Errata and updates for the interdisciplinary survey article

**Atmospheric dynamics: some fundamentals, with observational implications**
by M. E. McIntyre.

(Further comments, criticisms, etc., welcome at M.E.McIntyre@amtp.cam.ac.uk. Updates of this sheet available from our web site: http://www.atmos-dynamics.damtp.cam.ac.uk, also available from ftp://ftp.amtp.cam.ac.uk (give login name 'anonymous'; cd pub/papers/mem; get mcintyre.ps).

Full reference is: Proc. Internat. School Phys. "Enrico Fermi" CXV Course, *The Use of EOS for Studies of Atmospheric Physics,* edited by J. C. Gille and G. Visconti. North-Holland (Amsterdam, Oxford, New York, Toronto), pp. 313–386 (1992). ISBN 0-444-89896-4.

**Updates to bibliography of Fermi review:**

A more thorough discussion of stratosphere–troposphere exchange, including the 'sideways–downward' control of tropical upwelling by extratropical wave driving — the mechanism discussed in §5 of the review, which we now tend to think of as a kind of '**gyroscopic pumping**' — is now given in:

Holton, J. R., Haynes, P. H., McIntyre, M. E., Douglass, A. R., Rood, R. B., Pfister, L., 1995: *Stratosphere–troposphere exchange.* Revs. Geophys. Space Phys., **33**(4), 403–439.

New and very clean evidence about gyroscopic pumping rates, hence tropical upwelling rates, also supporting partial isolation of tropics hence favouring 'leaky pipe models' of large-scale long-lived tracer transport, as opposed to globally integrated one-dimensional vertical diffusion models, is given in:

Mote, P. W., *et al.*, 1996: *An atmospheric tape recorder: the imprint of tropical tropopause temperatures on stratospheric water vapor.* J. Geophys. Res., 101, 3989–4006.

For the leaky pipe models themselves, see:

Plumb, R.A., 1996: *A "tropical pipe" model of stratospheric transport.* J. Geophys. Res., **101**, 3957–3972, 1996.

For recent remarks on the 'flowing processor hypothesis' and more on 'gyroscopic pumping versus solar driving', see

McIntyre, M. E., 1995: *The stratospheric polar vortex and sub-vortex: fluid dynamics and midlatitude ozone loss.* Phil. Trans. Roy. Soc. London, **352**, 227–240. [Special issue on the Arctic and Environmental Change, ed. J. Dowdeswell, A. Schofield and P. Wadhams.]

**Ref. [20]:** the second half should read "See also C. R. Philbrick,..."

**Ref. [48]:** some important updates are:

U. Schmidt and A. Khedim, 1991: *In situ measurements of carbon dioxide in the winter Arctic vortex and at midlatitudes: an indicator of the age of stratospheric air*, Geophys. Res. Lett., **18**, 763–766. [The technique is to exploit the well known trend in tropospheric $CO_2$ mixing ratio to estimate how long, in some average sense, the mixture of air observed in the vortex has been in the stratosphere. The results suggest that this "$CO_2$ age" has average value $5.6\pm1.1$ year, but may fluctuate systematically by almost a factor of two on a timescale of 3 to 5 years.]

W. H. Pollock, L. E. Heidt, R. A. Lueb, J. F. Vedder, M. J. Mills and S. Solomon, 1992: *On the age of stratospheric air and ozone depletion potentials in polar regions*, J. Geophys. Res., **97**, 12993–12999. [This paper suggests $CO_2$ ages of order "3–5y" at pressure altitudes of order 17–21km.]

L. Heidt, S. Hovde, A. F. Tuck, J. F. Vedder and R. Weiss, 1993: *The age of the air in the Arctic lower stratospheric vortex during late winter 1988/9*, J. Geophys. Res., submitted Nov 92. [Nominal $CO_2$ age $\simeq$ 4y but highly variable; probably consistent with Schmidt and Khedim.]

See also related work reported at European Geophysical Society, April 1995, by Daniel, Solomon, Weaver, Schauffler, Pollock, Heidt, Garcia and Atlas. Abstracts book, p. C 409: *On the age of* *stratospheric air and inorganic chlorine release.*

T. M. Hall and M. J. Prather, 1993: *Simulations of the trend and annual cycle in stratospheric $CO_2$*, J. Geophys. Res., **98**, 10573–10581. [Also bibliography.]

**Ref. [83]:** for some further relevant points about the 'wave momentum myth', see §5 of M. E. McIntyre, 1993: *On the role of wave propagation and wave breaking in atmosphere–ocean dynamics*, Sectional Lecture, Proc. XVIII Int. Congr. Theoret. Appl. Mech., Haifa, ed. S. R. Bodner, J. Singer, A. Solan, Z. Hashin. Elsevier, 281–304.

**Ref. [111]** on PV inversion and related concepts: see also, e.g.,

C. A. Davis, 1992: *Piecewise potential vorticity inversion*, J. Atmos. Sci., **49**, 1397–1411.

D. J. Raymond, 1992: *Nonlinear balance and potential-vorticity thinking at large Rossby number*, Q. J. Roy. Meteorol. Soc., **118**, 987–1015.

M. E. McIntyre, 1993: *Isentropic distributions of potential vorticity and their relevance to tropical cyclone dynamics.* Proc. ICSU/WMO International Symposium on Tropical Cyclone Disasters, ed. J. Lighthill, Z. Zheng, G. Holland and K. Emanuel. Peking [sic] University Press, Beijing, China, 143–156.

**Ref. [126]:** the second half should read "R. R. Garcia, F. Stordal, S. Solomon and J. T. Kiehl, 1992: *A new numerical model of the middle atmosphere. 1. Dynamics and transport of tropospheric trace source gases*, J. Geophys. Res., **97**, 12967–12991."

**Ref. [142]:** Should read "W. A. Norton, 1994: *Breaking Rossby waves in a model stratosphere diagnosed by a vortex-following coordinate system and a technique for advecting material contours*, J. Atmos. Sci., **51**, 654–673; see also the independent work of D. W. Waugh and R. A. Plumb, 1994: *Contour advection with surgery: a technique for investigating fine scale structure in tracer transport.* J. Atmos. Sci., **51**, 530–540."

**Miscellaneous small improvements and corrections:**

p 315, end of second bottom paragraph (after "ref.[16]"): Alternative references are the textbook by J. M. Wallace and P. V. Hobbs, 1977: *Atmospheric Science*, New York, Academic, p.346; also R. J. List (ed.), 1958: *Meteorological Tables*, 6th edn., Washington DC, Smithsonian Inst., table 132, p. 417. If a computer is closer to hand than any of these references, one can plot $\bar{S}/S_\perp$ for any specified time of year by replacing $\alpha$ in eqs. (1) and (2) by the appropriate solar declination or 'effective tilt angle' $\alpha_{\text{eff}}$ ($|\alpha_{\text{eff}}| \le \alpha$). This is such that $(\frac{1}{2}\pi - \alpha_{\text{eff}})$ is the angle between two vectors one of which gives the direction of the Earth's axis, i.e., points toward the pole star, and the other points from the Earth toward the Sun at the time of interest. Note, however, that eq. (1) assumes $\alpha \ge 0$, so that to allow for negative $\alpha_{\text{eff}}$ (northern cold season) one must replace $\operatorname{sgn}\phi$ in (1) by $\operatorname{sgn}(\phi\alpha_{\text{eff}})$. Or, more elegantly, rewrite (1) as $\pi^{-1}\arccos[\max\{-1, \min(1, -\tan\alpha_{\text{eff}}\tan\phi)\}]$. A simple approximation to $\alpha_{\text{eff}}$, idealizing the Earth's orbit as circular, would be $\alpha_{\text{eff}} = -\arcsin\{\sin\alpha\cos\Delta t\}$ where $\Delta t$ is the time after the December solstice measured in units of $(1\text{ year})/(2\pi)$.

Further comments on this in McIntyre 1995 (ref. above).

p 336, second row of table: "Basic restoring mechanism"

p 349, caption to fig. 8: "rearrangement rate..."

p 363, 13th line from bottom: Should read "will remain a key issue both for data analysts and for modellers. ..."

p 365, 15th line from bottom: Should read "because wave–mean interaction theory would otherwise predict..."

p 366, 5th line of first paragraph: Should read "til now. As already mentioned, the two points to be made..."