Mobile system propagation models.
- Effects of small particles on propagation.
- Rain models.
- Radio noise models.
PROPAGATION MODELS DATABASE

1. Propagation Model Selection
2. Model as Excel Sub or Function
3. Input Parameter Values
4. Numerical Computations & Results
5. Tables & Plots Generation
6. Print And/Or Plot
PROPAGATION MODELS DATABASE

➤ System Requirement:
  ➤ Windows NT or Windows 95
  ➤ At least 8 to 16 Mbytes of RAM
  ➤ 2 Mbytes of disk space.
  ➤ 486 or Pentium processor with at least 25 MHz clock rate.
PROPOSITION MODELS DATABASE

➢ Properties of the current version.
  ➢ Enhanced graphics.
    ➢ Allows the user to produce many different types of graphs from the same vectors.
  ➢ New propagation models added.
  ➢ Enhanced a few existing models.
PROPAGATION MODELS DATABASE

➢ Conversion of the Propagation Models Database from Excel environment to C++ environment.

➢ Design Concepts

➢ Isolation of:
  ➢ User Interface
  ➢ Databases
  ➢ Computational Engine.

➢ Make the Propagation Database software more compatible with other software the user may have.

➢ Make the Propagation Database software independently accessible from a server by remote users.

➢ Make the Propagation Database software platform independent.
WET ANTENNA STUDIES
NASA LeRC

By: R. Acosta

SUMMARY OF PRESENTATION

- EXPERIMENT OVERVIEW
- EXPERIMENTAL RESULTS
- THEORY vs. EXPERIMENT
- CONCLUSIVE REMARKS
ANTENNA WETTING FACTOR - EXPERIMENT

Fig. 1 - Rain Event 304
Fig. 2 - Rain Event 286
ANTENNA WETTING FACTOR - EXPERIMENT

Fig. 3 - Rain Event 291
Wet Antenna Studies at LeRC

Conclusions

- The antenna wetting factor for the 1.2 m antennas is very similar to the 0.35 m antennas.

- Maximum antenna wetting factor was measured to be between 3 and 4 dB.

- Wet antenna fade availability differed from dry antenna fade availability by 2 dB at lower fades (5-10 dBs)

- Rain shield was not perfect but seemed to work most of the time

- Higher antenna wetting factors tend to occur at rain rates of the order of 10 - 40 mm/hr.

- At very high rain rates and high fades both antennas (dry and wet) have a negligible wetness factor.
ANTENNA WETTING EXPERIMENT

EXPERIMENTAL SET-UP

EXPERIMENTAL RESULTS
Theoretical Model - WET REFLECTOR

Segmented Reflector Thickness Computation

Rain (mm/hr)

Elevation Angle

$\theta_i$: $i^{th}$ Inclination Angle

$t_i$: $i^{th}$ water thickness

$\phi_i$: $i^{th}$ incident angle
Theoretical Model - WET REFLECTOR

Thickness of water sheet

\[ \tau = \sqrt{3 \Gamma \mu \rho \tan \theta} \]

\( \theta \): Inclination angle
\( \Gamma \): Rain rate
\( \mu \): Viscosity of water
\( \rho \): Density of water
\( g \): Gravity
\( ds \): Differential length
\( \tau \): Average water thickness
Transmission Line Model - signal loss vs effective water thickness
WET REFLECTOR MODEL - Results
THEORY vs. EXPERIMENT

Light Rain Case – Antenna Wetting Factor

Medium Rain Case – Antenna Wetting

Heavy Rain Case – Antenna Wetting

Exp. Data
Light Rain
Acosta Approx.
Text Book Approx.
Reflector Att.

Exp. Data
Medium Rain
Acosta Approx.
Text Book Approx.
Reflector Att.

Exp. Data
Heavy Rain
Acosta Approx.
Text Book Approx.
Reflector Att.
Wet Antenna Studies at LeRC

Conclusive Remarks

- The antenna wetting factor for the 1.2 m antennas is very similar to the 0.35 m antennas.

- Maximum antenna wetting factor was measured to be between 3 and 4 dB and it was limited by dynamic range of the system.

- Wet antenna fade availability differed from dry antenna fade availability by 2 dB at lower fades (5-10 dBs)

- Rain shield was not perfect but seemed to work most of the time

- Higher antenna wetting factors tend to occur at rain rates of the order of 10 - 40 mm/hr but it may be limited to dynamic range of system.

- Antenna wetting factor is a random variable.

- Future work will include feed compensation and statistical data.
Use of a Software Simulator for Modeling the ACTS Link

Roy Laurens
Parag Manihar
Ioannis Pavlidis
Satish Shetty

ACTS Propagation Workshop
Oklahoma City, OK
October 22-23, 1998

Information Networking Institute
Carnegie Mellon University
Agenda

- CMU/NASA ACTS Experiment
- Network Simulator (ns)
- Error Modeling for the ACTS Link
- Data collection and analysis
- Conclusions and Future Research
Goals

- *ACTS Error Modeling module for NS*
- Performance analysis and Improvement of TCP behavior over ACTS
- Mobile IP performance over ACTS
CMU/NASA ACTS Experiment

NASA

LET

EFData SDM9000

Comstream CM701

HSSI

RS449

Cisco 3640 Router

Cisco 1548 Dual Speed Hub

6 Mbps

45Mbps

ACTS

6 Mbps

45Mbps

CMU

USAT

Comstream CM701

EFData SDM9000

RS449

HSSI

Cisco 3640 Router

Hammershlag Hall

Network B
CMU ChaosNet

FreeBSD Router

Network A
NASA

FreeBSD Router

Correspondent Node

NASA Router

100Mbps

Internet

"Mobile Node"

Correspondent

"Mobile Node"

Correspondent

Ethernet
Network Simulator (ns)

- Collaborative effort: USC/ISI, PARC, LBNL & UCB
- Event based queue modeling
- Easily extendable modular framework
- Protocol definition and simulation configuration using scripting language
- Graphical tools for animation and configuration
ns Architecture

Application

Transport

Network

Link

Traffic

Agent

Demux

Routing

Queues

Error Model
Error modeling in ns

- Bit Error Rate
- \textit{Error inter-arrival time}
Experiment Data

- Eb/No, BER, Beacon Fade and TCP data
- Signal Degradation on a Rainy day
- Effect on the TCP tests performed
Fade data on Rainy Day from Beacon Signals at 20GHz and 30GHz

![Graph of Fade Levels Compared to Clear Sky (dB) vs Time (Hour of Day)]
TCP Test Before Fade Event

Receiver Acknowledgements vs. Time (seconds)

- ACK Sequence number
- Unique Duplicate ACKS
Simulation verification

- Modeling the Observed Link Conditions
- Model vs Observed Link Behavior
- Multiple Simulation Run Results
Simulation Verification for Tests Near Fade Event
Simulation Run for TCP Test on a Clear Day
Multiple Simulation Run Results

![Graph showing frequency over time with bars and a curve]
Conclusions

- BER and error inter-arrival time used for modeling
- NS: modular extendable tool for modeling propagation
- ACTS ns model can be used for research of current and future protocols over similar links
Future Research

• ns in emulation mode
• Mapping of fade data and atmospheric conditions to predict expected Bit Error Rate
Special Thanks

- Kul Bhasin
- Bob Bauer
- Mike Zernic
- Rich Reinhart
- Adesh Singhal
- ACTS Control Room Team at NASA Lewis
SESSION 4. PROPAGATION CAMPAIGN
WITH ACTS IN INCLINED ORBIT
Chair: R. Acosta
(NASA/LeRC)
BLUE RIBBON PANEL & I/O OPERATIONS
ROBERT BAUER

ACTS PROPAGATION STUDIES WORKSHOP XI
Oklahoma City, OK
October 23, 1998

ACTS INCLINED ORBIT READINESS REVIEWS

• SYSTEM TECHNICAL READINESS REVIEW
  - 6/10/98
  - IN-HOUSE PANEL FROM LEWIS ENGINEERING DIRECTORATE
  - OPERATIONS PLANS AND PROCEDURES

• PROGRAM READINESS REVIEW
  - 6/12/98
  - 8 MEMBER BLUE RIBBON PANEL (BRP) FROM INDUSTRY & GOVT
    • Dr. Leonard Golding, Hughes Network Systems (Chair)
    • Dr. Louis Ippolito - Stanford Telecommunications, Inc.
    • Mr. Brian Abbe - Booz, Allen, Hamilton
    • Ms. Charlene Gilbert, NASA JSC
    • Mr. Frank Dixon, NCS
    • Dr. Al MacRae, MacRae Technologies
    • Dr. Stephen Goldstein, NSF
    • Dr. Prakash Chitre, Comsat Labs
  - PROGRAM PLANS AND DIRECTION
SOMO DIRECTION (ROADMAP)

SOMO (JSC) TASKED WITH:
• LOWERING OF NASA'S OPERATIONS COSTS BY
  - COMMERCIAL ASSET UTILIZATION
    • Space Network (TDRSS); Ground Network (shuttle launch, polar programs); Deep Space Network; NASA Information System Network (NREN, HPCC...); Mission Control Center (Houston)
  - INTEROPERABILITY AND STANDARDIZATION
  - FLIGHT AND GROUND SEGMENT SYSTEM AUTOMATION
  - PROCESS INNOVATION TOOLS
• PROVIDE ENABLING DATA AND MISSION SERVICES TO THE NASA ENTERPRISES
  - HIGH PERFORMANCE COMMUNICATIONS
  - INTELLIGENT SYSTEMS AND AUTONOMY
  - INNOVATIVE MISSION INFORMATION SYSTEMS
• ADVANCE US INDUSTRY LEADERSHIP IN COMMERCIAL SATELLITE COMMUNICATIONS
  - HYBRID NETWORK UBIQUITY
  - PRE-COMPETITIVE RESEARCH AND TECHNOLOGY TO OPEN NEW MARKETS
  - SPACE ENVIRONMENT CHARACTERIZATION

SPACE COMMUNICATIONS OFFICE

ACTS DIRECTION

• PROGRAM AND ACTIVITIES MUST BE RELEVANT TO NASA ENTERPRISES AND SOMO ROADMAP
• NEW GOALS DEFINED FOR ACTS IN INCLINED ORBIT. USE ACTS AS A TESTBED TO:
  1. DEMONSTRATE NASA & OTHER GOVERNMENT USES OF TRANSITIONING TO COMMERCIAL SATELLITE SERVICES.
  2. TEST, VERIFY & RESOLVE TECHNICAL ISSUES USING ASYNCHRONOUS TRANSFER MODE (ATM), INTERNET PROTOCOL (IP), OR OTHER PROTOCOLS OVER SATELLITE, INCLUDING INTEROPERABILITY ISSUES WITH TERRESTRIAL NETWORKS.
  3. EVALUATE SPOT BEAM SATELLITE OPERATIONS IN AN INCLINED ORBIT.
  4. VERIFY NEW SATELLITE KA-BAND TECHNOLOGY AND HARDWARE.

SPACE COMMUNICATIONS OFFICE
HIGHLIGHTS OF BRP RECOMMENDATION

• CONTINUATION OF THE 2 YR. INCLINED ORBIT OPERATIONS IS MERITED WITH HIGH PAYOFF POTENTIAL
• THREE CLASSES OF EXPERIMENTS
  - PROPAGATION
  - TECHNICAL VERIFICATION
  - APPLICATIONS
• 14 RECOMMENDATIONS
  - 8 CURRENTLY PLANNED
  - 2 NOT CURRENTLY PLANNED, BUT EASILY MET
  - 2 NOT CURRENTLY PLANNED, CHALLENGING TO MEET
  - 2 NOT PLANNED, INFEASIBLE
• STRONG SUPPORT TO CONTINUE PROPAGATION PROGRAM.

SPACE COMMUNICATIONS OFFICE

PLAN
MEET RECOMMENDATION AS BEST AS POSSIBLE

✓ BEING PLANNED:
  - SITE DIVERSITY
  - WET ANTENA MEASUREMENTS
  - COMPARE RESULTS OF PRE-V/O WITH V/O MEASUREMENTS
  - TCP/IP AND ATM OVER SATELLITE
  - MULTICASTING OVER SATELLITE
  - BANDWIDTH ON DEMAND/QUALITY OF SERVICE
  - DEMONSTRATIONS
  - CASTING STRATEGIC DIRECTION IN TERMS OF NASA, LERC GOALS

✓ BEING CONSIDERED:
  - WIDEBAND MEASUREMENTS
  - NGS/GSO INTERFERENCE MEASUREMENTS
  - (LIMITED) CONTINUATION OF DATA COLLECTION
  - DEPOLARIZATION EFFECTS

✗ NOT CONSIDERED
  - SHUTTLE EXPT.
  - MEASUREMENTS DURING SUPER-ORBIT

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CONTINUATION OF DATA COLLECTION

- TWO SITES ARE BEING CONSIDERED FOR 1 MORE YEAR OF DATA COLLECTION

- FLORIDA
  - SUBTROPICAL (GLOBAL RAIN CLIMATE ZONE "E")
  - CLOSEST TO MEETING RECOMMENDATION FOR DATA FROM A TROPICAL SITE

- OKLAHOMA
  - MID LATITUDE (GLOBAL RAIN CLIMATE ZONE D2/D1)
  - RECOMMENDED BY PANEL FOR DEPOL MEASUREMENTS

- UNIVERSITY SITES CONSIDERED FOR EASE IN "EXTENDING" THROUGH A GRANT
- MOVE SECOND APT TO SITES FOR DEPOLARIZATION
- MODIFY TERMINALS FOR INCLINED ORBIT OPERATIONS
- IS THERE INTEREST TO CONTINUE DATA COLLECTION ON A NO-COST BASIS (TO NASA) AT OTHER SITES?

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ISSUES/CONCERNS/QUESTIONS

- IS THERE VALUE IN COLLECTING PAST 1 MORE YEAR IF 2 FULL YEARS CAN'T BE MET?
- WHAT IS ADDED PRECISION TO DATA BASE BY CONTINUING?
- WHAT IS THE VALUE OF CONTINUING BEACON MEASUREMENTS AS SPACECRAFT SUPER-ORBITS TO THE HORIZON?
- WHAT DATA IS STILL NEEDED FOR SITE DIVERSITY?
- QUANTIFY HOW ACTS PROPAGATION DATA LOWERS NASA'S OPERATIONS COSTS.
  - IF STATISTICS ARE IMPROVED BY X%, WHAT DOES THAT MEAN TO NASA IN $'S SAVED?
  - CAN DATA BE USED IN DEEP SPACE NETWORK Ka-BAND OPERATIONS TO LOWER COSTS OR IMPROVE OPS?
  - WHAT DOLLAR SAVINGS DOES IMPROVED SYSTEM DESIGN MEAN TO A COMMERCIAL OPERATOR?

SPACE COMMUNICATIONS OFFICE
ACTS Propagation Terminals
Tracking ACTS in Inclined Orbit

David B. Westenhaver
Westenhaver Wizard Works, Inc.
746 Lioness Ct SW
Stone Mountain, GA 30087-2855
770-925-1091, wwwinc@crl.com

Presented at ACTS Propagation Studies Workshop XI
Oklahoma City, OK
October 23, 1998
ACTS Propagation Terminals Tracking ACTS in Inclined Orbit requirements.

- The APT tracking is much more stringent than a VSAT system.
- Keep the APT antenna pointed at the ACTS at all times via "Program Tracking".
- All antenna tracking motion to result in less than 0.4 dB signal change with a goal of less than 0.1 dB.
- Antenna mount position and motion time tagged in the raw data files.
- Use "Step-Tracking" peaking algorithm only for "Zeroing" operations.

Mechanical Positioning system requirements.

- Stiff mechanical support.
- Long lever arms for jack screws.
- Motorized jack screws with incremental motor position indicators.
- Limit switches.
Motion Motor Controller requirements:

• Move the mount small angles in a slow controlled predictable manner.
• Accept and perform position commands via RS-232 interface.
• Report selectable and detailed status via RS-232 interface.
• Hold position under wind loading conditions.
• Provide high speed motion for zeroing incremental position counters.
• Retain detailed incremental and initial setup information during power cycling.

Integration with current DACS Collection System requirements.

• Connect Motor controller to DACS at Antenna.
• Add Software to DACS & TSR for the control and motion logging.
• Develop a method to read the ACTS Ephemeris from pointing angle file.
• Retain detailed incremental and initial setup information during power cycling.

Operational Support Issues.

• Develop program to convert ACTS Ephemeris to pointing angle counts for each site.
• Provide the sites with corrected ACTS Ephemeris weekly.
• Keep it working by resolving all antenna pointing issues.
Remove Wet Antenna Surface Effects of Composite Antenna

- The composite antenna's reflecting surface is an aluminum wire mesh imbedded under a plastic textured surface.
- The surface can be re-manufactured to provide a smooth metallic "front surface" reflector.
SESSION 5. PLENARY

Chairs: R. Crane (Univ. of Oklahoma)

D. Rogers (CRC, Canada)
REPORT OF APSW XI PLENARY MEETING

D.V. Rogers and R.K. Crane

At the Eleventh ACTS Propagation Studies Workshop (APSW XI), the ACTS Working Groups held the customary Plenary meeting on 23 October 1998 to address project issues related to experiments being conducted with the NASA ACTS Propagation Terminals (APTs). Results of that meeting are reported here.

I. ACTS Experimenter Issues and Concerns

A. Data Collection/Quality

During the meeting, NASA LeRC announced that, consistent with recommendations of the Blue Ribbon Panel, measurements are planned to be continued during the next calendar year in the inclined-orbit mode, but at only two of the ACTS Propagation Terminal (APT) sites, Oklahoma and Florida. The new configuration will deploy two existing APTs at each of these sites to permit site diversity measurements. Consideration will also be given to incorporating the capability to collect path depolarization data at these two sites.

The APTs to be used during the inclined-orbit phase of ACTS operations will have to be adapted with satellite tracking capability. A tracker designed for this purpose was illustrated during the presentation by NASA LeRC (R. Bauer). A method to minimize the antenna wetting effects for the APTs was also presented by D. Westenhaver. The approach is to machine the dielectric surface to the level of the embedded wire-reflecting surface, and to paint the new surface with conductive paint. Presumably, a shield or blower would also be installed to keep the antenna feed window dry.

The new configuration will require redeployment of two of the seven terminals. NASA also plans to locate another terminal at the site-support contractor’s facility to serve for spare parts, so that five of the existing APTs are then obligated under the official NASA measurements program. New Mexico (S. Horan) offered to upgrade, at no cost to NASA, their APT, assuming that the APT can be removed from the current location at White Sands. Colorado (J. Beaver) expressed some interest in retaining an APT as well. Deployment per this arrangement would utilize all seven of the APTs.

Experimenter interested in continuing measurements with upgraded APTs were requested to inform R. Bauer of NASA LeRC promptly. However, it was made clear by NASA LeRC (R. Acosta) that if existing APTs are needed for redeployment in the new measurement configuration, they will be recalled.

With incorporation of an antenna tracking capability, ACTS measurements with the APTs should be feasible until the planned deorbit of the satellite in September 2000.

Mention was also made of the requirement to have all ACTS preprocessed data for calendar year 1998 delivered to the ACTS Data Center by March 1999.
ACTIONS:

Experimenters should inform NASA LeRC (R. Bauer) of any interest in upgrading and retaining an ACTS Propagation Terminal for inclined-orbit operations. All experimenters should also be aware of the need to complete delivery of all preprocessed data through December 1998 by March 1999.

B. Reporting of ACTS Data and Results

Development and reporting of results and propagation models within the ACTS project was discussed. A general proposal was made that another special issue be planned much like the June 1997 Proceedings of the IEEE Special Issue on “Ka-band Propagation Effects on Earth-Satellite Links.” N. Golshan, R. Acosta and D. Rogers were proposed as guest editors. Support was expressed to approach the IEEE to determine if another special issue of Proc. IEEE is possible for reporting of the ACTS results.

During the discussion, various subject areas and coordinators were identified for inclusion in a special issue as follows:

- signal scintillation - C. Mayer;
- ACTS system overview - D. Westenhaver
- summary of basic ACTS propagation statistics - R. Crane;
- antenna-wetting model/experimental verification - R. Crane
- radar issues - J. Beaver;
- fade durations - H. Helmken;
- fade slopes - J. Pinder;
- fade mitigation - R. Acosta;
- site diversity - H. Helmken;
- cloud effects - C. Mayer.

ACTION:

N. Golshan will approach the IEEE to determine if a special issue of Proc. IEEE is possible and what the corresponding schedule will be.

II. Other Topics

During the Plenary, a wide-ranging discussion was pursued on future needs for propagation data. Propagation information for the Q/V-bands, which feature 3 GHz of spectrum (37.5 - 40.5 GHz downlink, 47.2 - 50.2 GHz uplink) allocated in each direction for earth-space services, was noted as a prime area requiring study and preferably measurements. J. Goldhirsh pointed out the need to validate nongeostationary orbit (NGSO) and Low Earth Orbit (LEO) link calculations with measurement data. S.
Horan noted that these two requirements might be met by flying a Q/V-band beacon package on the
Space Station for a year or two. R. Bauer reported that there is indeed interest in using the Space Station
for scientific projects of this nature.

L. Ippolito remarked that the Iridium system has already deployed about 60 satellites in orbit,
each with a 20-GHz beacon, which could be used to study LEO propagation characteristics. He
suggested that NASA might want to contact Motorola about this possibility. R. Crane concurred that the
LEO prediction problems may be important.

N. Golshan stated that for NASA to fund any endeavor, it would have to relate to NASA’s
requirements (e.g., work related to LEO issues would need to address the interests of Goddard Space
Flight Center) or to NASA enterprises. R. Bauer remarked that NASA has prime interests in the 40/50-
GHz band and the bands above 71 GHz (precompetitive technology). L. Ippolito stated that the NAPEX
group should try to determine what information is needed at Q/V band. A. Dissanayake recalled that a
40/50-GHz satellite system had been mentioned at the previous NAPEX meeting in Austin, and that it
might be usable for some of the requirements.

N. Golshan noted that optical communication issues are also important to NASA (due to the
ability to focus the beam). Prime propagation concerns arise related to signal scintillations, cloud effects,
etc. Wideband transmission at gigabit rates is also of interest, and might be achieved by using earth
terminals situated in desert locations, perhaps with site diversity, etc. He also remarked that NASA’s
Deep Space Network typically uses 5° - 10° as the lowest operating angle.

R. Bauer stated that NASA hasn’t done a good job of explaining its new requirements per the
new “roadmap” (mainly because the shift was so sudden), and that perhaps NASA/JPL and LeRC can
collaborate to get this information to the propagation community.

**ACTION:**

R. Bauer, R. Acosta and N. Golshan will collaborate to explain the future requirements of the
new NASA “roadmap,” and try to identify sources of funding for future needs.

**III. Next Meeting**

The group tentatively agreed to hold the next NASA Propagation Experimenters Meeting in
Herndon, Virginia, during 3-4 June 1999. It is hoped that this venue will promote involvement by
NASA/GSFC personnel.

**IV. Information**

E. Smith (U. Colorado) reported that U.S. ITU-R Study Group 3 (Radiowave Propagation),
Chaired by Eldon Haakinson of NTIA/ITS, is scheduled to meet Wednesday, January 6, 1999, from
0900-1100 in the Engineering Center at the University of Colorado, Boulder, during the URSI National
Radio Science Meeting.
XXI ACTS WORKSHOP ATTENDEES

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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACA</td>
<td>attenuation with respect to clean air (or clear air)</td>
</tr>
<tr>
<td>ACS</td>
<td>Advanced Communications Systems (in Stanford Telecommunications, Inc.)</td>
</tr>
<tr>
<td>ACKS</td>
<td>acknowledgements</td>
</tr>
<tr>
<td>ACTS</td>
<td>Advanced Communications Technology Satellite</td>
</tr>
<tr>
<td>ACTSPP</td>
<td>Advanced Communications Technology Satellite (ACTS) preprocessing program (translates raw beacon data)</td>
</tr>
<tr>
<td>AFS</td>
<td>attenuation with respect to free space</td>
</tr>
<tr>
<td>AGA</td>
<td>attenuation due to gaseous absorption</td>
</tr>
<tr>
<td>APL</td>
<td>Applied Physics Laboratory</td>
</tr>
<tr>
<td>APSW</td>
<td>Advanced Communications Technology Satellite (ACTS) Propagation Studies Workshop</td>
</tr>
<tr>
<td>APT</td>
<td>ACTS Propagation Terminal (at Colorado State University)</td>
</tr>
<tr>
<td>ARD</td>
<td>radiometrically derived attenuation</td>
</tr>
<tr>
<td>ARS</td>
<td>statistical attenuation ratio</td>
</tr>
<tr>
<td>ATM</td>
<td>asynchronous transfer mode</td>
</tr>
<tr>
<td>BER</td>
<td>bit error rate</td>
</tr>
<tr>
<td>CCIR</td>
<td>(now changed to ITU-R—International Telecommunications Union-Radio)</td>
</tr>
<tr>
<td>CDF</td>
<td>cumulative distribution functions</td>
</tr>
<tr>
<td>CHILL</td>
<td>University of Chicago and Illinois Water Survey (radar)</td>
</tr>
<tr>
<td>CMU</td>
<td>Carnegie Mellon University</td>
</tr>
<tr>
<td>COAG</td>
<td>group of surface weather stations in Colorado</td>
</tr>
<tr>
<td>COAGMET</td>
<td>group of surface weather stations in Colorado (same as COAG)</td>
</tr>
<tr>
<td>COMSTAR</td>
<td>(communications satellite)</td>
</tr>
<tr>
<td>CONSTMM</td>
<td>calibration constant for successive months</td>
</tr>
<tr>
<td>CRG</td>
<td>capacitive rain gauge</td>
</tr>
<tr>
<td>CSU</td>
<td>Colorado State University</td>
</tr>
<tr>
<td>DAH</td>
<td>Dissanayake, Allnutt, and Haidara (rain attenuation model, also called the USA model)</td>
</tr>
<tr>
<td>DRX</td>
<td>data receiving (collection)</td>
</tr>
<tr>
<td>Eb/No</td>
<td>energy per bit by noise density ratio</td>
</tr>
<tr>
<td>ExCell</td>
<td>exponential cell (model)</td>
</tr>
<tr>
<td>FEC</td>
<td>forward error correcting</td>
</tr>
<tr>
<td>FTS</td>
<td>field test site</td>
</tr>
<tr>
<td>GBS</td>
<td>Global Broadcast System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HDR</td>
<td>high data rate</td>
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<tr>
<td>IEEE</td>
<td>The Institute of Electrical and Electronics Engineers, Inc.</td>
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<tr>
<td>INMARSAT</td>
<td>International Maritime Satellite</td>
</tr>
<tr>
<td>IP</td>
<td>internet protocol</td>
</tr>
<tr>
<td>ITU-R</td>
<td>ITU-R: International Telecommunications Union—Radiocommunications</td>
</tr>
<tr>
<td>JHU</td>
<td>Johns Hopkins University</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>Kdp</td>
<td>specific differential phase</td>
</tr>
<tr>
<td>LBNL</td>
<td>Lawrence Berkeley National Laboratory</td>
</tr>
<tr>
<td>Ldr</td>
<td>linear depolarization ratio</td>
</tr>
<tr>
<td>LEO</td>
<td>low earth orbit</td>
</tr>
<tr>
<td>LET</td>
<td>Link Evaluation Terminal</td>
</tr>
<tr>
<td>LMSS</td>
<td>Land Mobile Satellite System</td>
</tr>
<tr>
<td>LeRC</td>
<td>Lewis Research Center (Cleveland, OH)</td>
</tr>
<tr>
<td>MARECS-B2</td>
<td>(International Marine Satellite Consortium satellite)</td>
</tr>
<tr>
<td>m.a.s.l.</td>
<td>meters above sea level</td>
</tr>
<tr>
<td>Mesonet</td>
<td>mesoscale meteorological network of Oklahoma</td>
</tr>
<tr>
<td>MPM</td>
<td>Microwave Propagation Model (Basically Liebe's Atmospheric Model)</td>
</tr>
<tr>
<td>NCDC</td>
<td>National Climatological Data Center</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanographic and Atmospheric Administration</td>
</tr>
<tr>
<td>NS</td>
<td>Network Simulator</td>
</tr>
<tr>
<td>OU</td>
<td>Oklahoma University (Norman, OK)</td>
</tr>
<tr>
<td>PARC</td>
<td>Palo Alto Research Center</td>
</tr>
<tr>
<td>PDF</td>
<td>probability density function</td>
</tr>
<tr>
<td>R-H</td>
<td>Rice-Holmberg (rain model)</td>
</tr>
<tr>
<td>RHI</td>
<td>Range Height Indicator</td>
</tr>
<tr>
<td>RHV (%)</td>
<td>cross correlation coefficient</td>
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<tr>
<td>RMS</td>
<td>root mean square</td>
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<tr>
<td>Satcom</td>
<td>satellite communications</td>
</tr>
<tr>
<td>SCTC</td>
<td>Space Communications Technology Center</td>
</tr>
<tr>
<td>STel</td>
<td>Stanford Telecomunications, Inc., Reston, VA</td>
</tr>
<tr>
<td>TBG</td>
<td>tipping bucket gauge</td>
</tr>
<tr>
<td>TBRG</td>
<td>tipping bucket rain gauge</td>
</tr>
<tr>
<td>T-C</td>
<td>two component (model)</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
</tr>
<tr>
<td>TDRSS</td>
<td>Telecommunications and Data Relay Satellite System</td>
</tr>
<tr>
<td>TEC</td>
<td>total electron content</td>
</tr>
<tr>
<td>TSR</td>
<td>transmit &amp; stay resident</td>
</tr>
<tr>
<td>UAF</td>
<td>University of Alaska, Fairbanks</td>
</tr>
<tr>
<td>UBC</td>
<td>University of British Columbia</td>
</tr>
<tr>
<td>UCB</td>
<td>University of California at Berkeley</td>
</tr>
<tr>
<td>URSI</td>
<td>The International Union of Radio Science</td>
</tr>
<tr>
<td>USAT</td>
<td>ultrasmall aperture terminal (transportable 36-cm) station</td>
</tr>
<tr>
<td>USC/ISI</td>
<td>University of Southern California's Information Sciences Institute</td>
</tr>
<tr>
<td>UTC</td>
<td>universal time coordinates (Greenwich mean time)</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>--------------</td>
<td>-------------</td>
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<tr>
<td>VSAT</td>
<td>very small aperture terminal</td>
</tr>
<tr>
<td>wrt</td>
<td>with respect to</td>
</tr>
<tr>
<td>WWV</td>
<td>plugin card in the ACTS propagation terminal's collection PC, which is used to receive the standard time from Colorado and adjust the PC clock accordingly</td>
</tr>
<tr>
<td>XPD</td>
<td>Cross-polarization discrimination</td>
</tr>
<tr>
<td>Zdr</td>
<td>differential reflectivity</td>
</tr>
<tr>
<td>Zhh</td>
<td>horizontal reflectivity</td>
</tr>
</tbody>
</table>

Nasser Golshan and Christian Ho, editors

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National Aeronautics and Space Administration
Washington, DC 20546-0001

The Advanced Communications Technology Satellite Propagation Studies Workshop (APSW) is convened each year to present the results of the Advanced Communications Technology Satellite (ACTS) Ka-band propagation campaign. Representatives from the space community including industry, academia, and government who are interested in radiowave propagation at Ka-band are invited to APSW for discussions and exchange of information. The ACTS Propagation campaign will complete five years of Ka-Band data collection at seven sites in North America by December 31, 1998. Through this effort, NASA is making a major contribution to the effective utilization of this band by providing timely propagation data and models for predicting the performance of Ka-band links between space and ground.