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RESPONSE CHARACTERISTICS OF METEOROLOGICAL ROCKET WIND REDUCTION TECHNIQUES

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16. Abstract

By use of analytical expressions for position and time as functions of height the response characteristics of the height-based and time-based manual wind reduction techniques for meteorological rocketsondes are deduced. It is shown that the height-based method is more consistent in depicting medium-scale perturbations than is the time-based method. This is accomplished, however, at the expense of the simplicity of the time-based system.

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INTRODUCTION

In general, the "mechanical" sources of error inherent in wind determinations for meteorological rocket systems can be divided into 3 categories: (1) sensor response to the wind, (2) radar accuracy of position and (3) finite-difference approximation of wind from the position data. While Eddy et al. (ref. 2), Malet (ref. 5) and Hyson (ref. 3) have investigated the first two aspects, the third has received very little attention to date.

Unfortunately, there exists no single procedure for wind reduction, mainly because the radar systems and capabilities at each site are so varied. Certain stations, for example, are equipped with extremely sophisticated radar systems with appropriate computer equipment so that winds with a high degree of resolution result. Other stations must rely on manual reduction of winds from position points depicted on a plotting board at finite time intervals (U.S. NASA, ref. 11; Mitchell, ref. 8).

In the case of the well equipped stations, the time resolution is, in general, such that vertical scales of motion on the order of 1 km are adequately depicted. Although a serious question exists as to how to smooth this detailed wind data or, indeed, if it should be smoothed at all before publication in the data books (MRN, ref. 10), we consider this data to be of sufficient accuracy for most planned usage (Miller et al., ref. 7). Therefore, we will not concern ourselves in this study with these data. In the case of the other stations, however, the finite-difference intervals employed in the calculations are such that perturbations with "wavelengths" of several kilometers are effectively filtered from the data. In view of the results of Lettau (ref. 4), Mahoney and Boer (ref. 6), and Cole and Kantor (ref. 1) that significant power exists in the wavelength range from 3-4 km, the exact degree of smoothing accomplished by the reduction techniques must be known if we are to interpret the data correctly. The purpose of this study, then, is to investigate the response of the manual wind reduction procedures with particular emphasis on the response to small- and medium-scale waves.

Basically, there are two manual reduction techniques in use at this time, height-based and time-based. In the former, (U.S. NASA, ref. 11)* data points on the plotting board are interpolated in the vertical so that a position and time is depicted at every whole kilometer. Winds are then determined by dividing the spatial separation of points 2 kilometers apart by their time difference. The wind value is then ascribed to the mid-kilometer level. In the time-based technique (Mitchell, ref. 8) position points are depicted at 30-second intervals for the first 5 minutes from launch, at 60-second intervals for the next 15 minutes and at 120-second intervals thereafter. Winds are determined by dividing the position difference by the appropriate time difference and the value ascribed to the mean height of the top and bottom points. While the time-based method is relatively simple compared to the height-based system in that no interpolations are required, it possesses the disadvantage that the vertical distance between points is not constant, since the sensor fall rate decreases with decreasing height.

In this paper analytical expressions are determined for the two methods under the assumption that a sinusoidal variation of wind with a fixed vertical wavelength exists in the atmosphere. The results are compared and the utility of the methods discussed. This analysis is based on a particular fall rate profile of the sensor and while this differs somewhat from station to station and from instrument to instrument our results should be indicative of the problems that arise.

ANALYTICAL MODEL

Since our purpose is to evaluate only the wind reduction techniques, we assume at the outset that the sensor is perfectly responsive to the winds and that the radar positions are exact.

The expression for the time rate of change of the sensor position (x direction only; the results for the y direction would be similar) may then be written as:

$$\frac{dx}{dt} = \frac{dx}{dz}\frac{dz}{dt} = U \cos Kz \qquad (1)$$

*It has recently come to the attention of the author that the height-based technique is to be the sole method employed at all U.S. sites.

where x is position, U is the amplitude of the sinusoidal wind variation and k is the wave number ($k = \frac{2\pi}{\lambda}$, λ is the vertical wavelength).

Clearly, if an analytical expression for dz/dt as a function of height could be determined, then $\frac{dx}{dz}$ would be analytically defined as a function of height. Integration would then yield both x as a function of height and t as a function of height.

For this study, fall rates of Arcasonde-1A instruments with 15 ft. diameter parachutes at Wallops Island, Virginia (Experimental Inter-American Meteorological Rocket Network (EXAMETNET), ref. 9) were plotted and an expression for dz/dt was determined by eye which seemed to represent the fall rate adequately. The expression for dz/dt is indicated in equation (2) and shown in Figure 1 along with the measured fall rates.

$$\frac{dz}{dt} = -A z^{-1} e^{bz} \tag{2}$$

where z is in km, $A = 2x10^{-2}$ km^2-sec^{-1}, $b = 0.103$ km^{-1}.

While other more complex expressions for dz/dt could be derived that would give a somewhat better fit, especially at levels below 30 km, the stringent requirement for this study was that finite integrals (non-series solutions) exist for both (1) and (2).

Substitution of (2) into (1) results in the following expressions for x and t:

$$x(z) = -UA^{-1}\left(b^4+2b^2k^2+k^4\right)^{-1} e^{-bz}\left\{\left(\left(k^2-b^2-z\left(k^2b+b^3\right)\right)\cos kz + \left(2kb+z\left(kb^2+k^3\right)\right)\sin kz\right\}\right. \tag{3}$$

$$t(z) = A^{-1}\left\{e^{-bz}b^{-2}\left(bz+1\right)\right\} \tag{4}$$

Using these exact expressions, the computation of $\Delta xt/\Delta t$ by the height-based system is relatively straightforward. The values of x and t were determined at every whole kilometer and the finite differences calculated as described above. However, because (3) and (4) are transcendental, the solutions for x and z as functions of t are not readily determined so that for the time-based computations a somewhat different procedure had to be followed. The values of x and t were determined at 100-meter intervals from 55 km to 25 km and the values linearly interpolated to the necessary points in time. While this introduces an uncertainty into the time-based calculations it is considered to be small. In all computations the sinusoidal

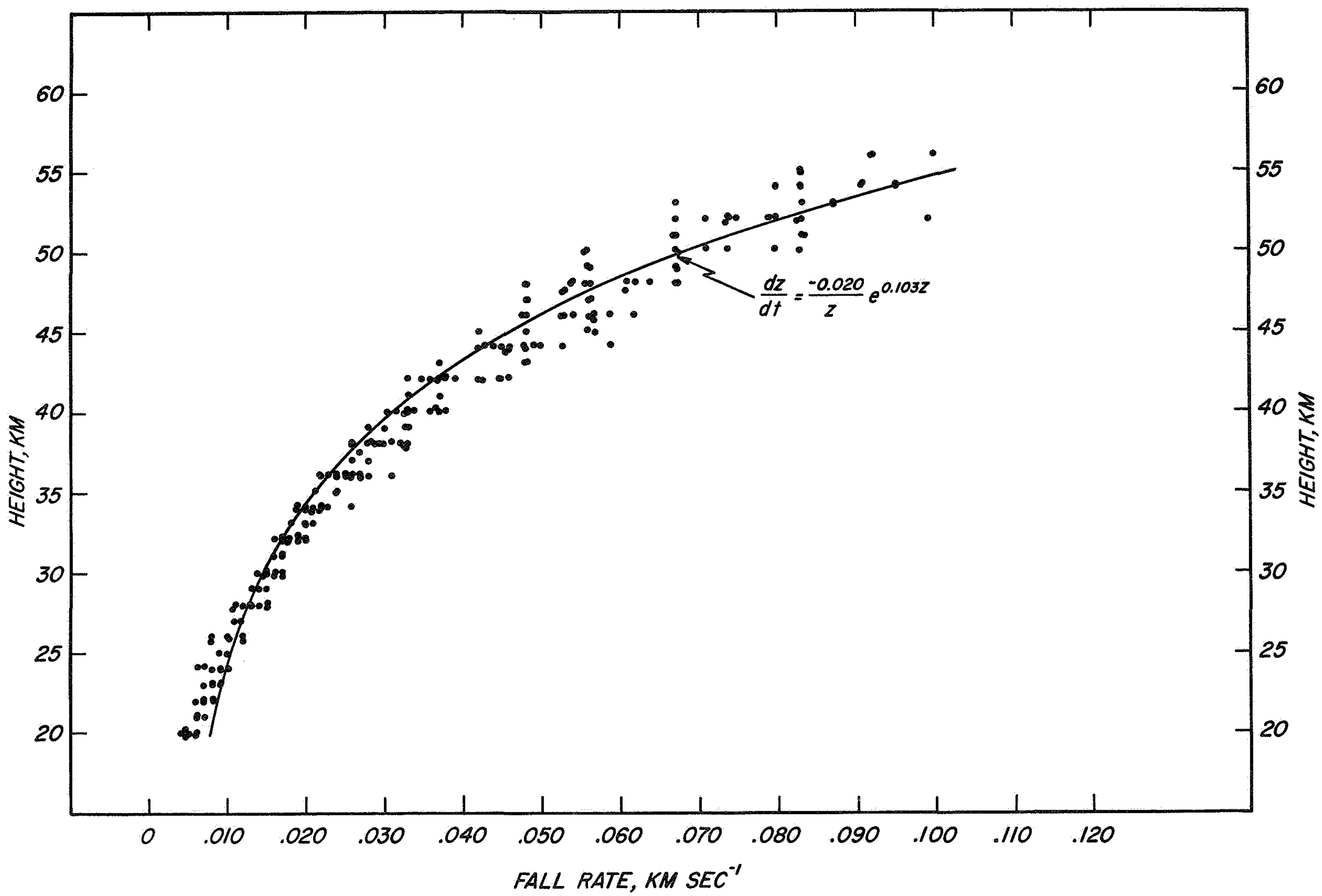

Figure 1. Measured (filled circles) and approximated (solid line) fall rate of Arcasonde 1A instrument with 15' diameter parachute at Wallops Island, Va.

variations were assumed to have unit amplitude.

RESULTS

Height-based Method

Illustrated in Fig. 2 are the results of the calculations for the height-based method when true wavelengths of 3.5 km and 4.0 km exist in the wind profile. The response is about 54% for the former and about 64% for the latter; both are essentially independent of height. Of interest is the chopping effect that occurs in the 3.5 km wave whenever the true wind maximum occurs at a level other than a whole kilometer. This, of course, raises the point that for the purposes of our calculations the phase of the sinusoid was held fixed. For waves with somewhat different phases, the calculated winds would be changed accordingly.

Figure 3 presents the maximum response for the wind computations, when the wind is measured at a level where the true wind is a maximum. The response, then, does not include the reduction effect for winds whose maxima are at levels other than whole kilometers. For this reason, these values should be considered indicative only and are not meant to be used as a correction scheme in the wind determinations.

As might be expected, the response is zero at a wavelength of 2 km and increases with increasing wavelength. The effect, then, on vertical scales of motion of 3-4 km is to reduce the amplitude by about 36-60%. This, of course, has serious repercussions when spectral analyses are attempted on this data or when vertical shears are calculated.

The response at wavelength less than 2 km is somewhat misleading in that by this method of wind computation these wavelengths are aliased into perturbations of larger scales. Figure 4 presents the results for wavelengths of 1.2 and 1.5 km, selected for illustrative purposes. The aliasing of 1.2 km wavelengths into 6-km waves is clearly evident. Unfortunately, information on the reality of these short waves is very scanty at present, but indications are (Miller et al., ref. 7) that they exist with amplitudes of the order of 5 m sec^{-1}. Considering however, that all responses for these wavelengths are less than 20% the effect of this aliasing does not, in general, appear to be significant.

As a test on the effect of the phase of the wave on the aliasing, computations were made for $\lambda = 1.5$ km with the peak of the sinusoid stepped down by 100 meter intervals till the next whole kilometer level was reached. No significant changes resulted.

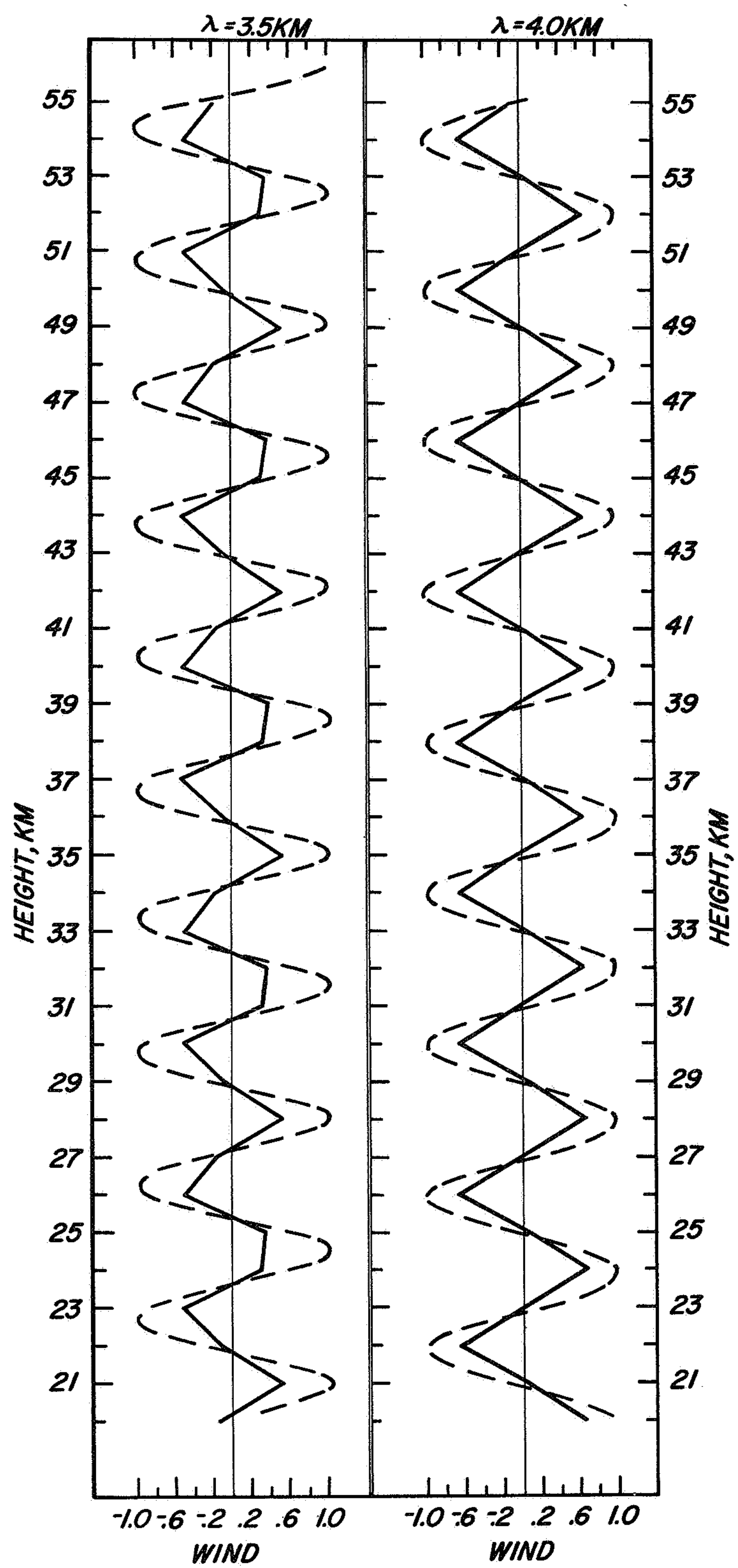

Figure 2. Winds computed by height-based technique (solid line) and true wind profile (dashed line) as a function of height. λ represents vertical wavelength of true wind profile.

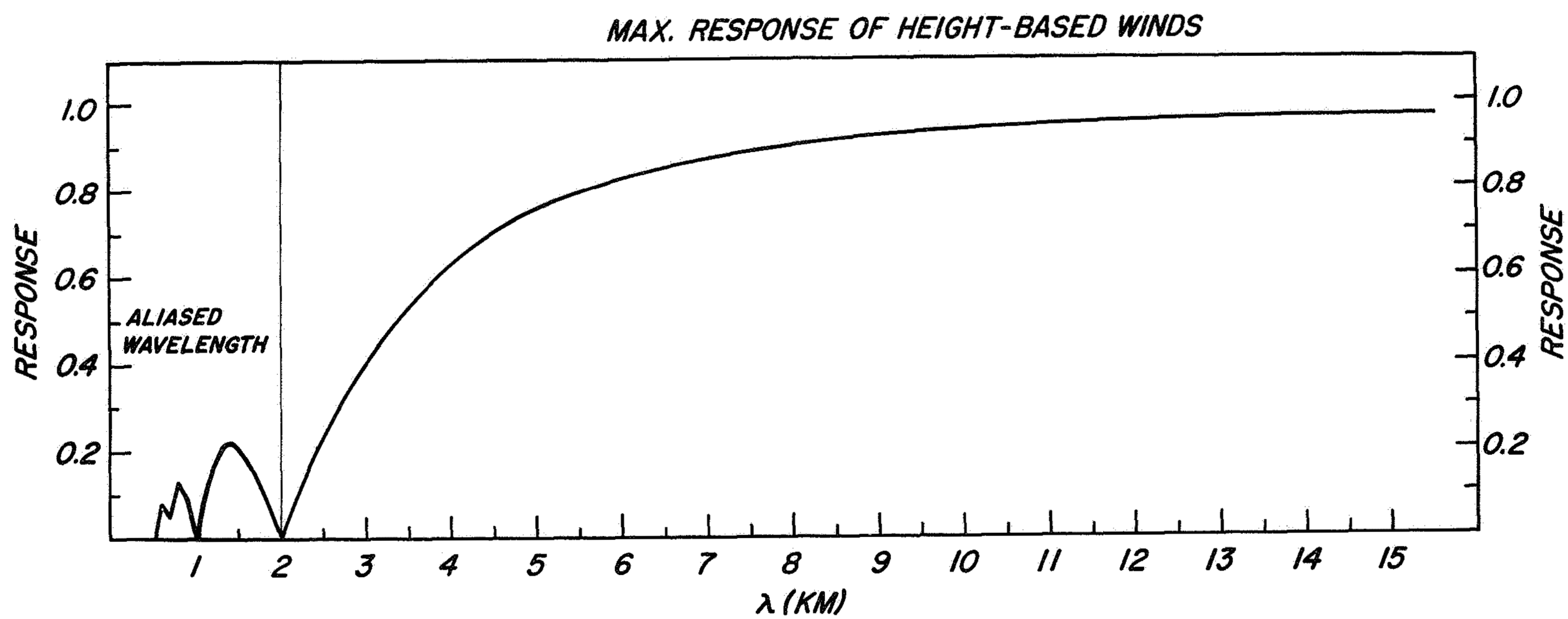

Figure 3. Maximum response of height-based wind computations as a function of vertical wavelength (λ).

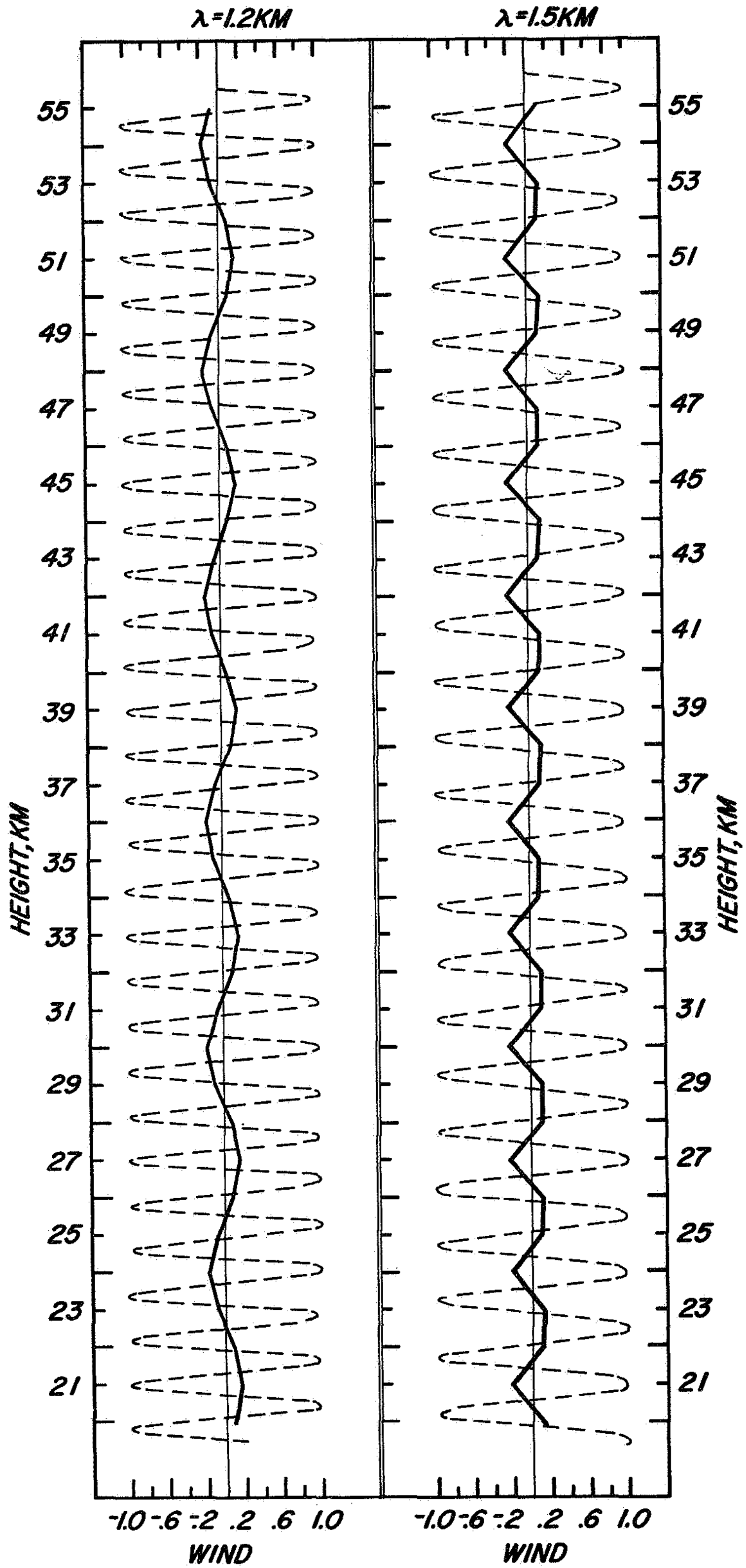

Figure 4. Winds computed by height-based technique (solid line) and true wind profile (dashed line) as a function of height. λ represents vertical wavelength of true wind profile.

Time-based Method

As indicated above, the time-based method involves the use of constant time increments that are increased as the fall rate of the sensor decreases. While the effect of the selected increments is to allow approximately 2 km between data points, it is clear that at the bottom of each time step the vertical distance between data points will be less than that at the top. The result is a variable smoothing effect in the vertical and we would therefore expect the least resolution at the top of each time step and the greatest resolution at the bottom. This is borne out by Figure 5 which illustrates the computed winds for wavelengths of 1.5 km and 3.5 km.

In both cases it was assumed that apogee and ejection of the sensor occurred within 2 minutes from launch and that 3 minutes of 30 second interval data resulted. With the assumption that $t=0$ at $z=55.0$ km, the heights for the first winds of the second and third time steps are 42.5 km and 25.38 km respectively. In the case of the 1.5 km wave, the effect of the variable vertical smoothing is clearly seen by the increased resolution at the lowest levels, with no pattern evident above about 34 km. With the wavelength set equal to 3.5 km, on the other hand, the main disparities seem restricted to levels above about 51 km. The effect of the decreased resolution at the top of the second step is, however, indicated by the relatively low wind value at 42.5 km. Again, the resolution increases with decreasing height.

If apogee were somewhat higher or rocket burn time somewhat longer than that assumed above, then the number of data points at the different time intervals would be accordingly reduced. As a test on this effect, winds were computed in the same way as above, but only 2 minutes of data at 30-sec. intervals were allowed. The results, also shown in Figure 5, indicate a much reduced response between 43 and 47 km compared to the previous case. This is due to the increased smoothing interval at these heights associated with the increase in time between data points.

Because of these disparities and the general increase of resolution with decreasing height, no attempt was made to portray a general response curve, as was done for the height based system. Clearly, though, the resolving power of this method follows a similar pattern with respect to wavelength as does the height-based procedure.

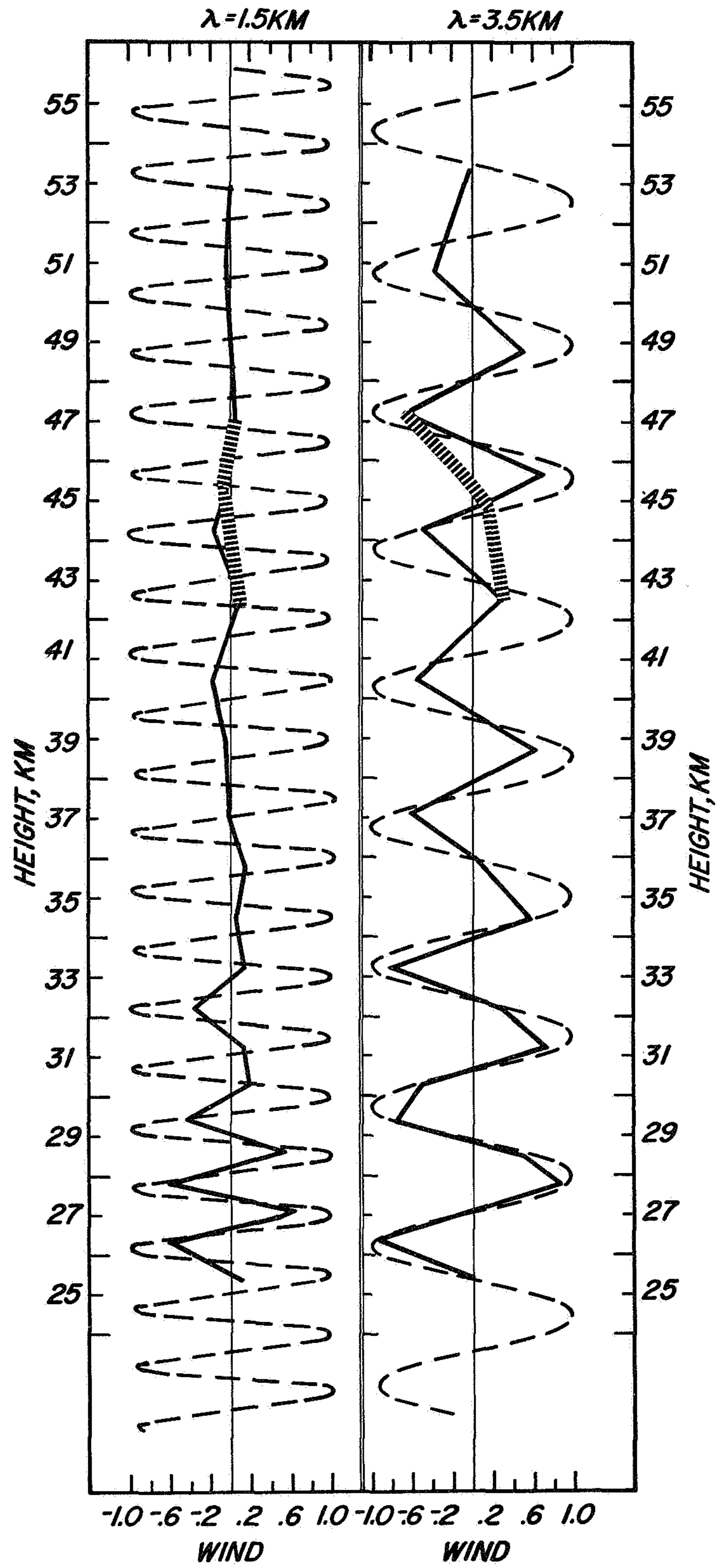

Figure 5. Winds computed by time-based technique assuming 3 minutes of data at 30 second intervals (solid line) and true wind profile (dashed line) as function of height. Winds computed assuming 2 minutes of data at 30 second intervals are indicated by the solid line that merges into the stippled line. λ represents vertical wavelength of true wind profile.

FINAL REMARKS

By use of analytical expressions for position and time as functions of height we have shown that the height-based technique is more consistent in portraying medium-scale perturbations than is the time-based method. This is accomplished, however, at the expense of the simplicity of the time-based system. It is not our intention to argue whether one system is effectively better than the other; that is too dependent on the purpose for which the data are to be used. Our objective merely is to illustrate the differences that result from calculations by the two methods, especially for perturbations on the scale of 3-4 km, so that a better understanding of their utility might emerge.

In general, the response of these wind determinations for perturbations of 3-4 km wavelength is about 50-60% of true value. This should be considered when any attempt at spectral analysis or shear determination is made. Both methods alias wavelengths smaller than 2 km with the consequence that the scale-lengths can not be defined in these data. However since both the response to these aliased waves and the relative power within them appears to be small, the addition of power to the larger wavelengths appears to be negligible.

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REFERENCES

1. Cole, A.E., and A.J. Kantor, 1968: Spatial variations in stratospheric and mesospheric wind fields. Proc. 3rd. Nat. Conf. on Aero. Meteor., May 6-9, 1968, New Orleans, La., 465-471.

2. Eddy, A., C.E. Duchon, F.M. Haase, and D.R. Haragan, 1965: Determination of winds from meteorological rocketsondes. Atmospheric Science Group, University of Texas, 29 pp.

3. Hyson, P., 1968: Windfinding data from radar tracking of high altitude sensors. Quart. J. Roy. Meteor. Soc., 94, 595-597.

4. Lettau, B., 1966: Persistence of small-scale features in the mesospheric wind field. AFCRL Environmental Res. Paper No. 198,10 pp.

5. Malet, L.M., 1963: Effet de la vitesse de chute d'un mobile sur les mesures du vent. Beitr. Phys. Atmos., 36, 264-275.

6. Mahoney, J.R. and G.J. Boer, Jr., 1967: Small-scale velocity structure in the 30-60 km region deduced from paired ROBIN soundings. Mass. Inst. of Tech., Dept. of Meteor., Contract No. AF 19(628)-5075, Scientific Report No. 1, 56 pp.

7. Miller, A.J.,H.M. Woolf and F.G. Finger, 1968: Small-scale wind and temperature structure as evidenced by meteorological rocket systems. J. Appl. Meteor., 7, 390-399.

8. Mitchell, L.V., 1968: The USAF environmental rocket sounding system data quality control and data reduction. Report. 6083, Environ. Tech. Applications Center (ETAC), Air Weather Service, Washington, D.C., 32 pp.

9. The EXAMETNET Data Report Series, Annual Report, 1966, 1968: NASA Report SP-175, Published by Shellenger Research Laboratories, University of Texas at El Paso, Texas, 184 pp.

10. The Meteorological Rocket Network (MRN), 1965: I.R.I.G. Document No. 111-64, Published by Shellenger Research Laboratories, University of Texas at El Paso, Texas, 324 pp.

11. U.S. NASA, 1968: EXAMETNET data preparation and guidance procedures manual. Meteorological Projects and Systems Section and Meteorology Section, Wallops Station (NASA), Va., 2nd ed., (Prepared for the Experimental Inter-American Meteorological Rocket Network.)

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