Vertical Velocity Variability in the Lower Stratosphere

REGINALD E. NEWELL
Massachusetts Institute of Technology, Cambridge

AND ALVIN J. MILLER
National Meteorological Center, U. S. Weather Bureau, ESSA, Hillcrest, Md.

7 December 1967 and 7 February 1968

1. Introduction

In studies of the transfer of trace substances by large-scale atmospheric motions, transport is often related to wind variability. Thus, for example, Flohn (1961) relates the latitudinal dispersion of marked particles to the standard deviation of the meridional component of the wind and Kao (1962, 1965) relates the eddy diffusion coefficient to the variance of the wind component. For a background to the problem of specification of eddy transports in terms of meteorological quantities, reference may be made to these latter papers and their discussion (Kao, 1967), and to the standard text by Pasquill (1962). Models based upon wind data have been used to study trace substance distributions by Davidson *et al.* (1966) and Karol.[1] A somewhat different approach in which an eddy diffusion coefficient is derived from heat transport data has been followed by Reed and German (1965) and Gudiksen *et al.* (1968). Eddy diffusion coefficients were derived from trace substance data in the model used by Prabhakara (1963).

At the IUGG Utrecht symposium on trace gases held in 1962 an attempt was made to summarize existing information on wind variability and compare the results with observations of trace substance distributions (Newell, 1963). Eddy diffusion coefficients were computed from variance data, and their variation with latitude, height and season were found to account for the general features of trace substance distributions. The summary of wind data was extended at the IUGG Visby symposium on atmospheric chemistry, circulation and aerosols held in 1965 (Newell *et al.*, 1966). Since that time we have completed an analysis of the vertical velocity and its variability in the lower stratosphere during the IGY. Results of the vertical velocity analyses and a description of the procedures followed have been presented by Miller (1966, 1967). A summary of the time and space variability is presented herein.

Adiabatic vertical velocities at 75 and 40 mb were computed from station observations 24 hr apart in time at levels of 100, 50 and 30 mb. Averages and standard deviations were computed at each station over 3-month time periods as indicated; the resulting values were plotted on maps, a hand analysis was made and grid points were read off at 10° longitude and 5° latitude intervals. A general critique of the adiabatic method and a statement of the difficulties encountered is presented by Craig and Lateef (1962).

As one of the reasons for analysing the time standard deviation maps was to give an indication of the probable limits to the mean vertical motion values, slightly more credence was given to individual observations in the $\sigma(\omega)$ analyses than to those in the vertical motion analyses. The procedure was carried out separately for all observations at 1200 and 0000 GMT and the two final values were averaged. Table 1 contains the results on the zonal mean time standard deviation at 75 and 40 mb. Table 2 contains the spatial standard deviations which are obtained from the mean vertical velocity data at a given latitude and give a measure of the variability of this mean with longitude. In order to facilitate comparison with measures of horizontal wind variability, the results for the time standard deviations have been converted from mb sec^{-1} to mm sec^{-1} using zonal mean temperature values already published (Newell, 1963; Peng, 1965); the converted values appear in Table 3.

2. Comments

Values of the transient eddy component in Table 1 are consistently higher than those of the standing eddy component in Table 2. The latter is, of course, quite strongly dependent on the time period selected for averaging. The standing waves in the stratosphere have a greater amplitude for 1-month than for 3-month periods, but data limitations and the processing procedure did not permit vertical velocity computations on a 1-month basis. In the summer $\sigma(\omega)$ has a maximum at middle latitudes and comparable values at high and low latitudes. In winter the maximum occurs at high middle latitudes and the high latitude values exceed those at low latitudes. There is good agreement between the two independent sets of results for 0000 and 1200 GMT (not shown here) and for the two independent sets for July-September and October-December. Such agreement was also noted in the mean ω fields at middle and high latitudes (Miller, 1967). Both ω and $\sigma(\omega)$ are difficult to estimate at low latitudes where the local temperature change with time and the temperature change produced

[1] Karol, I. L., 1967: Calculation of planetary distributions of radon and its long-lived daughter concentrations in the troposphere and lower stratosphere. Paper presented at the General Assembly of IUGG, Lucerne, Switzerland.

TABLE 1. Zonal mean of time standard deviation of vertical velocity. Units: 10^{-6} mb sec^{-1}.

Period	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°
								40 mb							
July–Sept. 1957	14	15	15	16	17	19	21	21	20	19	17	15	15	15	13
Oct.–Dec. 1957	12	12	13	15	15	17	19	24	29	34	38	40	39	35	25
Jan.–Mar. 1958	17	18	19	20	21	23	29	36	40	39	36	34	32	29	26
Apr.–June 1958	14	15	16	17	17	18	19	20	22	22	23	24	25	24	21
July–Sept. 1958	17	18	18	19	20	20	21	21	20	20	20	20	18	16	14
Oct.–Dec. 1958	16	16	17	18	19	21	22	25	29	33	36	38	37	32	26
								75 mb							
July–Sept. 1957	30	31	33	35	37	41	45	44	40	36	33	33	30	28	25
Oct.–Dec. 1957	28	29	32	36	39	43	48	53	57	68	75	78	72	58	47
Jan.–Mar. 1958	35	39	44	50	55	56	56	56	56	57	58	59	64	66	65
Apr.–June 1958	28	30	31	33	35	38	40	41	37	35	36	33	31	30	28
July–Sept. 1958	27	27	27	27	29	32	35	37	39	40	36	32	26	22	19
Oct.–Dec. 1958	28	30	33	36	39	43	46	50	54	61	64	58	56	53	53

TABLE 2. Spatial standard deviation of standing eddy component of vertical velocity. Units: 10^{-6} mb sec^{-1}.

Period	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°
								40 mb							
July–Sept. 1957	1	2	3	3	3	3	4	4	4	4	4	4	4	4	3
Oct.–Dec. 1957	2	3	4	4	4	4	6	8	10	11	10	12	11	10	6
Jan.–Mar. 1958	1	1	2	2	2	3	5	7	8	6	6	7	5	5	5
Apr.–June 1958	1	1	2	2	1	2	2	2	3	3	3	2	2	2	2
July–Sept. 1958	4	4	5	6	6	6	6	7	7	7	6	6	5	3	2
Oct.–Dec. 1958	6	6	6	7	7	7	9	12	15	15	14	13	13	11	6
								75 mb							
July–Sept. 1957	4	7	9	12	12	11	10	10	8	7	6	6	6	5	4
Oct.–Dec. 1957	5	5	6	8	9	10	11	13	18	21	23	26	21	17	12
Jan.–Mar. 1958	5	7	5	7	13	13	12	17	17	17	13	12	13	12	7
Apr.–June 1958	4	7	7	7	8	9	6	6	7	7	5	4	3	3	3
July–Sept. 1958	9	11	15	18	17	16	16	17	14	12	10	11	8	5	2
Oct.–Dec. 1958	7	7	7	9	11	13	15	20	25	30	30	24	20	17	11

TABLE 3. Zonal mean of time standard deviation of adiabatic vertical velocity. Units: mm sec^{-1}.

Period	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°
								40 mb							
July–Sept. 1957	2.2	2.3	2.4	2.6	2.7	3.0	3.3	3.3	3.2	3.1	2.7	2.5	2.5	2.4	2.2
Oct.–Dec. 1957	1.9	1.9	2.1	2.3	2.5	2.6	3.1	3.8	4.6	5.4	5.9	6.3	6.2	5.4	3.9
Jan.–Mar. 1958	2.6	2.8	2.9	3.1	3.3	3.7	4.6	5.7	6.3	6.2	5.7	5.4	5.1	4.5	4.1
Apr.–June 1958	2.2	2.3	2.5	2.6	2.7	2.9	3.1	3.3	3.5	3.6	3.7	3.9	4.1	4.0	3.5
July–Sept. 1958	2.6	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.2	3.3	3.2	3.2	3.0	2.7	2.4
Oct.–Dec. 1958	2.4	2.5	2.7	2.8	3.0	3.3	3.5	4.0	4.6	5.2	5.7	6.1	5.8	5.1	4.1
								75 mb							
July–Sept. 1957	2.3	2.4	2.6	2.7	2.9	3.3	3.6	3.6	3.3	3.0	2.8	2.8	2.6	2.4	2.1
Oct.–Dec. 1957	2.1	2.2	2.4	2.8	3.1	3.4	3.8	4.3	4.6	5.5	6.1	6.3	5.8	4.7	3.7
Jan.–Mar. 1958	2.6	2.9	3.4	3.9	4.3	4.4	4.5	4.6	4.6	4.7	4.8	4.9	5.3	5.4	5.3
Apr.–June 1958	2.1	2.3	2.4	2.5	2.8	3.1	3.3	3.4	3.1	3.0	3.0	2.7	2.7	2.5	2.4
July–Sept. 1958	2.1	2.1	2.1	2.1	2.3	2.5	2.8	3.0	3.2	3.3	3.1	2.7	2.2	1.9	1.7
Oct.–Dec. 1958	2.2	2.3	2.5	2.8	3.1	3.4	3.7	4.1	4.4	5.0	5.3	4.8	4.6	4.4	4.3

by advection are small and errors in temperature and wind, as well as the omission of radiative effects, may mask their true values. The reported values for the tropics may best be regarded as upper limits for $\sigma(\omega)$ but elsewhere, except perhaps at the pole in summer, it is considered that atmospheric variability is presented.

The magnitudes of the values at the two levels are about the same when expressed in mm sec^{-1}. The winter values are greater than those in summer and while at 60 and 70N the largest values occur in October-December, at middle latitudes the largest values occur in the January-March period. The latter is of interest in view of suggestions that the spring maxima in trace substance concentrations may be due to additional down-gradient mixing in the lower stratosphere in late winter which carries material down to the region above the mid-latitude tropopause from where it can escape into the troposphere (Newell, 1961; Newell and Miller, 1965). Again the time resolution in this study is not adequate to explore thoroughly such problems. Indeed it is a valid question to ask whether the large-scale eddy motions are responsible for the vertical transfer of trace substances, although they appear to be responsible for the horizontal transports. Above 27 km there are observed small-scale motions which have been suggested as a possible mechanism contributing to the vertical distribution of trace substances in that region (Newell *et al.*, 1966). At the recent IUGG Lucerne meeting, at which some of the data herein were presented, Prof. Danielsen expressed the opinion that a similar type of small-scale motion observed at lower levels (Weinstein *et al.*, 1966; Danielsen and Duquet, 1967) could also play a part in vertical mixing at lower levels. If a typical horizontal eddy velocity for the small scale features is taken as 5 m sec^{-1} and typical dimensions at 30 km are 600 m and 100 km in the vertical and horizontal, respectively, then an appropriate vertical velocity is about 1 cm sec^{-1}, and is thus a little greater than the values in Table 1. It would seem that both scales of motion have to be explored fully before a complete understanding of vertical mixing processes above the tropopause is obtained.

Acknowledgments. This work was supported by the U. S. Atomic Energy Commission under contract AT (30-1) 2241. We are grateful to Mrs. Dorothy Berry for her analysis of the $\sigma(\omega)$ maps.

REFERENCES

Craig, R. A., and M. A. Lateef, 1962: Vertical motion during the 1957 stratospheric warming. *J. Geophys. Res.*, **67**, 1839–1854.

Danielsen E. F., and R. T. Duquet, 1967: A comparison of FPS-16 and GMD-1 measurements and methods for processing wind data. *J. Appl. Meteor.*, **6**, 824–836.

Davidson, B., J. P. Friend and H. Seitz, 1966: Numerical models of diffusion and rainout of stratospheric radioactive materials. *Tellus*, **18**, 301–315.

Flohn, H., 1961: Meridional transport of particles and standard vector deviation of upper winds. *Geofis. Pura Appl.*, **50**, 229–234.

Gudiksen, R. H., A. W. Fairhall and R. J. Reed, 1968: The roles of mean meridional circulation and eddy diffusion in the transport of trace substances in the lower stratosphere. *J. Geophys. Res.* (in press).

Kao, S.-K., 1962: Large-scale turbulent diffusion in a rotating fluid with applications to the atmosphere. *J. Geophys. Res.*, **67**, 2347–2359.

——, 1965: Some aspects of the large-scale turbulence and diffusion in the atmosphere. *Quart. J. Roy. Meteor. Soc.*, **91**, 10–17.

——, 1967: Discussion of papers. *Quart. J. Roy. Meteor. Soc.*, **93**, 387–390.

Miller, A. J., 1966: Vertical motion atlas for the lower stratosphere during the IGY. Rept. No. 16, Planetary Circulations Project, Dept. of Meteorology, M. I. T., 268 pp.

——, 1967: Note on vertical motion in the lower stratosphere. *Beitr. Phys. Atmos.*, **40**, 29–48.

Newell, R. E., 1961: The transport of trace substances in the atmosphere and their implications for the general circulation of the stratosphere. *Geofis. Pura Appl.*, **49**, 137–158.

——, 1963: The general circulation of the atmosphere and its effects on the movement of trace substances. *J. Geophys. Res.*, **68**, 3949–3962.

——, and A. J. Miller, 1965: Some aspects of the general circulation of the lower stratosphere. *Radioactive Fallout from Nuclear Weapons Tests*, U. S. Atomic Energy Commission, 392–404.

——, J. M. Wallace and J. R. Mahoney, 1966: The general circulation of the atmosphere and its effects on the movement of trace substances: Part 2. *Tellus*, **18**, 363–380.

Pasquill, F., 1962: *Atmospheric Diffusion*. London, D. Van Nostrand Co., 297 pp.

Peng, L., 1965: Stratospheric wind temperature and isobaric height conditions during the IGY period: Part III. Rept. No. 15, Planetary Circulations Project, Dept. of Meteorology, M. I. T., 201 pp.

Prabhakara, C., 1963: Effects of non-photochemical processes on the meridional distribution and total amount of ozone in the atmosphere. *Mon. Wea. Rev.*, **91**, 441–431.

Reed, R. J., and K. E. German, 1965: A contribution to the problem of stratospheric diffusion by large scale mixing. *Mon. Wea. Rev.*, **93**, 313–321.

Weinstein, A. I., E. R. Reiter and J. R. Scoggins, 1966: Mesoscale structure of 11–20 km winds. *J. Appl. Meteor.*, **5**, 49–57.