Comparative Statistical Analysis of Soaring Competitions

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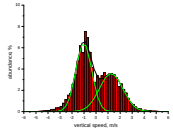

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(Some) history:

Pre flight recorder: updraft maps (Germany: Müller/Kottmeier, Kreipl, Frettlöh)

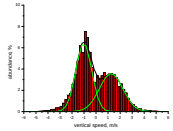
Post flight recorder I: Obvious application – "hot spots"

Examples: Polyteknisk Flyvegruppe Kopenhagen, Termikanalyse
(www.pfg.dk/termikanalyse)
Akaflieg Frankfurt LIFT project
(Aerokurier 10/03, www.akaflieg-frankfurt.de)
Track2Thermic (www.friulano.it/t2t.htm)
Augustin et al.: "Thermal Updraft Maps for Gliders", Tuesday, 10.30

Do they exist in unstructured terrain?
Influence of day time, weather?
Three-dimensionality (x, y depend on z)?

Post flight recorder II: Second thought – Characterize pilot's usage of air

Speed to fly? Aligned lift? Potential flight distances?



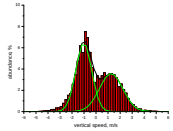
Utilize the enormous amount of flight recorder data

```
B1400235136607N01245193EA01698018100020817300 8
B1400475136514N01246159EA0167901780002071690 10
```

Convert data string to 5-dimensional flight vector V(t, y, x, h, w=dh/dt)
14.0064, 51.6101, 12.7532, 1698, -2.67
14.0131, 51.6086, 12.7693, 1679, -0.79

Beware! Air is not systematically sampled.
FR data reflect meteorological conditions filtered by pilot's response and external constraints (e.g. airspace regulations).

Having this in mind, what are possible
1) relevant (desired) results?
2) good source data?



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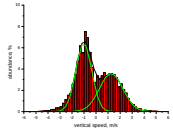
Desired results: (A few) questions – what do we want to know?:

- What altitude band is utilized in "real" soaring?
  relevant for PFD calculations
- How does updraft strength vary?
  in dependence of time, altitude, geographical position,
  statistically (from updraft to updraft)
- Are there correlations between components of the 5D vector?
  w(h) – validity of speed to fly theory
  $h_{max}(t)$ – forecast verification
  $w(h_{max})$ – relevant for PFD calculations

Some general answers:

- Distributions of vector components $f(v_i)$
- Correlations between vector components $v_j(v_i)$
  and related quantities (mean values, maximum values…)



Source data:

1) Online Contest (OLC) – www.onlinecontest.org

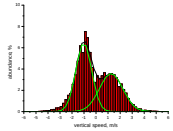
Advantage: Most complete data set available

Drawbacks: Restricted Access
Huge variation of terrain and weather
Ill-defined pilot strategy (from student to world champion)

2) Competition flights

Advantages: Open access
Well-defined pilot strategy
Well-defined terrain and weather conditions

Drawback: Less data available



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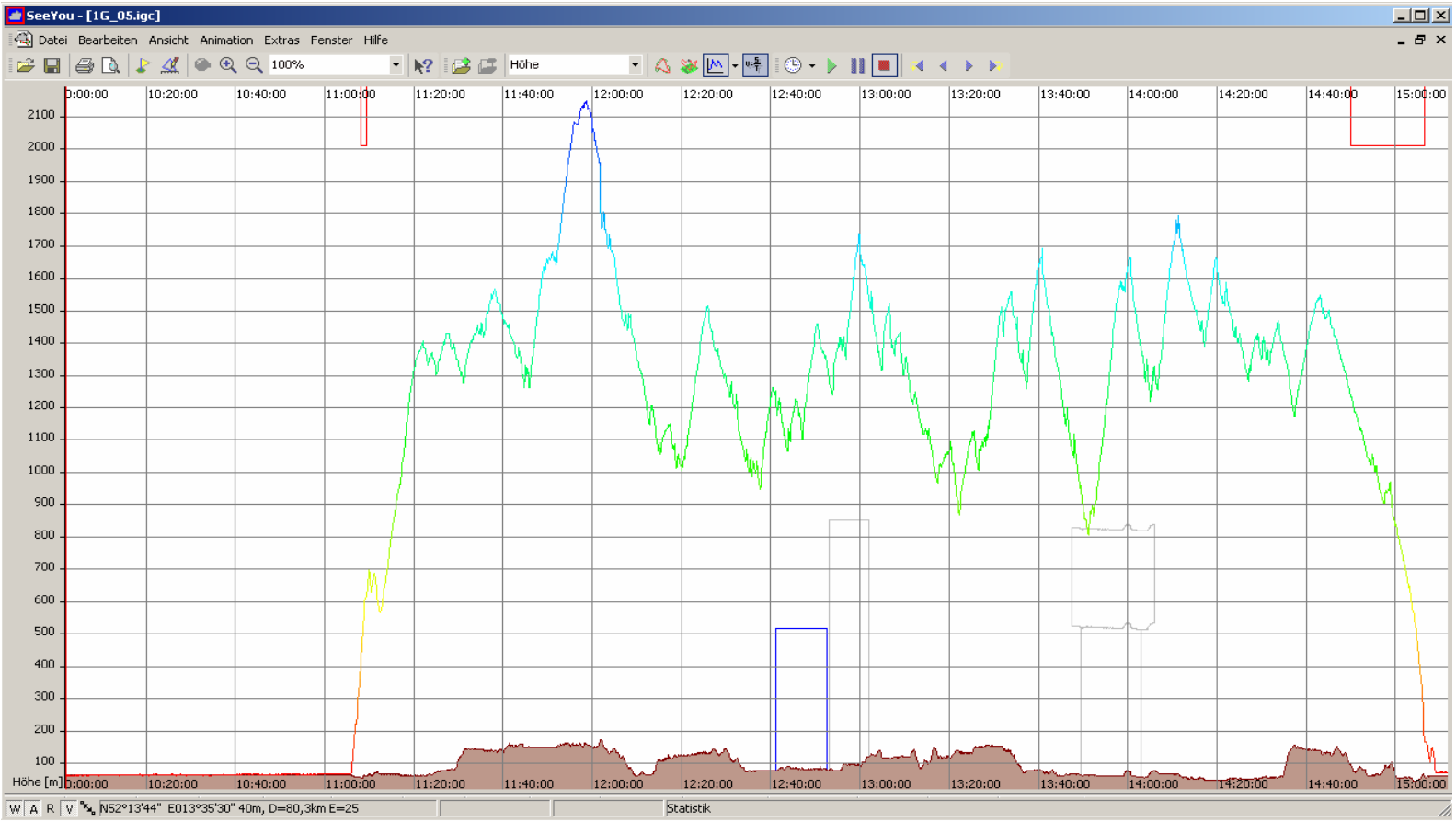
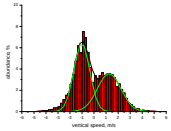
Competition data pre-treatment

removal of pre-start and post-finish data





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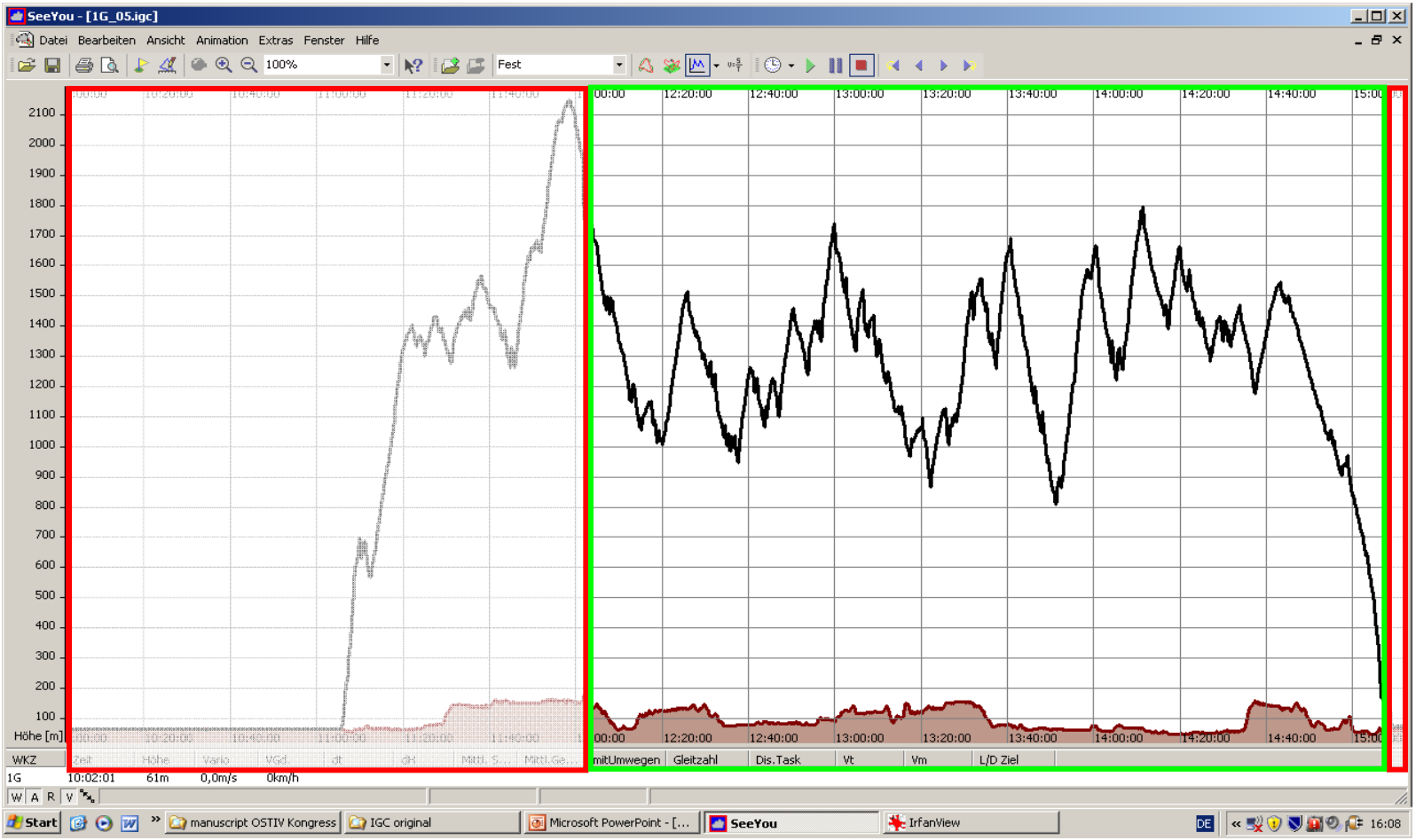

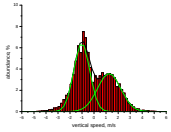

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Analyzed competitions (2007):

1) Lilienthal Glide, Lüsse, Germany, July 14 to 27

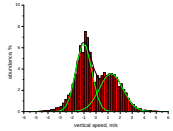
97 competitors
July 16, 23, 26
254 flights
127,000 data points

2) European Gliding Championships, Issoudun, France, Aug 6 to 19

91 competitors
August 9, 12, 13, 16, 18
386 flights
177,000 data points

3) Junior World Gliding Championships, Rieti, Italy, July 28 to Aug 11

53 competitors
July 29, 30, August 4, 6, 7
221 flights
95,000 data points



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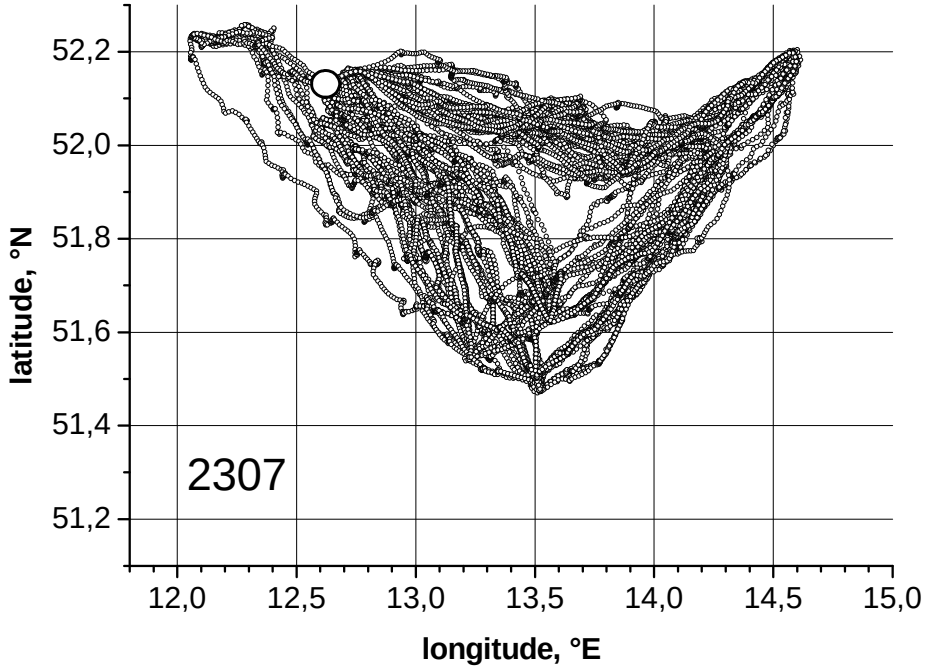
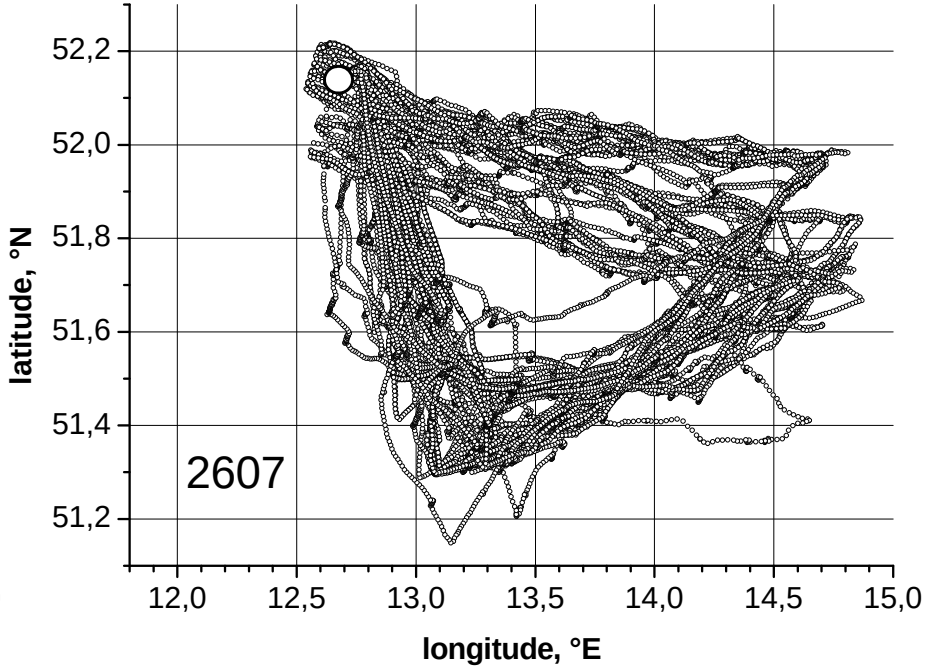
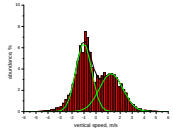
Basic results – tracks – y(x):

well defined geographical area with homogenous sampling

Lilienthal Glide







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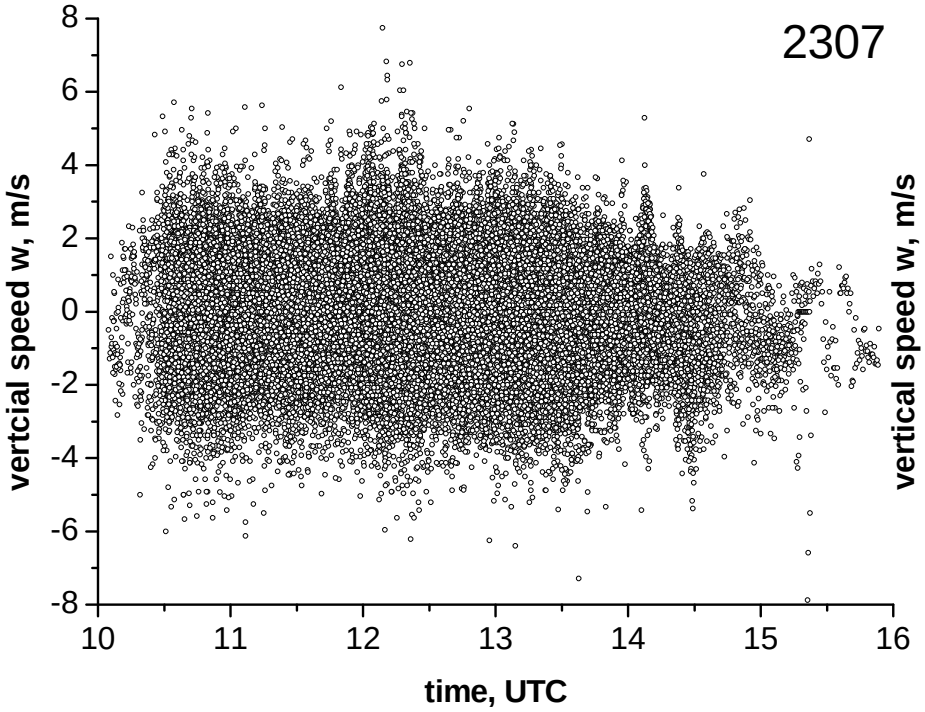
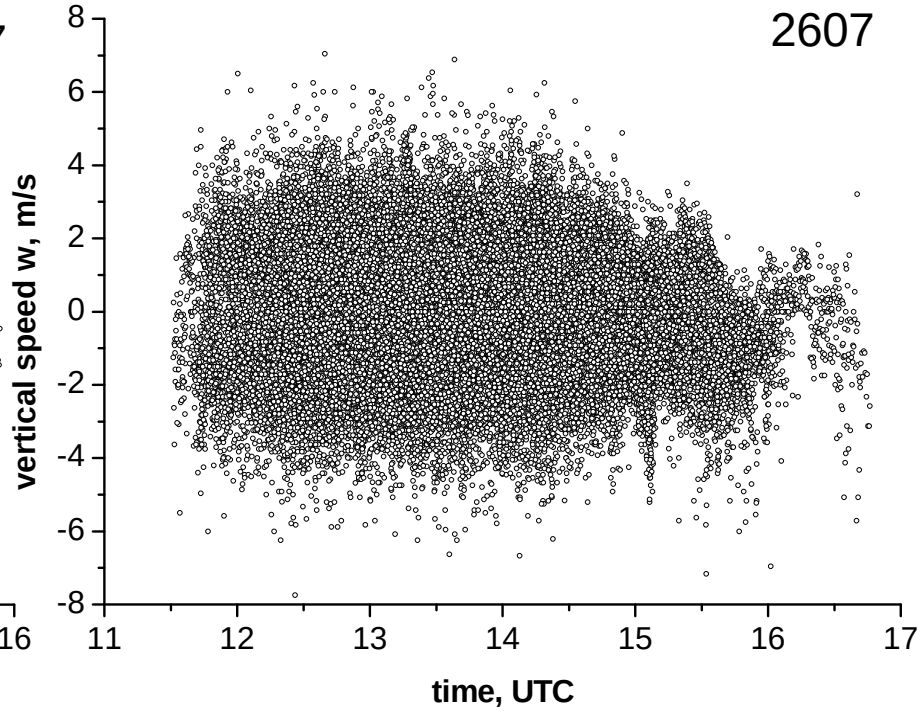
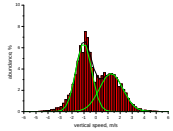
Basic results – variograms – w(t):

vertical speeds

Lilienthal Glide

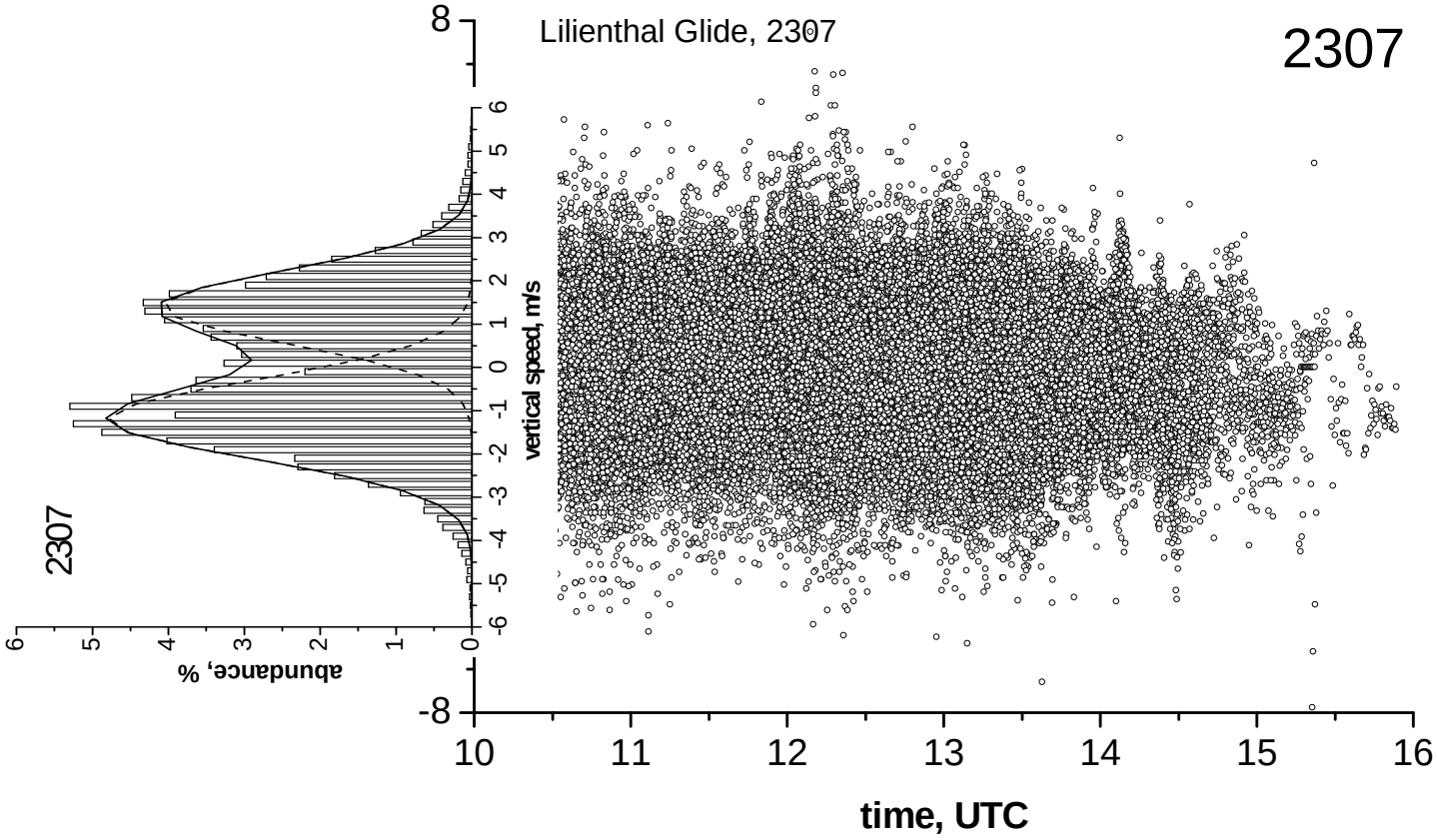


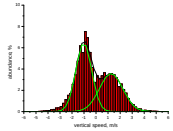




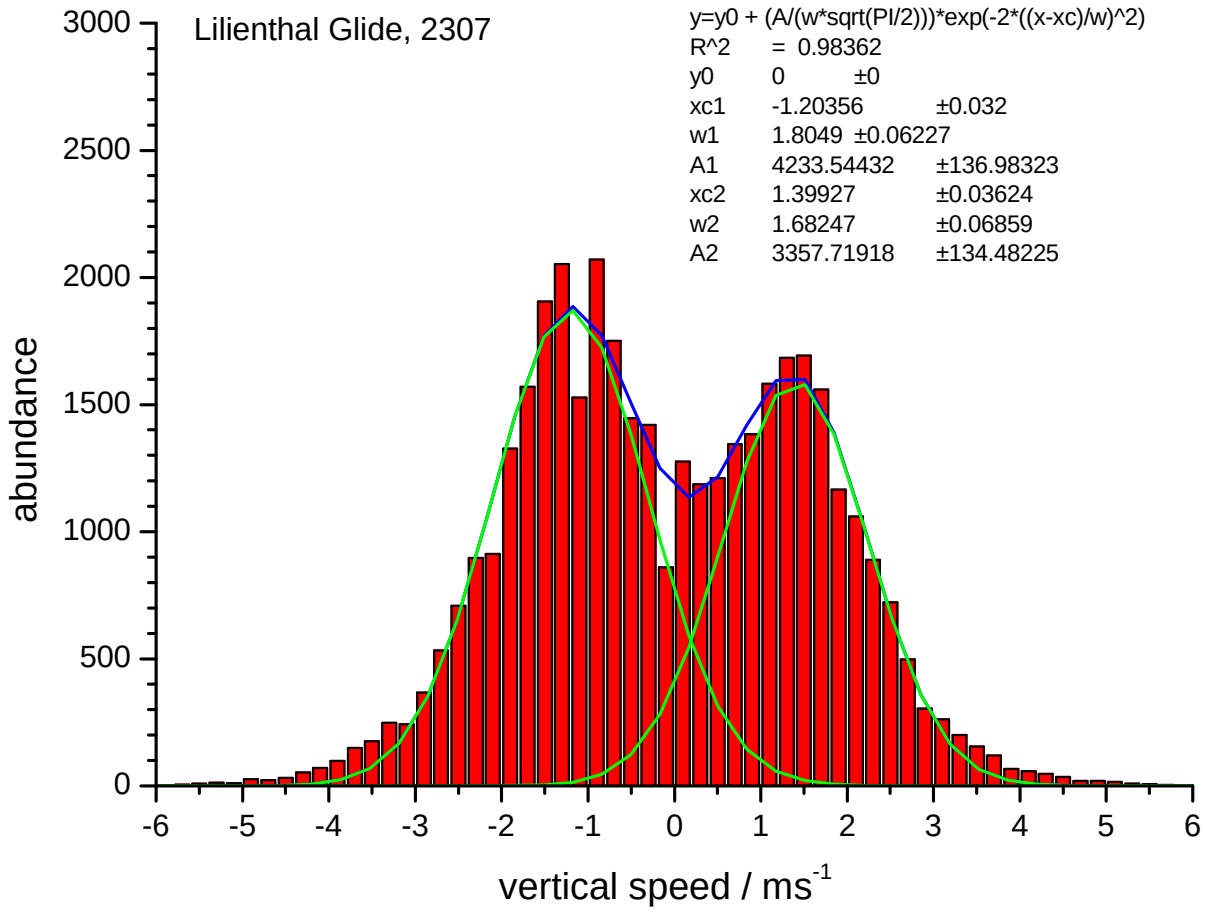
From variograms w(t) to vertical speed distributions f(w):

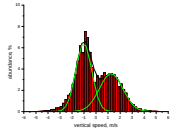
projection of variogram onto w axis



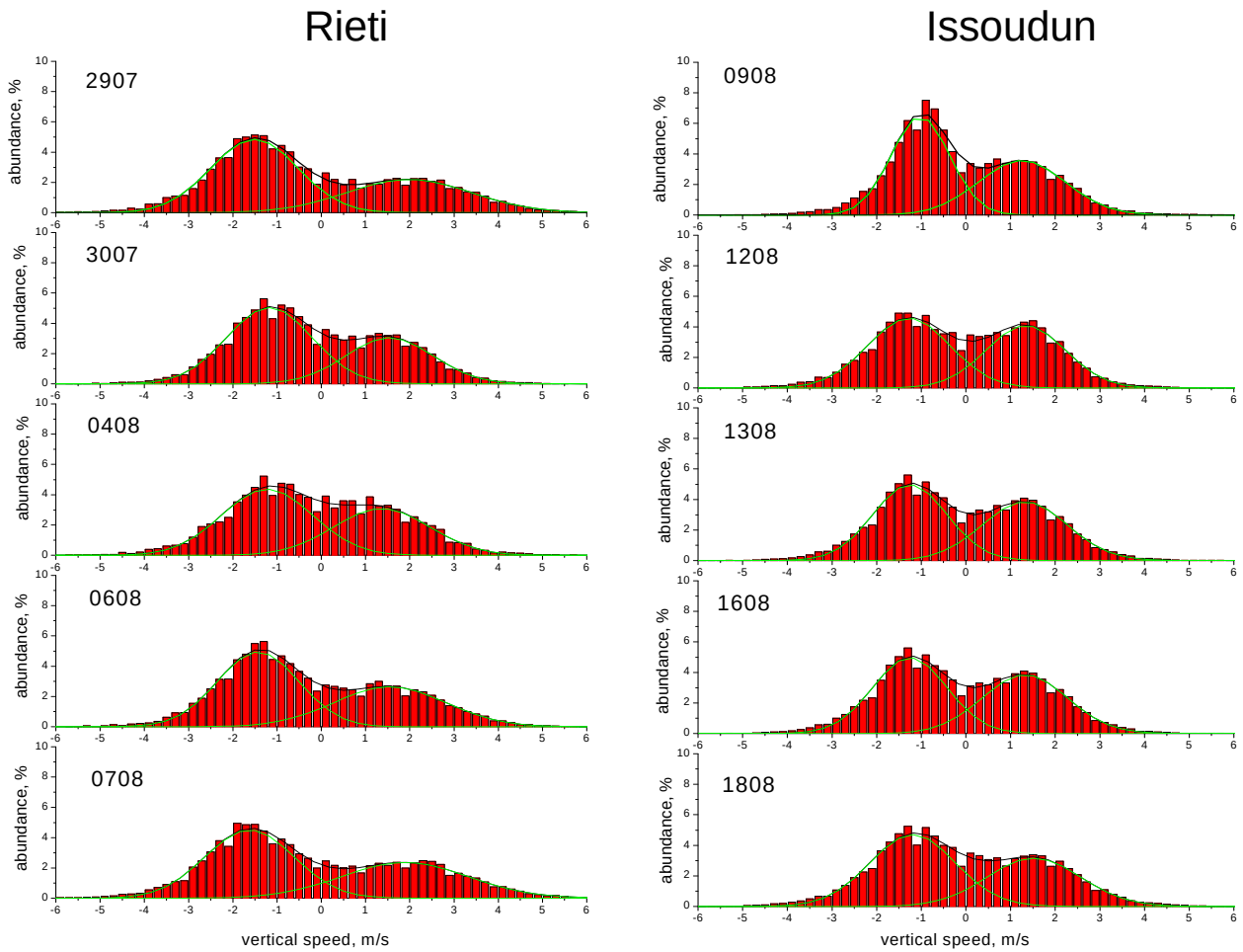


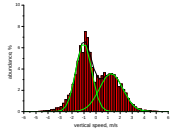
Vertical speed distributions f(w) can be fitted to two Gaussian normal distributions, one representing climb, one representing sink





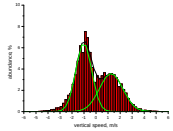
Climb and sink vertical speed distributions are general features





Vertical speed distributions - Summary:

	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



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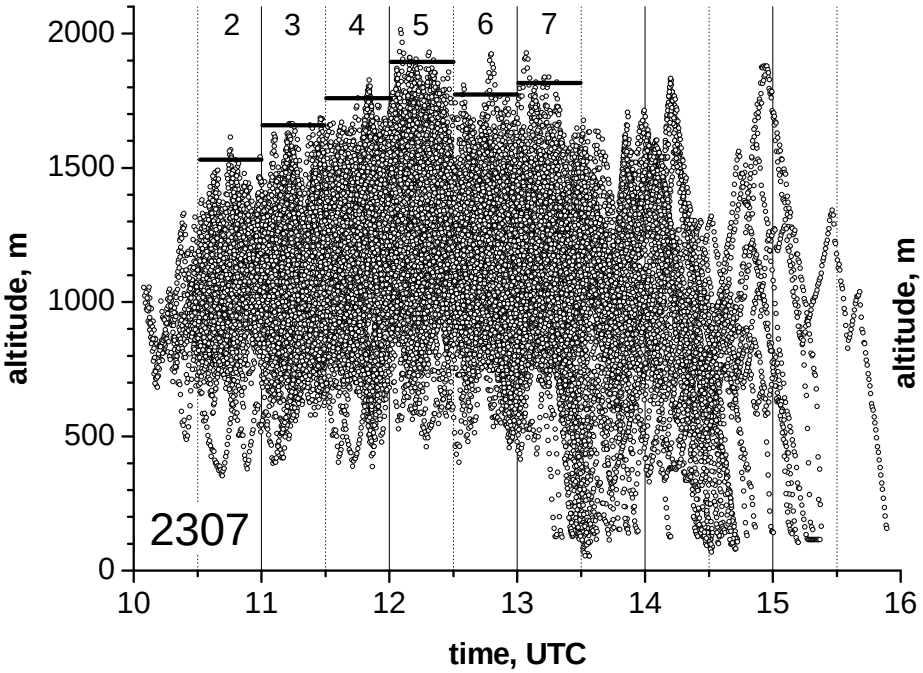
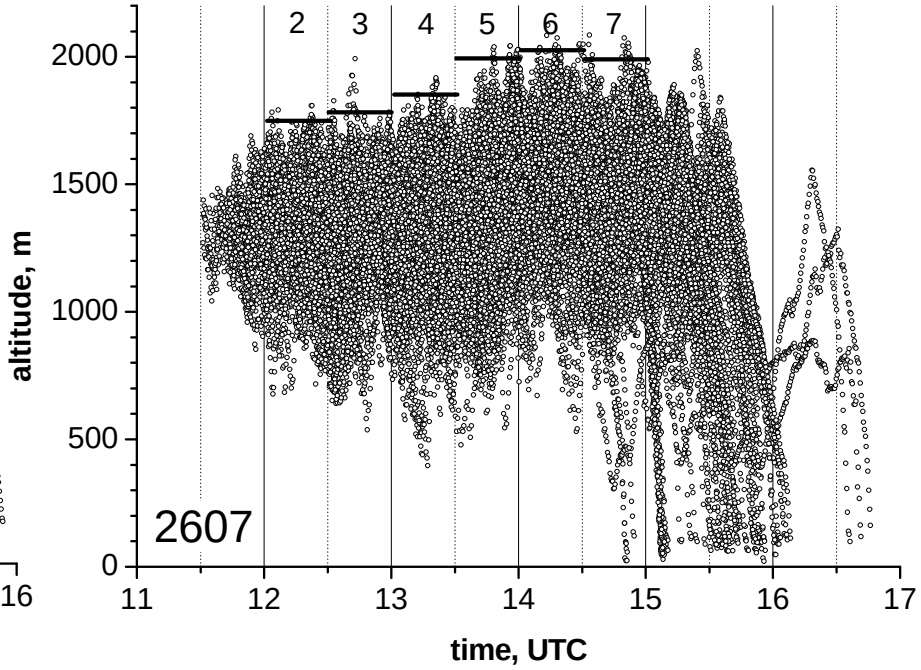
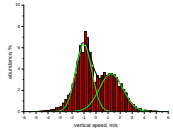
Basic results – barograms – h(t):

altitude bands with maximum altitude determined as 99.75 percentile

Lilienthal Glide

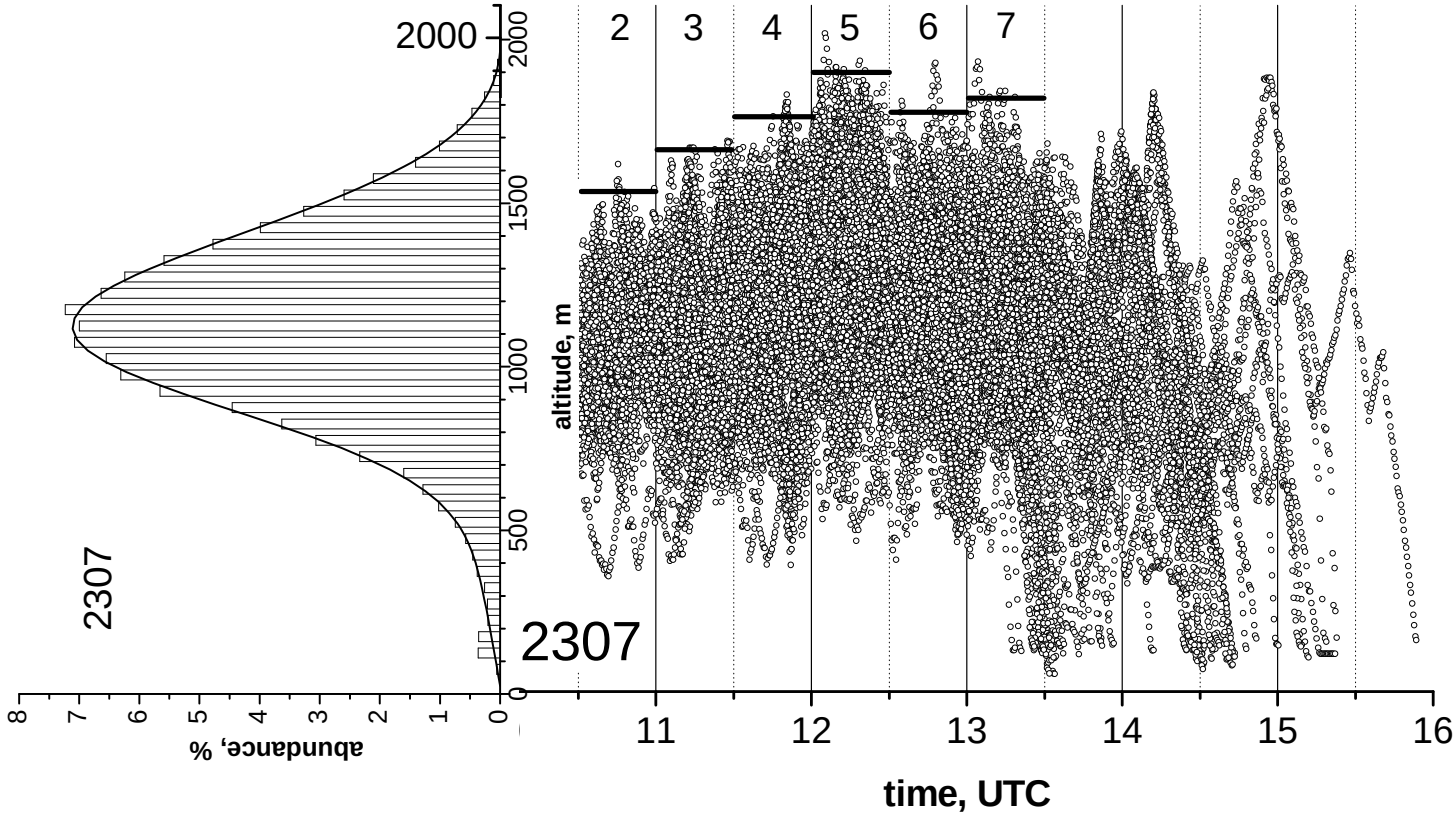


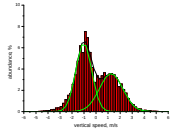




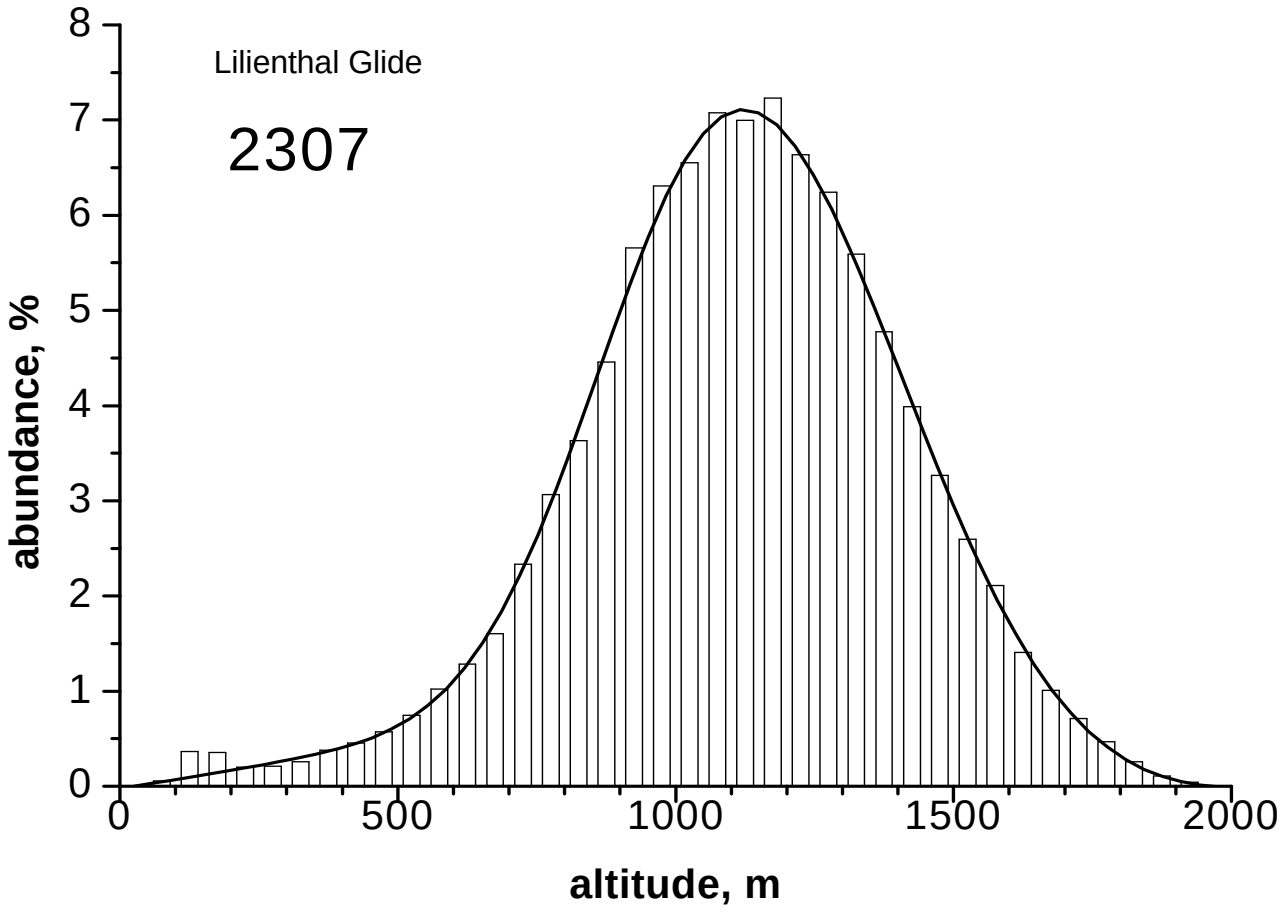
From barograms h(t) to altitude distributions f(h):

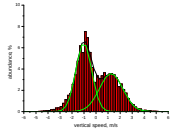
projection of barogram onto h axis



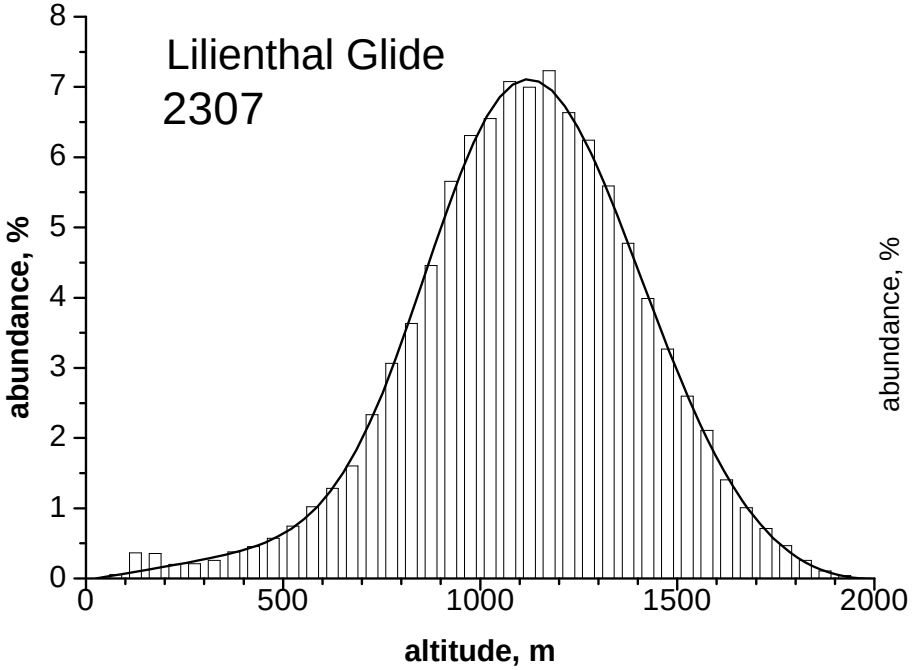


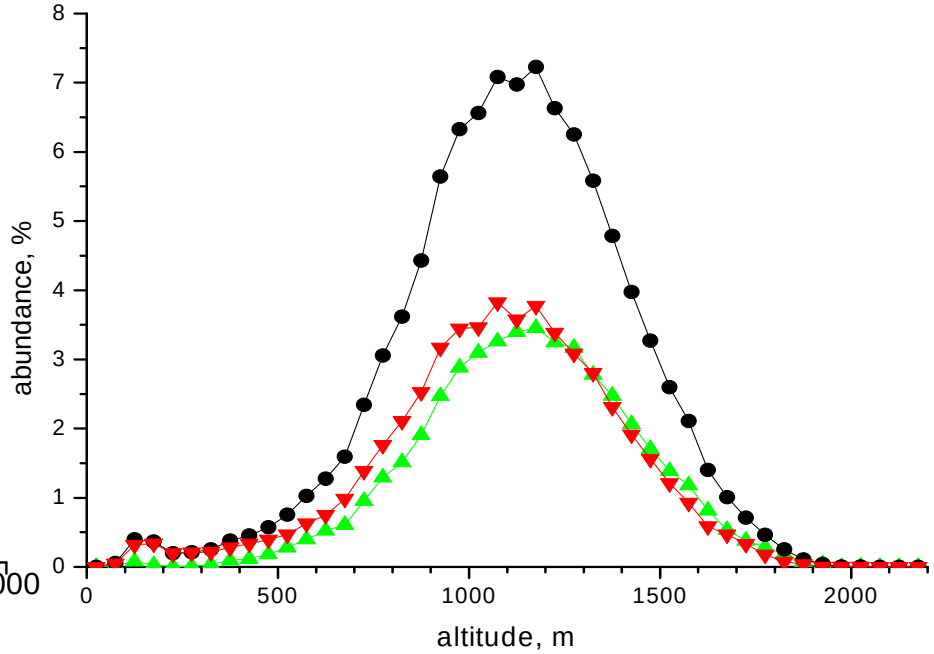
Altitude distributions f(h).
Fitting is not as straightforward as in the vertical speed case.



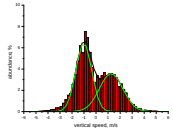


Conditional analysis of altitude distributions f(h).
Climb (Δ) $f_c(h,w>0)$ vs. sink (∇) $f_s(h,w<0)$ altitude distributions.





Climb and sink altitude distributions are almost identical.
Either there is no w-h correlation (likely) or, if there is,
it is identical for flight in climb and in sink (unlikely).



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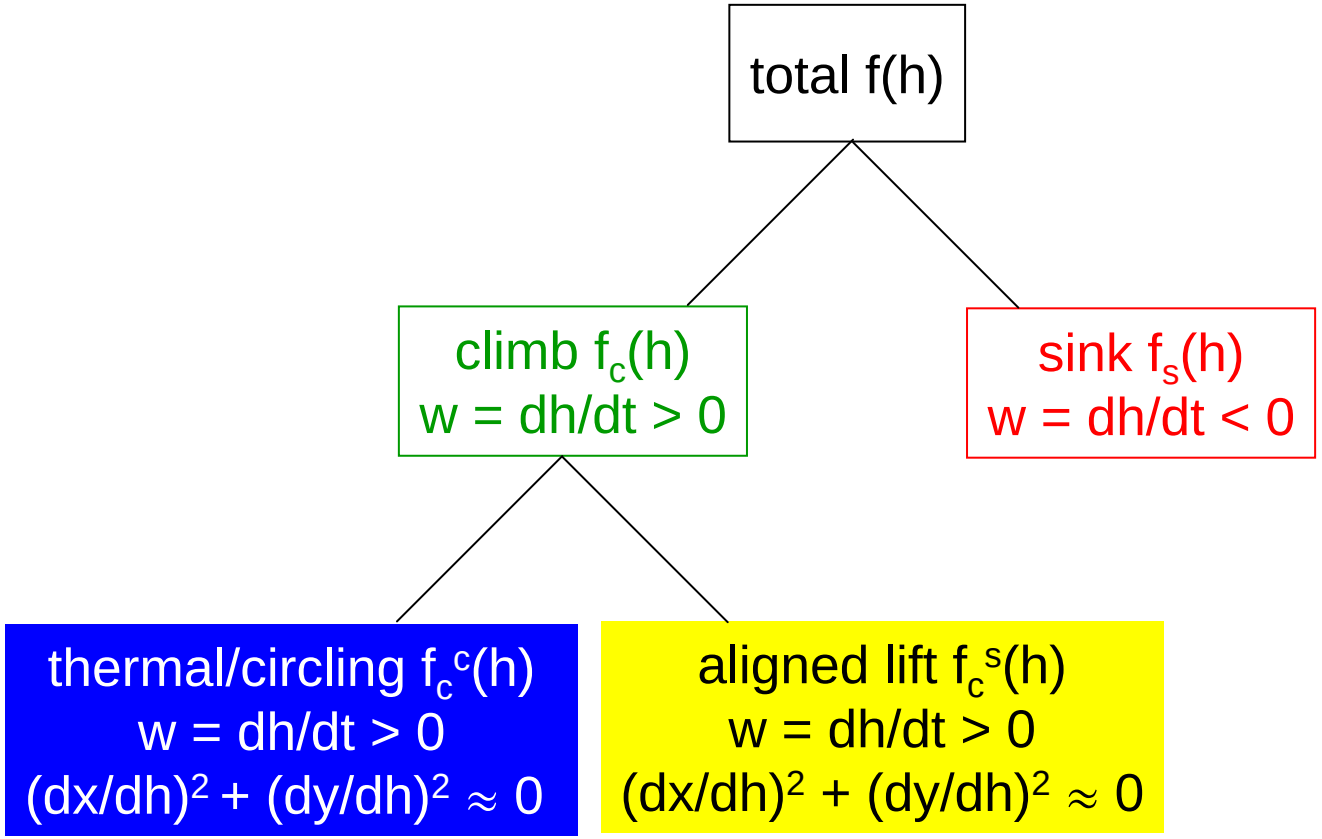
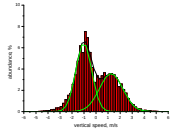
Conditional analysis of climb altitude distributions $f_c(h)$.

Circling climb $f_c^c(h)$ (in thermals) vs. straight climb $f_c^s(h)$ (aligned lift)





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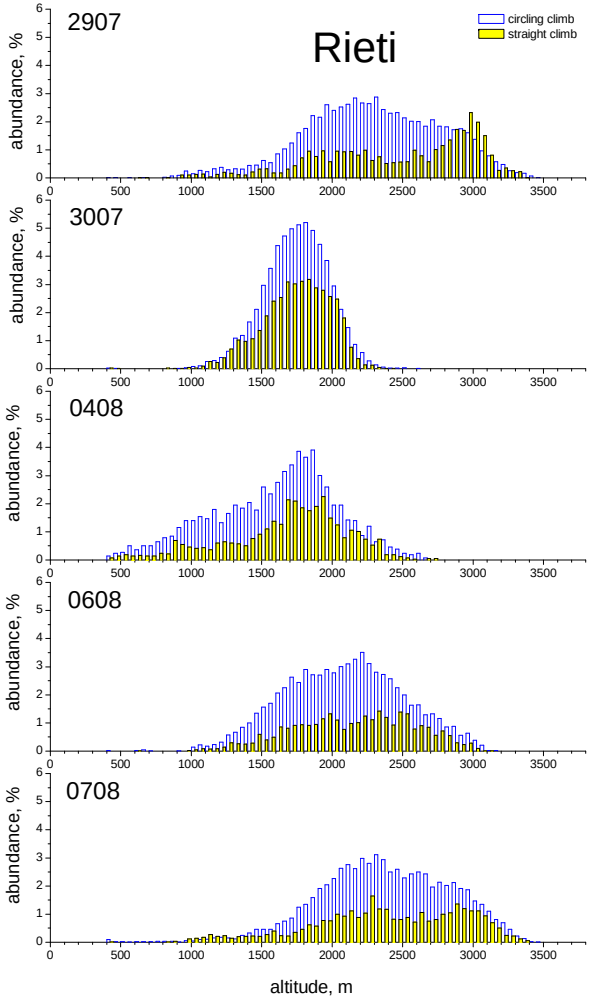
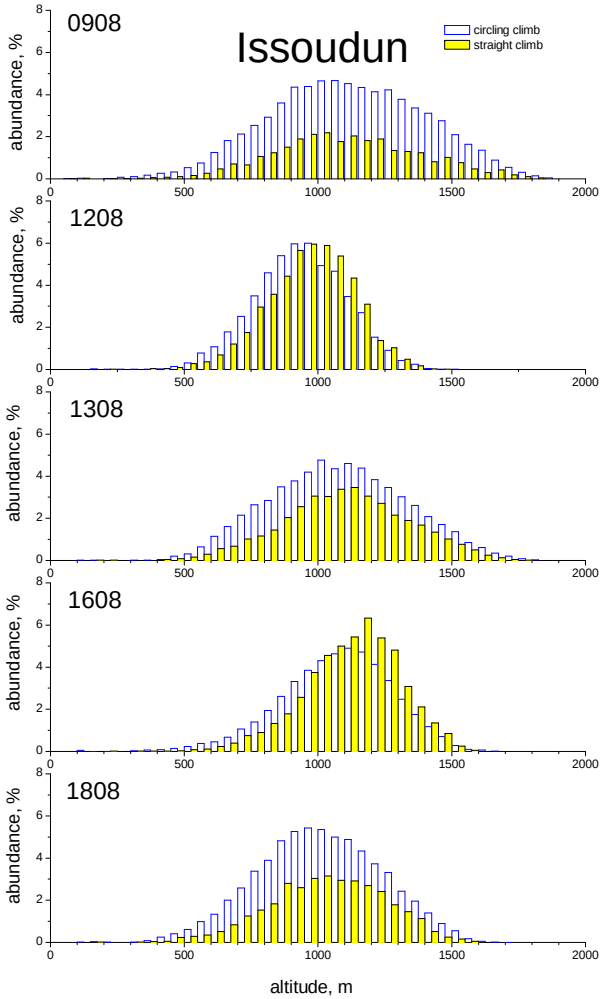
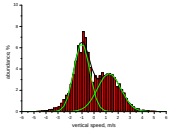
Altitude distributions of thermal $f_c^c(h)$ (⊓) vs. aligned $f_c^s(h)$ (⊓) lift.
Significant variations, aligned lift accounts for as much as 50% of total lift!







Description of circling climb altitude distributions $f_c^c(h,w>0)$.

If w-h correlatins are absent, $f_c^c(h,w>0)$ can be obtained by integrating over thermal entering and thermal exiting altitude distributions $f_{in}(h)$ and $f_{out}(h)$:

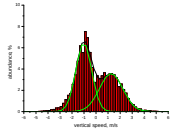
$$f_c^c(h) = \int_0^h \left(f_{in}(h') - f_{out}(h')\right) dh' \qquad (1)$$

Consequently, $f_{in}(h)$ and $f_{out}(h)$ can be obtained by differentiating f(h):

$$\frac{df_c^c(h)}{dh} = f_{in}(h) - f_{out}(h) \qquad (2)$$

Alternatively, $f_{in}(h)$ and $f_{out}(h)$ can be directly obtained from identifying thermals from flight recorder data.

Both methods should give identical results!



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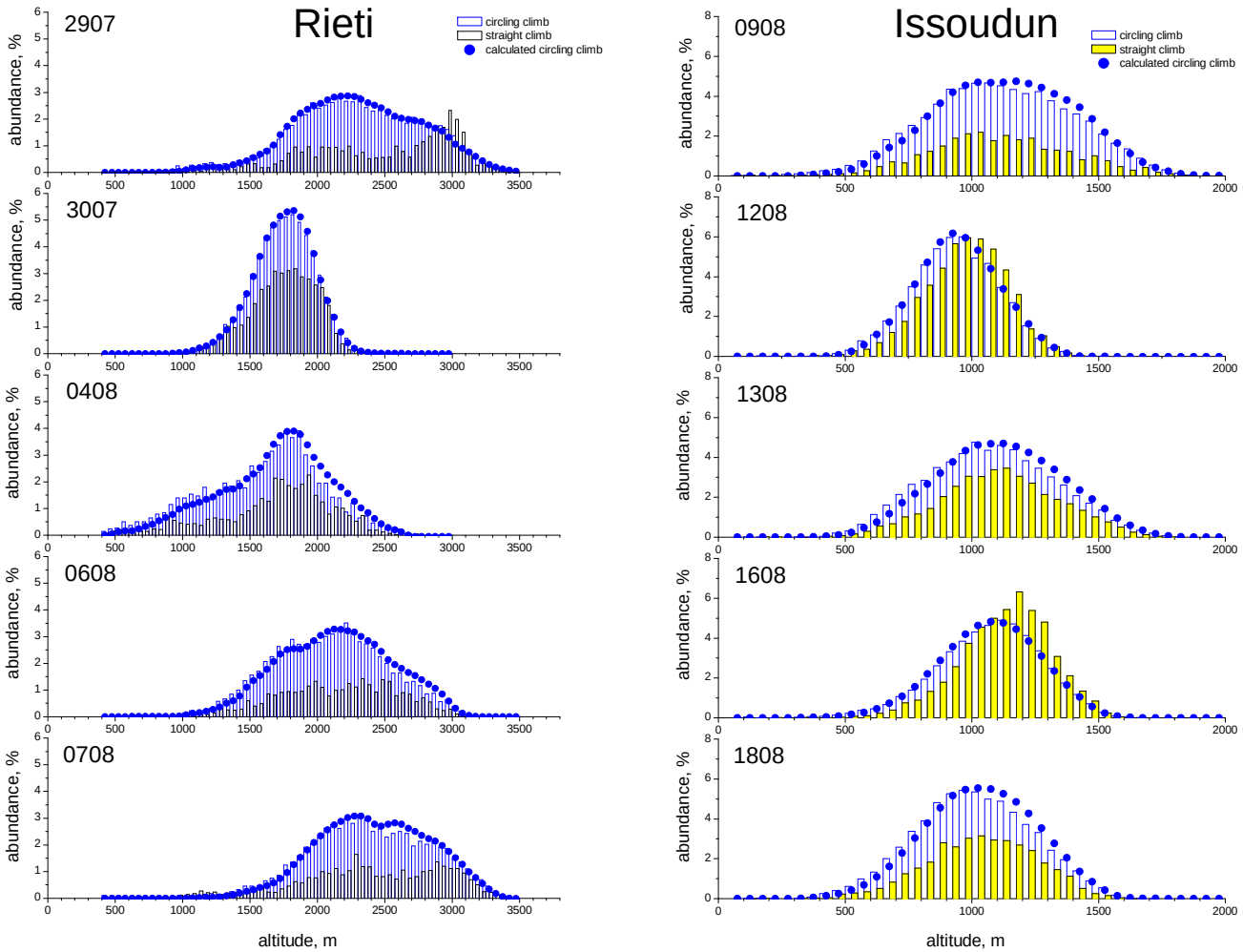
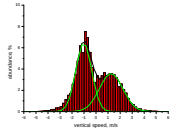
Excellent agreement between altitude distributions $f_c^c(h)$ obtained from flight recorder data (⊓) and from integration of eq.1 (●).





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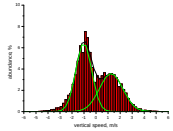
Altitude bands (of $f_c^c(h)$) utilized for circling in thermals

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%



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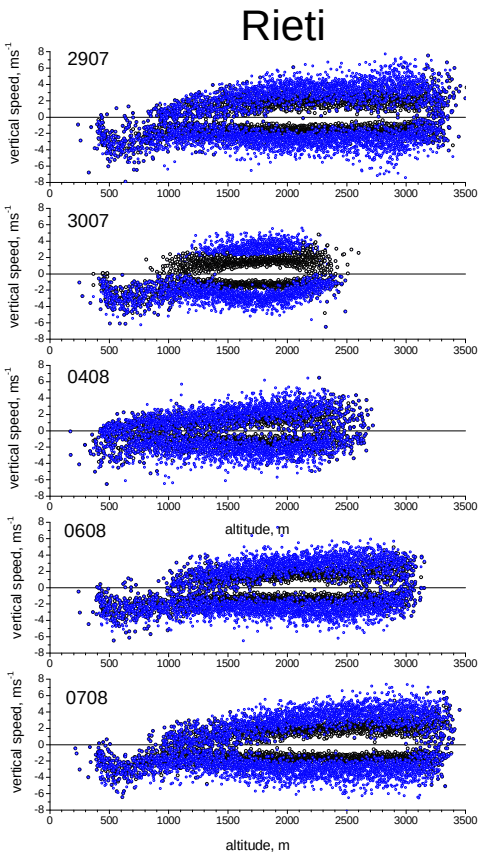
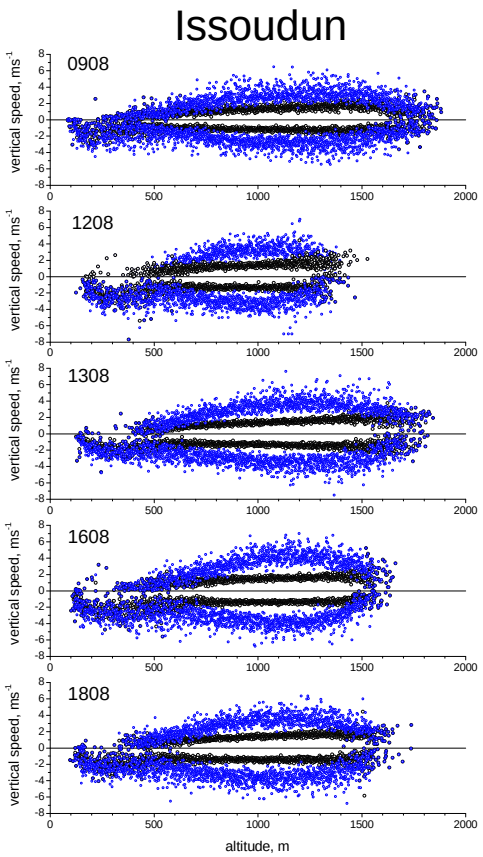
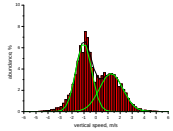
Result corroborated by absence of w-h correlation.

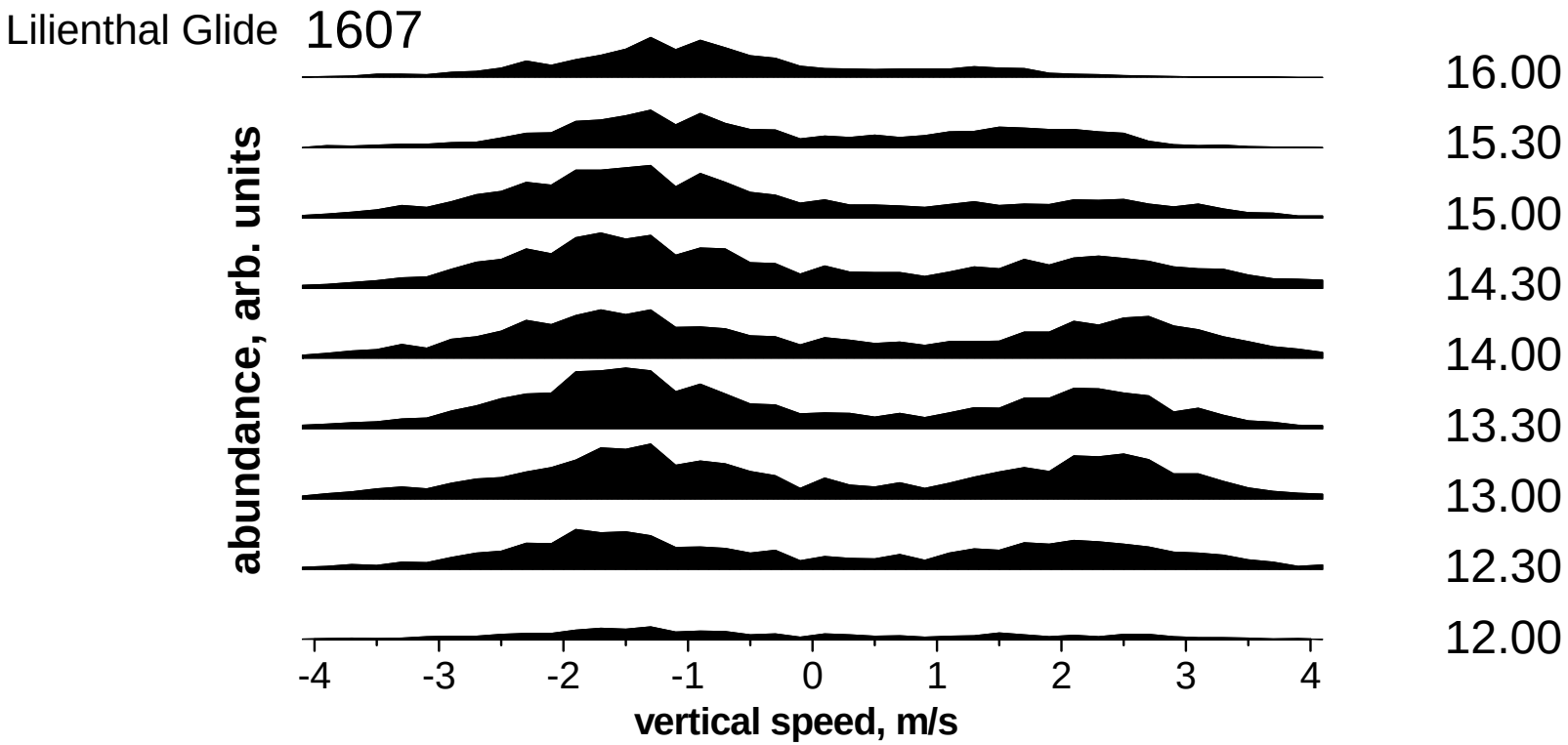


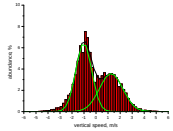


Mean vertical speeds (**black**) are essentially independent of altitude. In contrast, maximum and minimum vertical speed values (**blue**) occur at medium altitudes.



Adding temporal resolution. Vertical speed distributions





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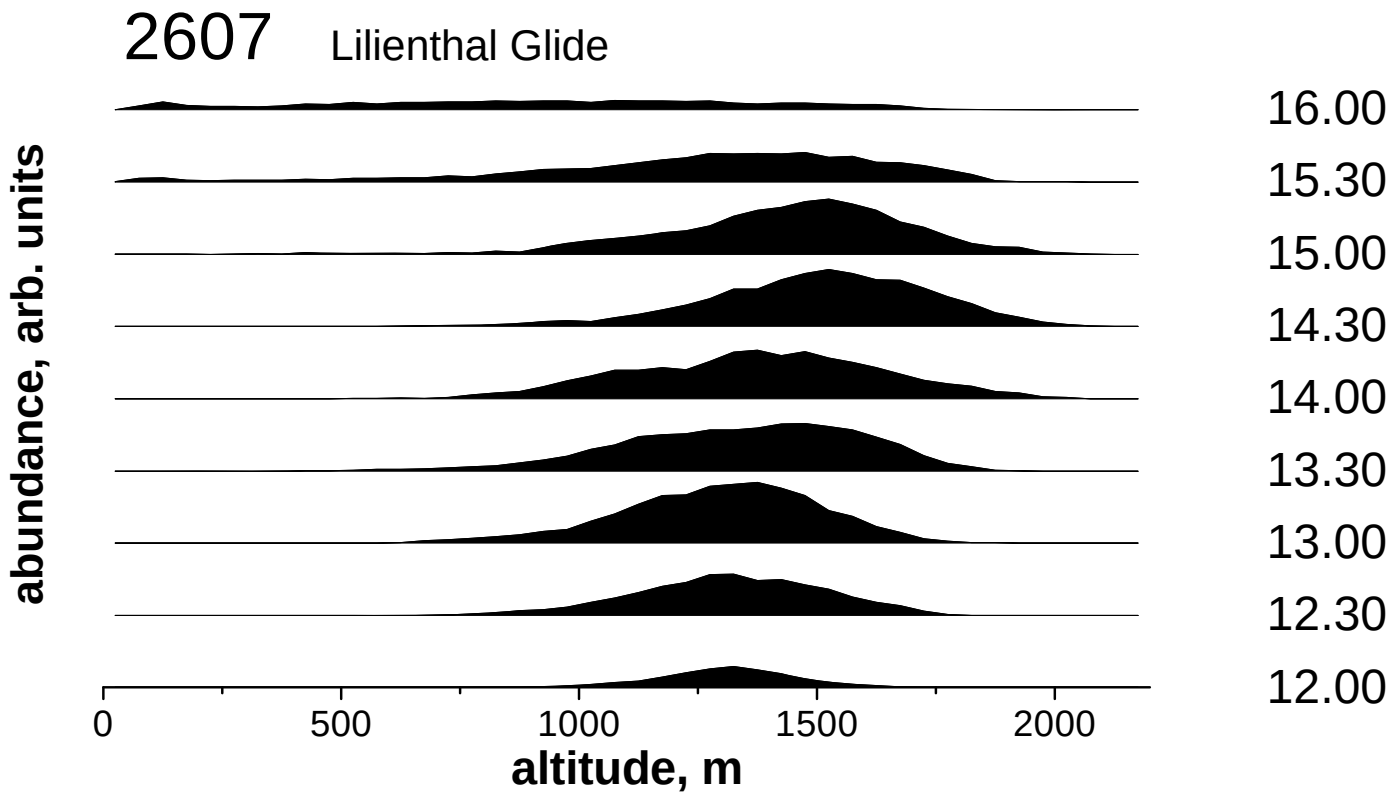
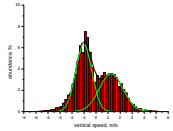
Adding temporal resolution. Altitude distributions.





Conclusions - Outlook

Methodical comments:
Powerful method for analyzing interplay of weather conditions with pilot strategy.
Careful choice of data set is important: Homogenous pilot mixture!
Good statistics require at least 40,000 data points/day (Rieti was too small.)

So far:
Mean climb and altitude are uncorrelated for all studied cases!
Method allows distinction between aligned lift and circling in thermals.
Aligned lift plays a major role in flat terrain as well as in mountains.
Aligned lift can account for more than 50% of total lift.

To come:
More competitions, more data: Assessing the role of aligned lift.