Comparative analysis of 405 Central European ball lightning cases

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## Abstract

Two Austrian BL data banks (ABLD 1 - 150 cases, and ABLD 2 - 103 cases) and a Central European BL data bank (CEBLD, 152 cases, mostly German) were analyzed and compared<sup>1</sup>. Data collection with witness contacts by the first author had used the same field investigation and questionnaire scheme since 1974, which means high documentary consistency.

The analysis found unexpectedly constant statistical patterns with regard to reporter populations, social witness reactions, time cycles and durations, meteorological conditions, distance, size, motion data and phenomenological details of BL (form, colour, surface, luminosity). The data were compared with the old European BL data bank of Brand (1923) and other sources. An extreme group test showed high stability of the patterns over time within the 20<sup>th</sup> century. The three data bank profiles indicate one time-constant, space-invariant set of BL phenomena all over Central Europe.

## Introduction

In 27 years (1974-2000), the first author as meteorologist and psychologist has collected and investigated 650 ball lightning (BL) reports. Several outstanding cases have already been published (Keul, 1992, 1994, 1997, 1999a, 2000; Keul, Gugenbauer & Diendorfer, 1993). 150 Austrian BL cases were put in a first BL data bank called ABLD 1, statistically evaluated for ISBL 1 at Tokyo (Keul & Schwarzenbacher, 1988) and with the Russian Stakhanov-Grigoriev data bank (Bychkov, Smirnov & Stridjev, 1993). 134 more cases, 103 already coded, make up a second Austrian BL data bank called ABLD 2. From German-speaking witnesses around Austria, 152 BL cases have been collected and coded as data

<sup>&</sup>lt;sup>1</sup> The comparative evaluation of ABLD 1, 2 and CEBLD was supported by Verbund (Austria's main power company) and Siemens in 2000 and 2001 by the research grant "Verbund Forschungsinitiative MBE 25.11.1999".

bank CEBLD. Cases with insufficient information, under investigation, not fully coded or outside Central Europe are not presented here.

The documented BL case density for Austria (8 million inhabitants, population density 95, 284 cases on file) of one case per 28.000 inhabitants is two times higher than for densely populated Japan (126 million inhabitants, population density 333, 2.060 cases according to Ohtsuki & Ofuruton, 1989) with one case per 61.000 inhabitants.

With the help of director Alfred Geiswinkler, state and industry research funds made it possible in 2000/2001 to code, statistically evaluate ABLD 2 and CEBLD, and match them with ABLD 1. Although the European data sets are smaller than the collection of Stakhanov/Grigoriev by the factor ten, they are very homogenous: 85% of the cases were documented systematically by the same questionnaire type following first reports. The two parallelAustrian data banks enable a split-half stability test.

## Material and method

A series of calls for BL reports started 1974 in Austrian newspapers and magazines. Besides, several existing BL records at the Central Meteorological Station at Vienna were used, and a number of reports travelled through meteorological or astronomical channels. Most German reports were triggered by a 1981 BL article in the science magazine "Bild der Wissenschaft" and by extensive press coverage on the Salzburg BL congress Vizotum (Keul, 1993). Of 650 raw reports, 11% were eliminated as non-BL, 14% had insufficient data for coding, 2% were under investigation, 10% still uncoded and 1% outside Central Europe. 405 cases from Central Europe - 62% of the raw data - were coded/rechecked and evaluated in this research project.

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		4% lightn. after BL	7% lightn. after BL	, 2% lightn. after BL

Table 1. Descriptive statistics of the three Central European data banks

Variables (continued)	ABLD 1 (n = 150)	ABLD 2 (n = 103)	CEBLD (n = 152)
Number of objects	Mean 1,3 [range 1-8]	Mean 1,0 [range 1-2]	Mean 1,1 [range 1-5]
_	92% 1 object	99% 1 object	94% 1 object
	2% 2 objects	1% 2 objects	3% 2 objects
	1% 3 objects		3% 3 objects
Duration	Mean 7,7 sec.	Mean 28,2 sec.	Mean 15,4 sec.
	Median 3, Mode 2	Median 5, Modes 2, 4	Median 5, Mode 5
	Range 1-180 sec.	Range 1-900 sec.	Range 1-600 sec.
Shape	91% round	88% round	96% round
	6% oval, elliptical	6% other	2% variable
	2% oblong	4% oval, elliptical	2% other
	1% other, variable	2% oblong	1% oblong
Distance	Median 5 m	Median 10 m	Median 6 m
object-observer	Range 0-8 km	Range 0-5 km	Range 0-10 km
	50% < 5 m	$50\% \le 6 \text{ m}$	$50\% \le 5$ m
Object size	Mean 30,1 cm	Mean 68.8 cm	Mean 41.6 cm
	Median 25. Mode 30	Median 30, Mode 30	Median 30, Mode 30
	Range 1-150 cm	Range 1-1.000 cm	Range 1-500 cm
Object surface	74% sharply defined	74% sharply defined	77% sharply defined
	18% fuzzy	17% fuzzy	10% fuzzy
	7% core + halo	7% non homogenous	7% core + halo
	1% transparent	2% core + halo	6% non homog etc
Colour	32% vellow	29% vellow	43% vellow
Colour	17% orange	24% orange	12% orange
	14% white	15% white arev	10% white arev
	11% red	12% fierv	10% variable
	8% blue-white	9% red	10% fiery
	8% blue violet	6% green variable	8% red
	7% variable	3% blue-white	5% green blue viol
	3% green	2% blue, black	2% blue-white
Brightness	82% not blinding	68% not blinding	73% not blinding
Diightheos	15% blinding	21% blinding	21% blinding
	3% flickering	8% flickering	4% flickering
	e /e menering	3% other	2% other
Primary motion	50% horizontal	46% horizontal	53% horizontal
	25% downwards	33% downwards	23% downwards
	12% complex	10% stationary	13% complex
	11% stationary	9% complex	10% stationary
	1% upwards	2% upwards	1% upwards
Secondary motion	86% none	82% none	85% none
	6% hopping	13% honning	9% honning
	4% oscillating	2% circling	3% circling
	2% circling	2% irregular	2% irregular, jerky
	2% irregular, jerky	1% oscillating	1% oscillating
Other details	35% inside buildings	27% inside buildings	33% inside buildings
	14% smell	14% smell	11% smell
	15% sound	14% sound	18% sound
Individual phenomena.	14% sparks, 4% tail	11% sparks, 9% tail	9% sparks, 6% tail
no sum-up to 100%	22% residue	23% residue	26% residue
	24% formation seen	23% formation seen	28% formation seen
	80% end seen	71% end seen	76% end seen
	(38% explosive)	(36% terminal band)	(53% terminal band)
Investigation quality	73% quest/phone int*	78% phone interview*	89% questionnaire*
	11% field investia *	11% questionnaire*	10% written report
*contact first	11% written report	11% written report	1% scientific journ
author-witness	5% secondary rep.		

Most first contacts were written reports. All reporters were sent a standard questionnaire made up of 54 questions to be filled in and returned by the witness. Others were filled in by the first author during phone interviews. Field investigations used the same instrument. With only minor variations in the questionnaire over the years, 84-89% of the BL cases were documented in the same data format.

The coding scheme used 46 variables. 11 variables had absolute values, 5 were ordinals and 12 nominals. 18 other (nominal) phenomena were coded binary (existent/non-existent) and added as a data string. 150 cases of ABLD 1 had been coded by the first author and a colleague (1989), the 103 cases of ABLD 2 and the 152 cases of CEBLD were freshly coded by the second author and control-read by the first.

The 28 non-binary variables were transferred to a SPSS file for statistical analysis. After the descriptive statistics (see Table 1 for the main results), hypothesis-based correlations were computed.

### Results and discussion

The results of three different BL data banks from Central Europe gave the opportunity for a statistical comparison of data collected in countries with a common language, and documented in a continuous format. Thus, major differences between ABLD 1, 2, and CEBLD should be due to variations in the BL phenomenon or reporting behavior in time and space. Comparing the three data banks, the following structures were noticed:

*Location*: The data are a *report* distribution, not a clear *occurrence* statistics of BL phenomena. Media calls-for-reports had certain social and age impacts. The *potential* for BL reports appears as a superposition of thunderstorm frequency and population density (Keul & Schwarzenbacher, 1989).

*Reporter population/behavior*: With the exception of ABLD 2, the witness ratio male:female was balanced. Long time-to-report deltas (27-34 years) occurred. All observer age distributions are skewed to the left, all reporter age distributions skewed to the right. This means that BL were more readily observed by young people active in open countryside, and reported by interested old newspaper readers who had time and motivation to write a message. The profession

statistics shows a high percentage of young people in training (school, apprenticeship, army) and of academics (a reporter self-selection effect).
35 to 50% became frightened by BL, 45 to 60% stayed calm or were fascinated. Only up to 5% showed flight and/or panic.

Every second case was a one-witness case. About 25 to 40% of the cases had two observers, 10 to 25% happened with more than two people.

*Years*: With ranges of 80 to over 90 years, all three data banks cover most of the 20<sup>th</sup> century. The peaks are different in the three data sets.

*Month and time of day*: Summer is European thunderstorm and BL season with a peak in July. The afternoon BL peak (Austria 2:30 – 5:00) overlaps with the local thunderstorm maximum.

*Coincidence with thunderstorms/precipitation/lightning*: With 60 to 70%, the thunderstorm connection is prominent. Precipitation, often strong, occurs simultaneously in over 50%. A cloud-to-ground flash precedes/goes with BL in 30-60% of the cases, according to the witness, i.e. with room for speculation. Object number: With well over 90%, the typical case is a single object event. However, up to five or even eight objects may appear on rare occasions. *Duration*: No BL cases were eliminated due to long durations reported. Anyway, 50% of the cases last less than 2 to 5 seconds. Medians and modes are all in the area of 2 to 5 seconds.

Shape: Around 90% (Austria) to 95% (Europe) of the objects are reportedly globular. In Austria, 6 to 8% other round shapes are seen, outside Austria less.
Distance: In 50% of all cases, the minimum distance observer-phenomenon was under 5 or 6 meters. This means descriptions of close-up phenomena. Objects are seen in open countryside to a maximum distance of 10 kilometers.
Object size: No BL cases were eliminated due to large sizes reported. The median and modal sizes lie between 25 and 30 centimeters. Very large objects are rare.
Surface/colour/brightness: Around 75% were sharply defined objects, 10 to 20% had fuzzy outlines, a small but consistent percentage a central core with halo. The main colour ranks were highly similar in all data banks: yellow-orange-white-fiery/red. 70-80% were non-blinding objects, i.e. easy to look at.
Motion: About 50% showed horizontal motion, 20-30% moved downwards. A steady proportion of 20-25% in all data sets moved erratically or not at all.

Around 85% had no secondary motion pattern. The rest showed consistent secondary patterns described as circling, bouncing, oscillations or jerks. *Other details*: Every third BL phenomenon happened inside a building. The percentages for smell, sound, and sparks are very similar. Every fourth report includes residue – big damage is rare. In about 25% of the cases, BL formation was seen, and in 70-80%, the final stage was seen (40-50% being explosive). *Investigation quality*: 84-89% of the data bank cases had been investigated in direct interaction of the first author and the witness (field trip, phone, by mail), the rest of 14-16% consists of "handwritten" (10%) or secondary reports with sufficient details given.

## Austrian split-half statistics (ABLD 1 and 2)

To perform a split-half test, Austrian cases forthcoming after 1988 were put into a second data bank. Looking at the main witness, object and location variables in Table 1, the data sets are remarkably similar except for some differences: Locations differ after the first author had moved from Vienna to Salzburg in 1980. ABLD 1 data were collected until 1988, thus stop with observation year 1986, ABLD 2 data - collected later on - with year 1998. The reported occurrence of lightning flashes is different for ABLD 1 and 2, but similar between ABLD 1 and CEBLD. Reported durations range much higher in ABLD 2, also in CEBLD. The same effect is noticeable for object sizes.

		-	-	
Variable	ABLD 1	ABLD 2	CEBLD	Brand, Egely, Russia, USA
Month	max 30%July	37%July	35%July	max July: 23%(B,E), 39%(R)
Hour (PM)	2:30-5:00	2:30-5:00	2:00-6:00	4:00-6:00 (B), 12:00-3:00 (R)
Thunderstorm	72%simult	68%simult	64%simult	>50% (B)
Lightning	57% none	33% none	40% none	K = 0,8 (R), 85% (U)
	22%simult	24%simult	24%simult	
Duration (sec)	50% <3	50% <5	50% <5	>50% 1-5 (B), 43% 1-5 (E),
				10±3 (R), 61% 1-4 (U)
Distance (m)	50% <5	50% <6	50% ≤ 5	49% 1-5 (E), 33% 1-5 (R)
Size (cm)	50% < 25	50%<30	50%<30	10-20 (B), 23% 20-30 (E),
				64% 10-50 (R), 55% 13-40 (U)
Colour	49% yellow-	53% y-o,	55% y-o,	26% y-o, 43% r (B), 24% y-o,
	orange, 11%r	9% red	8% r	27% r (E), 35% y.o, 19% r (R),
Explosion	31%	26%	38%	29% (B), >50% (R)

Table 2.	Comparison	with four	BL (	data	banks
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#### Comparison with four published BL data banks

Stenhoff (1999, 12) recently listed up nine national BL data sets with 5.700 reports. Details of an early Central European archive (n = 215, Brand, 1923), US survey data (n = 513, Dewey, 1954), the Russian Stakhanov-Grigoriev data bank (n = 2.500, Smirnov, 1993; Bychkov, Smirnov & Stridjev, 1993) and a Hungarian collection (n = 278, Egely, 1987) were accessible to the authors.

Table 2 gives a phenomenological data comparison of the three data sets evaluated above with the four sources listed. It is apparent that the case distribution by month has a uniform maximum in July. The diurnal case maximum is earlier with Brand and later in Russia. Brand lists over 50% heavy thunderstorms associated with his cases. The US lightning connection is much stronger than in Central Europe. Smirnov computed a correlation coefficient of 0,8. The duration data show a high consistency in the region of 1 to 5 seconds. Smirnov gets a lifetime of  $10 \pm 3$  seconds. The distance data in Hungaria are similar with every second case under 5 meters, in Russia every third case. All size curves peak in the area under 50 centimeters with a maximum region between 10 and 30 centimeters. The three Central European data banks presented here have every second object in the yellow-orange colour range. Other data banks contain less (24-35%) objects in this range, but more objects described as red (except Russia). Nevertheless, the yellow-orange-red sector is most dominant. The old Brand data collection records a similar frequency of exploding objects; the percentage is even higher in Russia.

## Hypothesis testing by nonparametric correlations

Systematic testing as in an experimental design is not encouraged by the relative paucity of absolute-scaled data (11 variables) compared to ordinal (5) and nominal/binary data (30 variables). Kolmogorov-Smirnov tests done in SPSS with all three data banks indicated that only the witness age and report year data did not deviate significantly from a normal distribution. Therefore, nonparametric tests were run in SPSS:

Searching hypothesis-bound for a possible dependency of (subjectively reported) physical data and psychosocial data, three strong correlations were detected and tested with Kendall's tau and Spearman's rho.

Phenomenon	Data bank	<i>Kendall's tau</i> τ	Spearman's rho ρ	Significance level
Sex - reaction	ABLD 1	τ-,252 p<,006	ρ-,268 p<,005	* *
	ABLD 2	τ-,164 p<,093	ρ-,172 p<,095	n.s.
	CEBLD	τ-,211 p<,009	ρ-,224 p<,008	* *
Reaction -	ABLD 1	τ-,308 p<,000	ρ-,374 p<,000	* * *
distance	ABLD 2	τ-,317 p<,000	ρ-,404 p<,000	* * *
	CEBLD	τ-,358 p<,000	ρ-,450 p<,000	* * *
Distance - size	ABLD 1	τ ,323 p<,000	ρ ,421 p<,000	* * *
	ABLD 2	τ ,247 p<,002	ρ ,334 p<,000	* * *
	CEBLD	τ ,283 p<,000	ρ ,383 p<,000	* * *

Table 3. Significant and stable non-parametric correlations found

Table 3 gives the details on stable relations, i.e. occurring in all three data banks: A significant (\*\*) correlation witness sex - witness reaction in ABLD 1 and CEBLD means that women either displayed or reported more fright than men. ABLD 2 contains only 37% female observers, ABLD 1 and CEBLD each over 50%. Short distances observer-object have a highly significant (\*\*\*) correlation with fear reactions in all three data banks. This makes sense from a psychological point of view. A highly positive correlation (\*\*\*) distance - object size means that objects further away are only seen when they are considerably bigger than BL seen nearby. Aerial perspective takes its toll.

Further results not shown in Table 3 are: Observation age is not related to object size or duration in all three data banks. The same is true for witness sex and object size/duration. A significant (p < ,003) correlation between observation age and witness reaction in ABLD 1 does not hold for ABLD 2 or CEBLD. A significant (p < ,010) correlation for number of persons and witness reactions only appeared in CEBLD, not in the Austrian data banks. Witness reaction and object size is not related in all three data sets. Witness reaction and object duration is significantly correlated (p < 0,15) in CEBLD, but not in Austrian cases. Object size and object duration is not related in all three data collections.

#### Stability test of the patterns over time

Are the reported BL patterns stable over the decades of the 20<sup>th</sup> century? ABLD 1 and 2 cover the century from 1900 to 1998. Two extreme groups - 1900-1935 and 1970-1990 - were extracted from the data sets and analyzed.

The results are shown in Table 4. Month data were mostly missing for the old report group. The distance observer-object was twice bigger for the old case group. However, a good match indicating stability of patterns was obtained for time of day, duration and size.

Variable	1900-1935 (n = 23)	1970-1990 (n = 50)
Month	3x July, rest: missing data	30% August, 27% July, 24% June
Time of day	Peak 2:30 - 3 P.M. (25%)	Peak 2:30 - 4 P.M. (26%)
Object distance	Median 12,5 m; 50% < 10 m	Median 5 m; 55%<5 m
Duration	Median 3 sec; 81%<5 sec.	Median 3 sec; 77% < 5 sec.
Size	Median 30 cm; 47%<25 cm	Median 30 cm; 49%<25 cm

	Table 4. S	Stability	of re	ported	ΒL	patterns	from	Austria
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## Conclusion

The statistical analysis of three Central European data banks found *unexpectedly constant patterns across the files* with regard to reporter populations, social witness reactions, time cycles and durations, meteorological conditions, distance, size, motion data and phenomenological details of BL (form, colour, surface, luminosity). The main examples: Percentages of fear/no fear reactions are nearly identical. Time-of-year (July) and daytime (2-5 P.M. CET) is similar. 70% are thunderstorm-, 50% rainshower-, 25% cloud-ground-flash-related. Median durations are 3-5 seconds, median sizes 25-30 centimeters, 50% of the distances fall below 5 meters. 75% show a sharp outline, all colour rankings start with yellow, orange, white, 70-80% have non-blinding brightness. Comparisons with the old Central European data bank by Brand and other archives put the new Central European data statistically into the mainstream.

Summing up the results, the three data profiles obtained suggest one *time-constant, space-invariant* set of BL phenomena all over Central Europe.

Further evaluations of the three data banks are to follow. Recently, the growth of high-precision electronic lightning detection networks in Europe enables detection checks for lightning strokes associated with BL reports (Keul, 1999b). Innovation has also changed BL reporting. Now, first reports are often send as emails via internet. The first author offers a BL homepage and can be reached under alexander.keul@sbg.ac.at

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