Comparative Statistical Analysis of Soaring Competitions

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Abstract

In continuation of similar work for the Lilienthal Glide 2007 (Lüsse, Germany) flight log data of 10 competition days of the European Gliding Championships 2007 (Issoudun, France) and of the Junior World Gliding Championships 2007 (Rieti, Italy) have been analyzed in order to extract vertical speed distributions and altitude distributions. The data allow comparison between meteorological conditions and pilot strategy over flat land and mountainous terrain. Climb in straight flight contributes from 20% to 50% essentially independent of orography. Differences between climb in thermals and climb in straight flight are outlined.

Nomenclature

t	time (UTC)
x	longitude
y	latitude
v	horizontal (air) speed
w	vertical speed
f(w)	vertical speed distribution
h	altitude
f(h)	total altitude distribution
$f_s(h)$	sink altitude distribution
$f_c(h)$	climb altitude distribution
$f_c^c(h)$	circling climb altitude distribution
$f_c^s(h)$	straight flight climb altitude distribution

Introduction

Satellite-aided navigation in cross-country soaring provides data which can be employed in order to characterize meteorological conditions or pilots' tactical decision making. The available data set is huge and its density and global availability are large, making these data a most useful tool for the characterization of cross-country flying. However, pilots' tactical decisions and meteorological conditions strongly depend on each other and cannot be assessed isolated from each other by analyzing standard flight log data which necessarily describe the entire system of the glider pilot in his meteorological environment. On the other hand, the description of this complex system is exactly what speed-to-fly theory aims at[1]. Thus, the statistic analysis of flight log data allows assessment of the assumptions inherent in speed-to-fly theory.

To this end, in a previous publication one of us has, for the first time, performed a systematic statistical analysis of flight log data of the Lüsse National Gliding Competition (Lilienthal Glide 2007).[2] Flight log data were analyzed in order to extract vertical speed distributions and altitude distributions in space and time, with a temporal resolution of 30 minutes. The motivation for this work was to provide experimental data for comparison of the real behavior of competition pilots to the assumptions underlying speed-to-fly theory. Main issues addressed were 1) the distribution f(h) of flight altitudes h and 2) the distribution f(w) of vertical speeds w. Whereas speed-to-fly theory does not make assumptions on the altitude band which is used by a pilot, weather conditions, in the first place the wind vector, are not the same for all altitudes. Therefore, the flight altitude will have an impact on the pilot's performance, even if the possible event of an outlanding is not considered. Secondly, speed-to-fly theory assumes a fixed average climb rate value as criterion for accepting a lift. Clearly, actual as well as lift-averaged climb rates used by a cross country pilot will considerably vary in the course of a flight. Vertical speed distributions were found to be bimodal and could be described well by the sum of two Gaussian functions, one centered at positive values (climb) characterizing lift and one centered at negative values characterizing straight flight (sink). The assumption of constant lift throughout a day and the employed altitude band was found to be a surprisingly good description of the real situation. Altitude distributions were singly peaked and generally asymmetric. They could be described well by integrating two Gaussian normal distributions which characterize the frequencies of thermal entering and exiting altitudes. Soaring altitude bands used were relatively narrow and accounted for about 25% of the thickness of the convective boundary layer.

Two methods were presented for the determination of thermal entering and exiting altitude distributions, one relying on identifying begin and end of circling in thermals, the second using mathematical manipulation of climb altitude distributions. Both methods are equivalent if standard speed-to-fly theory conditions are met. For Lilienthal Glide 2007 it was shown that this was the case.

In continuation of this work we present here similar statistical analyses for two further soaring competitions, both held in 2007: 1) the European Gliding Championships (EGC07) at

Issoudun, France, from August 6 to 19 and 2) the Junior World Gliding Championships (JWGC07) at Rieti, Italy, from July 28 to August 11. EGC07, like the previously analyzed Lilienthal Glide, reflects the case of a competition held in unstructured, flat terrain, while JWGC07 is an example of a competition taking place in a mountainous environment. For EGC07, the dates analyzed are August 9, 12, 13, 16, and 18, for JWGC07 July 29 and 30 and August 4, 6, and 7. Table 1 presents a summary of the analyzed data and shows an overview of the set tasks.

This work represents both an extension and a refinement of the previously published data. The role of the terrain is addressed by analyzing competitions held under different topographic conditions, and the previously averaged data were separately analyzed for circling and for straight flight.

Otherwise, employed methods are the same as in Ref. 2. Flight logs have been cleaned from pre-start and post-finish data points, and in order to reduce the number of points without losing relevant information, the minimum time interval between adjacent data points has been set to 24 seconds. Each data point is a vector consisting of five components: time t, latitude y, longitude x, altitude h and vertical speed w. For the calculation of vertical speeds w the barometric altitude information was used instead of GPS-based altitude readings because GPS-based data contain numerous bad data points. Almost 300,000 such data vectors have been collected and analyzed for altogether 10 competition days.

Vertical speed

Vertical speed distributions f(w) presented in this section have resulted from integration over full competition days.

Vertical speeds w have been calculated from barometric altitude information and averaged over two neighboring points. Vertical speeds w describe the actual vertical movement of the glider, not the updraft or downdraft of the air it flies in. Thus, calculated vertical speeds w are lower than meteorological values by the sink rate of the glider. In particular, climb rates will be smaller than the updraft by the rate of least sink of the glider, and the calculated sink rates will reflect the (horizontal) air speed v of the glider rather than any vertical speed of the air itself. Also, vertical speeds w are not corrected for changes in horizontal speed v. Correction of the data set for these two effects was not performed for reasons discussed in detail in Ref. 2.

In Figs. 1 and 2, overviews of time-integrated vertical speed distributions f(w) for EGC07 and JWGC07 are shown. Qualitatively, the distributions for all 10 days are similar. All are characterized by bimodal distributions, reflecting the two flight modes "climb" and "sink". Again, the bimodal vertical speed distributions can be described well by sums of two Gaussian functions, one accounting for climb and the other one accounting for sink. Centers and widths of the distributions returned as fit parameters are listed in Table 2. No qualitatively different behavior is observed for EGC07 and JWGC07, with absolute values of vertical speeds being generally larger for JWGC07.

As shown in Figs. 3 and 4, maximum climb and sink rates (open circles) correlate with soaring altitude. They are largest for medium soaring altitudes and become smaller for the smallest and for the largest soaring altitudes. Nevertheless, mean vertical speed (filled circles) and soaring altitude are essentially uncorrelated. Strict absence of such correlations would manifest itself by straight lines for the mean vertical speeds in the w-h plots of Figs. 3 and 4. Some weak, mostly positive correlations exist for individual competition days and can be recognized in Figs. 3 and 4 from the slight deviation of mean vertical speed values from the horizontal straight line. As the further analysis will show, the correlation is weak enough to be neglected, and the simple assumption of constant climb rates for all altitude levels throughout a competition day is equally valid for EGC07 and JWGC07 as it was the case for the Lüsse Lilienthal Glide 2007. The noise level for JWGC07 is larger than for EGC07 owing to the smaller number of data points and the larger spread in soaring altitudes. Independence of mean vertical speed of soaring altitude also implies that altitude distributions calculated from flight data in sink and in climb do not show any significant difference from each other, as is discussed in the following section.

Altitude distributions

Altitude distributions f(h) are shown in Figs. 5 and 6. The altitude distributions for EGC07 are singly peaked and similar to the ones obtained for the Lüsse Lilienthal Glide 2007. JWGC07 altitude distributions are more complex and show a larger variation for different competition days.

Total altitude distributions f(h) have been decomposed into climb and sink altitude distributions $f_c(h)$ and $f_s(h)$ the nearly identical shapes of which confirm the absence of a significant w-h correlation. Nevertheless, for addressing the issue of altitude distribution for circling and for straight climb, it is necessary to further analyze the climb altitude distributions $f_c(h)$ only which are marked by the upward triangles in Figs. 5 and 6.

Thermal entering and exiting altitudes were determined by identifying circling in thermal lift. For identification of a thermal the following criteria were used. First, the vertical speed w must be positive: $dh/dt > 0$. Second, ground speed must be small: $dx/dt \approx dy/dt \approx 0$, or combined in one condition: $(dx/dh)^2 + (dy/dh)^2 \approx 0$. If these conditions were met for at least four consecutive data points, it was assumed that the glider had entered thermal lift and the altitude of the first data point satisfying all aforementioned conditions was taken to be the thermal entering altitude. Similarly, thermal exiting altitudes were determined. The corresponding distributions of thermal entering and exiting altitudes $f_{in}(h)$ - $f_{out}(h)$ are shown in Figs. 7 and 8. Values are listed in Table 3. Independent of terrain, thermal entering altitudes are approximately 60% and thermal exiting altitudes are approximately 80% of the maximum altitude with variation of these values of about 10%.

Climb occurs during straight flight and while circling in thermals. In order to assess the role of climb during straight flight, one needs to distinguish between straight climb and circling climb. To this end the same criterion is used as for identifying thermal entering and exiting altitudes. Correspondingly decomposed straight and circling climb altitude distributions $f_c^s(h)$ and $f_c^c(h)$ are shown in Figs. 9 and 10. For EGC07, the shapes of circling and straight climb altitude distributions are identical with straight climb accounting for up to 50% of total climb. For JWGC07, the shapes of circling and straight climb altitude distributions $f_c^s(h)$ and $f_c^c(h)$ are also similar for all days with the exception of July 29, where straight climb dominates at large altitudes. Surprisingly, in the mountainous terrain at Rieti the contribution of straight climb to total climb is of the same order of magnitude or even smaller than in the flat terrain at Issoudun.

If mean climb is independent of altitude, i.e. if no w-h correlation exists, integration of $f_{in}(h)$ - $f_{out}(h)$ over h must yield the circling climb altitude distribution f(h). The results of these integrations also are shown in Figs. 9 and 10. The agreement is excellent between circling climb altitude distribution $f_c^c(h)$ calculated from integration over distributions of thermal entering and exiting altitudes (open circles in Figs. 9 and 10) and those from direct analysis from flight log data (grey columns in Figs. 9 and 10). Small deviations between distributions are due to a non-zero, weak w-h correlation. The excellent agreement proves that the assumption of constant and altitude-independent mean climb is valid.

Results and Conclusions

The statistic analysis of flight log data has been extended from Lilienthal Glide 2007 at Lüsse to the European Gliding Championships 2007 (EGC07) at Issoudun, France and the Junior World Gliding Championships 2007 (JWGC07) at Rieti, Italy.

Vertical speed distributions exhibit the same general features for all three competitions. Vertical speed distributions are bimodal reflecting cruising and climbing modes. The assumption of constant lift throughout a day and at all altitudes employed seems to be valid independent of the topography of the terrain. However, aligned lift is found to play a significant role by accounting for 20% to 50% of total climb. Thus, the role of aligned lift deserves a more detailed investigation in that it is not accounted for by speed-to-fly theory, opening up the possibility to push cruising speeds and potential flight distances beyond the classic limits defined by speed-to-fly theory. The absence, or rather the weakness of a w-h correlation might appear surprising at first sight in view of previously published results[3] where a pronounced correlation between maximum climb rate and altitude is postulated. The existence of this correlation is confirmed by the data shown in Figs. 3 and 4. However, the average climb rate realized by the pilot-environment system is found to be only weakly dependent or completely independent of flying altitude. In this respect, speed-to-fly theory seems to be a sufficiently well performing approach. At the same time, this seeming contradiction highlights the importance of analyzing the entire pilot-environment system when it comes to assessing maximum cruising speeds and potential flight distances

Altitude distributions for Lüsse and Issoudun competitions are similar. They are singly peaked and the circling climb can be described well by Gaussian distributions of thermal entering and exiting altitudes. For the Rieti championships in mountainous terrain, altitude distributions are significantly more complex. A geographic distinction between different competitions areas would help to reveal the underlying dynamics. Unfortunately, the relatively small number of data points forbids performing this kind of analysis for JWGC07. It is hoped that sufficient data points will be available from the WGC08 at Rieti.

Acknowledgments

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References

[1] Reichmann, H., *Streckensegelflug*, Motorbuch Verlag, 4th ed., 1979, pp. 146-179.

[2] Maul, C., "Statistical analysis of competition soaring", *Technical Soaring*, 32(3), 2008, 97-106.

[3] Bradbury, T., *Meteorology and Flight*, A & C Black, 3rd ed. 2000, p. 54.

Table 1
Set tasks and number of analyzed flights (SAT: speed area task).

	day	number N of analyzed flights	number P of data points	task
Issoudun	09.08.	21	29460	324 racing, 331 racing, 314 racing
Issoudun	12.08.	84	24407	1:30 h SAT, 2:00 h SAT, 2:00 h SAT
Issoudun	13.08	86	49995	423 racing, 403 racing, 428 racing
Issoudun	16.08.	45	51820	4:00 h SAT, 4:00 h SAT, 4:00 h SAT
Issoudun	18.08.	83	43093	309 racing, 360 racing, 352 racing
Rieti	29.07	52	20163	289 racing, 369 racing
Rieti	30.07	52	22931	2:30 h SAT, 2:30 h SAT
Rieti	04.08.	26	9934	3:00 h SAT, 3:00 h SAT
Rieti	06.08	51	17969	225 racing, 283 racing
Rieti	07.08.	53	24455	339 racing, 404 racing

Table 2
Results of fitting two Gaussian distributions to vertical speed distributions of Figs.1 and 2 (HWHM: half width at half maximum). Data obtained for the Lilienthal Glide 2007 in Lüsse are also shown.

	day	climb center, m/s	climb HWHM, m/s	sink center, m/s	sink HWHM, m/s
Issoudun	09.08.	1.25	1.14	-1.02	0.77
Issoudun	12.08.	1.29	1.07	-1.20	1.09
Issoudun	13.08	1.32	1.12	-1.25	0.98
Issoudun	16.08.	1.52	1.24	-1.19	1.13
Issoudun	18.08.	1.34	0.99	-1.28	1.03
Rieti	29.07	1.98	1.65	-1.51	1.16
Rieti	30.07	1.54	1.10	-1.17	1.08
Rieti	04.08.	1.36	1.22	-1.22	1.15
Rieti	06.08	1.55	1.41	-1.43	1.02
Rieti	07.08.	1.90	1.60	-1.62	1.12
Lüsse	16.07.	2.15	1.14	-1.47	1.13
Lüsse	23.07.	1.40	0.99	-1.20	1.06
Lüsse	26.07.	1.56	1.06	-1.31	1.10

Table 3

Integrated thermal entering (f_{in}) and exiting (f_{out}) altitude distributions. Results of fitting two Gaussian distributions to thermal entering and exiting altitude distributions directly determined from the flight log data. h_{in} and h_{out} are distribution centers. Maximum altitudes h_{max} are the 99.75 percentile of altitude data. (HWHM: half width at half maximum; $\Delta = h_{out}/h_{max} - h_{in}/h_{max}$)

day	h_{max}, m		f_{in} h_{in}, m	f_{in} HWHM, m	f_{out} h_{out}, m	f_{out} HWHM, m	h_{in}/h_{max}	h_{out}/h_{max}	Δ
09.08.	1778	Issoudun	787± 15	174± 21	1510± 16	196± 23	44.3%	84.9%	40.6%
12.08.	1357	Issoudun	828± 63	165± 46	1016±313	214±115	61.0%	74.9%	13.9%
13.08.	1698	Issoudun	836± 29	225± 28	1381± 35	256± 35	49.2%	81.3%	32.1%
16.08.	1528	Issoudun	898± 18	201± 15	1279± 14	181± 11	58.8%	83.7%	24.9%
18.08.	1539	Issoudun	780± 8	172± 10	1312± 8	189± 11	50.7%	85.3%	34.6%
29.07.	3320	Rieti	1753± 21	199± 27	2926± 53	468± 75	52.8%	88.1%	35.3%
30.07.	2248	Rieti	1549± 18	220± 21	2007± 10	160± 11	68.9%	89.3%	20.4%
04.08.	2608	Rieti	1641± 15	132± 26	2083± 75	447± 85	62.9%	79.9%	17.0%
06.08.	3039	Rieti	1630± 68	370± 84	2670± 73	408± 93	53.6%	87.9%	34.3%
07.08.	3317	Rieti	1896± 21	221± 28	3052± 29	284± 38	57.2%	92.0%	34.8%
16.07.	2777	Lüsse	1469± 13	453± 20	2206± 28	550± 43	52.9%	79.4%	26.5%
23.07.	1831	Lüsse	950± 5	265± 6	1346± 7	288± 10	51.9%	73.5%	21.6%
26.07.	1970	Lüsse	1187± 6	281± 8	1625± 6	240± 7	60.3%	82.5%	22.2%

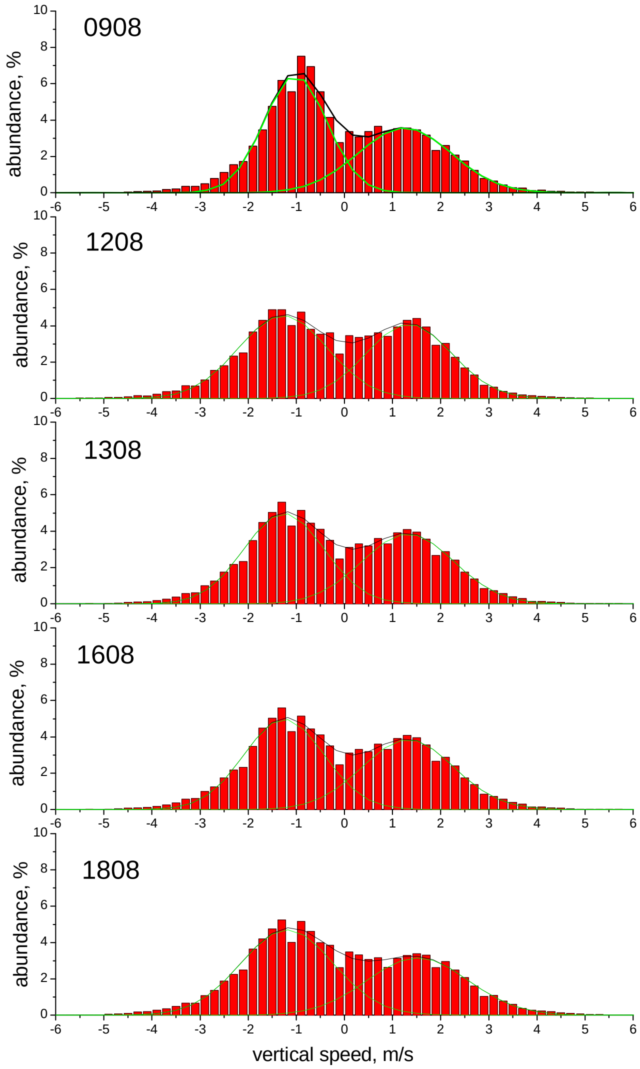


Figure 1 Normalized vertical speed distributions for EGC07 in Issoudun. Bimodal distributions have been fit by a sum of two Gaussian distribution. Fit parameters are listed in Table 2.

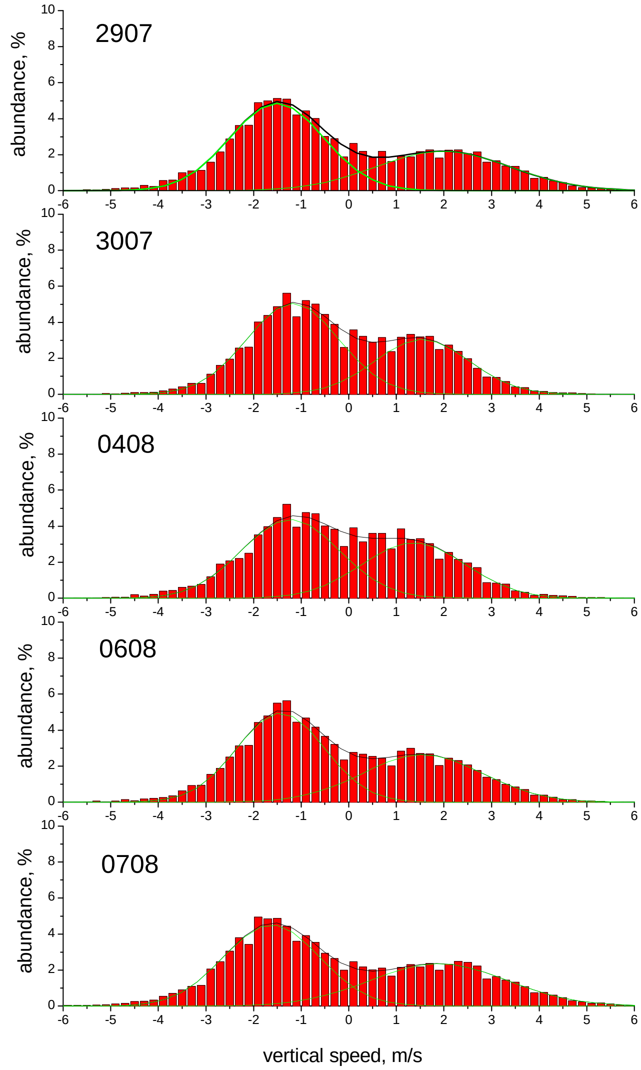


Figure 2 Normalized vertical speed distributions for JWGC07 in Rieti. Bimodal distributions have been fit by a sum of two Gaussian distribution. Fit parameters are listed in Table 2.

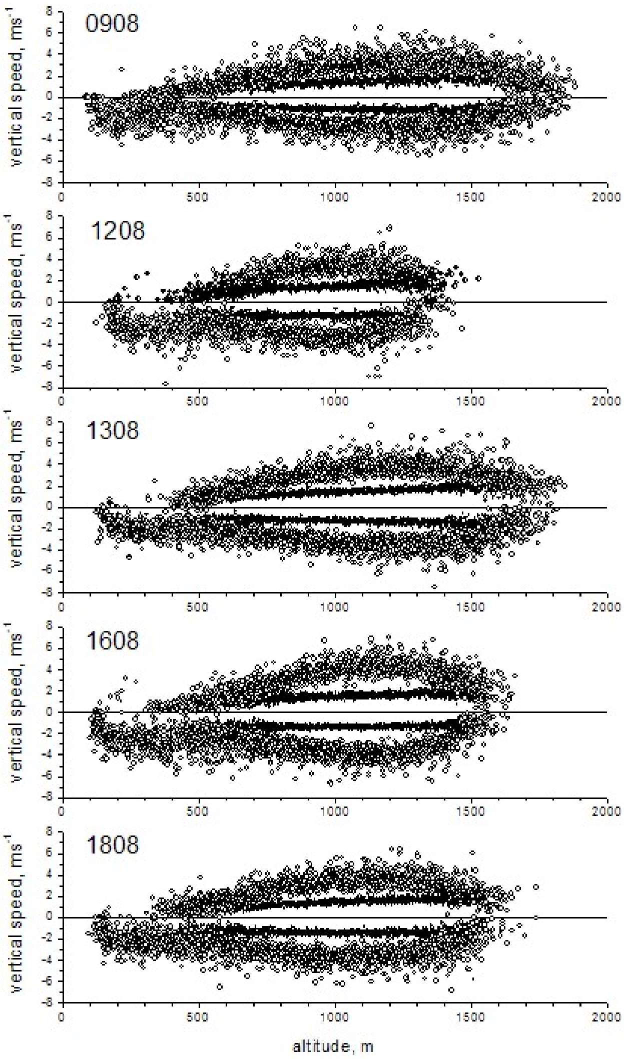


Figure 3 Altitude dependence of extreme (open circles) and altitude averaged mean (filled circles) climb and sink rates for EGC07. Averaged values are essentially uncorrelated with altitude, whereas extreme values peak at medium altitudes.

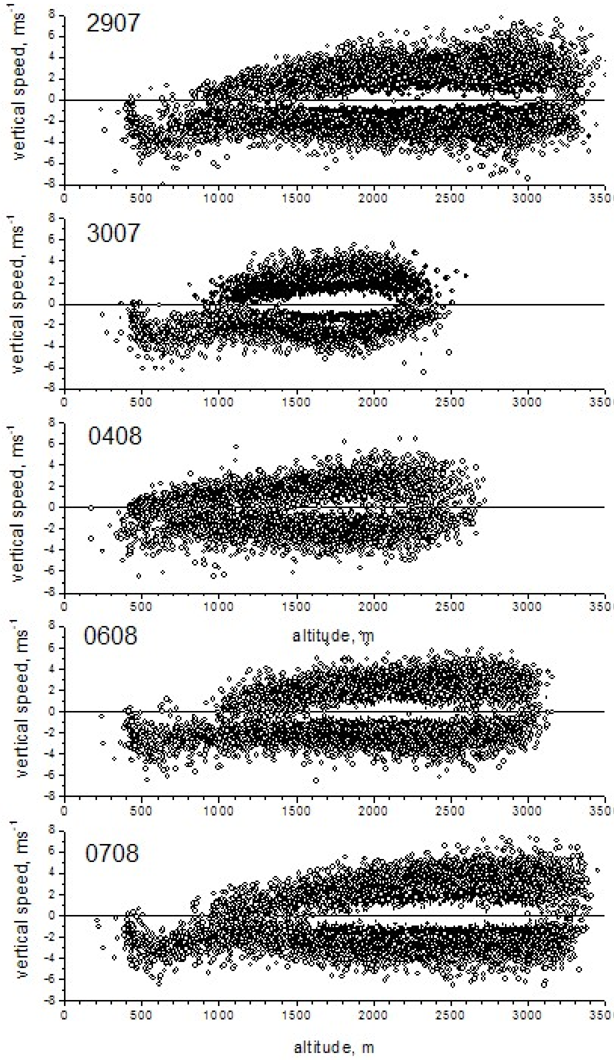
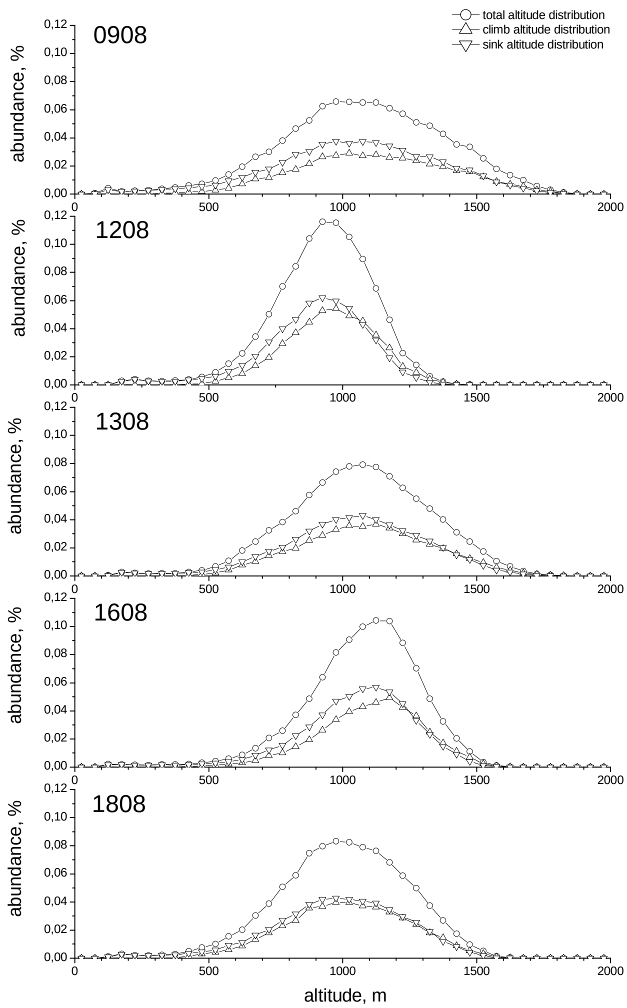


Figure 4 Altitude dependence of extreme (open circles) and altitude averaged mean (filled circles) climb and sink rates for JWGC07. Averaged values are essentially uncorrelated with altitude, whereas extreme values peak at medium altitudes. The noise level is larger than for EGC07 (cf. Fig. 3) owing to the smaller number of data points and the larger spread in altitude.



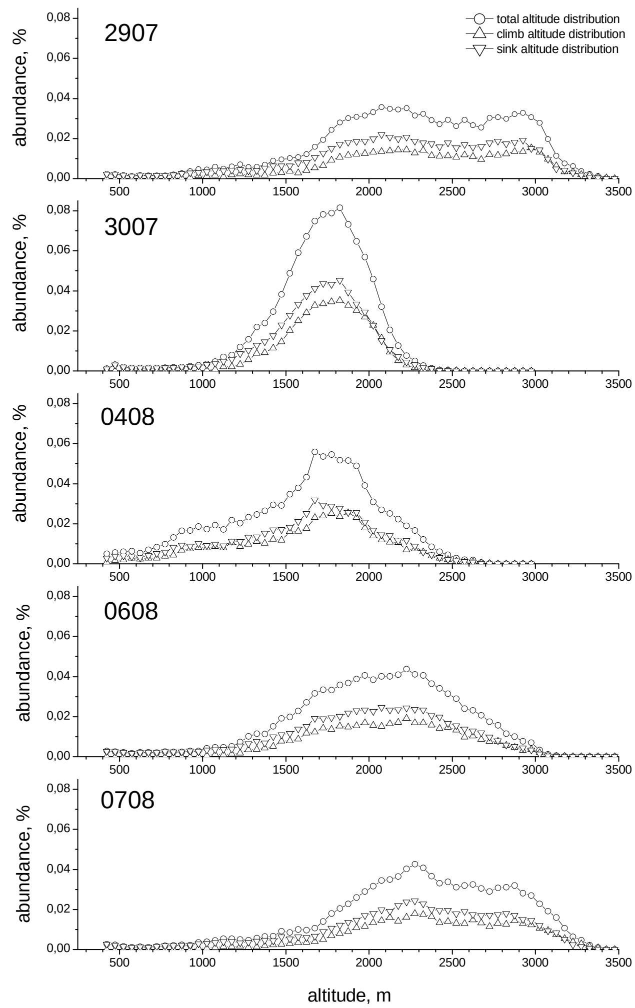


Figure 5 Normalized total (open circles), climb (upward triangles) and sink (downward triangles) altitude distributions for EGC07.

Figure 6 Normalized total (open circles), climb (upward triangles) and sink (downward triangles) altitude distributions for JWGC07.

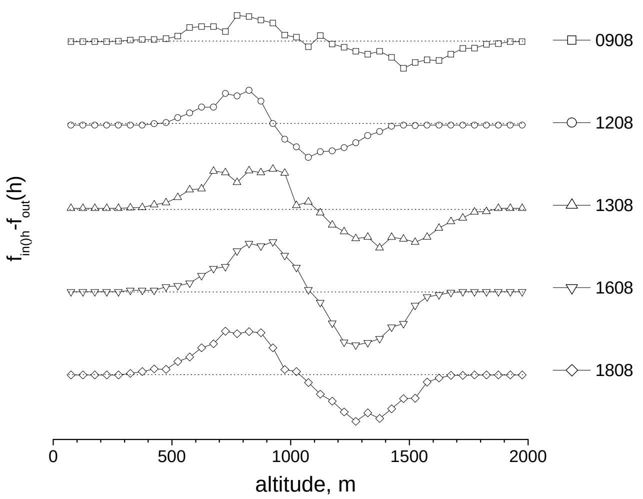


Figure 7 Distributions of thermal entering and exiting altitudes $f_{in}(h)$ - $f_{out}(h)$ for EGC07.

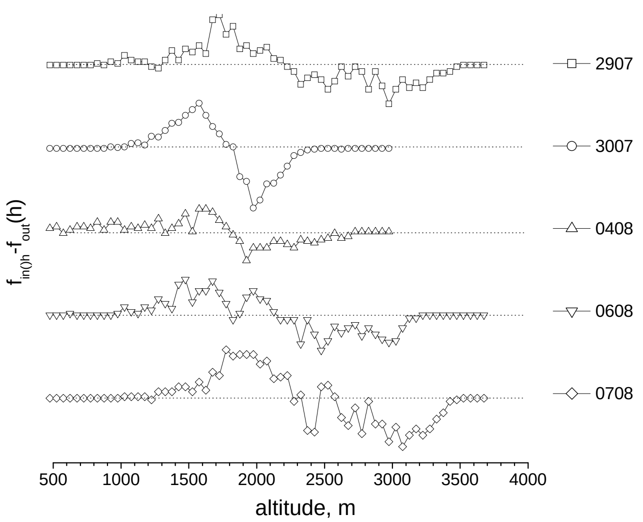


Figure 8 Distributions of thermal entering and exiting altitudes $f_{in}(h)$ - $f_{out}(h)$ for JWGC07.

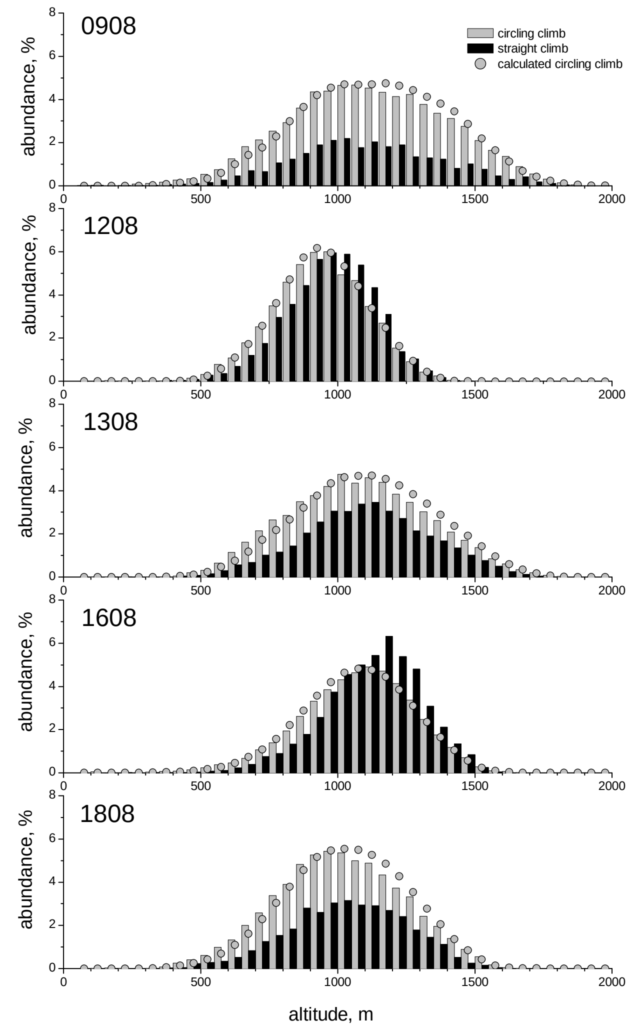


Figure 9 Circling climb altitude distributions $f_c^c(h)$ (grey columns) and straight flight climb altitude distribution $f_c^s(h)$ (black columns) for EGC07. Grey circles represent and circling climb altitude distributions calculated from thermal entering and exiting distributions.

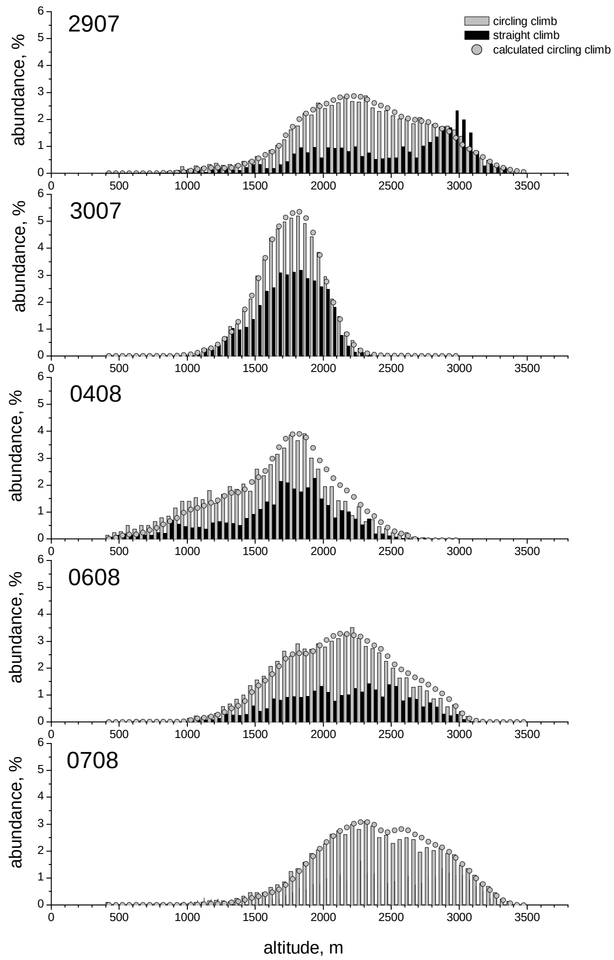


Figure 10 Circling climb altitude distributions $f_c^c(h)$ (grey columns) and straight flight climb altitude distribution $f_c^s(h)$ (black columns) for JWGC07. Grey circles represent and circling climb altitude distributions calculated from thermal entering and exiting distributions.