Reconstruction and Homogenization of the Wolf series from 1849 to 2015

Space Climate 6 Symposium

Levi, Finnish Lappland, April 4 – 7 2016

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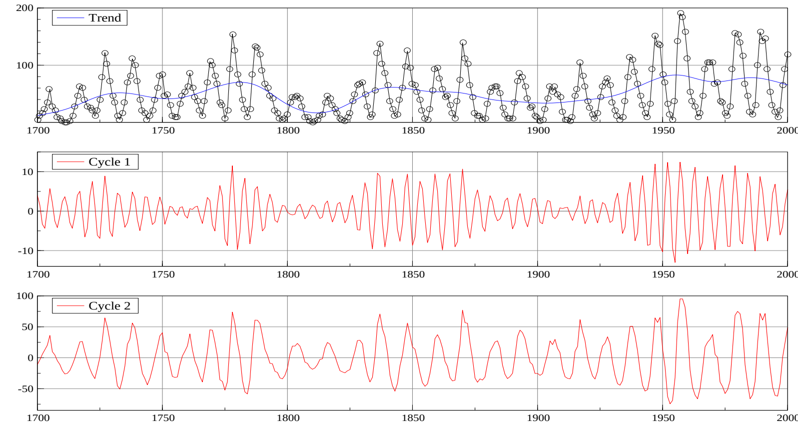
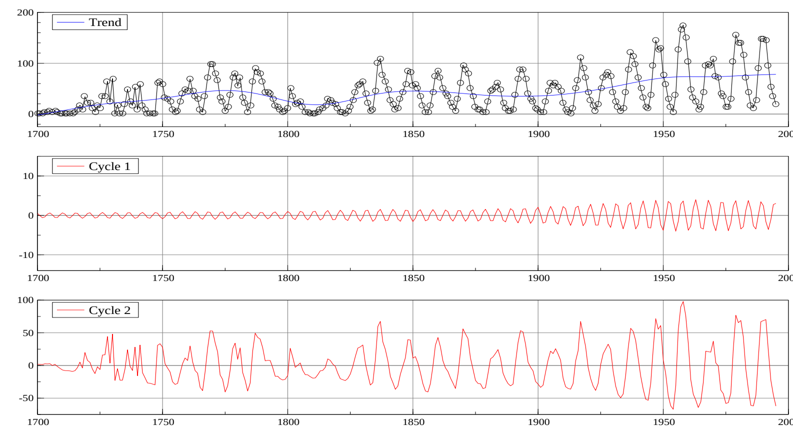
“Do we have the right reconstruction of solar activity ?”

Reliability of the Wolf Series

- Basic requirement of long-term homogeneity
  - Without a stable scale no valid conclusions about variations in the long-term course of solar activity can be drawn
- Series of daily values is unreproducible
- Data reduction and series construction details are unknown
- Our role in the international effort to correct possible issues
  - Expertise in the data generation process
  - Access to the archives of the former Swiss Federal Observatory in Zurich





Sunspot relative number

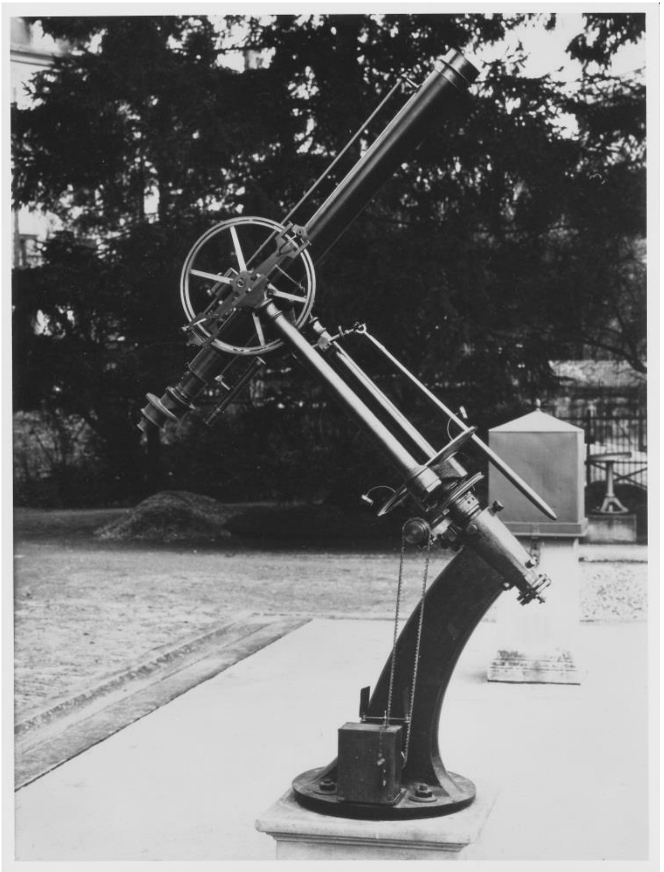
$$R = k \cdot (10 \cdot g + f)$$

g: number of groups

f: number of individual spots within the groups

k: personal reduction factor

k:= 1 for Wolf on the 83 / 1320 mm Fraunhofer refractor



Source Book

Reconstruction of the Wolf series

- Rosetta stone of Wolf series reconstruction
  - Some years ago we identified in the archives of the former Swiss Federal Observatory in Zurich a manuscript containing the raw data of the Wolf series
  - Source book contains the daily group number, the daily number of individual spots, the reduced Wolf number, the observer and the corresponding k-factor from the beginnings in 1610 up to 1876.

Beobachtungen

der

Sonnenflecken

Von der Zeit ihrer Entdeckung bis auf die Gegenwart.

Gesammelt

von

Rudolf Wolf.

Source Book

1849 Sonnenflecken-Beobachtungen.

	I.			II.			III.			IV.			V.			VI.			
1	ɔ	9.31	151	ɔ	3.6	45	ɔh	6.[illegible]	92	w	10.70	170	w	9.30	120	w	8.48	128	1
2	ɔ	9.34	155	w	7.40	110	K	5.[illegible]	82	K	7.[illegible]	170	w	9.40	130	w	9.64	154	2
3	w	15.[illegible]	180	ɔh	5.[illegible]	65	w	6.12	72	ɔ	10.38	172	K	5.12	93	w	8.50	130	3
4	ɔ	9.31	151	w	7.27	97	w	7.15	85	w	12.58	178	w	7.45	115	w	10.50	150	4
5	ɔ	9.[illegible]	147	w	9.22	112	ɔh	7.[illegible]	90	K	8.20	150	w	8.50	130	w	8.45	125	5
6	ɔ	8.[illegible]	143	w	10.34	134	w	7.24	94	w	10.60	160	w	7.36	106	w	7.45	115	6
7	ɔh	12.[illegible]	139	ɔh	8.[illegible]	110	ɔh	8.[illegible]	100	K	8.24	156	w	6.[illegible]	90	K	5.[illegible]	100	7
8	ɔ	8.28	135	w	10.21	121	K	4.[illegible]	70	K	6.20	120	w	6.20	80	K	5.12	93	8
9	ɔ	8.30	137	w	10.35	135	ɔh	5.[illegible]	50	w	9.45	135	w	6.25	85	ɔh	5.[illegible]	70	9
10	ɔ	8.[illegible]	132	w	10.[illegible]	140	ɔh	6.[illegible]	60	w	7.[illegible]	100	w	6.[illegible]	80	ɔh	4.[illegible]	50	10
11	ɔ	7.[illegible]	127	K	8.20	150	w	5.20	70	w	6.24	84	K	4.10	75	ɔh	5.[illegible]	60	11
12	ɔ	7.28	122	w	9.56	146	w	7.30	100	w	6.[illegible]	74	K	1.2	18	w	5.12	62	12
13	ɔ	7.[illegible]	132	w	11.64	174	w	7.[illegible]	107	w	5.14	64	K	0.0	0	ɔ	5.14	80	13
14	ɔ	8.[illegible]	142	K	7.[illegible]	115	ɔ	7.22	115	ɔ	5.16	82	w	5.16	66	ɔ	6.14	92	14
15	ɔh	9.[illegible]	152	ɔ	2.2	27	ɔ	6.23	104	w	5.10	66	ɔ	4.[illegible]	65	K	4.8	72	15
16	ɔh	9.[illegible]	162	K	6.[illegible]	100	K	4.[illegible]	40	ɔ	2.2	27	w	4.25	65	K	3.4	51	16
17	K	9.25	172	w	15.40	190	K	4.14	81	K	2.2	33	w	4.[illegible]	65	w	4.8	48	17
18	w	11.60	170	K	8.[illegible]	160	w	7.30	100	K	5.[illegible]	82	w	4.30	70	w	5.35	85	18
19	K	10.25	187	w	11.36	146	K	4.[illegible]	90	w	6.25	85	w	4.[illegible]	70	w	5.35	85	19
20	ɔ	11.74	230	w	13.60	190	w	5.30	80	K	6.11	106	w	3.42	72	K	2.5	37	20
21	w	12.75	195	w	12.[illegible]	170	w	5.30	80	K	6.[illegible]	120	ɔ	3.22	65	w	4.42	82	21
22	w	9.46	136	ɔ	10.21	151	w	6.35	95	K	6.36	144	w	3.28	58	w	6.56	116	22
23	K	10.[illegible]	146	w	11.58	168	w	6.[illegible]	90	K	3.12	63	w	4.25	65	w	5.38	88	23
24	K	10.[illegible]	156	w	11.40	150	w	5.[illegible]	80	K	2.10	45	K	3.8	57	ɔh	4.[illegible]	80	24
25	w	10.65	165	w	10.68	168	K	3.[illegible]	70	w	5.30	80	w	6.25	85	w	5.30	80	25
26	w	10.76	176	ɔ	10.35	169	K	4.[illegible]	85	K	4.10	75	w	5.12	62	w	4.25	65	26
27	w	10.95	195	ɔh	8.[illegible]	120	K	4.[illegible]	100	w	6.44	104	w	6.20	80	w	2.15	35	27
28	w	9.63	153	w	7.36	106	w	12.50	170	K	3.[illegible]	85	w	8.30	110	w	2.10	30	28
29	ɔ	9.62	190		.		ɔh	9.[illegible]	160	K	3.20	75	K	6.10	105	w	4.6	46	29
30	w	9.[illegible]	160		.		ɔ	9.31	151	K	3.20	75	w	7.40	110	w	5.[illegible]	55	30
31	w	8.[illegible]	130		.		w	11.58	168		.		K	6.10	105		.		31
M.			156,7			131,7			96,5			102,5			80,6			81,2	M.

Bemerkungen:

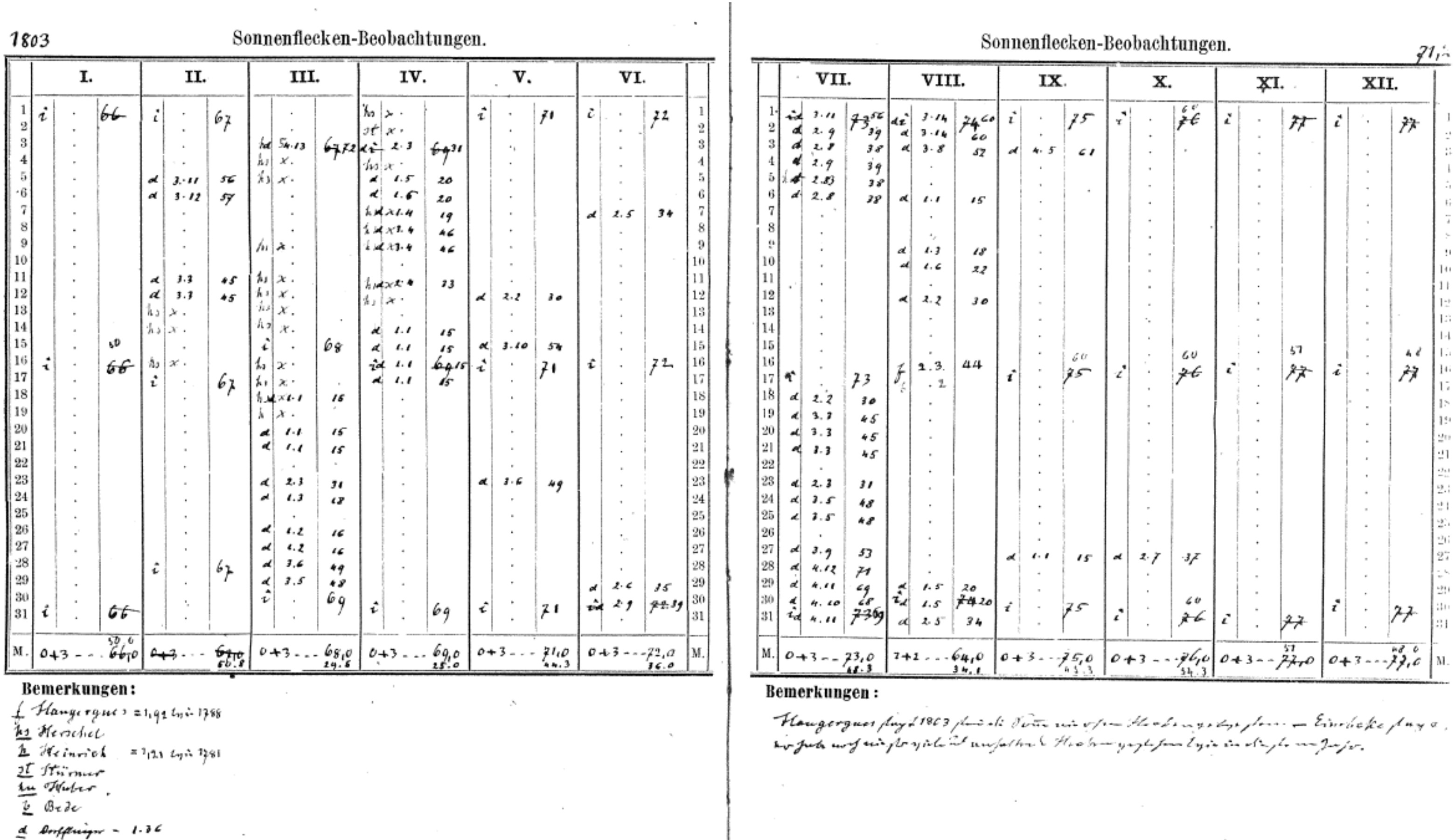
w Wolf mit 4' = 1,00 angenommen als Einheit
K – – 2' = 1,50 aus zahlreichen in diesem und folg. Jahren mit w angest. Vergl.
ɔ Schwabe = 1,25 – – – –
c Colla fällt nicht in Berechnung
ɔh Schmidt " "

Sonnenflecken-Beobachtungen. 95.

	VII.			VIII.			IX.			X.			XI.			XII.			
1	ɔ	4.13	66	w	4.15	55	w	7.64	134	w	8.10	90	K	5.16	99	w	10.[illegible]	145	1
2	K	3.3	49	w	6.18	78	w	5.35	85	K	7.10	120	w	7.41	111	K	8.9	133	2
3	K	3.6	54	w	6.15	75	w	4.27	67	K	3.4	51	w	3.10	40	w	8.17	97	3
4	K	3.10	60	w	4.12	52	w	5.41	91	K	2.3	34	w	4.31	71	ɔh	5.[illegible]	117	4
5	ɔh	5.[illegible]	70	w	5.20	70	ɔh	7.[illegible]	100	K	1.2	18	w	4.[illegible]	74	w	9.47	137	5
6	K	4.8	72	w	4.18	58	w	6.25	85	K	4.6	69	w	5.[illegible]	78	ɔh	4.[illegible]	107	6
7	K	5.30	90	w	3.20	50	w	7.48	118	K	4.[illegible]	68	w	6.22	82	w	7.[illegible]	100	7
8	K	6.15	112	w	3.15	45	w	5.38	88	w	5.16	66	w	7.35	105	w	6.[illegible]	92	8
9	K	7.20	135	w	4.14	54	w	7.50	120	w	5.26	76	w	6.20	80	w	5.[illegible]	84	9
10	K	3.6	54	w	5.27	77	w	9.26	116	ɔh	3.[illegible]	40	ɔh	6.[illegible]	70	w	5.[illegible]	76	10
11	K	2.4	36	w	5.32	82	w	7.25	95	w	2.5	25	ɔh	5.[illegible]	60	w	4.[illegible]	68	11
12	K	3.8	57	w	7.25	95	ɔ	6.[illegible]	65	w	3.[illegible]	40	ɔh	3.[illegible]	45	w	4.[illegible]	60	12
13	K	4.10	75	w	7.24	94	w	4.40	80	w	4.26	66	w	5.11	61	w	3.22	52	13
14	*K	3.12	63	w	6.15	75	K	5.15	77	ɔh	4.[illegible]	60	w	6.22	82	w	3.12	42	14
15	K	3.12	63	w	6.14	74	w	9.59	149	ɔh	3.[illegible]	40	w	5.20	70	w	4.19	59	15
16	w	7.45	115	w	7.21	91	w	7.54	124	w	3.5	35	w	4.[illegible]	60	K	3.5	52	16
17	w	8.40	120	ɔ	6.[illegible]	90	w	6.32	92	w	4.21	61	ɔh	3.[illegible]	50	w	5.22	72	17
18	w	9.30	120	w	6.30	90	w	5.19	69	w	4.25	65	w	2.22	42	w	7.37	107	18
19	w	7.22	92	w	5.26	76	w	3.9	39	w	6.56	116	w	5.25	75	K	6.10	105	19
20	w	7.22	92	K	3.5	52	w	4.26	66	w	6.41	101	w	7.47	119	K	4.5	67	20
21	w	7.15	85	w	5.10	60	w	6.24	84	w	8.36	116	K	6.16	114	ɔh	10.[illegible]	100	21
22	w	6.8	68	w	4.4	44	w	7.28	98	ɔh	8.[illegible]	110	ɔh	9.[illegible]	121	ɔh	9.[illegible]	115	22
23	w	5.12	62	w	4.7	47	w	7.34	104	w	7.46	116	ɔh	9.[illegible]	129	ɔh	9.[illegible]	130	23
24	w	5.9	59	w	3.4	34	w	7.23	93	K	5.8	87	c	9.[illegible]	136	w	10.[illegible]	140	24
25	w	7.14	84	w	3.10	40	w	5.22	72	K	4.4	66	w	9.[illegible]	143	w	11.43	153	25
26	w	4.8	48	w	5.20	70	w	5.15	65	c	4.[illegible]	60	w	9.[illegible]	150	K	6.13	109	26
27	w	5.7	57	w	5.21	71	w	8.15	95	c	3.[illegible]	55	w	9.68	158	K	5.[illegible]	95	27
28	w	7.20	90	w	3.15	45	w	9.16	106	K	3.4	51	w	11.72	182	K	5.7	85	28
29	w	7.24	94	w	4.24	64	w	8.17	97	K	5.11	91	w	13.74	204	w	8.52	132	29
30	w	8.20	100	w	5.36	86	w	8.17	97	w	7.48	118	w	11.52	162	K	4.11	76	30
31	w	6.16	76	w	6.45	105		.		K	5.16	99		.		c	5.[illegible]	100	31
M.			78,0			61,3			93,7			71,5			99,7			97,0	M.

Bemerkungen:

Source Book


1803
Sonnenflecken-Beobachtungen.
I. II. III. IV. V. VI.
M. 0+3 - - - 66,0 | 0+3 - - - 67,0 | 0+3 - - - 68,0 | 0+3 - - - 69,0 | 0+3 - - - 71,0 | 0+3 - - - 72,0
Bemerkungen:
Hangerguer
Herschel
Heinrich
Stürmer
Huber
Bede
Sonnenflecken-Beobachtungen.
VII. VIII. IX. X. XI. XII.
M. 0+3 - - 73,0 | 7+2 - - - 64,0 | 0+3 - - - 75,0 | 0+3 - - - 76,0 | 0+3 - - 77,0 | 0+3 - - - 77,0
Bemerkungen:

Source Book

1612

Sonnenflecken-Beobachtungen.

Day	I.		II.		III.		IV.		V.		VI.		Day
1	h 3.7	37	.		h 2.6	26	h 2.2	22	h 2.11	31	.		1
2	.		h 5.8	58	h 0.0	0	.		h 5.17	67	g 7.21	48	2
3	.		.		.		h 4.6	46	h 4.14	54	h 4.10	50	3
4	h 2.4	24	.		h 0.0	0	h 3.4	34	h 4.16	56	h 4.12	52	4
5	h 3.4	34	h 4.7	47	h 0.0	0	.		h 2.10	30	g 7.25	50	5
6	h 3.4	34	h 3.7	37	h 0.0	0	h 3.5	35	h 1.9	19	h 4.15	55	6
7	h 2.2	22	.		h 1.2	12	h 3.6	36	h 2.12	32	g 7.40	58	7
8	.		.		h 1.2	12	.		h 2.5	25	h 5.12	62	8
9	.		.		.		h 1.5	15	h 2.4	24	g 8.44	66	9
10	.		h 5.7	57	.		h 2.3	23	h 3.4	34	h 6.14	74	10
11	h 3.3	33	.		h 4.7	47	h 2.3	23	.		g 8.24	55	11
12	.		h 3.4	34	h 4.9	49	.		.		h 5.14	64	12
13	h 3.5	35	h 2.2	22	h 4.6	46	h 0.0	0	h 2.2	22	g 6.32	49	13
14	h 4.6	46	h 3.3	33	.		h 0.0	0	h 2.2	22	g 8.41	64	14
15	.		h 2.2	22	.		h 0.0	0	h 2.2	22	h 4.14	54	15
16	h 5.11	61	h 2.2	22	.		h 0.0	0	h 3.4	34	h 3.8	38	16
17	h 5.11	61	h 1.1	11	.		h 0.0	0	.		h 3.8	38	17
18	.		.		.		h 1.2	12	h 3.4	34	g 7.33	55	18
19	.		h 2.2	22	h 1.1	11	.		h 3.4	34	h 3.4	34	19
20	h 4.5	45	.		h 2.2	22	.		.		h 3.7	37	20
21	h 4.7	47	h 3.3	33	h 3.3	33	h 1.1	11	.		h 5.11	61	21
22	.		h 3.7	37	h 2.2	22	h 1.1	11	.		g 5.31	48	22
23	h 3.5	35	.		h 1.1	11	h 0.0	0	h 3.5	35	g 5.49	52	23
24	h 3.6	36	h 7.12	82	.		.		.		g 5.57	57	24
25	h 6.13	73	h 8.13	93	.		.		h 3.8	38	g 7.79	78	25
26	.		h 6.8	68	h 2.2	22	.		.		h 4.17	57	26
27	h 3.6	36	h 4.8	48	h 2.2	22	h 1.3	13	h 3.7	37	g 7.60	69	27
28	.		h 4.8	48	h 2.2	22	.		h 4.11	51	g 7.68	73	28
29	h 3.6	36	h 2.3	23	.		h 2.13	33	h 6.14	74	g 7.53	65	29
30	h 4.8	48	.		.		h 2.15	35	h 6.14	74	h 6.17	77	30
31	.		.		h 3.3	33	.		h 6.12	72	.		31
M.		41,3		41,8		20,5		17,5		40,0		56,5	M.

Bemerkungen:

ɔ Scheiner 0,80
h Harriot 1,00 angenommen
g Galilei 0,53
j Jungius 1.38 aus 35 Vgl. m. Harriot.

Sonnenflecken-Beobachtungen.

Day	VII.		VIII.		IX.		X.		XI.		XII.		Day
1	g 8.69	79	h 4.5	45	.		.		h 4.14	54	.		1
2	h 5.9	59	h 2.7	27	h 5.17	67	.		.		h 5.6	56	2
3	g 7.57	67	h 4.11	51	.		h 6.15	75	.		.		3
4	g 7.57	67	j 4.13	73	h 5.12	62	.		h 6.18	78	.		4
5	h 6.13	73	j 3.10	55	.		h 6.18	78	.		.		5
6	h 5.19	64	h 6.11	71	h 6.16	76	.		h 8.14	94	h 4.12	52	6
7	g 6.58	63	.		.		h 5.10	60	.		.		7
8	h 5.11	61	j 4.7	65	h 4.15	55	h 4.10	50	.		.		8
9	.		j 1.2	17	.		h 4.14	54	.		.		9
10	.		h 3.4	34	h 5.16	66	.		h 6.13	73	.		10
11	j 4.9	68	j 2.5	35	.		h 4.12	52	h 7.20	90	.		11
12	h 5.11	61	h 5.13	63	h 4.14	54	.		.		h 6.7	67	12
13	h 4.7	47	j 4.13	73	.		h 5.14	64	.		.		13
14	.		h 5.16	66	.		.		.		.		14
15	h 4.5	45	j 3.17	65	.		.		.		h 4.4	44	15
16	h 6.11	71	j 4.26	91	h 5.11	61	h 4.6	46	h 6.29	89	h 3.4	34	16
17	h 6.9	69	h 5.22	72	.		.		.		.		17
18	h 5.11	61	j 4.12	72	j 3.5	48	h 4.5	45	h 5.20	70	.		18
19	h 5.11	61	h 6.24	84	h 3.4	34	h 4.4	44	.		.		19
20	h 3.16	46	g 7.58	68	h 3.4	34	.		.		.		20
21	h 4.22	62	h 7.23	93	h 4.4	44	.		.		.		21
22	h 9.33	123	j 2.7	37	.		h 2.3	23	.		.		22
23	j 5.14	88	h 6.15	75	.		ɔ 1.1	9	h 5.13	63	h 9.19	109	23
24	j 6.23	115	j 4.12	72	h 3.3	33	.		.		.		24
25	h 7.30	100	h 5.15	65	h 5.5	55	h 3.3	33	.		.		25
26	h 8.23	103	.		.		.		.		ɔ 5.31	65	26
27	.		.		h 6.8	68	.		ɔ 5.13	50	h 7.17	87	27
28	j 2.4	33	h 5.8	58	.		h 8.14	94	.		.		28
29	h 4.8	48	h 5.10	60	.		.		ɔ 5.13	50	.		29
30	h 5.5	55	j 3.8	52	h 9.13	103	.		.		.		30
31	h 5.5	55	.		.		.		.		j 5.8	80	31
M.		68,5		60,7 ~~61,8~~		57,3 ~~58,0~~		51,9		71,1		66,0 ~~64,2~~	M.

Bemerkungen:

67 Harriot = 63 Scheiner aus 1 Vergl.
1063 " = 1997 Galilei — 18 —
2178 " = 1576 Jungius. 35 Vgl. Für Jungius vgl. Litt. Nr. 573. Mitth. 71.

Source Book

1643 Sonnenflecken-Beobachtungen.

	I.	II.	III.	IV.	V.	VI.	
1	.	.	.	.	.	.	1
2	.	.	.	.	. 29	.	2
3	.	.	.	.	.	.	3
4	.	.	.	.	.	.	4
5	.	.	.	.	.	.	5
6	.	.	.	.	.	.	6
7	.	.	.	.	.	.	7
8	.	.	.	.	.	.	8
9	.	.	.	.	.	h 0.0 0	9
10	.	.	.	.	. 28	h 0.0 0	10
11	.	.	.	.	.	h 0.0 0	11
12	.	.	.	.	.	h 0.0 0	12
13	.	.	.	.	.	h 0.0 0	13
14	.	.	.	.	.	h 0.0 0	14
15	.	.	.	.	.	h 0.0 0	15
16	.	.	.	.	.	h 0.0 0	16
17	.	.	.	.	. 28	h 0.0 0	17
18	.	.	.	.	.	h 2.2 22	18
19	.	.	.	.	.	h 3.8 38	19
20	.	.	.	.	.	h 3.7 37	20
21	.	.	.	.	.	h 4.8 48	21
22	.	.	.	.	h 2.6 26	h 3.8 38	22
23	.	.	.	.	h 3.8 38	h 3.4 34	23
24	.	.	.	.	.	h 2.4 24	24
25	.	.	.	.	h 3.7 37	h 3.12 42	25
26	.	.	.	.	h 3.5 35	h 3.16 46	26
27	.	.	.	.	.	.	27
28	.	.	.	.	h 3.3 33	h 3.9 39	28
29	.	.	.	.	h 2.3 23	h 3.3 33	29
30	.	.	.	.	h 2.2 22	.	30
31	.	.	.	.	h 1.1 11	.	31
M.	34,5	33,0	31,5	30,0	28,1	20,0	M.

Bemerkungen:

h Hevel

Sonnenflecken-Beobachtungen.

	VII.	VIII.	IX.	X.	XI.	XII.	
1	h 1.5 15	h 1.1 11	h 0.0 0	h 0.0 0	. 11	.	1
2	h 1.3 13	h 1.1 11	h 0.0 0	h 0.0 0	.	.	2
3	h 1.1 11	h 1.2 12	h 1.2 12	h 0.0 0	.	h 2.2 22	3
4	h 0.0 0	h 1.3 13	h 2.2 22	.	.	.	4
5	h 0.0 0	h 1.4 14	h 1.2 12	h 0.0 0	h 0.0 0	.	5
6	h 0.0 0	h 1.4 14	.	h 0.0 0	.	.	6
7	h 0.0 0	h 1.6 16	h 1.1 11	h 0.0 0	.	.	7
8	h 2.3 23	h 1.2 12	.	h 0.0 0	.	.	8
9	h 2.3 23	h 2.2 22	.	h 0.0 0	h 0.0 0	.	9
10	h 1.2 12	h 2.2 22	h 2.3 23	h 0.0 0	h 1.1 11	.	10
11	h 1.2 12	h 2.2 22	h 1.1 11	h 1.2 12	.	. 18	11
12	.	h 2.2 22	h 2.2 22	.	.	.	12
13	h 1.1 11	h 3.3 33	h 2.2 22	.	.	.	13
14	h 1.1 11	h 3.3 33	h 3.3 33	.	.	.	14
15	h 1.2 12	h 2.6 26	h 2.3 23	h 1.2 12	. 19	.	15
16	.	h 2.7 27	h 2.3 23	h 1.3 13	.	.	16
17	h 2.4 24	h 2.14 34	h 2.4 24	.	.	.	17
18	h 3.4 34	h 2.9 29	h 2.3 23	.	.	.	18
19	.	h 2.8 28	h 1.1 11	h 1.2 12	.	. 18	19
20	h 3.7 37	h 2.7 27	h 1.1 11	h 1.2 12	h 0.0 0	.	20
21	h 3.7 37	h 2.3 23	h 1.1 11	h 2.5 25	.	.	21
22	h 3.6 36	h 3.4 34	h 1.1 11	h 2.5 25	.	.	22
23	.	h 3.5 35	h 1.1 11	h 2.3 23	.	.	23
24	h 3.7 37	h 2.2 22	h 0.0 0	h 1.3 13	h 2.5 25	.	24
25	h 2.5 25	h 0.0 0	h 0.0 0	h 1.3 13	h 3.10 40	h 1.1 11	25
26	h 2.3 23	h 0.0 0	h 1.1 11	.	.	h 1.1 11	26
27	h 2.3 23	h 0.0 0	h 0.0 0	.	h 3.10 40	.	27
28	h 0.0 0	h 0.0 0	.	h 1.2 12	h 2.9 29	.	28
29	h 0.0 0	h 0.0 0	h 0.0 0	h 1.2 12	.	h 1.1 11	29
30	h 1.1 11	h 0.0 0	h 0.0 0	h 1.2 12	.	h 1.1 11	30
31	h 1.1 11	h 0.0 0	.	h 1.1 11	.	h 1.1 11	31
M.	16,3	17,5	12,6	9,0	17,5	14,1	M.

Bemerkungen:

Source Book

Reconstruction of the Wolf series

- Rosetta stone of Wolf series reconstruction
  - Some years ago we identified in the archives of the former Swiss Federal Observatory in Zurich a manuscript containing the raw data of the Wolf series
  - Source book contains the daily group number, the daily number of individual spots, the reduced Wolf number, the observer and the corresponding k-factor from the beginnings in 1610 up to 1876.
  - **Digitizing is ongoing.** Recently we finished the period of 1849 to 1876 spanning all the observations of Rudolf Wolf.
  - The already digitized parts of the Source Book are published on the site http://www.wolfinstitute.ch and there under “Heritage”
  - A description of Wolf’s instruments and methods of observation is contained in the forthcoming paper “Sunspot observations of Rudolf Wolf from 1849 – 1893” in the T.I. in Solar Physics.


Beobachtungen

der

Sonnenflecken

Von der Zeit ihrer Entdeckung bis auf die Gegenwart.

Gesammelt

von

Rudolf Wolf.

The Wolfian Period 1849 - 1893

Known issues

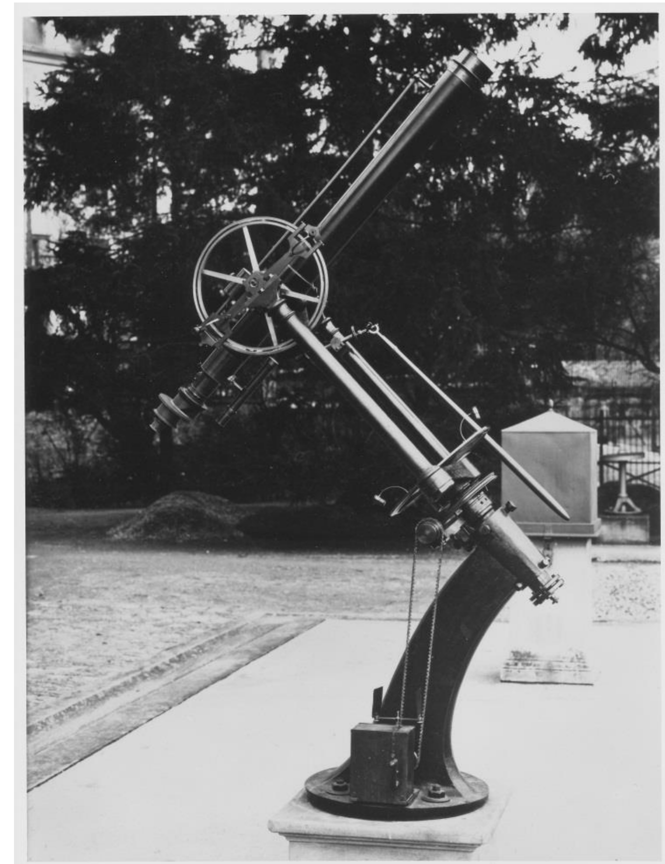
- Wolf used several standard instruments
  - 83 / 1320 mm Fraunhofer refractor
  - 40 / 700 mm Parisian spy refractor
  - 42 / 800 mm Fraunhofer spy refractor
- Wolf did not distinguish between his own observations and those from Heinrich Schwabe for some years
- Wolf changed the data reduction method in 1877, Wolfer changed it another time in 1894
- Wolf suffered from an eyesight diminishment in his later years
- Wolfer made an approximate scale transfer, but did never recalculate the series (and neither did anyone else)

► Wolfer was adopted as standard observer of the new Wolf series version 2.0, but there was not enough information available to do all the necessary corrections. Thus, let's try it!

Standard Instruments

1849 83 / 1320 mm Fraunhofer refractor in Berne, mag. 64, sunglass

1855 83 / 1320 mm Fraunhofer refractor in Zurich, mag. 64, sunglass



Standard Instruments

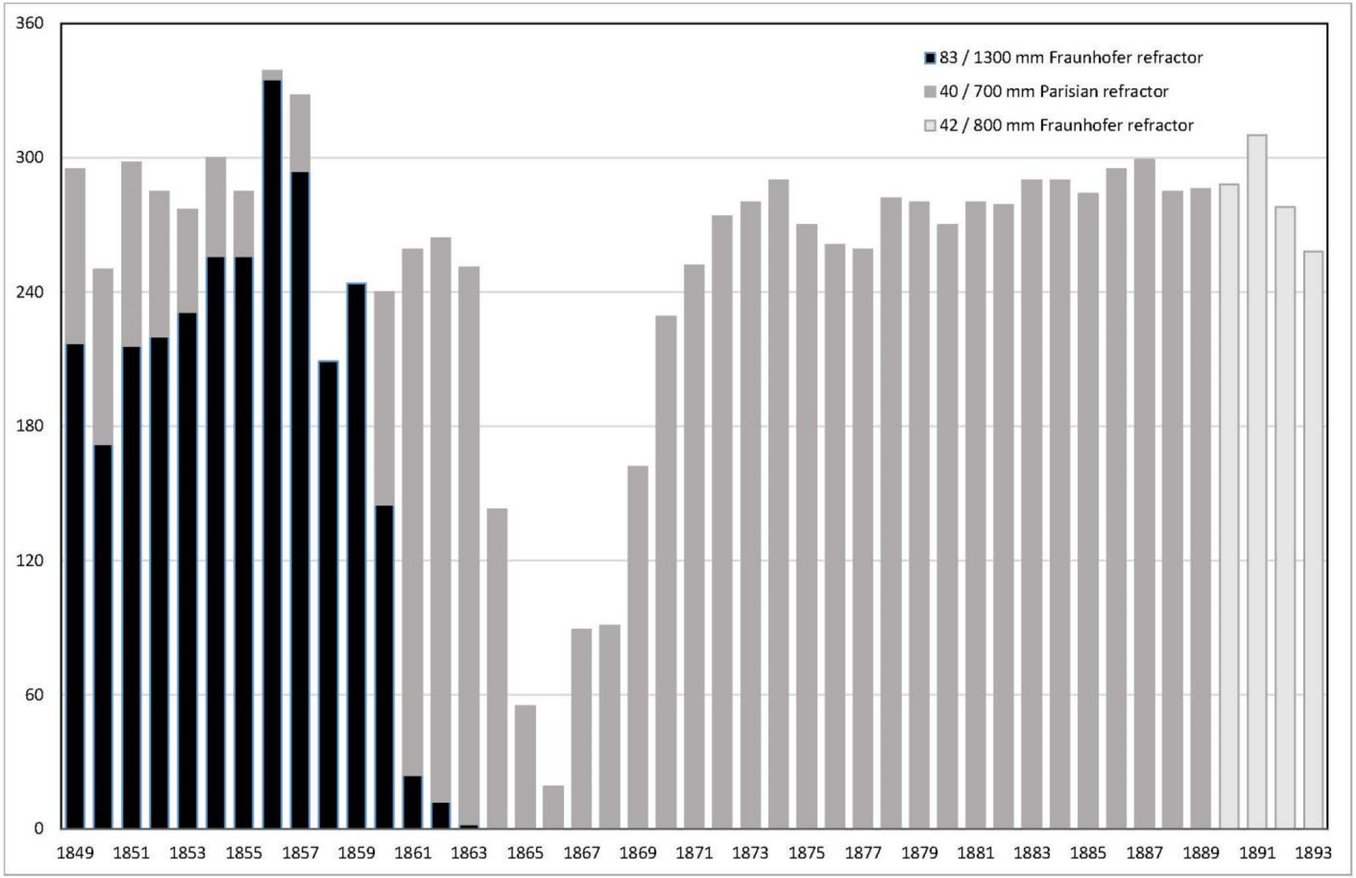
1849 83 / 1320 mm Fraunhofer refractor in Berne, mag. 64, sunglass

1855 83 / 1320 mm Fraunhofer refractor in Zurich, mag. 64, sunglass

1861 40 / 700 mm Parisian refractor in Zurich, mag. 20, sunglass

1890 42 / 800 mm Fraunhofer refractor in Zurich, mag. 29, sunglass

Reconstructed Observations of Rudolf Wolf

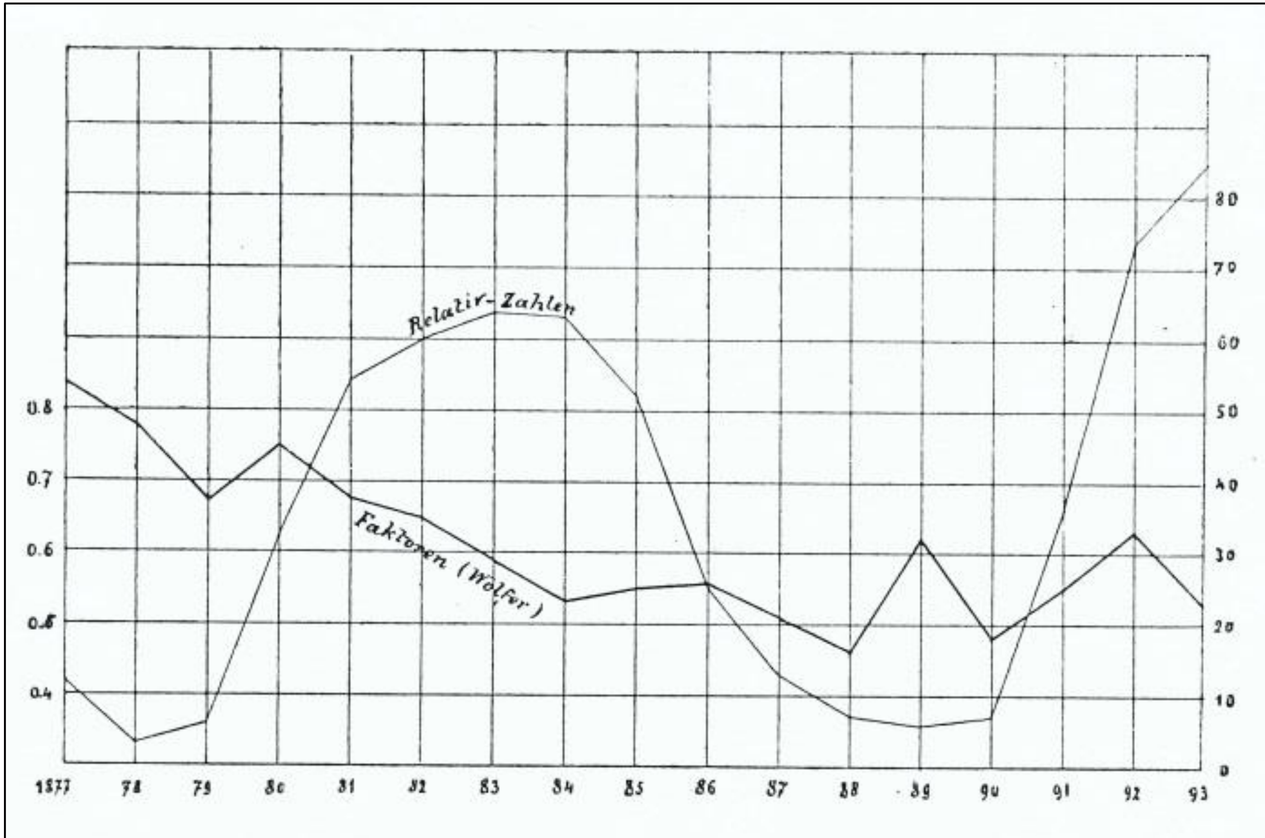


The Wolfian Period 1849 - 1893

Recalculation

- Basic principle
  - We take Alfred Wolfer as standard observer and apply exactly the same data reduction procedure as Wolfer used from 1894 on.
  - Wolfer is set as standard observer, Wolf as his assistant, all others as secondary observers
- This approach relies on the long-term stability of Wolfer's instrumental system which is not obviously given, since he began his career in 1876

The Wolfian Period 1849 - 1893



Wolfer (1895)

The Wolfian Period 1849 - 1893

Recalculation

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  - Wolfer is set as standard observer, Wolf as his assistant, all others as secondary observers
- This approach relies on the long-term stability of Wolfer's instrumental system which is not obviously given, since he began his career in 1876
  - Shows the graph from Wolfer (1895) a learning curve ?
  - Wolfer examined 4 series (Zurich, Madrid, Rom and Catania), including his own and found, that they show all more or less the same pattern.
  - Thus, Wolfer concluded that his instrumental system was stable and that the lowering of the k-factors was due to a an eyesight diminishment of Wolf which was also observable in every days life.
- Wolfer adopted an overall mean value of 0.60 as his k-factor.

Tab. I.

			f				f — fm			
		r.	Wolfer Zürich	Ventosa Madrid	Tacchini Palermo Rom	Riccó Palermo Catania	Wolfer	Ventosa	Tacchini	Riccó
1877	I	15,9	0,86	0,90	0,81	—	+0,25	+0,30	—0,06	—
	II	8,7	0,82	0,88	0,87	—	+0,21	+0,28	0,00	—
1878	I	4,9	0,67	0,66	0,56	—	+0,06	+0,06	—0,31	—
	II	1,9	0,89	0,69	0,52	—	+0,28	+0,09	—0,35	—
1879	I	2,5	0,65	0,58	1,07	—	+0,04	—0,02	+0,20	—
	II	9,5	0,69	0,66	0,95	0,81	+0,08	+0,06	+0,08	+0,21
1880	I	24,7	0,76	0,75	0,93	0,82	+0,15	+0,15	+0,06	+0,22
	II	39,9	0,74	0,75	0,79	0,81	+0,13	+0,15	—0,08	+0,21
1881	I	49,3	0,67	0,66	0,83	0,63	+0,06	+0,06	—0,04	+0,03
	II	59,0	0,69	0,75	0,92	0,66	+0,08	+0,15	+0,05	+0,06
1882	I	64,5	0,62	0,67	0,91	0,65	+0,01	+0,07	+0,04	+0,05
	II	54,8	0,67	0,62	0,90	0,65	+0,06	+0,02	+0,03	+0,05
1883	I	56,8	0,64	0,61	0,98	0,66	+0,03	+0,01	+0,11	+0,06
	II	70,6	0,54	0,57	0,87	0,65	—0,07	—0,03	0,00	+0,05
1884	I	76,5	0,54	0,60	0,80	0,59	—0,07	0,00	—0,07	—0,01
	II	50,4	0,52	0,54	0,78	0,56	—0,09	—0,06	—0,09	—0,04
1885	I	62,7	0,54	0,60	0,95	0,54	—0,07	0,60	+0,08	—0,06
	II	41,6	0,56	0,55	0,97	0,47	—0,05	—0,05	+0,10	—0,13
1886	I	35,8	0,58	0,61	1,08	0,59	—0,03	+0,01	+0,21	—0,01
	II	15,0	0,54	0,50	1,01	0,53	—0,07	—0,10	+0,14	—0,07
1887	I	11,7	0,51	0,49	0,91	0,54	—0,10	—0,11	+0,04	—0,06
	II	14,4	0,51	0,59	1,10	0,64	—0,10	—0,01	+0,23	+0,04
1888	I	7,8	0,49	0,48	0,74	0,47	—0,12	—0,12	—0,13	—0,13
	II	5,7	0,43	0,32	0,57	0,31	—0,18	—0,28	—0,30	—0,29
1889	I	4,9	0,72	0,63	1,08	0,61	+0,11	+0,03	+0,21	+0,01
	II	7,6	0,52	0,57	0,90	0,57	—0,09	—0,03	+0,03	—0,03
1890	I	3,1	0,48	0,29	0,50	0,45	—0,13	—0,31	—0,37	—0,15
	II	11,0	0,48	0,46	0,83	0,49	—0,13	—0,14	—0,04	—0,11
1891	I	26,0	0,52	0,48	0,75	0,52	—0,09	—0,12	—0,12	—0,08
	II	45,2	0,58	0,57	0,88	0,59	—0,03	—0,03	+0,01	—0,01
1892	I	70,0	0,62	0,62	0,96	0,68	+0,01	+0,02	+0,09	+0,08
	II	75,9	0,64	0,65	0,99	0,65	+0,03	+0,05	+0,12	+0,05
1893	I	79,1	0,52	0,58	0,92	0,60	—0,09	—0,02	+0,05	0,00
	II	90,8	0,54	0,64	0,87	0,61	—0,07	+0,04	0,00	+0,01
Mittel			0,61	0,60	0,87	0,60				

The Wolfian Period 1849 - 1893

Recalculation

- Basic principle
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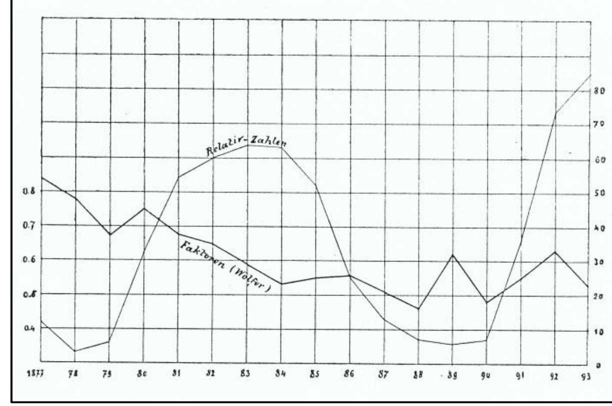
	II	70,6	0,54	0,57	0,87	0,65	−0,07	−0,03	0,00	+0,05
1884	I	76,5	0,54	0,60	0,80	0,59	−0,07	0,00	−0,07	−0,01



Recalculation

- Algorithm outline
  - Wolfer's $R = 10 \cdot g + f$ were multiplied by 0.6
  - On days with an observation of Wolfer, his reduced Wolf number was inserted as Wolf series value.
  - For Wolf, a semesterly k-factor was calculated. $k = R_{Wolfer}/R_{Wolf}$
  - In the gaps of Wolfer, the reduced Wolf numbers of Wolf were filled in
  - In the remaining gaps, the values of the original Wolf series were inserted, which were multiplied with the same k-factor as Wolf
  - Rounding to the nearest integer was performed on each calculation step

The Wolfian Period 1849 - 1893

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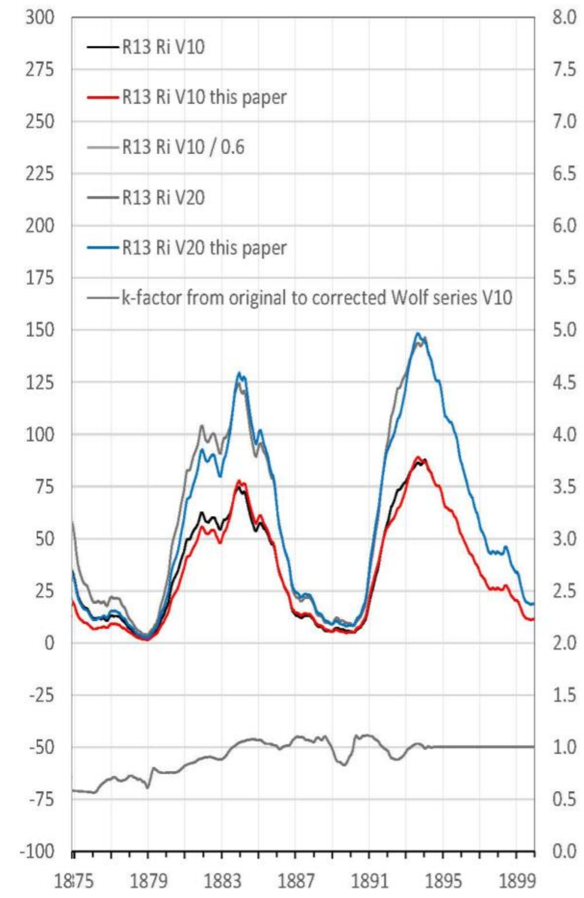
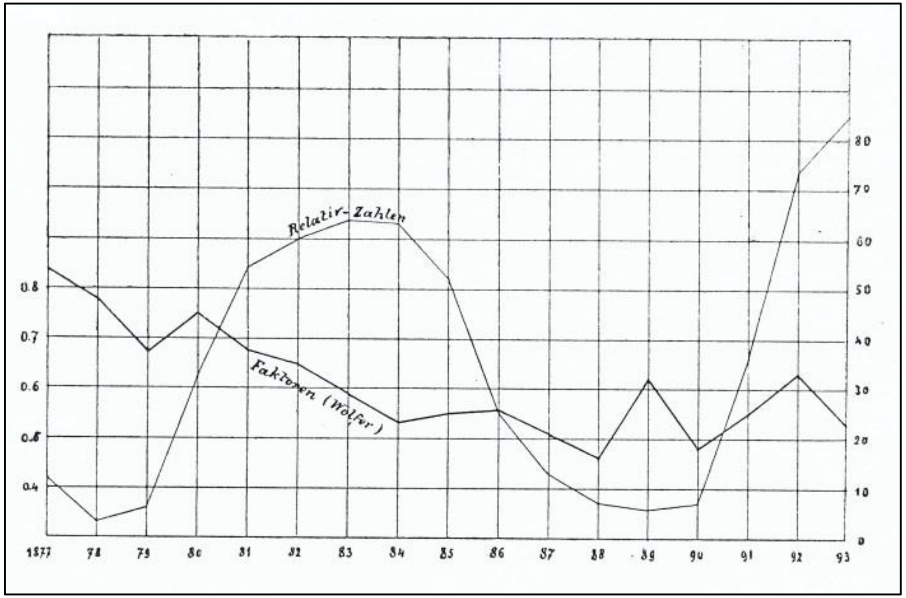
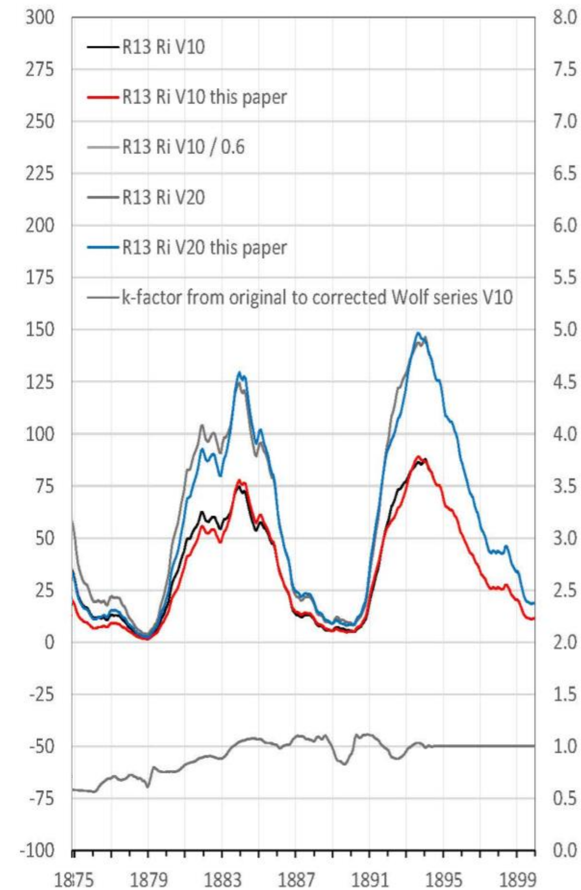


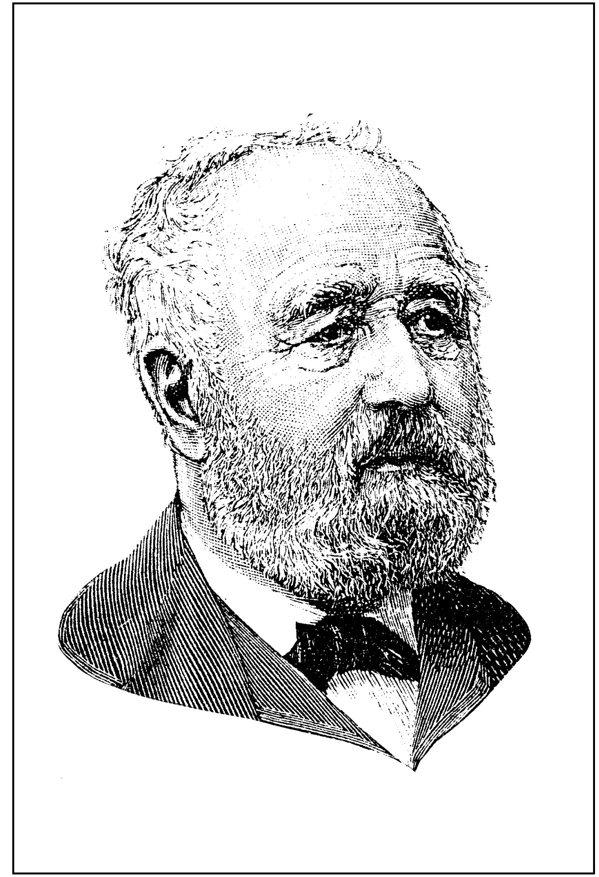
The Wolfian Period 1849 - 1893





- Eye-sight diminishment corrected
  - In 1876 the k-factor dropped to **0.54**. Thus, this is the reverse calculation Wolfer should have done, although he rather had risen his own observations than lowered Wolf's. Additionally, all historically grown inhomogeneities due to a variable data reduction methods are corrected, too.

Contents

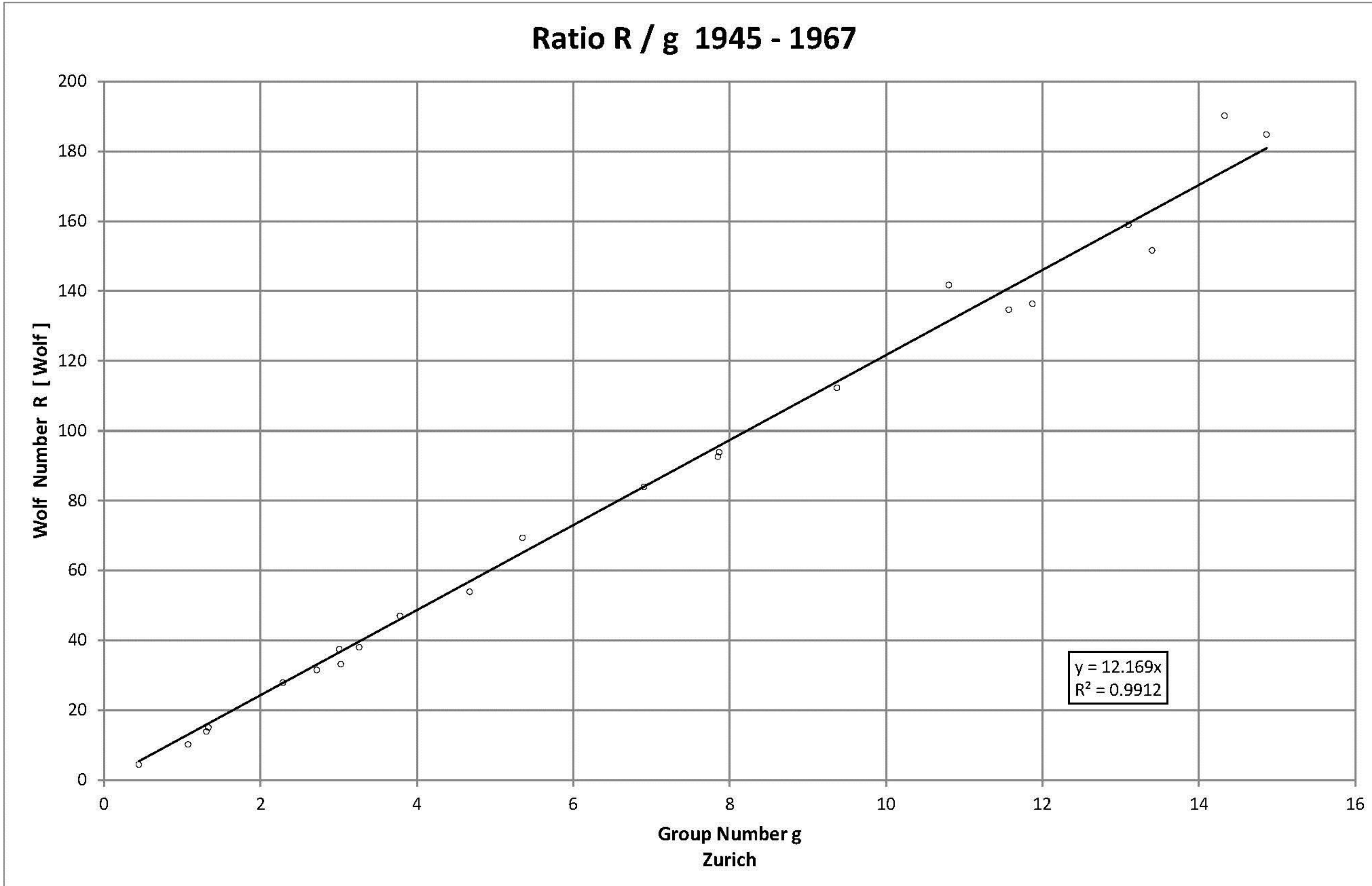


- Reconstruction
- Scale Homogenization

Scale Homogenization

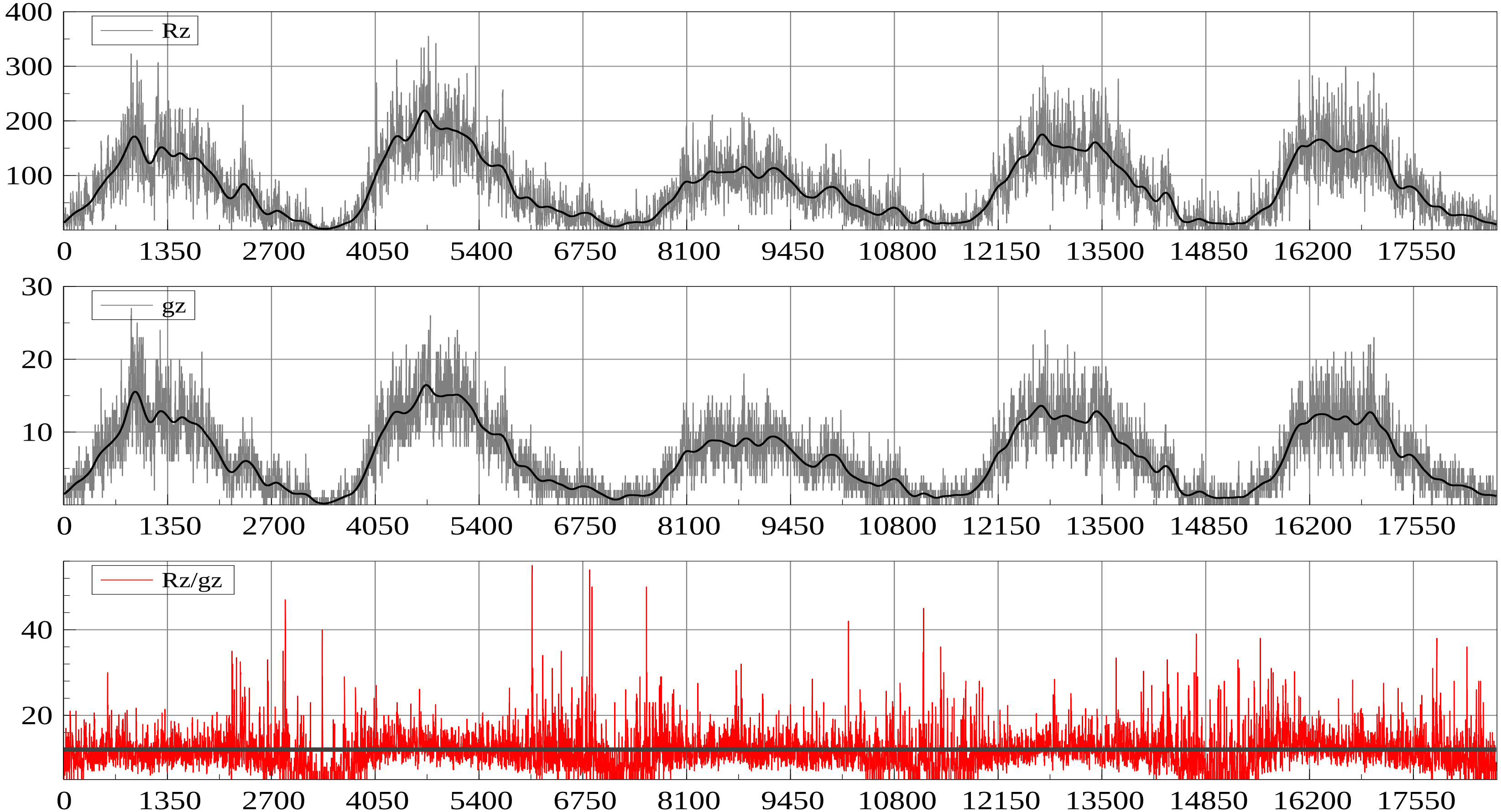
What is the scale? And how we can measure it?

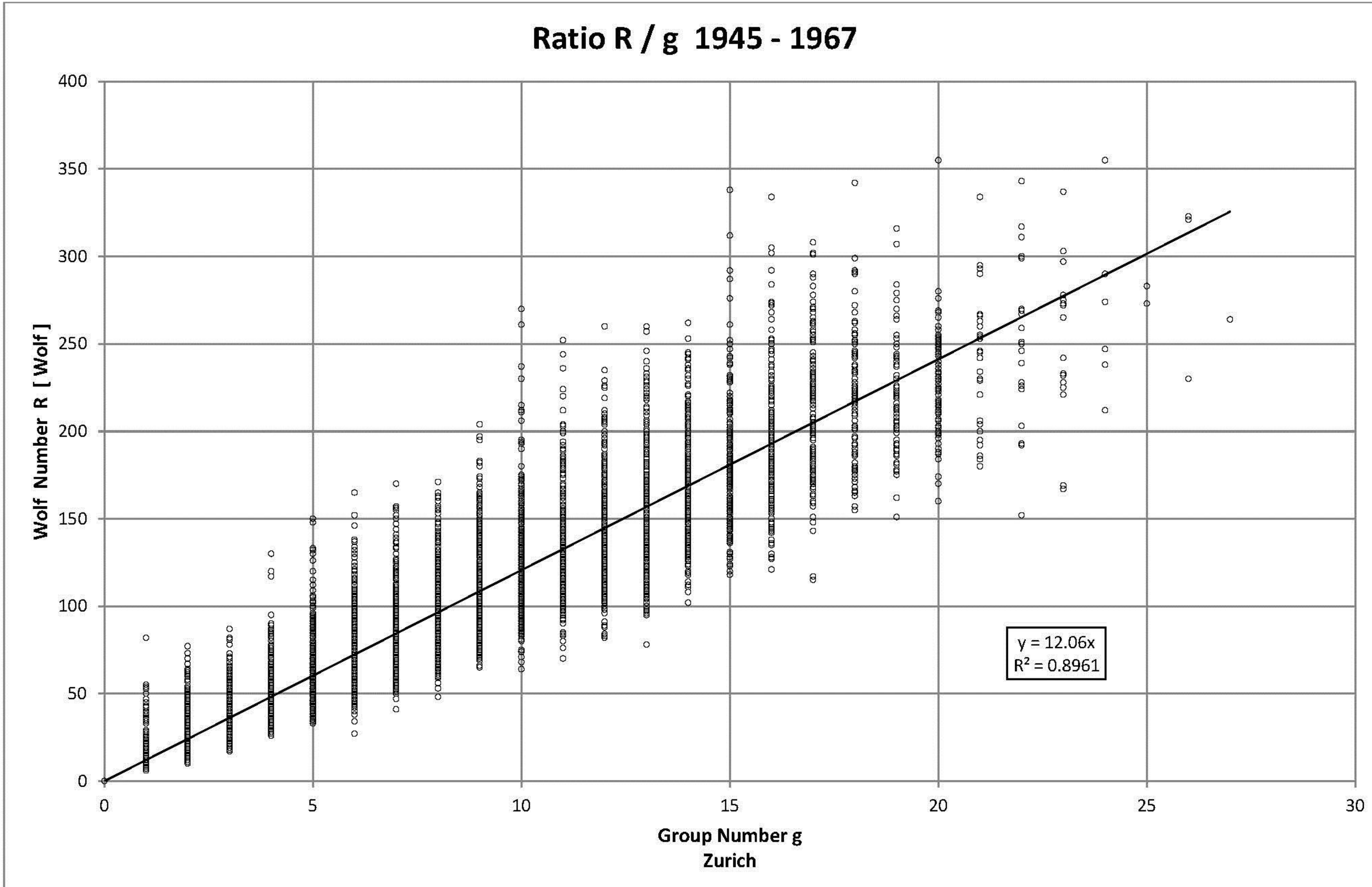
- Scale is only implicitly known
  - Determined by the combination of instrument, observer and environmental conditions (thus defining an instrumental system)
  - Affected by various aging-effects during an observational career
  - Especially the training and the experience plays a mayor role
  - Wolf assumed in 1859 that the homogeneity of the scale is reflected by the constancy of the k-factors
  - In 1872 Wolf discovered, that the k-factors are varying with solar activity
- Wolf number is a index with two components
  - It was forgotten, that the Wolf number consist of two components which could provide additional information about the scale



Ratio R / g 1945 - 1967
Wolf Number R [Wolf]
Group Number g
Zurich
y = 12.169x
R² = 0.9912
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
14
16

Zurich Sunspot Number





Ratio R / g 1945 - 1967
Wolf Number R [Wolf]
Group Number g
Zurich
y = 12.06x
R² = 0.8961
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30

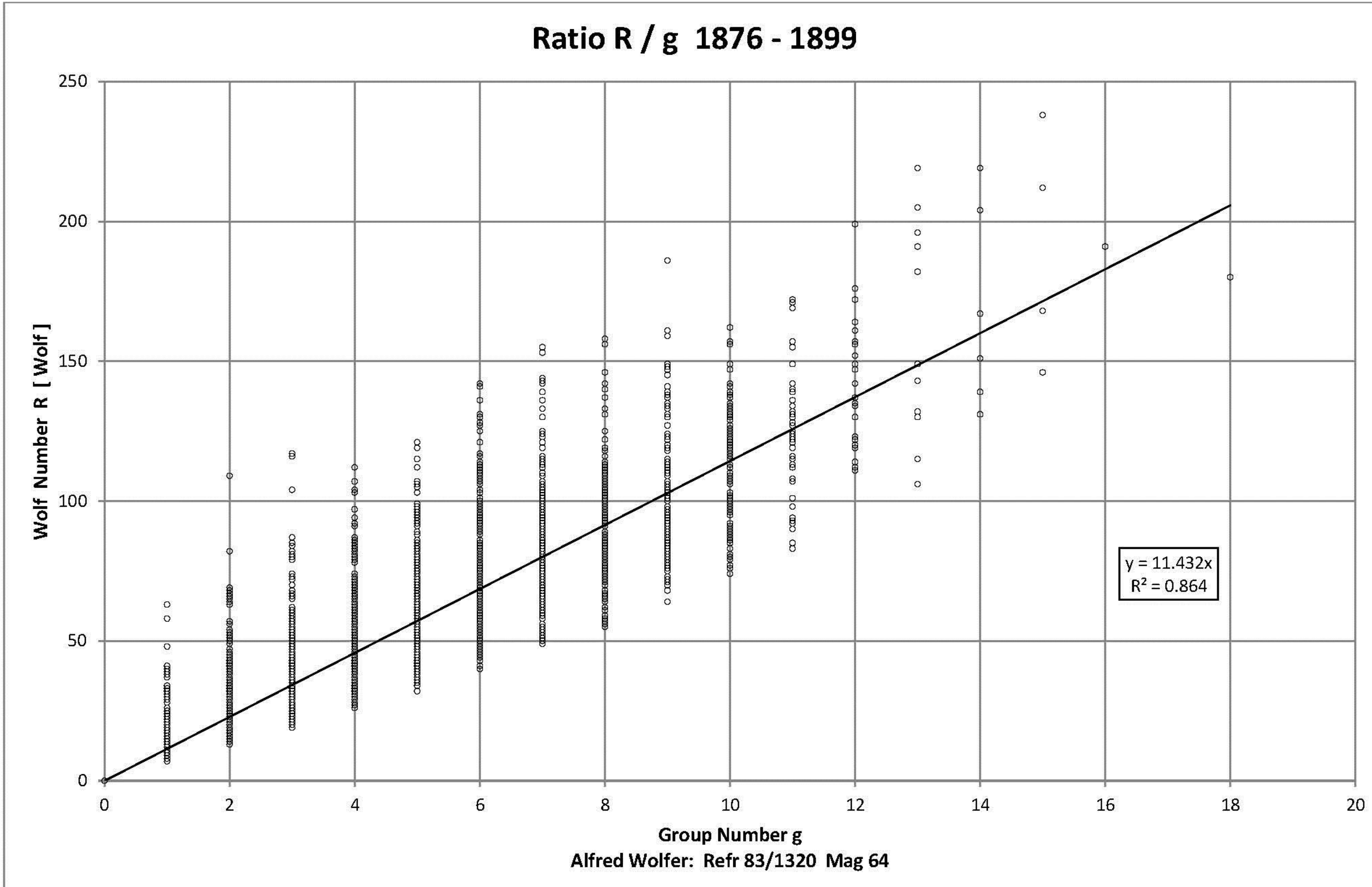
Scale Homogenization

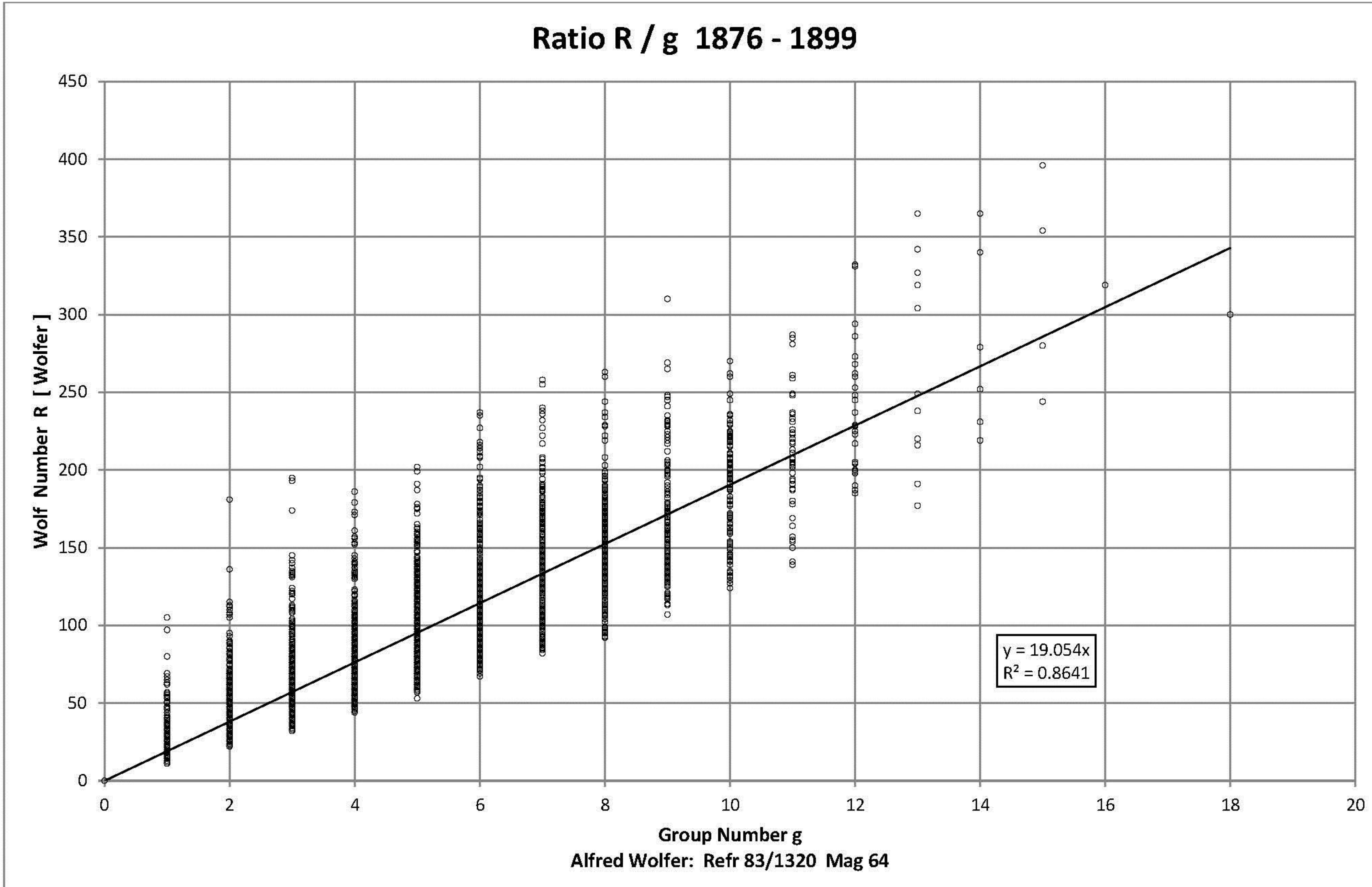
What is the scale? And how we can measure it?

- Scale is measured by the ratio R / g
  - $R_S = k_B \cdot (10 \cdot g_B + f_B) = \beta_S \cdot g_B$
  - $R_B = 10 \cdot g_B + f_B = \beta_B \cdot g_B$
  - I call β the scale constant
  - It has to be measured over one cycle length or a multiple thereof
  - For shorter periods, β will vary according the local realization of R / g.
  - Thus, the β can be measured only retrospectively and are rather an instrument for calibration and homogenization than for data reduction.
- Calibration and scale
  - $k_B = \frac{R_S}{R_B} = \frac{\beta_S \cdot gB}{\beta_B \cdot gB} = \frac{\beta_S}{\beta_B}$
  - Transforming one system into the other means stretching the scales

Scale calibration and homogenization

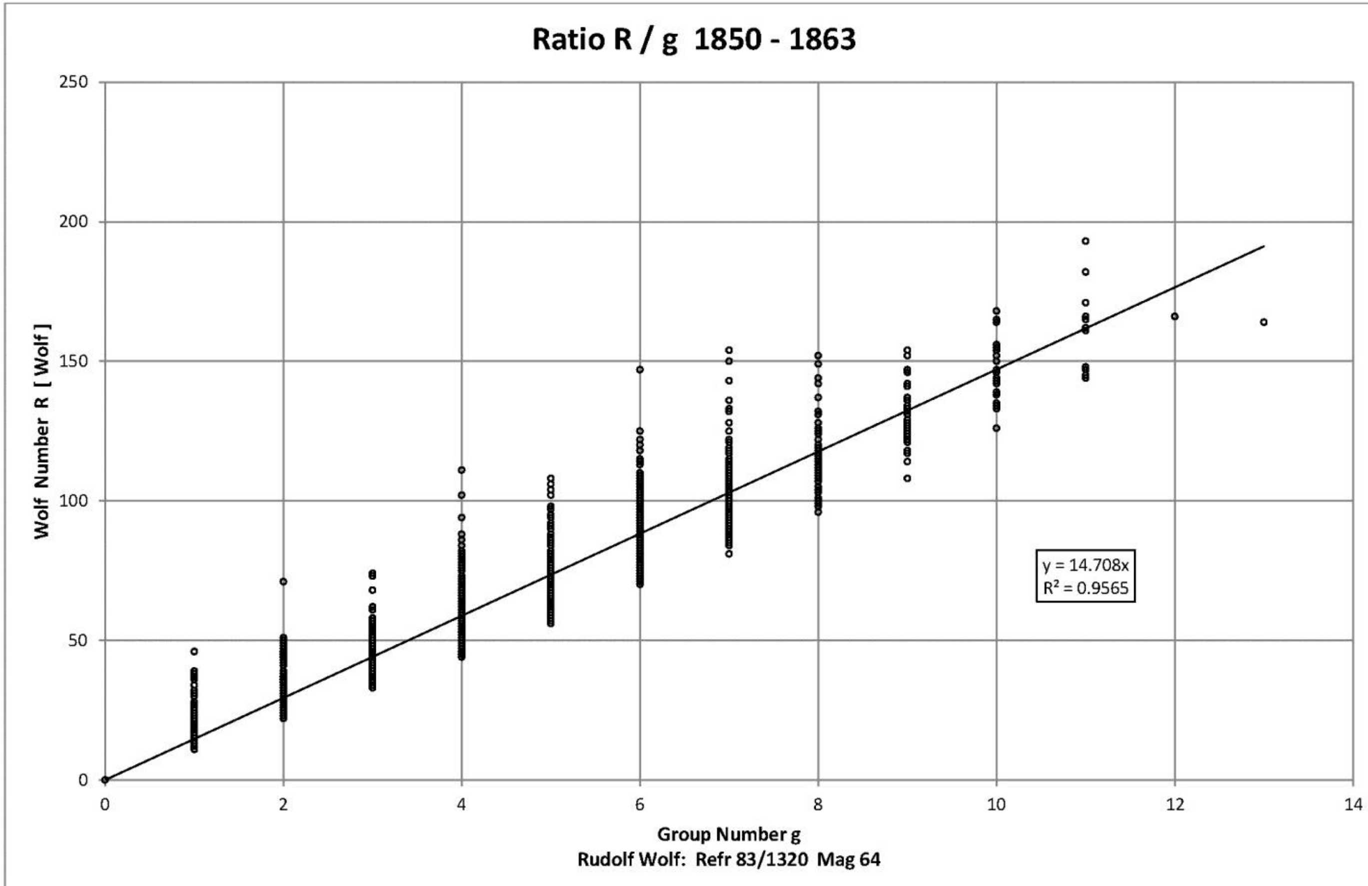
- Scale transformation
  - $k_B = \frac{\beta_S}{\beta_B}$
  - Thus k_B may be estimated solely with information from the instrumental system itself. Corresponding observations are not needed any more.
  - Each instrumental system can be transformed to another
  - The scale may be set freely, e.g. $\beta_S = 20$ (this will equalize the weight of g and f to the index). But we recommend to use a value which is realized by a reference station, preferably Locarno.
- Scale homogenization
  - All instrumental systems of the long-term standard observers will be homogenized to the standard scale
  - As standard scale we should adopt the instrumental system of Wolfer


Ratio R / g 1876 - 1899
Wolf Number R [Wolf]
Group Number g
Alfred Wolfer: Refr 83/1320 Mag 64
y = 11.432x
R² = 0.864
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
18
20



Ratio R / g 1876 - 1899
Wolf Number R [Wolfer]
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20
y = 19.054x
R² = 0.8641
Group Number g
Alfred Wolfer: Refr 83/1320 Mag 64

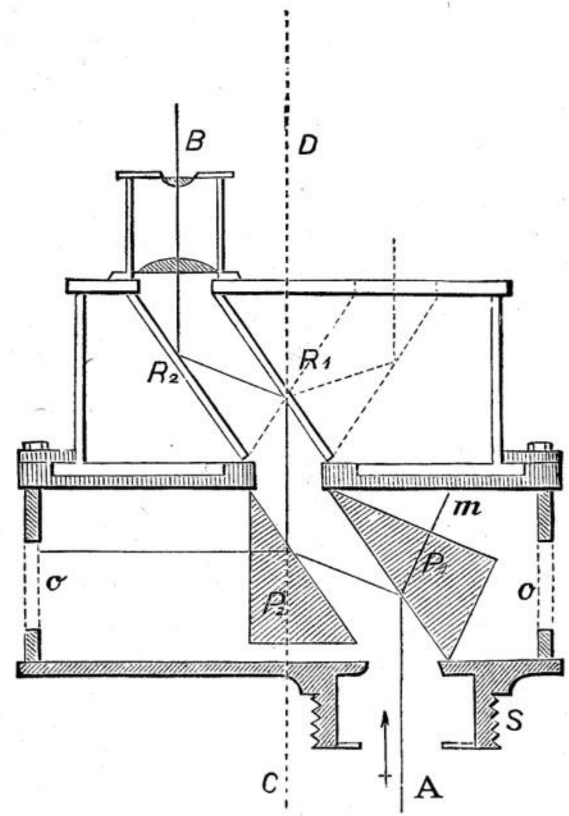
The Wolfian Period 1849 - 1893



The Wolfian Period 1849 - 1893

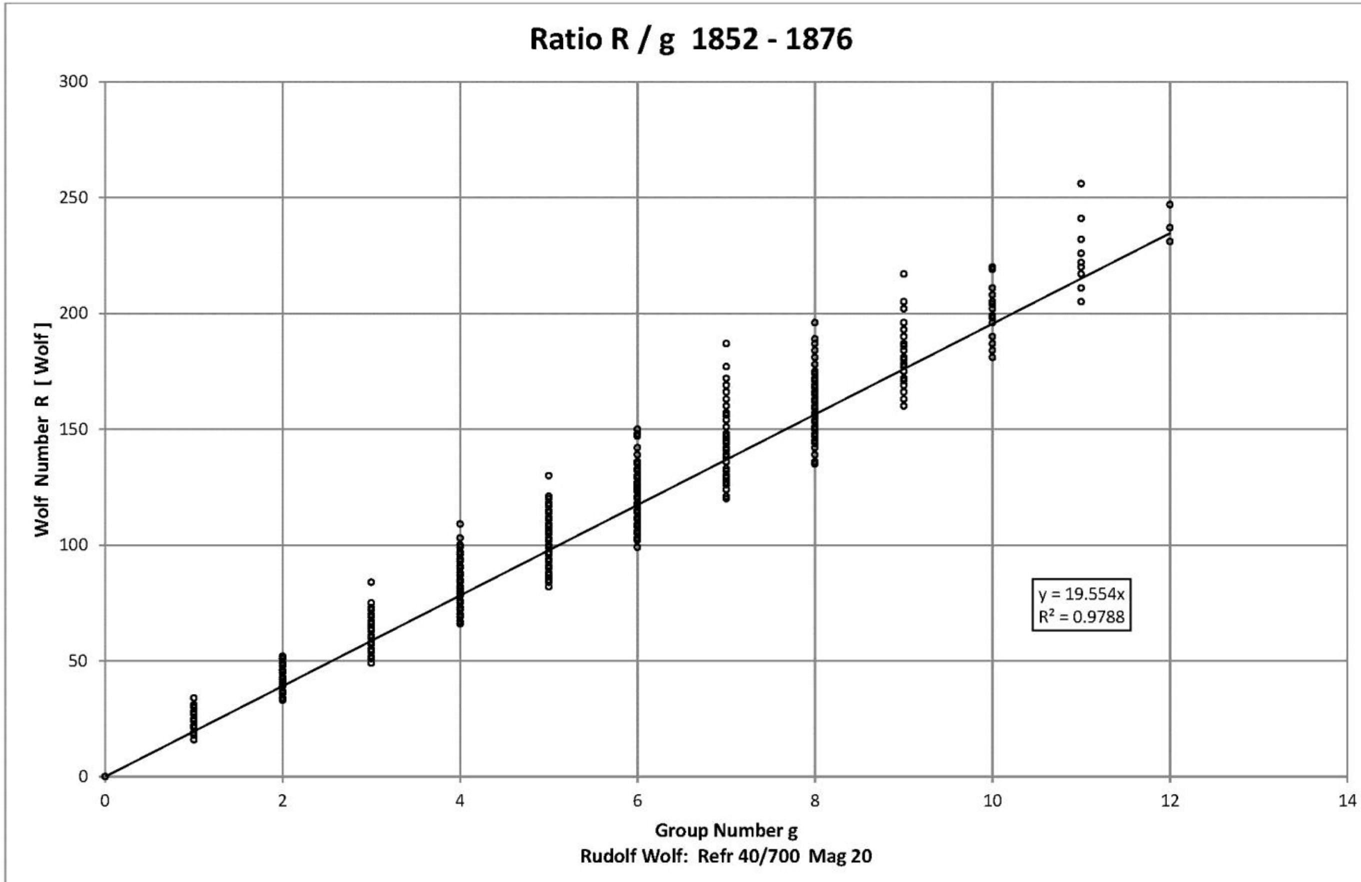
Recalculation

- Scale constant β of Rudolf Wolf 1849 - 1863 at the 83 / 1320 mm Fraunhofer refractor
  - $\beta_S = 14.708$
  - Significantly higher than Wolfer's $\beta_S = 11.432$
    - Wolfer has lowered the Series in 1894 too much, due to the eyesight diminishment of Rudolf Wolf
  - Significantly lower than Wolfer's instrumental $\beta_S = 19.054$
    - Wolf was not eagle-eyed:
      - Emil Jenzer in Berne had a k-factor of 0.85 at the same instrument
      - August Weilenmann in Zurich had a k-factor of 0.90 at the same instrument
    - In 1870 a polarizing helioscope was attached to the Fraunhofer refractor which improved the image quality considerably. The k-factor of Gustav Adolf Meyer droped some 15%
    - Wolfer made drawings and measured positions of every group, a control Wolf never had



Merz's Helioscope.

The Wolfian Period 1849 - 1893

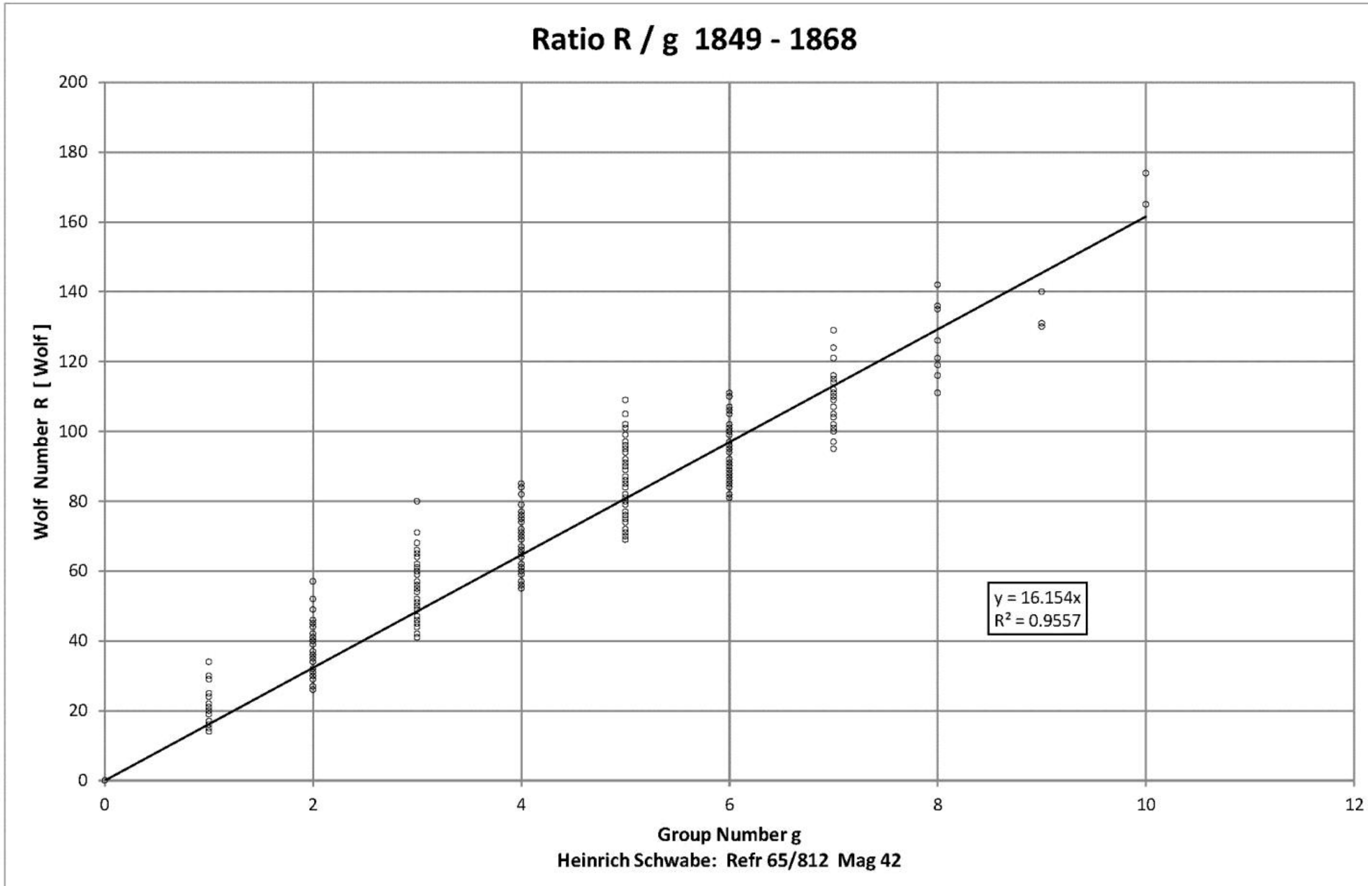


The Wolfian Period 1849 - 1893

Recalculation

- Scale constant β of Rudolf Wolf 1852 - 1876 at the 40 / 700 mm Parisian refractor
  - $\beta_S = 19.554$
  - Significantly higher than Wolfer's $\beta_S = 11.432$
    - $\beta_S = 19.554$ is higher than Wolfer's $\beta_S = 19.054$
    - The correct k-factor should have been
      k = 14.708 / (19.554 / 1.5) = 1.13
    - k = 1.5 was based on 255 comparison observations from the years 1860 to 1862 during maximum phase
  - Re-examination of Wolf's observation with the Parisian refractor by Alfred Wolfer and Thomas K. Friedli
    - Wolfer 1894 - 1926: k = 1.22
    - Friedli 2006 – 2015: k = 0.98

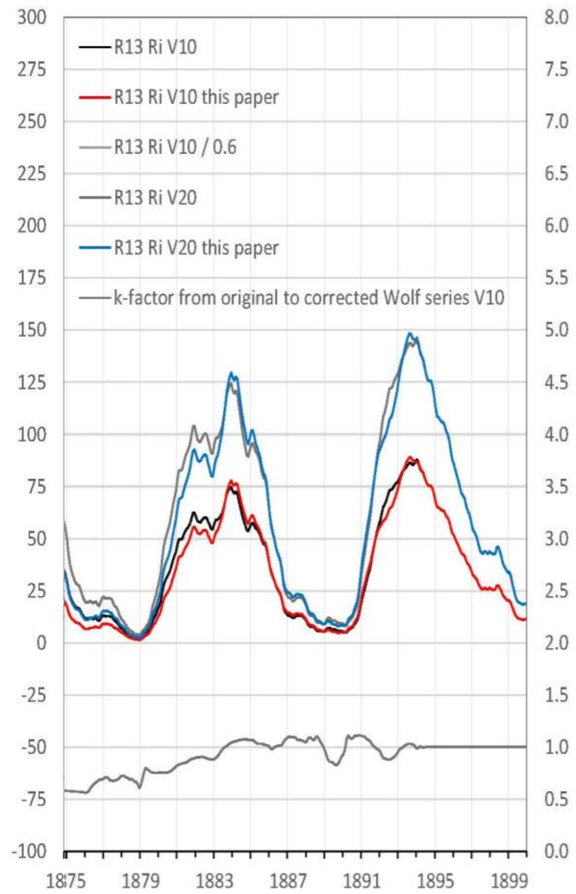
The Wolfian Period 1849 - 1893



The Wolfian Period 1849 - 1893

Recalculation

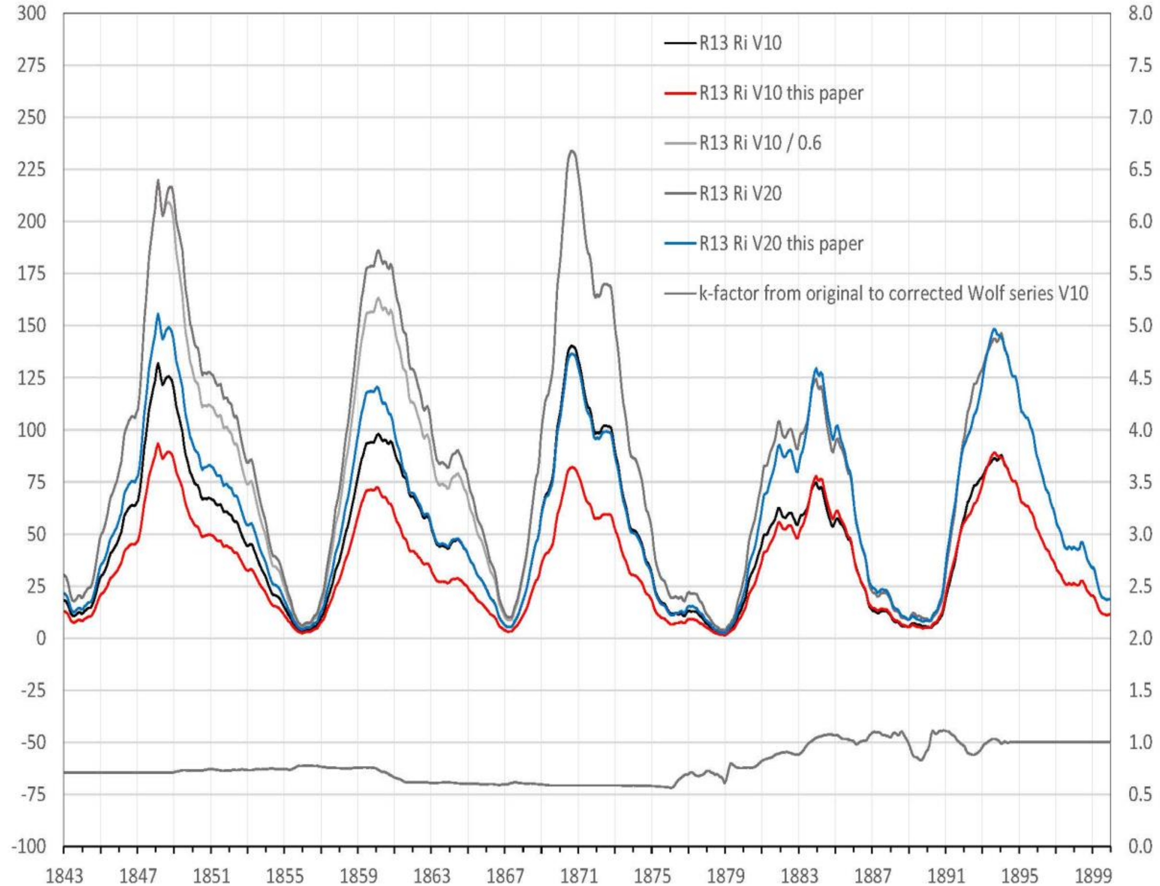
- Corrected data reduktion factors 1849 - 1876
  - **Rudolf Wolf** at the 83 / 1320 mm Fraunhofer refractor
    - $\mathbf{0.777} = 0.6 \cdot \frac{19.054}{14.708}$
  - **Rudolf Wolf** at the 40 / 700 mm Parisian refractor
    - $\mathbf{0.584} = 0.6 \cdot \frac{19.054}{19.554}$
  - **Heinrich Schwabe**
    - $\mathbf{0.708} = 0.6 \cdot \frac{19.054}{14.708} \cdot \frac{14.708}{12.923} \cdot \frac{1}{1.25}$
  - **Secondary observers**
    - 1849 – 1860: **0.777** as 83/1320 mm Fraunhofer refractor
    - 1861 – 1869: **0.584** as 40/700 mm Parisian refractor
  - **Wolf series 1749 to 1848**: **0.708** as Heinrich Schwabe
- Separation of standard instruments and scale jumps corrected



The Wolfian Period 1849 - 1893

Recalculation

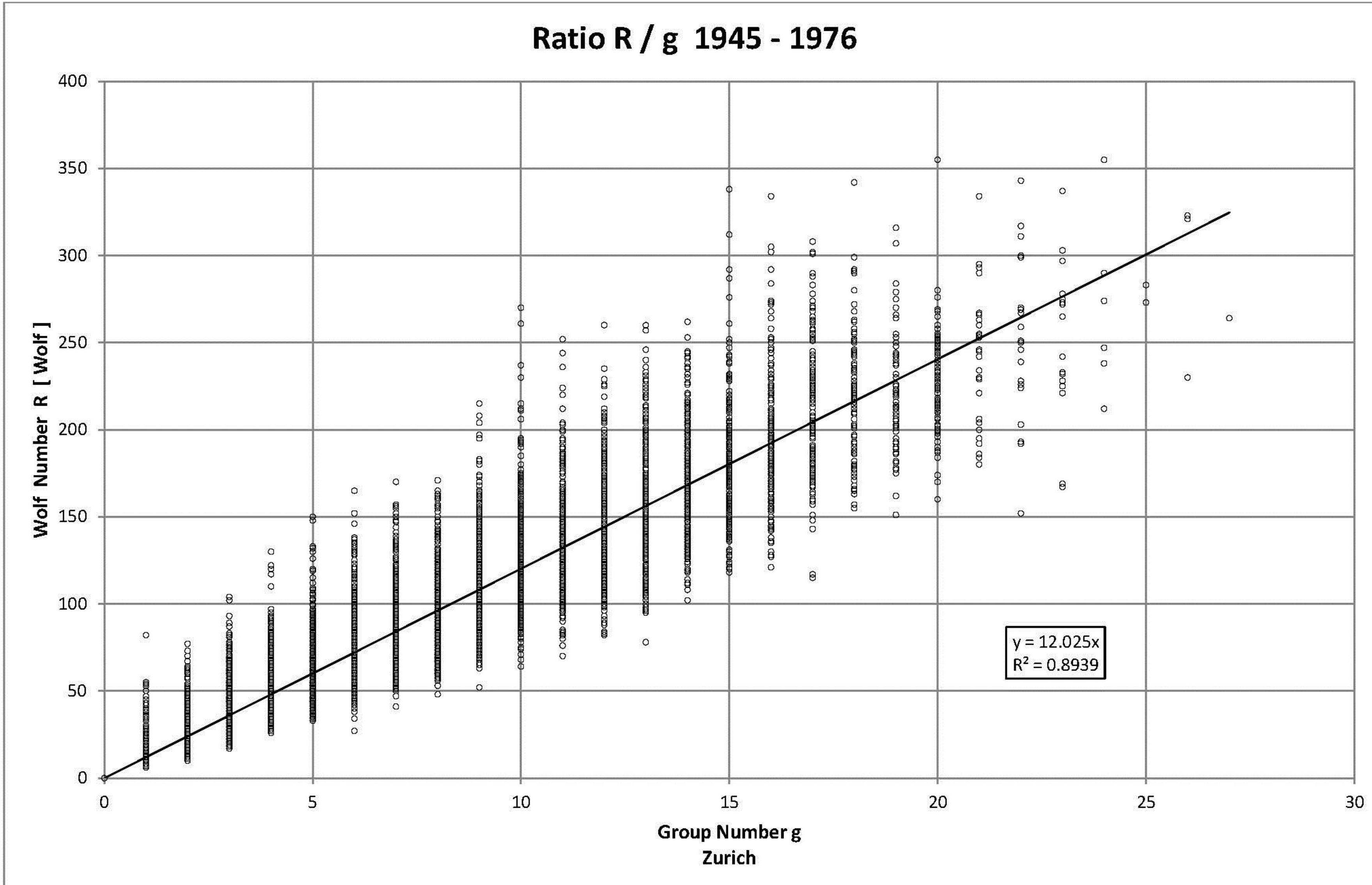
- Corrections in cycle no.
  - 13: Minor corrections
  - 12: Ascending phase lower
  - 11: Cycle lowered most
  - 10: Ascending phase higher
  - 9: Additional lowering due to Schwabe
- Comparison cycles 9 & 10 with WDC-SILSO version 2.0
  - Corrections for Wolf are more or less the same, but with better separation of the instruments and additional effect due to Schwabe in our recalculation



The Waldmeier Period 1945 - 1980

Known issues

- Group definition
  - Brunner introduced G Classes in the 1930ies
  - Introduction of the Zurich Classification in 1938
  - ► Scale homogenization will fully account for this issue
- Weighting of sunspots according to their extent
  - Possible level break near the beginning of the period
  - Possible gradual change over the years
  - ► Scale homogenization will fully account for this issue
  - ► Daily de-weighting should be applied before scale homogenization
- New k-factor definition
  - Simulation study reveals that new approach will rise the level of the secondary observations about 5%
  - ► Scale homogenization will account for this issue, but introduce an intra-cycle secondary bias, since Waldmeier's own observations are not affected

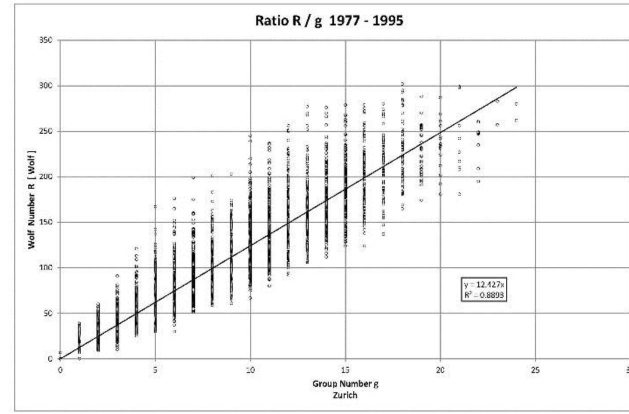


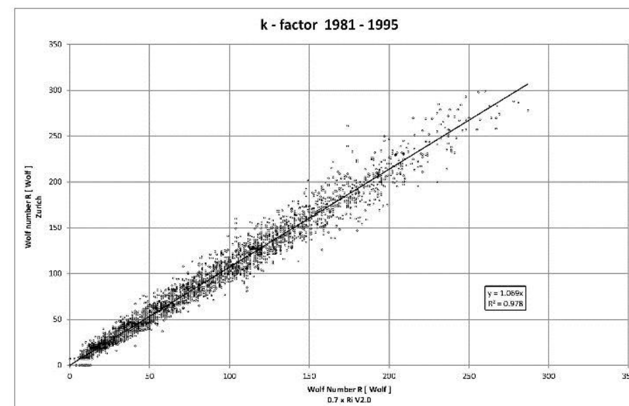
Ratio R / g 1945 - 1976
Wolf Number R [Wolf]
Group Number g
Zurich
y = 12.025x
R² = 0.8939
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30

Period 1945 - 2016

Scale Homogenization

- Data reduktion factors 1945 - 2008
  - **Wolf series 1945 - 1980**
    - $0.951 = \frac{11.432}{12.025}$
  - **Wolf series 1981 - 1995**
    - $0.983 = 1.069 \cdot \frac{11.432}{12.427}$
  - **Wolf series 1996 - 2008**
    - $0.927 = 0.981 \cdot \frac{19.054}{20.154}$
  - **Wolf series 2009 - 2016**
    - As in the last homogenization period: 0.927
- The k-factors for the years 1981 - 2008 have to be calculated with R's and g's from the Ri series





Period 1945 - 2016

Scale Homogenization

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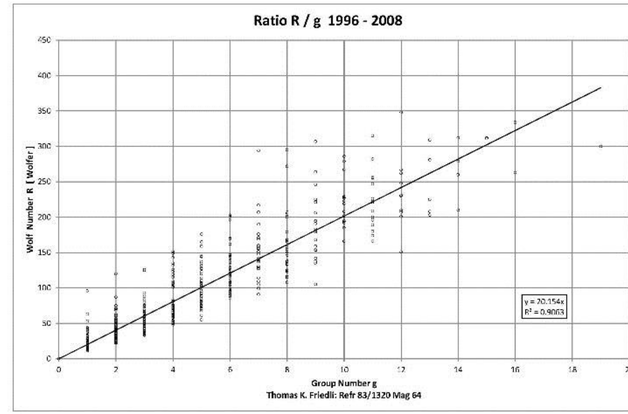
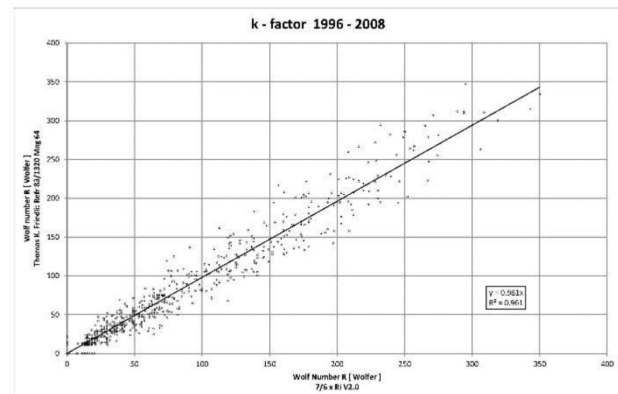
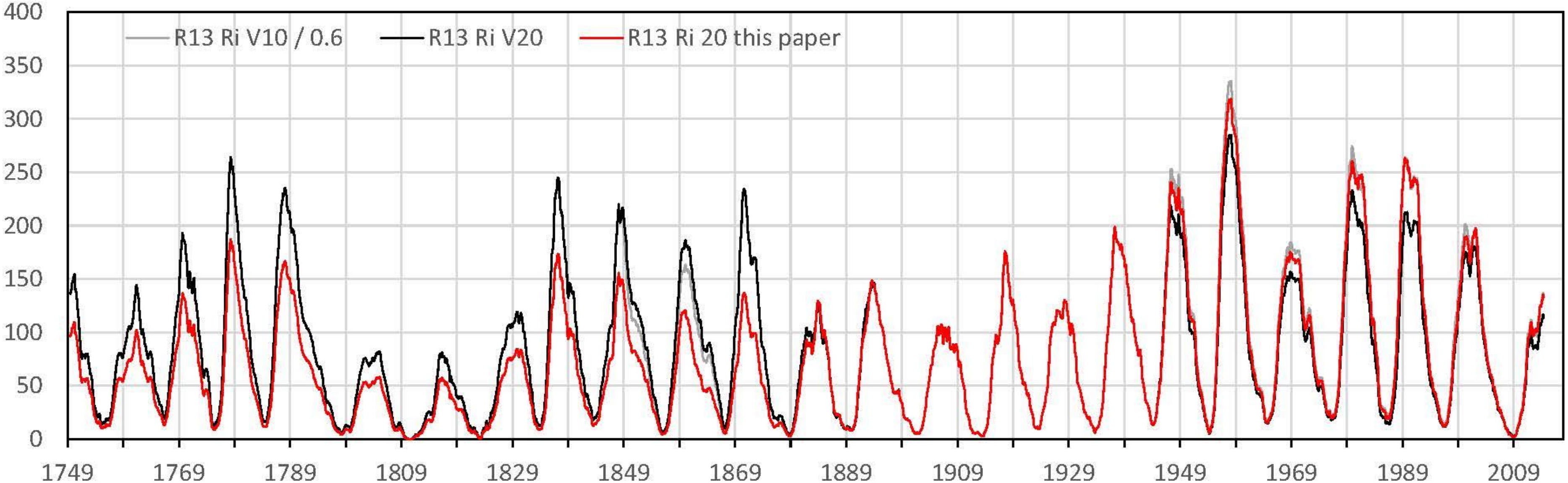
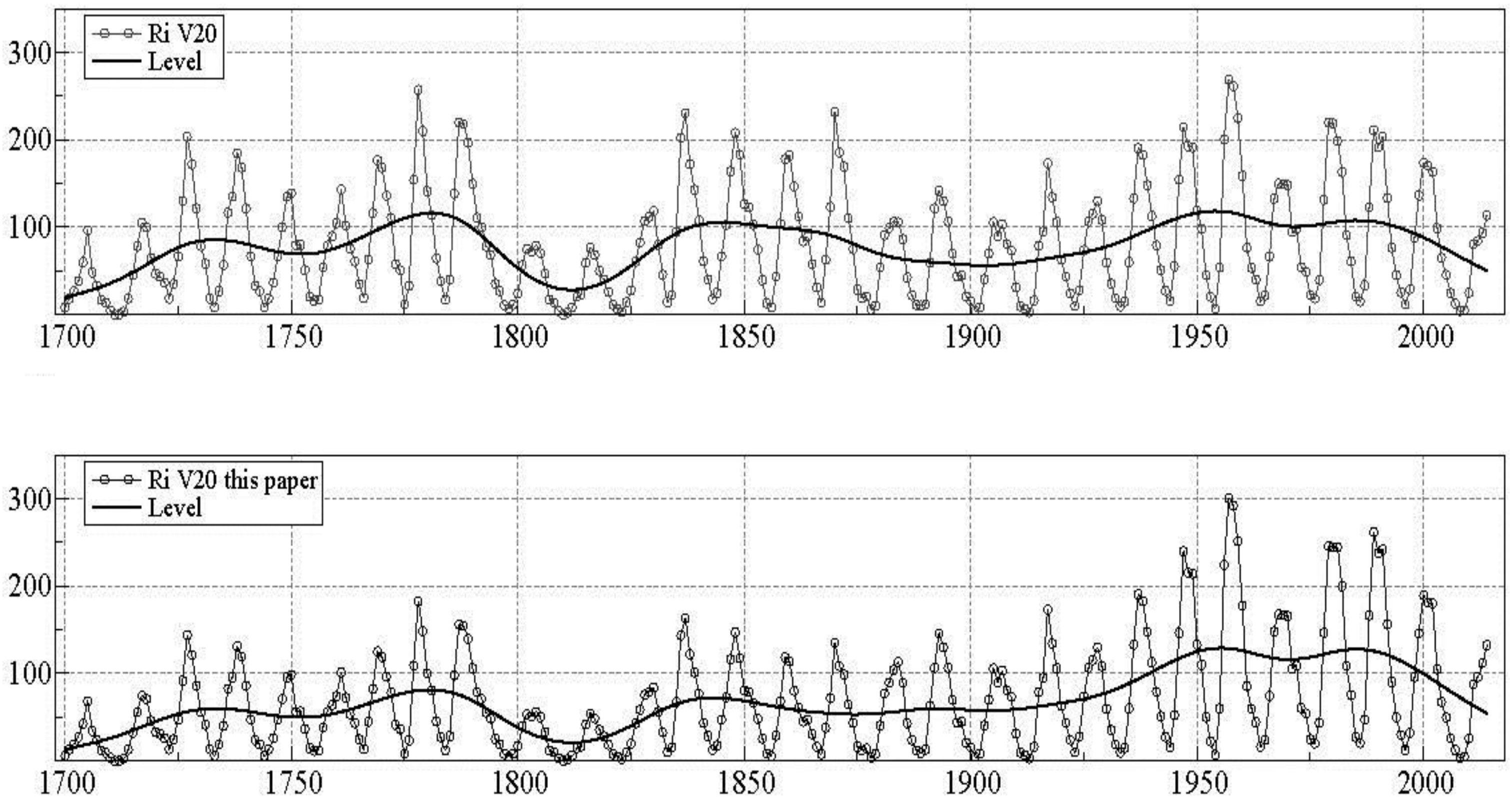




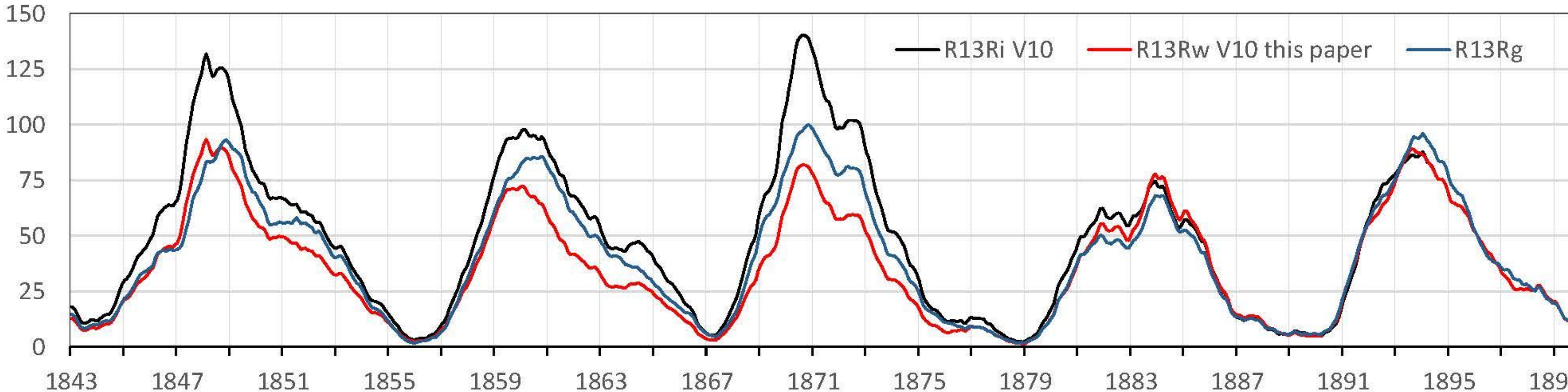
Partly homogenized Wolf series v2



Comparison v2 with partly homogenized v2



Comparison Rg with partly homogenized v1



Conclusions

- Spot numbers are not superfluous!
  - A proper scale homogenization without individual spot numbers is impossible
  - We should determine the individual spot numbers to the group numbers of Hoyt and Schatten
  - The actual series of Wolf numbers should be extended with a homogeneous series of group numbers (done).
- We have to distinguish between data correction and series homogenization
  - First the data correction then the series homogenization
  - Each correction step should be completed by a re-homogenization step

Next Projects

- **Digitization of the Source Book**
  - First back to 1749, later back to 1610
  - Digitization of the data from the years 1900 to 1944
- **Transition from Zurich to SIDC**
  - Digitization of the observations from Zurich 1975 to 1995
  - Modelling of the transfer by different methods
- **Modelling of intra-cycle scale variability**
  - Construction of a model for monitoring and statistical testing of the long-term scale homogeneity not only from one cycle to another, but on a yearly or even monthly basis.
- **Modelling of data reduction algorithm incorporating scale**
  - The preserved scale constant of the standard system will give the necessary constraint on the population mean in a mixed-effects type model for data reduction.