LONDON, METEOROLOGICAL OFFICE.

Met.O. 19 Branch Memorandum No.9.

An empirical method for deducing clear-column radiances in partly cloudy situations for channels one to five of the VTPR. By MAY,B.R.

London,Met.Off.,Met.O.19 Branch Mem.No.9, [1974],31cm.Pp.5,pls.4.Abs.p.l.

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An empirical method for deducing clear-column radiances in partly-cloudy situations for channels one to five of the VTPR.

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Abstract: It is demonstrated that for channels four and five of the VTPR clouds cause a spatial variability of the radiance over an area of the atmosphere whose magnitude is related to the reduction of the mean radiance within that area. Channel three of the VTPR seldom shows the effect of cloud while channels one and two not at all.

1. The VTPR observations

The Vertical Temperature Profile Radiometer (VTPR) is an eight-channel infra-red scanning radiometer, two of which are mounted on each of the NOAA 2 and 3 spacecraft. Six of the VTPR channels measure the thermal radiation emitted by the earth's surface and atmosphere in the 15 μ CO_2 band, one channel observes in the water-vapour band near 18.7 μ and the remaining channels observe in the atmospheric window near 12 μ. The CO_2 and the window channel radiances can be used to determine the atmospheric temperature and thickness profile while the H_2O channel radiance can be used to deduce the water vapour concentration in the lower troposphere. In this work we are concerned only with the radiances measured in the channels one to five in the 15 μ band. The radiations observed in these channels are not emitted by discrete levels of the atmosphere but by broad layers defined by the weighting functions which are shown in figure 1. The weighting function is the derivative of the transmission coefficient τ from the top of the atmosphere with respect to some suitable vertical coordinate ($\log_e$ (pressure) in figure 1). The approximate pressure of the weighting function peak, and the transmission coefficient τ_s to the ground for these five channels are given below, for a dry atmosphere:

Channel Number	Pressure at Weighting Function Peak	τ_s
1	40 mb	0.00
2	60 "	0.00
3	170 "	0.00
4	400 "	0.01
5	700 "	0.12

The VTPR field of view is about 60 km square on the ground at the sub-spacecraft point and the radiometer makes 23 contiguous observations across the spacecraft track in each scan. The successive scans are also contiguous so that within the swathe, which is about 1700 km wide, all of the earth's surface is observed.

Within each field of view there is likely to be some cloud which, in general, radiates efficiently at its own temperature while absorbing the radiation emitted by the atmosphere below which it is at a higher temperature than the cloud. Thus a smaller radiance is observed than would be in the absence of the cloud (the "clear-column" radiance). The effect of a cloud field with a particular cloud-top height and fractional cover is greatest for channel 5 and least for channel 1 due to the difference in height of their weighting functions, but for any channel, the reduction in radiance increases with both cloud height and cover. For the purpose of deducing the clear-column radiances from which the SIRS soundings are derived, NESS (National Environmental Satellite Service of the USA) group the observations from eight VTPR scans into three boxes arranged in lines of three across the space-craft track. The two outside boxes consist of 8 by 8 observations and the centre box of 7 by 8 observations. Using a knowledge of the sea-surface temperature NESS produce estimates of the mean clear-column radiance in selected boxes in the CO_2 and H_2O channels (channels 1 to 7) using a method described in NOAA Technical Report NESS 65. An archive tape containing values of the mean clear-column radiances for boxes over the sea and also the original cloudy radiances over both sea and land for two orbits of the NOAA 2 spacecraft between 08 and 11Z on 18 July 1973 has been obtained by Met O 19.

2. Results of a study of apparent cloud effects on VTPR radiances

While the archieved radiances were being studied it was noticed that, for those channels which showed substantial cloud effects, the presence of cloud not only caused the expected general reduction in the mean radiance for a particular box but also resulted in an increase in the variability of the radiances within the box. This is demonstrated in figure 2 which is an ESSA 8 APT cloud picture of Europe at very nearly the same time at which the radiance measurements were made. Superimposed on this cloud picture are the contours of the standard deviation of the channel 5 radiances s.d.(R_5obs) in radiance units (RU) within the VTPR boxes for the two orbits, along with the positions of the major depressions, fronts and anti-cyclones. A close relationship between the variability of the channel 5 radiance (as measured by the s.d.) and the apparent cloud cover amount seems to exist - the largest s.d.s. are situated close to the dense cloud cover associated with depressions and frontal systems while the smallest s.d.s. are to be found in clear or broken-cloud areas. This suggested that some empirical relationship exists between the variability of the radiances within a box and the reduction in the mean radiance of the box due to the effect of cloud, which was established in the following way. Values of the clear-column radiance in channel 5, $\bar{R}_5$clr, were obtained from the NESS archived tape along with the corresponding values of $\bar{R}_5$obs and s.d.(R_5obs) for ninety-nine boxes over the sea. The values of $\Delta\bar{R}_5 = \bar{R}_5\text{clr} - \bar{R}_5\text{obs}$ are plotted against s.d.(R_5obs) in figure 3(a). For s.d.(R_5obs) < 6.0 RU there is a marked correlation of $\Delta\bar{R}_5$ with s.d.(R_5obs) which is well represented by the trend line:

$$\Delta\bar{R}_5 = 2.1 \times \text{s.d.}(R_5\text{obs}) - 2.7 \qquad 1$$

The values of $\Delta\bar{R}_5$ have an s.d. of about 1.5 RU above the trend line (for comparison 1 RU is approximately equivalent to 1°K in black-body temperature).

For s.d.(R_5obs) $>$ 6.0 RU, corresponding to heavy cloud, the values of $\Delta \bar{R}_5$ are very scattered making it difficult to establish any trend. Because NESS do not attempt to deduce clear-column radiances for heavily-clouded areas it is not possible to give an accurate figure for the percentage of all boxes for which s.d.(R_5obs) $<$ 6.0, but for these two orbits 85% of the boxes for which NESS quote a value of $\bar{R}_5$clr satisfy this condition. The results for eight boxes within which the visually estimated fractional cloud cover from the photograph in figure 2 is less than 10% are shown as crosses in figure 3 - the mean value of $\Delta \bar{R}_5$ for these boxes is close to zero while the mean value of s.d.(R_5obs) is 1.8 RU. This latter value represents the combination of the variability of the radiation from the clear atmosphere over the area of the boxes, the instrumental noise ($\sim$ 0.02 RU), and the variability of the surface radiation (for channel 5 about 15% of the observed radiation comes from the surface and the rest from the atmosphere in clear conditions).

Thus we see that it is possible to select boxes which are nearly free of cloud simply by imposing a stringent upper limit on s.d.(R_5obs) or alternatively, in order to reject less data, to use an empirical correction provided by equation 1 to estimate $\bar{R}_5$clr from R_5obs for s.d.(R_5obs) $<$ 6.0 RU.

Many of the features of the effect of clouds in the channel 5 radiances also occur in the channel 4 radiances but to a lesser degree due to the greater height of the channel 4 weighting function. The variation of $\Delta \bar{R}_4$ with s.d.(R_4obs) is shown in figure 3(b); for this channel the trend is represented by

$$\Delta \bar{R}_4 = 1.6 \times \text{s.d.}(R_4\text{obs}) - 0.7$$

for s.d.(R_4obs) $<$ 3.0 RU. The s.d. of the values of $\Delta \bar{R}_5$ about the line increases from about 0.4 RU for s.d.(R_4obs) = 1.0 RU to 1.5 RU for s.d.(R_4obs) = 3.0 RU. For the two orbits, 86% of the boxes for which NESS quote a value of $\bar{R}_4$clr satisfy the condition that s.d.(R_4obs) $<$ 3.0 RU. Again the eight crosses represent points from boxes with less than 10% cloud cover - for these points the mean value of $\Delta \overline{R}_4 = +0.2$ RU while the mean s.d.(R_4obs) = 0.7 RU.

The plot of $\Delta \overline{R}_3$ as a function of s.d.(R_3obs) (for the next highest channel) is shown in figure 4(a). For this channel by far the greater proportion of points lie in a compact symmetrical group centred at $\Delta \overline{R}_3 = 0.0$ RU (with an s.d. of about 0.5 RU) and s.d.(R_3obs) = 0.5 RU. Four outlying points, associated with an extremely cloudy area at low latitudes, give the only indication of a trend of $\Delta \overline{R}_3$ with s.d.(R_3obs). Since so few boxes appear to be affected by cloud it is adequate simply to eliminate them by imposing the condition that s.d.(R_3obs) $<$ 1.0 RU - this condition is satisfied by 93% of all boxes in these two orbits.

For channels 1 and 2 (figures 4(b) and 4(c) there is no obvious trend of $\Delta \overline{R}$ with s.d.(Robs) indicating that these channels have weighting functions which are too high in the atmosphere to be affected by clouds.

3. Use to be made of clear radiances

If clear radiances in channels 1 to 4 only are available then they can be used to deduce the temperature and thickness profile from 30 mb down to about 500 mb. If the radiances in channels 1 to 5 are used then an atmospheric temperature and thickness profile down to 700 mb can be obtained providing that some estimate is available of a) the surface contribution to the observed clear radiance in channel 5 and b) the water vapour concentration in the lower troposphere, as this effects the shape of the weighting functions, especially that of channel 5. The temperature profile in the lower troposphere can be improved by using an estimate of the screen temperature as a restraint on the solution profile.

4. Acknowledgements

I wish to acknowledge the assistance of D Chapman in extracting magnetic tape data, and useful discussions on this topic with Mr A Farag, visiting scientist from Egypt.

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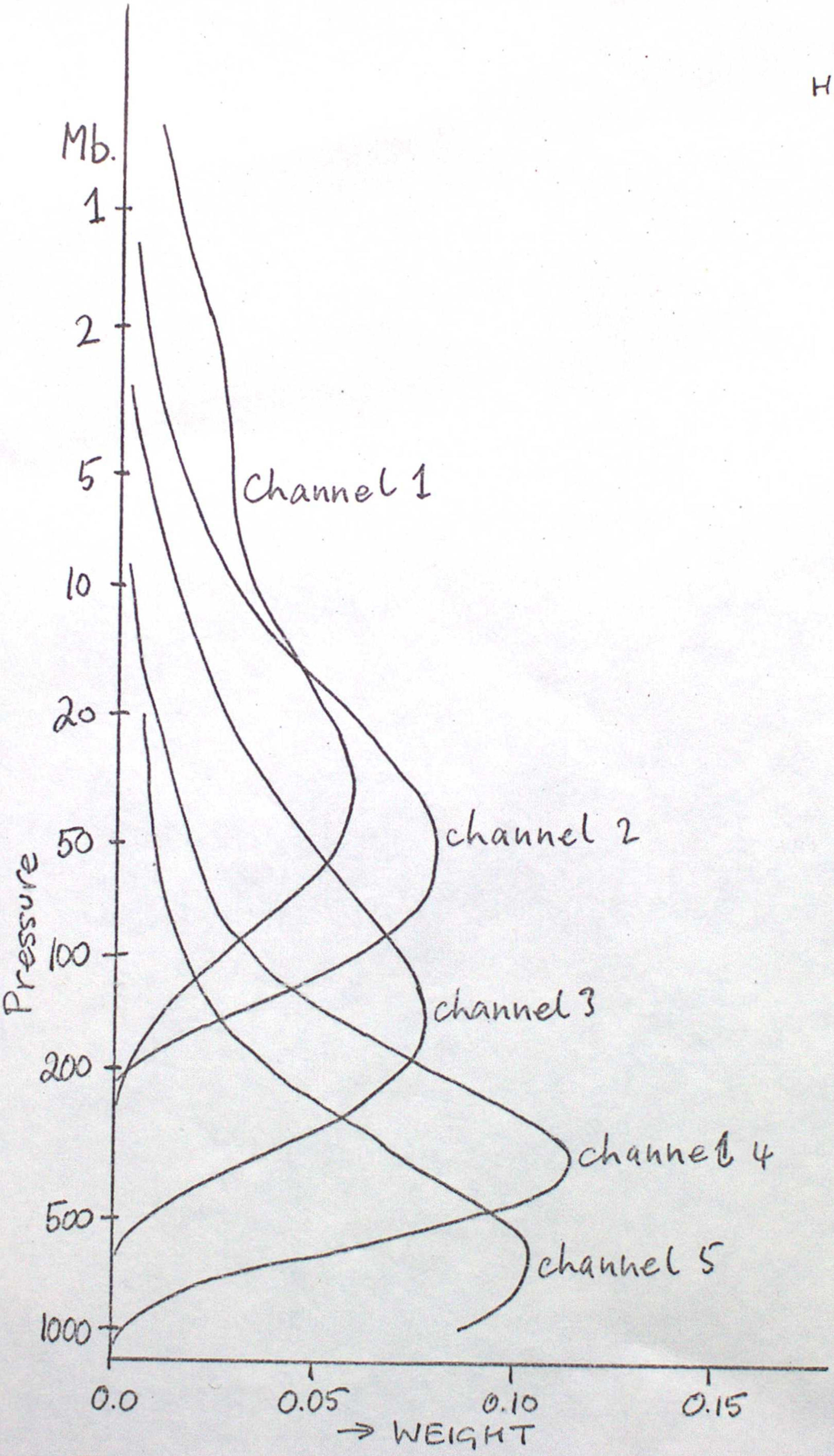
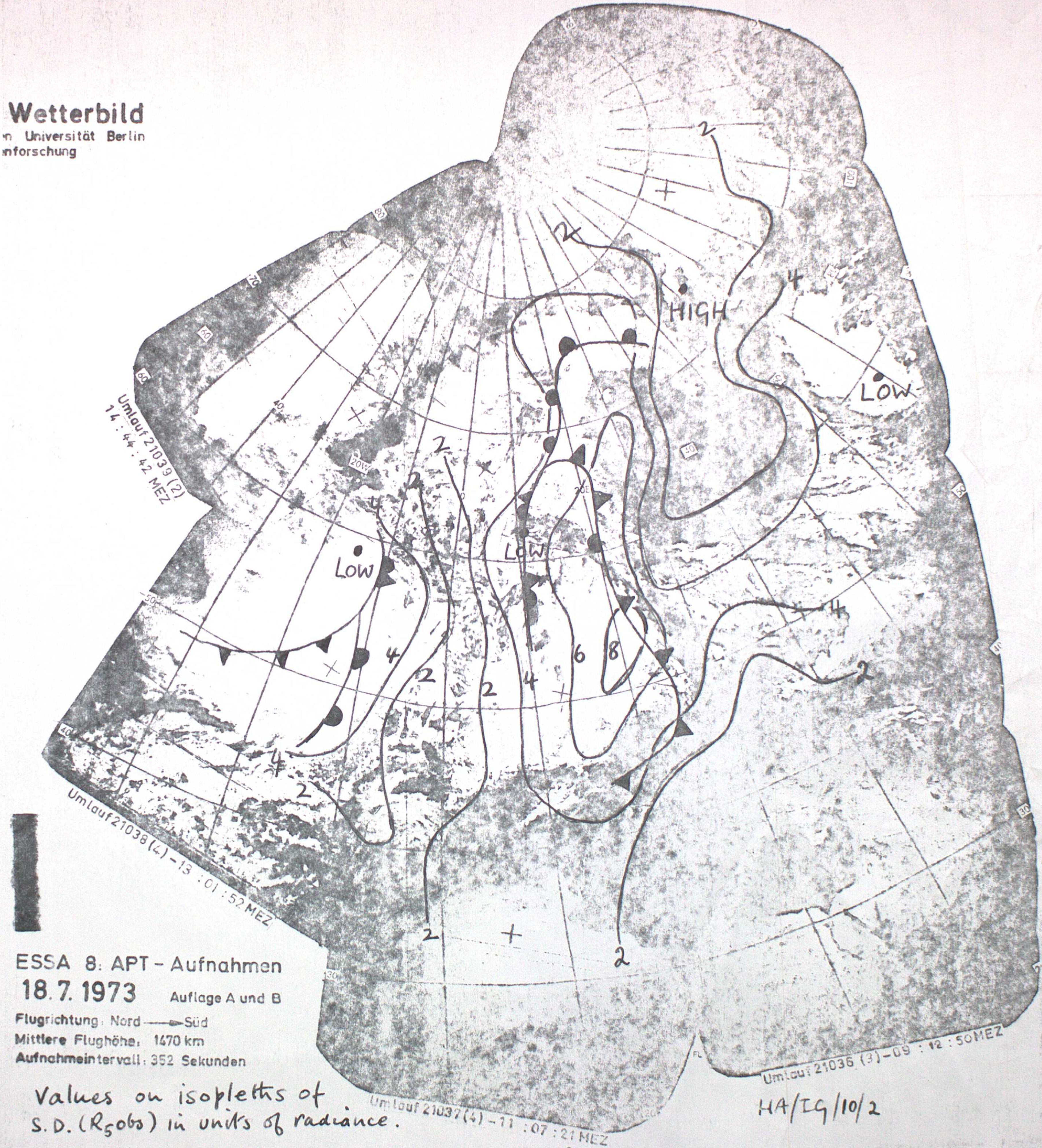


FIGURE 1 — VTPR WEIGHTING FUNCTIONS



Values on isopleths of S.D. (R_5 obs) in units of radiance.

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FIGURE 2 — CONTOURS OF S.D. (R_5 obs) FOR VTPR BOXES

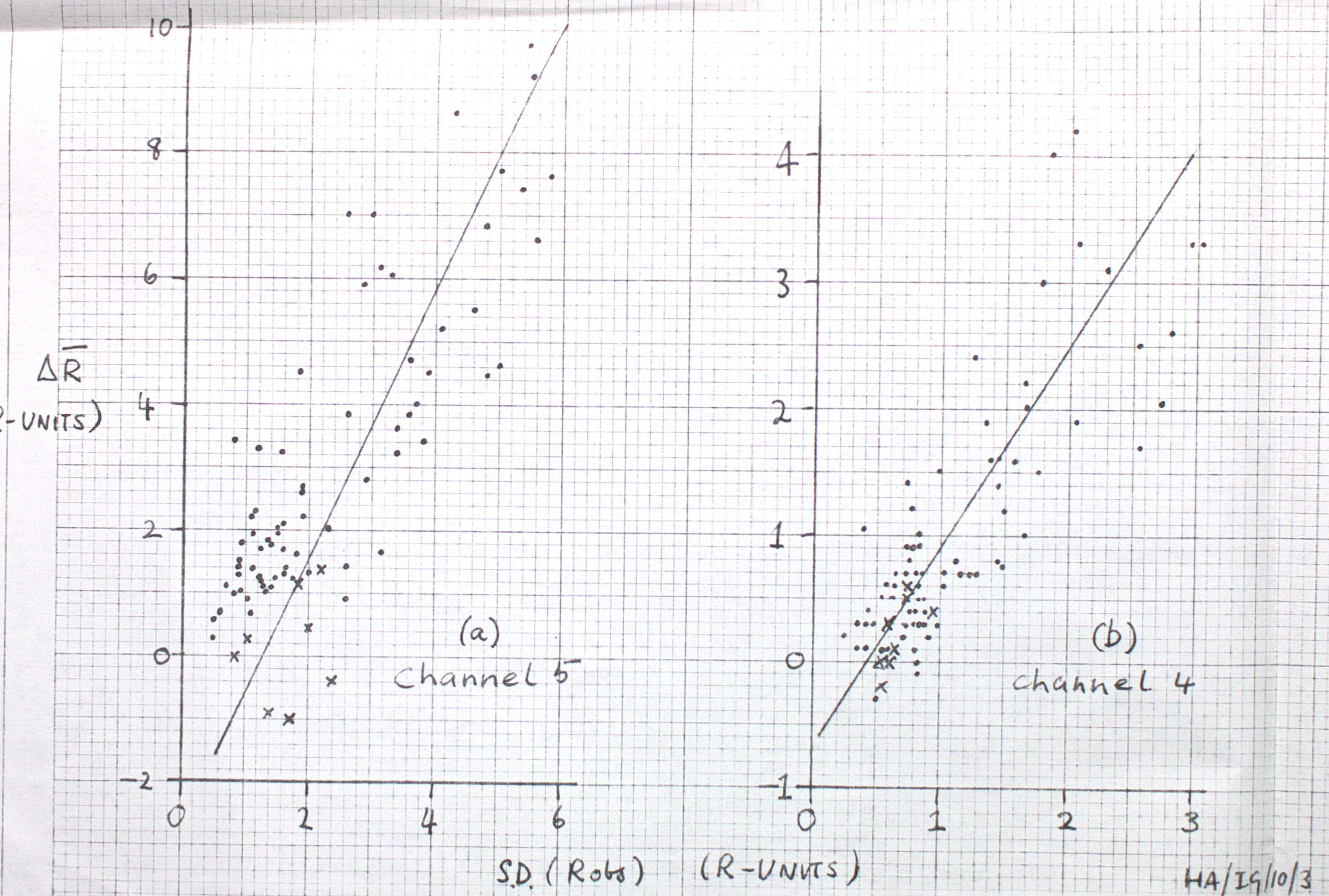

FIGURE 3 - PLOT OF $\Delta\overline{R}$ AGAINST S.D.(Robs) FOR VTPR CHANNELS 4 and 5

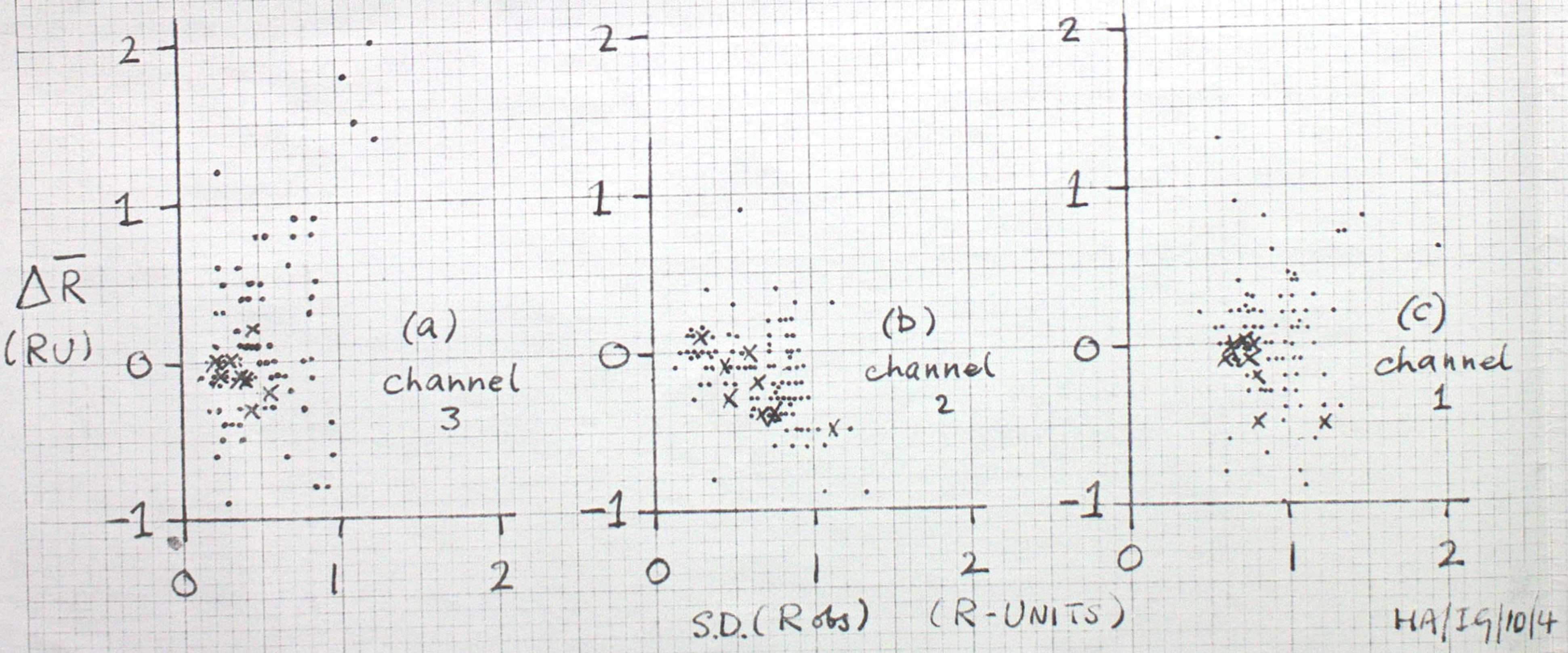

FIGURE 4 - PLOT OF $\Delta\bar{R}$ AGAINST S.D.(R_{obs}) FOR VTPR CHANNELS 1, 2 and 3