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EVALUATION OF METEOROLOGICAL ROCKET DATA

by A. Belmont, R. Peterson, and W. Shen

Prepared under Contract No. NASw-558 *by*
GENERAL MILLS, INC.
Minneapolis, Minn.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1964

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ABSTRACT

The published properties and accuracy of meteorological rocket and rawin systems are summarized. Rocket and rawin wind observations for about three years are compared. Eighty percent of the differences between them are within 5 m/sec, although the extremes may reach 25 m/sec. The atmospheric layer represented by each reported M/R wind varies from about 800 meters at 20 km to 2700 meters near 55 km, compared with about 1300 to 1600 meters for rawin winds below 30 km. There are no rocket data yet available to show the vertical progression of the fall reversal process at high latitudes. Both rocket and rawin data agree on downward progression in spring. Recommendations are offered to enable more significant use of rocket data.

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I. INTRODUCTION

The aims of this study are to: 1) compare Meteorological Rocket Network (MRN) data and their interpretation with the corresponding data and interpretation of highest level rawinsondes (R/W) to determine their compatibility, and 2) make recommendations on the desirable density of the MRN for the requirements of synoptic meteorology of the atmosphere below 50 km.

To do this, a summary was first made of the literature describing the many rocket and rawin systems and their accuracy. The results have been arranged in tables to enable convenient summarization of the properties of the many methods and comparison of present estimates of accuracy.

Using this material as a background, statistical studies were prepared of the variation in thickness of the atmospheric layer represented by a given meteorological rocket (M/R) wind, and also of the agreement of M/R and R/W winds in regions of overlapping data.

An interpretation of rocket wind data was also made to see how well the conclusions agreed with results from balloon data. The subject was the vertical progression of the seasonal reversal of wind in spring and especially in fall, for which various results have been reported in the literature based upon mean balloon or individual rocket ascent data.

The density of the MRN is considered from various aspects, and recommendations made from the viewpoint of atmospheric circulation research requirements.

Finally, some suggestions are offered on the improvement of the present network's rocket firing program and data reduction methods to provide data of maximum usefulness for upper atmospheric research.

II. REVIEW OF CHARACTERISTICS AND ACCURACY OF METEOROLOGICAL ROCKET AND RAWIN SYSTEMS

A. Properties of Meteorological Rocket (M/R) Systems

There are now so many different combinations of meteorological rockets, carriers, sensors and ground tracking methods, each of which has different characteristics which affect the final data interpretation, that Tables la to le have been constructed in an attempt to summarize some of the major properties of these methods of observation. No attempt has been made to document all the details of all available references, but rather to compile some of the basic facts and opinions regarding the general characteristics of M/R systems. For specific details regarding the various M/R systems, reference can be made to articles by the Joint Scientific Advisory Group (1961), Keegan (1961), Webb, et al. (1961), Webb, et al. (1962) and aufm Kampe and Lowenthal (1963). In addition, IRIG Document No. 105-60 (1961) contains extensive descriptions of M/R equipment and techniques.

Some of the properties of M/R systems which relate to the basic study problem will now be briefly discussed.

1. Carrier Vehicles

A variety of carrier vehicles have been used for M/R observations since the pioneering Loki-chaff experiments reported by Thaler and Masterson (1956). At the time when the Meteorological Rocket Network (MRN) was initiated in October 1959, the predominant rocket carriers were Loki I, Loki II and Arcas. The latter two have rated altitude capabilities, with standard payloads, somewhat in excess of 60 km. The Loki I, which was limited to an altitude capability of 160, 000 ft at best, has now become obsolete. The rocket carrier vehicles now in use (Arcas, Loki II, Hasp II, Roksonde 200, Judi and Raven) apparently all have about the same operational capability for releasing chaff, parachute and balloon sphere sensors

TABLE 1a. CHARACTERISTICS OF METEOROLOGICAL ROCKET SYSTEMS

TYPE OF SYSTEM				ASCENT CARRIER VEHICLES	PARAMETERS MEASURED	SENSORS
CHAFF	FOIL (aluminum coated plastic 2" x .0157" x .0006")			Deacon-Arrow has been used for foil chaff to 300,000 ft. (L.B. Smith 1960). Loki I has obtained winds at typical altitudes below 125,000 ft. with the 8-ft. diam. parachute while the Loki II has used .010 copper foil for winds above 150,000 ft. ARCAS, Loki II, Hasp II, Roksonde 200, Judi and Raven are roughly equivalent in performance; they are used for altitudes up to 200,000 ft., the present effective limit of Meteorological Network data.	WIND	Chaff cloud provides radar target for tracking to determine angular and slant range data, which is processed to compute winds.
	CYLINDRICAL DIPOLE	COPPER	.005" Dia.			
			.010" Dia.			
		METALIZED NYLON "SUCHY"	.008" Dia.			
			.012" Dia.			
PARACHUTE	8 Ft. Dia.				WIND TEMPERATURE PRESSURE ETC.	Metallized parachute provides radar target for tracking data to determine winds. 10 mil spherical bead thermistor (VECD 43A6) is standard for temperature measurements. High-altitude hypsometer under development (uses saffrote). Thermal conductivity pressure sensor has been proposed. Ion gauge proposed for density. Film type sensor proposed for ozone.
	15 Ft. Dia.					
"ROBIN" BALLOON SPHERE					WIND DENSITY	Metallized mylar corner reflector provides radar-target. Very accurate tracking data provides wind and density (based on drag calculation).

TABLE 1b. CHARACTERISTICS OF METEOROLOGICAL ROCKET SYSTEMS

TYPE OF SYSTEM				DESCENT RATE OF M/R SENSORS	
CHAFF	FOIL (aluminum coated plastic 2" x .0157" x .0006")			70 mps at 85 km and 3 mps at 50 km (Smith 1960).	Acceptable range of descent rate for effective wind sensing is 50-200 fps (Beyers et al 1962).
CHAFF	CYLINDRICAL DIPOLE	COPPER	.005" Dia.	60 fps at 100,000 ft; 150 fps at 150,000 ft; 320 fps at 200,000 ft. (Beyers and Thiele 1961).	
CHAFF	CYLINDRICAL DIPOLE	COPPER	.010" Dia.	23 mps at 30 km; 43 mps at 45 km; 75 mps at 60 km (JSAG 1961). 220 fps at 130,000 ft; 140 fps at 100,000 ft; 60 fps at 50,000 ft. (Beyers and Thiele 1961).	
CHAFF	CYLINDRICAL DIPOLE	METALIZED NYLON "SUCHY"	.008" Dia.	3 mps at 30 km; 6 mps at 45 km; 11 mps at 60 km (Barr 1960).	
CHAFF	CYLINDRICAL DIPOLE	METALIZED NYLON "SUCHY"	.012" Dia.	3 mps at 30 km; 9 mps at 45 km; 19 mps at 60 km (Barr 1960). 30 fps at 150,000 ft; 55 fps 200,000 ft. (Beyers and Thiele 1961).	
PARACHUTE			8 Ft. Dia.	20 fps at 60,000 ft; 60 fps at 100,000 ft; 320 fps at 140,000 ft. - average values (Beyers and Thiele 1961). 40 mps at 45 km; 12 mps at 30 km (JSAG 1961).	
PARACHUTE			15 Ft. Dia.	45 fps at 100,000 ft; 155 fps at 150,000 ft; 360 fps at 200,000 ft.- average values (Beyers and Thiele 1961). 13 mps at 30 km; 45 mps at 45 km; 140 mps at 60 km (JSAG 1961). 455 fps at 200,000 ft; 193 fps at 150,000 ft; 62 fps at 100,000 ft (Coppola 1963). Probable accuracy of fall rate below 220,000 ft; is ± 20 fps (Beyers et al 1962).	
"ROBIN" BALLOON SPHERE				50 fps at 100,000 ft; 185 fps at 150,000 ft; 515 fps at 200,000 ft. average values (Beyers and Thiele 1961).	

TABLE 1c. CHARACTERISTICS OF METEOROLOGICAL ROCKET SYSTEMS

TYPE OF SYSTEM				RADAR TRACKING EQUIPMENT	RDF TRACKING EQUIPMENT	TELEMETERING EQUIPMENT
CHAFF	FOIL (aluminum coated plastic 2" x .0157" x .0006")			Various radars have been used, including: MPQ-31 AN/MPQ-12 AN/MPQ-16 AN/MPQ-18 Mod II (SCR 584) AN/MSQ-1 AN/FPS-16 M-33 T-33 The AN/FPS-16, a c-band radar, is preferred, since it can skin track ARCAS to apogee and it permits the most accurate determination of winds and density for ROBIN observations.		
CHAFF	CYLINDRICAL DIPOLE	COPPER	.005" Dia.			
CHAFF	CYLINDRICAL DIPOLE	COPPER	.010" Dia.			
CHAFF	CYLINDRICAL DIPOLE	METALIZED NYLON "SUCHY"	.008" Dia.			
CHAFF	CYLINDRICAL DIPOLE	METALIZED NYLON "SUCHY"	.012" Dia.			
PARACHUTE			8 Ft. Dia.		Since the parachute may carry a transmitter for temperature data, GMD-1, double GMD-1 and GMD-2 tracking by RDF is possible.	Various telemetering units-Alpha and Gamma packages, and Arcasondes have been used. They involve essentially a modified AN/AMT-4 for use with GMD-1 - the AN/DMQ-6 is designed for use with GMD-2 and has 4 channels for variable resistance type sensors. The AN/DMQ (XE-1) is presumably another 4-channel telemetering device.
PARACHUTE			15 Ft. Dia.			
"ROBIN" BALLOON SPHERE						

TABLE 1 d CHARACTERISTICS OF METEOROLOGICAL ROCKET SYSTEMS

<table>
<tr><th colspan="4" rowspan="2">TYPE OF SYSTEM</th><th colspan="2">DATA RECORDING AND PROCESSING TECHNIQUES</th></tr>
<tr><th>"GRAPHICAL"</th><th>"DIGITAL"</th></tr>
<tr><td rowspan="6">CHAFF</td><td colspan="3">FOIL (aluminum coated plastic 2" x .0157" x .0006")</td><td rowspan="10">WINDS:
At fixed intervals of 1 minute, 30 seconds or more frequently, the radar tracking data of slant range, azimuth and elevation angles of the target are fed from the tracking radar to a computer which prints out the position in rectangular co-ordinates and also prints out graphical x-y and Z-R plots. The component winds are computed manually at ½ minute intervals to T + 5 minutes, at 1 minute intervals from T + 5 to T + 20 minutes and at 2 minute intervals from T + 20 minutes to the end of the observation.
Jenkins (1962) has pointed out that 15-, 30- and 60- sec winds are possible from AN/FPS-16 tracking data. Keegan has stated that 5-10 second winds are feasible.
Bruch and Morgan (1961) have normalized wind data to a 5 km vertical scale for climatological analysis of M/R data.
TEMPERATURE
The AN/TMQ-5 recorder is used to record temperature and other telemetered data vs. time. Time vs. altitude data is provided from the radar tracking.</td><td rowspan="10">Digital data processing has been applied almost exclusively to the processing of wind and density values from ROBIN observations, where the AN/FPS-16 has been used for radar tracking. The data are recorded on magnetic tape for computer processing. The basic data acquisition rate for the AN/FPS-16 is 10 per second; these data are preliminarily smoothed to ½ sec averages. Then digital computers (IBM 7090, IBM 1620, Burroughs 220) are used to apply 31 point smoothing to the ½ second point averages and the winds computed over the selected ½, 1 or 2 minute time intervals.
The computer program uses the standard drag equation to compute density values: to compute pressure from the hydrostatic equation and finally the temperature as a function of the computed density and pressure.</td></tr>
<tr><td rowspan="4">CYLINDRICAL DIPOLE</td><td rowspan="2">COPPER</td><td>.005" Dia.</td></tr>
<tr><td>.010" Dia.</td></tr>
<tr><td rowspan="2">METALIZED NYLON "SUCHY"</td><td>.008" Dia.</td></tr>
<tr><td>.012" Dia.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3" rowspan="2">PARACHUTE</td><td>8 Ft. Dia.</td></tr>
<tr><td>15 Ft. Dia.</td></tr>
<tr><td colspan="4">"ROBIN" BALLOON SPHERE</td></tr>
<tr><td colspan="4"></td></tr>
</table>

TABLE 1 e CHARACTERISTICS OF METEOROLOGICAL ROCKET SYSTEMS

TYPE OF SYSTEM				ALTITUDE RANGE OF EFFECTIVE DATA: WIND		ALTITUDE RANGE OF EFFECTIVE DATA: TEMP., PRESSURE & DENSITY
CHAFF	FOIL (aluminum coated plastic 2" x .0157" x .0006")			140-280,000 ft. (Bruch and Morgan 1961).	Chaff is applicable to 85 km, with accurate tracking (Lally & Leviton 1958). 40,000 ft. is effective vertical depth of chaff observations, on the average. (Keegan 1961)	
CHAFF	CYLINDRICAL DIPOLE	COPPER	.005" Dia.	100-180,000 ft. (Beyers et al 1962).		
CHAFF	CYLINDRICAL DIPOLE	COPPER	.010" Dia.	40-120,000 ft. (Beyers et al 1962).		
CHAFF	CYLINDRICAL DIPOLE	METALIZED NYLON "SUCHY"	.008" Dia.	Suchy chaff (including .0035" diam) is effective from 140-280,000 ft. (Bruch and Morgan 1961).		
CHAFF	CYLINDRICAL DIPOLE	METALIZED NYLON "SUCHY"	.012" Dia.	Suchy chaff (including .0035" diam) is effective to 250,000 ft. (Jenkins 1962).		
PARACHUTE			8 Ft. Dia.	50-125,000 ft. (Bruch and Morgan 1961). 150,000 ft. down to balloon altitudes (Webb et al 1962).		TEMPERATURE Bead thermistor ineffective above 170,000 ft. at prevailing fall rates (Coppola 1963). 10 mil bead thermistor is effective from 180,000 ft. to balloon winds. (Webb et al 196 PRESSURE 80-220,000 ft. with hypsomet (Coppola 1963).
PARACHUTE			15 Ft. Dia.	100-180,000 ft. (Bruch and Morgan 1961). 220,000 ft. upper limit (Jenkins 1962). Applicable to 70 km (Lally and Leviton 1958). 100-200,000 ft. (Webb et al 1962).		
"ROBIN" BALLOON SPHERE				100-200,000 ft. (Bruch and Morgan 1961). down to 27 km (aufm Kampe & Lowenthal 1963). 220,000 ft. upper limit (Jenkins 1962). Can be traced from 90-250,000 ft. (Keegan 1961).		DENSITY Balloon sphere remains inflated down to 27 km. (aufm Kampe & Lowenthal 1963).

at altitudes of approximately 60 km. During the recent 6-month period, April to September 1963, when a total of 487 M/R observations were reported, the following numbers of individual carrier rockets were used: Hasp II (166), Arcas (143), Roksonde 200 (110), Judi (65) and Raven (3).

At the present time, there does not appear to be any systematic bias in the M/R data associated with the specific type of rocket which is used for an individual observation. However, there are certain bias problems which apply to rocket vehicles in general; a discussion of such factors as thermal calibration shift and rocket velocity initially imparted to the ejected sensors will be contained in Section II. B.

2. Wind Sensors

As indicated in the format of Tables la to le, there are three major categories of wind sensor: chaff, parachute and balloon sphere (Robin). They have been used in varying proportions since the MRN was instituted. During the initial 27-month period from October 1959 to January 1962, out of the total of 950 reported observations, the approximate breakdown by major sensor category was as follows: parachute, 590; chaff, 250; balloon sphere, 90 (Webb, et al., 1962). Recently, however, there has been a significant change in the relative numbers of wind sensor types which are being used. During the 6-month period from April to September 1963, out of a total of 487 observations, 276 were chaff, 159 were parachute and 52 were balloon sphere. It is quite apparent that chaff is not becoming obsolete, even though this type of sensor cannot provide for concurrent temperature or density measurements, as in the case of parachute and balloon sphere sensors.

Various types of chaff have been used over the past 8 years for rocket wind observations. Smith (1960) has reported on the use of foil chaff for measuring winds between 100-300,000 ft. However, foil chaff has not been used to any appreciable extent by the MRN; it may for all practical purposes be regarded as obsolete. Cylindrical dipoles in various diameter sizes of copper and metallized nylon ("suchy") are now in standard use; 1 to 3 lb of chaff will provide the order of a million dipoles as a cloud target for radar tracking. Chaff can provide desirable fall rate characteristics over the entire 30-60 km altitude range, as judged against the customary criterion that the fall rates of effective wind sensors should fall within the range of 50-200 ft/sec. Suchy chaff has exceptionally good fall rate characteristics in the 45-60 km range, where the 0.012-inch diameter chaff, for example, has a fall rate of 30-60 ft/sec; however, below 45 km, slow descent rates are a serious disadvantage because of the continual diffusive spreading of the chaff cloud. Clumping and diffusion problems which are inherent in chaff observations, will be discussed in a later section of this report. Keegan (1961) has commented that chaff soundings will, on the average, extend through a vertical depth of about 13 km and occasionally reach 30 km; however, examination of recent MRN data reports has revealed that chaff wind soundings now extend more typically over 25-30 km.

The parachute category of wind sensors includes: 1) an 8-ft metallized Mylar parachute used with the Loki I system, and 2) a 15-ft silvered silk parachute originally developed for use with the Arcas but now deployed from other comparable rocket carriers. The 8-ft parachute is currently used only to a limited extent since it can only provide data to an altitude of 120-140,000 ft. The 15-ft parachute system, now the standard sensor of this type with an altitude capability extending to 200,000 ft, not only provides a radar tracking target for wind measurements but frequently carries a modified radiosonde (R/S) flight unit suspended beneath the parachute in order to provide temperature sounding data.

The average fall rates presented by Beyers, et al. (1962) show that the 15-ft parachute descent velocity exceeds the 200 ft/sec criterion at an altitude of 50 km; this poses a serious problem in terms of averaging out layers of significant wind shear.

At the present time, other serious problems under active investigation are concerned with incomplete deployment, poor response to the wind and pronounced oscillation of parachute systems (Murror and Barker, 1961; Murrow and Dozier, 1963).

The Robin balloon sphere represents the most recent development in wind sensors; a detailed description is provided by Leviton (1961). In brief, it is a 1-m diameter sphere fabricated from 0.5-mil Mylar which contains inside a corner reflector made from aluminized 0.25-mil Mylar. It is inflated to a superpressure of about 12 mb by the vaporization of liquid isopentane. The Robin is deployed from an Arcas rocket vehicle; its aluminized radar target is cutomarily tracked by FPS-16 precision tracking radar. The fall rate of the Robin sphere is somewhat higher than that of the 15-ft parachute and, in fact, on the average exceeds 200 ft/sec above 155,000 ft (Beyers and Thiele, 1961). If precision tracking is available, and if the sphere maintains its shape without deformation or collapse, density values can also be obtained on the basis of drag considerations. A development program is currently being conducted to improve the Robin sphere, primarily in the area of weight reduction, i.e., thinner gauge material and lighter weight inflation medium. In addition, an analytical program is being carried out at NASA's Langley Research Center (Reed, 1963) to assess the response characteristics of various falling and rising spherical balloon systems, including the Robin.

3. Temperature and Other Sensors

The temperature sensing element in currently standard use in the MRN is a glass-coated, nearly spherical bead thermistor (VECO 43A6) which has a diameter of approximately 10 mils and 1-mil platinum-iridium wires. The temperature element is mounted such that the air will come into contact with it before reaching any other portion of the instrument package.

The 10-mil bead thermistor has been used for several hundred temperature soundings, mostly as a part of the Gammasonde package, a modified AN/AMT-4 R/S flight telemetry unit designed for the GMD-1 R/S ground equipment. Other flight instruments, such as the Areasonde, have also been developed and used which are also based upon the GMD-1 R/S ground equipment. The AN/DMQ-6 flight unit, under development by USAERDL, is designed for use with the GMD-2 sounding system. This latter unit will provide four channels for variable resistance type sensors, so that hypsometric pressure sensors and ozone sensors may also be incorporated at some future date.

As will be shown in Section II. B, temperature measurements accurate to within a few degrees are possible at altitudes to 180, 000 ft, and adequate corrections may possibly be applicable at even higher altitudes to compensate for compressional radiational and internal heating effects.

The Robin balloon sphere is capable of providing vertical soundings of density on the basis of accurate radar tracking data, estimated drag coefficients and the assumption of no vertical wind. Engler (1963) has described rather completely the mathematical rationale and machine data processing methods which are currently being applied to some of the Robin flights, in order to compute appropriately smoothed values of density and, thereby, the pressure and temperature.

4. Tracking, Telemetering and Recording Equipment

Listed in Table 1c are most of the types of radar equipment which have been used at the various MRN stations to track the sensor-targets. This array of radar equipment can be divided, fortunately, into two general classes: 1) the C-band precision AN/FPS-16 radar, and 2) all the remaining radars, which usually operate in the S and X bands and are considerably less precise. For example, the tracking precision of AN/FPS-16 is ±0. 14 mils and ±15 yards, as compared to the AN/MPQ-12 (typical of the large class of modified SCR-584 radars) which has a tracking precision of approximately ±2 mils and ±40 yards.

In addition to radar, RDF tracking may be used in the case of parachute observations, where a flight transmitter can be used in conjunction with such ground equipment as GMD-1, double GMD-1 and GMD-2.

A variety of telemetering units have been developed for use with the M/R parachute system. The flight units which operate in conjunction with the GMD-1 ground equipment includes the Alpha package, the Gammasonde (or Gamma package) and Arcasonde. These units represent varying degrees of modification and redesign of the basic AN/AMT-4 radiosonde telemetry unit.

Developed for use with the AN/GMD-2 system is the AN/DMQ-6 Rocketsonde, which carries a hypsometer in addition the bead thermistor. The AN/DMQ-6, which has been successfully flight tested, permits the M/R observations to be made independently of the radar equipment on the missile ranges. Also in the design stage for eventual use with the GMD-2 is the AN/DMQ (XE-1) four-channel parallel telemetering rocketsonde; sensors flown with this unit will not have to share the telemetering system but can each telemeter simultaneously.

The standard MRN practice regarding the recording of tracking data for wind computation is to feed the basic slant range, azimuth and elevation angles of the target into a computer which will print out the position in rectangular coordinates and also print out graphical X-Y and Z-R plots of the target trajectory. The graphical plots are on a scale of 4000 yd/inch; time marks at 30 sec or 1 min intervals are indicated on the trajectory plot. Average wind components can then be read off between the plotted positions using a calibrated wind scale overlay.

In the case of Robin observations with AN/FPS-16 radar tracking, a more elaborate digital data recording scheme is employed. The tracking data, acquired at a basic rate of 10 per second, is recorded on magnetic tape for computer processing to apply the necessary smoothing and to calculate the average winds over selected time intervals. The basic data tapes can also be used with appropriate computer programs to calculate density, pressure and temperature.

In the case of telemetered data such as temperature, the AN/TMQ-5 R/S recorder is used. A reference frequency is also recorded at 2-min intervals to provide a check on "drift" and to thereby enable corrections to be made to the recorded frequency values.

B. Accuracy of Rocket Data

1. Wind

A brief summary of available information relating to M/R wind errors is presented in Tables 2a to 2c. The separate categories of target response error, tracking error and total wind error, as well as special remarks concerning instrumental problems and wind variability implications, have been considered for each basic type of M/R wind sensor.

The first extensive analyses of M/R wind errors were those published by L. B. Smith (1960) and Rapp (1960); these articles are both concerned with the same series of foil chaff wind observations made over Johnston Island and Tonopah, Nevada in 1958, prior to the initiation of the MRN. Smith's analysis considered all 23 observations covering an overall altitude range of 130-300,000 ft; Rapp's sample was limited to selected observations within the altitude range of 235-265,000 ft. In order to estimate the total wind error, Rapp and Smith both used a statistical estimation technique which depends upon the analysis of differences between simultaneous sets of data obtained by two individual radars. The conclusions of Rapp and Smith regarding the total wind error were in substantial agreement: 20 vs 23 knots, respectively, as the standard error deviation of the vector wind.

a. Instrumental Error

Smith (1960) provides a detailed estimate of the wind error due to instrumental inaccuracies alone, based upon the method described by de Jong (1958). This procedure provides estimates of maximum wind errors as a

Table 2 a ERRORS IN METEOROLOGICAL ROCKET WIND DATA

TYPE OF SENSOR				TARGET RESPONSE ERRORS	TRACKING ERRORS	
CHAFF	FOIL (aluminum coated plastic 2" x .0157" x .0005")			Standard error deviation of ~10 knots due to target inhomogeneity (Smith 1960). Deviation between chaff and wind velocity ~1.5 mps (Rapp 1960).	Response time of wind sensors not a serious problem below 200,000 ft. (Jenkins 1962). The ability of a falling object to respond to a given wind shear is a function only of the fall velocity. (Lally and Leviton 1958).	The error standard deviation due to positioning is ~8 knots. (Smith 1960)
CHAFF	CYLINDRICAL DIPOLE	COPPER	.005" Dia.		Response time of wind sensors not a serious problem below 200,000 ft. (Jenkins 1962). The ability of a falling object to respond to a given wind shear is a function only of the fall velocity. (Lally and Leviton 1958).	
CHAFF	CYLINDRICAL DIPOLE	COPPER	.010" Dia.		Response time of wind sensors not a serious problem below 200,000 ft. (Jenkins 1962). The ability of a falling object to respond to a given wind shear is a function only of the fall velocity. (Lally and Leviton 1958).	
CHAFF	CYLINDRICAL DIPOLE	METALIZED NYLON "SUCHY"	.008" Dia.	Suchy chaff approaches wind velocity very rapidly, ie. $\frac{1}{2}$ min.	Response time of wind sensors not a serious problem below 200,000 ft. (Jenkins 1962). The ability of a falling object to respond to a given wind shear is a function only of the fall velocity. (Lally and Leviton 1958).	
CHAFF	CYLINDRICAL DIPOLE	METALIZED NYLON "SUCHY"	.012" Dia.	Suchy chaff approaches wind velocity very rapidly, ie. $\frac{1}{2}$ min.	Response time of wind sensors not a serious problem below 200,000 ft. (Jenkins 1962). The ability of a falling object to respond to a given wind shear is a function only of the fall velocity. (Lally and Leviton 1958).	
PARACHUTE	8 Ft. Dia.			Lag time for parachute sensing of wind is a significant factor (Beyers and Thiele 1960).	Response time of wind sensors not a serious problem below 200,000 ft. (Jenkins 1962). The ability of a falling object to respond to a given wind shear is a function only of the fall velocity. (Lally and Leviton 1958).	
PARACHUTE	15 Ft. Dia.				Response time of wind sensors not a serious problem below 200,000 ft. (Jenkins 1962). The ability of a falling object to respond to a given wind shear is a function only of the fall velocity. (Lally and Leviton 1958).	The estimated radar tracking error, for the 15-ft. parachute system, is of the order of 3 mps or less for FPS-16 and Mod II radars (JSAG 1961).
"ROBIN" BALLOON SPHERE				Representative RMS wind vector error for collapsed ROBIN spheres is 7 knots, compared to 1 knot for fully inflated spheres. (Lenhard & Wright 1963).		

TABLE 2 b ERRORS IN METEOROLOGICAL ROCKET WIND DATA

<table>
<tr><th colspan="4">TYPE OF SYSTEM</th><th colspan="3">OVERALL WIND ERRORS</th></tr>
<tr><td rowspan="5">CHAFF</td><td colspan="3">FOIL
(aluminum coated plastic 2" x .0157"x .0006")</td><td>Estimated standard error deviation in total wind vector is 20 knots under optimum conditions (Rapp 1960).
Standard error deviation in wind estimated to be 23 knots (Smith 1960).</td><td rowspan="5">Variability due to errors in tracking chaff actually decreases with altitude (JSAG 1961).</td><td rowspan="8">The uncertainty in rocket-sonde wind speeds is approximately 8 mps or 10% of speed, whichever is greater (Smith and Waughan 1961).
The wind velocity accuracy is ± 5 mph overall (aufm Kampe & Lowenthal 1963).
Estimated error of ~12 kt at 30 km and ~14 kt at 40 km, as a crude average from tabulated data (Bruch & Morgan 1961).
A 30-knot difference in easterly winds has been noted in "simultaneous" chaff and parachute observations at 200,000 ft. (Jenkins 1962).
Wind accuracy is 10 mps for assumed conditions where wind shear is 0.02 units/sec and fall velocity of sensor is 70 mps (Lally & Leviton 1958).
Bias effects due to carry over of rocket speed to sensor may be significant (Bruch and Morgan 1961).</td></tr>
<tr><td rowspan="4">CYLINDRICAL DIPOLE</td><td rowspan="2">COPPER</td><td>.005" Dia.</td><td rowspan="2"></td></tr>
<tr><td>.010" Dia.</td></tr>
<tr><td rowspan="2">METALIZED NYLON "SUCHEY"</td><td>.008" Dia.</td><td rowspan="2"></td></tr>
<tr><td>.012" Dia.</td></tr>
<tr><td colspan="3" rowspan="2">PARACHUTE</td><td>8 Ft. Dia.</td><td colspan="2"></td></tr>
<tr><td>15 Ft. Dia.</td><td colspan="2">Total wind error is ~3 mps for 1-minute average winds based on FPS-16 or Mod II tracking (JSAG 1961).</td></tr>
<tr><td colspan="4">"ROBIN" BALLOON SPHERE</td><td colspan="2">Below 180,000 ft. standard error deviation ~10 knots (Keegan 1961).
RMS wind errors with FPS-16 tracking and "31-7" smoothing are 4.4 kt at 60-70 km, 1.8 kt at 50-60 km and 1.1 kt at 40-50 km (Lenhard & Wright 1963).
Estimated 2σ error of 1.5-2.0 knots: 1.5 knots from 30-50 km and 2.0 knots from 50-70 km (Engler and Wright 1962).</td></tr>
</table>

TABLE 2c ERRORS IN METEOROLOGICAL ROCKET WIND DATA

TYPE OF SYSTEM				SPECIAL REMARKS: INSTRUMENTAL PROBLEMS	SPECIAL REMARKS: PROBLEMS OF WIND VARIABILITY
CHAFF	FOIL (aluminim coated plastic 2" x .0157" x .0006")			Clumping ("birdnesting") problems on occasion, with rainout of clumped or matted chaff.	Wind variability is a very important problem since it serves to confuse the issue of basic wind errors to a rather uncertain extent.
CHAFF	CYLINDRICAL DIPOLE	COPPER	.005" diam.	Dispersion problems - hunting and twinkling, and the limitation of vertical resolution caused by a dispersing sensor.	Wind variability increases between 25-65 km to a value of approximately 8 mps (aufm Kampe & Lowenthal 1963).
CHAFF	CYLINDRICAL DIPOLE	COPPER	.010" diam.	The slow descent rate at lower levels may frequently lead to conflict with other range tracking requirements.	RMS wind variation due to tidal motions: 4.9 mps at 35 km, 7.4 mps at 43 km, and 12.4 mps at 64 km.
CHAFF	CYLINDRICAL DIPOLE	METALLIZED NYLON "SUCHY"	.008" diam.		RMS wind variation due to turbulence: 1.7 mps at 35 km, 5.1 mps at 43 km and 5.7 mps at 64 km (Lenhard and Wright 1963).
CHAFF	CYLINDRICAL DIPOLE	METALLIZED NYLON "SUCHY"	.012" diam.		
PARACHUTE	8-ft. diam.			No deployment problem (Beyers and Thiele 1961). Acquisition problem for Mod SCR 584 and M33 radars (Beyers & Thiele 1961).	
PARACHUTE	15-ft. diam.			Deployment problem severe above 200,000 ft. Parachute glide, slip and under-inflation. (Murrow and Dozier 1963). Initial acquisition problem for Mod SCR 584 and M33 radars (Beyers & Thiele 1961). Pronounced oscillations & excessive fall velocities.	
"ROBIN" BALLOON SPHERE				Partial collapse	

function of rated instrumental errors in slange range and the elevation and azimuth angles. It is assumed that the instrument error is independent of the measured argument, e.g., the error in elevation angle does not depend upon the particular value of the elevation. de Jong considers the two limiting cases wherein the target is either moving away along the line of observation or it is moving in a direction perpendicular to the line of observation.

de Jong's two expressions, as presented in L. B. Smith's slightly modified notation, are as follows:

$$\sigma_s = \frac{\sqrt{2}}{\Delta t} \left[\frac{h^2 (d^2 + h^2) \sigma_{eL}{}^2 + d^2 \sigma_R{}^2}{d^2 + h^2} \right]^{1/2} \tag{1}$$

$$\sigma_s = \frac{d \sqrt{2}}{\Delta t} \sigma_\alpha \tag{2}$$

where:

σ = error standard deviation

Δt = time interval between observations

h = height of the target

d = horizontal distance out

s = speed

eL = elevation angle

R = slant range

α = azimuth

Equation (1) applies to a target moving directly away, and Equation (2) applies to target motion perpendicular to the line of observation.

Smith computed values of σ_s for altitudes 60-90 km and horizontal distances 20-150 km on the basis of both Equations (1) and (2) and presented in his table the greater of each pair of values as the maximum rms error due to tracking inaccuracy. Using these same expressions, we have carried out the calculations for the altitude range 30-60 km; the results are presented in Table 3.

Table 3. Estimated Range of rms Wind Error (knots) due to Tracking Error for Modified SCR-584 Radar*

Altitude	Horizontal Distance (km)				
(km)	20	40	60	100	150
30	1.8 - 2.7	2.8 - 3.6	2.8 - 5.4	2.8 - 9.0	2.8 - 13.5
40	1.8 - 3.6	3.6	3.6 - 5.4	3.7 - 9.0	3.7 - 13.5
50	1.8 - 4.5	3.6 - 4.5	4.5 - 5.4	4.5 - 9.0	4.5 - 13.5
60	1.8 - 5.4	3.6 - 5.4	5.4	5.4 - 9.0	5.4 - 13.5

*See text for description of method and assumptions involved.

It should be noted that the table contains the range of error values resulting from the separate calculations with Equations (1) and (2); the error which would apply to a particular observation would usually fall somewhere within the indicated range. The values computed from Equation (1) have been underlined. For a given altitude, the wind error is relatively constant for a target moving along the line of observation, but increases linearly with horizontal distance in the base of a target moving perpendicular to the line of observation. On the other hand, for a given horizontal distance out, the wind error computed from Equation (1) increases rather linearly with altitude, and the wind error calculated from Equation (2) is relatively constant.

It should also be noted that σ_s in both cases is inversely proportional to the Δt, the time interval between observations. The calculations presented here, it should be stressed, apply to a Δt of 1 min and would significantly change for other Δt values.

If we now consider the estimated radar tracking error for M/R winds presented by the MRN Joint Advisory Scientific Group (1961), i.e., of the order of 3 m/sec or less for FPS-16 and Mod II radar, this estimate would appear to be a reasonable one to apply to typical conditions where the horizontal distance does not exceed 60 km.

Realistic estimates of the tracking error can be made, therefore, on the basis of de Jong's mathematical model. It should be pointed out, however, that there are sophisticated statistical techniques for data "beneficiation" which can reduce the effective tracking error for a particular system. For example, in the case of winds computed from Robin-FPS/16 observations, the basic radar tracking data can be obtained at a high acquisition rate and then subjected to various smoothing processes in order to eliminate the effect of larger errors. Engler and Wright (1962) and Engler (1963) have discussed in detail the rationale, the problems and the benefits of such smoothing procedures as applied to Robin wind observations.

b. Target Response Error

Another important category of errors in M/R wind measurements is that associated with target response. Jenkins (1962) has stated that the response time of sensors is not a serious problem below 200, 000 ft, and that is certainly the case relative to the extremely serious problems generally encountered above this altitude. There are, nevertheless, certain aspects of the M/R target response problem which will now be briefly considered.

Lally and Leviton (1958) have provided the basic paper dealing with the response of falling objects to the vertical wind pattern. Their frequently quoted conclusions are: 1) "the ability of a falling object to respond to a given wind shear is a function only of the fall velocity", and 2) " an object falling at speeds in excess of 70 m/sec will not respond satisfactorily to a wind shear of as little as 0.02 units/sec". Lally and Leviton also concluded that proposed balloon sphere, parachute and chaff systems could each perform satisfactorily to 60 km. The conclusions of more recent investigators, e.g., Beyers, et al. (1962) and Jenkins (1962) have substantially agreed with Lally and Leviton's initial estimates.

Beyers, et al. (1962) clearly point out that there are problems inherent in rocket wind measuring systems which are not found in other standard methods, i.e., rawinsonde (R/W) systems. These problems include possible errors introduced through excessive fall velocities of both parachutes and chaff, chaff dispersion, and parachute slip and glide. The criticality of high sensor fall rates varies with the particular vertical wind structure through which the sensor is falling. Beyers, et al. (1962) present a graph of wind shear error vs altitude for the 15-ft parachute system (based upon Lally and Leviton's tabular values, 1958). An impressively large spread of error values is possible, depending upon the wind shear; as an example, a 24-knot error at 60 km would be associated with a rather modest vertical wind shear of 6 knots/1000 ft.

Cylindrical dipole chaff has excellent fall rate characteristics above 150,000 ft as compared to the 15-ft parachute and Robin systems, but the basic dispersion problem significantly detracts from the usefulness of chaff systems and serves to introduce a somewhat unassessable element of error into winds obtained by this method. Radar observations of 0.012 cylindrical nylon chaff indicate that these chaff payloads disperse over regions of greater than 35 cu miles within 20 min of chaff deployment and over 50 cu miles in 30 min (Beyers, et al., 1962). In addition, the radar usually shows two or more particular areas within the chaff cloud that reflect substantially more energy than other areas within the cloud, and it may be assumed that these bright spots will vary with time. Aside from qualitative comparison of vertical wind profiles obtained by chaff with those made with other sensors, no practical assessment has been made of the wind error resulting from chaff dispersion. It would appear that undue emphasis has sometimes been placed upon Barr's (1960) theoretical computations, which showed that below 200, 000 ft, the chaff would track the wind practically instantaneously and no correction to the wind as measured by the radar would have to be made; this statement is certainly true as far as it goes, but does not encompass all aspects of the target response problem for chaff wind sensors.

In the case of the Robin sphere, Lenhard and Wright (1963) have shown that the representative rms vector error for Robin winds increases from 1 to 7 knots for collapsed spheres, as compared to those which remain fully inflated.

Another special problem related to M/R wind measurements is the possible bias effect on wind measurements made close to the time of sensor explusion from the rocket. It has been shown, however, that all of the initial horizontal velocity component due to the rocket velocity disappears within less than 2 minute (Beyers, et al., 1962).

c. Overall Error

As indicated in Table 2b, there are numerous published estimates and opinions regarding the overall error in M/R wind data. Each reflects the type and number of data which happened to be available at the time, as well as the nature of the assumptions which were made in performing the error analysis. In addition, there is somewhat of a "semantic barrier" to be contended with: the exact meanings of "uncertainty", "error" and "accuracy", and whether they are being applied to component or vector error, are not always clear.

Our studies have shown that the size of the tracking error and the target response error depend to a large extent upon the ambient wind conditions. Therefore, any realistic estimates of overall M/R wind error should properly be based upon appropriately weighted samples which would take into full account the various diverse factors which may contribute to the overall error. However, true scientific caution cannot always be conveniently exercised. Thus, as a general estimate of the overall wind error (vector standard deviation), a value of 10-20 knots seems reasonable. Aufm Kampe and Lowenthal's wind accuracy estimate (1963) of 5 mph seems to be quite low for present-day conditions. However, only more careful, comprehensive parametric evaluation of M/R wind error can yield the definitive answer.

2. Temperature

A summary of estimated errors in M/R temperature and density data is presented in Table 4. It is not absolutely certain whether these values represent standard errors, probable errors or two-standard deviation errors. In the case of Wagner, et al. (1961), the estimate of ±2°C for temperature error to 60 km can be taken to represent the standard error; the estimate of temperature error within ±2°C below 45 km and within ±5°C to 56 km (Wagner, 1961) can be taken to represent approximately the two-standard deviation error, or the range within which some 95 percent of a population of normally distributed errors would occur. The estimate by Beyers, et al. (1962) of ±2°C for uncorrected temperature data to 57-60 km is regarded as a standard error; similarly, the estimate of ±0.5°C for corrected temperature data by the same authors is regarded as a standard error. The estimate of ~1°C error in temperature measurements to 50 km (aufm Kampe and Lowenthal 1963) is regarded a standard error; this estimate, it should be noted, applies to perfectly aluminized thermistor beads, otherwise the error is larger, although it probably does not exceed 5°C.

By way of summary, then, the standard error in M/R temperature measurements is approximately ±1°C in the 30-45 km range, increasing to a value of ±2°C near 60 km. These values apply to uncorrected temperature data obtained under average conditions; Beyers, et al. (1962) have reported that appreciable error reduction can be achieved by applying appropriate corrections. It should be mentioned in passing that the temperature error increases very rapidly above 60 km.

TABLE 4 ERRORS IN M/R TEMPERATURE AND DENSITY DATA

TYPE OF SYSTEM	ERRORS	SPECIAL REMARKS
PARACHUTE (8 ft. and 15 ft. diam.)	The temperature error at 50 km is ~1°C with a perfectly aluminized bead thermistor, otherwise higher but not > 5°C. (aufm Kampe and Lowenthal 1963). Error of ± 0.5°C for corrected temperature data to 57-60 km and ± 0.5°C for corrected data (Beyers et al 1962). Temperature error is within ± 2°C below 45 km and within ± 5°C to 56 km (Wagner 1961). Temperature error is ± 2°C to 60 km (Wagner et al 1961). Occasionally large temperature errors may result from a calibration shift due to nose cone heating during rocket ascent (Wagner et al 1961). Density data derived from rocketsonde temperature measurements have a probable error of 2% and are all accurate to within 5% (Thiele 1963).	Strange spikes on the temperature traces have been noted these may be due to heat flow from thin support wires. The major problem areas, however, involve self-heating, solar radiation, fall velocity and time constant.
"ROBIN" BALLOON SPHERE	RMS error in density is 3% at 60 km and about 2% at lower levels, assuming no vertical winds (Leviton and Wright 1961). Density values are accurate to within ± 3%, for an assumed "normal" wind of 1 mps (Engler 1963). Neglect of vertical motion may significantly affect calculated density values. A vertical wind ~0.5-1.5 mps causes ~2% density error and a vertical wind ~2-8 mps produces a ~10% density error in the altitude range of 40-60 km. (Kern and Rapp 1963). ROBIN density data appears suitable for climatological studies (Engler 1963).	Density computation from ROBIN critically depends upon the drag coefficient and this in turn upon the state of inflation of the balloon sphere. Smoothing is another vital area as shown by Engler's detailed studies.

Certain problem areas are still not completely resolved in regard to self-heating, solar radiation, fall velocity and instrumental time constant. In addition, Wagner, et al. (1961) have pointed out that very large temperature errors may occasionally result from a calibration shift due to nose cone heating during rocket ascent. Large systematic errors of this type can be corrected, however, if parallel R/S temperature data are available. Indeed, as will be discussed in Section VI of this report, the current practice is to correct the M/R temperature profile to agree with the overlapping portion of the R/S temperature profile, when such data are available.

The error situation in regard to density measurements with the Robin system have been brought into focus by several writers, including Leviton and Wright (1961), Engler (1963), and Kern and Rapp (1963). It seems reasonable to assume that the density can be measured by the Robin sphere to within $\pm 3\%$ over the 30-60 km altitude range if the vertical motion is really negligible and if the balloon is in a fully inflated state.

C. Properties of Rawinsonde (R/W) Systems

The general characteristics of R/W systems are considered to be so well known that specific details of the equipment and procedures which are used for a series of observations are seldom made a part of the final data record. For example, the IRIG-MWG series of data reports for the MRN do not specify the carrier vehicles, sensors and other equipment used to make the accompanying R/W observations. Nor do any of the upper-air stations in the U. S. report the type of equipment used. This is a serious omission, as the R/W wind error is dependent upon the type of flight and ground equipment used.

A small attempt has been made in Tables 5a and 5b to summarize a few of the significant characteristics of current R/W systems, including the new rising sphere method of detailed wind determination based upon very accurate FPS-16 radar tracking. There are numerous references which deal comprehensively with certain particular aspects of R/W systems or which deal

TABLE 5 a CHARACTERISTICS OF U.S. RAWINSONDE AND SIMILAR ASCENDING SYSTEMS

TYPE OF SYSTEM	CARRIER VEHICLE	ASCENT RATE	MAX. ALTITUDE ATTAINABLE	PARAMETERS MEASURED	SENSORS
RAWINSONDE	Various-sized neoprene and rubber balloons in the range of 350-3300 gm, mostly 1000-1400 gm.	Ascent rates average 1000-1200 fpm for the complete sounding, and are probably 1300-1400 fpm in the vicinity of 25-35 km.	35 km represents the practical limit of present-day balloons. The ultimate limit of R/S flights is 45 km (Myers 1962).	WIND	RDF tracking of radio transmitter AN/AMT-4 (or AN/AMT-12 or 15) provides vertical and azimuth angles; altitude from synchronous pressure-temperature data.
					RDF tracking of radio transmitter AN/AMT-9 provides vertical and azimuth angles; remitter unit provides slant range.
					Radar tracking of passive target carried on balloon train.
				TEMPERATURE	3-cm rod thermistor, 10-mil bead thermistor externally mounted. Shielded type obsolescent.
				PRESSURE	Hypsometers for high-altitude pressure measurement, used with AN/AMT-12 or 15; altitude from hypsometric equation. Aneroid cell.
"ROSE"	2-meter diameter aluminized spherical balloon	Average ascent rate approximately 1500-1600 fpm.	45 km represents the effective altitude limit for future versions of this type balloon.	WIND	Radar tracking of metallized balloon provides required angles and slant range.

TABLE 5 b CHARACTERISTICS OF RAWINSONDE AND SIMILAR ASCENDING SYSTEMS

TYPE OF SYSTEM	PARAMETERS MEASURED	TRACKING AND RECORDING EQUIPMENT	ALTITUDE RANGE OF EFFECTIVE DATA	DATA PROCESSING TECHNIQUES
RAWINSONDE	WIND	SCR-658 (obsolescent)	SCR-658 has a limiting low angle of 15°. (Circular 0, 1959)	A 2-minute averaging interval is used <14 km and a 4-minute averaging interval >14 km. (Circular 0, 1959) Averaging over a vertical interval of 6000 ft. will remove the maximum amount of variability desirable for application of the wind data to routine aviation forecasting. (Ellsaesser 1960)
		GMD-1	GMD-1 has a limiting low angle of 6°. (Circular 0, 1959)	
		WBRT-57	WBRT has a limiting low angle of 4.5°. (Harmantas 1961)	
		GMD-2		
		VARIOUS RADARS	Under optimum conditions of balloon performance and low wind velocity profile, data to 35-40 km is possible.	
	TEMPERATURE AND PRESSURE	AN/TMQ-5 RADIOSONDE RECORDER	Average maximum altitude of USWB R/S flights is 90-95,000 ft. (Myers 1962)	
"ROSE"	WIND	FPS-16 and other radar trackers.		

in a very broad way with the general properties of atmospheric sounding systems. Unfortunately, there does not appear to exist at this time a complete, up-to-date detailed document which comparatively describes the various R/W systems, their accuracy, and the extent to which they are currently being used by U. S. military and civilian agencies; this deficiency is even more serious on the international scale. In the USAF Handbook of Geophysics (rev. ed., 1960), only a very brief account (one page of text and three pages of tables) is provided for R/W systems, as compared to the 20 pages devoted to the various detailed properties of constant level balloons, which are newer and more interesting but operationally still far less important. Haig and Lally (1958) and Myers (1962) provide general descriptions of the various R/W equipment which have evolved from the original Diamond-Hinman system of the 1930's.

Recent developmental work in fast-rising, high-altitude balloons, hypsometric pressure sensors, standardized radiation corrections for temperature measurements and GMD-2 remitter-type RDF tracking equipment will ensure a future R/W system which can provide acceptably accurate wind, temperature and other data to altitudes of 30-35 km. At the present time, however, the R/W wind data situation is confused, since improved equipment has been incorporated irregularly. Even at the various stations in the MRN, for example, R/W observations are still being made with the GMD-1, thereby providing a less detailed and accurate vertical wind profile than could be provided by GMD-2 data for comparison with meteorological rocketsonde winds.

The extent to which the hyposmeter has replaced the aneroid cell is not known, yet the difference in reliability of pressure heights at 10 mb by the two methods makes this sensor identification imperative. Similarly, the type of thermistor and its exposure and whether or not radiation corrections are included in the reported temperatures should be indicated.

There is, thus, a definite need at the present time to determine experimentally and to publish a comprehensive summary of the high-altitude performance characteristics of R/W systems in current use and to indicate in reported data, which sensors were used.

D. Accuracy of Rawinsonde Data

There were at least five different radiosonde systems used in the United States in 1958 (Teweles and Finger, 1960) each having different properties, and a large number of foreign sondes differing widely from the U. S. models and from each other. The accuracy of the R/S appears acceptable for routine use in the troposphere for which it was designed. Its gradual extension to the stratosphere by the use of larger balloons, however, has introduced serious questions of accuracy which are seldom faced until the application demands it. What is needed, clearly, is a stratospheric balloon sounding system designed for the levels from 15-35 km.

To properly interpret R/W wind data and to estimate its probable error, adequate information on thermistor, pressure sensor, balloon type, free lift, tracking equipment, data processing techniques, and operational practices must be known. For example, it is often believed that the vertical resolution of 4-min averaged R/W data is 4000 ft, based on an assumed constant ascent rate of 1000 ft/min. However, average ascent rates of 1400 ft/min at 100, 000 ft have been reported (Sharenow, 1958). The corresponding atmospheric layer represented by each observation is thus 5600 ft.

It would be most desirable if values of standard error could be included with all published meteorological data; at small additional cost, the usefulness of all R/W and rocket data would be considerably enhanced.

The errors in the present non-transponder R/W systems include all those of the R/S upon which it is dependent for height computations. A brief summary of information relating to R/W pressure, temperature and wind errors is presented in Table 6. Concerning the temperature error, there is little which can be added to the remarks contained in the table: the standard temperature error for U. S. instruments has been rather clearly established as approximately $\pm 1°C$ in the troposphere, gradually increasing to an approximate value of $\pm 2°C$ near 100, 000 ft.

TABLE 6 ERRORS IN RAWINSONDE WIND AND TEMPERATURE DATA

TYPE OF SYSTEM	PARAMETER	TYPE OF MEASUREMENT	COMPONENT ERRORS IN SENSOR, TRACKING, PROCESSING, ETC.	OVERALL ERRORS
RAWINSONDE	WIND	GMD-1 and WBRT-57	Appropriate smoothing technique might reduce GMD-1 wind errors (Lenhard 1959).	General agreement that the error increases with altitude--reaching an rms error value of 22 fps at 10 mb (Lenhard 1959). Wind vector error is dependent upon geometric position of balloon with respect to tracking equipment--the dominant term of the wind vector error can be written as $\sigma_v = 0.9\ h \times 10^{-2}/\sin^2\alpha$, where σ_v is rms vector error in knots, h is height of balloon in 1000's of feet and α is the elevation angle (Johannessen 1959).
RAWINSONDE	WIND	GMD-2		Average rms wind vector error for 4 Salton Sea tests was 0.34 mps--but this did not reflect behavior of GMD-2 at angles < 20° or at slant ranges > 140,000 ft. (Keily & Beaubien 1963). RMS wind vector error ~5 fps, for assumed low angle of 6° altitude of 40,000 ft. and 2-min. averaging interval. (Dvoskin & Sissenwine 1958).
RAWINSONDE	TEMPERATURE		Errors due to solar radiation, instrument radiation, lag, calibration and recording. Rad. error 3°C to 30 km 10°C at 45 km (Shaw 1959). RMS temperature error due to sensing is 1°C to 10 mb (Lenhard 1959). RMS temperature error due to pressure error increases from 0.2°C at 700 mb to 1.7°C at 10 mb (Lenhard 1959).	Standard error ± 1°C below 30 km (Leviton 1954). External thermistor 2°C at 25 km, smaller below and larger above. Duct type has larger errors in stratosphere (Teweles & Finger 1960). Standard temperature error of ± 1°C to 60,000 ft. and somewhat greater at higher altitudes (AWS TR 105-133, 1955). Total temperature error increases from ~1°C at 700 mb to ~2°C at 10 mb (Lenhard 1959). Temperature error ± 0.7°C (Johannessen 1959).
RAWINSONDE	PRESSURE		Aneroid cell--subject to hysteresis and lag at high altitudes.	± 1 mb at low pressure. At 10 mb, 1 mb = 600 m. At 2 mb, 1 mb = 1500 m. (Conover 1961).
RAWINSONDE	PRESSURE		Hypsometer: full range: 1060 to 40 mb, high altitude: 70 to 4 mb. Uses AN/AMT 12 or 15 modulator. In practice used from 50 to 4 mb (Conover 1961).	± 0.3 % of true pressure, 1060 to 40 mb. ± 0.7 % of true pressure, 70 to 4 mb. (Sapoff 1958).
"ROSE"	WIND	FPS-16 radar	FPS-16 has a theoretical rms tracking accuracy of 0.5 yards in range and 0.003° in azimuth and elevation angles--operational accuracy, however, not quite that good (Leviton 1962).	RMS speed errors for 5-sec. time-averaged sphere displacements, with FPS-16 tracking, are 2.0-2.6 fps at 60,000 ft., varying with the wind speed--errors would be higher at altitudes above. (Leviton 1962).

According to an Air Weather Service study (1955), there are two principal components to the error in the height of pressure surfaces: 1) the height error which corresponds to the pressure error in the aneroid unit, and 2) the error in the height of the pressure surface which results from the integrated error in successive thickness calculations. This latter error is predominantly caused by the error in determining the mean virtual temperature of each calculated layer (a negligible error effect is produced by the mean error in the measurement of pressure). Table 7 presents estimates of the pressure height error associated with R/S aneroid elements of that time.

Table 7. Pressure Height Errors of Radiosondes*

Pressure (mb)	Error in Height of Pressure Surface (σ_H), ft	Corresponding Pressure Error**, ft	Standard Deviation of True Height (σ_Z), ft
700	34	111	116
500	67	144	159
300	119	219	250
200	161	315	354
100	229	418	477
50	291	630	694
25	355	1257	1306
10	456	3140	3173

* From Table 12, AWS TR 105-133, Accuracies of Radiosonde Data (1955).
** 3 mb up to and including 200 mb; 2 mb at 100 mb, and 1.5 mb above.

Suprisingly little has ever appeared in the literature regarding the actual error distributions for high-level R/W winds measured by the SCR-658, GMD-1 and WBRT-57, and the GMD-2 systems, even though estimates of wind accuracy should be essential for all stratospheric circulation studies.

Some excellent articles have dealt with certain aspects of the upper level wind error problem, such as de Jong's generalized analysis of upper level wind errors (1958), but a comprehensive, definitive analysis of actual error distributions as a function of altitude, equipment and climatological wind profile has yet to be made. This is a rather glaring deficiency in view of the many articles which have been concerned with the problem of wind shear measurement but which have often avoided the question of basic errors in the reported winds.

The matter of R/W wind error assessment is admittedly difficult, as special observational series of R/W flights are required. The error analysis can be based upon: 1) ingenious statistical methods such as those developed by Rapp (1952) to estimate the variability and instrumental error of the AN/GMD-1 system, or 2) straightforward analysis of measured winds compared with an accurate standard, e.g., the comparison of winds measured by AN/GMD-2 with those measured by four-station Askania type photo-theodolites (Keily and Beaubien, 1963). However, in the former case, Rapp's estimates of wind error for the GMD-1 system only extend to 8.5 km, and in the latter case, Keily and Beaubien's results only apply to selected conditions of low wind speed profiles.

Any meaningful analysis of upper wind error must consider error as a function of the target-tracker distance and the elevation angle. Johannessen (1959) considers GMD-1A wind error in terms of balloon height and elevation angle, for averaging intervals of approximately 2000 ft below 14 km and 4000 ft above this level. He expresses the dominant term of the wind vector error as follows:

$$\sigma_v = \frac{0.9\, h \times 10^{-2}}{\sin^2 \alpha}$$

where:

σ_v = rms wind vector error in knots

h = height of the balloon in thousands of feet

α = elevation angle.

The elevation angle is determined by the mean wind speed below the level in question, except in cases of very pronounced directional variability where the mean wind speed and mean wind vector are substantially different. Johannessen proposes that this method be used to compute the error envelopes at selected probability levels for specific vertical wind profiles.

If, for example, we apply Johannessen's error equation at 100, 000 ft altitude, we can obtain an estimate of the wind error at this level as a function of the associated elevation angle: 4 knots at 30°; 8 knots at 20°; 13 knots at 15°; 27 knots at 10°. If we now associate each value of elevation angle with a mean speed from the surface to 100, 000 ft (neglecting for the moment, although still recognizing, the possible effects of directional variability), and assume a mean ascent rate of 17 ft/sec, we can compute a 4-knot error for a mean speed $\bar{V}_s$ = 17 knots; 8-knot error for $\bar{V}_s$ = 28 knots; 13-knot error for $\bar{V}_s$ = 38 knots; and 27-knot error for $\bar{V}_s$ = 57 knots. It is apparent, even from this crude example, that wind error at 100, 000 ft cannot be overly generalized, either as an absolute value or as a percentage of the mean wind. If we now consider Lenhard's (1959) estimate of 13 knots for the GMD-1 wind error at 100, 000 ft, it can be seen to correspond to a mean speed from the surface to 100, 000 ft of 38 knots and an elevation angle of 15 degrees, assuming no directional variability in the wind. (The values of mean speeds we have been considering here are the minimum possible speeds for the unidirectional case; they would, of course, be underestimates of the average speeds actually occurring from the surface to 100, 000 ft under condition of a pronounced stratospheric wind reversal).

The wind errors for the "Rose" system of small metallized ascending balloon spheres tracked by precision FPS-16 radar are estimated to be quite small, approximately 1.5 knots for 5-sec time-averaged winds at 60,000 ft (Leviton, 1962). There is still some question as to the applicability of this system at higher altitudes of 100,000 ft or more, but the possible advantages of wind measurements by this precise radar tracking system for the MRN should be more thoroughly explored.

The natural variability of the wind has an important bearing upon the size of the measuring error which can be tolerated and the type of data processing required to obtain "representative" wind values. The temporal and spatial variability of winds in the troposphere has been rather extensively explored down to scales of the order of several minutes and a few miles (Ellsaesser, 1960) but with one exception (Mantis, 1963) very little direct information on that scale is available for levels in the vicinity of 100,000 ft, which is often at the very fringe of electronic or optical tracking capabilities. The problem of wind variability will be discussed in the next section on the comparison of R/W and M/R wind data.

E. Comparison of Rocket and Rawin Systems

1. Wind

The basic aim of this study is to evaluate the degree to which current M/R and R/W data are compatible, and to recommend potential improvements for the increased compatibility of such data. Some of the characteristics of the two systems just outlined will now be compared as background for the statistical estimates in the next section.

a. Observational Bias

The limitations of R/W wind measurements at high altitudes have been long recognized and may very seriously affect the representativeness of upper wind statistics. Some of the principal deficiencies of R/W observations are:

1) There is a strong bias in favor of weak winds at high levels which permit a balloon to remain within observation range and acceptable elevation angles longer.

2) For the same reason, a reversal of flow at higher levels may be reported with greater proportional frequency than ascents without reversals.

3) Winds taken with radio direction equipment or other methods which utilize R/S data to determine height, suffer from all the errors inherent in stratospheric R/S measurements due to aneroid and thermistor errors and resultant errors in height computations. Hence, winds may be ascribed to incorrect levels in a not always systematic fashion since the instrumentation errors may be random.

4) The number of balloons reaching highest levels is frequently a function of air temperature; hence, ascents in warmest conditions are more likely to reach highest levels (10 mb, for example) than those taken during coldest air temperatures.

5) Certain large stations have better balloons, techniques, facilities and other supplies for obtaining high ascents.

The properties of MRN observations are not yet sufficiently recognized for their observational limitations to have been discussed in the literature. It is quite obvious, however, that the time and frequency of ascents are not yet regular, but are apparently determined by operational range support requirements. Thus, rocket winds at present suffer mainly from erratic and infrequent frequency of observation with the result that climatological reductions at most stations are of weak significance.

The common practice of extending R/W data upward using the nearest MRN station implies a continuity in space and time which is doubtful. Even when the MRN and R/W data are taken at the same station, large differences may result due not only to time and space differences but, characteristics of the measurements and processing methods, to which we now pass.

b. Sensor Response

Due to the more rapid movement of M/R sensors, the response lag problem is considerably more serious for M/R than R/W wind measuring systems. Relatively high fall rates for the 15-ft parachute and Robin sphere and the continuous diffusive spreading of chaff serve to limit the sensitivity and the accuracy of present-day wind observations by these methods.

The ascent rate of R/W balloon systems is of the order of 20-25 ft/sec and is relatively constant, possibly increasing on the order of 1 ft/sec per 10,000 ft throughout the altitude range of 80-100,000 ft. This relatively slow and steady ascent rate for R/S balloons is a great advantage in terms of providing a naturally consistent scale of wind measurement. By comparison, in the various M/R systems only 0.012 nylon chaff can be said to provide a reasonably consistent fall rate: a decrease from 55 to 30 ft/sec over the altitude interval 200-150,000 ft, and this represents a change in fall rate of approximately 5 ft/sec per 10,000 ft (or five times the comparable value for R/W systems). Unfortunately, however, chaff is a multiple sensor; its diffusive spread introduces an ever increasing uncertainty into the tracking positions as the sounding progresses. No objective procedure has apparently been stipulated by MRN for terminating chaff observations or rejecting chaff position data when the diffusion spread of the chaff cloud no longer permits effective tracking.

In the cases of the 15-ft parachute and the Robin sphere, the descent rates are not only a bit excessive from 50-60 km, but there is a very pronounced rate of change in the fall rate. For the parachute system, the average descent rate is some 350 ft/sec at 200, 000 ft, decreasing to approximately 160 ft/sec at 150, 000 ft (for a change in fall rate of 38 ft/sec per 10, 000 ft), and further decreasing to about 50 ft/sec at 100, 000 ft (for a change in fall rate over this lower altitude interval of 22 ft/sec per 10, 000 ft). For the Robin sphere system, the fall rates and rate of change in fall rates are even higher.

In the vicinity of 100, 000 ft, the average descent rates for all the various M/R systems are approximately twice the magnitude of the average R/W ascent rate. This disparity in the natural measuring scale, in addition to the opposite direction of the lag effect, are facts which should be considered and balanced against other factors, such as time and space resolution of measurements, especially when substantial vertical wind shear is present so that sensitivity of wind measurement becomes an important consideration.

Compatibility of M/R and R/W wind data is only obvious in the vicinity where these data overlap, but is nevertheless a significant factor to consider in the combined use of such data. Consider, for example, the joint use which is typically made of R/W and M/R data to construct vertical profiles of the component winds from the surface to 60 km, e.g., the IRIG-MWG data reports. The user of such information currently carries the burden of having to modify these profiles subjectively, if indeed he can at all, to account for effects arising from variable sensor response. This problem is further compounded, as will be shown, as a result of current data processing techniques.

c. Tracking Equipment

Another important category of M/R and R/W data differences is associated with the many diverse types of tracking equipment currently in use at the various MRN range stations. Some degree of standardization must occur; the present hodgepodge of RDF and radar tracking systems will eventually give way to a greater uniformity of tracking (and flight) equipment. In view of basic allocation and interference problems for radar operation at the larger missile ranges, an advanced RDF system such as the GMD-2 may be the solution. For M/R wind measurements, the 15-ft parachute with AN/DMQ-6 flight unit could then become the standard observational technique.

At the present time, however, the non-standardization of tracking equipment introduces a variable difference between R/W and M/R data. The R/W data are generally obtained with a GMD-1 tracking unit, and rather often (especially in winter during conditions of strong, consistently westerly flow) the wind data at the highest levels, say 80-100,000 ft, are based upon position data obtained at the outermost fringe of this tracking system's capability.

However, in the case of M/R wind data, the radar tracking equipment is operated well within its range and low angle capability since the carrier rocket releases the sensor approximately overhead and the fall rates are relatively high. It has been clearly demonstrated that the FPS-16 radar unit is capable of providing M/R wind data which is greatly superior in resolution to that obtained by the GMD-1 or by other radar trackers. The FPS-16 can skin-track the carrier rocket and thereby permit faster, more reliable acquisition of the wind sensor following ejection. Unfortunately, the FPS-16 is very expensive and can not be used everywhere; as a result, the tracking error in M/R wind data is variable, depending upon the particular tracking system. This strongly suggests the desirability of at least clearly labeling each M/R wind observation according to the type of tracking equipment used, and possibly even including as an integral part of the observational data an estimate of the wind tracking error.

d. Data Processing and Reporting Techniques

The disparity between M/R and R/W wind data which results from different techniques of processing and reporting represents another important problem area, but fortunately an area where significant improvement could be most readily made.

The standard procedure for R/W wind data above 14 km is to compute 4-min average winds reported at 2-min intervals from positions obtained at 1-min intervals. With GMD-1 observations, the heights corresponding to each minute of the observation are obtained from the pressure-height curve which is computed from simultaneous radiosonde data. A vertical profile plot of wind speed and direction (or of separate wind component values) is then made and wind values interpolated for standard pressure (or height) levels, as well as for additional selected levels wherever certain wind change criteria are satisfied. R/W wind values above 14 km thus represent 2-min overlapping 4-min average changes in the horizontal position coordinates (with some very slight additional smoothing). As mentioned earlier in Section II. E of this report, this 4-min time scale near 30 km probably represents a vertical distance of approximately 1600 m. Thus, the time scale of R/W data is contant, and the corresponding vertical scale is relatively so.

On the other hand, the current processing technique for M/R wind data is based upon three different time-averaging periods: a 0. 5-min interval to T + 5 min, a 1. 0-min interval from T + 5 to T + 20 min, and a 2. 0-min interval from T + 20 min to the end of the observation. The basic position data from the tracking radar may either be processed entirely by digital computer or may be automatically plotted into X-Y and Z-R graphs and the winds measured from the graphical plot with an appropriate wind scale.

The current M/R wind time scales attempt to compensate for the decreasing descent rate in order to provide a "quasi-constant" height scale for the data. As will be shown in the next section, this attempt is somewhat successful for chaff observation, but fails rather badly for parachute measurements above 35 km. The vertical resolution of M/R wind data between 30-60 km can vary from about 600 to 3900 m, as compared to a relatively constant 1600 m for R/W data. This difference in vertical resolution between R/W and M/R wind data, together with the great variability of the M/R scale, is serious but could be easily improved by increasing the frequency of reduced and reported values, as the basic radar measurements are recorded with far greater vertical resolution than is presently utilized. It is remarkable that this radar information is not used and apparently not even kept in original data records.

As no publication has appeared which gives the exact procedure used in reducing M/R wind data, proper evaluation of the data accuracy and representivity is not possible.

It is doubtful if the important intrinsic differences in M/R and R/W wind data can ever be entirely reconciled, at least so far as providing homogeneous wind data for relatively fine-scale applications. However, even at the present time M/R and R/W wind data are probably sufficiently compatible for combined use in broad-scale climatological studies, e.g., seasonal wind statistics and appropriately smoothed time cross-sections.

2. Temperature

The basic differences in R/W and M/R temperature measurements may be viewed as relatively minor compared to those associated with wind measurements. The sensor and telemetry units are essentially the same for R/W and M/R temperature observations. Nevertheless, there are some differences which arise in connection with dissimilar exposure conditions and vertical rate of movement.

There are a variety of published opinions regarding the basic compatibility of R/W and M/R temperature measurements. One report (Wright Instruments, 1961) is somewhat critical of the type of qualitative comparison which is usually made between overlapping or short-gapped data samples. This report states: "Many investigations have attempted to justify the accuracy of the temperature profiles they obtained by the excellence with which their data 'tied into' the radiosonde data. This agreement, however, does not demonstrate that the higher altitude data is accurate."

Another report by the USAF 4th Weather Group (1962), which provides meteorological support at Cape Canaveral, views the matter of temperature compatibility somewhat pragmatically: "No hard and fast rules are established for setting the maximum allowable difference between the rocketsonde and rawinsonde temperatures--However, since we are providing both rawinsonde data and rocketsonde data for support purposes, we can't tolerate wide differences in the data. Until definite proof is provided to the contrary, the rawinsonde data are assumed to be correct and the rocketsonde data must be adjusted to within reasonable limits." However, a more recent paper by Quinlan, Crutcher and Smith (1963) reviews this assumption, and states that: "this assumption may not be valid when the time and space differences between the two are considered."

These authors have made the most extensive statistical study of R/W - M/R temperature differences, based upon 27 pairs of observations taken between 80-100, 000 ft at Cape Canaveral from May 1960 to February 1963. Their conclusions were that: "In the 80, 000 to 100, 000 ft region the rocketsondes yield slightly warmer temperature than those of the radiosonde with significant differences at the 95, 000 and 100, 000 ft levels." The level of significance, in this case, was the 95 percent probability level. No effort was made in that study to determine the extent of instrumental and observational errors or to eliminate their effects.

Finger, et al. (1963) have compared a sample of overlapping rocketsonde and rawinsonde temperatures at Fort Churchill during November 1960. They conclude the following: "At the beginning of the period there is considerable difference, throughout the area of overlap, between reported rawinsonde temperatures and those measured during the single rocketsonde observation. During the middle of the period, however, the compatibility appears to be good with differences of 5°C or less--the deviations again increase as rawinsonde temperatures remain relatively cold...."

Miers and Beyers (1963) correct the M/R temperature data at several stations in accordance with a differential equation developed by Wagner (1963) which considers the effects of forced convection, radiation, self-heating (a result of the measuring current), viscous dissipation and conduction along the lead wires of the thermistor.

Thus, there are a variety of opinions related to M/R and R/W temperature differences and careful instrumental studies are obviously required to explain them. Meanwhile, some reasonable caution must be experienced in the use of present-day uncorrected M/R temperature measurements.

III. COMPATIBILITY OF ROCKET AND RAWIN WINDS

A. Previous Studies

A number of preliminary studies of compability between meteorological rocket (M/R) and rawinsonde (R/W) wind data have been made and the results and opinions, when considered together, provide an overall view.

On the scale of climatological interest, Diamond and Lee (1963) have recently compared R/W wind statistics at El Paso with M/R wind statistics at nearby White Sands (40 miles to the north). Their study revealed that the mean annual scalar wind speed at 30 km, as measured with M/R, differs by only 1 to 2 m/sec from the comparable speed at 29 km, as derived from R/W data. However, their comparison of more extreme wind speeds at the 1 percent calculated risk level indicated a large difference of about 10-15 m/sec in the M/R and R/W data near 30 km. Diamond and Lee attributed this large difference to "the bias of the rawinsonde system toward lower wind speeds at higher altitudes since high winds at these altitudes blow the balloon out of ground station range and consequently, the winds cannot be measured".

Kantor (1962) has presented a series of climatological wind profiles based upon M/R and radiosonde (R/S) data taken during 1959-1960 at Fort Churchill, Wallops Island, Tonopah, Point Mugu, White Sands and Cape Canaveral. His overall conclusions were: "At 25-30 km, the two mean wind profiles derived from rocket and rawinsonde data, respectively, are very nearly coincident. Hence, the rocket measurements should approach the accuracy of the rawinsonde at these levels and should be reasonably useful at higher altitudes, especially as the number and quality of rocket observations grow." It should be pointed out, however, that a close inspection of the mean wind profiles referred to above does not always reveal quite the degree of coincidence implied by the above quotation. In particular, the winter profiles of the east-west component at Point Mugu and White Sands show about 20-25 knot difference near 30 km between the M/R and R/W profile segments.

Smith and Vaughan (1961) have made a comparative study of overlapping M/R and R/W wind data at Cape Canaveral during the period, April 1959 to May 1960. They concluded the following: "Comparison of overlapping portions of rawinsonde wind measurements show there exists an uncertainty in the rocketsonde wind speed of approximately 8 mps, or 10 percent of the computed wind speed, whichever is greater." Thus, for climatological purposes averages should be reasonably accurate even though individual data points are questionable.

Keegan (1961) has studied a 2-month sample of M/R and R/W data used to prepare a time cross-section of winds over Wallops Island for January-February 1960. He concluded that "agreement was excellent between rocket and balloon winds at levels where there was an overlap."

Jenkins (1962) has presented two illustrative comparisons of component wind profiles derived from R/W and Arcas 15-ft parachute observations. In the first (White Sands, 5 June 1959) the wind data overlapped from 30-107, 000 ft; there was generally fair agreement throughout, including a sharply defined zone of wind maxima near 45, 000 ft. The differences in the respective altitude of significant profile excursions were attributed by Jenkins to errors in the height computations, or to space time considerations. It is also interesting to note that the profile for the parachute winds appears to be vertically displaced, in general, below that of the R/W winds; this would possibly suggest the combined effect of oppositely directed lag factors in the two observing systems.

The other illustrative example presented by Jenkins involved observations taken at White Sands on 18 May 1961, where the data overlapped between 66-100, 000 ft. A close inspection of the component wind profiles in this case reveals consistently close agreement to within a few knots. Jenkins remarks that "the comparisons are particularly encouraging in the magnitude of speeds indicated and the close correlation in the altitudes of shear layers."

Finger, et al. (1963) present an interesting comparison of nearly simultaneous R/W and rocketsonde wind observations taken at White Sands and nearby Holloman Air Force Base on 16 May 1961. The White Sands R/W winds overlap the White Sands 15-ft parachute winds from 13-35 km and overlap the Holloman Robin sphere winds from 28-35 km. The most significant disparity occurs in the zonal wind components between 28-35 km where the Robin and parachute winds (which themselves agree to within about 3 m/sec) differ from the R/W winds by about 10 m/sec.

The results of the studies which have been reported to date in the literature must properly be regarded as preliminary.

B. Vertical Resolution of Reported Winds

1. Vertical Resolution of M/R Winds from 25-35 km

As all winds are measured as the difference in position of a sensor which not only travels horizontally, but also vertically (either falling as the M/R or rising as a R/W), it is important to know the thickness of the atmospheric layer through which the instrument passes between consecutive measurements. This "vertical resolution" or "vertical averaging interval", (ΔH), of a system usually differs with height, (Z), depending upon the flight characteristics of the sensor, and upon data processing, and thus certainly differs between M/R and R/W. The vertical sampling should be known in order to interpret any single wind measurement properly, and must be known for studies of the vertical shear of the horizontal wind.

The altitude intervals between M/R wind measurements correspond to 0.5-, 1.0-, or 2.0-minute time intervals which are the current standards for processing of M/R wind data. The published values of W-E and S-N wind components are computed from the x-axis and y-axis displacements of the sensor during one of these selected time intervals. The choice of 0.5-, 1.0- or 2.0-minute time interval corresponds to the elapsed time from the beginning of the observation: < (T + 5), (T + 5) to (T + 20), and >(T + 20) minutes, respectively. These changes in time interval typically produce one or two abrupt changes in vertical resolution in every M/R wind sounding.

In order to obtain some preliminary estimate regarding the vertical resolution of M/R winds, and to compare it with that for R/W, the wind data for all stations contained in the IRIG-MWG Data Report for August 1963 were examined. Data from 25-35 km were chosen in order to have overlapping M/R and R/W wind data.

Cumulative frequency distributions of ΔH values were prepared using a class interval of 100 m for chaff, parachute and Robin sphere. The data in each category were further subdivided on the basis of time intervals (0.5, 1 and 2 min). For the month of August 1963 in the 25-35 km altitude range, a total of 269 data points were available from 41 chaff observations; 286 data points from 31 parachute observations; and 22 data points from only 3 Robin sphere soundings.

The analysis of vertical resolution in the parachute wind sample is presented in Fig. 1. Here the distributions of cumulative percent frequency are shown separately for the 1-min, 2-min and total parachute samples. For the 1-min winds, the 10, 50 and 90 percent cumulative frequency values are 720, 960 and 1320 m, respectively; corresponding values for the 2-min wind distribution are 930, 1090 and 1340 m. The differences in the 1- and 2-min distributions are greatest at lowest levels but are not as pronounced as might have been expected; apparently the two effects of doubled time scale and sharply decreasing fall speed balance each other to a large extent over this range of altitude.

The cumulative frequency distribution of vertical resolution for the chaff wind sample is shown in Fig. 2. There is obviously a very large spread between the 1- and 2-min distributions. For the 1-min winds, the 10, 50 and 90 percent cumulative frequency values of ΔH are 720, 950 and 1120 m, respectively; for the 2-min winds the comparable values are 1210, 1470 and 1830 m. Thus, the differences between the 1- and 2-min distributions for

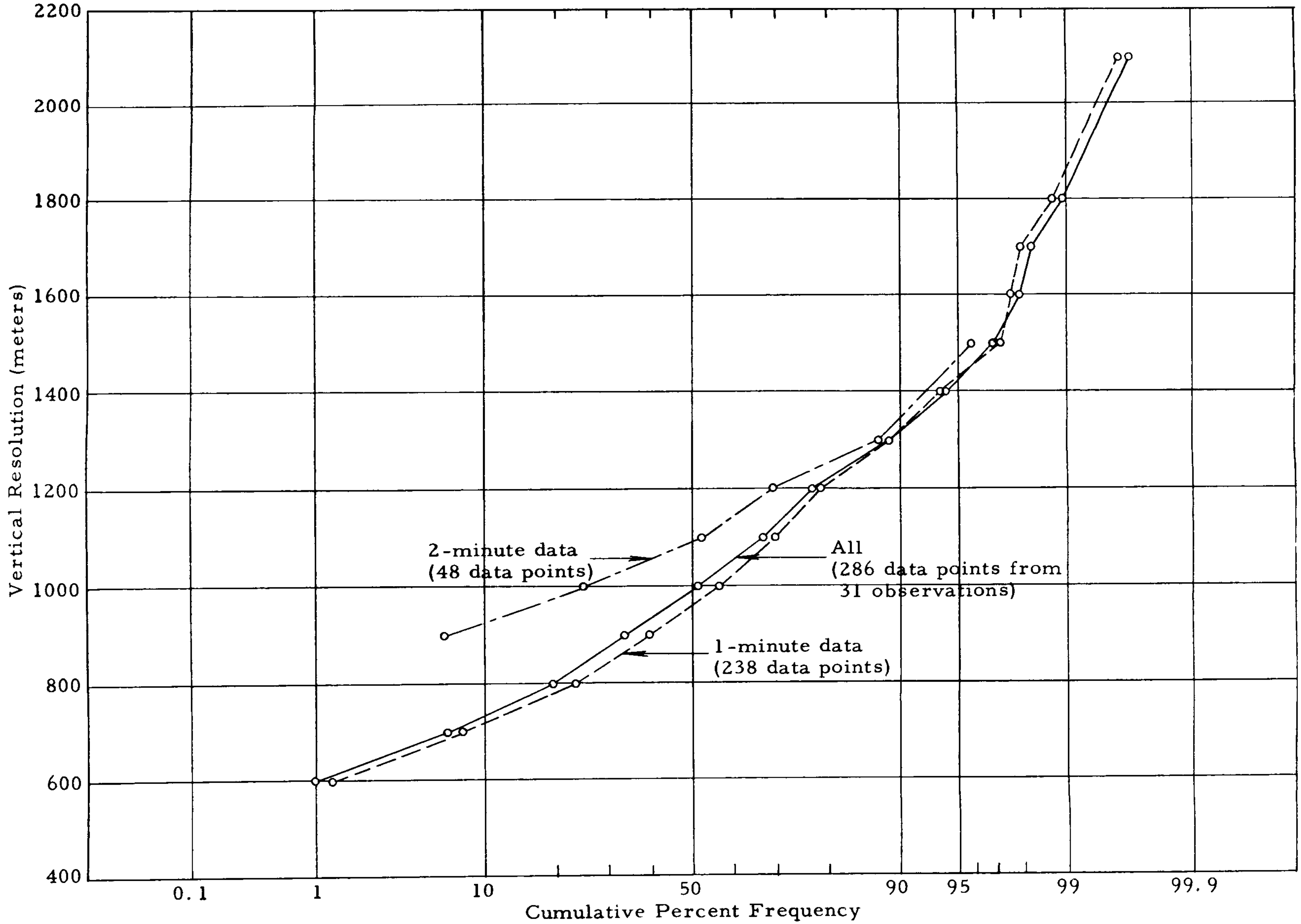

Fig. 1. Cumulative Frequency of Vertical Résolution of M/R Parachute Winds, 25-35 km, August 1963

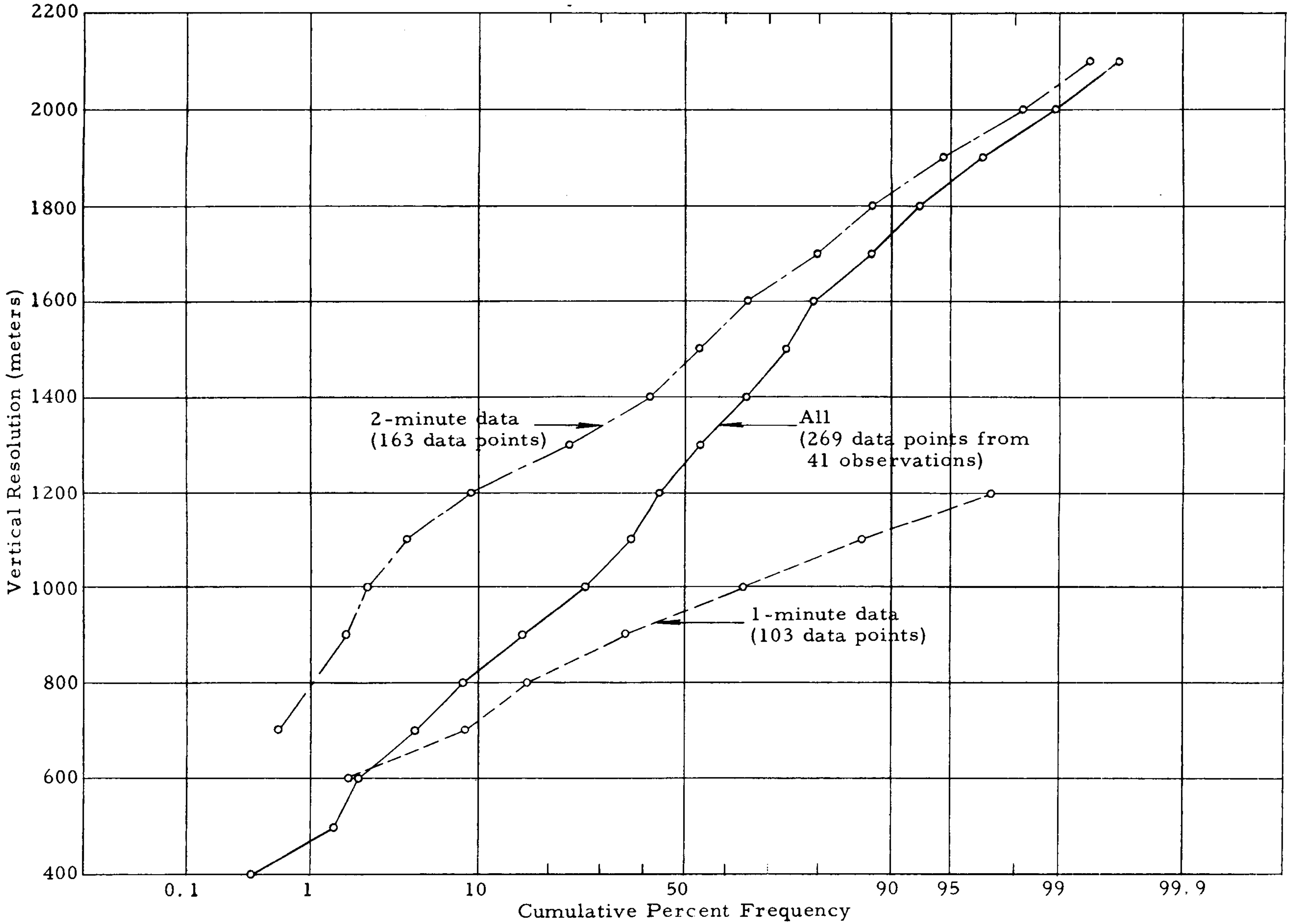

Fig. 2. Cumulative Frequency of Vertical Resolution of M/R Chaff Winds, 25-35 km, August 1963

chaff winds are several times larger than those which were noted in the case of the parachute winds, e.g., at the 50 percent level of cumulative frequency, the difference in chaff distribution is 520 m, as compared to a corresponding value of 130 m between the 1- and 2-min parachute distributions. This very pronounced difference in ΔH for 1- and 2-min chaff winds can be largely explained by the relatively slow decrease in the fall rate of chaff within the 25-35 km altitude range; thus, the 2-min ΔH tends to be almost twice the size of the 1-min ΔH, and are only slightly reduced in size by the effect of the decreasing fall rate.

Figure 3 summarizes Fig. 1 and 2. The cumulative frequency distributions are presented for each entire sample of parachute, chaff and sphere data, as well as all the data combined.

The ΔH for chaff data is about 300 m greater than that for the parachute data in the 25-35 km altitude range. The distribution curve for all the M/R data combined indicates 10, 50 and 90 percent cumulative frequency values of 750, 1070 and 1610 m. Corresponding estimated values for R/W data extend over a considerably smaller range: about 1300 to 1600 m. Most certainly, these results are highly preliminary as only data for a single month was examined. They do suggest, however, that significant resolution differences are present as functions of altitude and also between parachute and chaff data. In addition, the overall variability of vertical resolution of M/R winds appears to exceed considerably that for R/W wind observations.

2. The Change of Vertical Resolution with Altitude for M/R Winds from 20-60 km

The above results suggested the desirability of comparing the vertical resolution with altitude for the entire altitude range between 20-60 km. As a trial, the M/R parachute and chaff data published by IRIG-MWG for August 1963 were used again, separately.

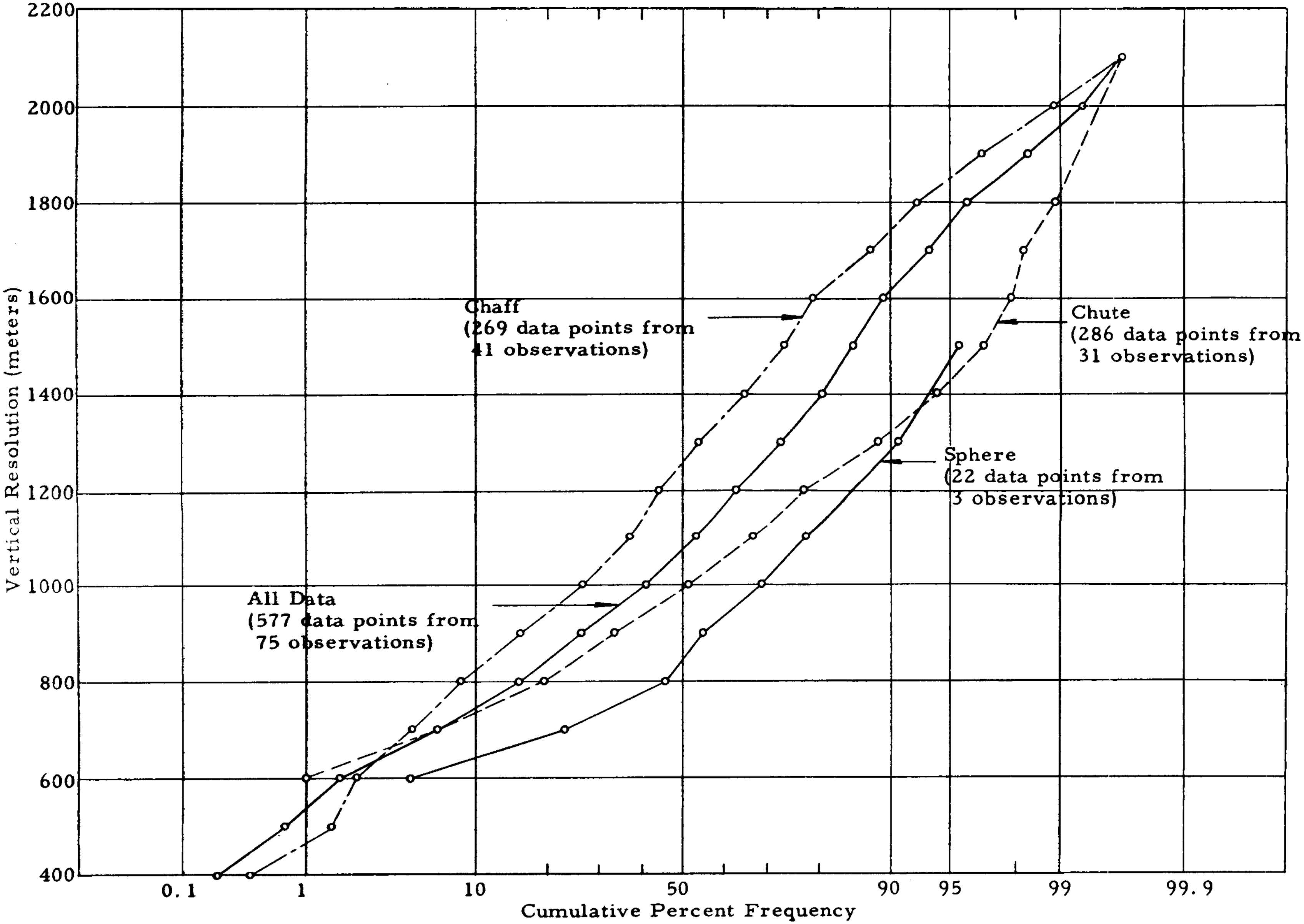

Fig. 3. Cumulative Frequency of Vertical Resolution of M/R Parachute, Chaff and Sphere Winds, 25-35 km, August 1963

A class interval of 100 m was again used in determining the frequency distribution of ΔH for each 5 km of altitude, e.g., 20-25, 25-30 km, etc. Cumulative frequency distributions were computed for each 5 km; these distributions were then individually plotted. Values of ΔH for each altitude category were then interpolated at selected values of cumulative frequency, (i.e., 5, 10, 20...90, 95 percent). These interpolated values of ΔH (taken to represent the midpoint in each altitude zone) were used to prepare Fig. 4, which contains the results from the chaff data. The sets of curves on these graphs depict selected values of cumulative frequency as a function of altitude and vertical resolution.

The outer boundaries of the curves shown in Fig. 4 resemble the outline of a distorted hourglass. The 5-95 percent range of ΔH is rather uniformly compressed between 37.5-47.5 km; this general feature can be readily explained by the fact that the vertical resolution of wind data in this particular altitude zone is almost entirely associated with a 1-min time interval. The rather uniform slope to all the frequency curves in this middle altitude zone reflects the consistent effect of a steady decrease in the fall rate of the chaff sensor. Within this 37.5-47.5 km altitude interval there is a rather uniform spread of about 600 m between the 5 and 95 percent cumulative frequency curves. Although much of this spread results from natural variability in fall rates, and some of the variation may also be attributed to occasional 0.5- and 2-min intervals, an error component is undoubtedly present also.

In the vicinities of 55 and 30 km, the 5 and 95 percent boundary curves on Fig. 4 clearly diverge in the cumulative frequency distribution of ΔH. These two "bulges" can probably be attributed to the blending of time scales which naturally occurs in the vicinity of these two altitudes: near 55 km a combination of 0.5- and 1-min time intervals, and near 30 km a mixture of 1- and 2-min intervals. As a result of this mixed time-scale effect, there is a spread of about 1200 m between the 5 and 95 percent cumulative frequency curves in the vicinity of both 55 and 30 km; this spread is approximately twice as large as that for the 37-47 km altitude interval. This is surely a

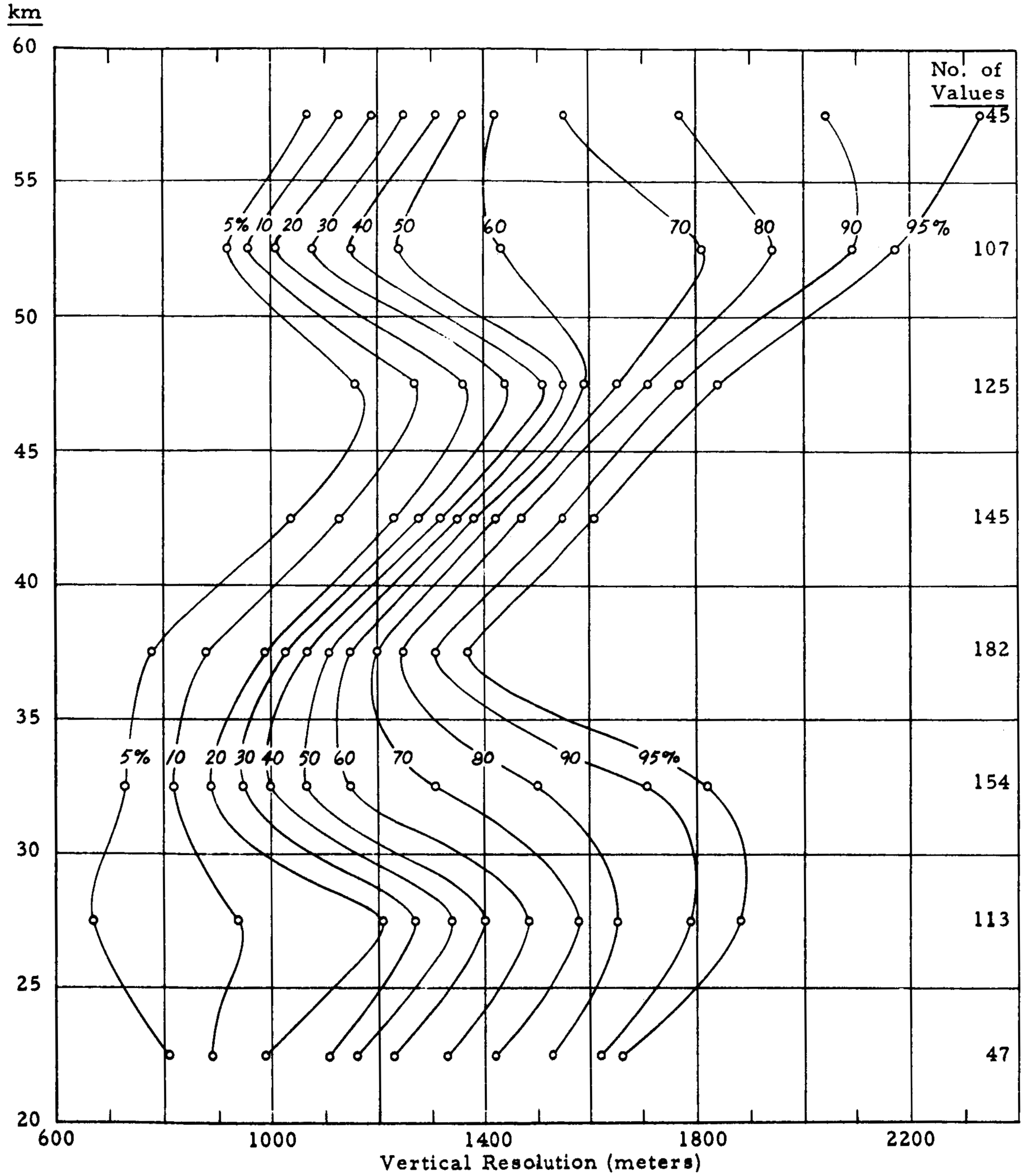

Fig. 4. Cumulative Frequency of Vertical Resolution of M/R Chaff Winds, 20-60 km, August 1963, for 5 km altitude classes

significant effect and deserves a more comprehensive evaluation than is possible here. Despite the small sample size, the results are probably typical of the general pattern.

A completely similar analysis of the parachute data was made and showed much larger values of ΔH and much sharper changes with height than in Fig. 4. Because of this, the original Fig. 5 was revised as follows: The individual values of ΔH were plotted directly against the corresponding altitudes. For convenience, the altitude used was not the average of the altitudes of the two consecutive observations, but was the altitude of the higher observation. The error of this is largely eliminated by computing cumulative frequencies of the ΔH values for 2 km layers, and plotting the value in the center of the ΔH-Z joint class interval. Isolines of these cumulative frequencies were then drawn. The resulting pattern yields greater detail especially near the levels of sudden change in ΔH from 40-50km.

Figure 5 clearly exhibits that there is a very pronounced decrease with altitude in the vertical resolution: for the 50 percent cumulative frequency (median) curve, there is an over three-fold increase in ΔH from 870 m near 27.5 km to 3020 m near 57.5 km. This result sharply contrasts with that derived from the chaff wind data, where there was relatively slight increase with altitude in the value of ΔH.

Another significant aspect shown in Fig. 5 is the large variation which occurs in the relative separation of the 5 and 95 percent cumulative frequency curves. A minimum spread of about 600 m between these curves may be noted near 35 km; and similarly, a maximum spread of about 2400 m is apparent near 50 km. The overall pattern of the frequency curves presented in Fig. 5 is rather different from that shown earlier in Fig. 4. In the latter instance, there were two bulges in the pattern near 55 and 30 km which could be both directly attributed to a mixed time-scale effect in the processing of chaff observational data. However, in the case of the parachute winds considered here, there is only one very large bulge in the pattern near 50 km, which extends from about 1600 to 3900 m between the boundary curves of

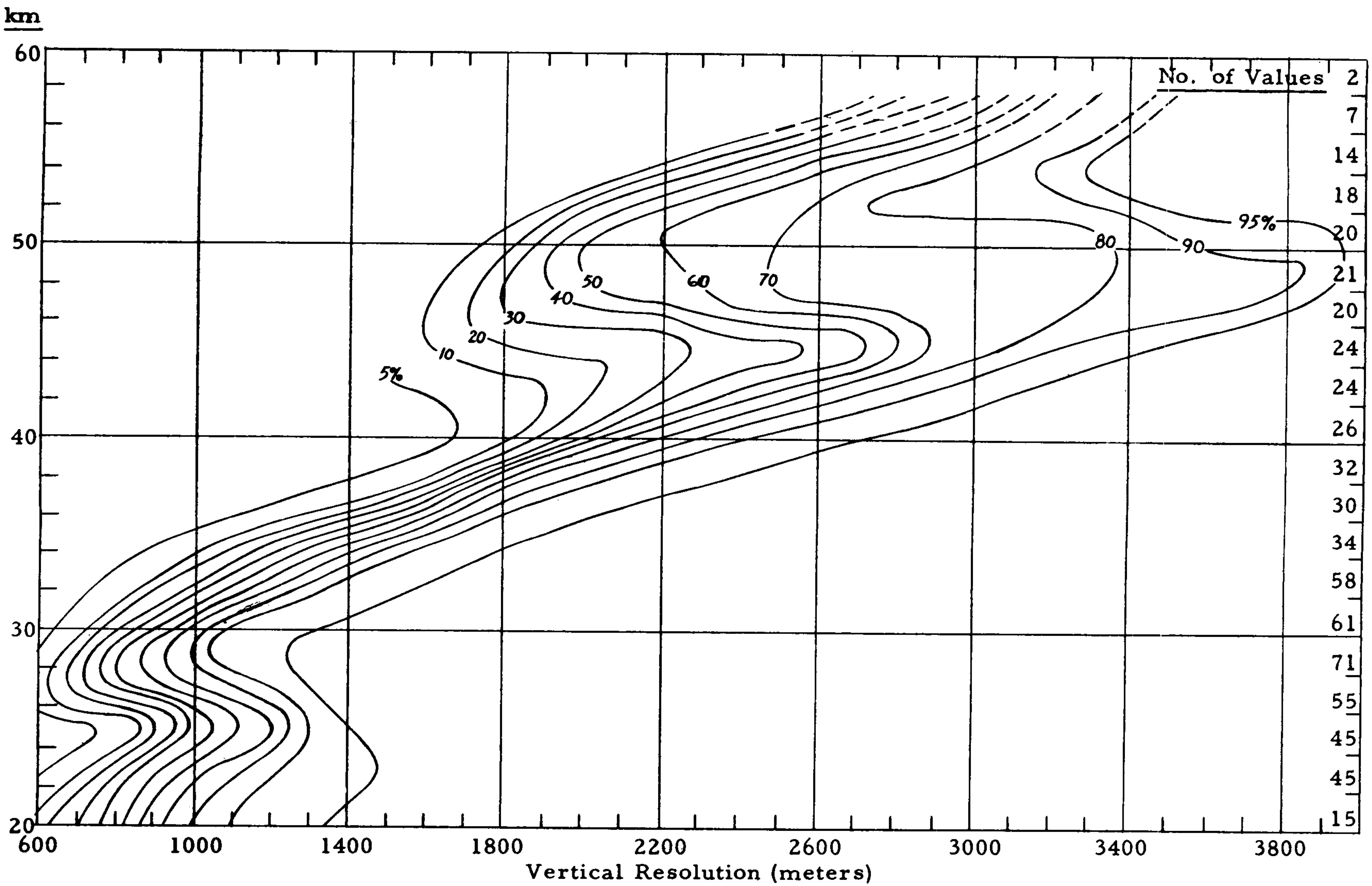

Fig. 5. Cumulative Frequency of Vertical Resolution of M/R Parachute Winds, 20-60 km, August 1963, for 2 km altitude classes

10 and 95 percent cumulative frequencies. This very large range is attributable to the mixed time-scale effect of 0.5- and 1-min average winds near 50 km, the altitude most closely associated with the (T + 5) minute change-over in time scale in the current data processing method. The bulge near 25-30 km associated with the (T + 20) minute change-over in time scale is very slight. Possibly, a parachute's fall rate is more uniformly retarded by the increased density at lower levels than is that of chaff, or expressed slightly differently, the variation of fall rate with height may be much larger for chaff than for parachute at levels below 35 km. However, a more likely reason is the increased dispersion of the chaff target as it descends to these levels while the parachute remains a constantly well defined target for the radar. The large range in ΔH for parachutes above 40 km may be caused by the large variations in the fall rate of parachute sensors. Incomplete deployment is an inherent problem in parachute systems which frequently causes abnormally high fall rates at higher levels.

This preliminary study of one month's data, as illustrated in Fig. 4 and 5, suggests that there are very significant differences with altitude in the vertical resolution of both chaff and parachute wind data between 20-60 km. These differences are apparently most pronounced in the vicinity of 45-50 km for parachute systems, but should be properly considered at all levels when using the upper wind data contained in the IRIG-MWG Data Reports. Variations of resolution with season and station should be determined from a complete study of all M/R wind data.

3. The Change of Time-Averaging Interval as a Function of Altitude for M/R Winds

The above results show there is significant variation in vertical resolution of M/R winds, and considerably more variation than for R/W data. This may be caused by the practice of changing the time-averaging intervals as a function of time after initial descent, at least to the extent that this practice is not compensated by density changes. At (T + 5) and at (T + 20) minutes in each M/R observation, the time scale is abruptly increased by a factor of 2. Corresponding to each of these times may be a characteristic altitude range which depends upon the ejection altitude and fall rate of the wind sensor. In view of the differences in the fall rates of chaff and parachute systems, such altitude ranges for these two systems are expected to be different, especially at (T + 20) minutes. To gain an impression of how these altitudes are distributed, Fig. 6 and 7 were compiled, again using August 1963 data.

Because of the small sample sizes, the altitude data were not grouped into class intervals but were used individually to derive the distributions of cumulative frequency.

Figure 6 presents the cumulative frequency distributions of sensor altitude at (T + 5) minutes for chaff and parachute systems. There is a fairly systematic altitude difference of about 1.5-4.5 km separating the two distribution curves. In the case of chaff observations, the change-over in time scale from 0.5 - 1.0 min is apparently made at a consistently higher altitude (at least for this limited sample).

Figure 6 shows a major discontinuity in the altitude distribution curve for chaff between 50 and 60 percent values of cumulative frequency. A re-examination of the original data reveals that there is a marked altitude bias in chaff observations which seems to vary as a function of the MRN stations involved. In this case, out of a total of 35 observations, the 16 observations which cluster between the altitudes of 49.7-51.7 km are from Point Mugu, Kauai and Wallops Island, whereas the 15 observations whose (T + 5) minute altitudes all exceed 55.4 km are either from Cape Canaveral or White Sands.

Figure 7 is the same as Fig. 6 for (T + 20) minutes. Here, the degree of separation between the chaff and parachute distribution curves is even more pronounced than it was at (T + 5) minutes: about 5.0-7.5 km. Thus, the change-over in time scale from 1.0 to 2.0 min is made at a consistently higher altitude in the case of chaff observations. In fact, at 30 km, which represents the very middle of the M/R-R/W wind data overlap zone, during

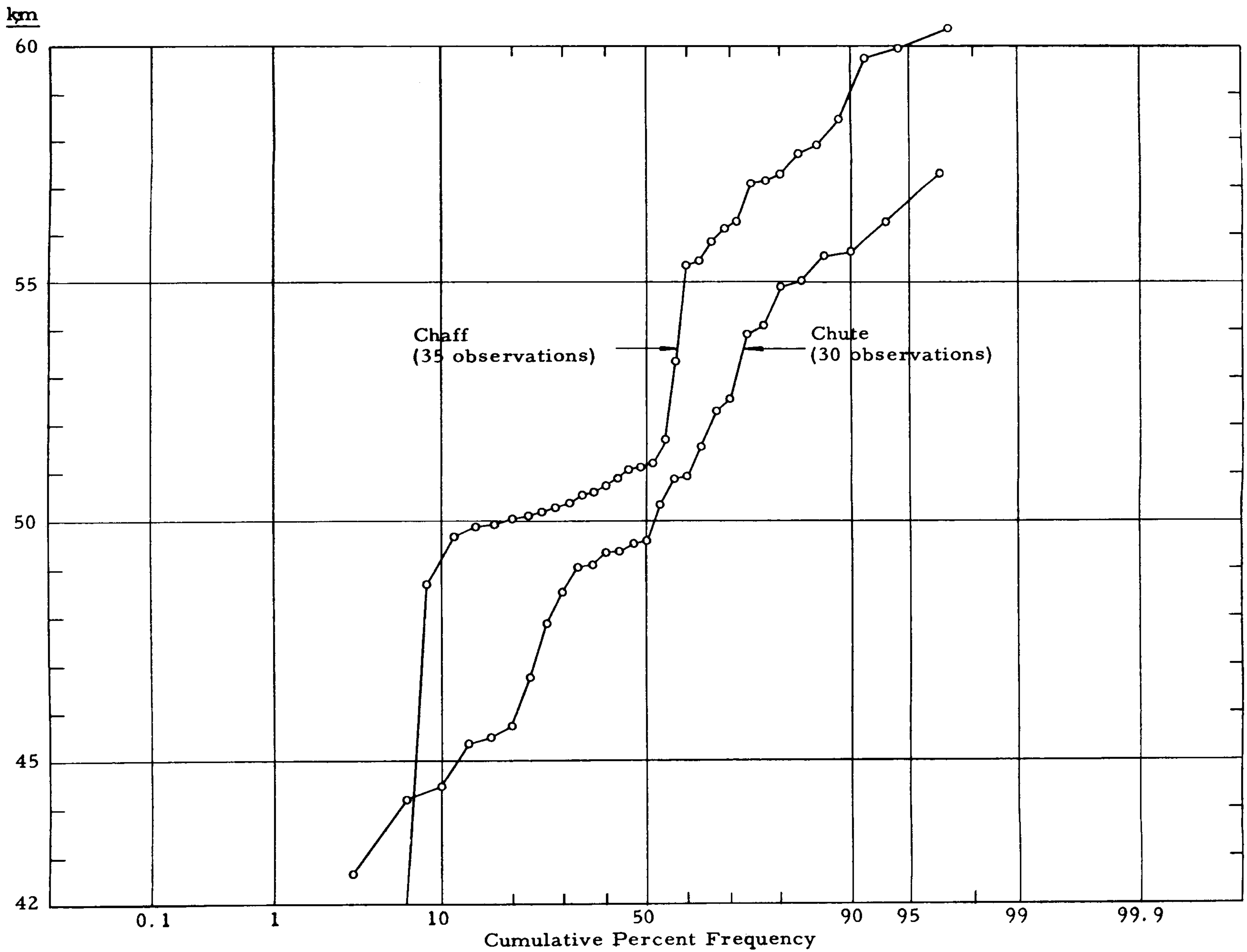

Fig. 6. Cumulative Frequency of Sensor Altitude at T + 5 Minutes, August 1963

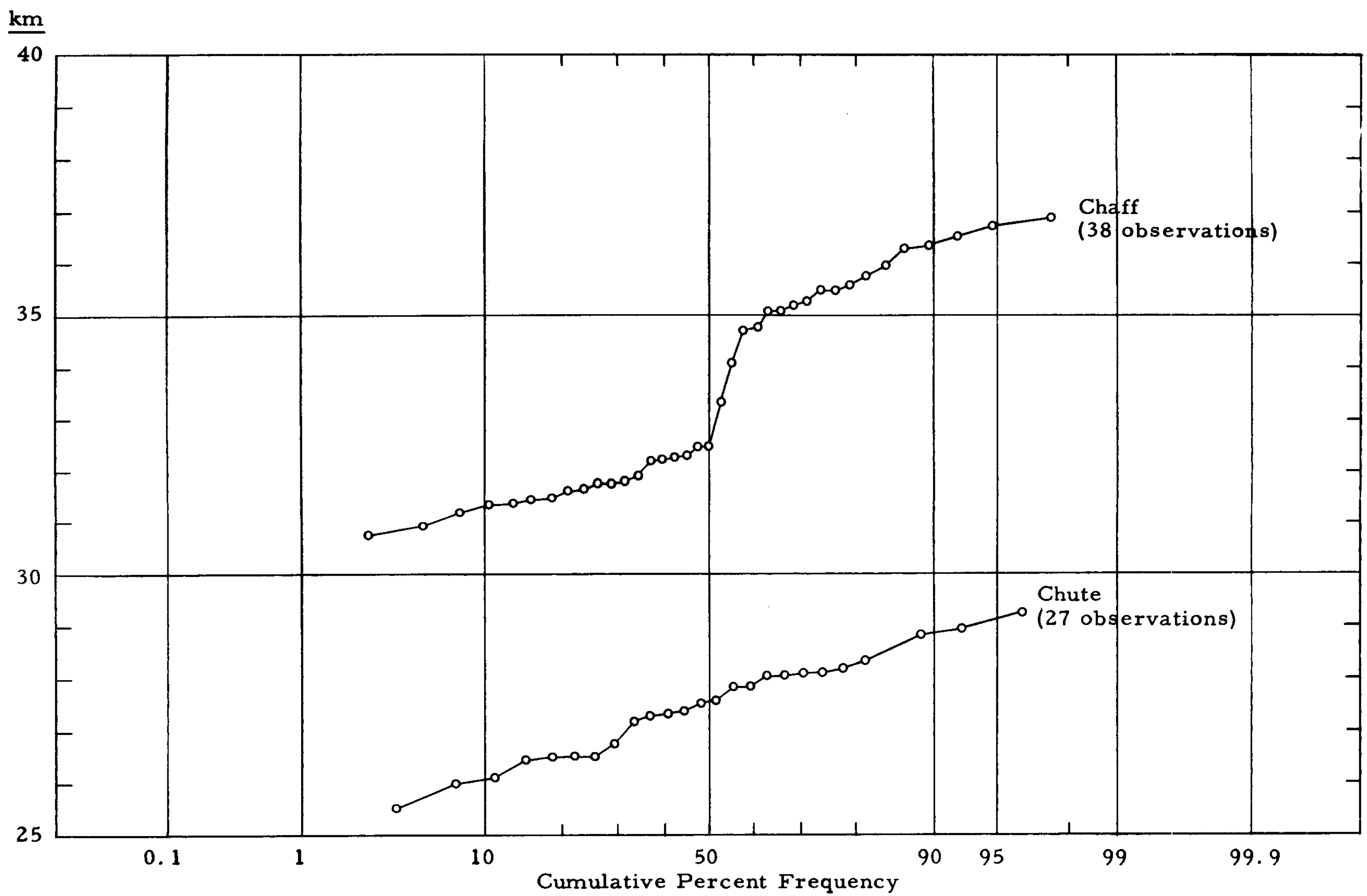

Fig. 7. Cumulative Frequency of Sensor Altitude at T + 20 Minutes, August 1963

August 1963 all 30 km chaff winds were averaged over a 2-min time interval and all 30 km parachute winds were averaged over a 1-min time interval. This may help explain the large difference in ΔH in Fig. 5 and 6 at 30 km.

Also to be noted on Fig. 7 is the discontinuity which again occurs in the altitude distribution curve for chaff. This feature is related to the discontinuity in the chaff curve previously noted in Fig. 6, and the same explanation applies, i.e., there are two very distinct component distributions associated with the same two groups of stations.

In order to provide some preliminary confirmation of these results, the (T + 20) minute altitude distributions were also determined for the month of April 1963. These distributions, presented in Fig. 8, are in agreement with those in Fig. 7. The disparity between the chaff and parachute altitude distributions at (T + 20) is slightly greater during April 1963.

It is obvious, from these results, that a thorough evaluation should be made of all M/R wind data to determine the net effect of these differences in chaff and parachute observations. Such a comprehensive task is beyond the scope of this study. However, the results of this preliminary study are believed to be sufficiently representative to illustrate the possible extent to which chaff and parachute data may differ from each other and from R/W data.

C. Statistical Comparison of Rocket and Rawin Winds

1. Introduction

The IRIG Serial Publication of rocket winds also includes data from a nearby R/W, released within 6 hours of the rocket ascent, to enable the rocket wind profile to be extended from lowest rocket levels to the ground. Frequently such rocket and rawin data overlap in the region from 20-35 km. It is the purpose here to compare the agreement of the wind components for days with several overlapping data levels.

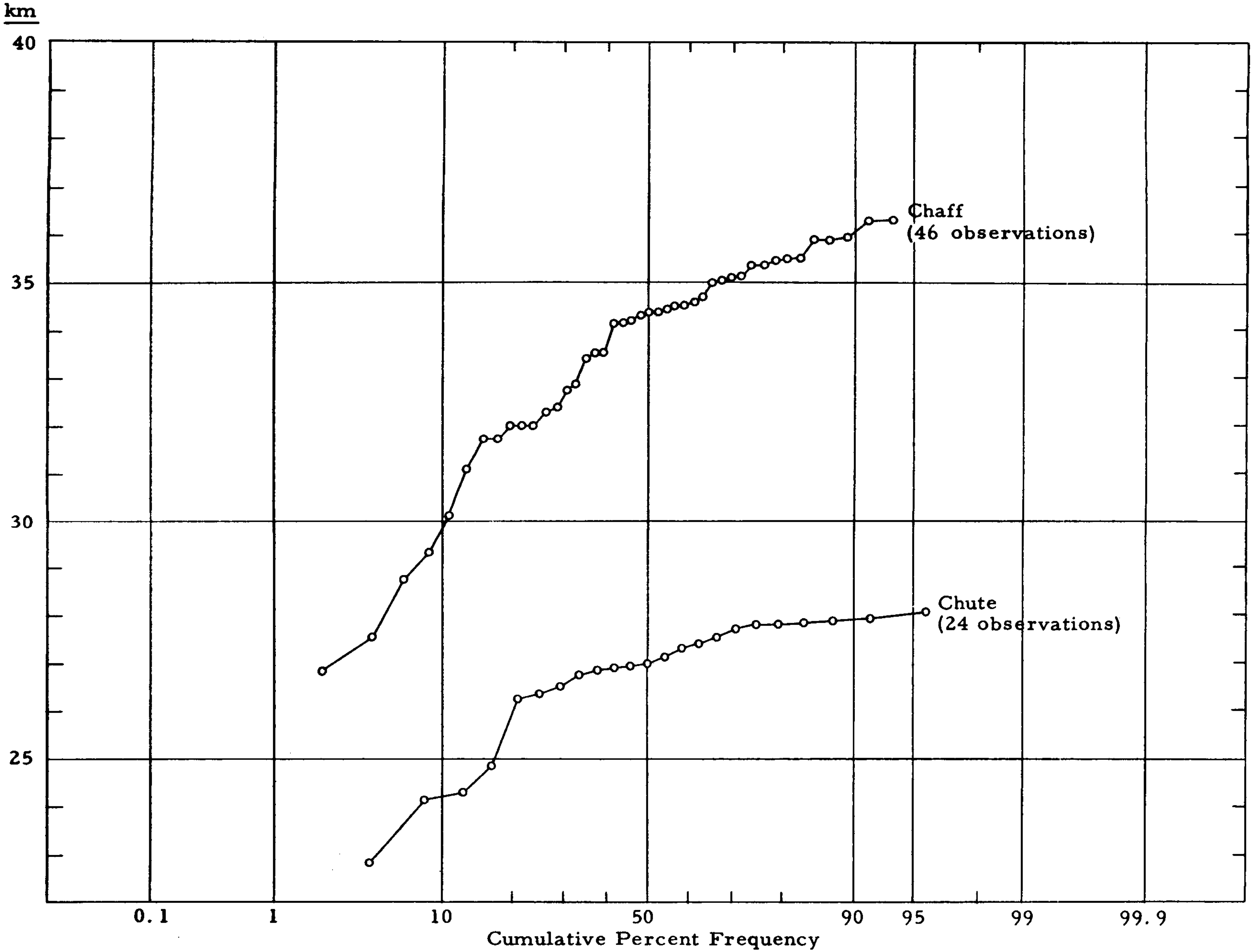

Fig. 8. Cumulative Frequency of Sensor Altitude at T + 20 Minutes, April 1963

Although the relative accuracy of various wind sensors have been studied, (Bruch and Morgan, 1961) and rocket wind sensors graphically compared (Jenkins, 1962), (Finger, et al., 1963), no statistical comparisons of M/R and R/W wind data, based on a large sample, appear to have been made. In view of the deficiencies and variability of both methods of wind observation, neither can be taken as an absolute standard. However, as R/W data are so commonly used, it is interesting to know how much M/R data differs from rawin data as functions of altitude, sensor, time difference between M/R and R/W data, and by latitude.

2. Data Processing

The M/R wind data from "Data Reports, Meteorological Rocket Network", prepared by the Inter-Range Instrumentation Group, are for the following stations:

Fort Churchill, Canada (58° 47' N, 94° 17' W)
Fort Greely, Alaska (64° 00' N, 145° 44' W)
Point Barrow, Alaska (71° 21' N, 156° 59' W)
Cape Kennedy, Florida (28° 14' N, 80° 36' W)
Eglin AFB, Florida (30° 23' N, 86° 42' W)
Point Mugu, California (34° 07' N, 119° 07' W)
White Sands Missile Range, New Mexico (32° 23' N, 106° 29' W)
Wallops Island, Virginia (37° 50' N, 75° 29' W)

The data are published both as tables and graphs. The tables give M/R wind components as a function of time since descent began, at half-minute intervals, and R/W wind components at fixed heights above sea level at intervals of 3040 m up to 25 km and of 1520 m above 25 km. Graphs also present vertical profiles of the tabulated data for both M/R and R/W data but terminate the R/W curve at a variable, arbitrary level above which only the M/R curve is shown. Thus, the overlapping levels are not shown on the graph.

The altitude range of 21-36 km was chosen as an appropriate interval where overlapping rocketsonde and R/W data are most abundant. The ten levels in Table 8a are those fixed heights for which rawin data are reported and which were used in this study. All ascents with four or more overlapping levels were used. In order to obtain M/R data for these same levels, the M/R graph was extended downward as necessary and values read from the graph at the rawin reporting levels. The data covers a period from January 1961 to October 1963. A total of 2381 corresponding sets of zonal and meridional wind components measured by rocketsondes and R/W was obtained.

The data were subdivided into two latitude groups: the arctic group contains Churchill, Fort Greely and Point Barrow, and the subtropical group contains all other stations. The subtropical group was further subdivided on the basis of wind sensors (chaff, parachute and Robin sphere). The chaff and parachute subgroups were further partitioned into two categories according to time difference of observations made by rocketsonde and R/W ($\Delta t \leq 0.2$ hr and $\Delta t \geq 3$ hr). A total of nine categories, as shown in Table 8b, was thus obtained for computation. As some levels had relatively few observations, some were combined with the following levels as shown in Table 8a in order to obtain a more representative sample for each category.

The basic parameters used in the computation are zonal and meridional wind differences which are defined as

$$\Delta u = u_R - u_W$$

$$\Delta v = v_R - v_W$$

where u_R and u_W are the zonal wind components observed by the rocketsonde and R/W, respectively, and v_R and v_W are the corresponding meridional wind components. The means, standard deviations, variances and frequency distributions for the zonal and meridional wind differences were computed, and also the mean absolute wind speed, $\overline{U}_R$. All values were rounded off to the nearest integer.

Table 8a. Levels at which Rocket and Rawin Data were Compared

Height (km)	
36.58	35.82
35.06	
33.52	
32.00	
30.48	
28.96	
27.44	26.67
25.90	
24.38	22.86
21.34	

Table 8b. Categories for which Rocket and Rawin Data were Compared

Category	Sensor Type	Time Difference (hours)	Latitude (°N)	Number of Observations ΔU, ΔV
1	chaff	0-2	30	518
2	chaff	3 or more	30	456
3	parachute	0-2	30	577
4	parachute	3 or more	30	649
5	Robin sphere	0 or more	30	80
6	parachute	0 or more	60	101
7	chaff & parachute	0 or more	30	2200
8	chaff	0 or more	30	974
9	parachute	0 or more	30	1226

3. Results

The frequency distributions of the rocket-rawin wind differences for both components, Δu and Δv, and their means and standard deviations are listed in Tables 9 to 20 for the various categories of Table 8b.

The wind differences, for both Δu and Δv are as likely to be one sign as another, as shown in the frequency distributions of Tables 9 and 10. Consequently, the mean Δu and Δv are generally near zero (Table 20). It is interesting to note that the frequency distribution of the differences is unimodal at the lower levels but bimodal at the upper levels. This indicates that the differences of the rocketsonde and R/W measurements become larger with increasing height up to about 32 km and then decrease slightly at higher levels. A few large differences (greater than 15 m/sec) occur in the vicinity of 32 km. However, 80 percent of the differences are within ±5 m/sec. The standard deviations in Tables 18, 19 and 20 also show an average value near 5 m/sec for both Δu and Δv. The standard deviations of both have their maxima between 30 and 34 km.

There appears to be relatively little difference in the statistics for chaff and parachute wind "errors" (Tables 18 and 19). The sphere (Table 15) seems to be slightly more compatible with R/W than either chaff or parachute are. The values of the standard deviation of the differences of the meridional wind components observed by rocketsondes for all three types of wind sensors are generally close to each other except that some individually large deviations exist in the 28-34 km layer. The general increase in standard deviation with height to about 34 km in all tables may be partly due to the increasing mean wind speed with height (Table 17). The decrease of variance above 34 km may correspond to the fewer observations at highest levels. Finger, et al. (1963) also found large differences between the zonal components in the layer from 25-35 km as measured by rocketsondes and R/W.

TABLE 9a FREQUENCY DISTRIBUTIONS OF Δu , Chaff

Ht (km)	-24.5 -	-19.5 -24.4	-14.5 -19.4	-9.5 -14.4	-4.5 -9.4	-0.5 -4.4	-0.4 +0.4	+0.5 +4.4	+4.5 +9.4	+9.5 +14.4	+14.5 +19.4	+19.5 +24.4	+24.5 - m/s
35.82				1	4	11	9	8	1				
33.52				2	9	27	8	24	8	2			
32.00	1			3	19	39	19	40	15	3	1		1
30.48				4	21	57	24	41	14	8	2		
28.96			1	3	15	57	29	55	15	3	1		
26.67					9	67	46	58	11	1		1	
22.86				2	3	58	59	48	3	2		1	

TABLE 9b FREQUENCY DISTRIBUTIONS OF Δv , Chaff

Ht (km)	-24.5 -	-19.5 -24.4	-14.5 -19.4	-9.5 -14.4	-4.5 -9.4	-0.5 -4.4	-0.4 +0.4	+0.5 +4.4	+4.5 +9.4	+9.5 +14.4	+14.5 +19.4	+19.5 +24.4	+24.5 - m/s
35.82					1	14	8	10	1				
33.52				2	8	29	9	25	6	1			
32.00				3	12	47	22	43	13	1			
30.48				2	10	66	19	55	16	3			
28.96					12	59	25	65	16	2			
26.67					3	58	59	68	4	1			
22.86					1	52	66	56	1				

TABLE 10a FREQUENCY DISTRIBUTIONS OF Δu , Parachute

Ht (km)	-24.5 -	-19.5 -24.4	-14.5 -19.4	-9.5 -14.4	-4.5 -9.4	-0.5 -4.4	-0.4 +0.4	+0.5 +4.4	+4.5 +9.4	+9.5 +14.4	+14.5 +19.4	+19.5 +24.4	+24.5 - m/s
35.82					3	14	8	13	2	2			
33.52			1	4	14	24	12	24	12	2	1		
32.00	1			3	19	48	19	55	15	6	1	1	
30.48		1	2	3	11	60	23	72	30	3	1	1	
28.96		1		2	17	76	36	70	24	1			
26.67			1	1	13	81	61	85	7	1			
22.86			1	1	6	73	85	70	2				

TABLE 10b FREQUENCY DISTRIBUTIONS OF Δv , Parachute

Ht (km)	-24.5 -	-19.5 -24.4	-14.5 -19.4	-9.5 -14.4	-4.5 -9.4	-0.5 -4.4	-0.4 +0.4	+0.5 +4.4	+4.5 +9.4	+9.5 +14.4	+14.5 +19.4	+19.5 +24.4	+24.5 - m/s
35.82					6	15	8	9	4				
33.52				1	12	33	15	24	6	3			
32.00				5	16	59	12	59	17				
30.48				2	17	72	21	66	23	4	2		
28.96			1	1	14	68	31	93	16	2	1		
26.67					5	74	83	86	2				
22.86				1	2	70	87	75	3				

TABLE 11a FREQUENCY DISTRIBUTIONS OF Δ u , Sphere

Ht (km)	-9.5 -14.5	-4.5 -9.4	-0.5 -4.4	-0.4 +0.4	+0.5 +4.4	+4.5 +9.4	+9.5 +14.4 m/s
35.82	1				1		
33.52			2	1		3	
32.00		1	1	1	6	1	
30.48		2	3	2	11	1	
28.96		1	9	2	6	1	1
26.67			5	4	7	2	
22.86			3	1	1		

TABLE 11b FREQUENCY DISTRIBUTIONS OF Δv , Sphere

35.82			2				
33.52		1	2		3		
32.00		1	5	1	3		
30.48		1	7	2	9		
28.96		2	7	3	8		
26.67			7	3	7	1	
22.86			2	1	2		

TABLE 12a FREQUENCY DISTRIBUTIONS OF Δu , Arctic Stations

35.82	1						
33.52			2	1			
32.00		1	1	1	1	1	
30.48		1	2		4	1	
28.96		3	4	1	7	2	
26.67	1	2	6	8	13	3	
22.86	2	1	6	12	12	1	

TABLE 12b FREQUENCY DISTRIBUTIONS OF Δv , Arctic Stations

35.82			1				
33.52		1	1		1		
32.00		1	2		2		
30.48			2	1	4	1	
28.96			4	1	9	3	
26.67			8	9	15	1	
22.86		2	8	7	16	1	

TABLES 13-16, 18-20: MEANS AND STANDARD DEVIATIONS OF Δu and Δv (m/s)

TABLE 13 Chaff, 30° N

	|Δt| < 2.4 hrs.					|Δt| ≥ 2.5 hrs.				
Ht. (km)	Δu M	Δu S.D.	N	Δv M	Δv S.D.	Δu M	Δu S.D.	N	Δv M	Δv S.D.
35.82	-1	3	12	-1	3	-2	5	22	0	3
33.52	-1	4	38	-1	5	0	6	42	-1	5
32.00	-1	8	72	-1	5	1	5	69	-0	5
30.48	-0	6	92	-0	4	0	6	79	1	5
28.96	-0	5	99	0	4	-0	5	80	1	4
26.67	-0	4	107	0	3	1	4	86	0	3
22.86	0	3	98	0	2	-0	4	78	0	2
			518					456		

TABLE 14 Parachute, 30° N

	|Δt| < 2.4 hrs.					|Δt| ≥ 2.5 hrs.				
Ht. (km)	Δu M	Δu S.D.	N	Δv M	Δv S.D.	Δu M	Δu S.D.	N	Δv M	Δv S.D.
35.82	0	5	22	-0	4	0	5	20	-1	4
33.52	-2	7	44	-0	6	1	6	50	-1	5
32.00	-1	7	78	-0	5	1	5	90	-0	5
30.48	1	6	97	-0	5	1	5	110	1	5
28.96	0	5	107	0	4	-0	4	120	1	4
26.67	0	3	118	-0	2	-1	4	132	0	3
22.86	0	2	111	-0	3	-1	3	127	0	2
			577					649		

TABLE 15 Sphere, 30° N

$\Delta t < 2.4$ hrs.

Ht. (km)	Δu		N	Δv	
	M	SD		M	SD
35.82	-6	10	2	-2	1
33.52	3	6	6	-1	5
32.00	2	3	10	-1	4
30.48	1	4	19	-0	4
28.96	-0	5	20	-0	4
26.67	0	3	18	0	3
22.86	-0	2	5	-0	2
			80		

TABLE 16 , Arctic

$\Delta t \geq 2.5$ hrs.

Ht. (km)	Δu		N	Δv	
	M	SD		M	SD
35.82	-15	0	1	-3	0
33.52	-3	2	3	-3	5
32.00	-0	5	5	-2	4
30.48	1	5	8	1	4
28.96	0	5	17	3	3
26.67	0	5	33	1	2
22.86	-0	5	34	1	3
			101		

TABLE 17 - MEAN ABSOLUTE VALUES OF ZONAL AND MERIDIONAL COMPONENTS OF ROCKET WINDS (m/s)

Ht (km)	CHAFF			PARACHUTE		
	No. of Obs.	$\overline{\lvert u_R \rvert}$	$\overline{\lvert v_R \rvert}$	No. of Obs.	$\overline{\lvert u_R \rvert}$	$\overline{\lvert v_R \rvert}$
35.82	43	15	3	57	17	5
33.52	80	17	4	95	17	5
32.00	142	16	4	169	16	5
30.48	172	15	4	208	14	4
28.96	184	13	3	232	13	3
26.67	379	11	3	492	12	3
22.86	281	9	3	398	9	3

TABLE 18 Chaff, 30° N, all Δt — TABLE 19 Parachute, 30°N, all Δt — TABLE 20 Chaff and Parachute, 30° N, all Δt

Ht. (km)	Table 18 Δu M	Table 18 Δu SD	Table 18 N	Table 18 Δv M	Table 18 Δv SD	Table 19 Δu M	Table 19 Δu SD	Table 19 N	Table 19 Δv M	Table 19 Δv SD	Table 20 Δu M	Table 20 Δu SD	Table 20 N	Table 20 Δv M	Table 20 Δv SD
35.82	-2	4	34	-0	3	0	5	42	-1	4	-1	5	76	-0	4
33.52	-0	5	80	-1	5	-0	6	94	-1	5	-0	6	174	-1	5
32.00	0	6	141	-0	5	0	6	168	-0	5	0	6	309	-0	5
30.48	0	6	171	0	5	1	6	207	1	5	0	6	378	0	5
28.96	-0	5	179	0	4	-0	5	227	0	4	-0	5	406	0	4
26.67	0	4	193	0	3	-0	4	250	0	3	-0	4	443	0	3
22.86	-0	3	176	0	2	-0	3	238	0	2	-0	3	414	0	2
			974					1226					2200		

One might expect that the longer the time difference between R/W and rocket observations, the larger the wind difference. The time difference between the rocketsonde and R/W observations varies in a time interval of about ± 6 hours. In Tables 13 and 14, this period was divided into two categories: 0-2.4 hr and 2.5 hr or more. Only data of chaff and parachute wind sensors were used to evaluate this effect. Recalling that all results are all rounded off to the nearest meter per second, no significant difference can be seen for the means of Δu or Δv. The chaff value of standard deviation for Δu at 32 km appears larger for on-time than off-time observations, but at higher levels it is larger for off-time observations. For parachute Δv data, on-time values of the standard deviations are larger than for off-time. All these larger standard deviation values result from the few large absolute differences (>15 m/sec) given in Tables 9a and 10a, for which no special reason is known. A check of these extreme differences shows they are all in the on-time data. From this data, then, one must conclude rather suprisingly that time differences between R/W and rocket observations (up to ± 6 hours) have no systematic bearing on the differences in the observations.

A comparison of data measured by M/R and R/W at stations in the arctic, and also in the subtropical region, can be seen in Tables 16 and 19. All wind sensors used in these measurements were parachute. Only a small number of observations, and that mainly for the layer 23-30 km, is available. There appears to be relatively little difference in the two latitude belts except that the Δu variances at 23-26 km in the arctic are larger than those in the subtropical region.

D. Comparison of M/R and R/W Data on the Seasonal Wind Reversal

1. The Reversal Process

The seasonal large-scale wind reversal is, in general, merely a reflection of the asymmetric changes in the synoptic pressure patterns at these levels which, in turn, are caused by the seasonal meridional reversal of the thermal gradient. At a given station, the spring reversal process seems to occur as the winter polar vortex is displaced from time to time by a warm high pressure cell moving from mid-latitudes to polar latitudes. Usually such intrusions are temporary and the vortex returns to its polar location; at other times (the final reversal) a complicated cellular pattern develops which eventually leads to a stable summer polar anticyclone. The preliminary disruptions of the strong winter vortex occur several times during the cold season, resulting in observed temporary wind reversals and associated "sudden warmings".

The large-scale pattern shows that in the spring, polar easterlies generally move southward and merge with the tropical easterlies moving northward. However, whether the early progression of easterlies at latitudes north of 50°N is from the south or from the north in spring depends on the particular longitude, latitude and year as it is due to the irregular development and migration of anticyclonic pressure cells during the cold season each year. Either easterlies or westerlies may be observed at a given station depending upon the relative orientation of such cells to the station. The duration of easterlies or westerlies at a single station, or the sequence of such winds along a meridian, depends only on whether a small temporary anticyclone is moving north or south at that place or along that meridian. In fall, the process is so rapid that even two weeks is not a sufficiently short averaging period to indicate the details of how the reversal progresses latitudinally. Although the polar westerlies and tropical easterlies both progress southward after September 1, it is possible the winds first become westerly at 60°N and slightly later at higher latitudes, at the time of the sudden upward change in the east-west wind boundary.

2. Determination of Reversal Dates

Before reversal dates can be compared, with respect either to latitude or altitude, it is necessary to agree on some definition of "reversal". We define it as the latest time at a given station and altitude when the 10-day average wind changes from westerly to easterly (or conversely) and remains so for at least one month.

Reversals may be determined from several different forms of data:

1) Large-scale circulation patterns over the hemisphere, i.e., seasonal establishment of the polar vortex in fall or anti-cyclone in spring, as determined from maps.

2) Time-speed graphs for each altitude at a given station.

3) Time-height graphs for a given station to find properties of the zero-wind surface.

4) Speed-height graphs are useful when there is a definite strong change in the sign of the zonal component, but almost useless when the winds are light and variable over a deep layer of the atmosphere.

Each of these has its advantages. Maps are probably the best single reference as they alone can identify the causes and extent of disturbances to the flow. Time-speed graphs allow smoothing of irregularities in speed or sign, as during periods of light and variable zonal components. Time-height graphs most easily provide interpolation of the zero wind surface with height. Purely statistical methods, such as frequency distributions, are more severely limited by scanty data than are the other methods, as trends are not apparent.

When zonal winds are weak and variable with height or time, the safest interpolations are probably made on height-time sections. Frequent changes in zonal components may represent conditions of strong meridional flow (as often exist in the Alaska-Canada border region in winter), or of a transient anticyclone passing over the station for a few days. Both of these situations are temporary, not seasonal, reversals. The nature of the reversal process is erratic and varies by weeks from place to place at a given latitude, as well as with latitude, and from year to year at a given place. The 1963 spring reversal is a good example of how the date can vary at the same latitude. From 30 mb maps, it can be seen that at 60°N, it started on May 4 over Greenland, on May 17 over Southern Alaska and about May 30 over Central Siberia. Hence, any measurements of the reversal process at given stations must take into account the likelihood that the results are not typical for entire latitude belts or other arbitrary large regions.

Several papers have appeared in the last few years presenting conclusions on the nature of the seasonal reversal in the stratosphere and mesosphere. Table 21 summarizes the results. At first glance the principal difference appears to be between balloon evidence of upward propagation of the reversal process and rocket evidence of downward reversal in the fall.

However, it is not yet possible to generalize the reversal process for all latitudes and altitudes. A careful comparison of the latitudes and altitudes reveals no direct contradiction in the propagation processes in this table. There is no direct time-series evidence in these papers for any statement concerning the upward or downward progression of the fall reversal at high latitudes above 30 km. The closest indication comes from the fact that the mean zonal speed increases with increasing altitude, to a maximum near 60 km, and also increases in time at each level, in early winter, implying that the reversal first occurred near the level of maximum wind. Even if this later proves to be correct, there need not be a conflict in the results to date, as the direction of reversal propagation may vary from one major layer of the atmosphere to another. It is possible that it proceeds upward from 15-30 km, downward from 64-30 km, and upward from 64 km.

We turn next to examine the scanty direct M/R data for the fall months to see how the reversal appears in the arctic, antarctic and the 30-40° MRN latitude belt.

TABLE 21 THE VERTICAL PROGRESSION OF THE SEASONAL WIND REVERSAL

Ref.	Ht. (km)	Reversal at	Spring	Fall	Data
Batten (1959)	15	45° N	↓	↑	No. America, north of 45° N. Monthly freqs. 1957. R/W only.
Belmont (1960)	15-30	55° N	↓	↑	East and west coasts of No. Am. Monthly freqs. 3-10 yrs. R/W only.
(1962)	15-30	55° N	↓	↑	80°W and 120°W. 15 day freqs. 1957, 1958, 1959, separately. R/W only.
(1963)	15-30	55° N	↓	↑	Northern hemisphere, monthly freqs. 3-10 yrs. R/W only.
JSAG (1961)	20-70	32° N middle and high lats	↓	↓	White Sands M/R, Aug-Sept. 1960. 50 km maps of No. America, Apr & Sept 1960.
Wagner et al (1962)	25-60	32° N	—	↓	9-10/61 WSMR
Miers (1963)	25-70	32-24° N	↓	↓	WSMR 1960-62; Pt. Mugu 1961-62.
Appleman (1963)	46-60	21-38° N	↓	↓	7 stations south of 40°, 10/59-8/61 M/R. at 46, 53, 61 km.
Appleman (1964)	61-67	21-38° N	↓	↓ ↑ 64	10/59-11/62 M/R at 61,64,67 km.
Rotolante and Parra (1964)	0-60	78° S	↓	—	6-12/62, McMurdo, 14 M/R
Rofe (1963)	0-70	31° S	↓ ↑ 50	↓	Woomera: 12 spheres 12/61-5/63 (60-80 km); 17 grenades 1959-62 (30-85 km); meteor winds 1962 (70-100 km).

a. The Fall Reversal in the Arctic

As the firings for the MRN are apparently still scheduled for mid-seasonal months, based on the seasons of the conventional calendar, there are still no data for the period August 15 to September 15, the actual time of fall transition at high latitudes. However, Fig. 9 and 10 show the data that are nearest to this period. In Fig. 9 it was necessary to supplement Churchill with Fort Greely, as in 1960 the data at either station alone was too sparse to obtain any useful continuity. From July 18 to August 17, these 11 ascents show that above 20 km the anticyclonic easterly circulation predominates for almost all days. The maximum of at least 40 m/sec is above 50 km. The existence of a weak vertical wind shear between 20 and 40 km corresponds to the virtual absence of stratospheric disturbances. This flow is essentially barotropic in nature.

As the fall season begins, a rapid weakening of the easterly wind over the two stations occurred at 50 km in the early August due to seasonal atmospheric cooling. The greatest measured wind changes occurred in a layer between 40-60 km where the zonal wind speed decreased from 40-10 m/sec from August 1 to 17. Yet there is a suggestion that the zero wind surface rises from 20-35 km on August 17th. Since no rocket data were collected at these two stations after August 17, 1960, it is impossible to investigate in further detail the fall reversal of 1960 at levels above 30 km.

Figure 10 gives a time-height section of zonal wind at Fort Greely in September 1961. There are two distinct westerly wind regimes: the polar night vortex in the upper stratosphere with a maximum near 55 km and the polar tropopause maximum. Note that weak easterlies in the stratosphere occurred at 30-35 km on September 8 and 9, 1961, but changed into westerly completely after September 9. This represents a final stage of fall reversal. Unfortunately, no rocket data was available before September 8, 1961.

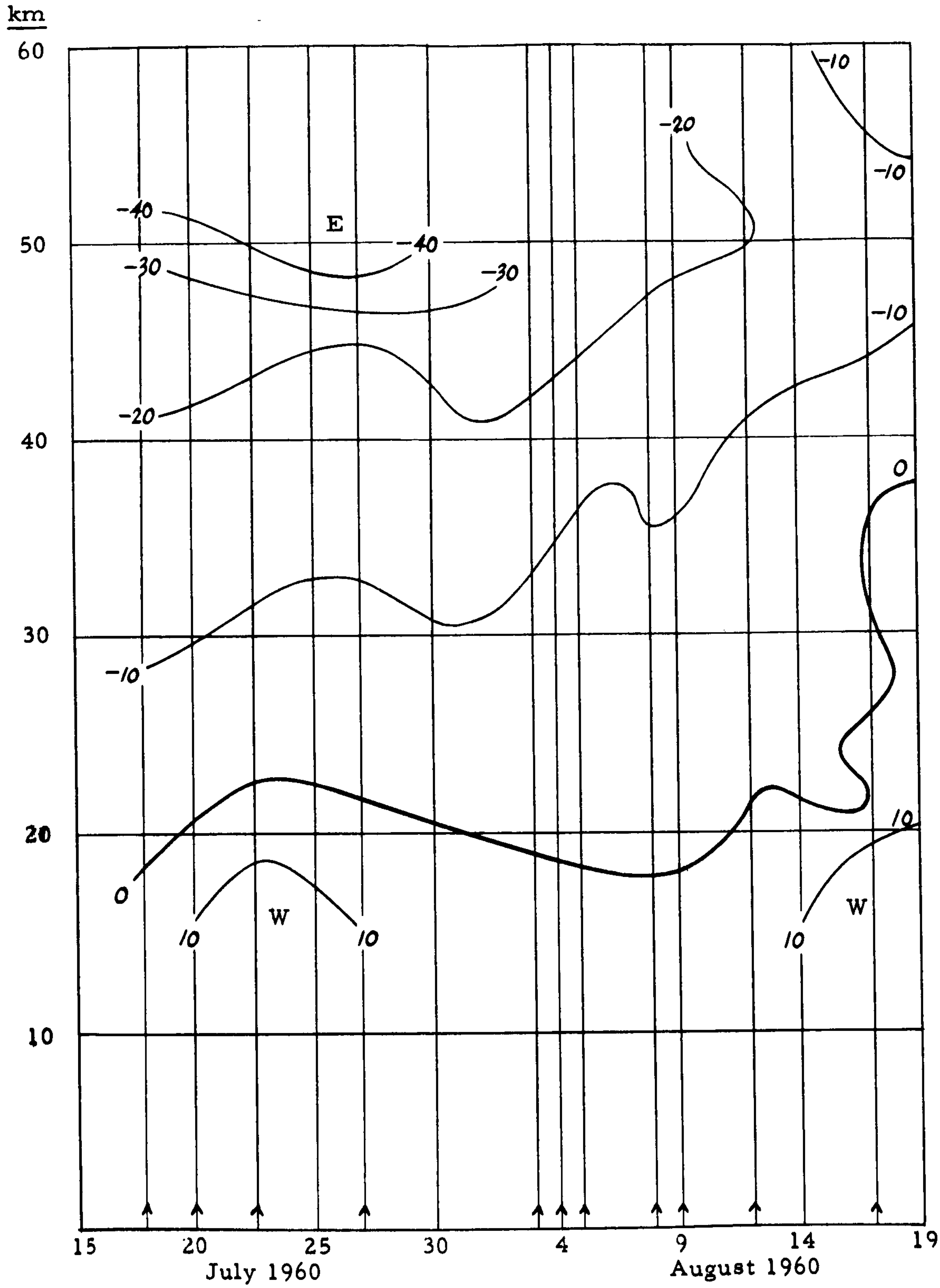

Fig. 9. Time-Height Section of Zonal Winds (m/sec) Observed at Churchill and Fort Greely, July and August 1960

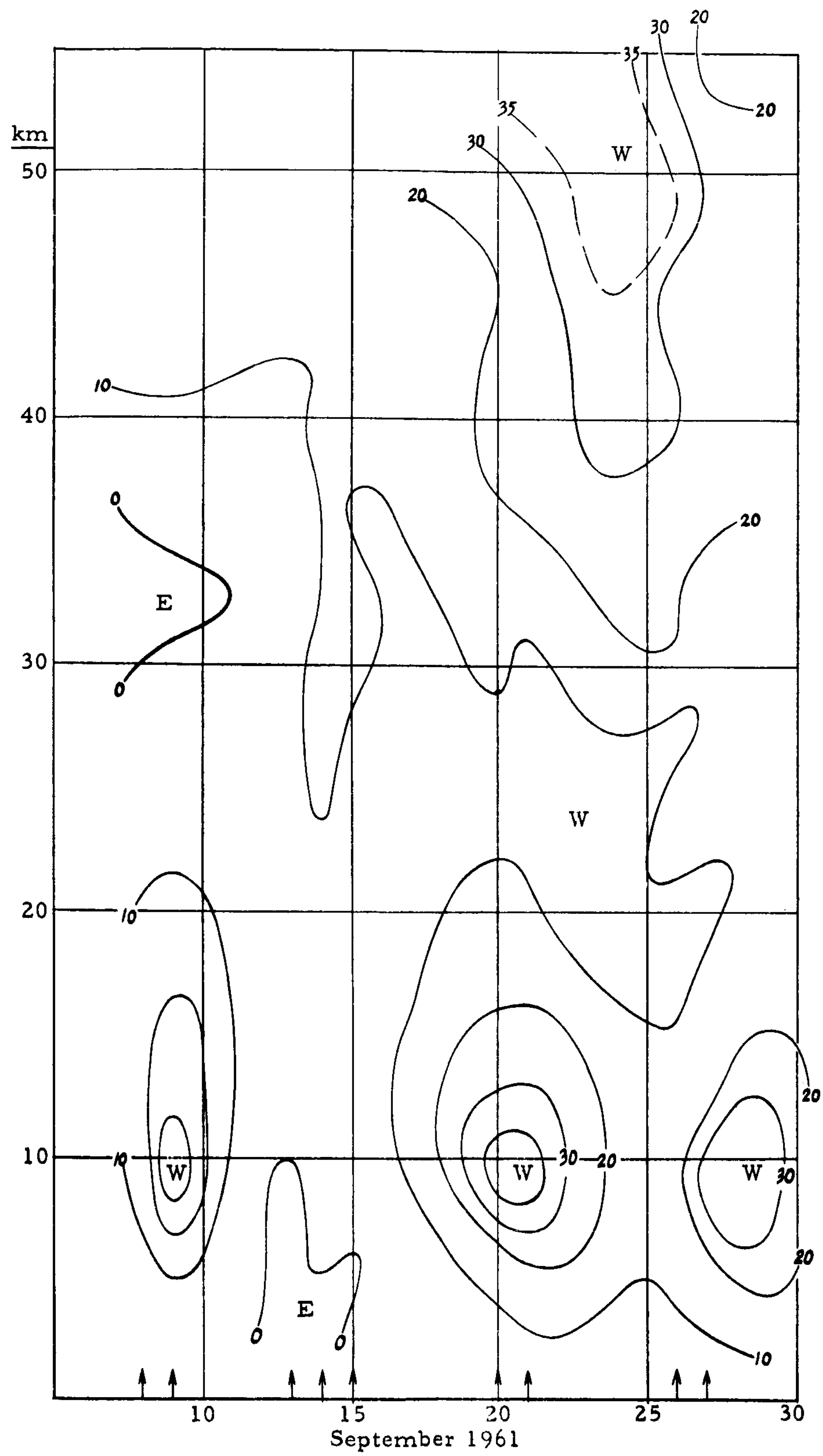

Fig. 10. Time-Height Section of Zonal Winds (m/sec) at Fort Greely, September 1961

b. The Fall Reversal in Middle Latitudes

As the data for Wallops Island, from August 8 to November 8, 1963, has not yet been discussed in the literature, it is shown in Fig. 11 as a time-height section. Note how the zero wind line definitely moves upward from August 28 at 20 km to 35 km on September 18. Westerlies also appear at 60 km on September 12 and move rapidly down to 35 km by the 17th. A region of light east or west winds is found from 15-20 km in early August, expanding to 15-40 km in late September, then narrowing and descending to about 15-30 km in late October. It may then be said that the reversal zone rises from near 20 km in August to 50 km in September and descends to near 25 km in October at Wallops Island in 1963.

c. The Spring Reversal in Polar Regions

Although it is well established at all stations that the spring reversal moves downward from highest levels yet sampled, recent data permit a comparison of arctic with antarctic data. Figure 12 shows the height-time change of the zero wind surface at McMurdo (78° S, 167° E) in the southern spring of 1962, compared with those for Fort Greely in northern springs of 1962 and 1963.

The heights for McMurdo were taken from the height-speed graphs in the IRIG data tabulations. As the vertical wind shears were strong, the intersections along the zero wind line were definite and reliable.

At Greely, the highest reported levels in March 1963 were 45-60 km which all showed westerly flow still, so the zero surface was above that region. In April the winds were frequently light and variable making multiple intersections with the zero wind line. To arrive at a better time interpolation, time-speed graphs for every 5 km were used for the levels above 30 km, and the Scherhag Group's 10 mb and 30 mb daily map series were used to select the dates of reversal at the two lowest levels.

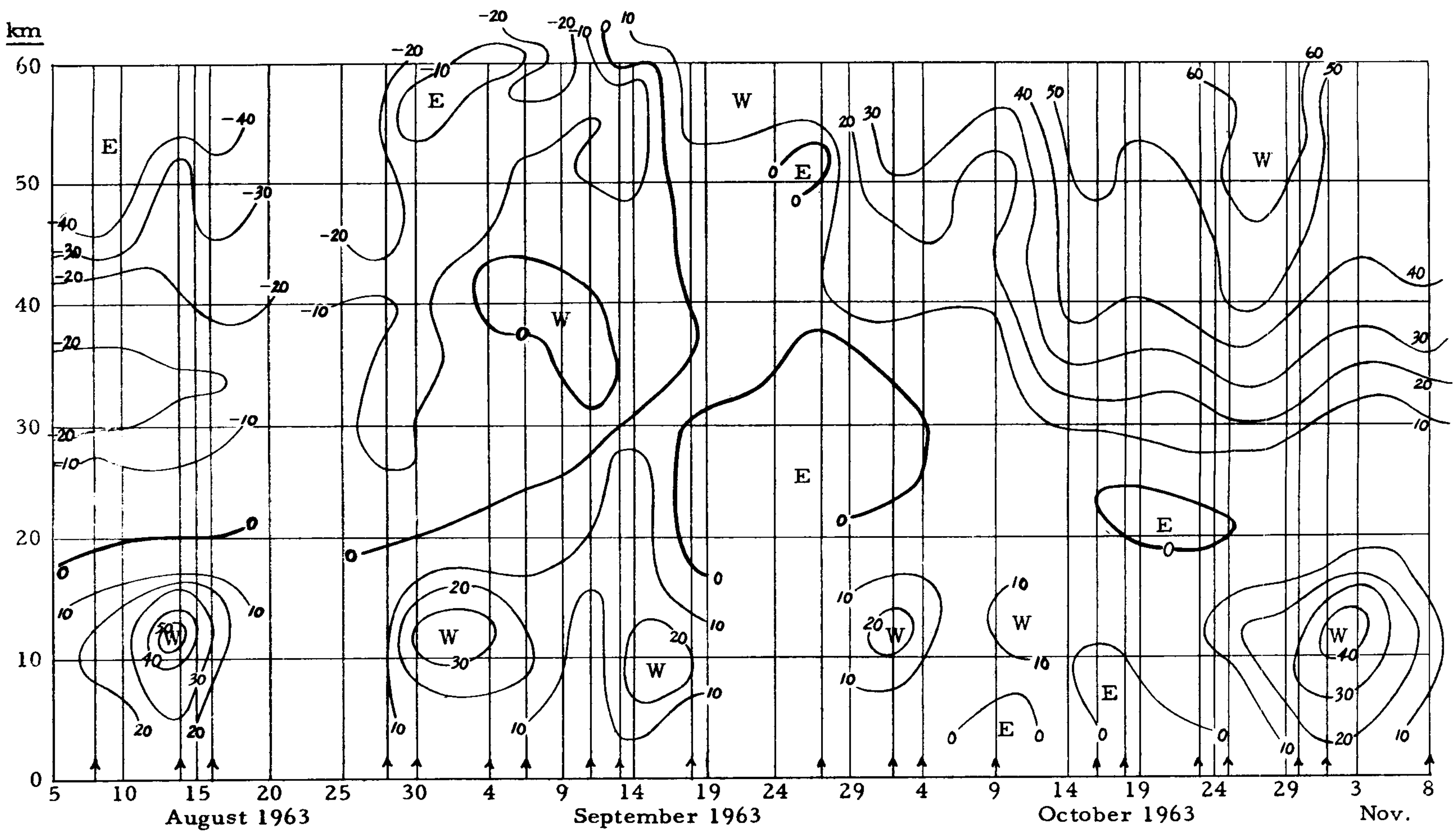

Fig. 11. Time-Height Section of Zonal Winds (m/sec) at Wallops Island, August-October 1963

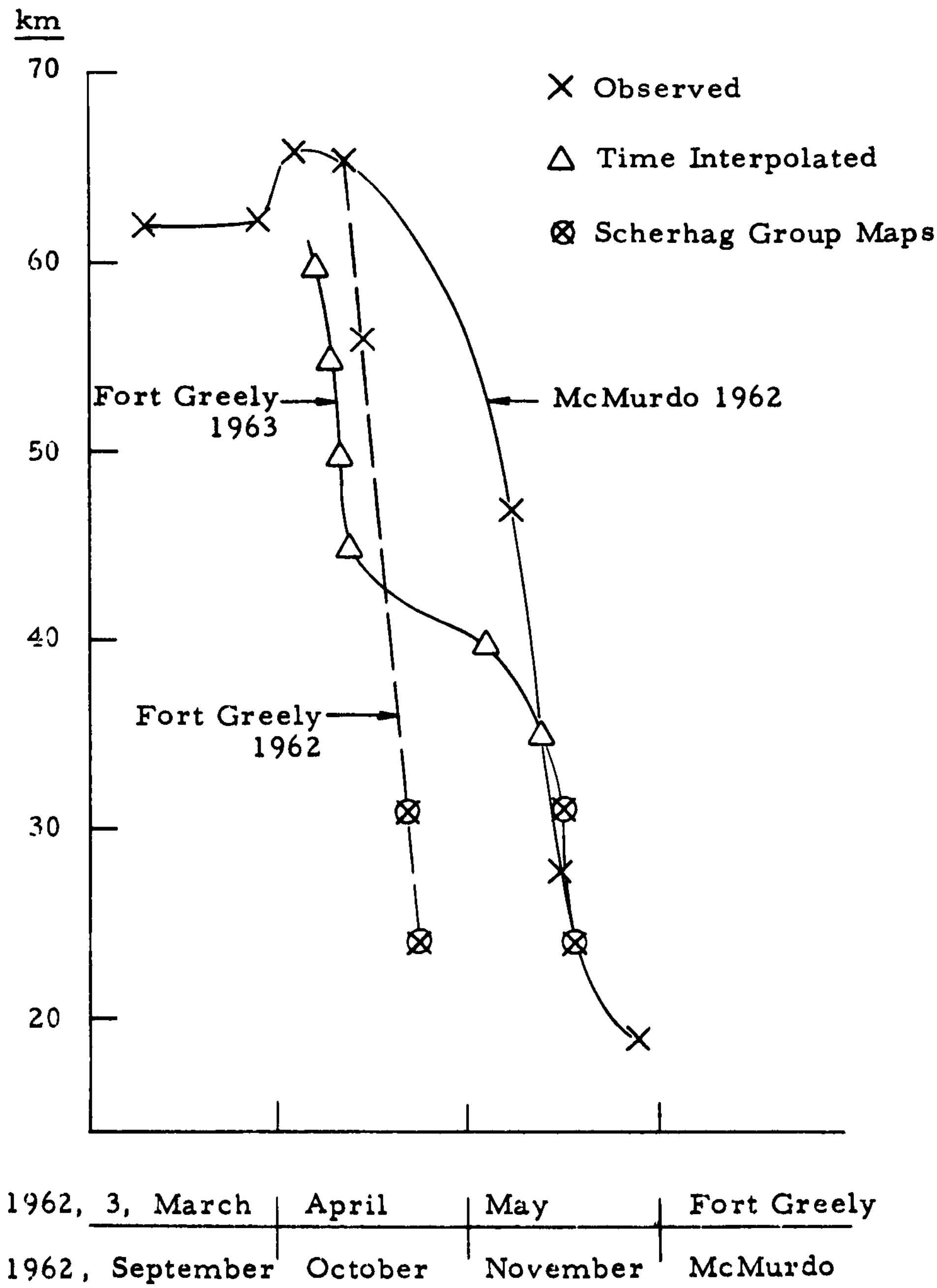

Fig. 12. Spring Reversal of Zonal Winds at McMurdo, 1962 and Fort Greely, 1962, 1963

In 1963 all levels were subjected to a 10-day period of anticyclonic influence in late April, which was strong enough to cause a return to easterlies at 40 km and below, but only reduced the speed of the westerlies at higher levels. Thus, the 1963 Greely reversal profile shows a staggered descent. The rate of descent of the transition level on the average is about 0. 8 km/mo at McMurdo, 3. 3 km at Greely in 1962, and 0. 8 at Greely in 1963.

In summary, so far as compatibility of M/R and R/W data as applied to this particular problem is concerned, there is no real difference demonstrated so far in this interpretation of M/R and R/W data. One must take into account the different altitude ranges and latitudes to which the data apply, the representivity of any single observation and the ranges of probable error. At this stage, the inaccuracies of both systems are sufficiently large and the variability of the variables so great that reasonable statistical samples are needed for both. This gives R/W one enormous advantage: The routine frequency of observation is so much higher than for M/R, that heavy reliance on a single observation is unnecessary. There is no reason why the fall reversal process at high latitudes cannot descend at levels from 60-35 km and ascend from 15-35 km. To date there are still no observations with which to verify this. At present, all data are compatible with respect to the seasonal reversal process.

IV. IMPROVEMENT OF THE METEOROLOGICAL ROCKET NETWORK

A. The Requirements and Uses for M/R Data

1. Operational Requirements

Operational support for aerospace systems is the sole requirement which has supported the present M/R network development. Unfortunately, the M/R program is still operated almost exclusively for this purpose and as a result the scientific uses below are not adequately met.

Although there is no present need for routine forecasts or numerical weather prediction (NWP) at levels above 30 km, and although the minimum upper-air requirements for NPW are still far from being satisfied in the lower atmosphere, eventually NWP may be applied in the upper stratosphere and mesosphere to help forecast the changes at lower levels. There is already operational need for forecasts at 20 km, and as aircraft ceilings continue to rise so will our need to understand atmospheric motions at highest possible levels. Also, large floating balloon systems now fly at levels above those for which there is any R/W wind data. To obtain climatological and forecasting experience at these levels before the operational requirements become more pressing, M/R data should be available on an experimental basis.

2. Scientific Research on Atmospheric Circulation

The present upper limit on routine studies of atmospheric motions is 30 km, although the M/R data has been used experimentally to estimate flow patterns at 50 km (Finger, et al., 1963, Keegan, 1961). The greatest benefits of M/R data will be to reveal physical processes at higher levels which may help explain the remarkable atmospheric changes observed at lower levels, such as sudden warmings, the timing of the annual ozone maximum, large-scale meridional circulations, the vertical extent and characteristics of the quasi-biennial wind oscillation, atmospheric tides, the seasonal coupling of the mesosphere to the stratosphere, etc. Thus, M/R data could serve as a valuable research probe into atmospheric circulations at levels from 30-60 km. To do so, however, the M/R data must be taken regularly and synoptically at an adequate number of stations.

B. Considerations of Network Density and Frequency of Observation

The WMO upper-air network recommendations (WMO, 1960) for use in NWP with present methods at temperate latitudes is that stations be 500-600 km apart as a minimum, provided pressure, temperature and wind are measured. If no wind is measured, then 300-350 km spacing is required. At high latitudes the distance should be smaller, in the tropics, larger. In order to place the Meteorological Rocket Network (MRN) problem in its proper perspective, it should be realized that even now, about 25 years after the introduction of the radiosonde, the world network still needs 775 additional upper-air stations and 3786 surface stations. As an immediate improvement, 53 new or improved upper-air and 100 surface stations are desired (WMO, 1963). Although the economic advantages of such stations are easily demonstrated (surface and aviation forecasts) the financial difficulties in getting these added stations are great.

All practicing stratospheric analysts will agree that despite the present large amount of M/R data, synoptic analysis is severely limited because of distribution and frequency of the observations.

Probably too little is known still about the regions above 30 km to yet make numerical estimates of the benefits to be derived from an improved MRN. However, the experience of the R/W network, which is currently undergoing just such an appraisal, may be of value. Among the experiments is one by Salmela (1959) who studied the effect of variable coverage at 500, 300, and 200 mb monthly mean maps. His main results are that: 1) errors in geostrophic winds read from incompletely plotted maps increase upward to the level of maximum wind speed; 2) when data are sparse the errors are greatest in troughs, but these errors decrease rapidly as network improves; 3) the rate of improvement in accuracy is greatest when going from zero to one-fourth network coverage and also from three-quarters to full coverage.

Thompson (1963) points out that the smaller the synoptic scale, the greater the observational accuracy required to compensate for the smaller intensity systems often found at a smaller scale. Thus, the accuracy of M/R data may have to improve as the density increases. He also holds out the hope that with new computer methods becoming available, it will be possible to carry out controlled numerical experiments with simulated networks having specified characteristics. This could show how the accuracy of analysis depends on density and location of stations, frequency of observations and their standard error.

The observational probability of a disturbance in the upper stratosphere and mesosphere being detected depends on the spacing of rocketsonde stations and their frequency of observation as well as the characteristic size of the disturbance and its velocity. The spectra of disturbances in this region includes energy contributions of: 1) high frequencies caused by atmospheric tides and gravity waves, 2) intermediate frequencies caused by baroclinic waves which project themselves as moving asymmetries of the circumpolar circulation, and 3) low frequencies due to the insolational cycle and perhaps the quasi-biennial cycle. At any given time, the resultant of several of these independent fluctuations may produce a characteristic synoptic pattern.

As our prime interest is to describe the intermediate and low frequency disturbances, the effect of atmospheric tides must be excluded from the data as the magnitude of these fluctuations in some cases is larger than the magnitudes of the disturbances we wish to describe. This can be done by synchronous firing of rockets from stations along different meridians taking into account the semidiurnal and diurnal effects or by using the combined results predictable by theory and from the few available observations to normalize the data with respect to local time. Once this has been done, the data contains primarily only information on the scale of features we wish to describe. Our next inquiry should be on the propagation of the intermediate and low frequency features. As ascents from rocket stations are not taken at the same time (although the frequency of observations may be nearly the same at all stations), it is necessary to define an interval of sampling in which all rocket stations have taken one ascent. This interval is approximately one week based on current operational rocket network requirements. It is clear that disturbances which pass through the network in less than one week's time will not be described. An idea of the scale and motion of synoptic disturbances at these levels can be seen from daily 10 mb maps (Scherhag Group). If the circulation at levels near 50 km can be expected to resemble that at 30 km, then we should expect it to be controlled by an active winter polar-night vortex which is frequently disturbed by perturbations from lower latitudes, especially from over the oceans, and by a stable and relatively quiet summer (June, July) anticyclone. The development and destruction of the polar-night vortex and the motion of troughs and ridges around its periphery as well as the motion of the maritime subtropical anticycles can only be detected by a properly spaced station network.

Gleeson (1959) suggests a method to estimate the probability of detecting a disturbance with a given network, which can be applied to this problem: The probability (P) of observing a disturbance of size (S) in a network of (n) stations in a region (R) is given by:

$$P = 1 - (1 - S/R)^n$$

if the (n) stations are randomly distributed. From the existing rocket stations, it is possible to define such a network if we pick stations that satisfy this criterion. It is to be noted that all rocket stations cannot be used to form such a network as there is a definite bias in their location, and the above equation would give erroneous results. If we choose (R) to be the region bounded by 20°-70° N latitude and 60°-160° W longitude and include the following six stations: Fort Greely, Churchill, Hawaii, Point Mugu, Cape Kennedy and Bermuda, we may be justified in using the above equation.

If we express the characteristic size of the disturbance (S) as a fraction of (R), then the probability of detection of the disturbance is shown by (P) in Table 22. In this table, the effects of including one more station and five more stations to this network are also calculated.

Table 22. Probability (in percent) of observing features of various sizes by different numbers of randomly spaced stations in an area of 42.5×10^6 km^2 and the magnitude of the uncertainty of isoline locations used to describe these disturbances.

Disturbance Diameter (km)	Average S/R	P_6	P_7	P_{11}
4000	0.30	88	92	98
3000	0.17	66	73	87
2000	0.074	37	42	57
1000	0.018	10	12	18
800	0.012	7	8	12
600	0.0067	4	5	7
400	0.0030	2	2	3
Uncertainty of isoline location, $(R/n)^{1/2}$, in km		2.7×10^3	2.4×10^3	2.0×10^3

Following the detection of a disturbance, it is desired to find out as much about its intensity and extent as possible. In particular, one wishes to know the uncertainty associated with the isolines describing the disturbance. Gleeson, in an application of uncertainty principles to meteorology, concludes that the uncertainty in the location of isolines is the same order of magnitude as $(R/n)^{1/2}$. This quantity is also indicated in Table 22 for various numbers of stations (n) in region (R).

It can be seen that current rocket stations are probably adequate for the detection of large scale features in mid-latitudes, but that the network should be expanded to include broader area coverage in the arctic and tropics. This will allow for a better chance of detection of disturbances common to these regions. Further, the uncertainty in locating isolines for a synoptic analysis is approximately 2700 km for the existing rocket network. This inaccuracy bars any reasonable description for climatic purposes.

C. Recommendations for Long-Term Improvements in the Meteorological Rocket System and Network

1. Network

It is suggested that additional stations be considered in the region of the Great Lakes, Great Slave Lake, Great Bear Lake, the Aleutians, the Canadian arctic islands, Greenland, the west coast and east coasts of Canada, the coasts of Alaska, as well as on ocean weather ships.

With regard to frequency of observation, this should be daily during the very active winter and transition seasons (August through May), especially at latitudes above 45 degrees, but during the relatively quiet months of June and July once weekly may be sufficient for most purposes. Ascents are particularly needed at high latitudes during the fall transition (August 15 to September 15).

To assure strictly synoptic observations, the M/R program should be operated independently of other missile operations, or coordinated in such a way that the range facilities are available at the specified scheduled time each day. Rocket ascents must be supported by nearly simultaneous rawin ascents taken nearby.

2. Data Reduction and Reporting

One cannot help wonder if there is any other physical science in which comparably expensive data are taken without knowing even the type of instruments used, let alone not having an estimate of the probable error of the data. An estimate of data accuracy and reliability should be included with each M/R ascent which takes into account the particular equipment and procedures used on each firing.

A detailed description of M/R data reduction methods should be published to allow users to evaluate significance of published data.

The observed radar data should be evaluated so as to give values both at regular height intervals and for significant levels. The present reported vertical resolution varies from 700-4000 m between consecutive winds. Intermediate radar measurements are actually made but are ignored in the data reduction process because of the fixed time interval rather than height interval over which data are averaged.

The desirable frequency for taking measurements during an ascent should be re-examined in view of their application to theoretical, climatological and practical problems. This may have to be a function of the particular sensor used.

The basic tracking and telemetered data should be on magnetic tape and copies of these data tapes should be available to potential users; otherwise, a standard processing procedure and publication format should be adopted which can most reasonably accommodate the various possible applications of the data.

The radar data reduction procedure appears to be unnecessarily complicated by using a combination of computer and manual methods. It should be possible to improve resolution and accuracy by use of automatic data processing methods alone.

Objective limits should be established for terminating chaff observations in terms of the diffusion of the chaff cloud.

3. Accuracy

Careful experimental accuracy determination of all systems and procedures is essential. Statistical evaluation of the properties of data reduction procedures, such as the example of variation with altitude of the vertical resolution of published M/R wind data which was manually evaluated here for a single month, should be carried out by computer for the entire record of M/R wind data in order to see what seasonal or latitudinal effects may exist.

4. Survey of M/R and R/W Systems

A current handbook is needed which describes the properties of all M/R vehicles, sensors, tracking equipment and data reduction procedures so that data can be compared on a rational basis. The handbook should include foreign M/R systems as well.

The brief tabular summary of properties and characteristics of M/R systems in this report is based only on available literature. A more specific evaluation of accuracy could be prepared from direct consultation with experienced instrumentation specialists.

As adequate lower atmospheric information is needed to interpret M/R data, a similar handbook should be prepared describing all radiosonde and rawin systems, explaining where and when used, and including all U. S. and foreign systems.

5. Goals for Eventual Improvement of the M/R System

The following possibilities should be considered:

1) The standardization of M/R wind finding systems; this should include ascent vehicles, targets, tracking methods and data reduction.

2) The development of a new type of inexpensive M/R with a frangible case and engine, which would reduce restrictions on observation sites and allow improved spacing of stations.

3) A single vehicle system which would give information from ground up to at least 60 km within one hour's time.

4) A system whose launch is less sensitive to winds, enabling more frequent ascents in bad weather.

5) An international competition to design more accurate and especially less expensive M/R systems to help meet the above goals. This incentive should help bring a stronger effort into solving these problems.

6) A modern, standard stratospheric rawinsonde system to be adopted by the many different users in the North America. An international instrument is needed even more.

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