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SEASAT ALTIMETER ATMOSPHERIC RANGE CORRECTION.(U)
SEP 80 J P HOLLINGER MIPR-HM0050-651
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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This report describes the development and validation of the wet term of the atmospheric range correction for the SEASAT altimeter by the Naval Research Laboratory as part of its contribution to the WAFER 82 Sub-Working Group on Acquisition and Exploitation of SEASAT Altimeter Data. The algorithm uses antenna temperatures from the SEASAT Scanning Multichannel Microwave Radiometer (SMMR).

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20. (continued)

It was developed by Macmillian M. Wisler at NRL using an optimal linear estimator, a theoretical-empirical atmospheric-ocean model and a statistical description of the environment. The algorithm tests were performed by the JPL SMMR Evaluation Task Group by comparing the range correction derived from the algorithm with the range correction calculated using radiosonde water vapor measurements from the islands of Bermuda and Kwajalein. The data used for the comparison were taken from eight different orbits during 13-30 September 1978. The wet term range correction varied from 19 to 42 cm. Apart from a relatively unimportant systematic bias, which is easily and accurately removed, the algorithm and radiosonde range corrections agreed very well with an RMS deviation of ± 2.0 cm. Improved calibration and antenna pattern corrections of SMMR data and greater radiometric accuracy of future passive microwave systems along with further algorithm development undoubtedly will allow improved accuracy in determination of the range correction.

CONTENTS

SEASAT ALTIMETER ATMOSPHERIC RANGE CORRECTION

I. INTRODUCTION

The Defense Mapping Agency (DMA) is responsible for the development of geodetic and geophysical data and for the dissemination of such information to the Department of Defense (DoD) community. As a portion of this activity DMA assembled the WAFER 82 Sub-Working Group on Acquisition and Exploitation of SEASAT Altimeter Data (1). This group is composed of eight DoD Laboratories and Centers including the Naval Research Laboratory (NRL).

One of the responsibilities accepted by NRL, as part of its contribution to the WAFER 82 effort, was to develop an algorithm to determine the atmospheric range correction to be applied to the altimeter data to correct for the time delay imposed on the altimeter pulse as it propagates through the atmosphere and to provide an assessment of the accuracy of this correction. The correction algorithm utilizes data obtained by the SEASAT Scanning Multichannel Microwave Radiometer (SMMR).

The range correction, developed by M.M. Wisler at NRL, is presented first. A test and validation of this algorithm conducted by the JPL SMMR Evaluation Task Group and implemented by John Lundberg from the University of Texas using radiosonde measurements is then given.

II. ALTIMETER RANGE CORRECTION ALGORITHM

The range correction ΔR is given by

$$\Delta R = \int_{\mathrm{PATH}} (n-1)dh = \int_{\mathrm{PATH}} N\mathrm{x}10^{-6}dh \tag{1}$$

where n is the refractive index and N is the refractivity. The refractivity of air recommended by Smith and Weintraub to yield an overall accuracy of ± 0.5 percent in N is given by Bean and Dutton (2) as

$$N = 77.6\,\frac{Pd}{T} + 72\,\frac{e}{T} + 3.75\mathrm{x}10^{5}\,\frac{e}{T^2}\,, \tag{2}$$

where Pd is the pressure of dry air in millibars, e is the partial pressure of water vapor, also in millibars, and T is the absolute temperature in degrees Kelvin. An improved equation for N, which is an order of magnitude more accurate than equation (2), has been derived by G.D. Thayer (3). However, this additional accuracy in the refractivity results in a refinement of the calculated range error of less than 0.1 cm and is not justified at present. Equation (2) is used throughout this report.

Combining equations (1) and (2) and using the ideal gas law yields the range correction, in cm, as

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Manuscript submitted July 23, 1980.

$$\Delta R = 0.227\ P_{od} + 0.332\ \rho_w dh + 1.731\text{x}10^3\ \frac{\rho_w dh}{T}\ , \tag{3}$$

where P_{od} is the surface pressure of dry air in millibars and ρ_w is the water vapor density. In obtaining equation (3) use has been made of the result, as shown by H.S. Hopfield (4), that the surface pressure alone is a direct measure of the zenith range correction caused by a dry atmosphere. We are concerned here only with the range correction due to water vapor, and given by the last two terms, both because the "wet" term is most variable and unpredictable and also because SMMR is sensitive to atmospheric water vapor, but sensibly independent of surface pressure.

The wet term range correction algorithm was developed by M.M. Wisler and is given in Appendix A. It was developed using an optimal linear estimator (5). This method uses a theoretical-empirical atmospheric and ocean surface model along with a statistical description of the environment to relate the environmental parameters to the measured microwave radiometric temperatures rather than using the covariance matrix of the environmental parameters with the calculated radiometric brightness temperatures.

The algorithm was designed to use antenna temperatures both because the antenna pattern corrections necessary to obtain brightness temperatures had not been implemented at the time the algorithm was developed but also to provide the simplest and quickest means of estimating the range correction by requiring as little processing as possible. It is intended that the algorithm will be extended and refined as requirements dictate and testing and validation allow.

III. VALIDATION OF RANGE CORRECTION ALGORITHM

The range correction has been tested by the JPL SMMR Evaluation Task Group as part of their overall program to validate SMMR data. The algorithm was implemented for these tests by John Lundberg. The description of these tests and the results are contained in Jet Propulsion Laboratory Interoffice Memorandum 315.6 - 598 of 6 November, 1979 which is included here as Appendix B.

The tests were made by comparing the range correction obtained using radiosonde water vapor density measurements from the islands of Bermuda and Kwajalein with the range correction derived from the algorithm using SMMR antenna temperature measurements. Eight separate satellite revolutions during the interval 13 through 30 September 1978 were analyzed. During this period the precipitable water vapor present in the atmosphere, as determined from the radiosonde measurements, varied from 3.0 to 6.5 gm/cm^2 and the range correction from 19 to 42 cm.

The results are shown in Figures 1 through 8 in Appendix B where the range correction determined from the Wisler algorithm is plotted versus latitude for each of the eight orbits (+ signs). Also shown is the range correction obtained from the radiosonde data appropriate to that orbit (letter R).

The results from the Wisler algorithm have been multiplied by 1.179 to remove a systematic difference between them and the radiosonde values. This difference may be due to a bias in the SMMR antenna temperatures or result from not applying antenna pattern corrections to obtain brightness temperature. It also may be due to the radiosonde data or, of course, it may be inherent in the Wisler algorithm. Final validation of the SMMR antenna temperatures and further testing are required to resolve the question. However, the bias is relatively unimportant since it is easily and accurately removed and can be incorporated into the algorithm. The RMS variation between the Wisler algorithm and radiosonde range corrections is ± 2.0 cm. This is very good agreement.

It is interesting to compare these results with the range correction developed by Dr. S. L. Smith at the Naval Surface Weapons Center, Dahlgren Laboratory (6). This correction uses only the surface air temperature and humidity obtained directly from the oceanographic and atmospheric prediction data fields produced by the Fleet Numerical Weather Central, Monterey, California. The Smith correction, in cm, is

$$\Delta R = 86400 \frac{e}{T^2} \tag{4}$$

where e and T are the surface values of the partial pressure of water vapor in millibars and air temperature in degrees Kelvin.

The range correction, determined from equation (4), for five of the eight orbits for which range corrections were obtained from radiosonde data and the Wisler algorithms are given in Table 1. There is a bias between the radiosonde values and the Smith correction of 1.17. This is the same as the bias between the radiosonde data and the results from the Wisler algorithm. It is not possible to draw reliable conclusions from only five points but it is possible that the radiosonde values are too high and not that the Wisler and Smith corrections are too low. Multiplication of the Smith values by the same 1.179 factor applied to the Wisler values resulted in an RMS variation between the Smith and Wisler range corrections of ± 6.7 cm. The RMS vairation between the Smith and radiosonde values is ± 10.8 cm.

The results presented here indicate that altimeter atmospheric range corrections can be obtained from SMMR measurements to an accuracy of ± 2.0 cm. Improved calibration and antenna pattern corrections of SMMR data and improved radiometric accuracy of future passive microwave systems along with further algorithm development undoubtedly will allow improved accuracy in determination of the range correction.

TABLE 1

REVOLUTION NUMBER									
1160		1172		1215		1258		1375	
LAT	ΔR	LAT	ΔR	LAT	ΔR	LAT	ΔR	LAT	ΔR
31	30.8	2	32.7	2	27.8	3	33.8	26	26.0
33	31.9	4	30.7	4	30.1	5	31.8	28	23.0
35	21.5	6	28.7	6	32.7	7	28.4	30	27.5
37	23.9	8	28.0	8	27.8	9	28.2	32	27.5
39	14.0	10	27.9	10	27.4	11	28.0	34	28.0
41	14.0	12	28.2	12	27.6	13	28.2	36	28.0
		14	29.2	14	28.5	15	29.5	38	18.1
								40	17.2

ACKNOWLEDGEMENTS

I am indebted to John Lundberg of the University of Texas who implemented the Wisler algorithm and to the JPL SMMR Evaluation Task Group in general and to Barbara B. Wind and Richard Lipes of JPL, in particular, for validating the SMMR data and providing us with the results of their algorithm and radiosonde range correction calculations. I am also grateful to Samuel L. Smith of Naval Surface Weapons Center for providing the range correction values he obtained using surface weather data.

REFERENCES

(1) "DMA Plan for Exploitation of SEASAT-1 Altimeter Data", Defense Mapping Agency, Building 56, Naval Observatory, Washington, D.C. 20305.

(2) Bean, B.R. and Dutton, E.J., "Radio Meterology", NBS Monograph 92, U.S. Government Printing Office, 1966, also Dover Publications, Inc., New York, 1968.

(3) Thayer, G.D., "An Improved Equation for the Radio Refractive Index of Air", Radio Science, Vol. 9, No. 10, pages 803-807, October 1974.

(4) Hopfield, H.S., "Tropospheric Effect on Electromagnetically Measured Range: Prediction from Surface Weather Data", Radio Science, Vol. 6, No. 3, pages 357-367, March 1971.

(5) Wisler, M.M., and Hollinger, J.P., "Estimation of Marine Environmental Parameters Using Microwave Radiometric Remote Sensing Systems", NRL Memorandum Report No. 3661, November 1977.

(6) Smith, S. L., private communication, May 1980.

APPENDIX A

SMMR WET ALTIMETER RANGE CORRECTION ALGORITHM

M. M. Wisler
Naval Research Laboratory

This algorithm is designed to calculate the wet part of the altimeter range correction "RC" in centimeters using antenna temperature measurements from the SMMR Intermediate Sensor Records.

Inputs

Variables to be used as input for the range correction calculation are taken from the Intermediate Sensor Record. From each Intermediate Sensor Record strip off the Time Tag, the Performance Flags for the 18, 21, and 37V GHz radiometers and the Antenna Temperature Measurements at the 18H, 18V, 21H, 21V, 37H, and 37V GHz frequencies and polarizations. The particular Antenna Temperature Measurements to be used are only those whose corresponding footprints intersect the sub-satellite ground track. There are 112 37 GHz vertical polarization measurements per record or scan cycle, choose only the 7th, 8th, 107th, and 108th from the string. Make four variables equal to these measurements A37V(I), I = 1,4 respectively. Do the same for the 37H measurements forming the variable A37H(I), I = 1,4. For the 21 GHz vertical measurement string, pick only the 4th number out of the 28 record and assign it A21V. For the 21H pick the 26th measurementment and call it A21H. Likewise pick the 4th 18V and the 26th 18H and assign them A18V and A18H respectively. The table below summarizes the variables to be stripped from each Intermediate Sensor Record.

TABLE 1

INPUT PARAMETER SPECIFICATION

Variable Name	Dimension	Number in Sequence or Name	Freq./Pol.
A18V	1	4th Ant. Temp. Meas.	18V
A18H	1	26th Ant. Temp. Meas.	18H
A21V	1	4th Ant. Temp. Meas.	21V
A21H	1	26th Ant. Temp. Meas.	21H
A37V(I)	4	7, 8, 107, 108th Ant. Temp. Meas.	37V
A37H(I)	4	7, 8, 107, 108th Ant. Temp. Meas.	37H
T	1	Time Tag	
P(I)	4	Performance Flags 18, 21, 37V, 37H	

Operation

1. Check the performance flags, P(I), if any are non-zero, do not use this algorithm.

2. Check each of the 37H measurements, if any is above T37HMAX do not use this algorithm. T37HMAX is initially 210.

3. Form a variable A(I), I = 1,6 where

$$A(1) = (A18V * 0.86 - A18H * 0.14)/0.72$$
$$A(2) = (A18H * 0.86 - A18V * 0.14)/0.72$$
$$A(3) + (A21V * 0.86 - A21H * 0.14)/0.72$$
$$A(4) = (A21H * 0.86 - A21V * 0.14/0.72$$

$$A(5) = \left[\sum_{I=1}^{4} (A37V * 0.86 - A37H * 0.14/0.72 \right] /4$$

$$A(6) = \left[\sum_{I=1}^{4} (A37H * 0.86 - A37V * 0.14/0.72 \right] /4$$

4. Calculate range correction by the formula:

$$RC = RCZERO + \sum_{I=1}^{6} ALPHA(I)*[A(I)-AZERO(I)]$$

$$0 \leq RC \leq 50$$

where

RC is the wet part of the altimeter range correction in centimeters,

RCZERO is a constant, initially 11.72,

ALPHA(I), I = 1,6 are estimator coefficients initially defined in Table 2 below,

AZERO(I), I = 1,6 are constants initially defined in Table 2 below, and

A(I), I = 1,6 are defined in 3 above.

TABLE 2

INITIAL COEFFICIENT VALUES FOR THE RANGE CORRECTION ALGORITHM

I	1	2	3	4	5	6
AZERO(I)	188.58	112.00	205.38	141.19	218.02	149.91
ALPHA(I)	-0.02021	-0.1905	0.1937	0.3064	-0.01647	-0.06694
RCZERO	11.72					
T37MAX	210.0					

Timing

The SMMR looks about 757 km behind the altimeter measurement. Subtract 116.19 seconds from the SMMR Intermediate Sensor Record Time Tag to make it correspond to the altimeter time.

Comments

1. Item 1 is designed to examine the instrument health parameters provided by the ISR so that erroneous antenna temperatures will not cause errors in the range correction algorithm.

2. Sun glint, land, and large rain cells can cause erroneous calculations. Item 2 in the operation section is designed to check for these conditions, however, when other checks become available, they should be used to augment item 2.

3. All constants should be user controllable and will be changed as analyses indicate after launch.

4. The calculations in item 3 above correct for the change in polarization due to the scanning system.

5. If the Intermediate Geophysical Data Record becomes available, the same algorithms may be used by assigning A(I), I = 1,6 to T_B18V, T_B18H, T_B21V, T_B21H, T_B37V, and T_B37H, respectively, then proceeding with item 4 above. Slight changes in the coefficients may be necessary.

6. The Range Correction should be restricted to positive values below 50 cm.

APPENDIX B

SMMR WET TROPOSPHERE ALTIMETER RANGE CORRECTION ALGORITHM

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM

315.6-598

November 6, 1979

TO: J. W. Brown

FROM: B. B. Wind bbw

SUBJECT: SMMR Wet Troposphere Altimeter Range Correction Algorithm

I have enclosed the algorithm specification sheet for the SMMR Wet Troposphere Altimeter Range Correction Algorithm.

Note that the SMMR antenna temperatures used for this paper may be in error; in particular the normalization factor applied to the Wisler algorithm may be revised when new antenna temperatures are available.

BBW:pro

cc: Altimeter Experiment Team
J. Alishouse
J. Hollinger
D. Lame
J. Lundberg
C. Yamarone

ALGORITHM TITLE:	SMMR Wet Troposphere Altimeter Range Correction Algorithm
ALGORITHM FUNCTION:	To calculate the altimeter range correction due to the wet tropospheric effect using antenna temperature measurements from the SMMR Supplemental Sensor Record
INPUTS:	1) Antenna temperatures from the 18, 21, and 37 GHz frequencies 2) Decoupling coefficients to decouple the antenna temperature vertical and horiztonal polarizations. 3) Latitude, longitude and time tags corresponding to the temperatures used in 1).
OUTPUTS:	Altimeter range correction in centimeters.
ALGORITHM PROCEDURE:	The algorithm decouples horizontal and vertical antenna temperature (T_A) polarizations. These decoupled temperatures, referred to here as brightness temperatures (T_B), are used to calculate the range correction. 1) To choose the T_A values corresponding to nadir, Appendices (I) and (II) are used to calculate the locations relative to the measurement indices of nadir for each frequency. 2) To calculate the antenna temperature along NADIR, the measurements bracketing each index in Appendix III were interpolated to that index. 3) The antenna temperatures were then converted to brightness temperatures by use of the constants in Appendix V. 4) The range correction was then calculated by using equation 3, Appendix VI.

Surface Truth Calculations of the Altimeter Range Correction

The water vapor and range correction surface truths were calculated by using radiosonde data. The water vapor measurement (mass/unit area) is given by the equation

$$WV = \int_L \rho \, ds \qquad (1)$$

where

WV is the water vapor measurement

ρ is the water vapor density

L is the atmospheric height

Reference 4 gives the wet tropospheric portion of the altimeter range correction as

$$RC = \Omega \int_L \rho \, ds + \eta \int_L \frac{\rho}{T} \, ds \qquad (2)$$

where

RC is the range correction

ρ is the water vapor density

Ω is a constant = .331 $\mathrm{cm}^3/\mathrm{gm}$

η is a constant = 1.731×10^3 cm.°k/gm

T is the temperature.

The integrals of equations (1) and (2) were evaluated by application of the trapezoidal rule to the radiosonde measurements.

A) South Pacific Measurements

Radiosonde data was available for some of the overflight passes of the Kwajalein and Majuro area. The integrals of equations (1) and (2) were evaluated and the results are shown in the following table. Since the water vapor density is contained in the three integrals of equations (1) and (2), the ratio of the range correction to the water vapor was also calculated.

Rev. #	Station	WV(gm/cm^2)	RC(cm)	RC/WV $\frac{cm^3}{gm}$
1215	Majuro	4.97	31.50	6.338
	Kwajalein	6.53	41.57	6.366
1301	Majuro	5.28	33.36	6.318
	Kwajalein	5.55	35.11	6.326
				6.337 avg.

Since radiosonde data were not available for revs 1128, 1172, and 1258, the range corrections were approximated by multiplying the water vapor measurements from Reference 5 by 6.34 cm^3/gm. The results were

Rev. #	Station	WV(gm/cm^2)	RC(cm)
1129	Kwajalein	5.6	35.5
1172	Kwajalein	5.1	32.3
1258	Kwajalein	6.3	39.9

B) Bermuda Measurements

The range correction calculations for the Bermuda overflights were taken from the graph on page 5-47 of Reference 6. The numbers used are given in the following table:

Rev. #	RC(cm)
1160	19.
1247	26.
1375	33.

Wisler Calculations

Comparing the initial results of the Wisler algorithm to the radiosonde data, it was observed that the range corrections from the Wisler algorithm tended to be less than range corrections derived from the radiosonde data. By comparing the radiosonde measurement to the closest Wisler calculation, it was found that a correction of about eighteen percent needed to be applied to the Wisler algorithm. In the final application, the results of the Wisler algorithm were multiplied by 1.179.

Results

The results of the Wisler algorithm were compared to near-overflight radiosonde measurements for eight revs. The plots of these comparisons are shown in figures one through eight. The results are summarized below:

Rev #	Station	Radiosonde RC(cm)	Wisler RC(cm)
1129	Kwajalein	35.5	36.7
1160	Bermuda	19.	19.2
1172	Kwajalein	32.3	34.5
1215	Kwajalein	41.57	38.0
1246	Bermuda	26.	26.2
1258	Kwajalein	39.9	37.5
1301	Kwajalein	35.11	37.4
1375	Bermuda	33.	33.0

APPENDIX:

I) The formula that relates time near-nadir scan reversal to angular position with respect to the center line of the scan is:

$$\phi(\text{degrees}) = 25^\circ \cos(2\pi t_i / 4.096 \text{ sec}) \qquad (1)$$

t_i is in seconds

II) The formulas that relate the index of a temperature measurement to time since near-nadir scan reversal are:

(t_i in msec)

18H: $245 + 64\,(i-1) = t_i \quad i = 1, 28$
18V: $2293 + 64\,(i-1) = t_i \quad i = 1, 28$
21H: $213 + 64\,(i-1) = t_i \quad i = 1, 28$
21V: $2261 + 64\,(i-1) = t_i \quad i = 1, 28$ (2)
37H: $213 + 32\,(i-1) = t_i \quad i = 1, 56$
$2261 + 32\,(i-57) = t_i \quad i = 57, 112$
37V: $221 + 32\,(i-1) = t_i \quad i = 1, 56$
$2269 + 32\,(i-57) = t_i \quad i = 57, 112$

III)

Given that $\phi = 22^\circ$ for NADIR, eqn. (1) gives $t_i = .3226$ sec and $t_i = 3.7734$ sec. Using these two times and solving eqn. (2) for the corresponding locations relative to the indices gives:

	$t_i = .3226$	$t_i = 3.7734$
18H	2.2125	
18V		24.116
21H	2.7125	
21V		24.616
37H	4.425	104.263
37V	4.175	104.013

IV) The formula that relates the location number of the footprint latitude and longitude to time since near-nadir scan reversal is:

$$63 + i \cdot 128 = t_i \text{ (msec)}$$

Note: for $t_i = .3226$ sec, $i = 2.028$
for $t_i = 3.7734$ sec, $i = 28.9875$

Footprints 2 and 29 were averaged to give the latitude and longitude. A time of approximately 116.19 seconds was subtracted from the time tag read from the Supplemental Sensor Record to account for the SMMR looking behind the altimeter.

V)

	A	B	C
18V	.82279642	-.17720358	1.562387
18H	-.1827501	.8172499	1.562387
21V	.79664937	-.20335063	1.607715
21H	-.1746485	.8253515	1.607715
37V	.82534043	-.17465957	1.495248
37H	-.1565521	.84344479	1.495248

Brightness temperatures:

B18V = (A18V·A(1) + A18H·B(1))·C(1)
B18H = (A18V·A(2) + A18H·B(2))·C(2)
B21V = (A21V·A(3) + A21H·B(3))·C(3)
B21H = (A21V·A(4) + A21H·B(4))·C(4)
B37V = (A37V·A(5) + A37H·B(5))·C(5)
B37H = (A37V·A(6) + A37H·B(6))·C(6)

where B18V denotes the brightness temperature and
A18V denotes the antenna temperature

VI) Reference 1 gives a relationship between brightness temperatures and the range correction. It is repeated here for convenience.

$$RC = RCZERO + \sum_{I=1}^{6} ALPHA(I)*[A(I) - AZERO(I)]$$

where:

RC is the range correction in centimeters.

A(I), I = 1, 6 are the brightness temperatures
B18V, B18H, B21V, B21H, B37V, B37H that are calculated in V).

RCZERO, ALPHA, AZERO are constants defined below

AZERO(I):	188.58	112.00	205.38	141.19	218.02	149.91
ALPHA(I):	-.02021	-.1905	.1937	.3064	-.01647	-.06694
RCZERO:	11.72					

References:

1) SMMR Wet Altimeter Range Correction Algorithm, M. M. Wisler, Naval Research Laboratory (attached), June 1978.

2) Estimation of Marine Environmental Parameters Using Microwave Radiometric Remote Sensing Systems, Macmillan M. Wisler and James P. Hollinger, Naval Research Laboratory, NRL Memorandum Report 3661, Nov. 1977.

3) Seasat Interim Geophysical Data Record (IGDR) User's Handbook, JPL Document 622-205, Jet Propulsion Laboratory, July 1979.

4) Altimeter Data Correction, Richard Lipes.JPL IOM 331-78-166A, Jet Propulsion Laboratory, Dec. 1978.

5) Seasat Scanning Multichannel Microwave Radiometer Mini-Workshop Report, JPL Document 622-208, Jet Propulsion Laboratory, June 1979.

6) Seasat Gulf of Alaska Workshop Report, JPL Document 622-101, Jet Propulsion Laboratory, April 1979.

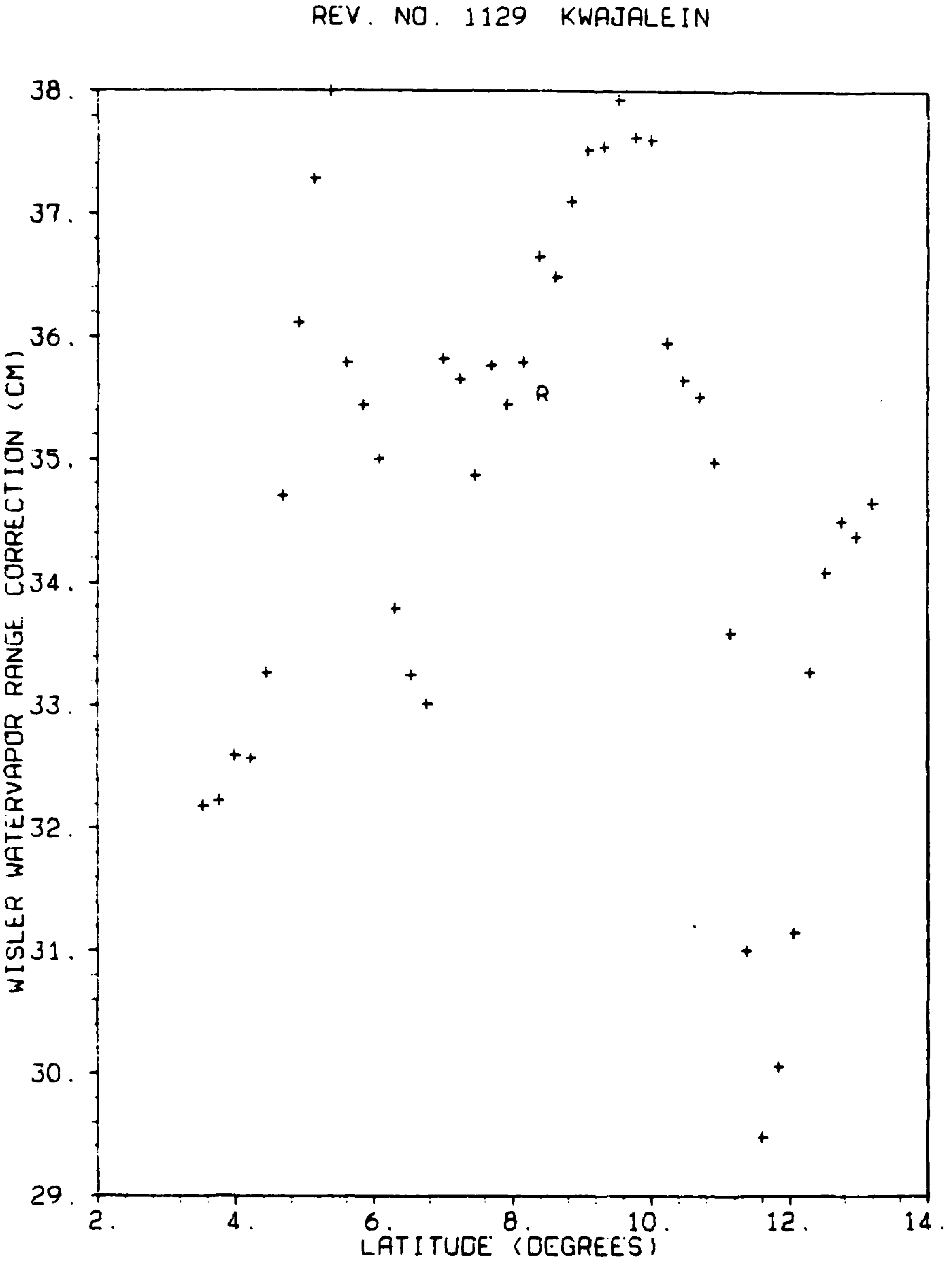
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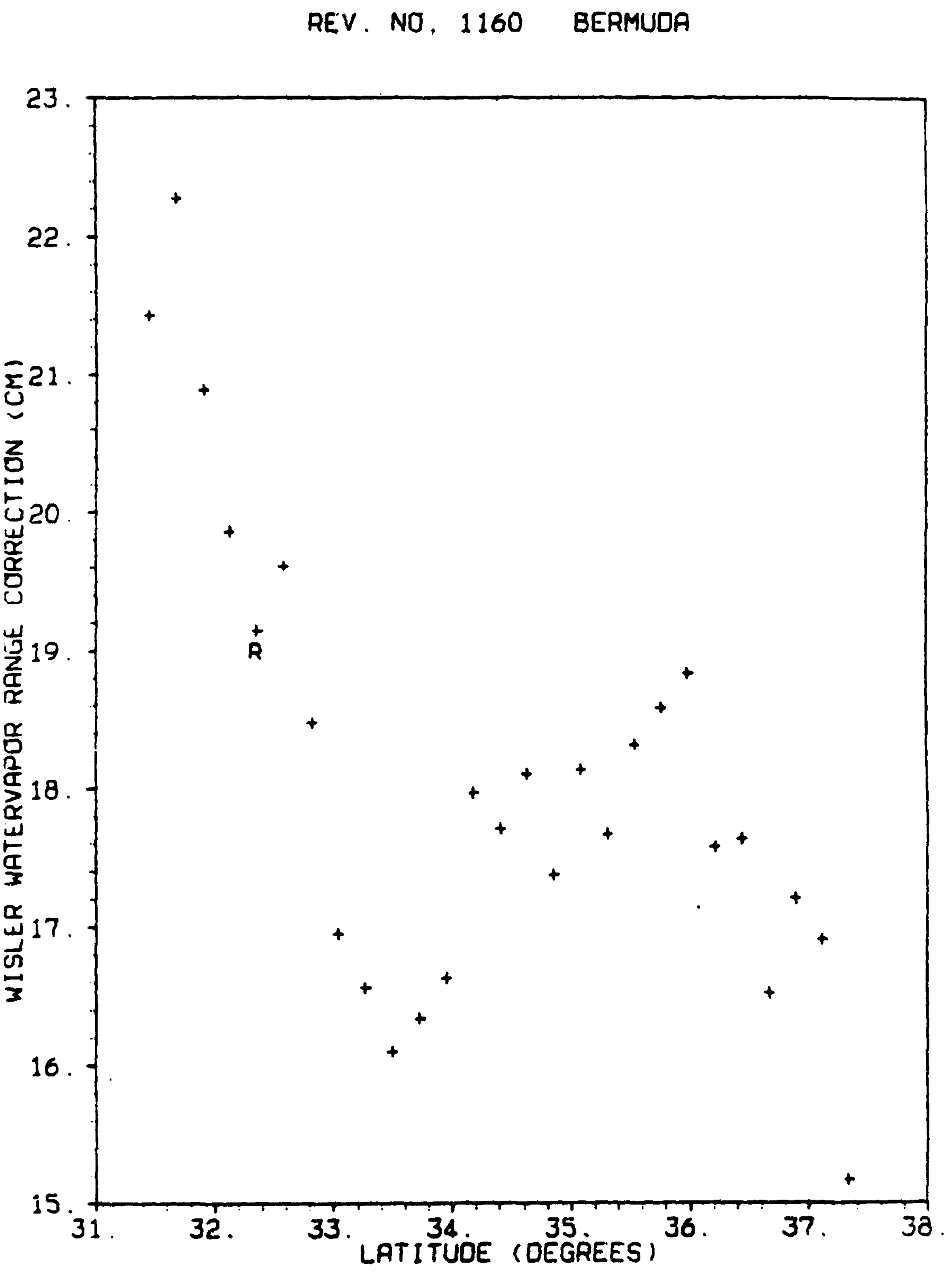
Figure 1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15.
31.
32.
33.
34.
35.
36.
37.
38.
R

Figure 2

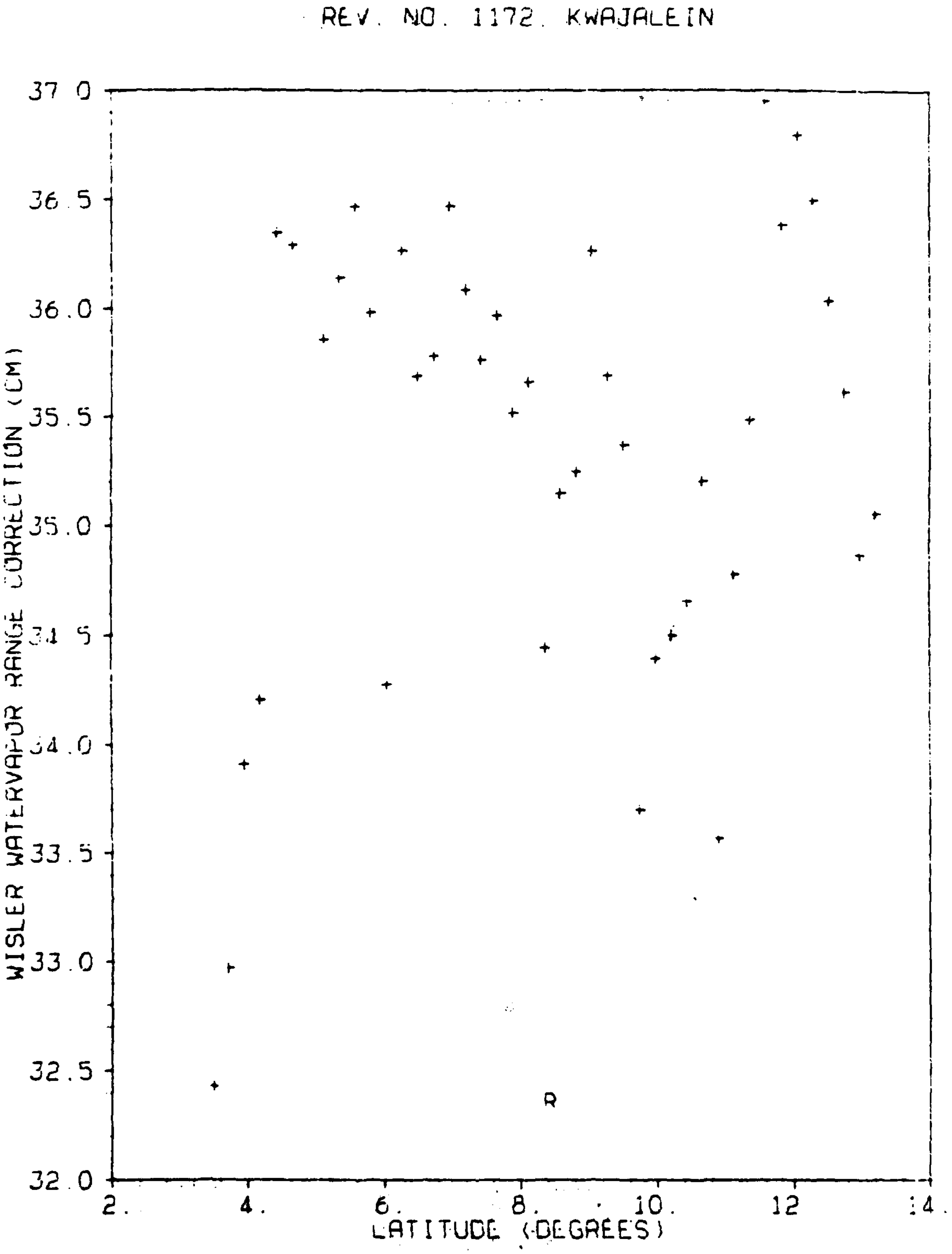
REV. NO. 1172. KWAJALEIN
WISLER WATERVAPOR RANGE CORRECTION (CM)
37.0
36.5
36.0
35.5
35.0
34.5
34.0
33.5
33.0
32.5
32.0
2.
4.
6.
8.
10.
12
14.
LATITUDE (DEGREES)
R

Figure 3

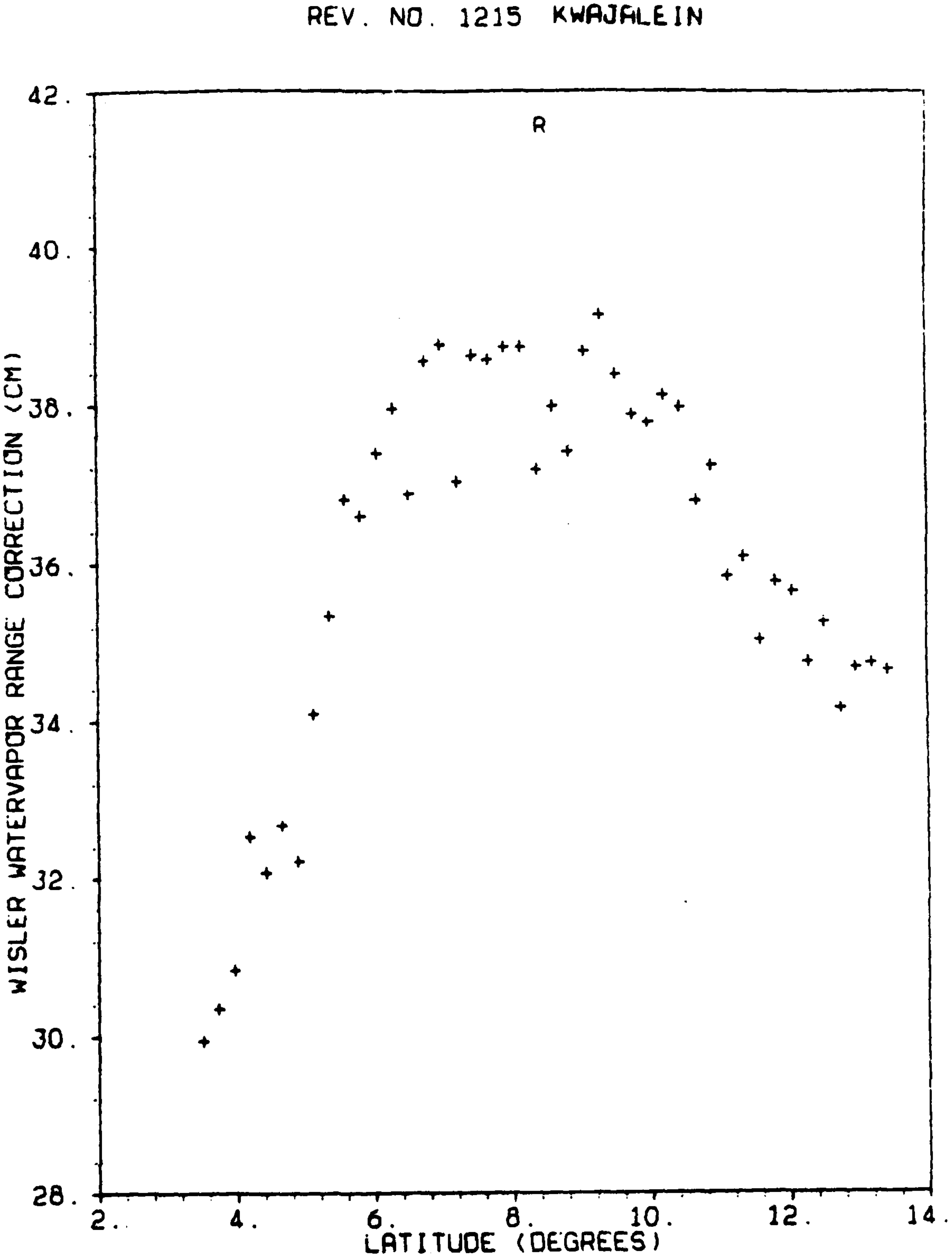
REV. NO. 1215 KWAJALEIN
R
WISLER WATERVAPOR RANGE CORRECTION (CM)
42.
40.
38.
36.
34.
32.
30.
28.
2.
4.
6.
8.
10.
12.
14.
LATITUDE (DEGREES)

Figure 4

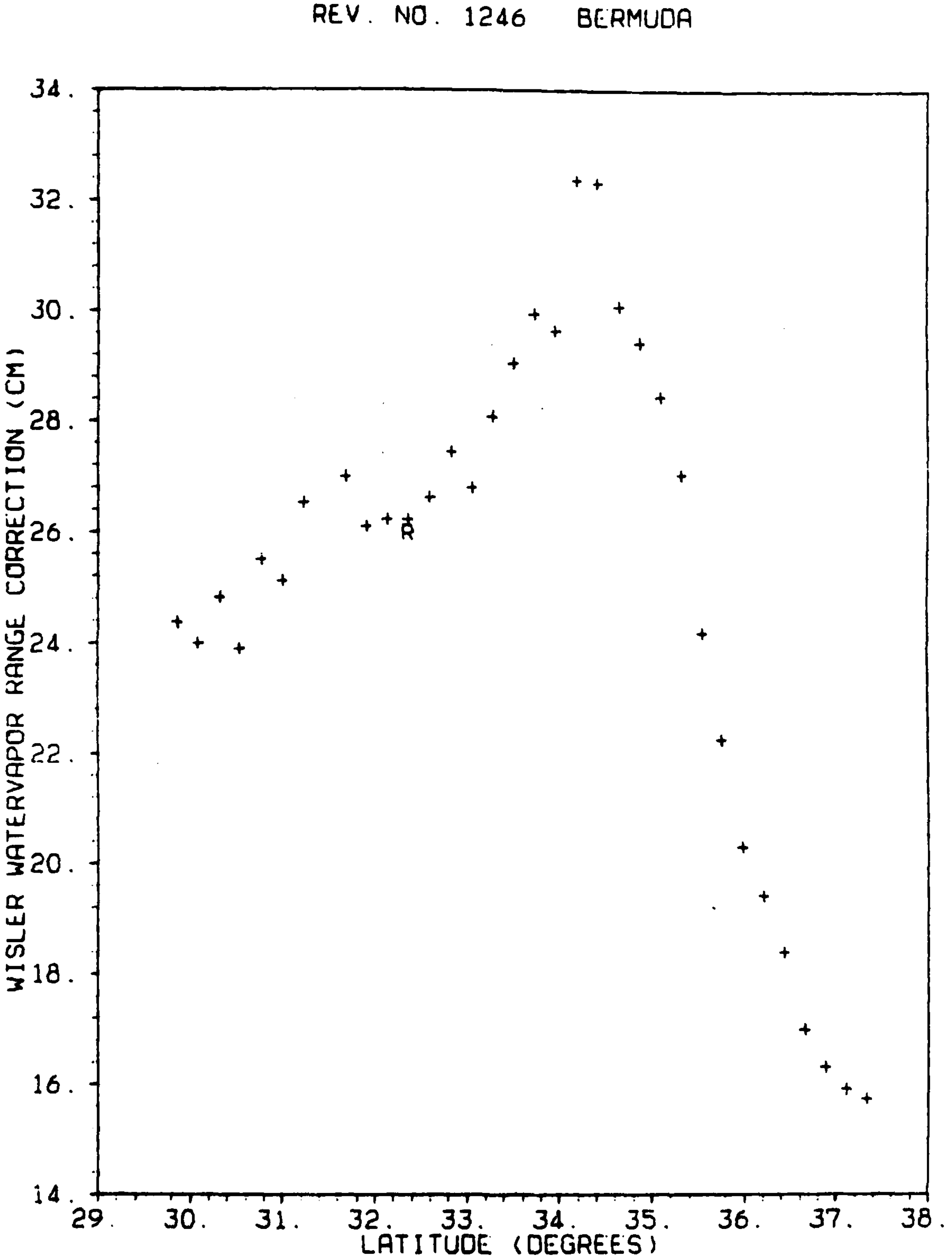
REV. NO. 1246 BERMUDA
WISLER WATERVAPOR RANGE CORRECTION (CM)
34.
32.
30.
28.
26.
24.
22.
20.
18.
16.
14.
29.
30.
31.
32.
33.
34.
35.
36.
37.
38.
LATITUDE (DEGREES)
R

Figure 5

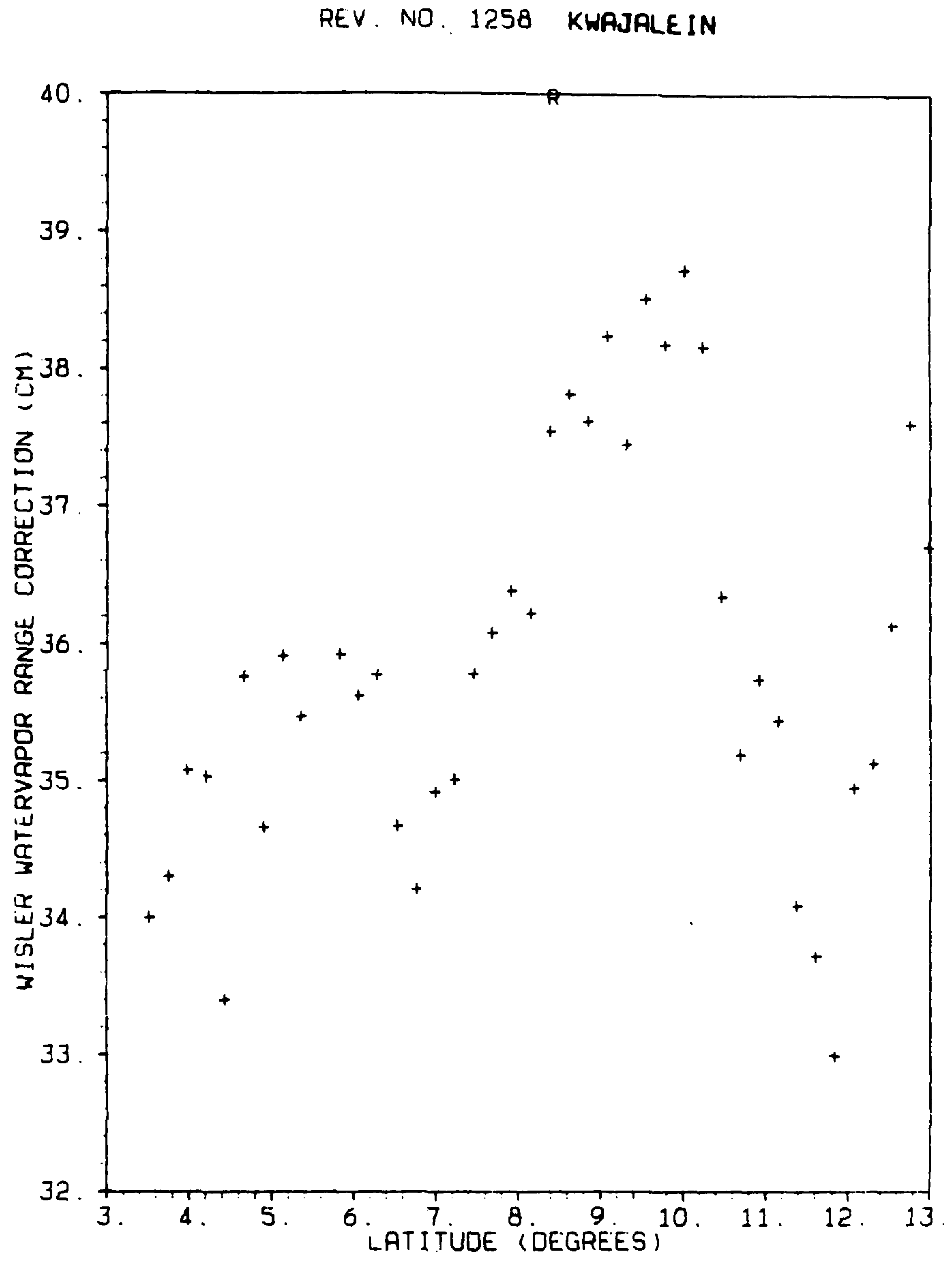
REV. NO. 1258 KWAJALEIN
R
40.
39.
38.
37.
36.
35.
34.
33.
32.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
WISLER WATERVAPOR RANGE CORRECTION (CM)
LATITUDE (DEGREES)

Figure 6

REV. NO. 1301 KWAJALEIN

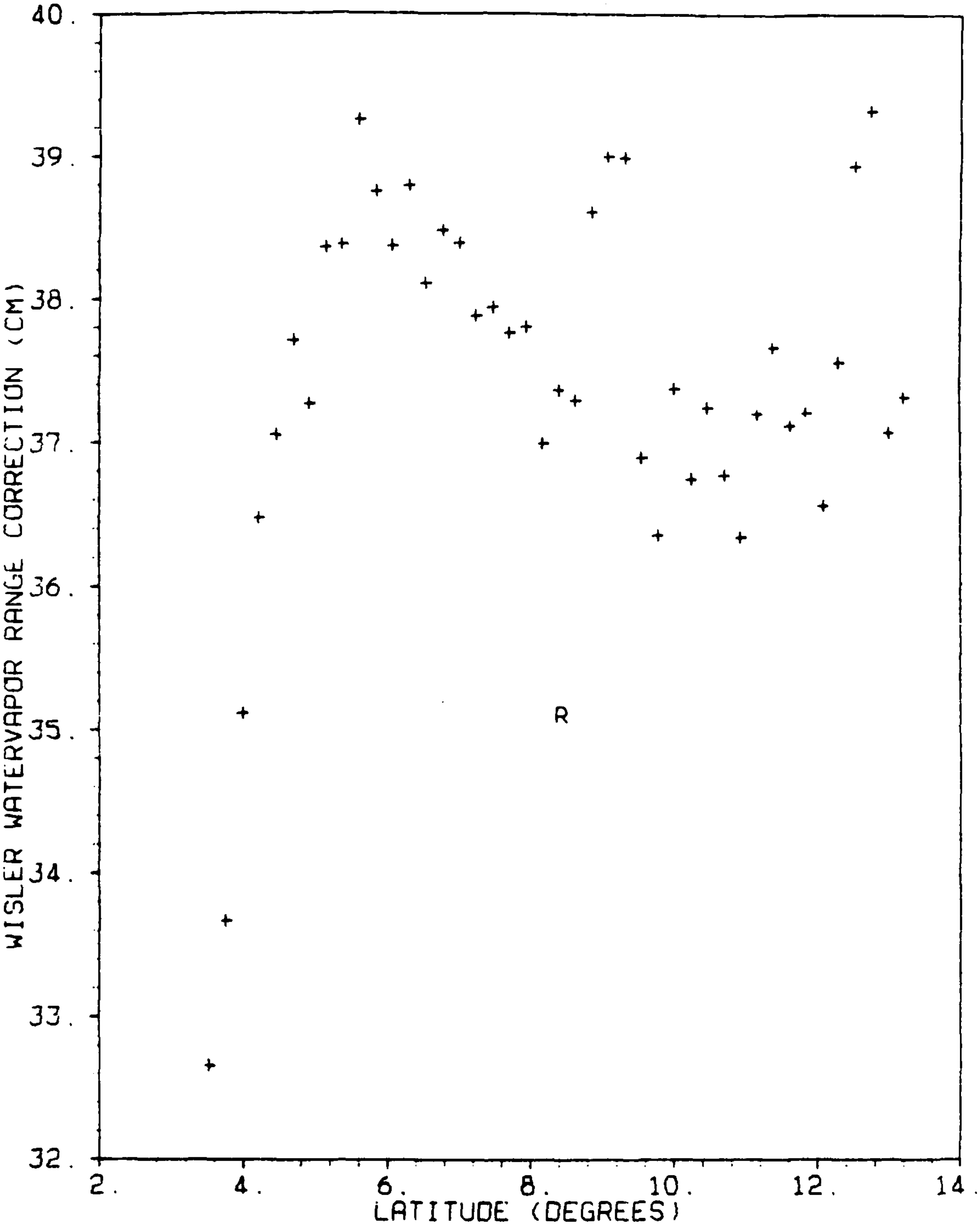

Figure 7

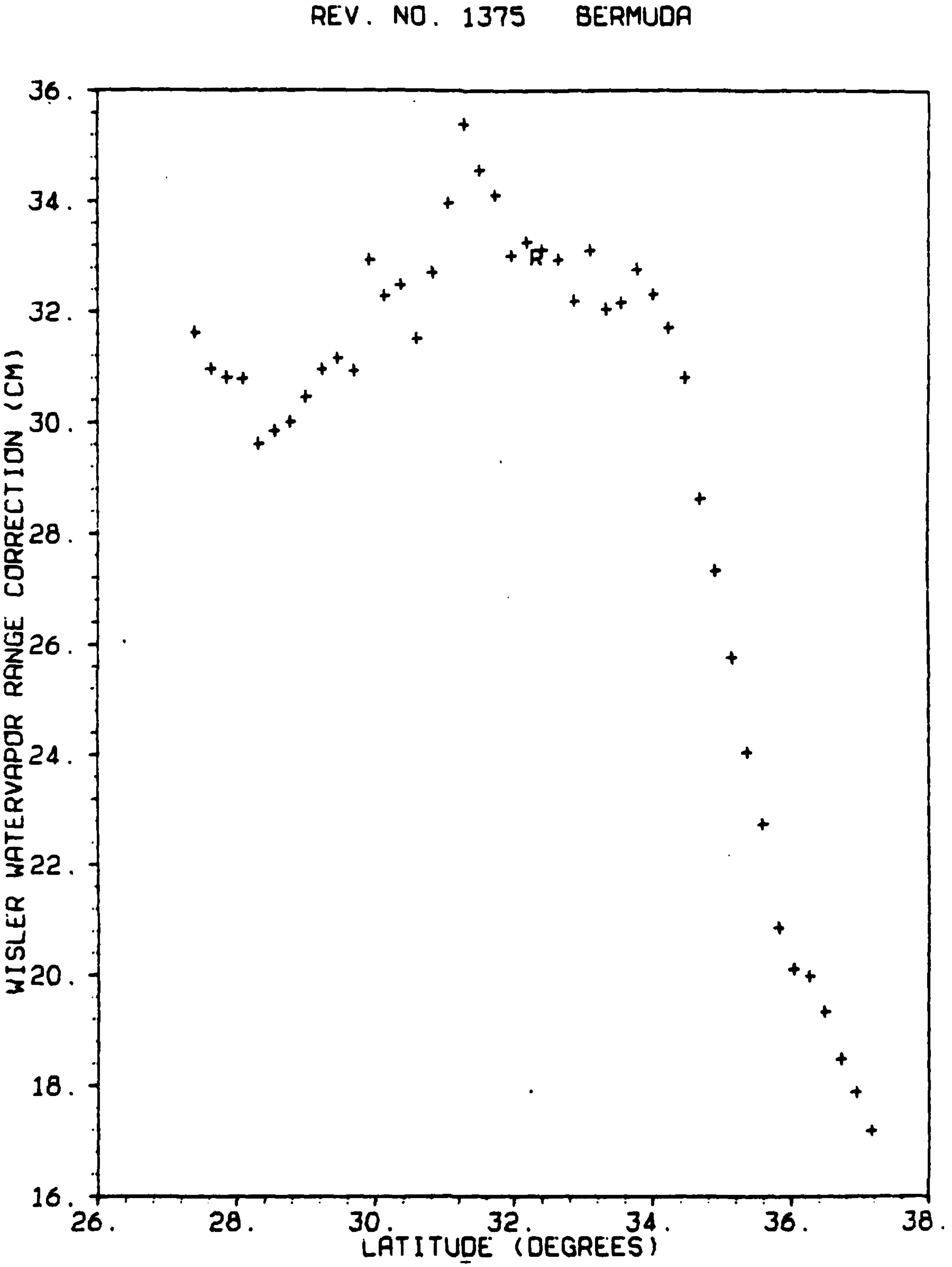
REV. NO. 1375 BERMUDA
WISLER WATERVAPOR RANGE CORRECTION (CM)
16.
18.
20.
22.
24.
26.
28.
30.
32.
34.
36.
26.
28.
30.
32.
34.
36.
38.
LATITUDE (DEGREES)
R

Figure 8