1994011565 N94-16038

Data Acquisition, Preprocessing and Analysis for the Virginia Tech OLYMPUS Experiment

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Abstract

Virginia Tech is conducting a slant path propagation experiment using the 12, 20 and 30 GHz OLYMPUS beacons. Beacon signal measurements are made using separate terminals for each frequency. In addition, short baseline diversity measurements are collected through a mobile 20 GHz terminal. Data collection is performed with a custom data acquisition and control system. Raw data are preprocessed to remove equipment biases and discontinuities prior to analysis. Preprocessed data are then statistically analyzed to investigate parameters such as frequency scaling, fade slope and duration, and scintillation intensity.

The OLYMPUS Experiment

The Virginia Tech experiment equipment consists of four terminals, each of which contains a beacon receiver and a radiometer. As shown in Figure 1, each terminal utilizes a separate antenna and all are frequency locked to the 12 GHz beacon. Locking to the less fade prone 12 GHz beacon allows measurement of 20 and 30 GHz fades to the noise floor. Sky noise measurements via radiometers provide a means to measure gaseous attenuation and hence the clear sky attenuation. Clear sky attenuation is then added to the measured beacon attenuation to obtain attenuation referenced to free space. System status and environmental data are collected to monitor system performance and examine correlations between propagation measurements and weather conditions.

Data Collection

Data collection and system control is performed by a standalone data acquisition and control system (DACS). Figure 2 is a block diagram of the major DACS components. The DACS is 80286 microprocessor based and is connected to the PS/2 Model 60 collection computer through a parallel data interface. I and Q detector cards each accept two 10 kHz IF signals from the receivers and output in-phase and quadrature power measurements for the two channels at a 10 Hz rate. Status signals and alarms, such as loss of lock, are input to the digital input card. Similarly, analog signals such as temperature, wind speed, barometric pressure... are recorded via the analog input card. The radiometer input card counts the pulse train from each of the radiometers while the digital output card controls the waveguide switches and noise diodes that are used for radiometer calibrations. Data from the DACS

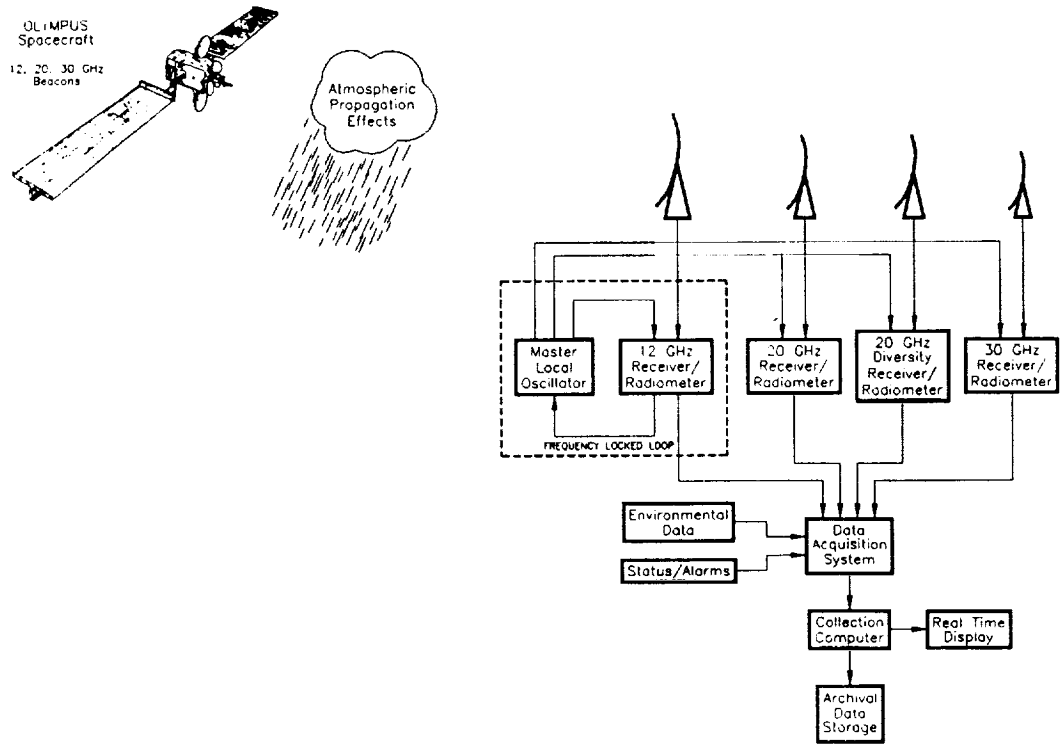

Figure 1: Virginia Tech OLYMPUS system hardware overview.

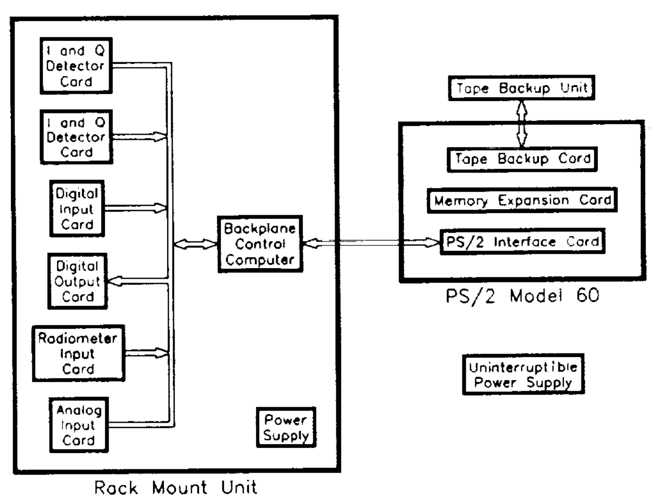

Figure 2: Data acquisition and control system overview.

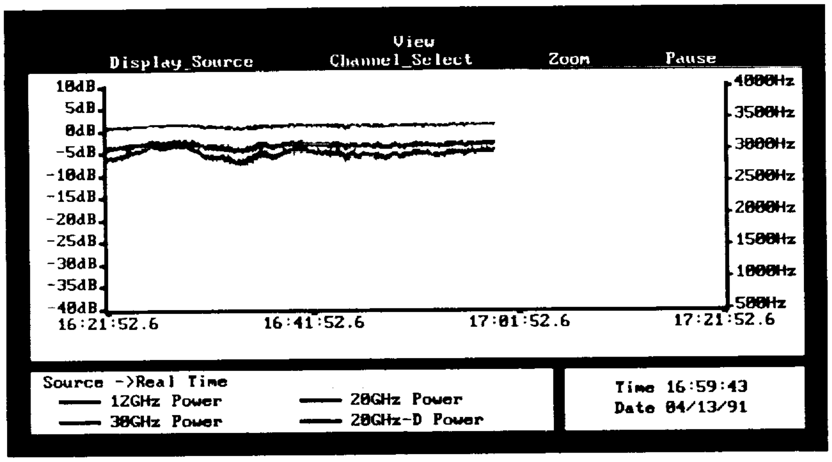

Figure 3: Real time display screen.

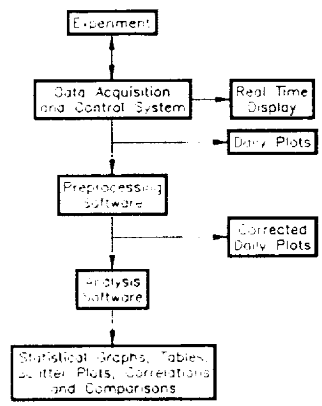

Figure 4: OLYMPUS experiment data flow.

are output to the Model 60 personal computer for storage to hard disk and realtime display. An example of a realtime display screen is presented in Figure 3. Once a day, the collected data are copied to tape for archival storage and input to preprocessing. Data flow within the experiment is shown in Figure 4.

Preprocessing

Raw data is generally not suitable for input to analysis. For example, discontinuities during system maintenance and random glitches in the data must be removed prior to statistical processing. Furthermore, collected radiometer data require the application of periodic calibration information to obtain sky temperature. Preprocessing at Virginia Tech consists of several computer programs. These programs are:

- **DP**: Generates daily plots using raw data.
- **EXAMINE:** Automatic location of data discontinuities and extraction of radiometer calibration information.

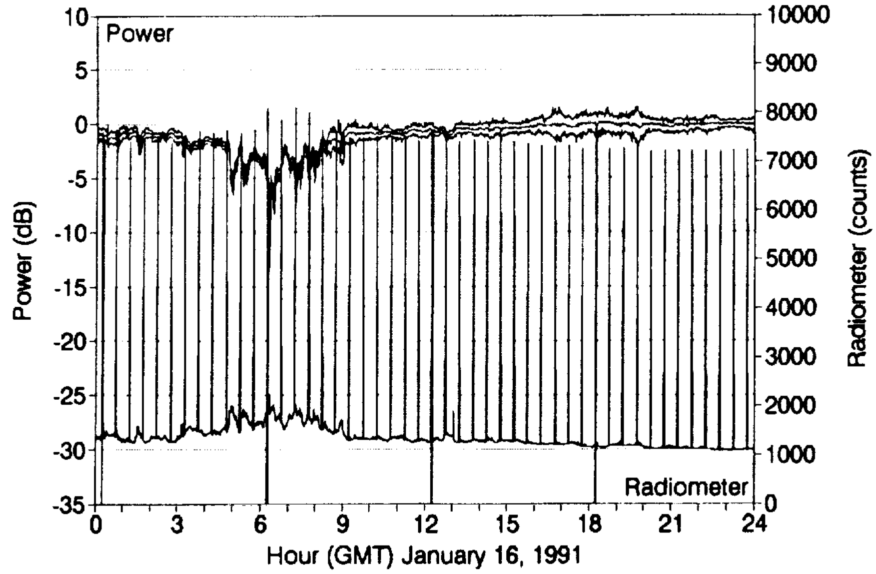

Figure 5: Daily plot of raw beacon and radiometer data.

- **EDIT:** Allows operator classification of data.
- **RPRECAL:** Calculates radiometer calibration parameters.
- **RCAL:** Converts collected radiometer data into sky temperature.
- **FILTER:** Low pass filters the radiometer data to improve resolution.
- **DIURNAL:** Removes the effect of spacecraft motion.
- **CDP:** Generates calibrated daily plots.

Within several days of collection, raw data is processed by **DP** to obtain daily plots for each of the four terminals. Figure 5 is a daily plot for the 20 GHz system on January 16, 1991. The upper three curves are one minute maximum, average and minimum levels of the received beacon signal. The separation between maximum and minimum curves provides an indication of scintillation activity. The large spikes in the radiometer data are periodic noise diode calibrations while the beacon dropouts correspond to radiometer ambient load calibrations. These plots along with written log information are invaluable to the operator when **EDIT** is executed. Prior to **EDIT**, the data is analyzed by **EXAMINE**.

EXAMINE attempts to autonomously find and classify discontinuities in the data and extract radiometric calibration information. Noise diode and ambient load calibration levels are easily removed since these events occur at known times during the day. However, data discontinuities are more difficult to locate. Three types of discontinuities are most prevalent in the data:

- DACS downtime
- Alarms
- Questionable data

DACS downtime is easily located because there is no collected data for the duration of the outage. Phase locked oscillator blocks and the 12 GHz frequency locked loop output alarms

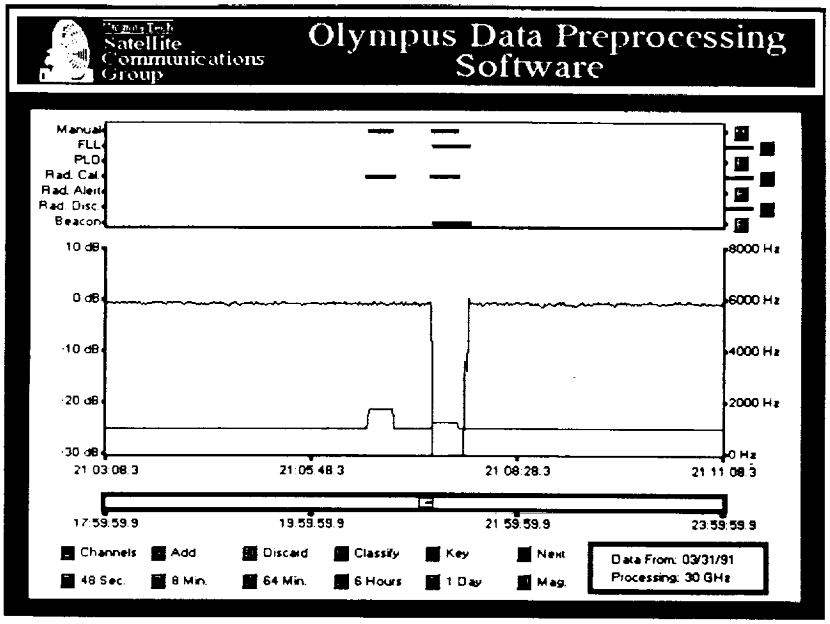

Figure 6: EDIT display screen in 8 minute mode.

are stored in the collected data. When an alarm condition is detected, all data channels that could be affected by the alarm condition are marked as discontinuous for the duration of the alarm. Questionable data are located by comparing the rate of change of a data channel with a limiting condition. Presently, beacon data are marked discontinuous for signal changes of greater than 1 dB/sec or phase differences of more than 15° between samples. Most beacon data with these characteristics are valid; however locating false discontinuities is preferable to missing actual discontinuities. The next phase of preprocessing, **EDIT**, allows the operator to add, modify or remove discontinuities located by **EXAMINE**.

EDIT is a mouse driven, graphical program which allows the operator to view data from one day and confirm, modify or add discontinuity classification information to the output from **EXAMINE**. Data can be marked as category:

- 0 Normal operation
- 1 Clear air downtime
- 2 Event downtime
- 3 Calibration downtime

Figure 6 is an example of the EDIT display screen in eight minute display mode. The top of the display uses color bars to indicate the classification of the data directly below. This display shows that an operator manually performed a noise diode calibration and then an ambient load calibration on the 30 GHz system. The buttons on the bottom portion of the screen allow the operator to select the channel for display, time period for display, and to classify data as desired.

After using **EDIT** to remove all data problems, **RPRECAL** and **RCAL** are executed to convert the radiometer data into sky temperature. **RPRECAL** processes calibration information from **EXAMINE** and **EDIT** for the previous, current and next day to obtain

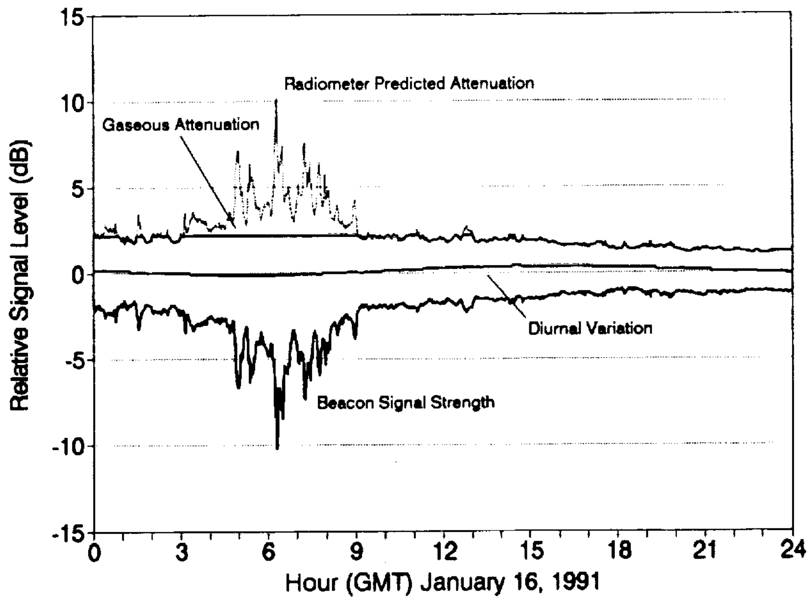

Figure 7: Diurnal bias removal.

the calibration parameters necessary to convert raw radiometer data into sky temperature. **RCAL** then applies these calibrations to the data. **FILTER** then applies a 10 second moving average filter to the radiometer data. This improves the resolution of the radiometer data to about 0.1 K.

The final stage of preprocessing is the removal of diurnal biases and calibration of the beacon data to attenuation relative to free space. Because Blacksburg is located far off the boresight of the OLYMPUS beacons, diurnal variations of several dB are commonly present. Removal of this bias can only be performed after the gaseous attenuation has been removed from the beacon signal thus leaving only the diurnal variation. Figure 7 illustrates the bias removal procedure for the 20 GHz system during a rain event on January 16, 1991. Each of the curves on the plot was obtained from six minute average data. Averaging is necessary to remove scintillations from the beacon signal and maintain a uniform number of points for each of the curves. The upper curve on the plot is the radiometer predicted attenuation in absolute dB. Note that the radiometer measures beacon attenuation quite accurately to about 3–4 dB. The lower curve on the plot is the beacon level during the day relative to an arbitrary 0 dB baseline. The middle curve is obtained from a sixth order curve fit of selected portions of the upper and lower curves added on a point by point basis. This curve fit information along with thresholded radiometer predicted attenuation is then applied to the raw beacon data to obtain attenuation referenced to free space. As shown in Figure 7, radiometer data is thresholded at 90 K for 12 GHz and 110 K for 20 and 30 GHz. Attenuation beyond this point is measured more accurately through beacon measurements. A plot of calibrated beacon and radiometer data is shown in Figure 8. If this plot showed any discontinuities or appeared incorrect, the operator would return to **EDIT** and remove any problematic data or modify radiometric calibration parameters. Once satisfied with the quality of the data it is input to the analysis software.

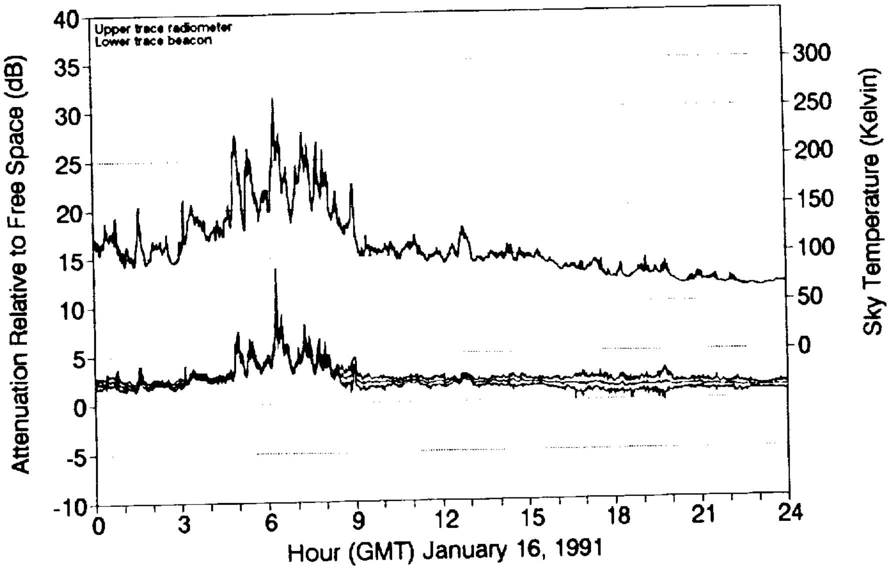

Figure 8: Calibrated daily plot.

Analysis

Presently, the analysis software is under development. Analysis requires the following data from each of the four terminals:

- Attenuation with respect to free space
- Attenuation with respect to clear air
- Sky temperature
- Rain gauge tip times

Output table and graphs include:

- Cumulative rain rate distributions
- Beacon attenuation with respect to free space
- Beacon attenuation with respect to clear air
- Scintillation index
- Fade slope
- Non-fade duration
- Ultimate fade depth versus fade slope
- Diversity gain
- Frequency scaling

Figure 9 is an exceedance plot of attenuation referenced to clear air for January 1991. Note that frequency scaling of attenuation is clearly present and that some scintillation activity is indicated by negative attenuation in the 99–100% region.

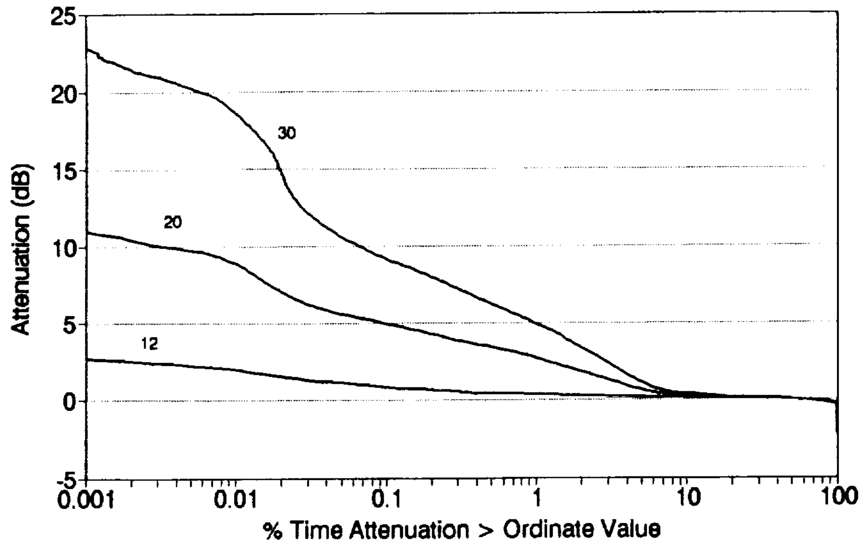

Figure 9: Exceedance plot of 20 GHz attenuation referenced to clear air for January 1991.

Conclusions

Virginia Tech has constructed and is operating a propagation measurement system for the OLYMPUS experiments. Procedures and methods for data collection, preprocessing and analysis have been selected and utilized successfully. Presently, data analysis software for primary statistics; rain rate, attenuation referenced to free space... is complete. Secondary statistical analysis; fade rate, fade duration... software is under development and should be completed in the near future.

EARTH-SPACE PROPAGATION RESEARCH AT CRC

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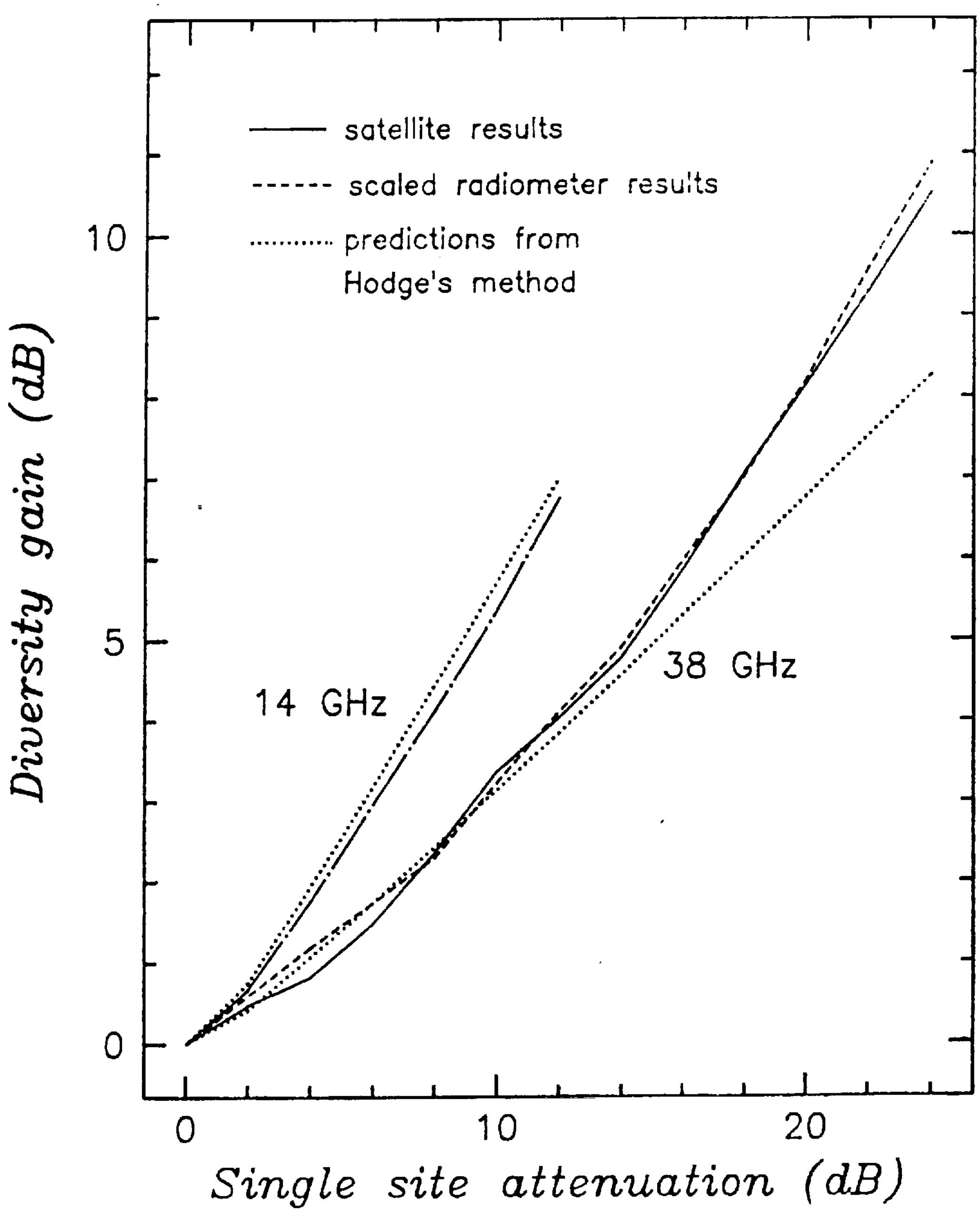
<u>OUTLINE</u>:

- 14/38 GHz site-diversity measurements (LES-8 satellite)
- Intercontinental rain attenuation studies for INTELSAT

  } Recent Past

- Low-angle fading project
- Rain attenuation measurements in SE Asia
- Studies of propagation mitigation at EHF
- Interference studies

SITE DIVERSITY RESULTS USING 38 GHz LES-8 SATELLITE AND 14 GHz RADIOMETER



(Lam and Olsen, 1988)

ASSESSMENT OF JOINT ATTENUATION ON LOW-FADE-MARGIN INTERNATIONAL SATELLITE SERVICES (Segal and Allnutt, 1991a,b)

- **INTELSAT International Business Service:**

Uplink	14 GHz
Downlink	11/12 GHz
Rain fade margin	2.5 dB

- **Study of possible detrimental effects due to correlation in rain attenuation between uplink and downlink during business hours (use of prediction approach based on rainrate statistics):**

  N.A. ↔ EUROPE ; N.A. ↔ PACIFIC

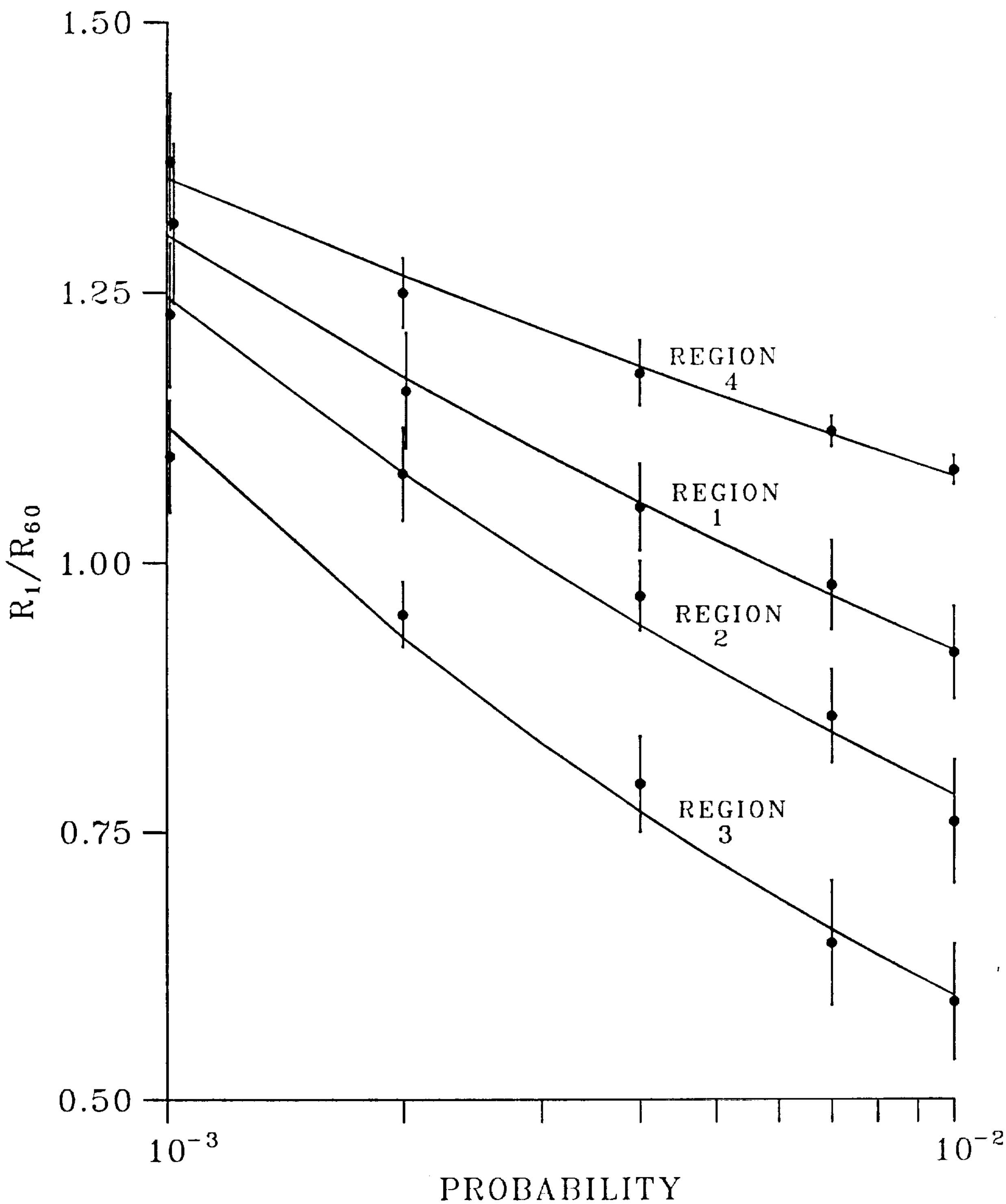
  <u>Main Conclusions</u>

  - **Max. diurnal enhancement approx. equal to max. seasonal enhancement**

  - **Effect of large diurnal variations in continental climate swamped by much larger fade probabilities (with smaller variability) in maritime climate**

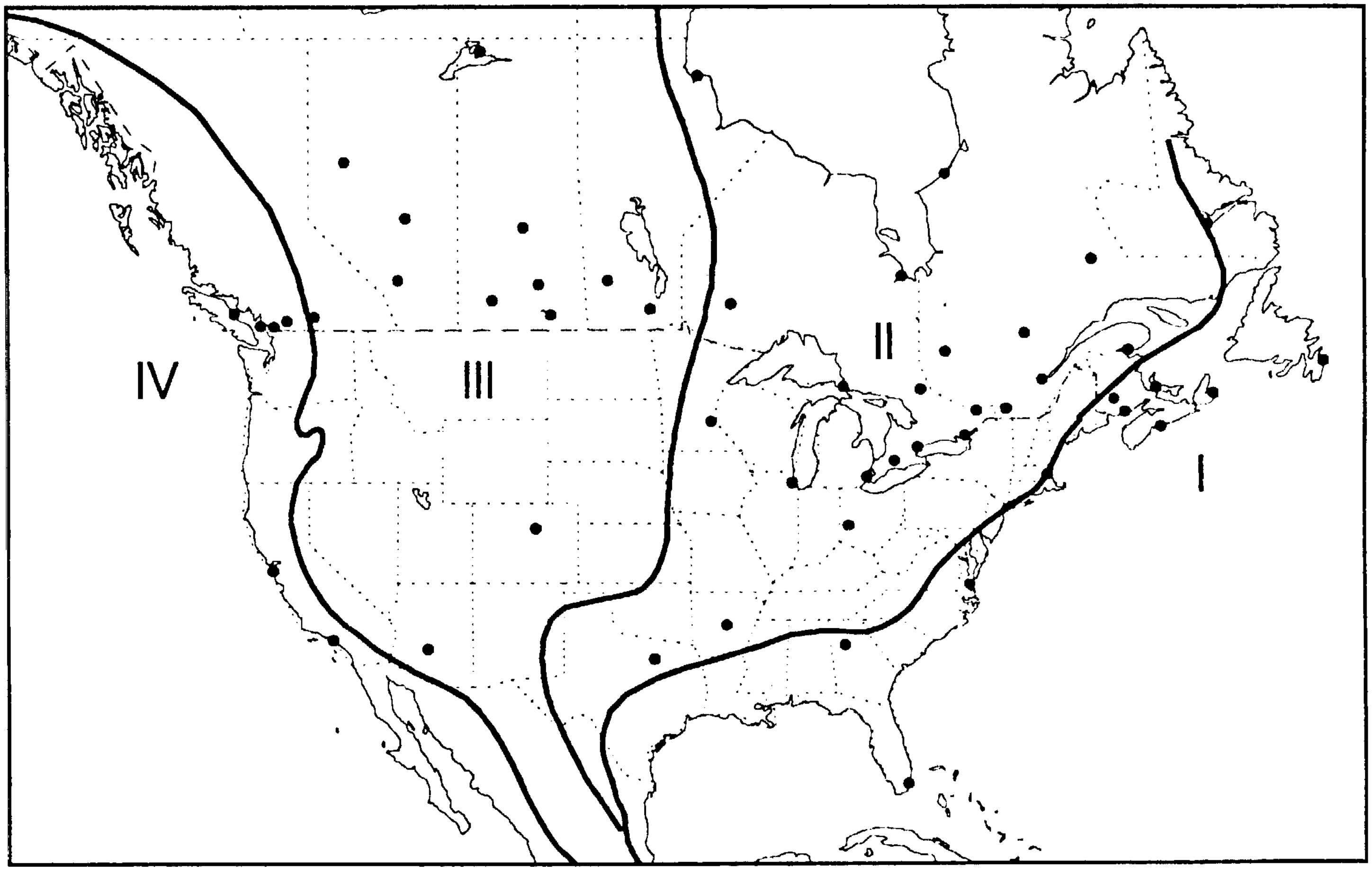
- **Side-benefit: Development of technique for predicting rainrate one-minute statistics from one-hour statistics**

ONE HOUR TO ONE MINUTE CONVERSION FACTOR CURVES



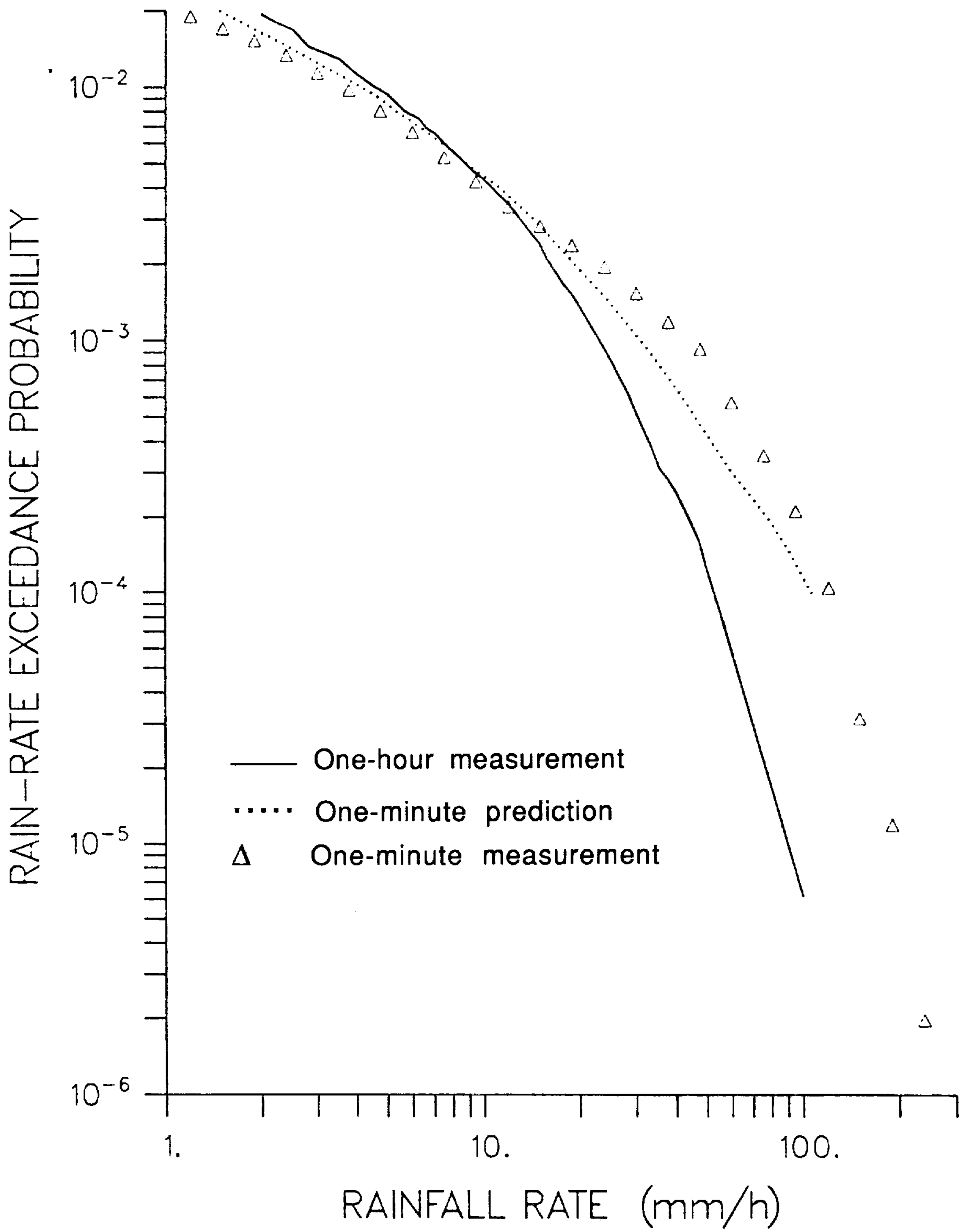
(Segal and Allnutt, 1991b)

NORTH AMERICAN RAIN ZONES FOR HIGH-PROBABILITY REGIME



(Segal and Allnutt, 1991b)

CUMULATIVE RAIN-RATE DISTRIBUTIONS FOR MIAMI



(Segal and Allnutt, 1991b)

LOW-ANGLE FADING PROJECT

OBJECTIVE: To develop a climatological model for fading at elevation angles less than about 4°

BACKGROUND:

- CRC has largest low-angle fading data base in the world (4, 6, 7, 30, 38 GHz; Ottawa, St. Johns', Resolute, Eureka, Alert) (e.g., see Lam, 1987)

- CRC has developed model for frequency and percentage-of-time scaling of low-angle fading data (< 4° elevation angles) (CCIR, 1989)

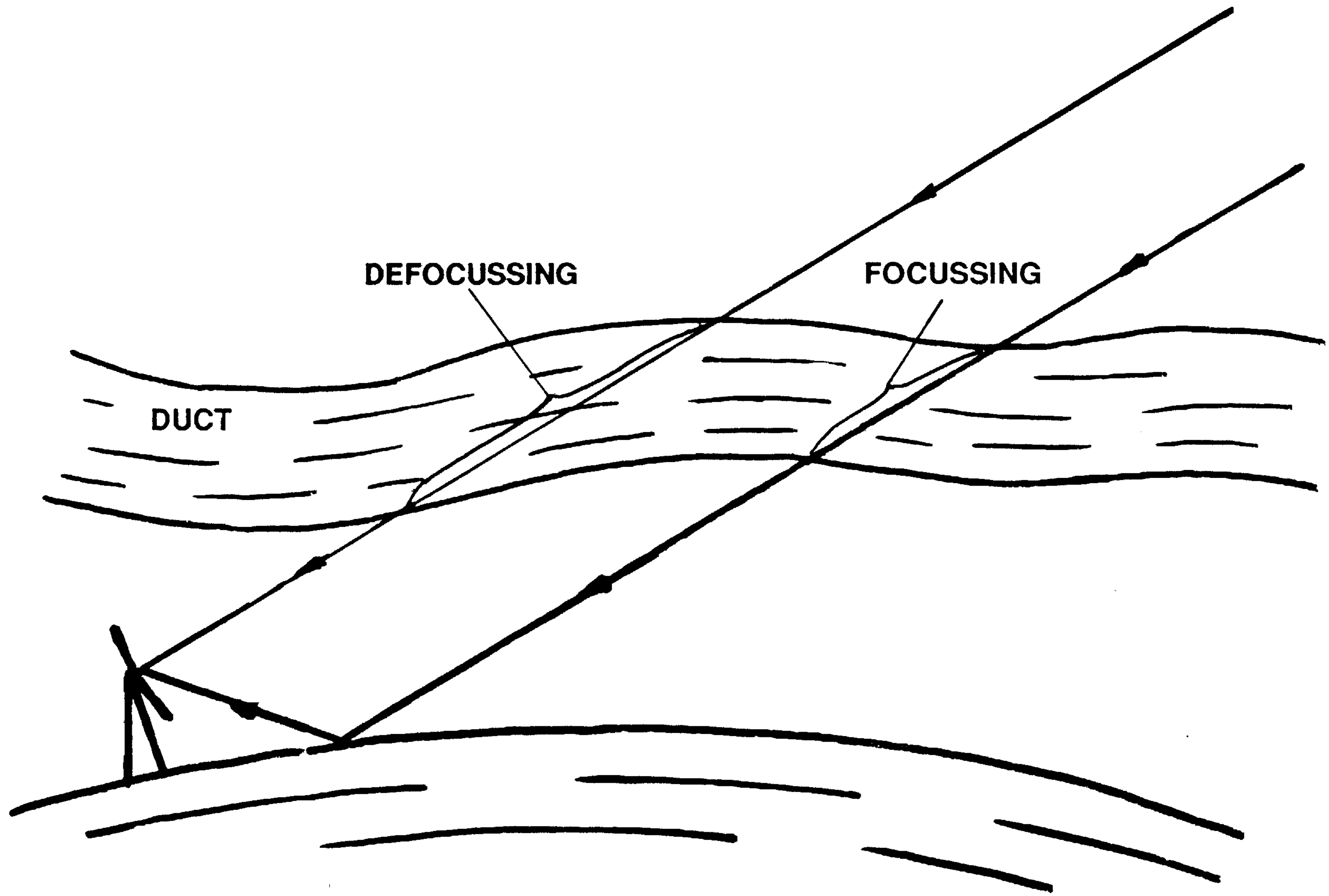
- CRC has new physical explanation of fading at the very lowest angles (Olsen *et al.*, 1987)

- CRC has developed climatological model for multipath fading statistics on terrestrial links (Worldwide version adopted by CCIR)

- CRC/University of Western Ontario conducting terrestrial experiment to compare refractivity profile and acoustic sounder measurements, etc. with phased array radio measurements

POSSIBLE APPROACHES: (a) Tie existing and new data to refractivity gradient statistics, (b) Ray tracing studies to determine beamwidth and elevation-angle dependence

PHYSICS OF VERY-LOW-ANGLE FADING



(Olsen et al., 1987)

RAIN ATTENUATION MEASUREMENTS IN ASEAN COUNTRIES OF SE ASIA

- **Project funded by Canadian International Development Agency**

- **12 GHz radiometric measurements of rain attenuation statistics along paths to future INTELSAT satellite**

  2 radiometers in Thailand (site-diversity configuration)
  1 radiometer in Singapore
  2 radiometers in Indonesia

- **Initial measurements in fall of 1991**

- **Aim is to have ASEAN researchers doing the analysis with CRC scientists as consultants**

CHANNEL IMPAIRMENT MITIGATION AND NETWORKING TECHNIQUES FOR EHF PERSONAL SATELLITE COMMUNICATIONS

- **Joint project with the University of Ottawa and Telesat Canada** - funding of 4 graduate students, 2 post-doctoral fellows over 3 years (Yongaçoglu *et al.* , 1991)

- **Use of existing EHF data and data from Olympus experiment** (see Olsen *et al.*, 1990)

OBJECTIVES:

- **Evaluate impairment mitigation techniques for both slowly and rapidly changing channel conditions**

- **Jointly optimize candidate techniques using software/hardware simulations**

- **Develop practical mitigation techniques using digital processing based hardware**

- **Test prototype hardware over satellite link**

- **Investigate new networking strategies**

INTERFERENCE STUDIES

1. DUCT PROPAGATION

- **Experimental investigation of negative correlation between transhorizon interfering signal from earth-station and fading signal at terrestrial receiver** (Olsen and Bilodeau, 1991; Bilodeau and Olsen, 1991)

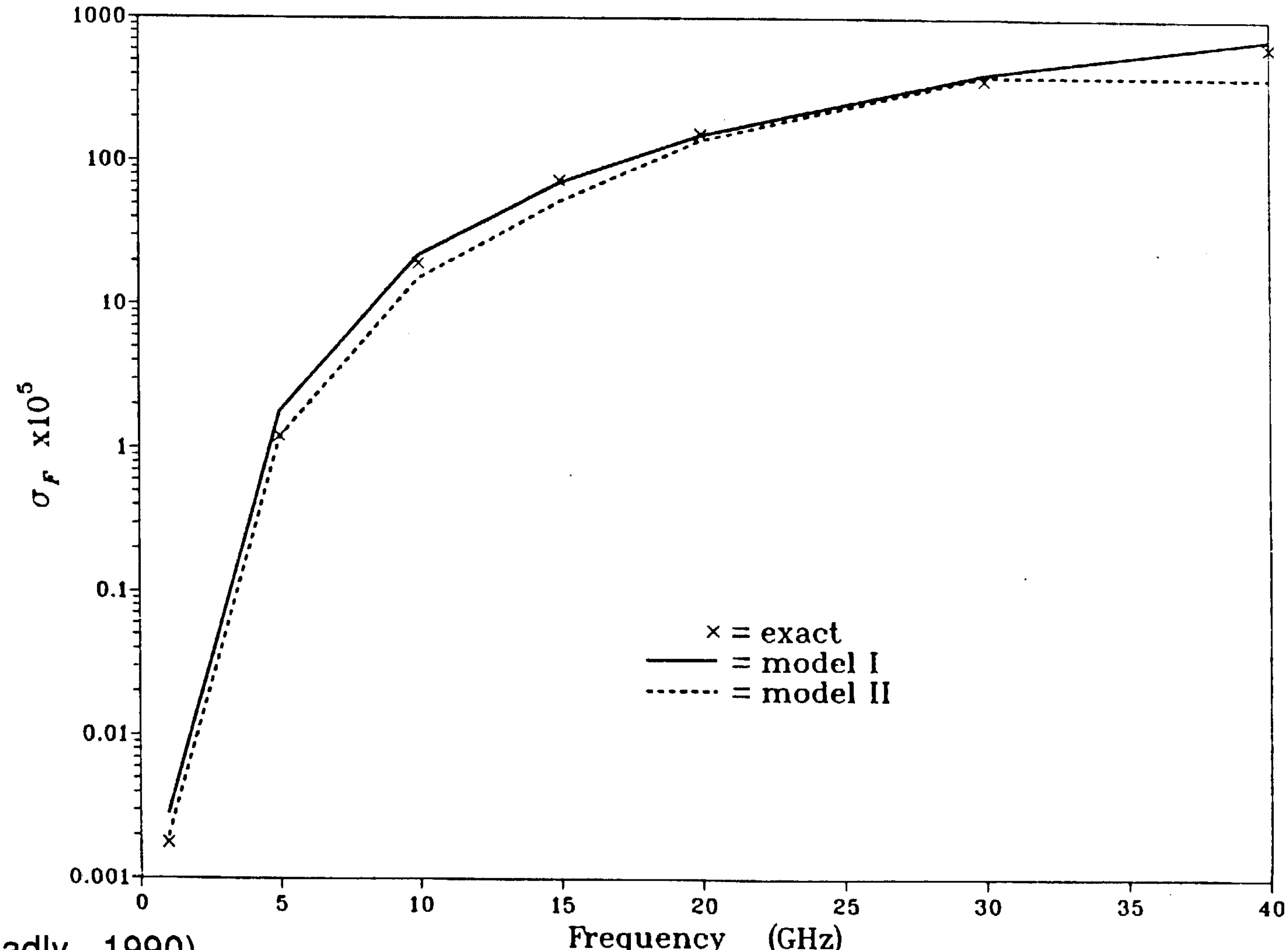
2. HYDROMETEOR SCATTER

- **Development of model for scattering cross-section of melting snow** (contracts to University of British Columbia, sub-contracts to University of Mississippi, earlier rain cross sections from Dartmouth College, see Kharadly, 1990,1991)

- **Comparison of relative importance of rain scatter and melting snow scatter** (contract to University of British Columbia)

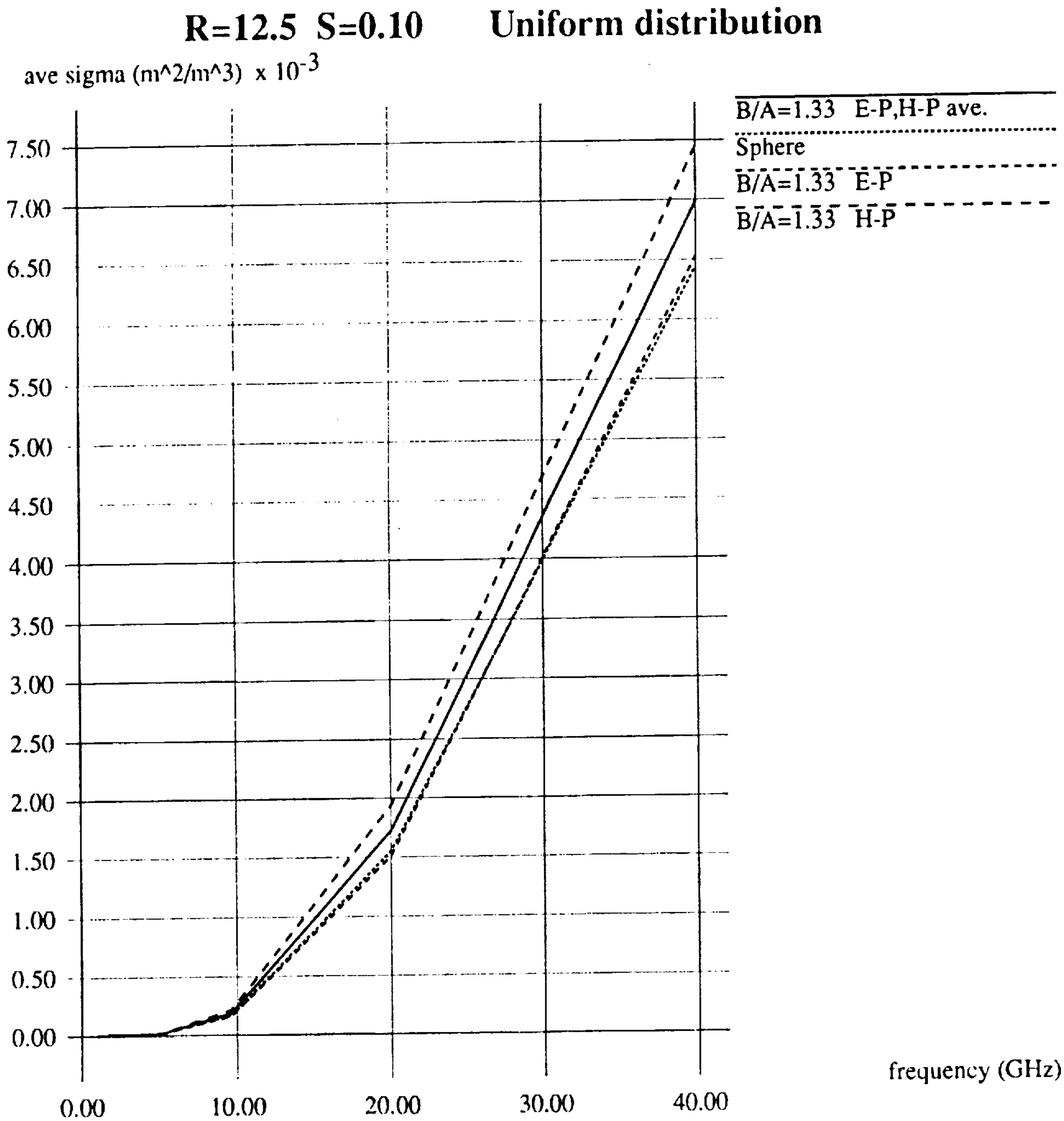
- **Calculation of new radar reflectivity profiles from polarimetric radar data** (contract to Alberta Research Council, see Kochtubajda *et al.*, 1991)

Forward–Scattering Cross Section of Melting Snow (m^2/m^3)
$R = 12.5\text{mm/h} \quad T = 0°C \quad S = 0.1$



(Kharadly, 1990)

COMPARISON OF SPHERICAL AND OBLATE SPHEROIDAL MODELS OF MELTING SNOW PARTICLES



(Kharadly, 1991)

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