Errata (third printed edition; c.a. August, 2000)
Doppler Radar and Weather Observations, Second Edition

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Academic Press, Inc., San Diego, 562 pp.
ISBN 0-12-221422-6.

Page	Para.	Line	Remarks: Paragraph 0 is any paragraph started on a previous page that carries over to the current page
14	2	1	Change to read: The path of electromagnetic waves depends principally on the change of refractive index $n = c/v$ (or relative permittivity $\epsilon_r = \epsilon/\epsilon_o = n^2$ because relative permeability μ_r of air is unity) with height. .
30	2	9	replace the italicized "*o*" from the first entry of the word "oscillator" with a regular "o", but italicize the "o" in the second entry of the word "*o*scillator"
	3	7	delete the parenthetical phrase
34	Eqs. 3.2		replace D with D_a
35	2	10	the equation on this line should read: $\sigma_b = \sigma_{bm}\left(1-\frac{\sin^2\psi}{\sin^2\theta}\right)^2 \frac{\cos^4[(\pi/2)\cos\theta]}{\sin^4\theta}$
40	Eq.(3.14b)		replace subscript "m" with "w"
47	Table 3.1		change footnote *c* to read: "Transmitted power, antenna gain, and receiver noise power are referenced to the antenna port, and a 3 dB filter bandwidth of 0.63 MHZ is assumed.
71	Eqs.(4.4a,b)		insert (1/) in front of the sum sign in each of these equations
	3	6	replace "p. 418" with "p. 498".
	Eq.(4.6)		Delete the first "2"
75	1	6	change to "$G(0) \geq 1$"

76	Fig.4.5	Change second sentence in caption to read: The broad arrow indicates sliding....
82	Eq.(4.31)	delete the subscript on *Z*
	Eq.(4.32)	delete the subscript on *Z*
	1 9	should read: ".. is the *reflectivity factor* of spheres."
	Eq.(4.34)	the overbar in this equation should be over *P* not *"r"*; i.e., $\overline{P}(\mathbf{r}_0)$
83	Eq.(4.38)	subscript "τ" should be the same size as in Eq.(4.37).
113	2,3	Delete the sentences beginning with "Furthermore, we assume..." and ending with "...scatterer's axis of symmetry)." in paragraph 3. Change Eq.(5.59a) to read

$$\begin{aligned} R(mT_s) &= E[V^*(\tau_s,0)V(\tau_s,mT_s)] \\ &= E\left[\sum_i \sum_k F_i^*(0)A_i^*(0)F_k(mT_s)A_k(mT_s)\exp\{j(\phi_i - \phi_j - 4\pi v_k mT_s/\lambda\}\right] \quad (5.59a) \\ &= \sum_k E[A_k^*(0)A_k(mT_s)F_k^*(0)F_k(mT_s)\exp\{-j4\pi v_k mT_s/\lambda\}] \end{aligned}$$

Following this equation write:

The expectation in Eq.(5.59a) includes averages over the ensemble of statistically stationary and homogeneous turbulent velocity fields. The expectations of the off diagonal terms of the double sum are zero because the phases ($\phi_i - \phi_k$) are uniformly distributed across 2π; thus the double sum reduces to a single one. To simplify further analysis, assume that the weighted scatterer's cross section F_kA_k is independent of v_k, and that F_k does not change appreciably [i.e., $F_k(0) \approx F_k(mT_s)$] while the scatterer moves during the time mT_s. Furthermore, assume A_k varies randomly in time (i.e., a hydrometeor may oscillate or change its orientation relative to the electric field). Thus Eq.(5.59a) reduces to

$$R(mT_s) = \sum_k R_k(mT_s)|F_k|^2\, E\{-j4\pi v_k mT_s/\lambda\} \quad (5.59b)$$

where

$$R_k(mT_s) = E[A_k^*(0)A_k(mT_s)]$$

Because $R(0)$ is proportional to......(continue from the sentence containing Eq.5.59c)

114 2 3-4 Modify to read: "...the velocities due to steady and turbulent wind that move the scatterer from one..."

6 Modify to read: "...the velocities associated with steady and turbulent wind can be placed...."

9-13 Delete lines 9-13 beginning with the sentence, "It can be shown..."

117 2 4-5 Modify these lines to read: "where the terms........*velocity* shear along the three spherical coordinates at $\mathbf{r}_0$. The assumption behind (5.70) is that components of the weighting function and reflectivity are product separable along the orthogonal spherical directions."

2 9 change to read: "the so-called beam-broadening term;...."

3 Replace the text in this paragraph up to, but not including Eq. (5.74) with: "We now express the dependence of σ_s^2 in terms of shears along the spherical coordinates centered on the radar. Spherical coordinate shears of the Doppler velocity can be directly measured with the radar, and thus it is natural to express σ_s^2 in terms of these shears. If the resolution volume V_6 dimensions are much smaller than its range and shears are uniform within V_6, the radial velocity within V_6 can be expressed as

$$v - v_o \approx k_\varphi r_o(\varphi - \varphi_o) + k_\theta(\theta - \theta_o) + k_r(r - r_o) \quad (5.71)$$

where $k_\varphi \equiv \frac{1}{r_o}\frac{\partial v}{\partial \varphi}$, $k_\theta \equiv \frac{1}{r_o}\frac{\partial v}{\partial \theta}$ $k_r \equiv \frac{\partial v}{\partial r}$ are the angular and radial shears of the radial component of the wind field at V_6. These spherical shears can be present even if Cartesian shears are non existent, and they are functions of V_6 location. For example, if wind is uniform,

$$\frac{\partial v}{\partial \phi} = (u_0 \cos\phi_0 - v_0 \sin\phi_0)\cos\theta_0; \ \frac{\partial v}{\partial \theta} = w_0 \cos\theta_0 - (u_0 \sin\phi_0 + v_0 \cos\phi_0)\sin\theta_0; \ k_r = 0 \quad (5.72)$$

where ϕ_o, θ_o are the angular locations of V_6. If the weighting function is product separable, that is,

$$I(r,\theta,\phi) = C|Ws(r)|^2 f_\phi^4(\phi) f_\theta^4(\theta) / r_0^2 \quad (5.73)$$

			and the reflectivity field is also product separable, substitution of these and (5.72) into (5.51) produces .....
125	2	10	after Eq.(6.5) add the sentences: ρ in chapter 5 (e.g., Eq.5.63) is the complex correlation function. Here, and henceforth it represents the magnitude of this complex function.
126	3	2-4	Change S to $\overline{S}$. Furthermore, the sentence: "The values of meteorological interest...range requirement" should be moved to the end of the para.1, but the parameter in that sentence needs to be replaced with P_k.
		5	change " " to " $\overline{S}$ ".
128	2	4-6	change to read "....The variance of signal power estimated...using the distribution of $S \equiv P$ [Eq. (4.7)] which gives $\sigma_Q^2 = \overline{P}^2 \equiv \overline{S}^2$, and Eq. (6.12)."
		7	change to read "...signal power estimate equals $\overline{S} / \sqrt{M_I}$."
	3	1-2	change to read "To estimate S in presence of receiver noise, we need to subtract an....of receiver noise power from the signal plus noise power estimate $\hat{P}$." *(Alternatively, see the section "The following comments should clarify...." attached to this errata)*
129	0	6-7	change last sentence to read: ....then the number of independent samples can be determined using an analysis similar to.....
130	Table 6.1		add above **"Reflectivity factor calculator"** the new entry "**Sampling rate",** and in the right column on the same line insert "0.6 MHz". Under "**Reflectivity factor calculator**", "Range increment" should be "0.25 km" and not "1 or 2 km". But insert as the final entry under "**Reflectivity factor calculator**" the entry "Range interval Δr", and on the same line insert "1 or 2 km" in the right column.
136	footnote		change to read: To avoid occurrence of negative , only the sum is used but multiplied with
137	2	1	Delete "( )"

171	0	3	T_s should be T_2
182	Eq.(7.12)		$W_i W_{i+1}$ should be $W_i W_{i+l}$
197	1	1	"though" should be "through"
	2	4	"Fig.3.3" should be "Fig.3.2"
200	Fig.7.28		Note the dashed lines are incorrectly drawn; they should extend from -26 dB at ±2^o to -38dB at ±10^o, and then the constant level should be at -42 dB.
201	0	2	"Norma" should be "Norman"
222	2	2	the differential d*D* on the left side of Eq.(8.18) must be deleted.
228	1	4	change Z_w to Z_e
	Eq.(8.24)		this equation should read as: (8.24)
	2	6	change to: ....to estimate the equivalent rainfall rate R_s (mm/hr) from the...
		7	delete "with $Z_w = Z_e$"
232	0	10-11	change to: ...microwave (λ = 0.84 cm) path....
234	Eq.(8.30)		right bracket "}" should be matched in size to left bracket "{"
248	Eq.(8.57)		parenthesize ")" needs to be placed to the right of the term "(b/a"
249	Eq.8.58		$\cos^2\delta$ should be $\sin^2\delta$; replace k_o with k; p_v and p_h should be replaced with p_a and p_b respectively
	Eq.8.59a,b		change the subscripts h to b, and v to a
	2	9	change to read: p_a and p_b are the drop's susceptibility in generating dipole moments along its axis of symmetry and in the plane perpendicular to it respectively, and *e* its eccentricity,
		12-13	rewrite as: ...symmetry axis, and ψ is the apparent canting angle (i.e., the angle between the electric field direction for "vertically" polarized waves

			(**v** in Fig.8.15) and the projection of the axis of symmetry onto the plane of polarization. The forward........
		17	modify to read: $f_h = k^2 p_b$, and $f_v = k^2\,[(p_a - p_b)\sin^2\delta + p_b]$ (Oguchi, ...
	3	4-5	Rewrite as: Hence from Eqs.(8.58) an oblate drop has, for horizontal propagation and an apparent canting angle equal to zero, the following cross sections for h and v polarizations:
268	Fig. 8.29		LDR_{hv} on the ordinate axis should be LDR_{vh}
	0		change LDR_{hv} to LDR_{vh} at the two places it appears in this paragraph.
269	Fig. 8.30		In the caption, change LDR_{hv} ato LDR_{vh} at the two places it appears.
298	Fig.9.5a		here and elsewhere in the text, remove periods in time abbreviations (i.e., should be: "CST", not C.S.T.")
390	0	1	change to read "along the path ℓ of the aircraft, and $S_{ij}(K_\ell)$ is the Fourier transform of $R_{ij}(\ell)$ for displacements along this path. In contrast...."
394	Eq.(10.37)		change to read: $R_{ii}(\rho, \tau_1 = 0) = R(0)[1 - (\rho / \rho_{oi})^{2/3}]$ (10.37)
404	4	7	place an overbar on the subscript "u"
412	2	5	change "polynomial plane" to "polynomial model"
	2	7	change "surface" to "model"
419	Fig. 10.18		The "-5/3" slope line drawn on this figure needs to be redrawn to have a -5/3 slope. Furthermore, remove the negative sign on "s" in the units (m^3/s^{-2}) on the ordinate scale; this should read (m^3/s^2).
433	2	4	insert the following after Eq.(11.31c): , here and henceforth we drop the term.
453	1	10	delete "(s)" from "scatterer(s)"; subscript "c" in $\rho_{c,\|\|}$ should be replaced with subscript "B" to read $\rho_{B,\|\|}$
		12	The subscript "c," in should be replaced by subscript "B" so the term reads:

454	0	6	change “blob” and “blobs” to “Bragg scatterer” and “Bragg scatterers”
	Fig.11.11		caption should be changed to read:........, a receiver, and an elemental scattering volume dV_c.
458	2	4	make a footnote after to read: z' is the projection of r' onto the z axis; not to be confused with z' in Fig.11.12 which is the vertical of the rotated coordinate system used in section 11.5.4.
459	1	4	change "production" to "proportion"
		5	change word order to read "...(the larger or are compared to....)"
	2	1	indent paragraph beginning with "Because we have.."
	3	10	modify sentence after condition (11.124) to read: If condition (11.124) is not satisfied, the Fresnel term in ...
		11	start new paragraph with sentence beginning with "Gurvich and Kon..." and delete the word "also".
		15	delete the word "near" and the parentheses around the word "Fresnel". ("near" commonly refers to the region within an aperture diameter away from the antenna)
459	Eq.(11.125)		delete the subscript “c” in this equation, as well as that attached to in the second line following Eq.(11.125) so that it reads “ ”.
460	0	2	add the following footnote or sentence at the end of the line: ρ_h given by Eq.(11.125) is the outer scale of the refractive index irregularities, but condition (11.124) applies to the transverse correlation lengths of the Bragg scatterers. Thus, the conclusion reached in this paragraph applies if the Bragg scatterer's correlation length equals the outer scale.
	1	4-9	delete the third to fifth sentences in this paragraph and replace with the following: Condition (11.124) is more restrictive than (11.106); if (11.124) is violated the Fresnel term is required to account for the quadratic phase distribution *across the scattering volume*, whereas (11.106) imposes phase uniformity *across the Bragg scatterer*. Bragg scatterers outside the first Fresnel zone have a relatively large change of phase across them compared to those at the same height but within it. Condition (11.124) has the

following physical interpretation: Bragg scatterers with transverse correlation lengths larger than an antenna diameter scatter mainly within a solid angle smaller than the transmitter's beam width, and the change of phase across the Bragg scatterer causes radiation to principally scatter in directions other than to the transmitter. Hence scatterers near the periphery of the illuminated area do not contribute as significantly to backscatter as those closer to the beam axis. The Fresnel term accounts for this diminished contribution from Bragg scatterers (also see comments at the end of section 11.5.3).

478 0 8 Change to read:
“...the gain g. Then g, now the directional gain (Section 3.1.2), is related...”

493 1 delete the last sentence and make the following changes:

1) change lines 2 and 3 to read: “... $C_n^2 = 10^{-18}$ m$^{-2/3}$ (Fig.11.17), the maximum altitude to which wind can be measured is computed from Eq.(11.152) to be about 4.5 km.

2) change lines 4 and 5 to read: “...with SNR = -19.2 dB (from Eq.11.153 for $T_s = 3.13 \times 10^{-3}$ s) and that σ_v = 1.5 m s^{-1}, SD(v) = 1 m s^{-1}, and a system temperature of about 200 K (section 11.6.3).

2 2-4 change to read: Assuming that the WSR-88D had 10 dB more of average power by adding another high power amplifier, and pulse coding is used to maintain the same long pulse range resolution (i.e., 700 m) and PRF, the WSR-88D could provide hourly profiles of winds with an accuracy of about 1 m s^{-1} to 15 km above ....

The following comments should clarify and/or enhance the text at the indicated places:

82 Because there is considerable confusion concerning the use of the unit dBZ, and because some writers use dBz for the decibel unit of reflectivity factor *Z*, we present the following comment:

The logarithm decibel dB is not an SI unit. On the other hand, the dB has been accepted widely as the symbol of the decibel as a "unit" (e.g., The International Dictionary of Physics and Electronics, D. Van Nostrand Co. Inc., 1961, 1355 pp). Furthermore, according to SI rules, units should not be modified by the attachment of a qualifier. Nevertheless, appendages to dB have been accepted in the engineering field to refer the dB unit to a reference level of the parameter being measured; e.g., dBm is the decibel unit for 10 $\log_{10}$ P where P is the power referenced to 1 milliwatt (e.g., Reference Data for Radio Engineers, 5th Edition, p.3-3). dBZ has been accepted by the AMS as the symbol for the "unit" decibel of reflectivity factor referred to 1 mm^6m^{-3} (Bulletin, 1987, p.38).

1 at the end of this paragraph add: "If scatterers are not *liquid* water spheres, Z_e will also account for the difference in the refractive index of water and that of the scatterers (e.g., ice)."

Because we hardly ever know the composition of the scatterers, even if we know they satisfy the Rayleigh approximation, the added sentence tells the reader that the radar equation always is written with the parameter $|K_w|$, *and not a generic parameter (e.g.,* $|K|$ *). Furthermore, if scatterers happen to be, for example, ice spheres, the equivalent reflectivity factor* Z_e *will account for our lack of knowledge of the scatterers' composition.*

113 1 1-4 change to read: "......associated with a spatially dependent steady wind $v_s(\mathbf{r})$ and turbulence $v_t(\mathbf{r},t)$. Each contributes to the width of the power spectrum (even uniform steady wind contributes to the width of the spectrum because radial velocities vary across V_6; steady wind also brings new...."

p.128, Eq.(6.12): this equation and the discussion which follows it, is valid when signal power is much stronger than noise power. The following text gives the standard deviation of the Logarithm of Reflectivity Factor *Z*(dBZ) estimates as a function of Signal-to-Noise ratio. This text could replace paragraph 3 on p.128.

To estimate *Z* in presence of receiver noise, we need to subtract receiver noise power *N* from the signal plus noise power estimate $\hat{P}$. Thus the reflectivity estimate is

$\hat{Z} = \alpha\hat{S} = \alpha(\hat{P} - N)$ where $\hat{P}$ is a uniformly weighted M sample average estimate of the power P at the output of the square law receiver (as in the WSR-88D), N is the receiver noise power, and α is a constant calculated from the radar equation. Because N is usually measured during calibration, many more samples are used to obtain its estimate. Therefore its variance is negligibly small, and the noise power estimate can safely be replaced with its expected value N. Z is usually expressed in decibel units; that is, $\hat{Z}(dBZ) = 10\log_{10}\hat{Z} = 10\log_{10}(\alpha\hat{S})$ where $\hat{Z}$ is expressed in units of mm^6 m^{-3}. The error in decibel units is now derived. Let $\hat{S}$, the M sample estimate of signal power, be expressed as $\hat{S} = S + \delta S$ where δS is the displacement of $\hat{S}$ from S. Thus

$$\hat{Z}(dBZ) = 10\log_{10}(\alpha S) + 10\log_{10}\left(1 + \frac{\delta S}{S}\right) = Z + \delta Z(dBZ) \qquad (6.13a)$$

For sufficiently large M, $\delta S/S$ is small compared to 1, and hence the second term can be expanded in a Taylor series. Retaining the dominant term of the series, the estimated reflectivity is well approximated by

$$\hat{Z}(dBZ) \approx Z + 4.34\left(\frac{\hat{S}}{S} + 1\right). \qquad (6.13b)$$

Because the first term and the constant 4.34 are not random, the standard error in the estimate is simply $S.D.[\hat{Z}(dBZ)] = 4.34 S.D.[\hat{S}/S]$. Because $\hat{S} = \hat{P} - N$ where N is a known constant (for a correctly calibrated radar),
$S.D.[\hat{S}] = S.D.[\hat{P}] = P/\sqrt{M_I} = (S + N)/\sqrt{M_I}$, where M_I is the number of independent signal plus noise samples. Hence

$$S.D.[\hat{Z}(dBZ)] = \frac{4.34(S + N)}{S\sqrt{M_I}} \qquad (6.13c)$$

The number of independent samples M_I that are contained in the M sample set, can be calculated from (6.12) in which $\rho_s(mT_s)$ is replaced by $\rho_{s+n}(mT_s)$ the magnitude of the correlation coefficient of the signal plus noise power samples.

Using (6.4), the correlation of signal plus noise for a Gaussian shaped signal spectrum and a white noise spectrum, normalizing it by $S + N$ to obtain the correlation *coefficient* of the signal plus power estimates, the correlation coefficient at the output of the square law receiver, can be written as

$$\rho_{s+n}(mT_s) = \left(\frac{S}{S + N}\exp\{-2(\sigma_{vn}\pi m)^2\} + \frac{N}{S + N}\delta_m\right)^2 \qquad (6.13d)$$

Under the condition that $\sigma_{vn} >> M^{-1}$ (i.e., the spacing between spectral lines is much smaller than the width of the spectrum), the sum in (6.12) can be replaced by an integral. Furthermore, if M is large so that $\rho_{s+n}(mT_s)$ is negligibly small at MT_s, the limits on the integral can be extended to infinity. Evaluation of this integral under these conditions yields

$$M_I = \frac{\left(1+\frac{S}{N}\right)^2 M}{1+2\frac{S}{N}+\frac{(S/N)^2}{2\sigma_{vn}\sqrt{\pi}}} \qquad (6.13e)$$

The formula for calculating the standard error in estimating Z(dBZ) as a function of S/N is obtained by substituting (6.13e) into (6.13c) yielding

$$S.D.[\hat{Z}(dBZ)] = \frac{4.34}{\sqrt{M_I}}\frac{N}{S}\left(1+2\frac{S}{N}+\frac{(S/N)^2}{2\sigma_{vn}\sqrt{\pi}}\right)^{1/2} dB \qquad (6.13f)$$

136 4 1-5 The form of Eq.(6.29) was first presented by Rummler (1968). But this form does not follow directly from Eq.(6.27) as in stated in the sentences preceding Eq.(6.29). Thus it would be more proper to change these lines to read:

"If spectra are not Gaussian, Rummler (1968) has derived an estimator valid for small spectrum widths (i.e.,). This estimator is

(6.29)

At large widths Eq. (6.29) has an asymptotic ( ) negative bias which causes an underestimate of the true spectrum width (Zrnić, 1977b), whereas .... spectrum is Gaussian)"

Added Reference:

Rummler, W. D. (1968), Introduction of a New Estimator for Velocity Spectral Parameters. *Technical Memorandum, April 3, 1968.* Bell Laboratories, Whippany, New Jersey 07981.

398 Section 10.2.1: we introduce the parameter $\Phi_v(\mathbf{K})$ in Eq.(10.46) but define it later in Eq.(10.46). We should place Eq.(10.48), but label it (10.46), before Eq.(10.46) which now become Eq.(10.47). Other adjustments should be made to correct equation numbers; these should be few.

459 4 at the end of this paragraph, "...in this section.", add: "Under far field conditions the beamwidth term in Eq.(11.122) does not contribute significantly to the <u>integral</u>, but the beamwidth, and also the range

			resolution, do contribute to the backscattered power because they multiply the integral in Eq.(11.122).”
461	0	11	insert after "...in space.": "This is a consequence of the greater importance of the Fresnel term relative to the resolution volume weighting term (i.e., in Eq.11.122) along the transverse directions."
Index			for usefulness add: Antenna; far field, 435-436, 459.

Some definitions:

Radial: A radial is the center of a band of azimuths over which the radar beam scans during the period (i.e., the dwell time) in which a number M of pulses are transmitted and echoes received and processed. M echo samples at each range are processed to obtain spectral moments (e.g., reflectivity, velocity, and spectrum width) which are assigned to the center azimuth (i.e., the "radial"). A "radial of data" is usually the set of spectral moments at all the range gates (or resolution volumes) along the assigned azimuth.