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PRELIMINARY REPORT ON SKYLAB S-193 RADSCAT MEASUREMENTS OF HURRICANE AVA

by

Vincent J. Cardone and
Willard J. Pierson, Jr.
University Institute of Oceanography
City University of New York

Richard K. Moore and
James D. Young
Remote Sensing Laboratory
The University of Kansas

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V. J. Cardone, R. K. Moore
W. J. Pierson, Jr., J. D. Young

Abstract

The SKYLAB RADSCAT instrument S-193 was operated on 6 June 1973 while the spacecraft flew past Hurricane Ava in the eastern Pacific Ocean. Scatterometer returns at all polarizations and radiometer measurements were obtained from a section through the storm with winds up to 48 knots at 52° incident angle and 35 knots at 45.5° incident angle. These first hurricane scatterometer measurements indicate reasonable correlation between wind speed and backscatter, with the horizontal response much stronger than the vertical response at 52°. Each of the sections through the hurricane contains an as yet unexplained dip in cross-section at a point 200 to 300 km prior to passing the eye. The response at a point where the radiometer signal's dramatic increase indicates strong rain is also accompanied by a strong increase in the backscattered signal. No attempt has been made to make a thorough correlation of radiometric response with wind speed, but the atmospheric contribution to the radiometer signal is quite apparent.

1.0 Background

On 6 June 1973 an opportunity was provided for the first scatterometer measurements of ocean backscatter during a hurricane. Hurricane Ava was located in the Pacific Ocean off the northwest coast of Mexico, and a Skylab pass was scheduled near the area. Although the Skylab vehicle was not oriented in its earth-observation mode, the geometry of the solar-pointed mode at the location of the hurricane permitted measurements to be made almost to the eye.

The S-193 RADSCAT is a radiometer-scatterometer operating at 13.9 GHz with multiple polarization capability in both its active and its passive modes. Microwave antenna temperatures were obtained with both vertical and horizontal polarization at 100 km intervals for about 800 km before the spacecraft passed the eye of the storm and 300 km after it passed the eye. Scatterometer measurements were obtained over the same region but measurements for the last 200 km are questionable because the Doppler frequency shifts were at the edge of the passband of the instrument. The points at an angle of incidence of about 52° came close enough to the eye so that 48 knots surface wind was observed at one point.

Both horizontally and vertically polarized scatterometer measurements correlate reasonably well with wind speed in the higher incidence angles, although some interesting deviations are noted between the scatterometer pattern and the calculated wind pattern. The horizontally polarized response at 52° incident angle seems much more sensitive to wind speed than the vertically polarized one. The passive microwave signals showed similar patterns for both polarizations, but the larger variation for the horizontal than for the vertical was not as much as expected. Elevation of radio temperature due to precipitation was quite noticeable.

This report presents a very preliminary analysis of the data from Hurricane Ava, based on results obtained with computer programs used in preflight testing. Some modifications may be expected when data from the production data processing programs are used, but the trends exhibited here should not change. These results are presented in a relatively simplified form, since much more analysis will be required before a final conclusion can be drawn.

2.0 The RADSCAT System

The S-193 RADSCAT operates at 13.9 GHz. Figure 1 shows a simplified block diagram of the S-193. The scatterometer uses a transmitter with about 20 watts output in an interrupted-continuous-wave mode. The transmitter is on for 5 ms and off for 3 ms during which the receiver is activated, after which the transmitter is again turned on. Each sequence consists of a number of such pulses that depends on the mode selected and the angle of incidence.

The microwave portion of the receiver is common to the scatterometer and the radiometer, with separate processing and calibration circuitry used for each. The radiometer has a 200 MHz bandwidth. In the mode used in this experiment, sequential measurements are made of vertical transmit-vertical receive (VV), vertical transmit-horizontal receive (VH), vertical radiometer receive (V), horizontal transmit-horizontal receive (HH), horizontal transmit-vertical receive (HV), and horizontal radiometer receive (H). Following such a sequence of measurements, the antenna moves to a different angle and the sequence is repeated (with different durations for each part of the cycle). The entire sequence of angles takes about 15 seconds, during which the spacecraft moves about 100 km.

The scatterometer signal passes through a bank of three filters with overlapping passbands. For the nominal pointing direction, the Doppler spectrum is centered in the center filter, but for deviations from nominal it may be in either of the other filters. If the Doppler frequency deviates from nominal by too large an amount, it cannot pass through the filters and no scatterometer measurement is possible. Because the experiment was performed in the solar-pointed mode, the Doppler signal moved out of the filter passband shortly after the spacecraft came abreast of the eye of the storm.

Although the antenna can be scanned in several different modes, the one used here was the CTNC (cross-track non-contiguous). In this mode, when the spacecraft is in earth-pointing operation, the scan is intended to produce a grid of points paced about 100 km in both across-track and along-track directions; because of the slightly different orientation of the spacecraft for this experiment, the across-track spacings are somewhat different from nominal. The antenna beam is approximately circular with two-way beamwidth of about 1.5° (scatterometer) and one-way beamwidth of about 2° (radiometer).

3.0 The Experiment

A preliminary wind analysis was performed for the conditions of the experiment and is presented in Figure 2 and Table 1. The wind flags for Figure 1 are shown on a computer-generated plot of the illuminated areas for the scan positions used in the experiment, so the scaled size of illuminated sample regions can be determined from this illustration along with the locations and winds.

The wind analysis is based on a model[1] that uses as inputs central pressure, radius of maximum wind, ambient pressure, and direction and speed of movement of the eye. All of these data are obtained from aircraft flights and satellite pictures. The model of the flow in the friction layer modifies the cyclostrophic and gradient winds and automatically accounts for inflow. The indicated winds are those that would be measured at a height of 20 meters above the sea. The wind profile down to the surface from this height would be logarithmic with neutral stability. The analysis of the wind field on the periphery of the hurricane circulation (winds less than 15 knots) was aided by sun glint measurements provided by NOAA (National Oceanographic and Atmospheric Administration).

This model has been tested in the past on several hurricanes and it was found to give a good picture of the conditions observed in these storms. Of course, it cannot account for such turbulent effects as local squall lines.

The figure shows that the larger incident angles represent tracks through the storm reasonably close to the eye, whereas the smaller incident angles are in a region influenced by the hurricane but well outside the high-wind-speed part of the storm. Unfortunately, the maximum available incident angle was too small to permit measurements in the eye itself. Since the illustration represents a sketch of the general situation rather than a true map of the conditions, the table should be consulted to obtain actual wind directions calculated by the model.

Cloud data are available for the various points on the grid, but they are not presented here, as further analysis will be required to attempt to ascertain whether the cloud data and RADSCAT data can be compared effectively in this kind of situation. Suffice it to say, the regions of elevated microwave brightness temperature where cloud/precipitation attenuation is indicated are definitely cloud-covered!

4.0 Preliminary Observations

The basic radiometer observations are summarized in Figure 3, and the scatterometer observations in Figure 4. Figure 3 shows the antenna temperature measurements as a function of position along the track for the different angles of incidence, plotted on a linear scale. The fact that both polarizations indicate a gradual rise at 52° suggests a gradual increase in atmospheric contribution as the hurricane is approached, since the vertical polarization temperature should be essentially independent of windspeed at this angle of incidence.[2] The rather sharp rise at point 8 would seem to be due to a significant increase in atmospheric attenuation since the windspeed increase between points 7 and 8 is not much different from that between 6 and 7 where a much smaller increase in antenna temperature is observed. Quite clearly, the dramatic rise in T_A at point 10 must be due to heavy precipitation that causes significant absorption. The low value obtained at point 11 is at present unexplained. Apparently a rain shower is observed at the smallest incident angle near the end of the pass.

Variations in the scatterometer data are more dramatic than those in the antenna temperature, except at point 10. The difference in behavior between horizontal and vertical was expected, but is somewhat greater than originally anticipated.[3] Because of the higher windspeeds encountered at 52° and 45.5° incidence angles, further analysis is restricted to those angles.

Figure 5 shows a summary of the responses at 52° on an expanded scale and with the wind plotted along with the microwave data. Because a logarithmic ordinate is used, the antenna temperature variations appear smaller and those at vertical polarization appear relatively smaller than those at horizontal polarization.

The apparent dip in the vertical scatterometer response at point 7 and the horizontal response at point 8 are unexplained by the wind field analysis. A conceivable explanation is the presence of a squall line followed by a lull. Such a situation would not be forecast by the model, but might well occur in this kind of storm. Unfortunately the aircraft flights were to the south of the eye, so no pertinent surface observations are available for this region.

The very large rise in scattering at point 10 is obviously associated with the dramatic rise in radiometric brightness at that point. It is probably partly caused by backscatter from precipitation, but other explanations may be in order also. For example, precipitation hitting the water makes significant changes in its capillary wave structure, and no observations have been made of the effect of this on back-scatter; it is known, however, that the capillary waves are primary contributors to the microwave backscatter at this angle of incidence, so some effect is to be expected.

Figure 6 shows the same kind of presentation of data for 45.5° incidence angle that Figure 5 showed for 52°. Here the difference between vertical and horizontal polarization is even more pronounced. The presence of some kind of lull in the wind at and near point 7 seems definitely indicated, although some other explanation may eventually be found for this.

These data have been presented in Figures 5 and 6 without any correction for change in angle with respect to the wind and for the effect of attenuation known to be present because of the large increases in antenna temperature. An attempt has been made to make such corrections. The scattering response is known to be stronger in an upwind-downwind direction than in a crosswind direction; yet Figure 2 shows that the observation changes from almost downwind at point 8 to almost crosswind at point 10. The effect of changing observation angle relative to the wind was strongly demonstrated with the AAFE RADSCAT;[4] a circular flight was made in 25 knot winds at 40° incident angle. Although the effect may be different for different incident angles and wind speeds, a preliminary correction can be made by use of these data. The correction factor used normalizes all scattering coefficients to those that would be observed in an upwind direction. Figure 7 shows the size of this correction for the 52° track (at the bottom of the figure), and also shows (top) the scattering coefficient modified by the corrections.

A second correction has been made for the effect of attenuation in the atmosphere. This is based on the increase in brightness temperature for the vertically polarized radiometer, using the results of Wu.[5] It is also shown at the bottom of Figure 7. The curves at the top were corrected by combining the two factors. The corrected scatterometer responses appear more consistently to follow the wind speed for both polarizations, but the effect is more noticeable on vertical polarization where the response to the wind is weaker than for horizontal polarization, so a correction represents a larger relative effect. For both polarizations, however, the scattering observed at point 10 is so high that some other phenomenon clearly must be operating there, as discussed above.

Figure 8 shows the corrections and the corrected curves for 45.5°. At this angle, the large decrease around points 6 and 7 is not removed, but point 9 seems more consistent with points 1 through 5 than it did before correction.

These corrections should be considered tentative, for the validity of the AAFE curve under the conditions encountered here has not been proven. Nevertheless, the general character of the corrections certainly is right even if some modification may be necessary later in their absolute magnitude.

5.0 Discussion and Conclusions

The flight of SKYLAB past Hurricane Ava provided the first opportunity to view a hurricane with a radar scatterometer, and the opportunity to compare radiometer and scatterometer responses to the varying sea conditions and wind conditions. This preliminary report has shown that both vertically and horizontally polarized radar backscatter at angles studied (45.5° and 52°) increase dramatically with the increasing wind of the hurricane. The horizontally polarized signal is more sensitive to the wind than the vertically polarized one, as expected. An anomaly in the apparent wind response occurred at one point, but it is not known whether to ascribe this to one of the significant perturbations in the wind field associated with the characteristic banded structure of the hurricane or to some as yet unknown phenomenon, perhaps associated with the waves; it does not seem to be due to the instrument itself.

Use of an aspect angle correction based on the AAFE RADSCAT experiment and an attenuation correction based on elevation of the microwave brightness temperature gives results that seem to improve the consistency of the measurements. In the one case where the brightness temperature rose so much that an attenuation for the radar of almost 4 dB was indicated, the scattering was quite large—whether this was due to rain scatter or to modification of the surface by the rainfall has not been determined. Further analysis of the meteorological data should permit an estimate to be made of the strength of the volume scatter from the rain.

This has been a very preliminary report to indicate the general character of the Hurricane Ava observations. A more complete investigation of these results is in progress, and will take several months to complete. Perhaps some of the apparent anomalies in these observations will be more readily explained after SKYLAB RADSCAT data have been analyzed for other areas.

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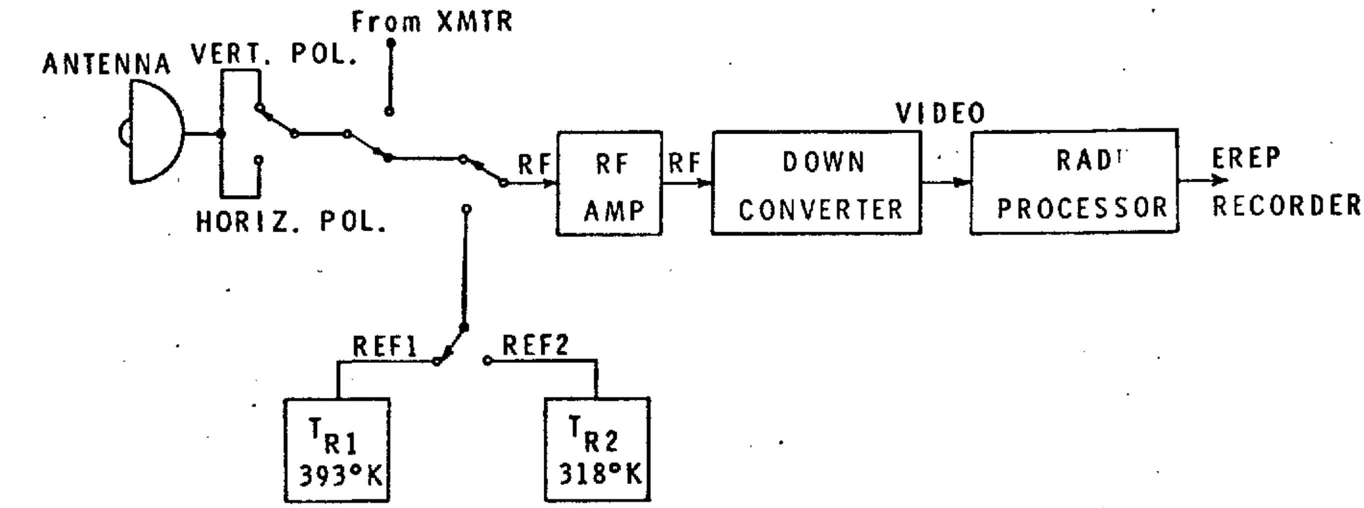
RADIOMETER BLOCK DIAGRAM



SCATTEROMETER BLOCK DIAGRAM

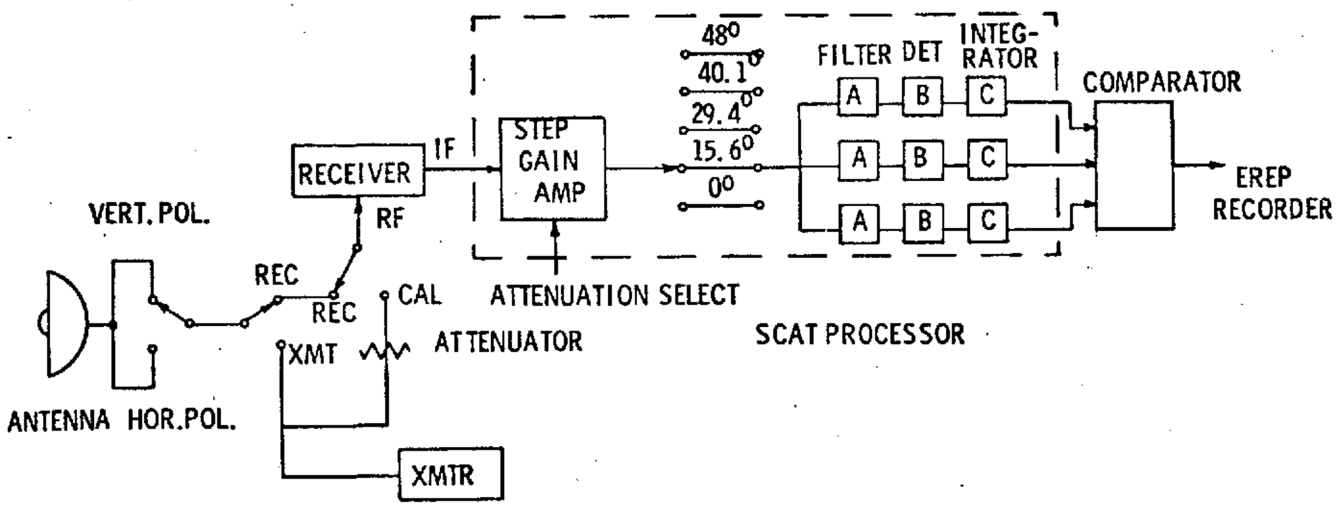


FIGURE 1. SIMPLIFIED BLOCK DIAGRAM OF THE S-193 RADSCAT

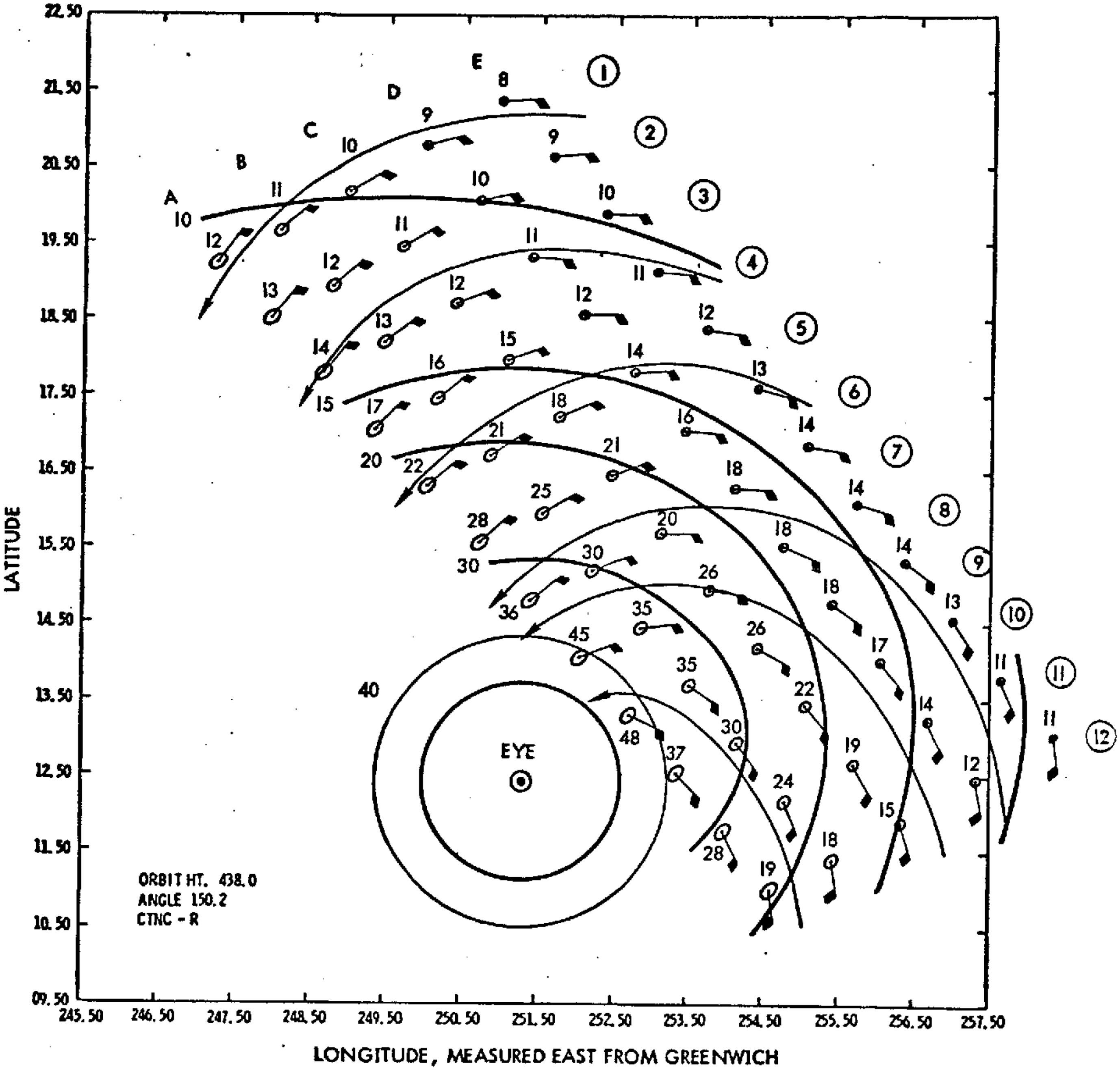


FIGURE 2. PRELIMINARY SKETCH OF WIND FIELD - HURRICANE AVA

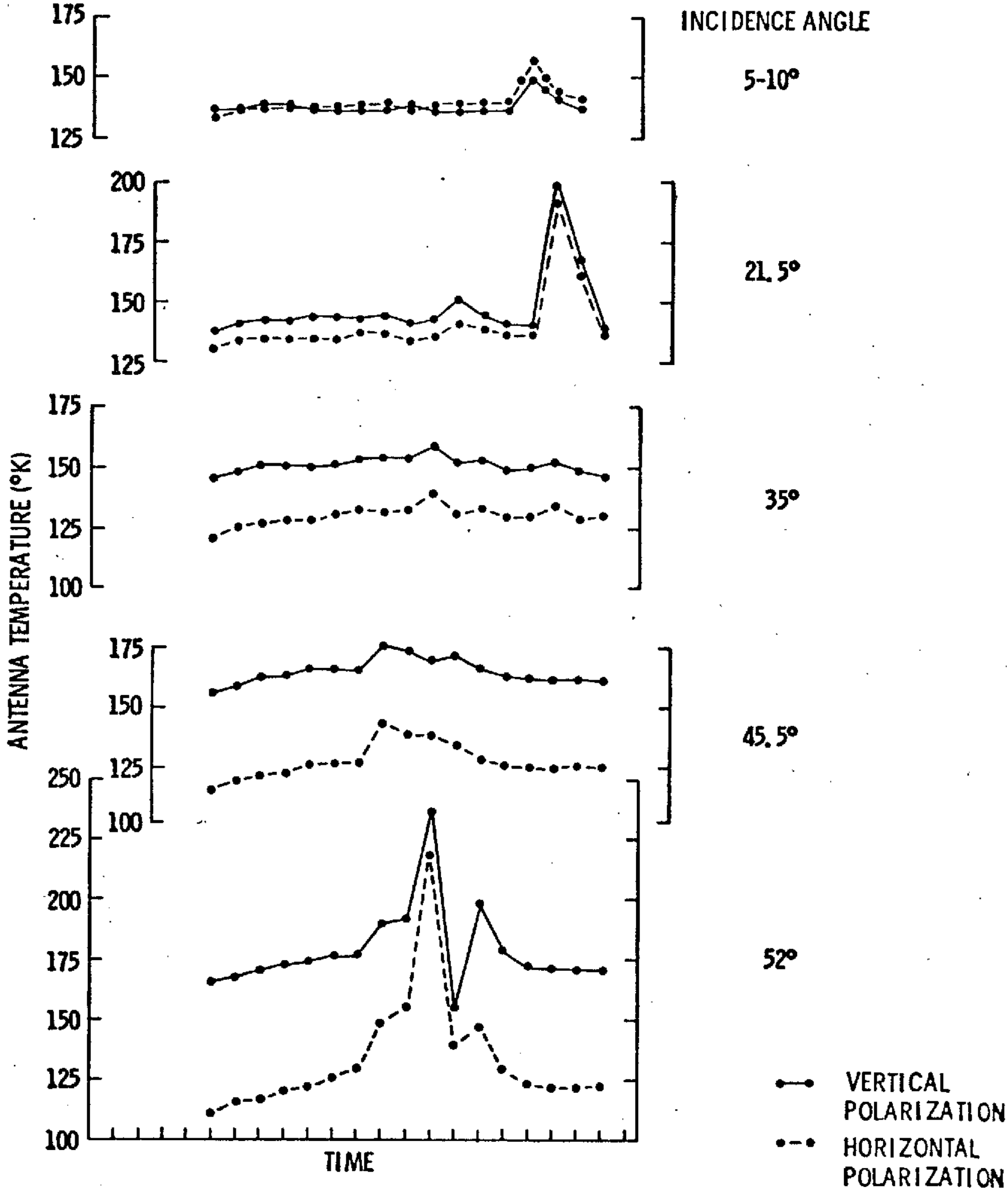


FIGURE 3. RADIOMETER RESPONSE - HURRICANE AVA

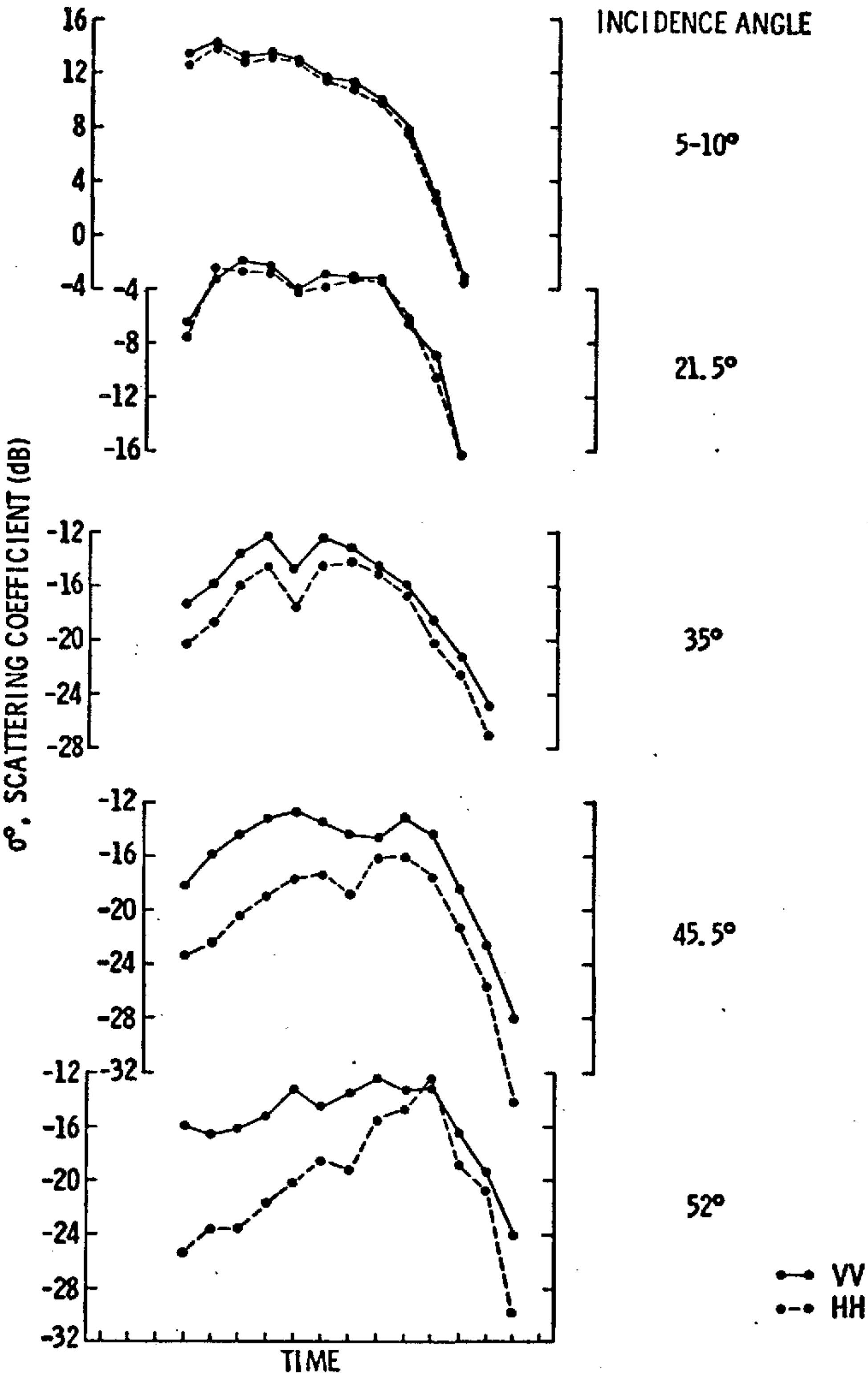


FIGURE 4. SCATTEROMETER RESPONSE - HURRICANE AVA

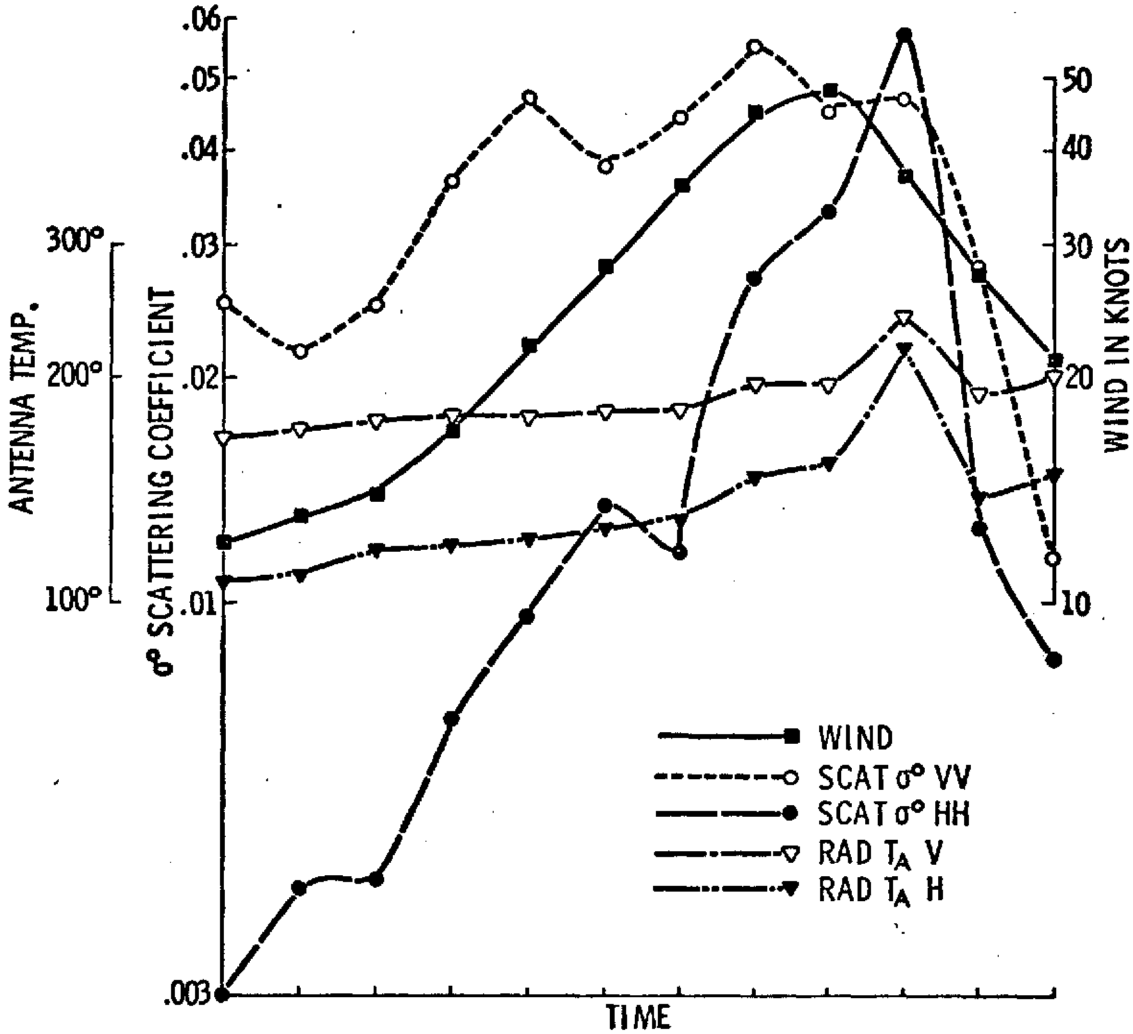


FIGURE 5. UNCORRECTED RESPONSES AT 52°-HURRICANE AVA

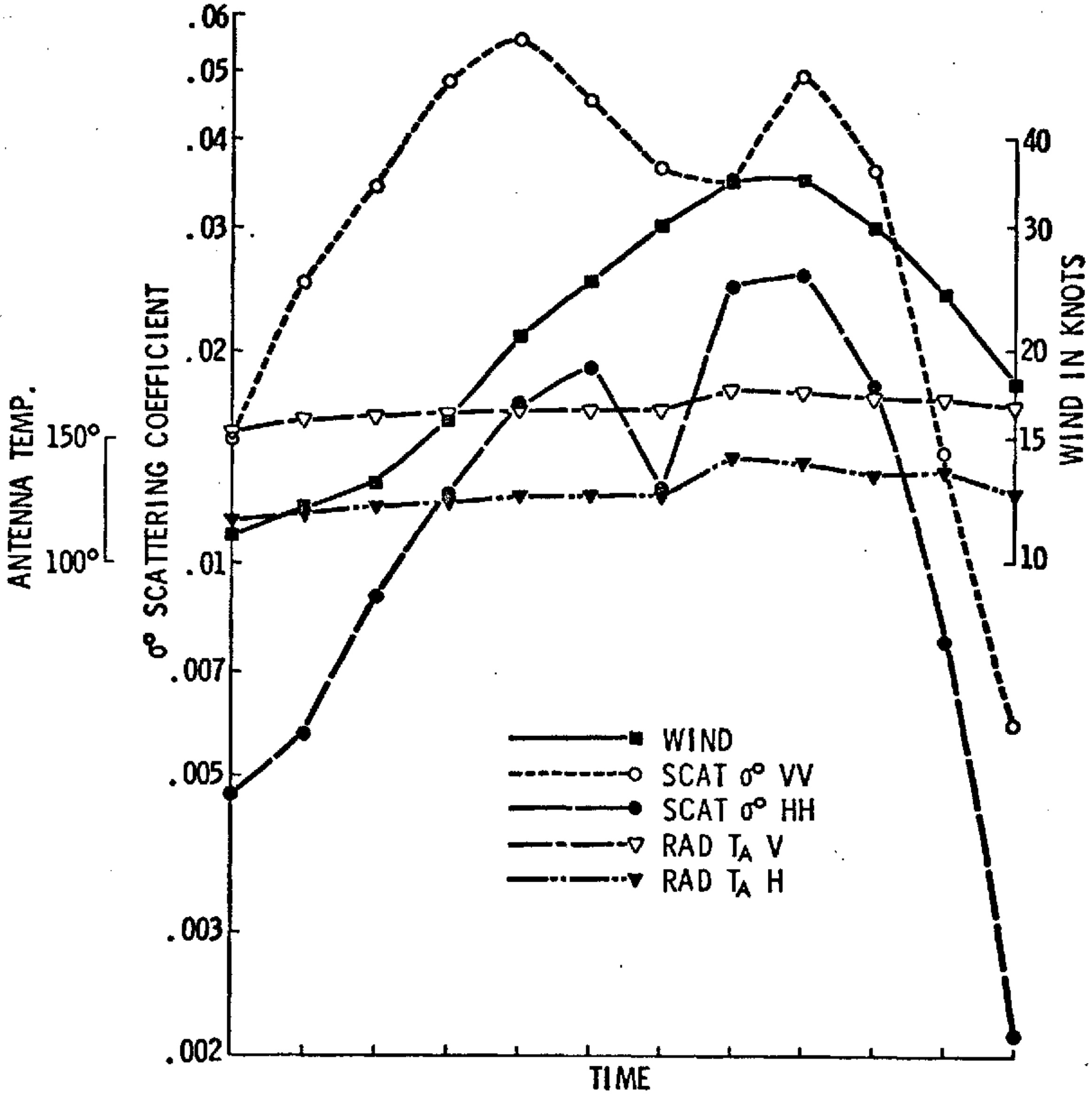


FIGURE 6. UNCORRECTED RESPONSE AT 45.5°-HURRICANE AVA

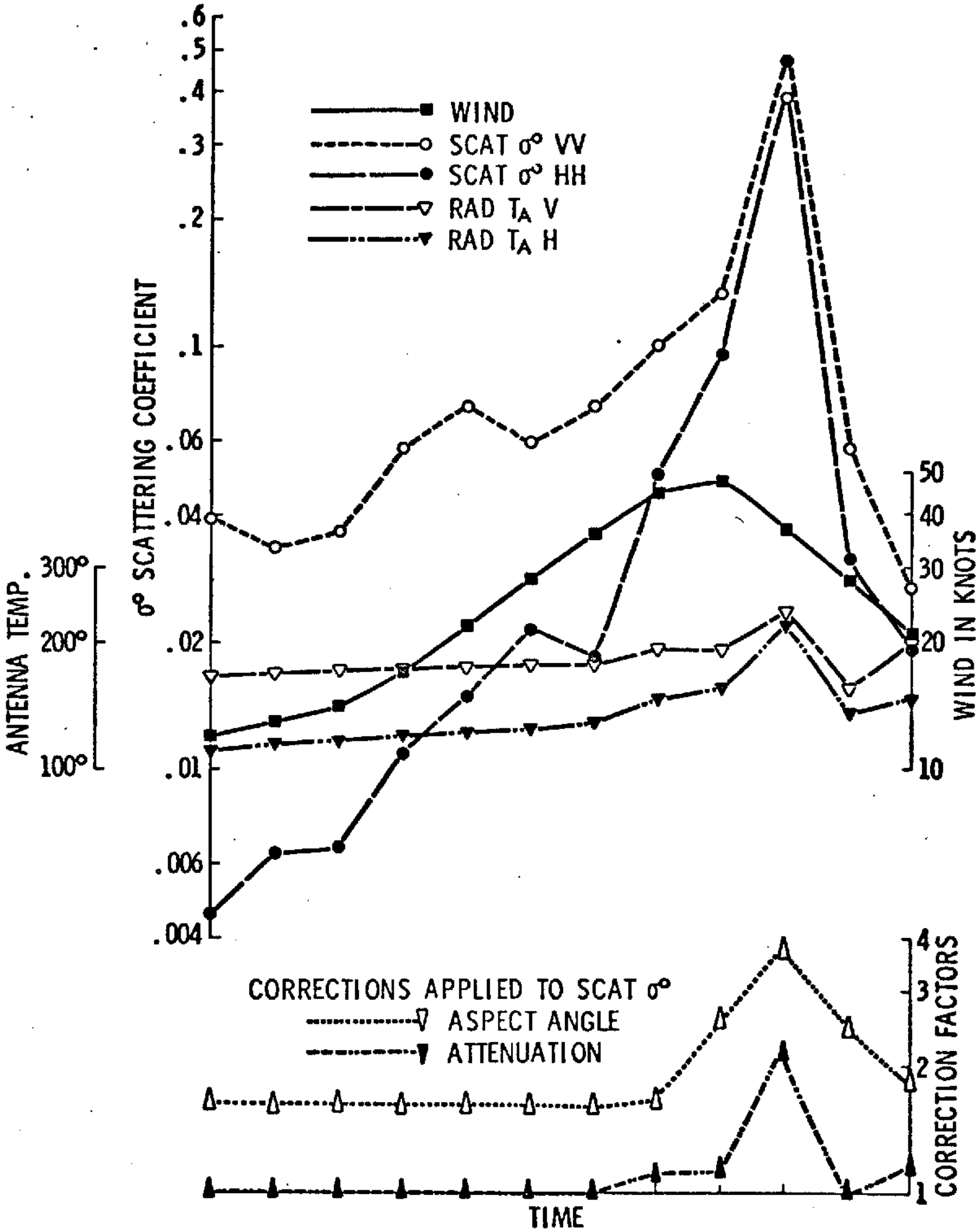


FIGURE 7. TENTATIVELY CORRECTED 52° RESPONSE - HURRICANE AVA

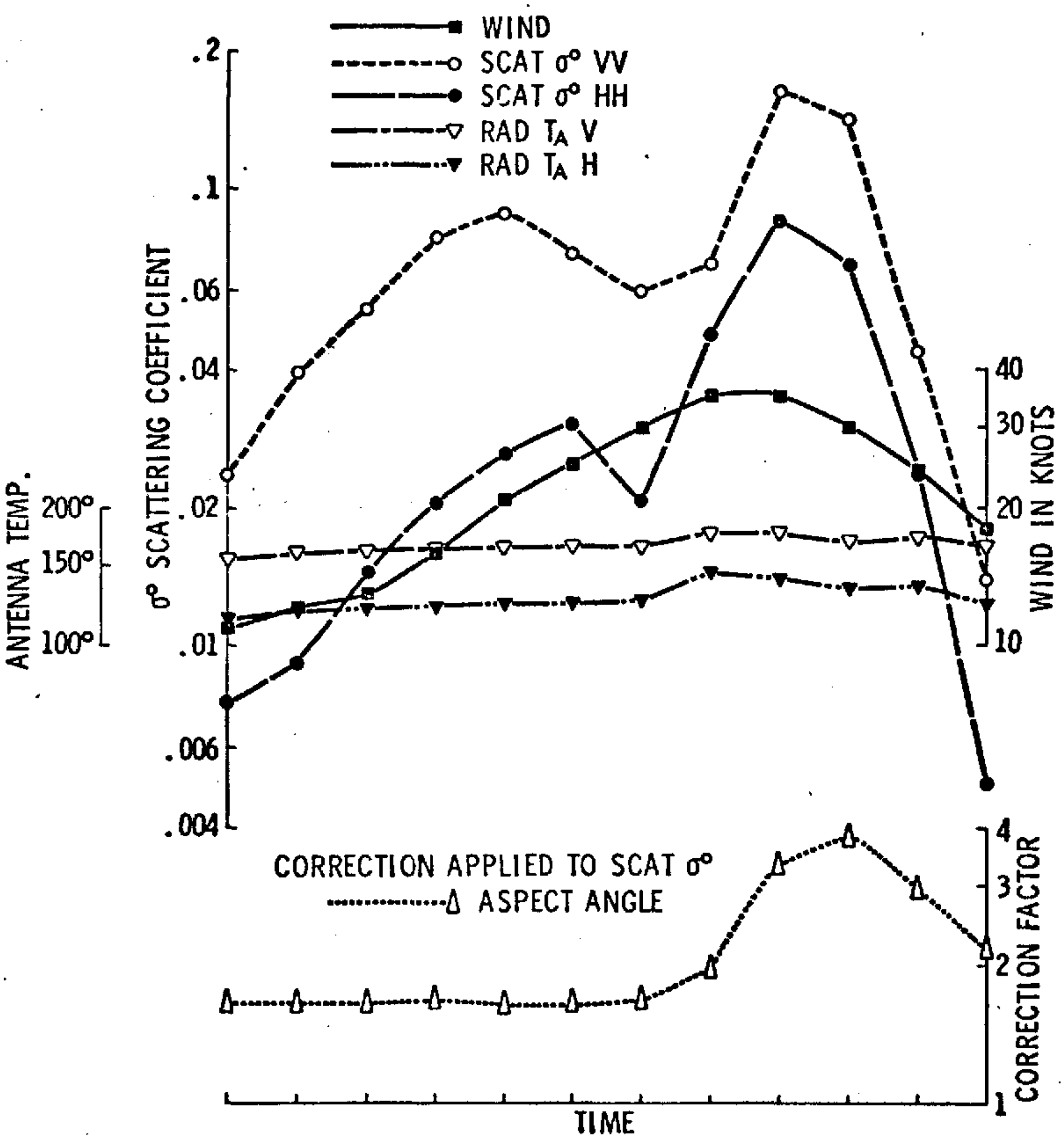


FIGURE 8. TENTATIVELY CORRECTED 45.5° RESPONSES-HURRICANE AVA