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ACCURACY OF OBSERVATIONS AND COMPUTATIONS OF UPPER WINDS USING PLESSEY RADAR TYPE WF2 AND PILOT BALLOON SLIDE RULE

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ABSTRACT

The radar observational errors and slide rule computation errors made by observers working under routine conditions are compared with the instrumental errors. Errors in vector winds and computed heights are derived and presented in diagrams and a summarizing table.

1. INTRODUCTION

Routine radar upper wind measurements are made in the Bureau of Meteorology by taking from the radar display readings of the range, azimuth and elevation of an ascending balloon-borne target every minute for the first 12 minutes after release, and every two minutes thereafter. In the time between readings the same observer uses a specially designed slide rule (British Meteorological Office pattern) to compute the wind vector and height, so that the results are available immediately. A buzzer warns the observer before the next reading is due. The balloon ascends at about 5 m sec^{-1}.

Both the radar and the slide rule are subject to instrumental errors, which for practical purposes may be assumed to be the same as the errors which occur when the radar or the rule is used with great care and precision by a skilled observer working as slowly as need be. Both items of equipment are subject to observational errors which depend on the skill of the observer and on the conditions under which he operates, one of the conditions being the speed at which he must work. The object of the present study is to obtain estimates of, (i) the accuracy of the radar and slide rule used firstly under "ideal" conditions and secondly in normal operational routine, and (ii) the resulting errors in the vector wind and computed heights. Since the radar errors are independent of the slide rule errors, each can be treated separately and then compounded to give the vector wind and height errors.

SYMBOLS

A	azimuth of the target
E	elevation of the target
R	range of the target
H	height of the target
t	time between observations
x	a symbol representing A, E, R or H
x'	A, E, R or H adjusted for separation of radar sets
D	distance between radar sets
β	bearing of radar No. 1 from radar No. 2

σ_x standard deviation of x

$|\sigma_{\tilde{v}}|$ magnitude of the vector s.d. of the wind vector error

N number of observations in a flight.

2. RADAR ERRORS

The radar instrumental error as defined above has been determined by Laby and Sparrow (1965), using two WF2 radar sets at Laverton (Victoria), both following the one balloon and assuming:

(i) that all the observations and hence their errors are independent,

(ii) that the two radar sets have equal instrumental errors, so that the error of each can be found by differences in observations made simultaneously by the two radars.

The errors determined in this way are given in row 1 of Table 1.

Table 1. Standard deviations of errors in measurements with WF2 radar

Error	Standard Deviations of errors		
	Range (km)	Azimuth (deg.)	Elevation (deg.)
Instrumental (Laby and Sparrow)	0.035	0.057	0.078
Total instrumental plus observational, under routine operation	0.12	0.29	0.19

Table 2. Analysis of the differences between observations in four flights with two WF2 Radar sets

Flight number	No. of obs.	Range (km)		Azimuth (deg)		Elevation (deg)	
		Av. diff.	s.d. of errors	Av. diff.	s.d. of errors	Av. diff.	s.d. of errors
1	31	+0.05	0.13	+0.14	0.42	+0.09	0.16
2	21	+0.00	0.06	+0.52	0.38	+0.20	0.30
3	39	+0.30	0.09	+0.06	0.20	+0.09	0.16
4	31	+0.02	0.16	+0.16	0.10	+0.09	0.17

The total instrumental plus observational errors in radar observations during routine operations were found in this study using the same method as Laby and Sparrow - two radar sets operating simultaneously. The total errors so found are given in row 2 of Table 1. The four flights studied all reached heights over 27 km, at ranges up to 60 km. They were fairly typical flights with light or moderate winds, maximum speeds in each flight ranging from 18 m sec^{-1} to 32 m sec^{-1}. All observations with one of the radar sets were made by the one observer for all four flights; three different observers operated the other radar.

Tables 1 and 2 were constructed as follows:

The two WF2 (3 cm) radar sets at Laverton are 168 m apart, No. 1 bearing 074 deg from No. 2. This separation produces slight differences in range, azimuth and elevation measured by the two radars, so approximate formulae were applied to adjust the readings of No. 2.

$$A' = A + \frac{180}{\pi} \cdot \frac{D \sin (A - \beta)}{R \cos E} \qquad \ldots (1)$$

$$\tan E' = \frac{\tan E}{1 - \dfrac{D \cos (A - \beta)}{R \cos E}} \qquad \ldots (2)$$

$$R' = R - D \cos E. \cos (A - \beta) \qquad \ldots (3)$$

In these equations A is the reciprocal bearing of the target, this being the form in which readings are taken from the radar display in order to simplify the slide rule computations of wind.

Using observations adjusted as above, the mean differences $(\Sigma \Delta x)/N$ were calculated for each flight and are tabulated in Table 2. Standard deviations of Δx were then calculated for each flight. On the assumption that the two radars with their observers contribute equally and randomly to the differences, the standard deviation of a radar error is given by:

$$\sigma_x = \frac{\text{s.d. of } \Delta x}{\sqrt{2}} \qquad \ldots (4)$$

and these are tabulated in Table 2 for each flight, and in Table 1 row 2 for all flights combined (by weighted variances).

The errors in the observed range, azimuth and elevation produce errors in the computed vector wind and in the computed height to which it is assigned. The formulae for errors in computed winds and heights, in terms of errors in the observations are:

$$|\underset{\sim}{\sigma_v}| = \frac{(2)^{\frac{1}{2}}}{t} \left\{ (\sigma_A R \cos E)^2 + (\sigma_E R \sin E)^2 + (\sigma_R \cos E)^2 \right\}^{\frac{1}{2}} \qquad \ldots (5)$$

$$\sigma_H = \left\{ (\sigma_R \sin E)^2 + (\sigma_E R \cos E)^2 \right\}^{\frac{1}{2}} \qquad \ldots (6)$$

In deriving equations (5) and (6) it is assumed that the error in a balloon displacement which is obtained by differencing two observations of position, has a standard deviation given by $2^{\frac{1}{2}}$ times the s.d. of the error in one observation. This is true only if the errors are random, which appears to be the case.