Errata for: Global Atmospheric Circulations
by R. Grotjahn
dated version: 17 December 2004

Dear reader:

My book was constructed from galley proofs I created in TEX, these were converted to page proofs and finally electronically typeset. While this scheme has advantages, it can have disadvantages. My book had more than 60 files. Unfortunately, several incorrect files, mainly early drafts, were sent by mistake. This led to some sections of the final product having lots of errors. This errata is my best recourse unless the book is ever reprinted. I encourage you to inform other readers that this errata exists and that I distribute it for free. Over the years more errors have been identified, please use the latest dated version you can find; it is complete.

This version considers about 4/5 the book. (Much of chapter 7 has not yet been re-checked.)

However I recommend that the reader look at the web pages I maintain for the course I teach from the book. Readers may wish to examine the lecture outlines on the web. My lectures on book sections 4.2, 6.1, and 6.5 are greatly improved over the book. A summary table of energy flow improves upon figure 4.33. And I have another on momentum. In 2003, summary articles I wrote on the general circulation mean characteristics and energy appeared in the Encyclopedia of the Atmospheric Sciences. Pdf files of these are posted on the course website. Instructors are encouraged to contact me if they are interested in seeing typed lecture notes, or examples of homework problems. I provide these materials free of charge to instructors. The URL is:

http://atm.ucdavis.edu/~grotjahn/course/atm240/index.html

Finally, errata after January 2000 use a different word processor that did an imperfect job of translating the earlier file. I corrected numerous translation errors, but I may have missed a few.

Thank you for your patience,

-Richard Grotjahn

Page   corrections, comments and clarifications
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ix   preface date changed by publisher; it should be 9/91. no material after 8/91 was included in this book.

18   ASDAR has horizontal resolution placed in column for vertical resolution

19   table 2.1: middle 3 columns for dropsondes should be shifted right by 1 column.

26   middle of page: buoys are dropped, not balloons

40   C_1 and C_2 are not defined. Actually, I would redo this discussion to include Planck's, Boltzmann's, and the speed of light constants. I would also include discussion of other relevant expressions, such as Wien's law, etc. But, for the current printing:
        $C_1 = \pi \, 1.19 \times 10^{-16} \, Wm^2 \quad C_2 = 1.44 \times 10^{-2} \, mK$
        E_i (perhaps call it E_λ since E_i in eqn 6.5 means something different) is MONOchromatic irradiance (from isotropic radiance in one hemisphere)

44   What do the "100 units" of fig. 3.4 equal? If the solar constant is 1368 W/m2, then the "100 units" equals $1368/4 = 342 \, Wm^{-2}$. The factor of 4 is the ratio of the surface area to cross sectional area of the earth.
        Also, recent references vary in their estimates, for example:

1380 C Wallace & Hobbs (1977);   1360 C Peixoto & Oort (1992);
1370 C James (1994)   1368 C Kiehl & Trenberth (BAMS, 2/97)
Also, some values in Fig. 3.4 differ significantly from corresponding values in Kiehl & Trenberth (1997). (And both of those from the 11/95 BAMS cover! etc.)

45-46   eqn (3.2) & fig 3.5 are not "wrong" but the "graybody" aspect can be done better. (I plan to redo it.) E of the ground might be $E_a + 21$. Note 2 typos: the summation in both cases should start at n=0; also, that summation = 3.333, not 3.28. Another explanation of the model is: 51 units absorbed by the ground, of which 51 units must be emitted in the net. The 21 (net) includes downward IR from the 20 units absorbed by clouds & clear air. From the 51 units 29.7 units come back down which the ground gains then looses soley as radiation. Thereafter 70% of ground emission comes back down each time (20.8, then 14.56, then 10.192, etc.)

66   (i) contour interval in fig 3.16b appears to be 1.0, but it is 0.5 in 3.16a.
(ii) the figure may be misleading -- if you use [v] to calculate a mass flux across 10N during DJF and assume that half that rate continues for 90 days (say) then the average N. Hemis. SLP change is ~100 mb! Clearly mass is not balanced.

67-69   Fig. 3.17 was intended to be a reproduction of Fig. 3.19 in Newell et al. (1972) which would be consistent with the eqns. (3.4) and (3.5). (Note sign error in Newell et al.'s corresponding formulae). Therefore my 3.17 would indeed show ψ, which Newell et al. plot as their fig. 3.19. ψ should have units mass/time from (3.4).
Unfortunately, I reproduced the wrong figure from Newell et al. Notice the figure includes a "chi" label in the upper right corner which reveals that I inadvertently used fig. 4.13 from Newell et al. (1972). What is shown is a mass streamfunction, suitable for showing fluxes of momentum. It is also clear from the units of "chi" that it differs from ψ. We cannot deduce meridional or vertical motion directly from "chi" since "chi" includes various momentum fluxes which mix together the velocity components; to see this point, note the partitioning of momentum flux in (4.5) on p 92 of my book. Having said that, one notices that the shapes in Newell et al. figs. 3.19 & 4.13 are quite similar. If one assumes the shapes to be the same, then a simple magnitude correction could be made to obtain the correct units, approximate amplitude, and roughly correct shape. (Newell et al. use cgs, I shall use mks units). Multiply the numbers in my fig 3.17 by A; where A ~ 3.5 x 10^{-17} (kg sec)/(gm cm^2) so that the "100" contour in my fig 3.17 becomes 3.5 x 10^{10} kg/s.

81   double maximum ICZ cloud cover

91   (i) continuity equation used to get (4.3). (ii) Also: lower case u in (4.1) And also:
(iii) Instead of calling M absolute "angular velocity" a more descriptive label might be that M be absolute angular momentum per unit mass. The new label has the correct units (= L*L/S). (Holton's 1992 text, p. 328, uses the suggested label.)

96   Fig 4.3: The units should have 10 raised to the 18th power.

97   in next two eqns AFTER (4.11): tanφ term already included in second term.

100   in eqn (4.16b) delete "R"; in (4.17) insert "+" before "v/R" in term (A)

100-103   =0 should NOT be on the RHS of eqns: 4.16a, 4.16b, 4.19a, 4.19b, top of p. 102, and 4.20.

101   Eqn (4.18) needs "+" sign before v/R in term (B); 3rd integrand in eqn. (4.19a) should be: g [u $\partial z/\partial x$] dm; similarly, 3rd integrand in eqn. (4.19b) should be: g [v $\partial z/\partial y$] dm.

108-109   The discussion of fig. 4.12 could be more clear. First, a key term in the K_Z tendency eqn (4.16a) is the first part of the first integrand on the RHS. Expanding with the chain rule gives two parts which partly cancel on the poleward side of the jet and reinforce each other on the equatorward side. Though convergence in the figure is poleward of the jet, geometry increases zonal KE close to the jet. Second, eddy fluxes of heat oppose those eddy momentum convergences poleward of the jet leading to "Ferrel" circulations which both oppose building the jet further poleward and which limit the meridional extent of the Hadley circulation.

109   line 7: the word 'be' is missing: "to *be* more"

98, 100, 105, 110   Some additional comments regarding figs. 4.7 & 4.12, using the zonal mean KE eqn (4.16a): (i) The derivation of (4.16) relys upon (4.14) which may be reasonable when considering the vertically averaged information in fig. 4.7. As for fig. 4.12e & f, one is better off not using (4.14), but using the form where momentum fluxes are differentiated (similar to (4.12).
(ii) The [u]/R profile may differ strongly from [u] shown in fig. 4.12. Newton (1972, fig 9.8) shows the latitudinal profile of annual and vertical average [u]/R. It has a max near 43 N.
(iii) A further sense of the picture in fig. 4.12 might be gained by examining the contributions to zonal flow KE tendency, as might be deduced from (4.16a). One may focus on Northern Hemisphere, winter, 200 mb level conditions near the jet stream, using data tabulated in Oort and Peixoto (O&P, 1983). The calculation may be approximated by finite differences and the estimates suggest the following: that KE is gained by Hadley cell fluxes, but lost by eddy momentum flux divergence in the tropics. In middle latitudes the opposite: eddy momentum convergence creates KE while the Ferrel cell reduces it. Using O&P's vertical velocities, the eddy vertical momentum term is comparable in magnitude to the horizontal eddy momentum term.

110   Side note: there is greater seasonal change in the N. Hemis. so, the atmosphere has greater westerly momentum in DJF than in JJA. Since total angular momentum of the air, ocean & solid earth may be assumed conserved, greater atmospheric westerly momentum means less solid earth rotational momentum. Thus the length of day (LOD) during DJF is slightly longer than in JJA. (by only a few milliseconds! and it is observed!)

113-115   A motionless reference state is the simplest case, but not necessarily a "must". A reference state with motion may be possible: tilted surfaces of Θ & P imply horizontal velocities which may not be balanced (must avoid inertial oscillations).

120   γ in (4.25) should have a $-\sigma$ overbar. Average in equation just before (4.25) is applied separately to P, Θ, and γ.

121   Table 4.1 uses data from a cross section at 75 W only. APE/unit area is found for 3 different domains. Since the calculation of A uses an average P value that is raised to a non-unity power, the "global" value will not necessarily equal the average of the two hemispheric values. See p. 374 in D&J (1967). Also, the units should be: J/m^2

123   (i) "dp" should not be in boundary integral at top of page; (ii) in eqn (4.27) (Θ/P^κ_{oo}) term on last line should not be raised to a power; (iii) "}dPdS" missing before "+" on last line

124   (i) 3rd integral in (4.29) needs g/C_p out front and (Θ/P^κ_{oo}) term should not be raised to a power; (ii) delete second "-" sign in first line of "W" eqn.

128   delete sentence on line -8 (count from page bottom).

127   Should be plus (+) sign in front of term (E) in (4.31)

130   (i) fig. 4.17 includes $\partial Z/\partial\Theta$ term which should be mentioned in caption. (already in text)
        (ii) The units in fig. 4.17 appear to be m/K. (D&J, 1967, do not state the units)

132   strong surface winds, not just T_A-T_S difference makes surface fluxes ($\uparrow$) in fig 4.19 large.

130   The units in fig. 4.17 appear to be m/K. (D&J, 1967, do not state the units)

133   The upper panel in Figure 4.19 has dashed contours of Θ, not "ε"

137   Note: divide "CKA" on this page by g (see eqn. 4.36) to obtain A_E to K_E conversion.

138   lines 14-15: shifting the mass up or down uniformly defines a new reference state.

139   no "ln" should appear in (4.43)

141   In discussion of fig 4.23d, Θ surfaces are distorted, not crossed by air motions.

141   (bottom) Terms C are more like divergences of energy due to motions: net transfer of heat or momentum out of the domain.

145   (i) eqn (4.70): each integral should have a "dM"; (ii) on second line of (4.70): first integral needs g added to integrand, last integral should have g removed.

149   Units in fig. 4.26: 10^5 J/m^2 for energy; W/m^2 for conversion, generation, & destruction terms. Several conversions/sources/sinks for Oort & Peixoto (1974) don't balance. One might substitute many later versions of the box diagram. Perhaps O&P (1983).

154   Caption of fig. 4.29 should refer to equation (4.70)

156   A general comment about fig. 4.31: the lower level max seems too far north in the N. Hemis. winter. Other figs. like 7.22c and 5.17a seem more consistent.

157   In fig. 4.32 the plotted values of CK have opposite sign to the CK def in (4.66).

167   "both" on line 10 may be too strong. The pattern is too weak to tell in S. Hemis.

176   Plate 1: the figs are reversed from caption: July is above, January is below

177   line -9: delete redundant phrase: "...in the subtropics."

183&185 The SPCZ is described as a NW-SE cloud band. But it may be more standard for the SPCZ label to include the western extension of this diagonal cloud band. The western extension is more zonally-aligned and extends west to roughly 130E and paralleling the equator. See Vincent, 1994, MWR, 122:1949-1970 for a review.

193   line 18: ...from Figures 5.7a and 5.9a...; line 20: note that the negative value is only on the west side of the tilted trough.

195   (line 6) In reference to fig 5.17c: note the large downstream maxima from semi-permanent lows.

Since sfc (fig 5.3) and 700mb thermal troughs are further west (fig. 5.4) the persistent wind yield persistent heat fluxes.

198   caption should indicate $(\omega')''(T')''$ with an overbar

207   2-dimensional isotropic turbulence in the enstrophy-cascade range is expected to vary with wavenumber raised to the -3 power. (Not the -5/3 power stated in the book; which is presumed to apply to 3-dimensional turbulence.) Such a power law, when plotted on Fig. 5.21 is nearly parallel to the kinetic energy spectrum for n > 12. So, the spectrum **DOES** look similar to expectations for 2-dimensional turbulence. (To draw a -3 power law line, make it parallel to a line connecting the "n=10" point to a point 3 powers of 10 up from the bottom on energy scale, e.g. the top left corner of Fig. 5.21a, or the "(10^1)" in Fig. 5.21b)

220-222 Some general comments should improve the presentation on these pages.
(i) I is the incident radiation (=b in fig. 6.1). As it passes through an absobing material, while I+dI comes out the other side. Since the material absorbs radiant energy, then the absorber must emit that energy to maintain energy balance. That emission is: $e * d\tau*\sec\varphi$, consistent with Kirchoff's law.
(ii) The problem is tricky since we can assume that e is isotropic, but its crucial that I vary with direction.
(iii) b, β, I, I^ω, U, D, and e are radiances, while F and B are irradiances
(iv) eqns (6.8) and (6.9) are just a way to replace the troublsome $dI/d\tau$ term in (6.5) with something easier to work with: $dF/d\tau$. The procedure is called the "method of moments" and is discussed in Goody & Yung's book (e.g. p. 57) The method of moments just multiples (6.5) by $\cos^n\varphi$ then integrates over all angles. While the LHS integral in (6.8: n=0) cannot be approximated (it is a small difference between two large items: U and D); the LHS integral in (6.9: n=1) can be approximated since $\cos^2\varphi$ has the same sign in the upward and downward pointing hemispheres.
(v) everything cast in terms of longwave emissions. Book treats case of no solar absorption, no convection or horizontal heat fluxes by atmosphere, so, F=constant. A simple incorporation of variable F (to model solar absorption) is illustrated in Goody & Yung's book (p. 393-5)

220   (i) In (6.3) "z" and "infinity" are limits of the integral.
(ii) In eqn (6.4) the last part of the eqn should read: $4\pi e_i = E_i$
(iii) First eqn with β in it: should have a + ("plus" sign) in front of the I. And change that "I" to "e".
(iv) In the next eqn: insert minus sign before left parentheses & the far RHS "b" (only) becomes "e"
(v) In the next eqn, (6.5): the "b" should be an "e".

221   (i) line 5: use B/π where there is presently a B
(ii) in eqn (6.9): Either use B/π where there is presently a B, OR, replace the B with e.
(iii) replace the first sentence after (6.9) with: "The last term vanishes because e is isotropic."

222   The 2 equations between (6.14) and (6.15) should have these changes: U instead of D, no minus sign removed, and the T_g and τ_1 should be switched.

223   (i) "tau" should have subscript A1" in eqn (6.19). Also: $\sigma = 5.67 \times 10^{-8}$ Wm^{-2} K^{-4} is not specified.
(ii) replace "with height" on line 19 with: "as height increases"

225   In figure 6.2 caption: (i) a = - 0.125 km^{-1} also (ii) $\tau_1 = 1.0$ was used.

229   One might include a discussion of cloud feedback conceptual models, similar to Wielicki et al (1995, BAMS, p 2129-2131) here.

234   replace [ ] in eqn (6.26) with { } to avoid confusion in notation. In eqn (6.27) are these typos: 4 is missing, 10^{-4} should be just 1, friction loss integral should approximately equal 6.6×10^{-2} N-s per second (a rate of change). In next eqn AFTER (6.27) 2nd integral should be designated dArea dP. In (6.28): replace power 7 with power 5, replace 10^{-4} with 1, result should equal 4×10^{4} N-s.

236   line 1-3 delete last sentence of paragraph. Replace [ ] in (6.33) with ( )

237   line -7: ...is almost %2...

241   The Grotjahn et al. 1992 reference appeared in 1995. (See page 398 below)

244   (i) 4th line: g should not be in definition of DSE. (ii) Fig 3.16 shows moist static energy (MSE), removing the Lq part obtains DSE. DSE < MSE at lower levels but MSE and DSE are essentially the same at high levels. One might use MSE and compare the flux F with summing the latent and sensible values reported in fig. 3.9. Alternatively, MSE values at 20N could be used to estimate sensible heat flux since the latent heat flux is ~zero there. For a mass flux with [v]=0.5 (say) in the 400-100 mb layer and [v]=1 in the 1000-850 mb layer (for mass balance), $F = 3 \times 10^{15}$ W which compares favorably with 2.5×10^{15} W in fig. 3.9.

254-255   the ellipticity can be estimated using fig 3.15.

271-275   Fig. 6.19a (@ 500mb) should be used in combination with 5.16a (a similar quantity, @ 200 mb) to deduce vertical derivative in the K-E eqn forcing. Hatched areas of fig 6.21 have $\partial\chi/\partial p > 0$ since $\chi < 0$ @ 200 but $\chi > 0$ @ 500 mb there.

281   in both (6.52) & (6.53) the $\tan\varphi$ terms should be deleted

286-297   The CISK mechanism is not the only explanation. While the discussion in this chapter is intended to show how feedback between vorticity and heating results in the smallest scale (i.e. convection) being selected (i.e. most unstable), readers may want to examine another mechanism: CAPE. In CAPE parcels gain moisture as they move equatorward becoming progressively more convectively unstable.

301   (7.8) follows from (7.7) using (4.51)

318   replace p_0 in (7.27), (7.28) and (7.30) with RT_0. T_0 is surface temperature, R is gas constant

332   wrong sign for the 2nd term on RHS of (7.59) -d/dx(v'du/dx)

333   (i) wrong sign for the 5th term on RHS of (7.61) -d/dx(v'du'/dx) (ii) inline divergence equation on line 7 (between 7.61 and 7.62) needs a minus sign on either the RHS or LHS.

372   lines 20-21: a word is missing: ...jet *maximum* not changed...

385   line 5: some may argue about GCMs not forming hurricanes. Manabe et al (J.Atmos.Sci., **31**,43-83) find hurricane-like features which are broader & weaker than observed ones due to the grid resolution. Resolution is partly my point. It is unclear if such weak approximations move nonlinearly in a similar way to real typhoons.

398   (i) Grotjahn (1991b) reference missing journal: Geophys. Astrophys. Fluid Dyn. (ii) The Grotjahn et al "1992" reference appeared in 1995: Grotjahn, et al (same authors) 1995, J. Atmos. Sci., 52:754-

763.

409   Rossow & Schiffer 1991 reference should have ISCCP

Items noticed by readers (Thank you!)

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*Item noted in I. James review:
36   Ian says the rotation rate of Jupiter is 9.925 hrs. I thought it was unclear if Jupiter even has a
        "surface", let alone figuring out how fast it rotates, hence my original wording...

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*Items noted in M. Hantel's review:

87-88   (note: my book manuscript was completed 8/91) more recent, and presumably more accurate
        moisture-related charts exist. For example, charts in Peixoto & Oort's 1992 book differ slightly from
        mine:
                My 3.28a C > P&O figs 7.25c & 7.27 & Table 7.1 (p. 168-170)
                My 3.28b C > P&O figs. 12.12a (p. 292)
                Half of my 3.29a C > P&O fig 7.27 (p. 169)
                Half of my 3.29b C > P&O fig 7.25c (p. 168)
                Half of my 3.29c C > P&O fig 12.12a (p. 292)

109   Fig. 4.11 has N and S reversed.

386   As to why one might make the indicated partitionings, (i) existing maps and (ii) ease of depiction are
        mentioned here. One could remind the reader of the discussion on p. 37: (iii) observed zonal
        orientation of properties. Perhaps also point out (iv) how the mathematics simplifies by removing
        (most) zonal derivatives from budget equations (mountain torque an exception).