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The determination of the Kolmogoroff constants for velocity, temperature and humidity fluctuations from second- and third-order structure functions

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Second- and third-order structure functions were computed from velocity, temperature and humidity fluctuations in the wind over the ocean. Universal inertial-convective subrange constants (Kolmogoroff constants) were computed from these structure functions. The constant for velocity is consistent with other recent observations. The temperature and humidity constants are found to be equal within the measurement error and have values of about 0·8.

Introduction

From measurements in the atmospheric boundary layer, second- and third-order structure functions were calculated to determine the Kolmogoroff constants for velocity, temperature and humidity fluctuations. R.V. *Flip* (floating instrument platform), which is operated by the Marine Physical Laboratory of Scripps Institution of Oceanography, was the platform for these measurements which were made during the BOMEX experiment in May 1969 and on a pre-BOMEX cruise off San Diego in February 1969. This programme was carried out in conjunction with the University of California San Diego, University of Washington, University of British Columbia and Oregon State University.

The instrumentation and data collection methods are described in detail by Pond *et al.* (1971). Velocity measurements were from a Kaijo Denki ultrasonic anemometer (model PAT-311), humidity from a Lyman–Alpha humidiometer (Electromagnetic Research Corp.), and temperature (for BOMEX) from a platinum resistance thermometer. The temperature data for the pre-BOMEX cruise was from a dry thermocouple operated by the University of Washington personnel (headed by Dr C. A. Paulson). The velocity and temperature sensors are virtually linear. The Lyman–Alpha humidometer is an exponential device but this behaviour is taken into account in computing the humidity from the observed voltages so it is effectively linear too.

Several factors have complicated the analysis of the velocity data. The instrument arrays were not always oriented to the mean wind, *Flip*'s motion contributed energy to the velocity spectra at wave frequencies and its presence in the fluid field distorted the flow. A discussion of these effects and the coordinate rotations and corrections necessary to minimize them appears in Pond *et al.* (1971). These complications have a fairly small effect on structure functions;

the contributions to the structure functions are of higher frequency than the waves and small errors in the final orientation of the co-ordinate system ($\pm 5^\circ$ to 10° in the horizontal and $\pm 1^\circ$ to 2° in the vertical) have negligible effect as will be demonstrated later.

Theoretical considerations

A one-dimensional energy spectrum ϕ_α for a fluctuating quantity α has the property that

$$\int_0^\infty \phi_\alpha \, dk = \overline{\alpha^2}, \tag{1}$$

where k is the downstream component of the radian wave-number and the bar represents an average (over time in our case). Assuming the Kolmogoroff hypotheses are valid, ϕ_u in the inertial subrange has the form

$$\phi_u = K' \epsilon^{\frac{2}{3}} k^{-\frac{5}{3}}, \tag{2}$$

where u is the downstream component of velocity, K' is an absolute constant (the one-dimensional Kolmogoroff constant for velocity fluctuations) and ϵ is the kinetic energy dissipation per unit mass. Assuming Kolmogoroff type hypotheses for a scalar quantity, γ, such as temperature T or humidity q (Obukhov 1949, Corrsin 1951), ϕ_γ in the inertial-convective subrange has the form

$$\left.\begin{aligned} \phi_\gamma &= B'_\gamma \epsilon^{-\frac{1}{3}} N_\gamma k^{-\frac{5}{3}}, \\ \text{where} \qquad N_\gamma &= 3\eta_\gamma \int_0^\infty k^2 \phi_\gamma \, dk = \eta_\gamma \overline{(\nabla \gamma)^2}, \end{aligned}\right\} \tag{3}$$

B'_γ is an absolute constant (the one-dimensional Kolmogoroff constant for scalar fluctuations), N_γ is the total dissipation of $\frac{1}{2}\gamma^2$, and η_γ is the diffusivity of the scalar, γ.

Pond, Stewart & Burling (1963) have shown that in the inertial subrange

$$S(r) = -0{\cdot}100 K'^{-\frac{3}{2}}, \tag{4}$$

where $S(r)$ is the skewness of the velocity differences defined as

$$S(r) = \overline{[u(x+r)-u(x)]^3} / \{\overline{[u(x+r)-u(x)]^2}\}^{\frac{3}{2}} = D_{lll}/D_{ll}^{\frac{3}{2}}, \tag{5}$$

where u is the velocity in the downstream x direction and r is a space lag in the downstream direction. Equation (4) was obtained by showing that the structure functions D_{ll} and D_{lll} have the following form in the inertial subrange:

$$\left.\begin{aligned} D_{ll} &= 4{\cdot}02 K' \epsilon^{\frac{2}{3}} r^{\frac{2}{3}}; \\ D_{lll} &= -\tfrac{4}{5}\epsilon r. \end{aligned}\right\} \tag{6}$$

As one might expect, it is possible to find an analogous relation between a skewness based on scalar quantities and the scalar Kolmogoroff constant. For temperature and humidity fluctuations Monin & Yaglom (1967) have shown that in the inertial-convective subrange

$$F_\gamma(r) = -\tfrac{1}{6} K'^{-\frac{1}{2}} B'^{-1}_\gamma. \tag{7}$$

$F_\gamma(r)$ is a skewness defined as

$$F_\gamma(r) = \frac{\overline{[u(x+r)-u(x)]\,[\gamma(x+r)-\gamma(x)]^2}}{\{\overline{[u(x+r)-u(x)]^2}\}^{\frac{1}{2}}\,\overline{[\gamma(x+r)-\gamma(x)]^2}} = \frac{D_{l\gamma\gamma}}{D_{ll}^{\frac{1}{2}} D_{\gamma\gamma}}, \tag{8}$$

where γ refers to either temperature or humidity. $D_{\gamma\gamma}$ and $D_{l\gamma\gamma}$ have the form in this subrange:

$$\left.\begin{aligned} D_{\gamma\gamma} &= 4{\cdot}02 B'_\gamma N_\gamma \epsilon^{-\frac{1}{3}} r^{\frac{2}{3}}; \\ D_{l\gamma\gamma} &= -\tfrac{4}{3} N_\gamma r. \end{aligned}\right\} \tag{9}$$

In the inertial subrange, the second-order cross-stream and vertical velocity structure functions

$$\left.\begin{aligned} D_{vv} &= \overline{[v(x+r)-v(x)]^2} \\ \text{and} \qquad D_{ww} &= \overline{[w(x+r)-w(x)]^2}, \end{aligned}\right\} \tag{10}$$

where v and w refer respectively to cross-stream and vertical components of velocity fluctuations, should equal $\frac{4}{3}D_{ll}$. The third-order structure functions

$$\left.\begin{aligned} D_{vvv} &= \overline{[v(x+r)-v(x)]^3} \\ \text{and} \qquad D_{www} &= \overline{[w(x+r)-w(x)]^3} \end{aligned}\right\} \tag{11}$$

will vanish in isotropic turbulence.

In practice, variables are measured as a function of time; time separations, $\Delta\tau$, are converted to space separations using Taylor's hypothesis

$$r = -U\Delta\tau, \tag{12}$$

where U is the mean wind speed. Lin (1953) has shown that Taylor's hypothesis is valid in a shear flow provided that $\overline{u^2} \ll U^2$ and that $r \ll 2\pi z$, where z is the distance to the boundary. Both these conditions are satisfied for the data considered. Pond *et al.* (1963) have shown that isotropy is possible only if $r < z$ and thus S and F_γ values are used to obtain K' and B'_γ for $r < z$ only.

The effect of instrument orientation on the velocity structure functions

As previously mentioned, the velocity-measuring instruments were not always oriented to the mean wind. The data were rotated mathematically to achieve proper orientation. The final rotated velocities are believed to be accurate in the horizontal, within 10° at worst, but probably less in the true downstream direction, with the vertical orientation more accurate. The possible effect of the misorientation for the worst case (10°) is estimated below.

Let primed quantities denote measured values, and unprimed quantities values in a properly oriented co-ordinate system. The measured second-order volocity structure function is then

$$D'_{ll} = D_{ll}\cos^2\theta + D_{vv}\sin^2\theta + 2D_{lv}\cos\theta\sin\theta, \tag{13}$$

where θ is the angle between the measured and true co-ordinates. For $\theta \leqslant 10°$, $1 \geqslant \cos^2\theta \geqslant 0{\cdot}97$. The quantity D_{vv} is approximately equal to D_{ll} and $\sin^2 10°$

is 0·03 so that the second term on the right-hand side of the above expression contributes a small amount to D'_{ll}, which in any case tends to compensate for the effect of the $\cos^2\theta$ factor in the first term. The term D_{lv} can be written

$$D_{lv} = \overline{u_B v_B} - \overline{u_B v_A} + \overline{u_A v_A} - \overline{u_A v_B}, \tag{14}$$

where the subscripts B and A refer to positions a distance r apart. Terms such as $\overline{u_B v_B}$ etc., are components of the double covariance tensor and all vanish in isotropic turbulence (Hinze 1959). Actual measurements of these covariances from spectral techniques indicate that they are small for the data considered and, since they are multiplied by $2\cos\theta\sin\theta$ (0·34 for $\theta = 10°$), they contribute small errors to D'_{ll}. The measured third-order structure function can be written

$$D'_{lll} = D_{lll}\cos^3\theta + D_{vvv}\sin^3\theta + 3D_{llv}\cos^2\theta\sin\theta + 3D_{lvv}\cos\theta\sin^2\theta. \tag{15}$$

The term D_{vvv} is $\gtrsim 0{\cdot}2D_{lll}$ and in addition is multiplied by $\sin^3\theta$ which is very small, so this term's contribution is vanishingly small. The term D_{llv} can be written

$$D_{llv} = \overline{u_B^2 v_B} - 2\overline{u_B u_A v_B} + \overline{u_A^2 v_B} - \overline{u_B^2 v_A} + 2\overline{u_B u_A v_A} - \overline{u_A^2 v_A}, \tag{16}$$

where the terms on the right are all components of the triple covariance tensor and all vanish in isotropic turbulence. In addition this term is multiplied by $3\cos^2\theta\sin\theta$ (0·51 for $\theta = 10°$) so contributions from D_{llv} to D'_{lll} should be small. The remaining term, D_{lvv}, can be shown to be related to D_{lll} by the following expression

$$3D_{lvv} = D_{lll} \tag{17}$$

for isotropic turbulence. Since $3D_{lvv}$ is of order D_{lll} and is multiplied by $\cos\theta\sin^2\theta$, it contributes $\sim 3\%$ or less to D'_{lll} and the contribution is such as to correct the effects of the $\cos^3\theta$ factor in the first term. Similar arguments can be made for a vertical misorientation and because it is much smaller than the horizontal one the effect is significantly less. We conclude that the structure functions are not very sensitive to small misorientations and that negligible errors are introduced if the co-ordinates of measurement are slightly misaligned with the mean wind.

Data analysis

The velocity, temperature and humidity signals were sampled at a rate of about ten/second. The data were treated in blocks of 4096 samples and the structure functions D_{ll}, D_{lll}, D_{vv}, D_{vvv}, D_{ww}, D_{www}, D_{lTT}, D_{TT}, D_{lqq} and D_{qq} were computed for each block of data for various lags between about 0·5 and 10 metres. The second-order velocity structure functions were corrected for the averaging distance of the sonic anemometer by the method suggested by Stewart (1963). This correction is

$$(D_{ll})_c = D_{ll}\{1 - \tfrac{18}{40}(L/r)^{\frac{4}{3}} - \tfrac{1}{54}(L/r)^2\}, \tag{18}$$

where c refers to the corrected structure function, L is the averaging distance for the instrument (taken as 20 cm) and r is the lag. The third-order velocity structure functions were not corrected for averaging distance since they do not depend strongly on the scale sizes for which this correction is significant (Stewart 1963).

Temperature and humidity structure functions were also uncorrected for this effect since for temperature the averaging distance is quite small and for humidity, it is not well-known, but is believed to be small.

The structure functions for a block of 4096 data points were calculated at various lags according to (5) and (8). The second- and third-order structure functions for each block were then divided by $r^{\frac{2}{3}}$ and r respectively ($r = -Un\Delta t$, $n = 1, 2, 3, \ldots$ and Δt is the interval between samples). Block values of these quantities for fixed n were averaged to produce the values for a run. Runs were from 2–14 blocks or 13–87 minutes in length. From these averaged quantities, skewnesses for each run were computed as a function of r. From (6) and (9), it is apparent that this normalization of the structure functions by $r^{\frac{2}{3}}$ and r should produce quantities which are proportional to $\epsilon^{\frac{2}{3}}$ in the case of second-order velocity structure functions and ϵ in the case of third-order velocity structure functions; for temperature and humidity these quantities should be proportional to N_γ. Other methods of averaging are also possible; for example the skewness for each block as a function of r or the quantities $D_{ll}^{\frac{3}{2}}/r$ instead of $D_{ll}/r^{\frac{2}{3}}$ could be averaged over a run. These methods of averaging were carried out but are not reported here since they produce essentially the same results.

In the region from two to five metres lag the skewnesses for a run were fairly constant. Below two metres lag instrumental effects were present and above five metres lag the assumption of an inertial-convective subrange becomes doubtful, because of the presence of the surface about eight metres away. Averages of the normalized structure functions over this two to five metre region were used to compute the final skewnesses and Kolmogoroff constants reported.

Results

As an indication of the degree of isotropy in the turbulence measured from *Flip*, the structure functions D_{vv}, D_{ww}, D_{vvv} and D_{www} were calculated and compared to the corresponding downstream values. Figure 1 is a plot of the ratios of D_{vv} and D_{ww} to D_{ll} and the ratios of D_{vvv} and D_{www} to D_{lll}. For lags in the region of one to five metres, D_{vv}/D_{ll} is of order one and the ratio D_{ww}/D_{ll}, although somewhat smaller, is not very different from one. This sort of deviation from isotropy has been noted before, e.g. by Weiler & Burling (1967). The ratios of D_{www} and D_{vvv} to D_{lll} are very scattered and typically of order $\pm 0{\cdot}1$–$0{\cdot}2$, or less. Thus from figure 1 we conclude that the departure from local isotropy is not very great and similar to that usually found in the atmospheric boundary layer.

Figure 2 is a plot of $D_{ll}^{\frac{3}{2}}/r$ and $-D_{lll}/r$ and the corresponding skewnesses for three representative runs. The interesting feature of this plot is that although the magnitudes of the structure functions vary considerably from run to run and from lag to lag the skewnesses are quite alike except at the short lags. The skewness values between two and five metres lag are almost constant for most runs and so averages over this range have been used to compute the Kolmogoroff constants. Figure 3 shows the results of the same runs for temperature and humidity structure functions. The structure functions for temperature decrease rapidly with r, except at short lags but the skewnesses are again nearly constant in the region from two to five metres. Humidity structure functions and skewnesses are quite well behaved except at short lags.

Figure 4 shows composite plots of F_T, F_q and S for all runs. With the exception of a few runs the skewnesses for velocity, temperature and humidity are almost

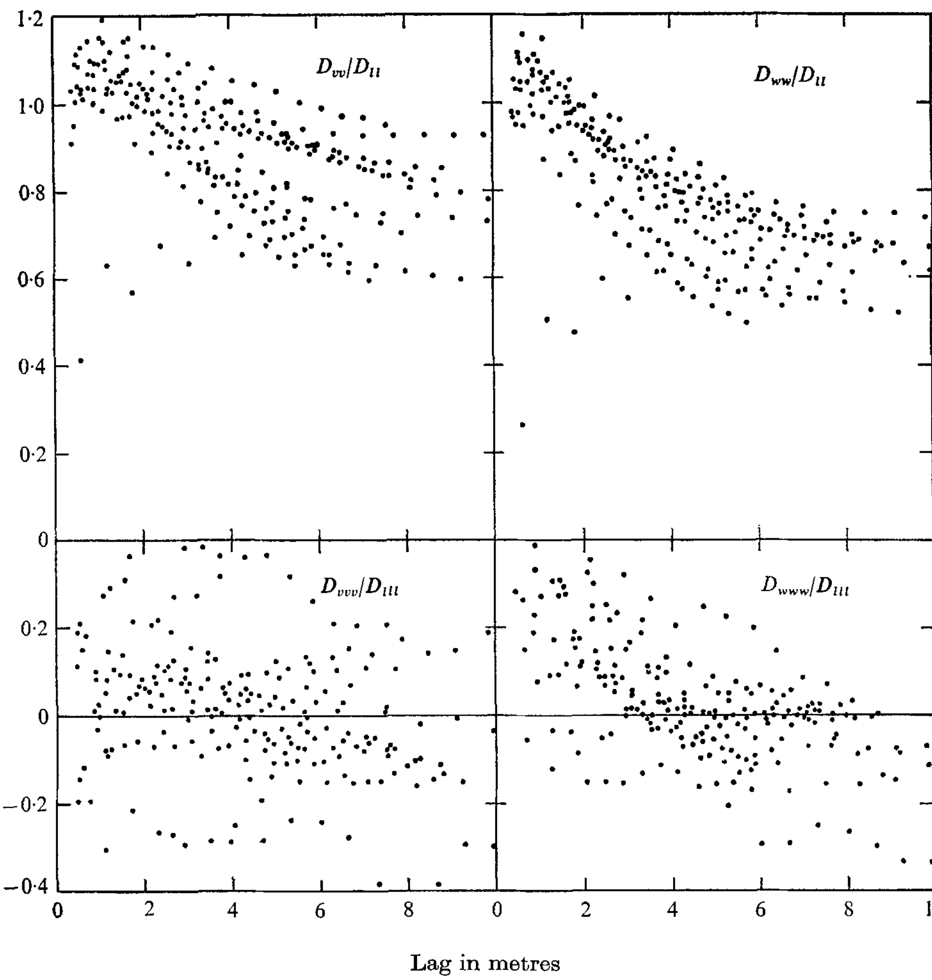

Figure 1. Ratios of cross-stream and vertical velocity structure functions to downstream velocity structure functions.

constant for lags greater than two metres. Table 1 is a summary of the results of the computations. It should be noted that in the computation of B'_γ a value for K' is required. We have computed B'_γ in two ways: one uses the value of K' measured from that run; the other uses a value of K' of 0·55. Both results are presented in table 1 although they do not differ significantly from each other. In table 1 average skewnesses are given, as well as averages for K', B'_T and B'_q. The K' and B'_γ from the average skewnesses do not differ significantly from the average K' and B'_γ. Except for 4*a* the runs 1–15 correspond to the OSU runs 1–15 in Pond *et al.* (1971). Run 4*a* is an additional short run not included in Pond *et al.*

The average of our calculations over the 16 runs gives a value of $0{\cdot}57 \pm 0{\cdot}10$ for the Kolmogoroff constant K'. (All values are given as mean ± standard deviation.) From the average skewness we get the value 0·54. For temperature

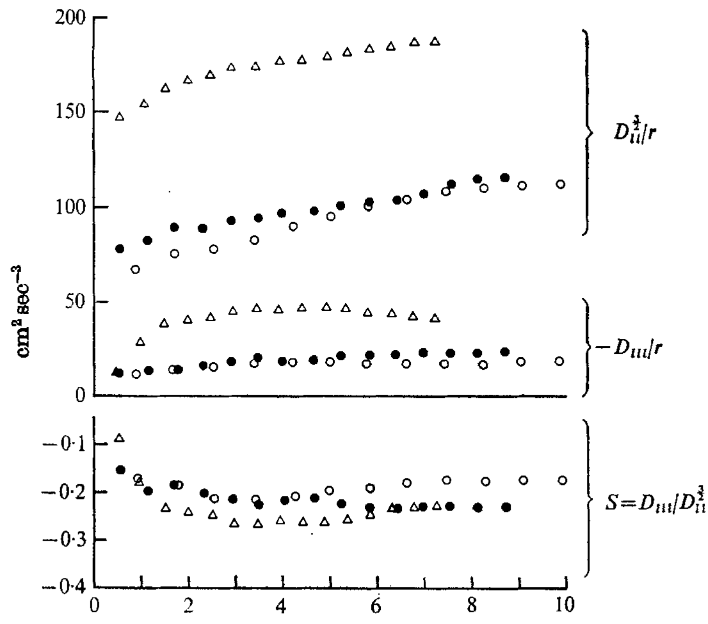

FIGURE 2. Downstream velocity structure functions and skewnesses as a function of lag. ●, run 1; ○, run 11; △, run 12.

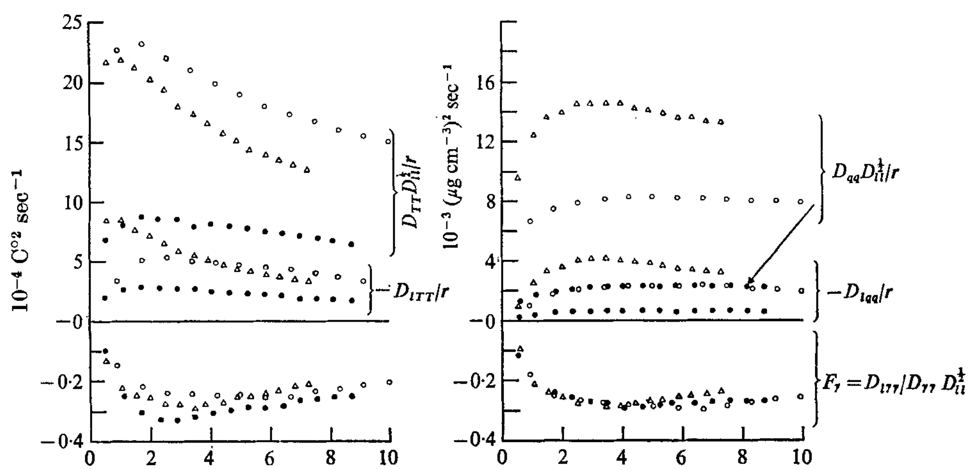

FIGURE 3. Temperature and humidity structure functions and skewnesses as a function of lag. ●, run 1; ○, run 11; △, run 12.

fluctuations we obtain a value of B'_T of $0{\cdot}83 \pm 0{\cdot}13$ using the observed value of K' for individual runs and a value of $0{\cdot}85 \pm 0{\cdot}14$ using $K' = 0{\cdot}55$; from the average F_T using $K' = 0{\cdot}55$ we get 0·83. To our knowledge, only one previous estimate of

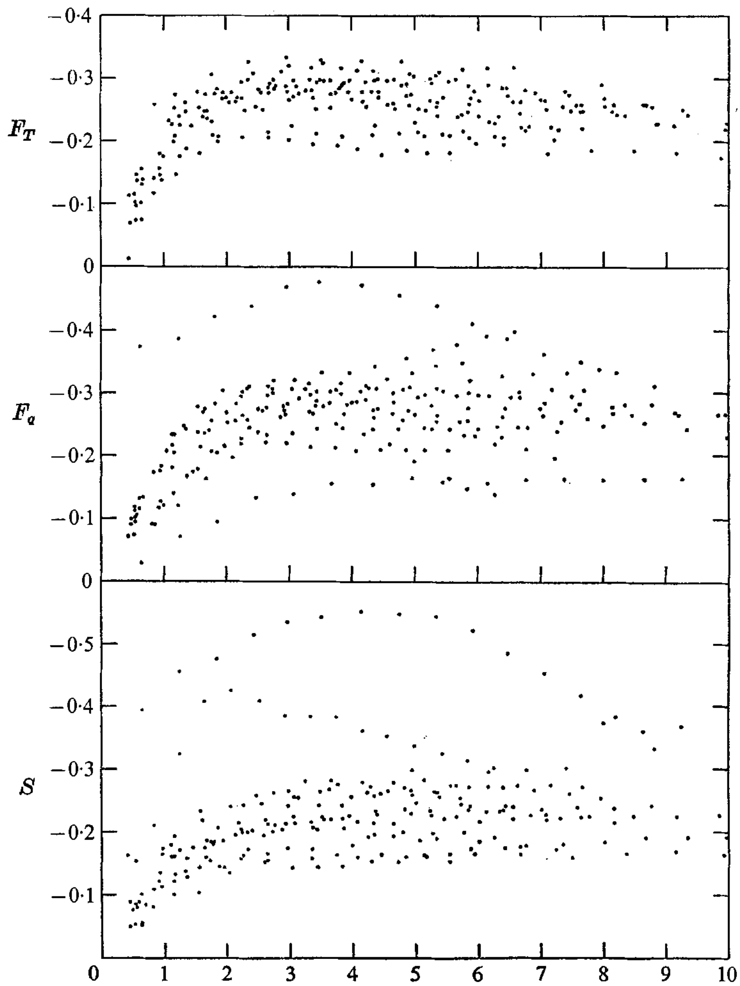

FIGURE 4. Skewnesses for all runs as a function of lag.

the Kolmogoroff constant for humidity fluctuations has been reported (Miyake, Donelan & Mitsuta (1970) estimate 0·63 based on one aircraft run). For B'_q we obtain a value of $0{\cdot}80 \pm 0{\cdot}17$ using measured values of K' and a value of $0{\cdot}81 \pm 0{\cdot}17$ using $K' = 0{\cdot}55$; from the average F_q assuming $K' = 0{\cdot}55$ we get 0·78.

Discussion

The skewness values calculated from *Flip* data show a considerable amount of scatter which seems to be due primarily to the variations in the third-order structure functions. It was observed that the second-order structure functions

Run	Time G.M.T./ day/month	Duration (min)	U (m/sec)	$-S$	K'	$-F_T$	B'_T	B'^*_T	$-F_q$	B'_q	B'^*_q
San Diego											
1	09.54 20. ii	40	5·8	0·215	0·60	0·316	0·68	0·71	0·276	0·78	0·81
2	11.04 20. ii	27	6·6	0·166	0·71	0·272	0·68	0·82	0·286	0·69	0·78
3	15.17 20. ii	40†	4·8	0·204	0·62	0·310	0·68	0·72	0·264	0·80	0·85
4	01.09 21. ii	54‡	6·1	0·268	0·52	0·250	0·92	0·90	0·167	1·38	1·34
4*a*	01.40 21. ii	13§	4·1	0·380	0·41	0·260	0·97	0·84	0·291	0·89	0·77
BOMEX											
5	19.09 3. v	87	4·7	0·167	0·71	0·195	1·01	1·15	0·218	0·91	1·03
6	04.55 4. v	37	5·6	0·224	0·58	0·334	0·65	0·67	0·334	0·66	0·67
7	05.32 4. v	25	7·2	0·266	0·52	0·276	0·84	0·81	0·304	0·76	0·74
8	07.02 5. v	37	5·9	0·236	0·56	0·293	0·76	0·76	0·314	0·71	0·71
9	11.25 5. v	37	7·2	0·548	0·32	0·323	0·91	0·69	0·467	0·63	0·48
10	03.17 6. v	62	6·8	0·220	0·59	0·282	0·77	0·79	0·310	0·70	0·72
11	18.16 6. v	75	5·3	0·200	0·63	0·248	0·84	0·90	0·284	0·74	0·79
12	18.54 9. v	62	6·5	0·260	0·53	0·274	0·83	0·81	0·279	0·82	0·80
13	07.54 11. v	62	5·9	0·153	0·75	0·195	0·99	1·15	0·238	0·81	0·94
14	12.35 11. v	62	5·0	0·236	0·56	0·238	0·93	0·94	0·275	0·81	0·81
15	13.11 12. v	62	6·8	0·254	0·54	0·264	0·86	0·85	0·288	0·79	0·78
Average	—	—	—	0·250	0·57	0·271	0·83	0·85	0·287	0·80	0·81
Std. dev.	—	—	—	—	±0·10	—	±0·13	±0·14	—	±0·17	±0·17
K' or B'_γ from avg. skewness	—	—	—	0·54	—	0·83*	—	—	0·78*	—	—

* Using $K' = 0{\cdot}55$.
† Duration was 27 min for temp. data.
‡ Duration was 40 min for temp. data.
§ Note short duration.

TABLE 1. Skewnesses and Kolmogoroff constants

are quite stable and do not vary much within a run. The third-order quantities which are not positive definite, on the other hand, show a great amount of variation and require long records to settle to a reliable average.

All the results presented are based on the assumption of local isotropy. The scale sizes over which the structure functions were calculated are at the large scale end of the approach to local isotropy and thus some doubt is cast on the reliability of the skewnesses reported. The skewnesses calculated for the short lags (less than two metres) are not reliable since the measuring instruments were not at the same point (the temperature, humidity and velocity sensors were within a radius of about 50 cm). There are also instrument-response limitations which affect the short lags.

Although the structure function method of determining these constants has more statistical scatter than determinations based on the whole spectrum and there are some limitations in the instruments, we have been able to make one of the first estimates of the Kolmogoroff constant for humidity fluctuations. In particular we can check whether the constant for humidity fluctuations is likely to be the same as that for temperature fluctuations. Although one might expect the same value, a check with actual measurements is more satisfying before using the constant (which we wished to do to test the dissipation method for estimating the moisture flux as reported in Pond *et al.* (1971)). The values obtained for the velocity constant are regarded as a check that our results are reliable in spite of the problems noted. The value for the temperature constant serves as a check too, although there are not very many measurements and some discrepancies. So our results are useful in checking earlier results by an independent method.

We obtain a value of 0·57 for K' which is somewhat larger but not really inconsistent with earlier results such as those summarized in Pond *et al.* (1966), $0{\cdot}48 \pm 0{\cdot}06$, and those of Grant, Stewart & Moilliet (1962). Nasmyth (1970) re-examined the data used to obtain K' in Grant *et al.* (1962) and noted some effects of scalar fluctuations on the velocity fluctuation measurements. By selecting data for which these effects were smallest he obtained a new value of 0·56. We have observed that in using the dissipation method for momentum flux a K' of 0·55 gives good agreement with the directly measured flux (Pond *et al.* 1971). Gibson, Stegen & Williams (1970) also suggest that the 'usual' value of 0·5 should be increased somewhat, perhaps to about 0·6. We note also that although the turbulent fields we have measured are not exactly isotropic, they are apparently close enough to isotropy for the constant to be the same as for more isotropic cases.

The value we obtain for B'_q is $0{\cdot}80 \pm 0{\cdot}17$; the value for B'_T is $0{\cdot}83 \pm 0{\cdot}13$. Hence we conclude that there is no difference between the value of the constant for temperature and humidity fluctuations. Based on our results, an overall value for B'_γ for γ either T or q is $0{\cdot}82 \pm 0{\cdot}12$.

Not all the reported values for the scalar constant are directly comparable with our results because there are at present two systems of defining this constant in common use. The system and notation that we have adopted is based on that of Monin & Yaglom (1967). The most common difference occurs because instead of using N_γ, the rate of dissipation of $\frac{1}{2}\overline{\gamma^2}$, the rate of dissipation of $\overline{\gamma^2} = 2N_\gamma$ [denoted by χ by Gibson & Schwarz (1963), Gibson *et al.* (1970) and Grant *et al.* (1968) and by ϵ_γ by Boston (1971)] is used in the definition of ϕ_γ (equation (3)). Thus the constant they report (denoted by β_1 or K'_T) must be multiplied by 2 for comparison. [It is also possible to use a non-radian wave-number as noted by Panofsky (1969). Further, a factor of $\frac{1}{2}$ has sometimes been inserted in the right-hand side of (1). Thus it is necessary to check definitions very carefully before comparing results.] We believe we have reduced everyone's results to a comparable system and will give comparisons in terms of B'_γ.

The value we have obtained for B'_γ ($0{\cdot}82 \pm 0{\cdot}12$) is consistent with the results of Wyngaard & Coté (1971), $0{\cdot}79 \pm 0{\cdot}10$, obtained by measuring all the terms in the energy budget for $\frac{1}{2}\overline{T^2}$. Gurvich & Zubkovski (1966) give values of 0·9 from structure functions and quote an earlier result of 0·7 for B'_T. Panofsky (1969) gives an estimate of 0·7. The value of 0·8 gives good agreement between directly measured moisture fluxes and those estimated by the dissipation method (Pond *et al.* 1971). Furthermore B'_γ should be independent of the fluid. From measurements in the ocean Grant *et al.* (1968) obtain a value of $0{\cdot}62 \pm 0{\cdot}12$ and Gibson & Schwarz (1963) obtain 0·70 from measurements in a water tunnel. Thus one might conclude that the value of the scalar Kolmogoroff constant is reasonably well established.

Unfortunately there are two other sets of measurements in the atmosphere which do not agree. These measurements by Gibson *et al.* (1970) and Boston (1971) are based on measurements of the whole spectrum ϕ_T and measurement of N_T by integration of $k^2\phi_T$. One feels that this method, which is based on fewer assumptions than the others, ought to give the 'best' results. Gibson *et al.* (1970 and personal communication) using a $0{\cdot}6\,\mu$ platinum wire obtain values from about 1·6 to 2·4 with an average value of 2·0 from measurements on *Flip* during BOMEX. Boston obtains $1{\cdot}62 \pm 0{\cdot}16$ using a $0{\cdot}25\,\mu$ wire.

The reason for the differences between the Gibson and Boston results and the other results given previously is not clear at present. There are many possibilities: the structure function and budget techniques are based on the spectrum at the large-scale limit of the approach to local isotropy, and the normalized spectra, while being similar, may have lower values than at smaller (but still $-\frac{5}{3}$ range) scales. The measurements in water are difficult because the spectra extend to very small scales and the measurements must be extended with Batchelor's theory to obtain N_γ by integration. Gibson's and Boston's results are based on much shorter averages than the structure function and budget results – the difference might be an effect of intermittency and of averaging length. Contamination of the very fine wires they use and neglect of the thermal lag of the thin laminar boundary layer around the wire could reduce their time constants leading to underestimates of N_T and hence overestimates of B'_T. Grant *et al.* (1968), because the boundary-layer lag is dominant in water, measure the actual response of their sensor – such checks for the atmospheric results would be very helpful. The structure function measurements should be extended to smaller lags to see if the skewness values remain the same as for the region observed in this study. Clearly further work needs to be done before the value of the scalar Kolmogoroff constant is definitely established. However, for estimating the dissipation from the large-scale end of the inertial-convective subrange (for budget studies or estimates of the scalar fluxes), it appears that a value of 0·8 for B'_γ can be used to obtain reasonable results.

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