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The Correction of Data from a Wrongly Calibrated Shipborne Wave Recorder

by

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ABSTRACT

A linear model of the operation of the Shipborne Wave Recorder is used to develop a method of correcting the measured wave height for a miscalibration of the pressure sensors. A sample of some 500 recordings of separate heave and pressure signals from O.W.S. Cumulus is used to develop and then test the method. Use of the technique will allow the recovery of several years of data from Ocean Station Lima.

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INTRODUCTION

The Shipborne Wave Recorder (SBWR) (TUCKER, 1956) enables measurements of wave conditions to be made from a stationary free-floating ship. The instrument comprises two sensor packages each consisting of a accelerometer and a pressure sensor which are positioned on each side of the ship near the plane containing the pitch axis.

The acceleration signals from each side are added together and then integrated twice with respect to time to give an analogue of the heave at the section containing the sensors. This composite heave signal is added to the sum of the pressure signals to form a single output which is an analogue of the instantaneous wave height at the position of the ship.

This technique provides compensation for the roll motion as it affects the accelerometers and for roll-induced pressure fluctuations. It also provides an approximate first-order compensation for the reflection of short waves by the ship.

OPERATIONAL BACKGROUND

SBWR measurements have been made onboard OWS Cumulus since May 1981 and a microprocessor system was installed in December 1983. During this time Cumulus was based in Rotterdam and on each occasion that the instrument was calibrated an IOS engineer was required to travel to Holland. The calibrator for the instrument (which contains the pressure reference) is heavy and bulky, and it proved inconvenient and costly to transport it repeatedly to Holland. The inconvenience was compounded by the customs formalities involved in the repeated import/export of the equipment into and out of Holland. The solution adopted was to leave the calibrator permanently aboard Cumulus.

The Cumulus moved her home port to Greenock in December 1985, and at that time an unexplained discrepancy was found in a Druck pressure sensor when checked using the SBWR calibrator. In September 1987 it was realised while checking a new instrument which had previously been calibrated in the laboratory that the calibrator pressure reference must be at fault. Subsequent tests showed that the calibrator reference was reading 19% too high.

THE EFFECT OF MISCALIBRATION OF THE PRESSURE SENSORS

We adopt a very simple linear model of the SBWR in which one accelerometer and one pressure sensor are attached to a spar buoy; see CRISP, 1987 and Fig. 1.

Suppose the sea surface elevation above the mean level is given by $\eta(t)$ and the heave of the buoy is h(t), then the pressure measured by the pressure sensor (in metres of sea water) is given by

$$p(t) = d - h(t) + \eta(t) * r_H(\tau) \qquad (1)$$

where d is the mean depth of immersion of the pressure sensor and r_H is the impulse response function of the pressure attenuation with depth. $*$ indicates convolution.

Considering only fluctuating quantities, i.e., neglecting the constant d, we may write the sum signal as

$$s(t) = p(t) + h(t) = \eta(t) * r_H(\tau) \qquad (2)$$

Taking Fourier transforms

$$S(f) = W(f).\ R_H(f)$$

where W is the Fourier transform of η, and forming the spectra we get

$$S_W(f) = S_S(f)/|R_H(f)|^2 \qquad (3)$$

This equation is used to correct the SBWR spectra.

Now, returning to Eqn. (1), and once more neglecting d, we may write

$$p(t) = -\eta(t) * r_b(\tau) + \eta(t) * r_H(\tau)$$

i.e., $$p(t) = \eta(t) * \{r_H(\tau) - r_b(\tau)\} \qquad (4)$$

where $r_b(\tau)$ is the impulse response function of the ship in heave.

So, the sum signal for the incorrectly calibrated SBWR can be written

$s_2(t) = h(t) + (1 + \alpha)p(t)$, and using (2) and (4)

$= \eta(t)*\{(1 + \alpha)\ r_H - \alpha r_b\}$.

Taking Fourier transforms

$$S_2(f) = W(f)\{(1 + \alpha)R_H - \alpha R_b\}$$

and forming the spectra

$$S_w(f) = \frac{S_{s2}(f)}{|(1 + \alpha)R_H - \alpha R_b|^2} \qquad (5)$$

Thus the hydrodynamic frequency response R_H is replaced by a modified expression which involves a linear combination of R_H and the heave response of the ship R_B. Let us call this modified response T, so that

$$T = (1 + \alpha)R_H - \alpha R_B$$

We should note that R_B and thus T are, in general, complex.

Also

$$|T|^2 = |(1 + \alpha)\ R_H - \alpha R_B|^2$$

Given separate recordings of h and p we may in principle estimate R_B and thence T. However, $|T|^2$ can be estimated more directly as follows.

We require separate recordings of h and p (with known calibration) from the ship in question. We then form the correctly calibrated sum h + p, call it s, and the incorrectly calibrated sum h + (1 + α)p, call it s_2. α is 0.19 in the case of <u>Cumulus</u>. We estimate the spectra of s and s_2, S_s and S_{s2}.

Then, $$S_w = \frac{S_s}{|R_H|^2} \qquad \text{from (3)}$$

and $$S_w = \frac{S_{s2}}{|T|^2} \qquad \text{from (5)}$$

so that $|T|^2 = \frac{S_{s2}}{S_s} \cdot |R_H|^2$ (6)

EXPERIMENTAL METHOD

A Microdata digital data logger was installed on Cumulus in October 1987 in order to record the pressure and heave data separately. 2048 simultaneous measurements of the heave and pressure signals were made at 0.5 second intervals and recorded on magnetic tape. Each 1024 second observation was identified by date and time, and one observation was recorded every hour and a half.

The magnetic tape cartridges were recovered at the end of each "voyage" (at about 3-weekly intervals) and sent to the Proudman Oceanographic Laboratory (P.O.L.), Bidston. Here they were transcribed to computer compatible magnetic tape and ultimately to disk. The Microdata logger was removed in July 1988.

DATA PROCESSING

The data processing took place on the NERC IBM's at P.O.L. and the Institute of Hydrology (Wallingford).

In former times, before the use of microcomputers for the checking and processing of digital wave data the work was done on a Honeywell mainframe at Bidston. Because of this programs were available to accomplish many of the tasks required, although a certain amount of rewriting was needed because of the change of computers and the requirements of this particular problem.

Programs were assembled to do the following:

1. Perform a quality control procedure comprising a number of range and rate of change checks on the data. The main data errors were due to electrical interference when the ship's radio was transmitting. This caused gross distortion of the heave signal and rather less obvious distortion of the pressure signal.

A program was written to plot the time histories so that the performance of the checking system could be monitored. Because of the severe nature of the errors, the checking program proved to be completely reliable.

2. Form the sums s and s_2 referred to above with variable α, and form the spectra S_s and S_{s2}.

3. Estimate the value of S_{s2}/S_s at each frequency. The method described in PITT, 1988a was used and a program existed to do this.

4. Calculate $|R_H|^2$ and multiply by S_{s2}/S_s to form $|T|^2$. R_H was taken as the empirical formula described in PITT, 1988b.

5. Fit a curve to $|T|^2$ using the same method as described in PITT, 1988b. This resulted in a modified set of fitting constants A_0, A_1, A_2, A_3.

6. The original response curve and the modified curve were plotted.

RESULTS

Data from November and December 1987 and January, February and March 1988 were used. There were many gaps and many data were lost because of interference. However, more than enough data were available and 500 spectra covering a wide range of conditions were used for the comparisons.

Fig. 2 shows a plot of the response measurements made by VAN AKEN & BOUWS, 1974 as recomputed by CRISP, 1987. The smooth line is the empirical fit to these data given by

$$R_H^2 = 1 - A_0\{1 - \exp[-A_1\xi_4 - A_2\xi_4^2 - A_3\xi_4^3]\} \qquad (7)$$

where ξ_4 is a scaled frequency variable given by $\xi_4 = \sqrt{\frac{2\pi\sqrt{Ld}}{g}}\,.f$

where f is the frequency in H_z

L is the ship's length

d is the mean pressure sensor depth

g is the acceleration due to gravity.

For the Cumulus measurements the constants have the value:

$$\begin{aligned} A_0 &= 0.7734 \\ A_1 &= 1.0832 \\ A_2 &= -19.05 \\ A_3 &= 64.05 \end{aligned} \tag{8}$$

In Fig 3 are plotted $|T|^2$ (for $\alpha = 0.19$) evaluated at the 64 frequencies available from the spectral analysis. $R_H{}^2$ was evaluated using Eqn. (7) with the values of the constants given in (8).

The smooth curve is the least squares fit to these data and is described by (7) with the values of constants given below:

$$\begin{aligned} A_0' &= 0.6944 \\ A_1' &= 1.5863 \\ A_2' &= -22.77 \\ A_3' &= 73.56 \end{aligned} \tag{9}$$

These constants (9) are the appropriate set to be used to correct the data from Cumulus over the period during which the pressure sensors were incorrectly calibrated.

Figs 4 and 5 show respectively H_s and T_z evaluated from the spectra S_{s2} plotted against H_s and T_z evaluated from S_s, the spectra being corrected using (8) in each case. The effect on H_s is remarkably small; while T_z is reduced by 5%.

Figs 6 and 7 show the same comparisons, but in this case the spectra S_{s2} are corrected using the modified constants (9). An almost exact correction has been achieved.

CONCLUSIONS

A spectral correction method has been developed which allows the recovery of several years of SBWR data measured by O.W.S. Cumulus at the Lima Station.

The method used was to record about five hundred sample records of separate heave and pressure data and from these infer a modified response function.

It was found that a 19% error in the calibration of the pressure sensors resulted in only small errors in H_S while T_Z was underestimated by 5%.

These relatively small errors are probably due to the small contribution to the wave height signal made by the pressure sensors at this mid-Ocean site.

The use of the modified response resulted in a satisfactory correction of the data.

ACKNOWLEDGEMENT

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Simple model of SBWR

Fig. 1

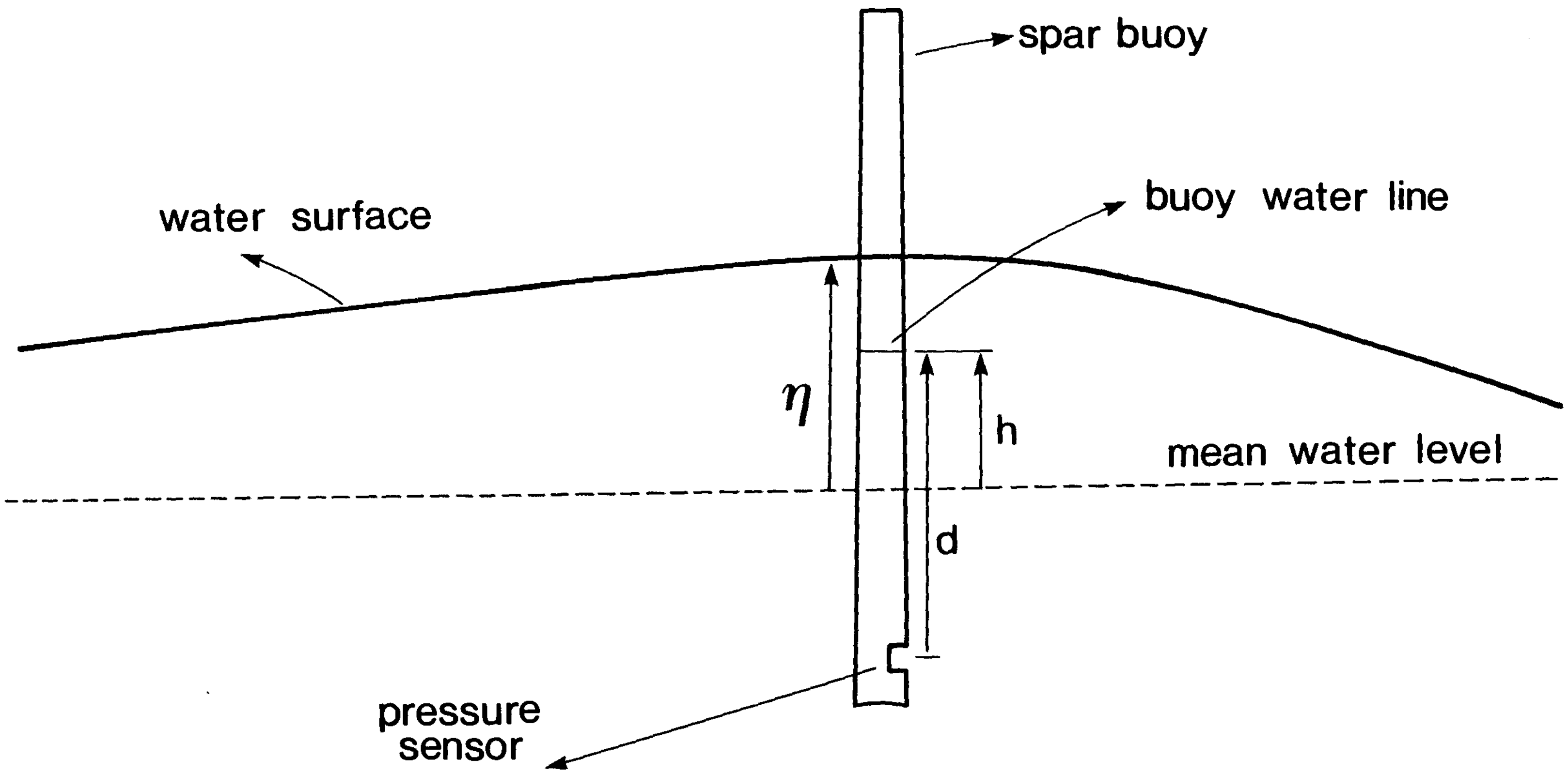


Fig. 2

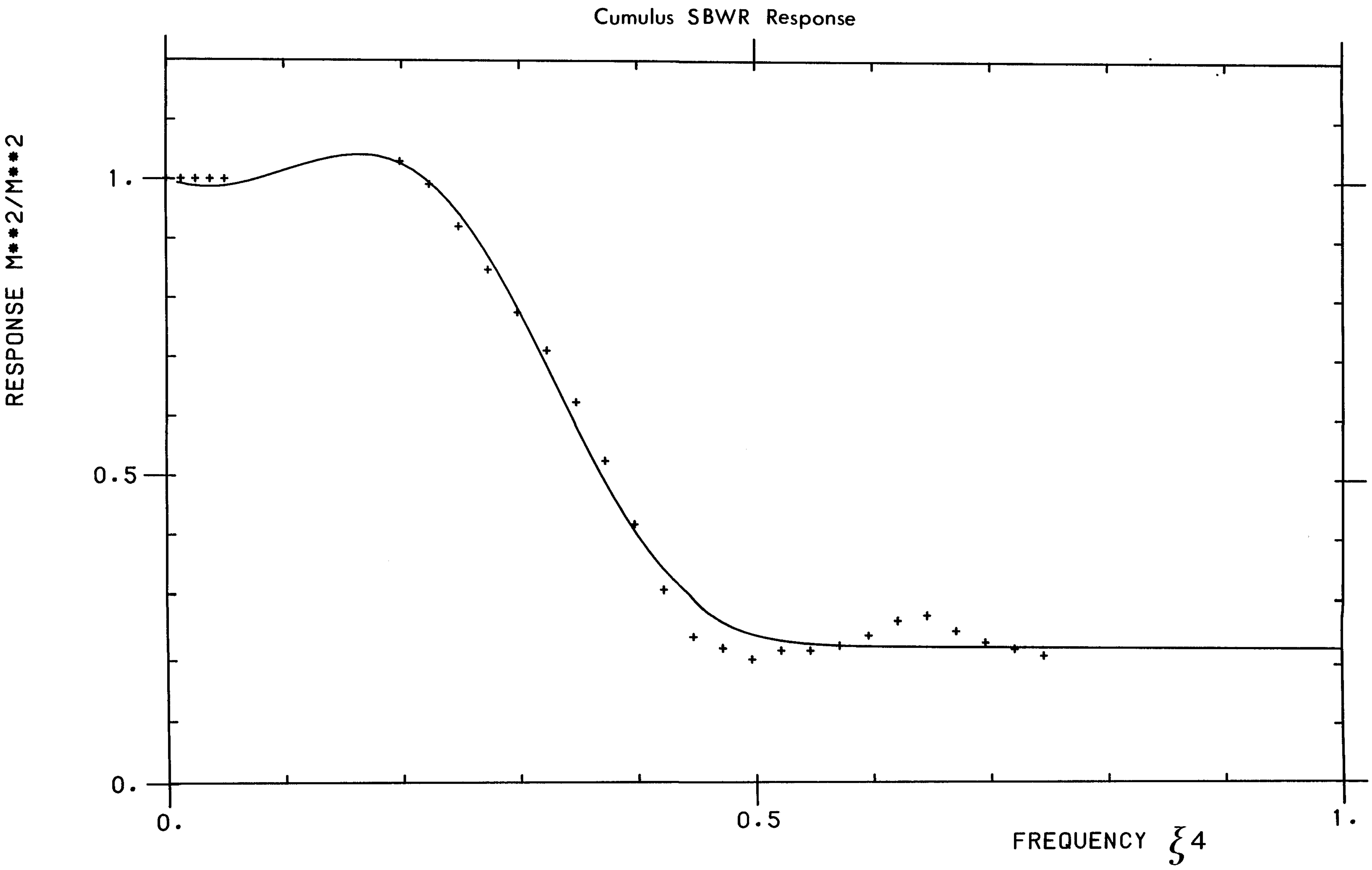
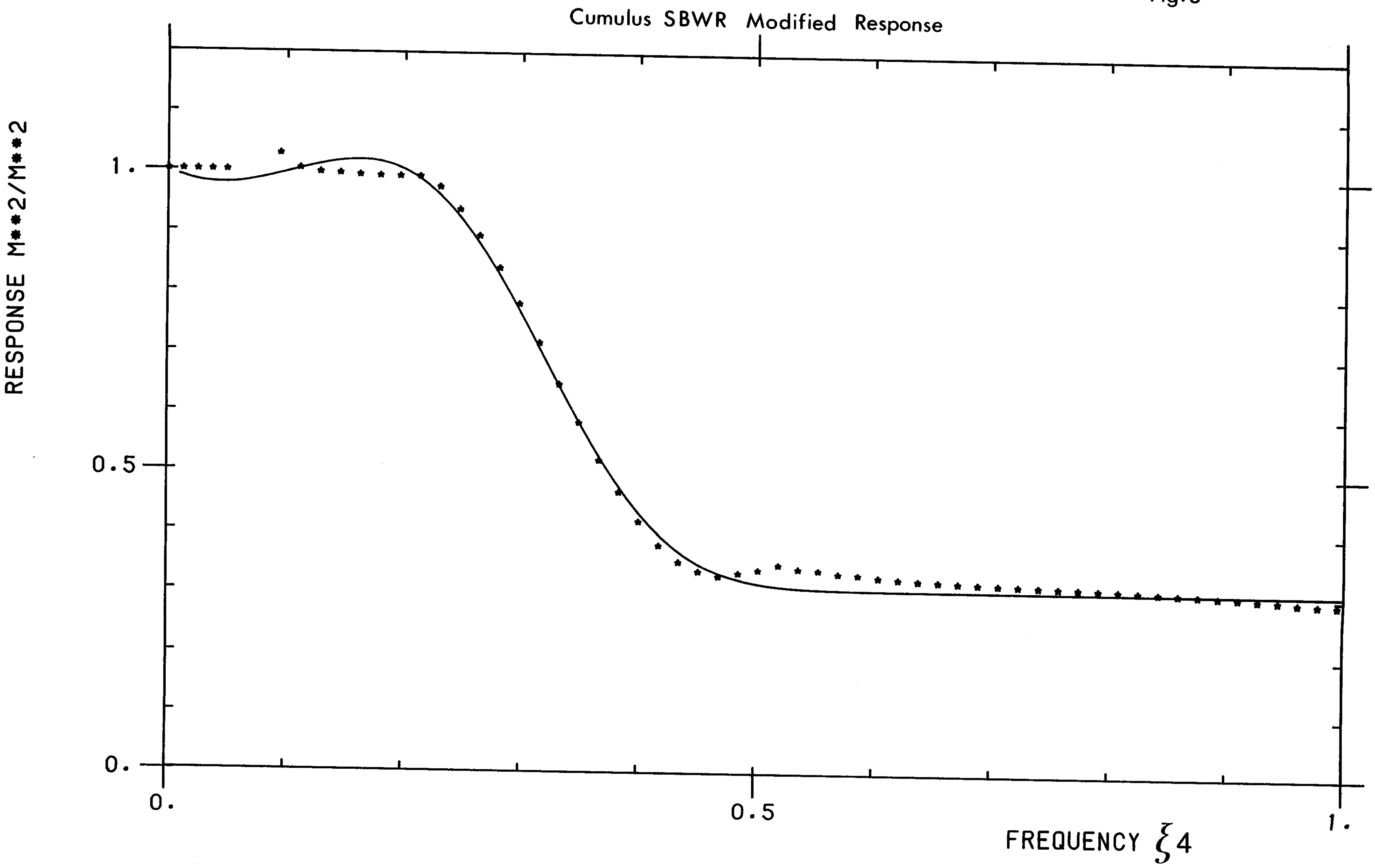

Cumulus SBWR Response
RESPONSE M**2/M**2
1.
0.5
0.
0.
0.5
1.
FREQUENCY ξ4

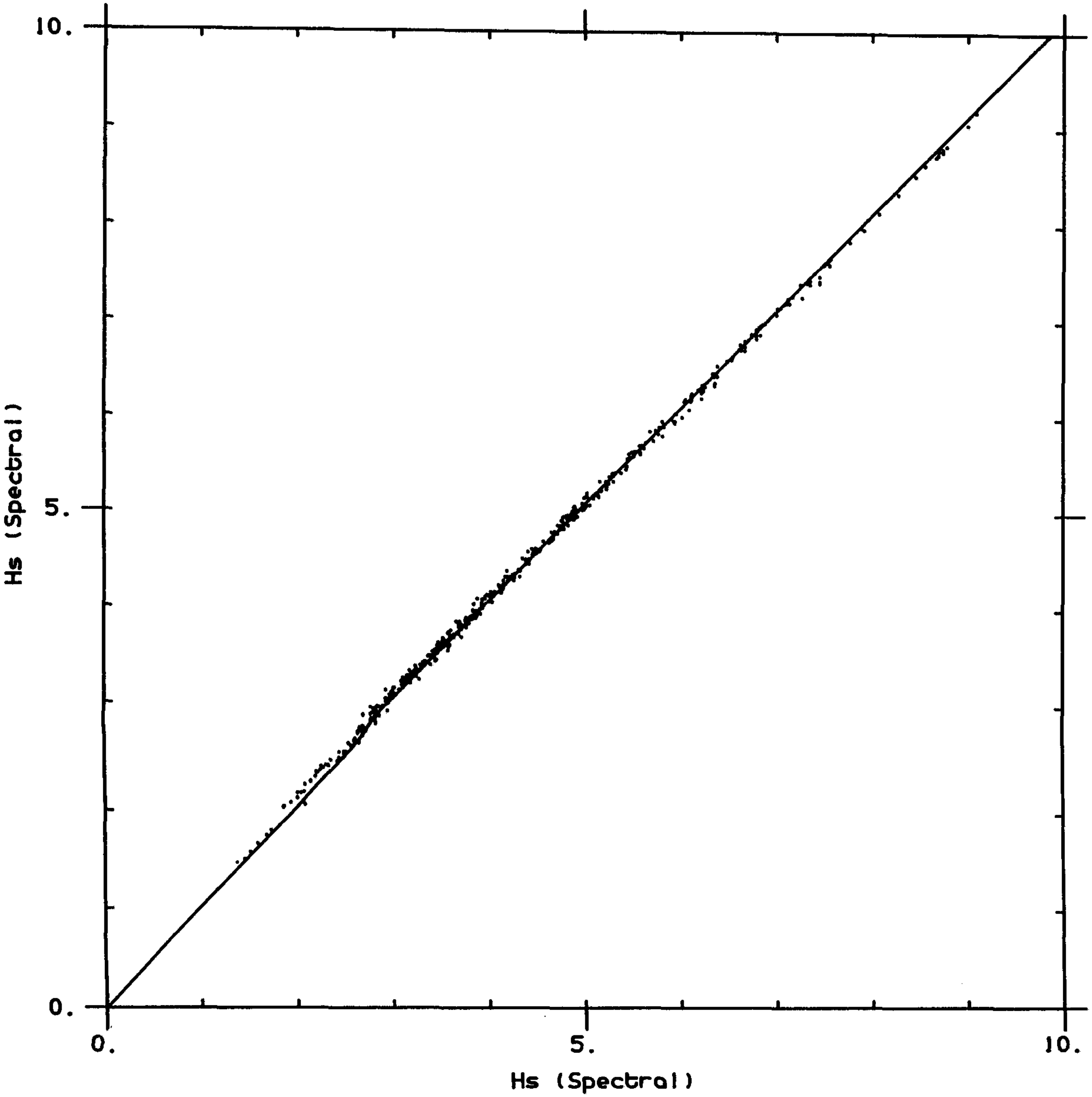
Fig. 3



Cumulus SBWR Modified Response
RESPONSE M**2/M**2
1.
0.5
0.
0.
0.5
1.
FREQUENCY ξ4

Fig. 4

Cumulus P +20% : Flat



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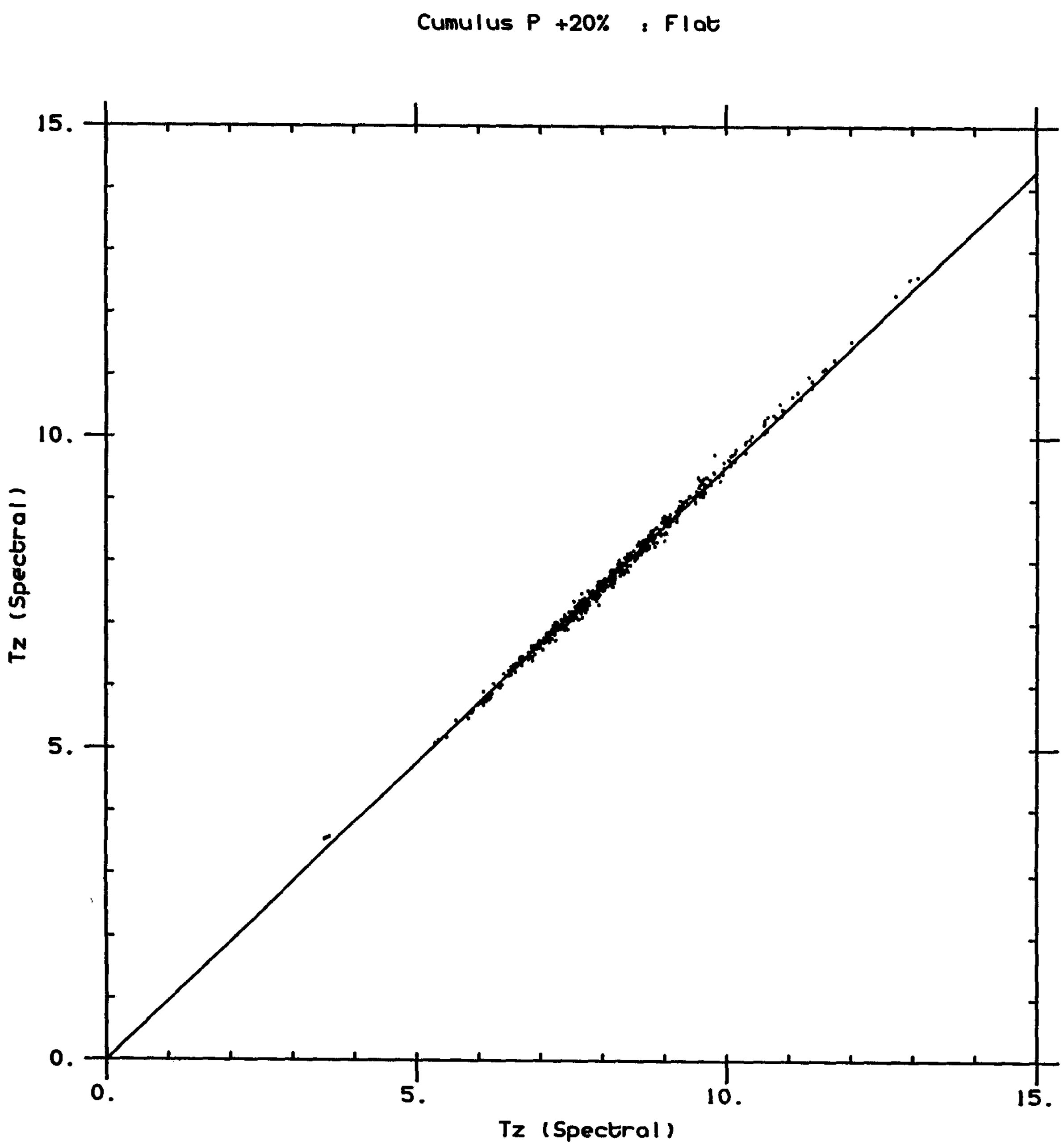
MEAN OF DEPENDENT VARIABLE	=	4.5065
STANDARD DEVIATION OF INDEPENDENT VARIABLE	=	1.5506
STANDARD DEVIATION OF DEPENDENT VARIABLE	=	1.5445
CORRELATION COEFFICIENT	=	0.9996
REGRESSION COEFFICIENT	=	1.0146
STANDARD ERROR OF COEFFICIENT	=	0.0005
T-VALUE FOR COEFFICIENT	=	********
REGRESSION CONSTANT	=	0.0000
STANDARD ERROR OF CONSTANT	=	0.0000
T-VALUE FOR CONSTANT	=	0.0000

Fig. 5



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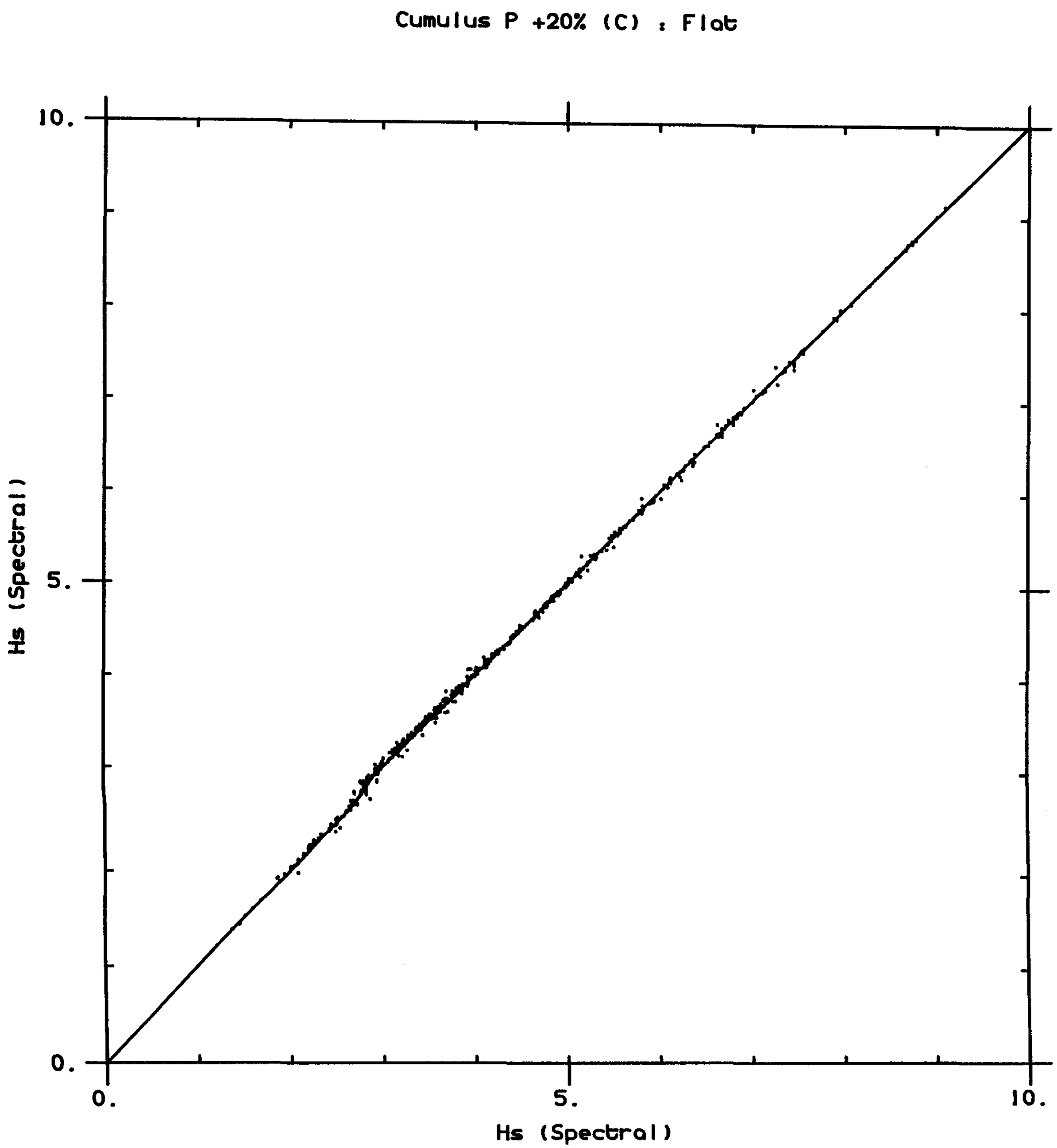
MEAN OF DEPENDENT VARIABLE	-	7.7871
STANDARD DEVIATION OF INDEPENDENT VARIABLE	-	1.3185
STANDARD DEVIATION OF DEPENDENT VARIABLE	-	1.2781
CORRELATION COEFFICIENT	-	0.9978
REGRESSION COEFFICIENT	-	0.9523
STANDARD ERROR OF COEFFICIENT	-	0.0005
T-VALUE FOR COEFFICIENT	-	********
REGRESSION CONSTANT	-	0.0000
STANDARD ERROR OF CONSTANT	-	0.0000
T-VALUE FOR CONSTANT	-	0.0000

Fig. 6



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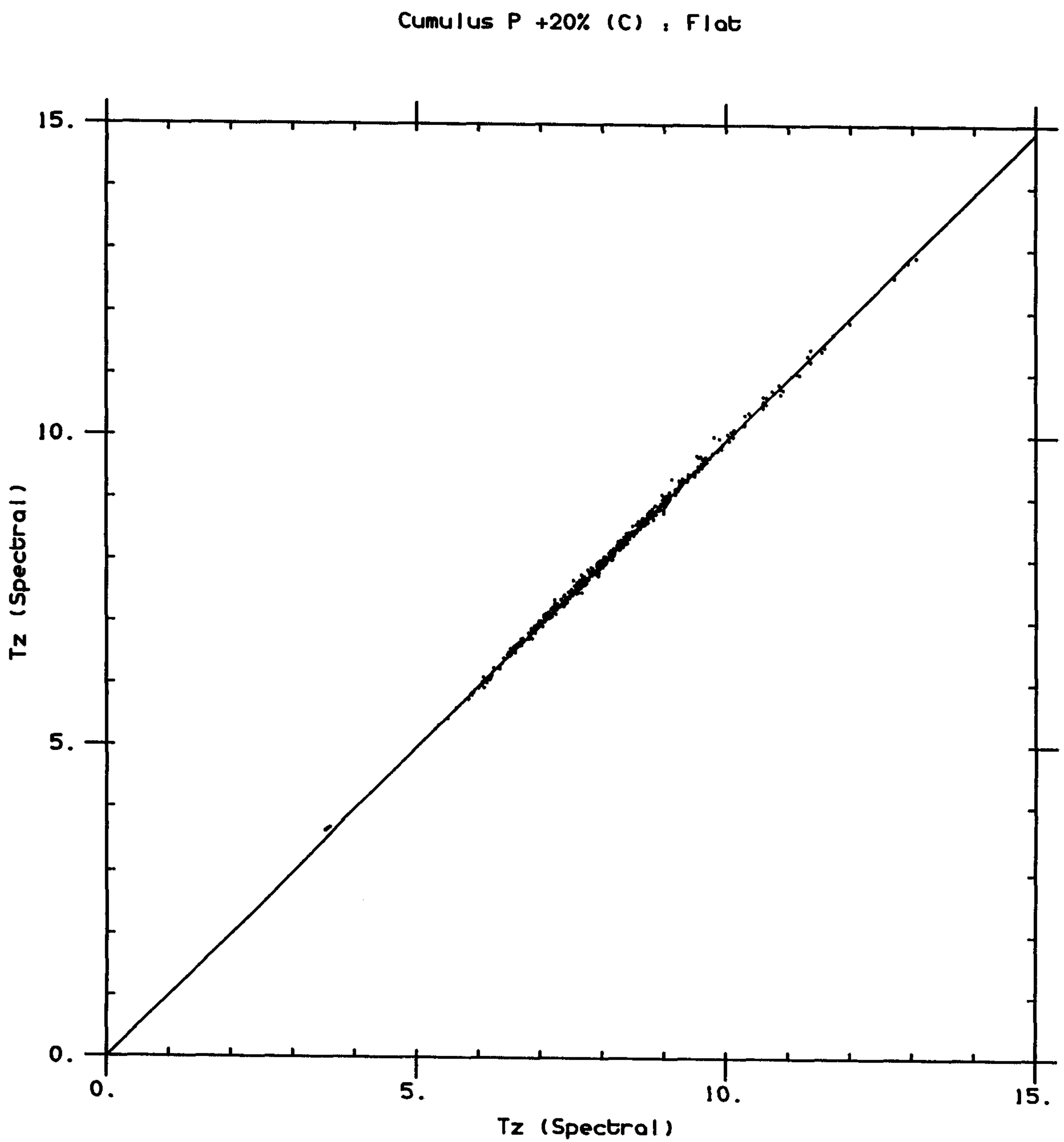
STANDARD DEVIATION OF DEPENDENT VARIABLE	- 1.5505
CORRELATION COEFFICIENT	- 0.9997
REGRESSION COEFFICIENT	- 1.0012
STANDARD ERROR OF COEFFICIENT	- 0.0004
T-VALUE FOR COEFFICIENT	- ********
REGRESSION CONSTANT	- 0.0000
STANDARD ERROR OF CONSTANT	- 0.0000
T-VALUE FOR CONSTANT	- 0.0000

Fig. 7



MEAN OF INDEPENDENT VARIABLE = 8.1801

MEAN OF DEPENDENT VARIABLE = 8.1148

STANDARD DEVIATION OF INDEPENDENT VARIABLE = 1.3185

STANDARD DEVIATION OF DEPENDENT VARIABLE = 1.3040

CORRELATION COEFFICIENT = 0.9989

REGRESSION COEFFICIENT = 0.9919

STANDARD ERROR OF COEFFICIENT = 0.0003

T-VALUE FOR COEFFICIENT = ********

REGRESSION CONSTANT = 0.0000

STANDARD ERROR OF CONSTANT = 0.0000

T-VALUE FOR CONSTANT = 0.0000