Preliminary Report

FUNDAMENTAL STUDIES OF RADAR SCATTERING FROM WATER SURFACES

The Lake Washington Experiment

\[ \sqrt{\text{NAGW-1278}} \]

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Abstract

The University of Kansas and the University of Washington conducted a series of experiments during July and August of 1989, and July and August of 1990, to study the effects of various geophysical parameters on radar backscatter. The experiments were conducted from a platform in Lake Washington. Measurements of backscattered power and radar range were made by the University of Kansas, and environmental data such as wind speed, wind direction, air and water temperature were measured by the University of Washington. Results of preliminary data processing are described here.

Radar data were acquired using two radars, one that operated at C and X bands and another at Ka band. Measurements were made at VV and HH antenna polarizations, at different angles of incidence and under various wind conditions. Plots of backscattered power, normalized radar cross section ($o^0$), and wave height, and the Modulation Transfer Functions of selected data are presented.
Introduction

The Lake Washington Experiment was a three-year joint experiment between the Radar Systems and Remote Sensing Laboratory of the University of Kansas and the Atmospheric Sciences Department of the University of Washington. It took place from January 1988 to December 1990. The primary objectives of the experiment were to study the influence of various geophysical parameters on the backscattered signals and to check the validity of existing theories of radar backscatter from oceans.

Radar backscatter from water bodies has been studied in considerable detail, especially backscatter from wave tanks and oceans using a radar located on a tower. The tower-based studies have been used to develop theories and models that could be applied to radars on aircraft or spacecraft. The conditions in wave tanks are unrealistic and bear little resemblance to those encountered in the open sea. Tower-based measurements of radar backscatter also suffer from drawbacks. Tower-based experiments are usually major expeditions of relatively short duration, involving several investigators with different goals. The time scales are rigid, and coordination of the efforts of a large number of experimenters can be difficult. Since the expeditions are usually of short duration, the environmental conditions over which measurements are made are dictated by nature rather than choice. The Lake Washington Experiment was envisioned as an intermediate step between the laboratory and a tower in the open sea, since the restrictions associated with towers in open sea could be avoided, while conditions that are considerably more realistic and closer to conditions in the open sea than those possible in a wave tank could still be provided.

During the experiment, simultaneous measurements of radar range and backscattered power were made at C band and X band in July and August of 1989, and at Ka band in July and August of 1990. Measurements were made at VV and HH polarizations in the up-wind and cross-wind antenna look directions. Results of preliminary data processing are presented as time series of backscattered power, $\sigma^0$, and wave height, along with the Modulation Transfer Function (MTF) for selected runs. Plots of the backscattered power and wave height are in Appendix A; those of $\sigma^0$ and wave height are in Appendix B, and plots of the MTF are in Appendix C.
Radar Systems

For the experiment, two different radar systems were developed. One was a frequency modulated continuous wave (FM-CW) radar operating on C band (6.0 GHz) and X band (11.0 GHz) simultaneously, capable of VV, HH, HV, and VH polarizations, and an FM-CW radar operating on Ka band, capable of VV and HH polarizations. The specifications of the C-and X-band system are given in Table 1 and those of the Ka-band system are given in Table 2.
<table>
<thead>
<tr>
<th>Radar Type</th>
<th>FM-CW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>6.0, 11.0 GHz</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>10 mW</td>
</tr>
<tr>
<td>Polarizations</td>
<td>VV, HH, HV, VH</td>
</tr>
<tr>
<td>FM sweep width</td>
<td>C-band: 850 MHz</td>
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<tr>
<td></td>
<td>X-band: 810 MHz</td>
</tr>
<tr>
<td>Modulation rate</td>
<td>70 Hz</td>
</tr>
<tr>
<td>Calibration</td>
<td>Internal: Delay line</td>
</tr>
<tr>
<td></td>
<td>External: Luneburg lens</td>
</tr>
<tr>
<td>Antenna</td>
<td>0.75 m. Parabolic dish with offset feed</td>
</tr>
<tr>
<td>Beamwidth in elevation</td>
<td>C-band: 12.7°</td>
</tr>
<tr>
<td></td>
<td>X-band: 8.5°</td>
</tr>
<tr>
<td>Beamwidth in azimuth</td>
<td>C-band: 5.0°</td>
</tr>
<tr>
<td></td>
<td>X-band: 3.0°</td>
</tr>
<tr>
<td>Sampling period</td>
<td>65.6 msec</td>
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</table>

Table 1. C-band/X-band radar specifications

<table>
<thead>
<tr>
<th>Radar Type</th>
<th>FM-CW</th>
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<tbody>
<tr>
<td>Frequency</td>
<td>34.0 GHz</td>
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<tr>
<td>Transmit Power</td>
<td>1 mW</td>
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<tr>
<td>Polarizations</td>
<td>VV, HH</td>
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<td>FM sweep width</td>
<td>234 MHz</td>
</tr>
<tr>
<td>Intermediate frequency</td>
<td>30 KHz</td>
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<tr>
<td>Calibration</td>
<td>Internal: Delay line</td>
</tr>
<tr>
<td></td>
<td>External: Metal Sphere</td>
</tr>
<tr>
<td>Antenna</td>
<td>Tx : 0.30 m Parabolic dish</td>
</tr>
<tr>
<td></td>
<td>Rx : collimating horn lens</td>
</tr>
<tr>
<td>Beamwidth in Tx</td>
<td>1.9°</td>
</tr>
<tr>
<td>Beamwidth on Rx</td>
<td>8.0°</td>
</tr>
<tr>
<td>Sampling period</td>
<td>100 msec</td>
</tr>
</tbody>
</table>

Table 2. Ka-band radar specifications
Experiment Description

During the Lake Washington Experiment, simultaneous recordings were made of radar backscattered power and radar range by the University of Kansas, while measurements of wire-gauge wave height, wind speed, wind direction, air and water temperature were made by the University of Washington. A video camera was used during some of the runs and provided a visual record of the activity within the radar footprint. The radar was mounted on a platform at a 5-meter height, and the camera was mounted below it at 1.5 meters, which allowed for a small footprint area and close-up observation.

The steady wind direction and wind speed at Lake Washington produce wave structures that are relatively simple compared to the open sea. The dominant wave is usually well defined, and wave height is typically 0.3 meters from trough to crest and rarely exceeds 0.6 meters. Occasional spilling breakers are observed above wind speeds of 4 m/s. During the period of observation, wind speeds ranged from 2 m/s - 7 m/s. Although 60 hours of data are available, 2 hours of which have video, the quality of data acquired during the initial days of the experiment is poor. These data have not been included in this report.
Description of the Data

Measurements were made at all three frequencies, under different environmental conditions. VV and HH polarizations were used, and the angle of incidence varied from 30° to 60°. Most of the measurements were made in the up-wind and cross-wind antenna look directions, with a few in between. The C-band and X-band data were sampled at 65.6 milliseconds/sample, with each run lasting 5 minutes. The Ka-band data were sampled at 100 milliseconds/sample, and the run length was either 5 or 10 minutes. Sampled backscattered power, slant range converted to wave height, normalized radar cross section (σ°) and the Modulation Transfer Functions (MTFs) of selected runs are included in this report. Low frequency noise was observed in some of the wave height series, and this has been filtered out. The MTFs have been calculated using two methods, one in which "sea spikes" are included in the backscattered signal, and another method that uses a moving-average threshold method to detect sea spikes and remove them from the data. This technique of spike removal usually enhances the coherence between the backscattered power and wave height around the spectral peak in the wave height series. A short description of the method of calculation of σ° and MTFs is given in the Data Analysis section.
Data Analysis

σ₀ have been calculated for the data included in this report. A few plots showing the instantaneous σ₀ and wave height can be found in Appendix B. The MTF of some runs have also been calculated, and plots of these are in Appendix C. The runs for the computed MTFs were selected on the basis of the stability of environmental conditions, shown by one major spectral peak in the wave height signal. Brief descriptions of the calculation of σ₀ and the MTF follow.

Calculation of Normalized Radar Cross Section (σ₀)

The radar equation is given by

\[ P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \]

where \( P_r \) is the received power, \( P_t \) the transmitted power, \( \lambda \) the transmitted wavelength, \( \sigma \) the radar cross section of the target and \( R \) the range to the target, \( G_t \) the gain of the transmit antenna, \( G_r \) the gain of the receive antenna. Hence \( \sigma \) is given by

\[ \sigma = \frac{(4\pi)^3 R^4 P_r}{P_t G_t G_r \lambda^2} \]

The normalized radar cross section, σ₀, which represents radar cross section per unit area, is given by
\[
\sigma^0 = \frac{(4\pi)^3 R^4 P_r}{P_i G_t G_r \lambda^2 A_{ill}}
\]

where \(A_{ill}\) is the area illuminated by the radar beam. The illuminated area is a function of the antenna beamwidth, the geometry of the surface and the angle of incidence among other parameters.

\(\sigma\) and \(\sigma^0\) can be calculated without direct determination of the antenna gains, the transmitter power and wavelength. If \(P_{\text{cal}}\) and \(R_{\text{cal}}\) are the power returned and range to a calibration target of a known radar cross section, then

\[
\sigma_{\text{cal}} = \frac{(4\pi)^3 R_{\text{cal}}^4 P_{\text{cal}}}{P_i G_t G_r \lambda^2}
\]

and

\[
\sigma^0 = \frac{\sigma_{\text{cal}} R^4 P_r}{P_{\text{cal}} R_{\text{cal}}^4 A_{ill}}
\]

\(P_r\) and \(R\) were measured during the field experiment while \(P_{\text{cal}}\) and \(R_{\text{cal}}\) were measured during the calibration process. \(\sigma_{\text{cal}}\) is known.

For each sample on the backscattered signal, the instantaneous \(\sigma^0\) was calculated and averaged over a five-minute period (the length of the run) to obtain the mean value of \(\sigma^0\). Several time histories of \(\sigma^0\) are presented in Appendix B.
Calculation of the MTF

The linear Modulation Transfer Function (MTF) describes the modulation of the backscattered power by long waves. It is complex since it describes both the amplitude of the modulation and the phase with respect to the long waves. The MTF aids in the interpretation of ocean images from active microwave radars and in determining the modulation of ripples by the long waves on which they appear.

The MTF is defined by

\[ M(f) = \frac{G_{pw}(f)}{pkG_{ww}(f)} \]

where \( G_{pw}(f) \) is the cross spectrum of power and wave height, \( G_{ww}(f) \) is the auto spectrum of the wave height, \( p \) is the average received power, \( k \) is the long wave number and \( f \) is the long wave frequency.

The coherence function is given by

\[ \gamma^2(f) = \frac{|G_{pw}(f)|^2}{G_{pp}(f)G_{ww}(f)} \]

Only those points for which the coherence between the backscattered power and wave height is greater than 0.25 are plotted.

The MTF is defined based on the assumption that there is a linear dependance between the long waves and the backscattered signal. "Sea spikes," or bursts in the backscattered signal seen in the time histories of backscattered power, make a significant contribution to the non-linearity of
the backscattered power. The removal of spikes from the backscattered signal should produce a better estimate of the MTF. To test this, MTFs were calculated using two methods, one in which the original backscattered signal was used and another in which the spikes were removed from the signal. Preliminary results show that spike removal improves the coherence between the backscattered power and wave height signal.

MTFs have been calculated for the C-band/X-band data. For the calculations, the wave height and power series were decimated by four to achieve an effective sampling rate of 3.8 Hz. The record length was then 1114 points. This was divided into 10 segments of 114 points each (approximately 30 seconds). Each segment was FFTed and accumulated to produce the spectra of the wave height and power signal. Spike removal was done before the decimation for the calculation for the MTF without spikes. Plots of the MTF for selected runs, with the original power signal and with the spikes removed, are presented in Appendix C.
Appendix A

Plots of Backscattered Power and Wave Height

A—1. C Band
Wave Height (m)

Power (V**2)

Wind speed = 4.2 m/s
Wind direction = UP wind
Incidence Angle = 34.0 deg.
Reflection - HH
Bend - C

Run 8, 18:24, Aug 3, 1989
Wind Speed - 4.7 m/s
Wind Direction - UP wind
Incidence Angle - 40.0 deg.
Position of W - C

Run 43, 20:46, Aug 4, 1989
A—2. X Band
Wave Height (m)

Power ($v^2$)

Wind Speed - 3.9 m/s
Wind Direction - Cross wind
Incidence Angle - 34 deg.
Production - HH
Bond - X

Run 1, 11:45, July 12, 1989
Wave Height (m)

Power (W**2)

Wind Speed - 7.1 m/s
Wind Direction - Up wind
Incidence angle - 40.0 deg.
Projection - W

Run 23, 18.55, July 19, 1989
Run 9, 13:39, July 25, 1989

Wind Incidence Angle = 40.0 deg
Wind Direction = Up wind
Wind Speed = 4.5 m/s

Band X = W
Incidence Angle = 34.0 deg
Wind Direction = Up wind
Wind Speed = 4.7 m/s
B-2. X Band
Wave Height (m) vs Time (sec)
B-3. Ka Band
Appendix C

Plots of PSD, MTF, Coherence Function and Cross-Correlation Function for

Wave Height and Radar Return Power

C—1. C Band
July 19, 1989, Run Time : 17:13:10, Run # 7, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 5.89 m/s, Air Temp. : 21.9 deg C, Water Temp. : 22.3 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
July 19, 1989, Run Time: 17:13:10, Run #7, C Band, HH Polarization, 34.0 deg. Incidence

Wind Speed: 5.89 m/s, Air Temp.: 21.9 deg C, Water Temp.: 22.3 deg C

Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 19, 1989, Run Time: 17:55:7, Run #13, C Band, HH Polarization, 40.0 deg. Incidence
Wind Speed: 6.56 m/s, Air Temp.: 21.1 deg C, Water Temp.: 22.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
July 19, 1989, Run Time : 17:55: 7, Run # 13, C Band, HH Polarization, 40.0 deg. Incidence
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
July 19, 1989, Run Time : 18:17:25, Run # 16, C Band, VV Polarization, 40.0 deg. Incidence
WindSpeed : 7.01 m/s, Air Temp. : 21.5 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
July 19, 1989, Run Time: 18:17:25, Run #16, C Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 7.01 m/s, Air Temp.: 21.5 deg C, Water Temp.: 22.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 25, 1989, Run Time : 13:23:37, Run # 7, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 4.46 m/s, Air Temp. : 21.9 deg C, Water Temp. : 22.3 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
July 25, 1989, Run Time: 13:23:37, Run # 7, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed: 4.46 m/s, Air Temp.: 21.9 deg C, Water Temp.: 22.3 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 25, 1989, Run Time : 113:58:14, Run # 12, C Band, VV Polarization, 40.0 deg. Incidence
WindSpeed : 4.39 m/s, Air Temp. : 21.9 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
July 25, 1989, Run Time: 113:58:14, Run # 12, C Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.39 m/s, Air Temp.: 21.9 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 25, 1989, Run Time : 14: 3:32, Run # 13, C Band, VV Polarization, 40.0 deg. Incidence
WindSpeed : 3.90 m/s, Air Temp. : 21.1 deg C, Water Temp. : 22.1 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time: 18:24:43, Run # 8, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed: 4.23 m/s, Air Temp.: 20.3 deg C, Water Temp.: 20.9 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 18:24:43, Run # 8, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 4.23 m/s, Air Temp. : 20.3 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time: 18:38:36, Run #10, C Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 3.91 m/s, Air Temp.: 20.2 deg C, Water Temp.: 20.9 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 18:38:36, Run # 10, C Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.91 m/s, Air Temp. : 20.2 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 18:44: 4, Run # 11, C Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 4.03 m/s, Air Temp. : 20.1 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 18:44:4, Run # 11, C Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 4.03 m/s, Air Temp. : 20.1 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Antenna Look Dir. : Up-Wind, Spikes Present
WindSpeed: 4.24 m/s, Air Temp.: 19.9 deg C, Water Temp.: 21.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 19:37: 5, Run # 16, C Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 4.65 m/s, Air Temp. : 19.9 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 19:37: 5, Run # 16, C Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 4.65 m/s, Air Temp. : 19.9 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 19:54: 5, Run # 19, C Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.38 m/s, Air Temp. : 19.9 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time: 19:54:5, Run # 19, C Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 4.38 m/s, Air Temp.: 19.9 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 20:11:10, Run # 22, C Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.09 m/s, Air Temp. : 19.4 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 20:11:10, Run # 22, C Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.09 m/s, Air Temp. : 19.4 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time: 17:35:50, Run # 18, C Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 5.18 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 4, 1989, Run Time: 17:35:50, Run # 18, C Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 5.18 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 17:46:58, Run # 20, C Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.98 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 17:46:58, Run # 20, C Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.98 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 17:53:50, Run # 21, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.75 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
August 4, 1989, Run Time: 17:53:50, Run # 21, C Band, HH Polarization, 34.0 deg. Incidence
Wind Speed: 3.75 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time: 18:5:40, Run # 23, C Band, HH Polarization, 34.0 deg. Incidence
Wind Speed: 3.61 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 18: 5:40, Run # 23, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.61 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time: 18:11:2, Run #24, C Band, HH Polarization, 34.0 deg. Incidence
Wind Speed: 4.26 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 18:11: 2, Run # 24, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 4.26 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.1 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time: 18:41:28, Run #29, C Band, HH Polarization, 34.0 deg. Incidence
Wind Speed: 3.86 m/s, Air Temp.: 22.9 deg C, Water Temp.: 22.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 18:41:28, Run # 29, C Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.86 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 7, 1989, Run Time: 18:39:40, Run # 13, C Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.46 m/s, Air Temp.: 24.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 7, 1989, Run Time: 18:39:40, Run #13, C Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.46 m/s, Air Temp.: 24.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
C—2. X Band
July 19, 1989, Run Time: 17:25:38, Run # 9, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 6.25 m/s, Air Temp.: 21.9 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
July 19, 1989, Run Time: 17:25:38, Run #9, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 6.25 m/s, Air Temp.: 21.9 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 19, 1989, Run Time : 17:55: 7, Run # 13, X Band, HH Polarization, 40.0 deg. Incidence
Antenna Look Dir. : Up-Wind, Spikes Present
July 19, 1989, Run Time: 17:55: 7, Run # 13, X Band, HH Polarization, 40.0 deg. Incidence
WindSpeed: 6.56 m/s, Air Temp.: 21.1 deg C, Water Temp.: 22.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 19, 1989, Run Time: 18:17:25, Run # 16, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed: 7.01 m/s, Air Temp.: 21.5 deg C, Water Temp.: 22.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
July 19, 1989, Run Time: 18:17:25, Run # 16, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed: 7.01 m/s, Air Temp.: 21.5 deg C, Water Temp.: 22.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 19, 1989, Run Time : 18:22:48, Run # 17, X Band, VV Polarization, 40.0 deg. Incidence
Antenna Look Dir. : Up-Wind, Spikes Present
WAVE-HEIGHT PSD

MAGNITUDE OF MTF

$5 \times 10^{-6}$ RADAR POWER PSD

PHASE OF MTF

SQUARED COHERENCE

CROSS-CORRELATION

July 19, 1989, Run Time : 18:22:48, Run # 17, X Band, VV Polarization, 40.0 deg. Incidence
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 19, 1989, Run Time: 19:51:3, Run #30, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 5.03 m/s, Air Temp.: 20.9 deg C, Water Temp.: 21.8 deg C
Antenna Look Dir.: Cross-Wind, Spikes Present
July 19, 1989, Run Time : 19:51:3, Run # 30, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed : 5.03 m/s, Air Temp. : 20.9 deg C, Water Temp. : 21.8 deg C
Antenna Look Dir. : Cross-Wind, Spikes Removed (4.5 dB Moving Averange Threshold)
July 19, 1989, Run Time: 19:56:23, Run # 31, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 5.39 m/s, Air Temp.: 20.9 deg C, Water Temp.: 21.7 deg C
Antenna Look Dir.: Cross-Wind, Spikes Present
July 19, 1989, Run Time : 19:56:23, Run # 31, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed : 5.39 m/s, Air Temp. : 20.9 deg C, Water Temp. : 21.7 deg C
Antenna Look Dir. : Cross-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
July 19, 1989, Run Time : 20:1:40, Run # 32, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed: 5.24 m/s, Air Temp. : 20.8 deg C, Water Temp. : 21.7 deg C
Antenna Look Dir. : Cross-Wind, Spikes Present
July 19, 1989, Run Time : 20:1:40, Run # 32, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed : 5.24 m/s, Air Temp. : 20.8 deg C, Water Temp. : 21.7 deg C
Antenna Look Dir. : Cross-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 19, 1989, Run Time: 20:7:34, Run # 33, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.89 m/s, Air Temp.: 20.0 deg C, Water Temp.: 21.6 deg C
Antenna Look Dir.: Cross-Wind, Spikes Present
July 19, 1989, Run Time: 20: 7:34, Run # 33, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.89 m/s, Air Temp.: 20.0 deg C, Water Temp.: 21.6 deg C
Antenna Look Dir.: Cross-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 19, 1989, Run Time: 20:12:50, Run #34, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed: 4.53 m/s, Air Temp.: 20.8 deg C, Water Temp.: 21.7 deg C
Antenna Look Dir.: Cross-Wind, Spikes Present
July 19, 1989, Run Time: 20:12:50, Run #34, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.53 m/s, Air Temp.: 20.8 deg C, Water Temp.: 21.7 deg C
Antenna Look Dir.: Cross-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
July 25, 1989, Run Time: 17:20:21, Run # 32, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed: 4.29 m/s, Air Temp.: 20.9 deg C, Water Temp.: 21.8 deg C
Antenna Look Dir.: 45 deg., Spikes Present
July 25, 1989, Run Time: 17:20:21, Run # 32, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.29 m/s, Air Temp.: 20.9 deg C, Water Temp.: 21.8 deg C
Antenna Look Dir.: 45 deg., Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 18:14:50, Run # 7, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.32 m/s, Air Temp. : 20.4 deg C, Water Temp. : 20.8 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 18:14:50, Run # 7, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 4.32 m/s, Air Temp. : 20.4 deg C, Water Temp. : 20.8 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 3, 1989, Run Time: 18:24:43, Run # 8, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed: 4.23 m/s, Air Temp.: 20.3 deg C, Water Temp.: 20.9 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time: 18:31:20, Run #9, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed: 4.40 m/s, Air Temp.: 20.2 deg C, Water Temp.: 20.9 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 18:31:20, Run # 9, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.40 m/s, Air Temp. : 20.2 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 3, 1989, Run Time : 18:38:36, Run # 10, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.91 m/s, Air Temp. : 20.2 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 18:38:36, Run # 10, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.91 m/s, Air Temp. : 20.2 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 18:44: 4, Run # 11, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.03 m/s, Air Temp. : 20.1 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time: 18:44: 4, Run # 11, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.03 m/s, Air Temp. : 20.1 deg C, Water Temp. : 20.9 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Wind Speed: 4.17 m/s, Air Temp.: 19.7 deg C, Water Temp.: 20.8 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
WindSpeed : 4.17 m/s, Air Temp. : 19.7 deg C, Water Temp. : 20.8 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
WAVE-HEIGHT PSD

FREQUENCY [Hz]

MAGNITUDE OF MTF

FREQUENCY [Hz]

RADAR POWER PSD

FREQUENCY [Hz]

PHASE OF MTF

FREQUENCY [Hz]

SQUARED COHERENCE

FREQUENCY [Hz]

CROSS-CORRELATION

TIME [sec]

Aug. 3, 1989, Run Time : 19:19:56, Run # 13, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.98 m/s, Air Temp. : 19.6 deg C, Water Temp. : 20.8 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 19:19:56, Run # 13, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.98 m/s, Air Temp. : 19.6 deg C, Water Temp. : 20.8 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Wind Speed: 4.21 m/s, Air Temp.: 19.9 deg C, Water Temp.: 21.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
WAVE-HEIGHT PSD

MAGNITUDE OF MTF

RADAR POWER PSD

PHASE OF MTF

SQUARED COHERENCE

CROSS-CORRELATION

Wind Speed: 4.21 m/s, Air Temp.: 19.9 deg C, Water Temp.: 21.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Antenna Look Dir. : Up-Wind, Spikes Present
Wind Speed: 4.24 m/s, Air Temp.: 19.9 deg C, Water Temp.: 21.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time: 19:37: 5, Run # 16, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed: 4.65 m/s, Air Temp.: 19.9 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 3, 1989, Run Time: 19:37:5, Run # 16, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed: 4.65 m/s, Air Temp.: 19.9 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 19:42:38, Run # 17, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.83 m/s, Air Temp. : 19.2 deg C, Water Temp. : 20.7 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 19:42:38, Run # 17, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.83 m/s, Air Temp. : 19.2 deg C, Water Temp. : 20.7 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 19:48:10, Run # 18, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.23 m/s, Air Temp. : 19.2 deg C, Water Temp. : 20.7 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 19:48:10, Run # 18, X Band, VV Polarization, 34.0 deg Incidence
WindSpeed : 4.23 m/s, Air Temp. : 19.2 deg C, Water Temp. : 20.7 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time: 19:54: 5, Run # 19, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed: 4.38 m/s, Air Temp.: 19.9 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 19:54: 5, Run # 19, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.38 m/s, Air Temp. : 19.9 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
WindSpeed : 3.86 m/s, Air Temp. : 19.9 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Wind Speed : 3.86 m/s, Air Temp. : 19.9 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time : 20: 5:22, Run # 21, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.86 m/s, Air Temp. : 19.8 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 20: 5:22, Run # 21, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.86 m/s, Air Temp. : 19.8 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Wind Speed: 3.87 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Wind Speed: 3.87 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
WindSpeed: 3.78 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Wind Speed: 3.78 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Wind Speed: 3.58 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Wind Speed: 3.58 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
A–3. Ka Band
Appendix B

Plots of $\sigma^0$ and Wave Height

B-1. C Band
Wave Height (m)

-0.4 -0.3 -0.2 -0.1 -0.0 0.0 0.1 0.2

0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320

time (sec)

Run 15, 18:11, July 19, 1990

Wind Direction: 40° deg.

Wind Speed: 5.6 m/s
Aug. 3, 1989, Run Time : 20:33:50, Run # 26, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 3.19 m/s, Air Temp. : 19.4 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 3, 1989, Run Time: 20:33:50, Run # 26, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed: 3.19 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
WindSpeed : 3.33 m/s, Air Temp. : 19.4 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Wind Speed: 3.33 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 3, 1989, Run Time: 20:51:0, Run # 29, X Band, VV Polarization, 34.0 deg. Incidence

WindSpeed: 2.87 m/s, Air Temp.: 19.4 deg C, Water Temp.: 21.0 deg C

Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 3, 1989, Run Time : 20:51:0, Run # 29, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 2.87 m/s, Air Temp. : 19.4 deg C, Water Temp. : 21.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 17:19:12, Run # 15, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.75 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 17:19:12, Run # 15, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.75 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 17:24:45, Run # 16, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 5.33 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.1 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time: 17:24:45, Run # 16, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed: 5.33 m/s, Air Temp.: 22.9 deg C, Water Temp.: 22.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 17:30:30, Run # 17, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 5.23 m/s, Air Temp. : 23.0 deg C, Water Temp. : 22.1 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time: 17:30:30, Run # 17, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 5.23 m/s, Air Temp.: 23.0 deg C, Water Temp.: 22.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 4, 1989, Run Time: 17:35:50, Run # 18, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 5.18 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 17:35:50, Run # 18, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 5.18 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 17:41:25, Run # 19, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.63 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 17:41:25, Run # 19, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.63 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 17:46:58, Run # 20, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 3.98 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 17:46:58, Run # 20, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 3.98 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 17:53:50, Run # 21, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.75 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 17:53:50, Run # 21, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.75 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 4, 1989, Run Time: 18:54:40, Run #23, X Band, HH Polarization, 34.0 deg, Incidence
Wind Speed: 3.61 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 18: 5:40, Run # 23, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.61 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 4, 1989, Run Time : 18:11: 2, Run # 24, X Band, HH Polarization, 34.0 deg. Incidence
Wind Speed : 4.26 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.1 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 18:11: 2, Run # 24, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 4.26 m/s, Air Temp. : 23.4 deg C, Water Temp. : 22.1 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 4, 1989, Run Time: 18:16:50, Run #25, X Band, HH Polarization, 34.0 deg. Incidence
Wind Speed: 4.29 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 4, 1989, Run Time: 18:16:50, Run # 25, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed: 4.29 m/s, Air Temp.: 23.4 deg C, Water Temp.: 22.1 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 18:29:15, Run # 27, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.17 m/s, Air Temp. : 23.0 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time: 18:29:15, Run #27, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 4.17 m/s, Air Temp.: 23.0 deg C, Water Temp.: 22.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time: 18:35:25, Run # 28, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 3.89 m/s, Air Temp.: 22.9 deg C, Water Temp.: 22.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Present
Aug. 4, 1989, Run Time: 18:35:25, Run # 28, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed: 3.89 m/s, Air Temp.: 22.9 deg C, Water Temp.: 22.0 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 18:41:28, Run # 29, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.86 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 18:41:28, Run # 29, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.86 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 19:04:44, Run # 32, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.87 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 19: 0:44, Run # 32, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.87 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 4, 1989, Run Time : 19: 6:20, Run # 33, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed : 3.83 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 4, 1989, Run Time : 19: 6:20, Run # 33, X Band, HH Polarization, 34.0 deg. Incidence
Wind Speed : 3.83 m/s, Air Temp. : 22.9 deg C, Water Temp. : 22.0 deg C
Antenna Look Dir. : Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 4, 1989, Run Time : 20:40: 0, Run # 42, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed : 4.40 m/s, Air Temp. : 20.4 deg C, Water Temp. : 21.8 deg C
Antenna Look Dir. : 60 deg., Spikes Present
Aug. 4, 1989, Run Time : 20:40: 0, Run # 42, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed : 4.40 m/s, Air Temp. : 20.4 deg C, Water Temp. : 21.8 deg C
Antenna Look Dir. : 60 deg., Spikes Removed (4.5 dB Moving Agerage Threshold)
Aug. 6, 1989, Run Time : 17:55:42, Run # 15, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 5.18 m/s, Air Temp. : 24.9 deg C, Water Temp. : 22.9 deg C
Antenna Look Dir. : Cross-Wind, Spikes Present
Aug. 6, 1989, Run Time: 17:55:42, Run #15, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed: 5.18 m/s, Air Temp.: 24.9 deg C, Water Temp.: 22.9 deg C
Antenna Look Dir.: Cross-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 6, 1989, Run Time : 18: 3:25, Run # 16, X Band, VV Polarization, 34.0 deg. Incidence
Wind Speed : 4.82 m/s, Air Temp. : 24.9 deg C, Water Temp. : 22.8 deg C
Antenna Look Dir. : Cross-Wind, Spikes Present
Aug. 6, 1989, Run Time : 18: 3:25, Run # 16, X Band, VV Polarization, 34.0 deg. Incidence
WindSpeed : 4.82 m/s, Air Temp. : 24.9 deg C, Water Temp. : 22.8 deg C
Antenna Look Dir. : Cross-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 7, 1989, Run Time : 17:59:19, Run # 11, X Band, HH Polarization, 34.0 deg. Incidence
Wind Speed : 5.19 m/s, Air Temp. : 24.9 deg C, Water Temp. : 22.3 deg C
Antenna Look Dir. : Cross-Wind, Spikes Present
Aug. 7, 1989, Run Time: 17:59:19, Run # 11, X Band, HH Polarization, 34.0 deg. Incidence
WindSpeed: 5.19 m/s, Air Temp.: 24.9 deg C, Water Temp.: 22.3 deg C
Antenna Look Dir.: Cross-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 7, 1989, Run Time : 18:34: 4, Run # 12, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed : 4.36 m/s, Air Temp. : 24.4 deg C, Water Temp. : 22.3 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 7, 1989, Run Time: 18:34:4, Run #12, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.36 m/s, Air Temp.: 24.4 deg C, Water Temp.: 22.3 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)
Aug. 7, 1989, Run Time : 18:45: 5, Run # 14, X Band, VV Polarization, 40.0 deg. Incidence
WindSpeed : 4.84 m/s, Air Temp. : 24.4 deg C, Water Temp. : 22.2 deg C
Antenna Look Dir. : Up-Wind, Spikes Present
Aug. 7, 1989, Run Time: 18:45: 5, Run # 14, X Band, VV Polarization, 40.0 deg. Incidence
Wind Speed: 4.84 m/s, Air Temp.: 24.4 deg C, Water Temp.: 22.2 deg C
Antenna Look Dir.: Up-Wind, Spikes Removed (4.5 dB Moving Average Threshold)