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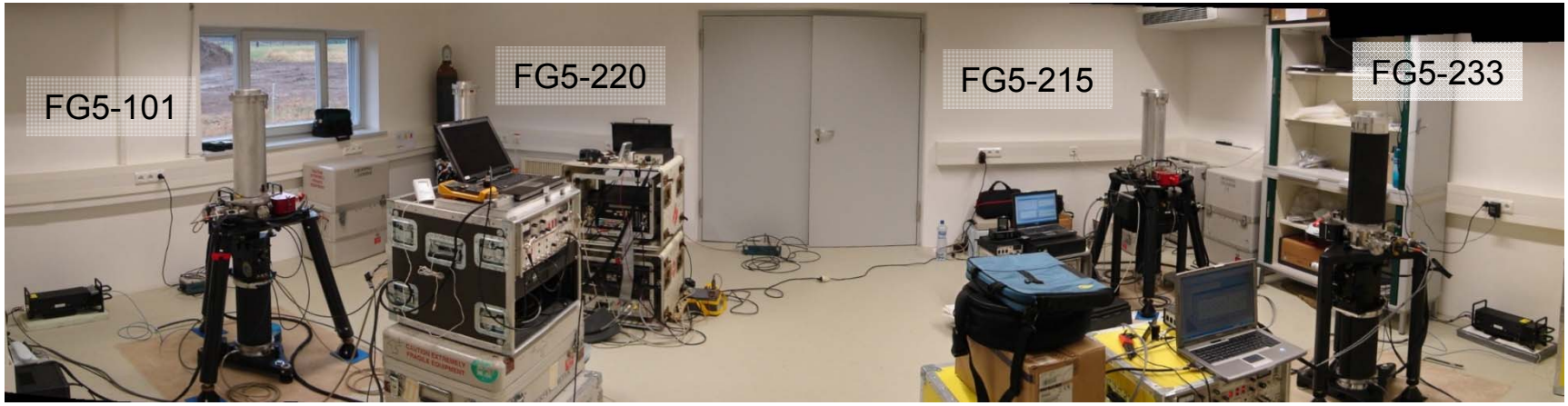
Integration of Regional Absolute Gravimeter Comparisons into the Framework of the International Comparisons

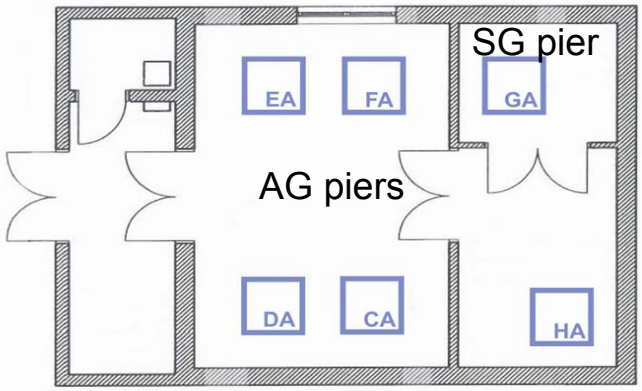
Hartmut Wziontek, Reinhard Falk, Herbert Wilmes
Bundesamt für Kartographie und Geodäsie
Frankfurt am Main / Leipzig
Germany

Gravity station at the Geodetic Observatory Wettzell: Development as Regional Comparison Site

Regional intercomparisons of absolute gravimeters Nov. 2010 and Feb 2013:
Five FG5 from three countries (Czech Republic, Sweden, Germany)



Ground plan



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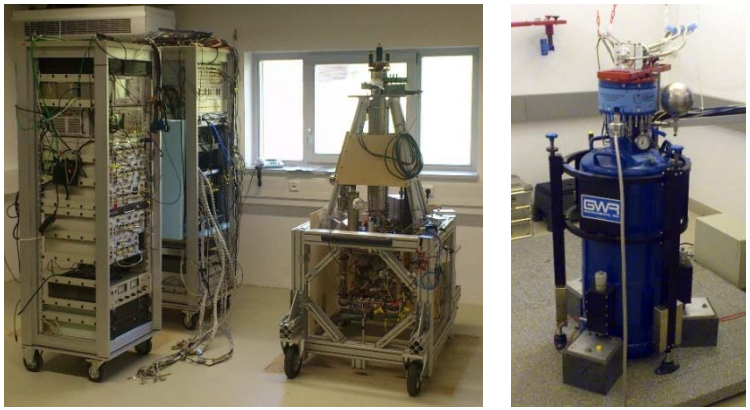
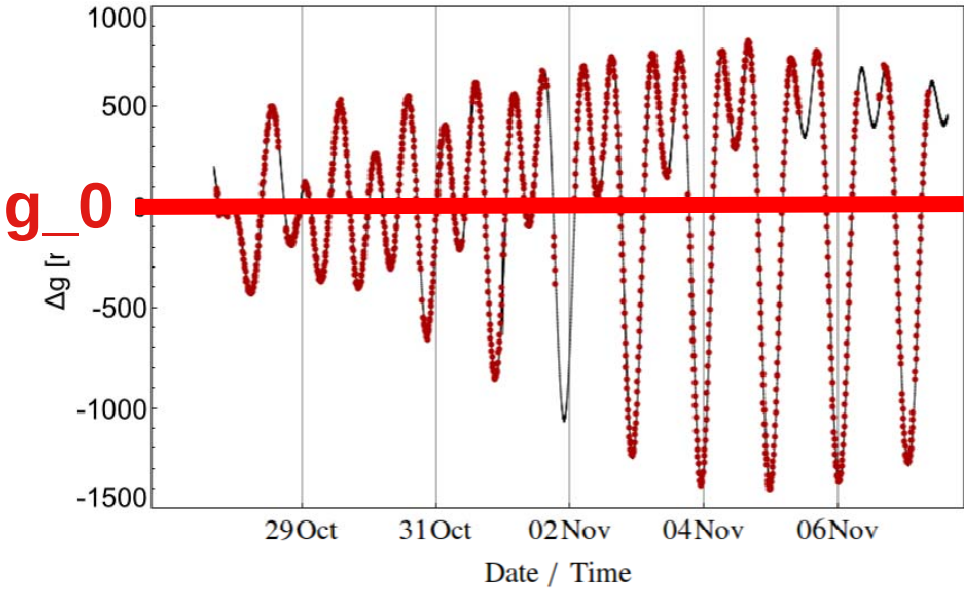
Mobile Atom Interferometer
GAIN (Gravimetric Atom Interferometer)

- Measurement at the Geodetic Observatory Wettzell (BKG)
- Transport from Berlin (small truck)
- 2 weeks of gravity recordings
- Simultaneous operation of super-conducting gravimeter SG30 on site



GAIN SG-30



Measured by GAIN:

- Tidal gravity variation
- Excellent agreement with model and the SG-30
- Reliable operation with only few gaps

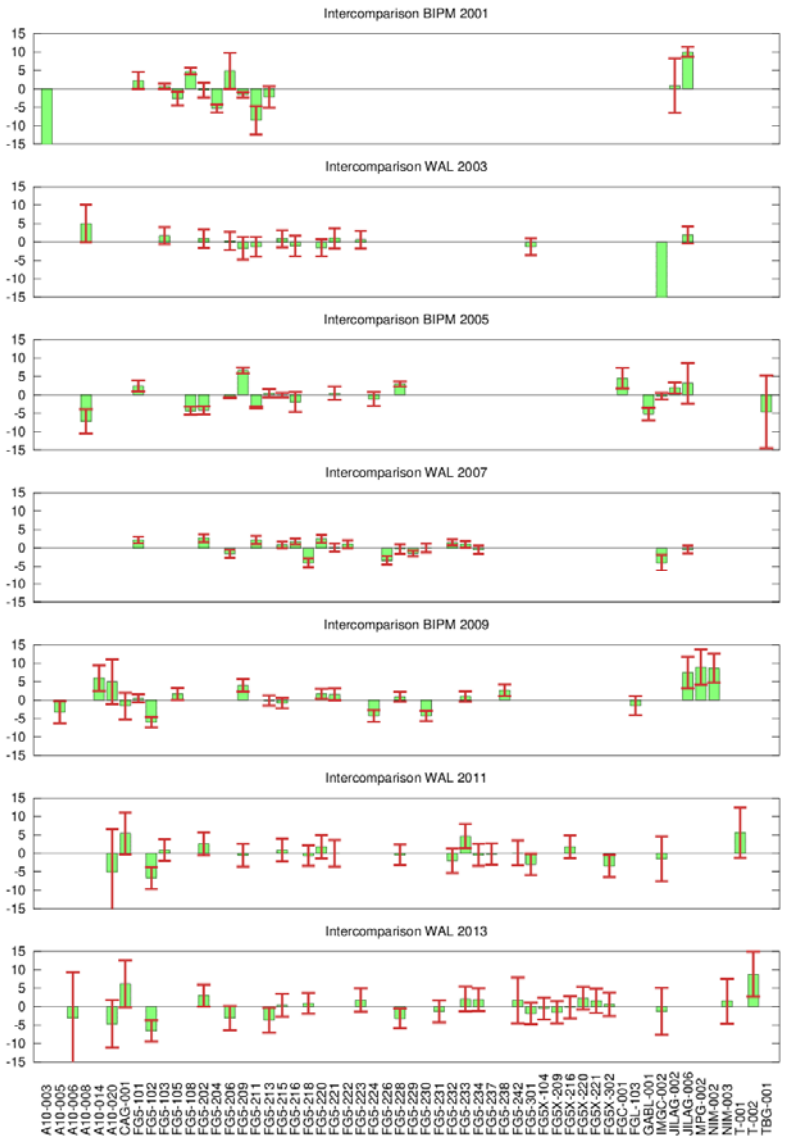
Next step:

- Comparison of absolute gravity value

Published in *Proceedings of the International School of Physics Enrico Fermi Course CLXXXVIII on Atom Interferometry*

International Comparisons of Absolute Gravimeters

- ICAG supported by BIPM from 1981 until 2009, repeat cycle: 4 years
  First CIPM Key Comparison in 2009,
- Intermediate comparisons at Walferdange/ Luxembourg since 2003, shifted by 2 years, first ICAG in 2013,
- Gravity standard: realized by all absolute gravimeters – no independent reference,
- Link to SI quantities by application of standards for time and distance (e.g. Rb-oscillator and stabilized laser),
- Consistency checks by repeated comparisons,
- Applications in Geosciences / Geodesy: Gravity *changes* over time → temporal stability of an AG most important (repeatability),
- Complementary regional comparisons, but compatibility to ICAGs needed.



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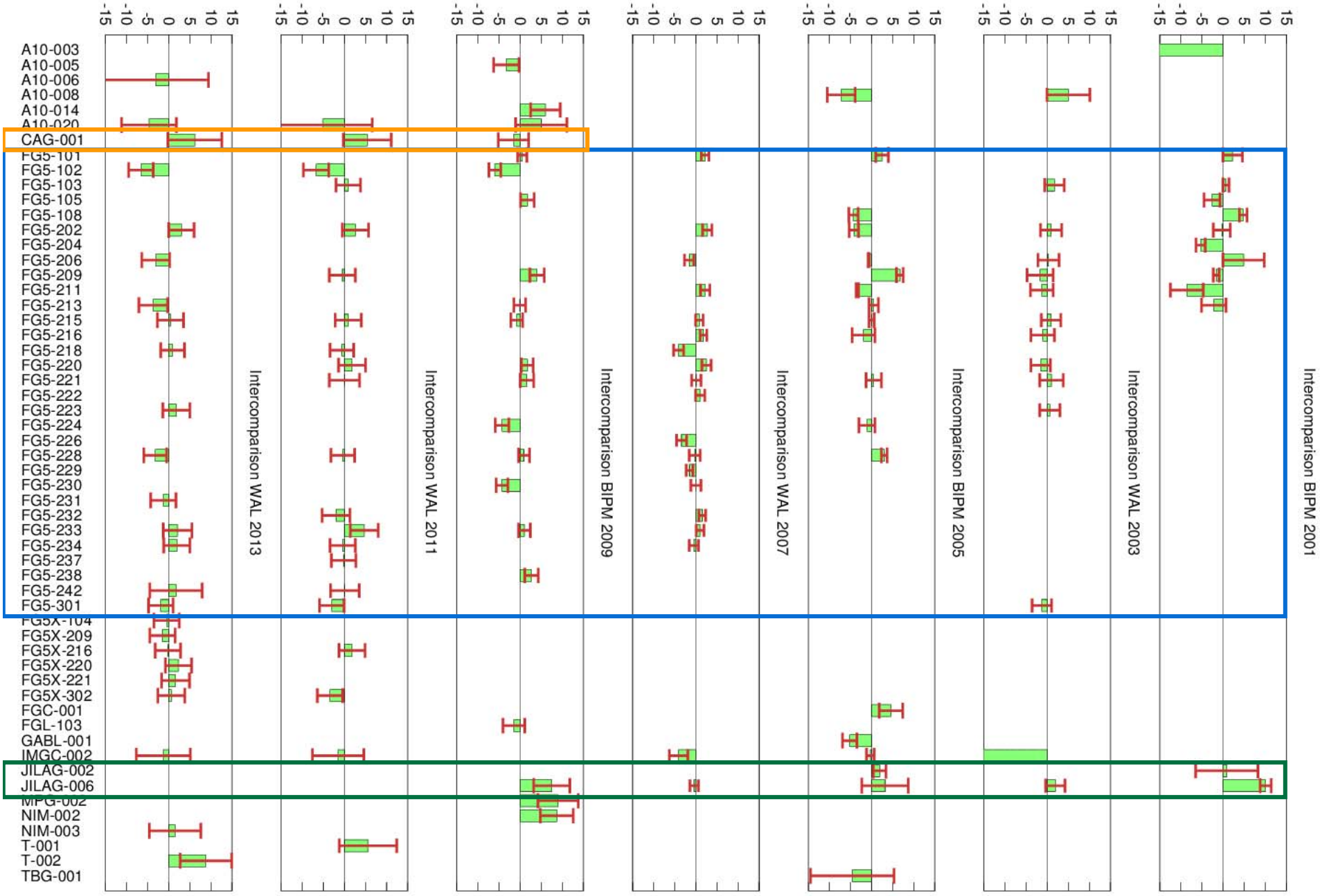
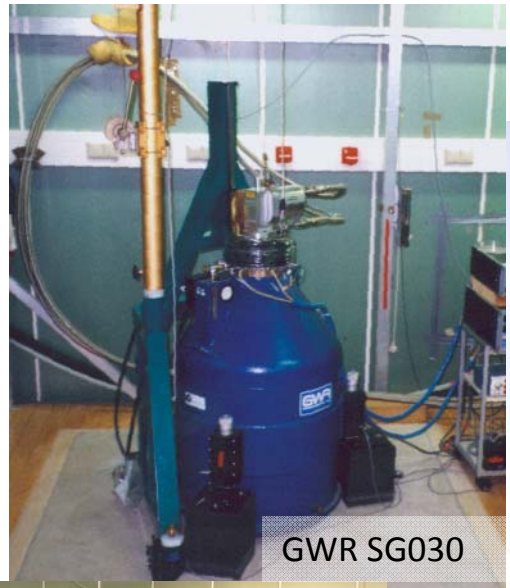
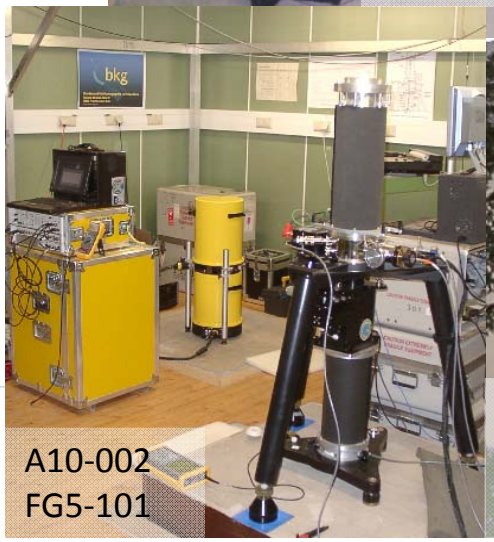
AG offsets from International comparisons 2001-2013



Regional Comparison Sites

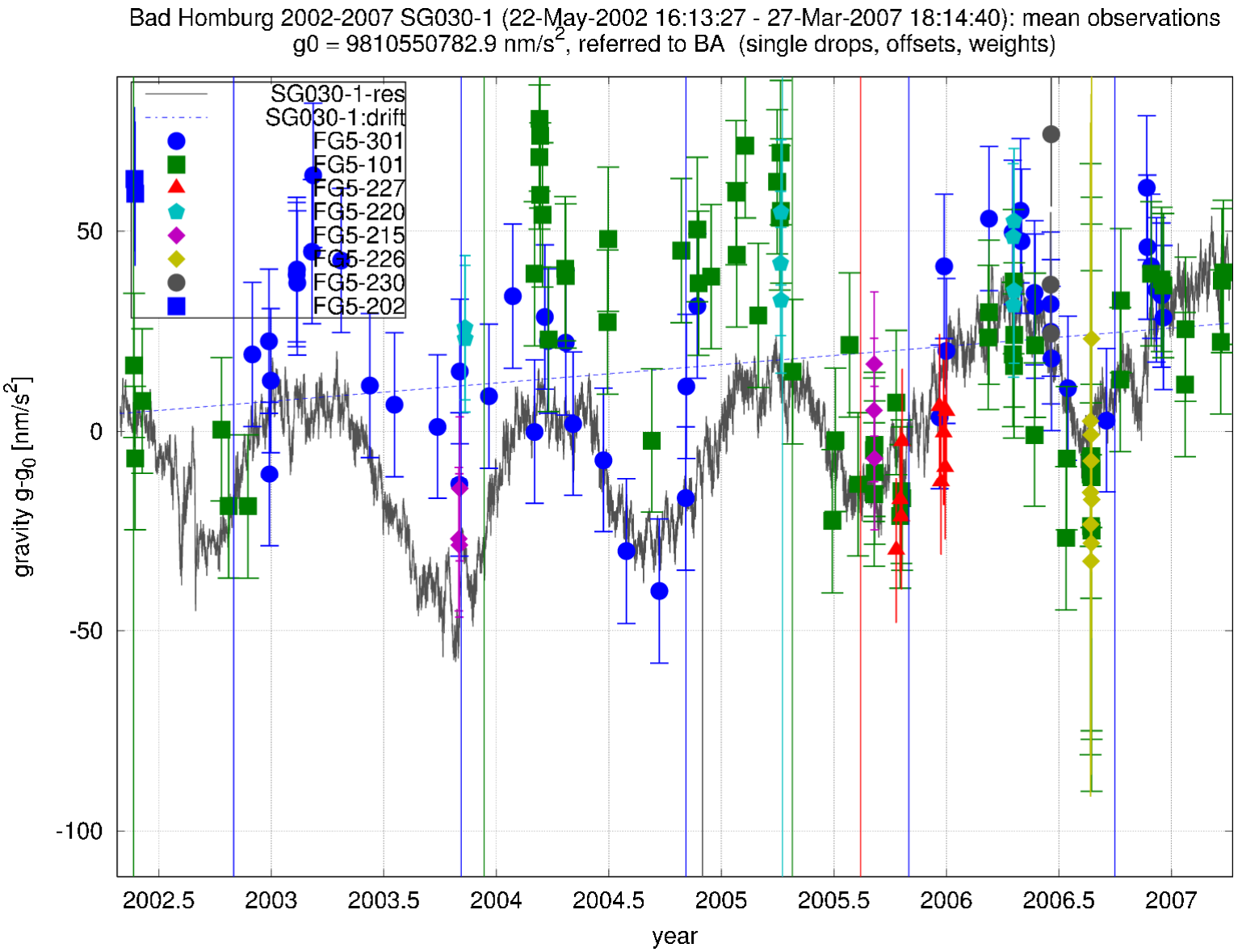
- Supplementary to international comparisons
- Frequently repeated absolute gravity measurements
- Monitoring of temporal changes with Superconducting Gravimeter (SG)
- Continuous reference *function* (CRF) by combination of both observation types
- Comparison of other AG against reference function possible at any time
- Problem:
  Bias estimate for the local CRF with respect to ICAG's?



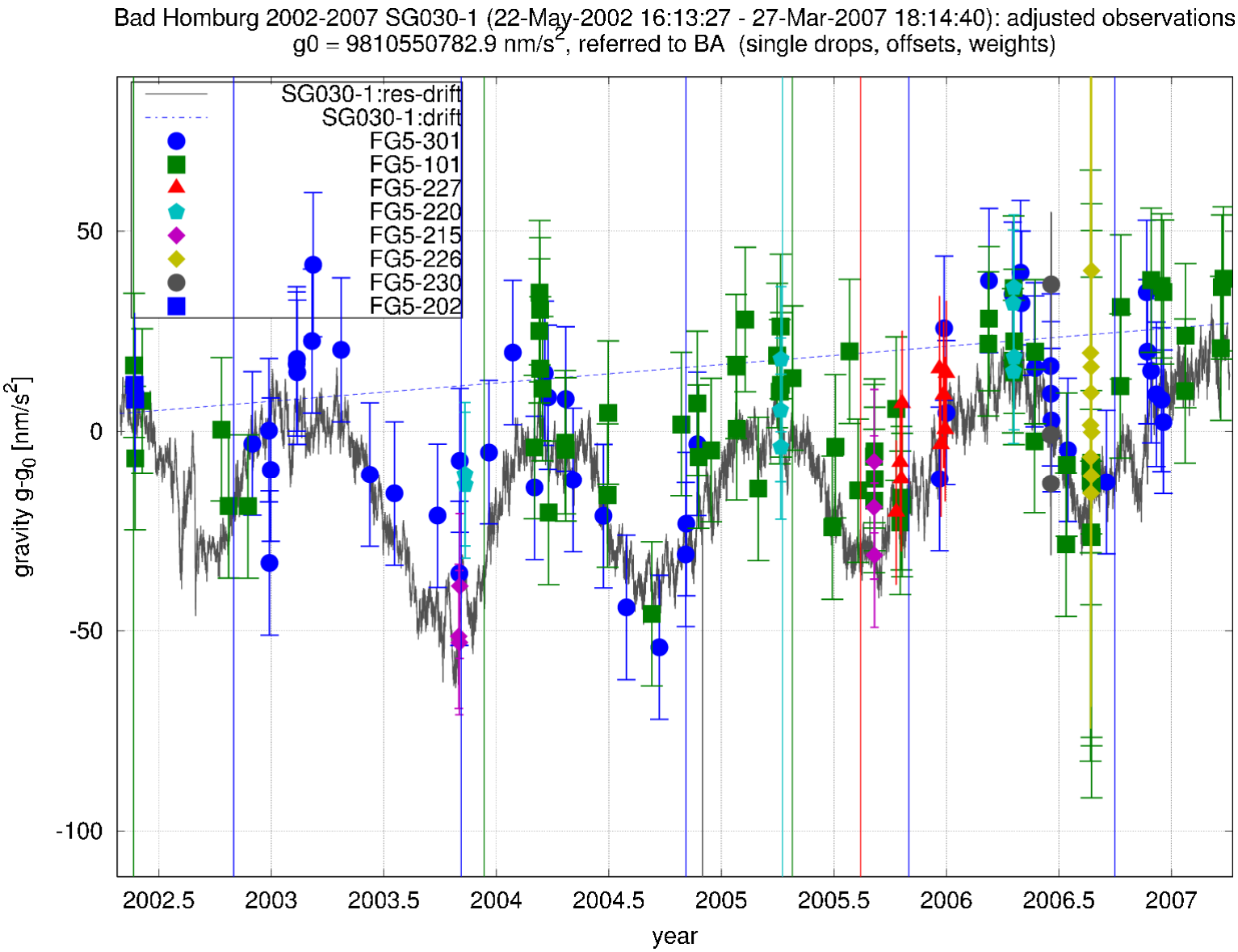



Station Bad Homburg:
Two monuments for AG,
SG030 / SG044

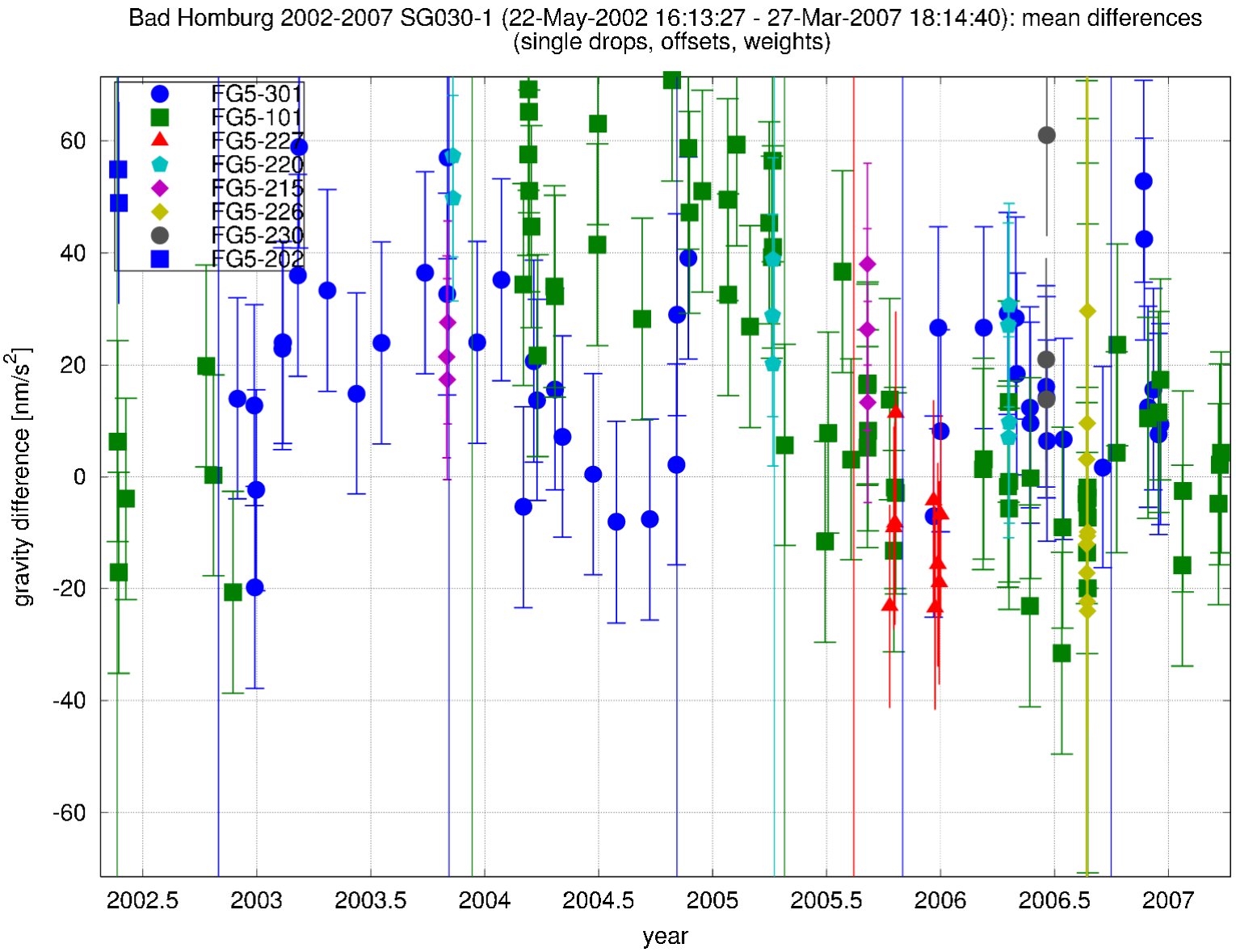
Bad Homburg 2002-2007: FG5 / SG030



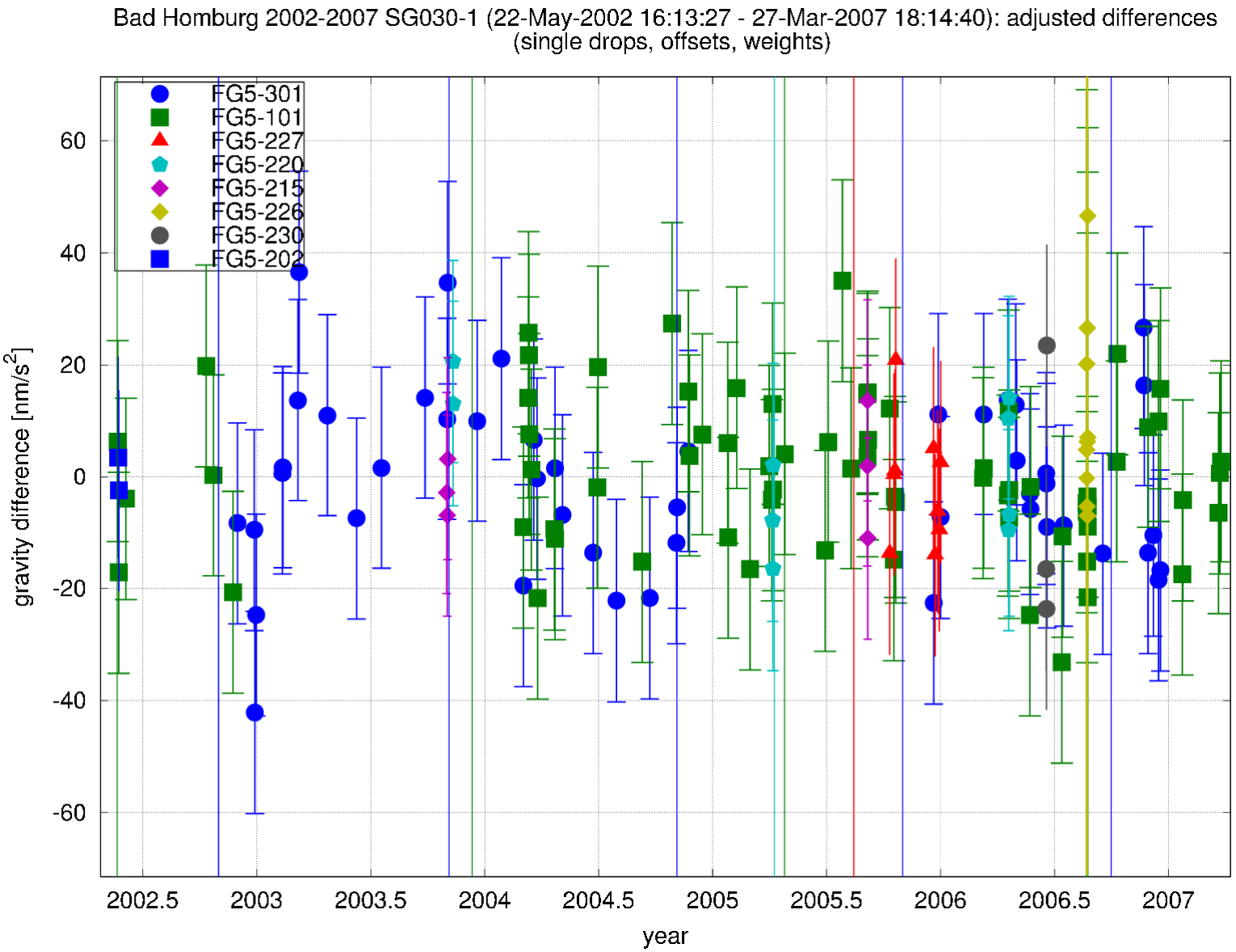
Bad Homburg 2002-2007: FG5 / SG030



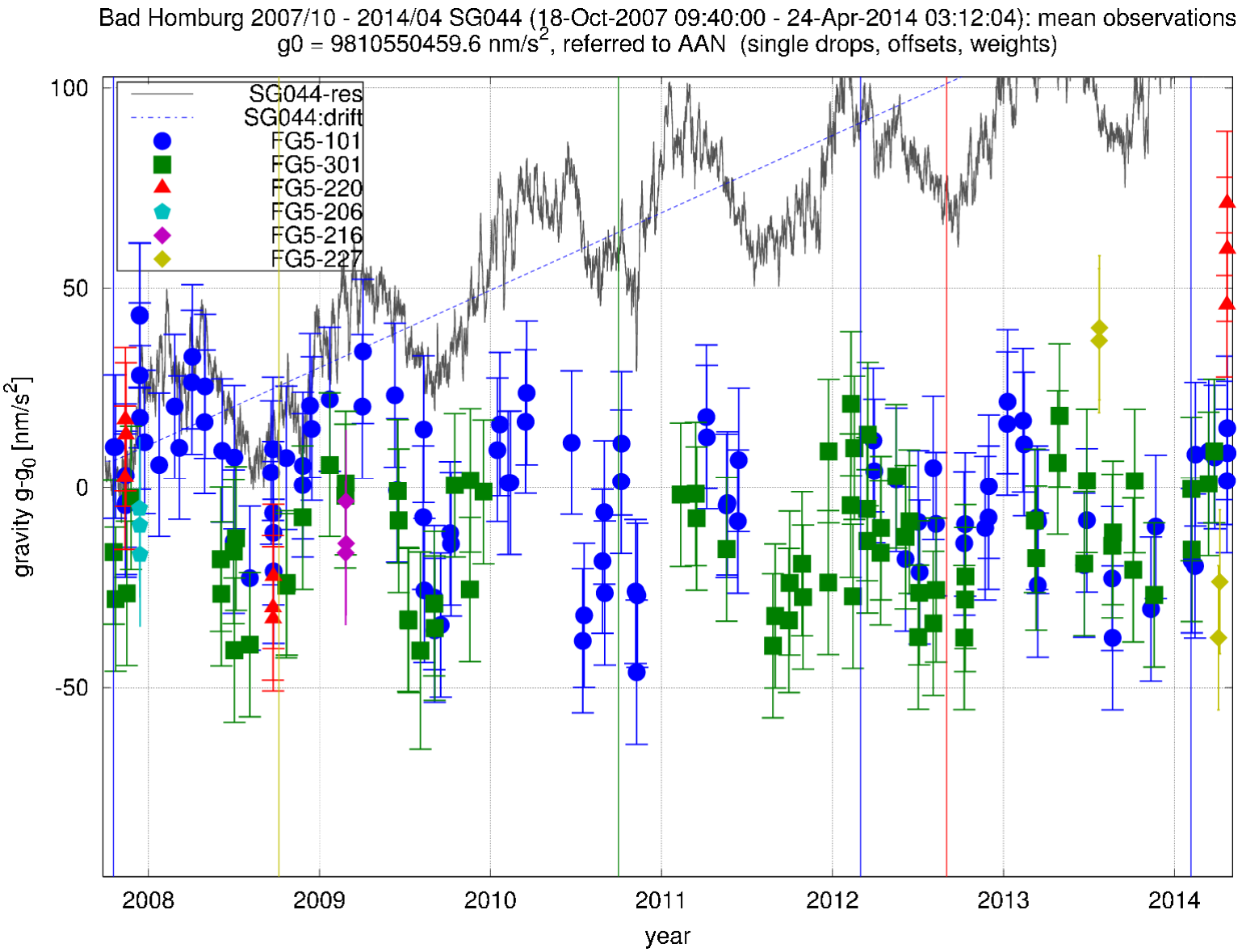
Bad Homburg 2002-2007: Differences AG - SG



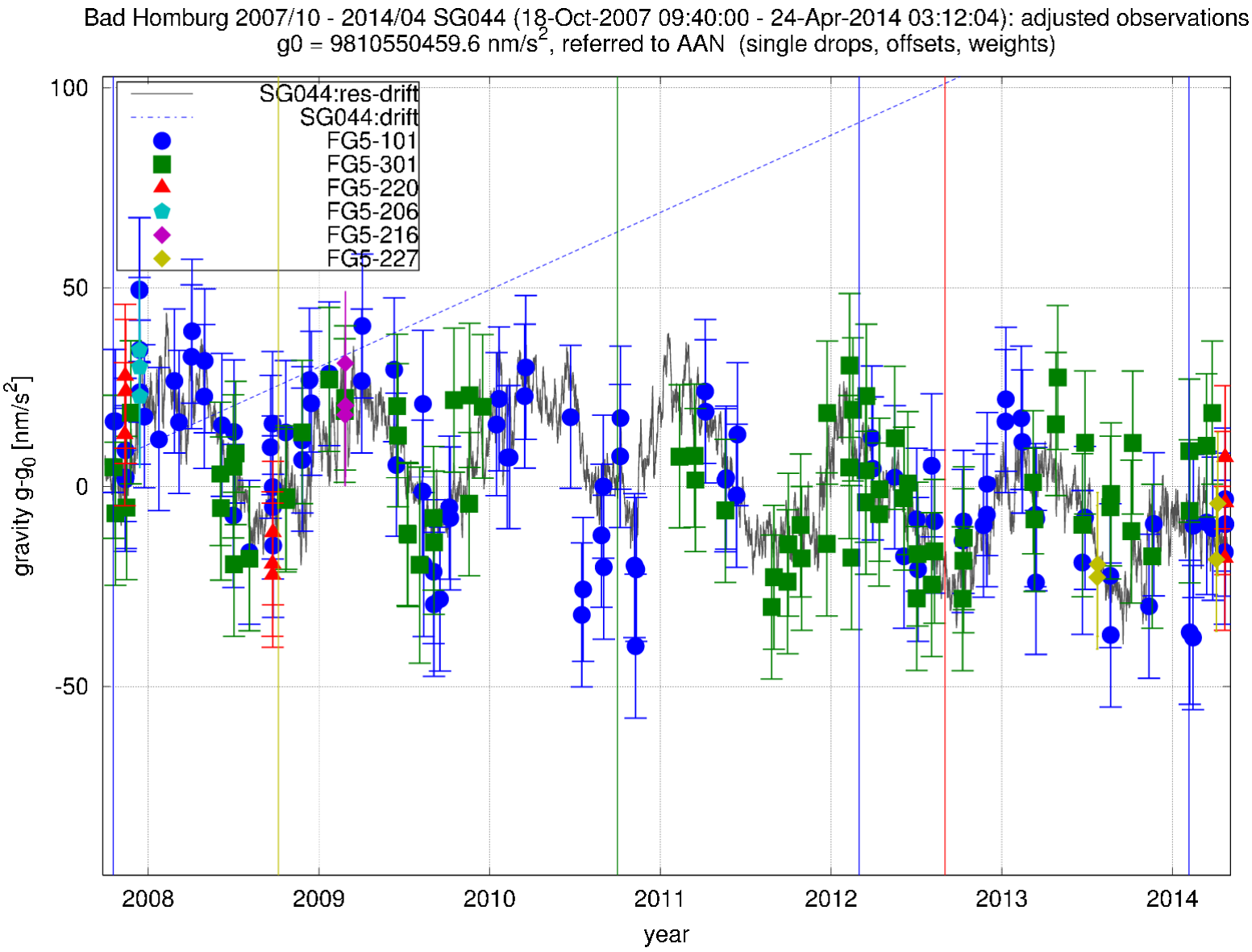
Bad Homburg 2002-2007: Differences AG - SG - offsets



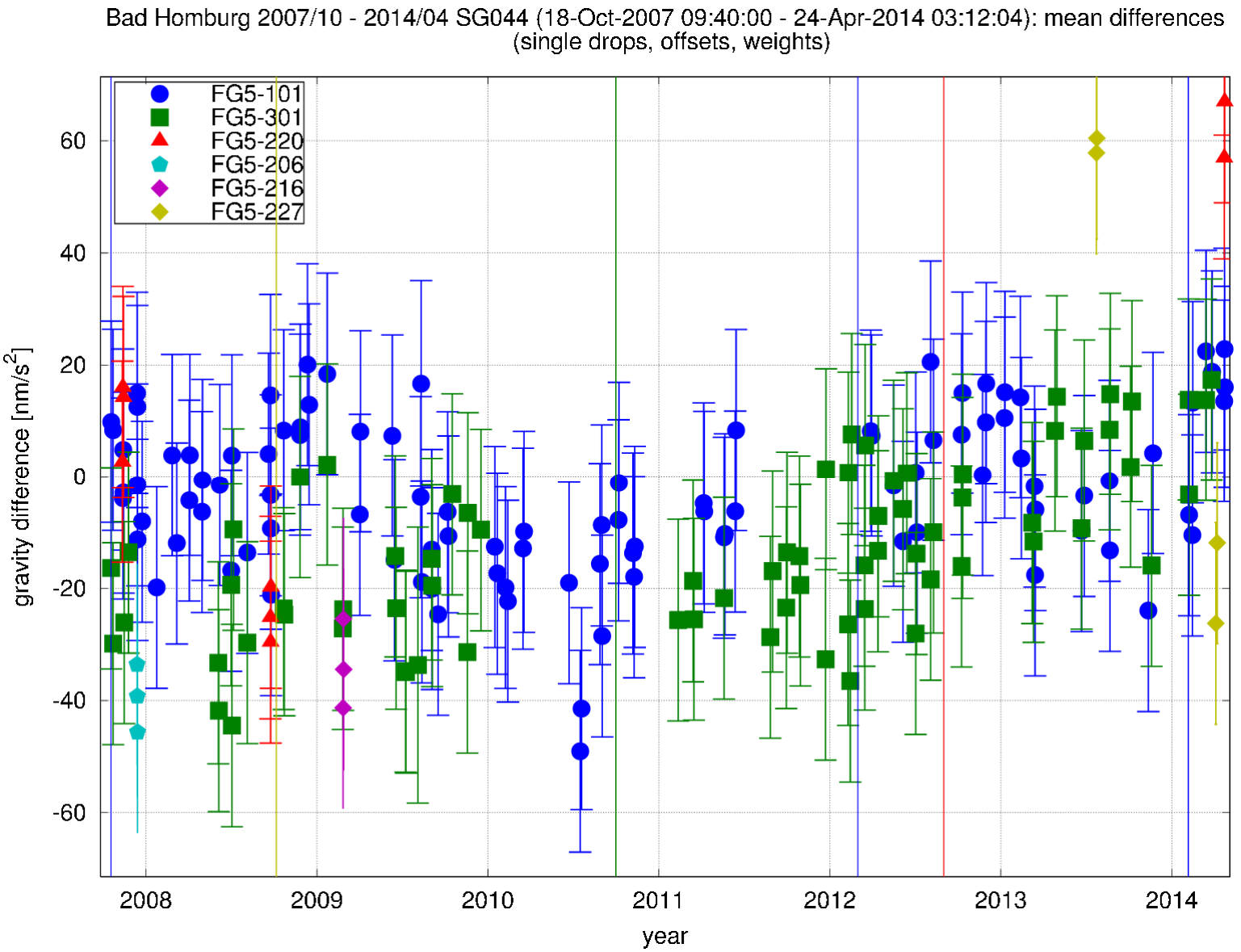
Bad Homburg 2007-2014: FG5 / SG044



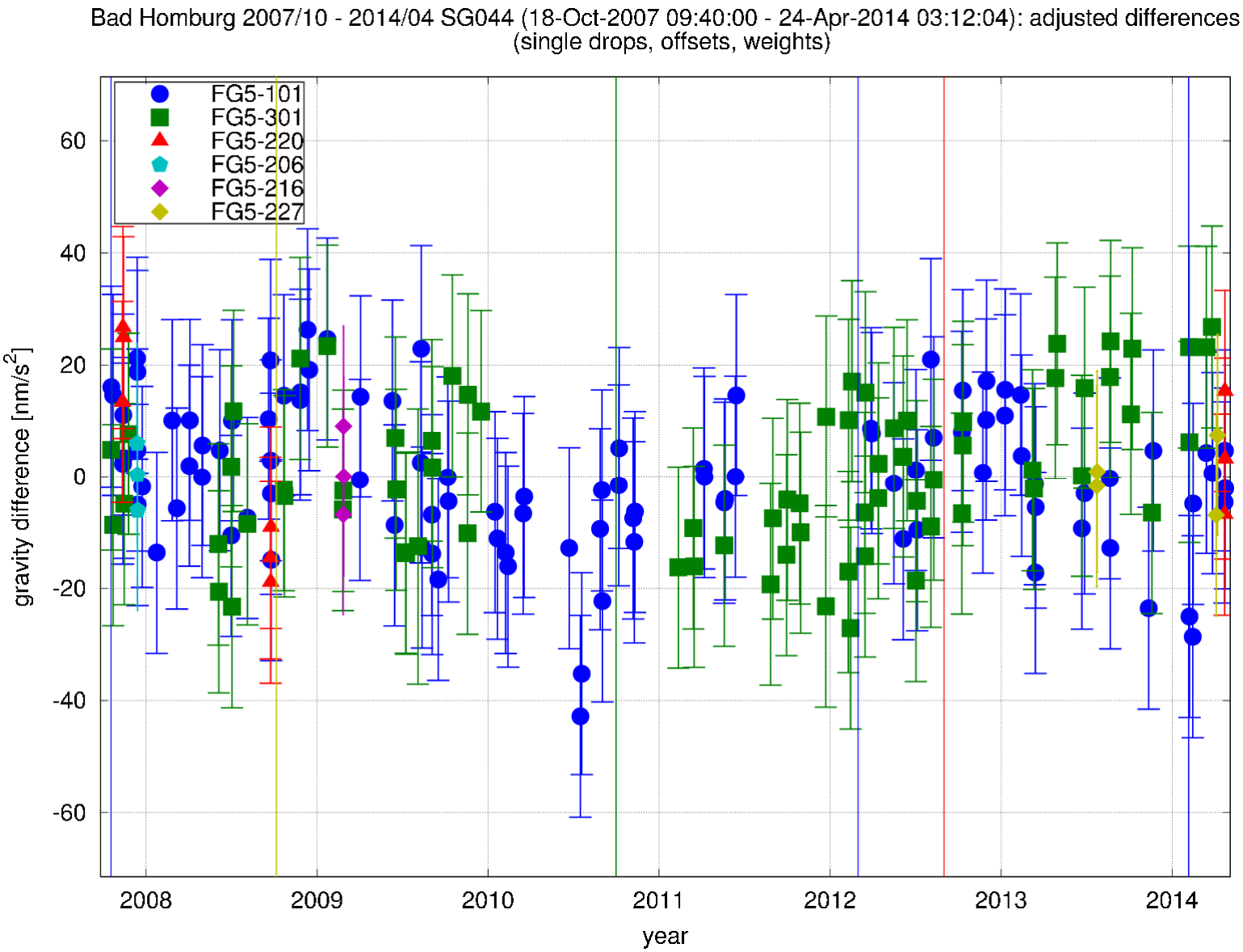
Bad Homburg 2007-2014: FG5 / SG044



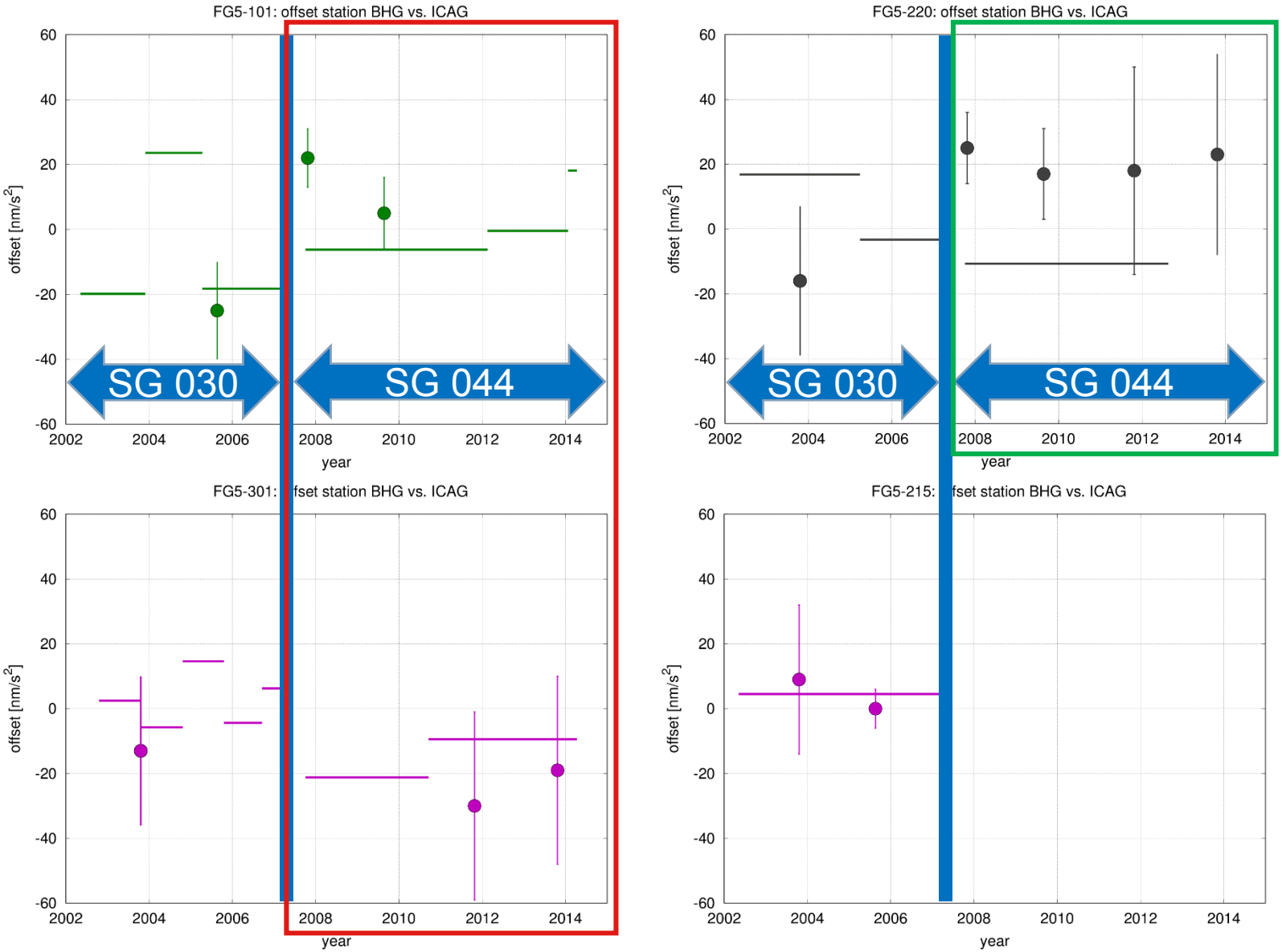
Bad Homburg 2007-2014: Differences AG - SG



Bad Homburg 2007-2014: Differences AG - SG - offsets

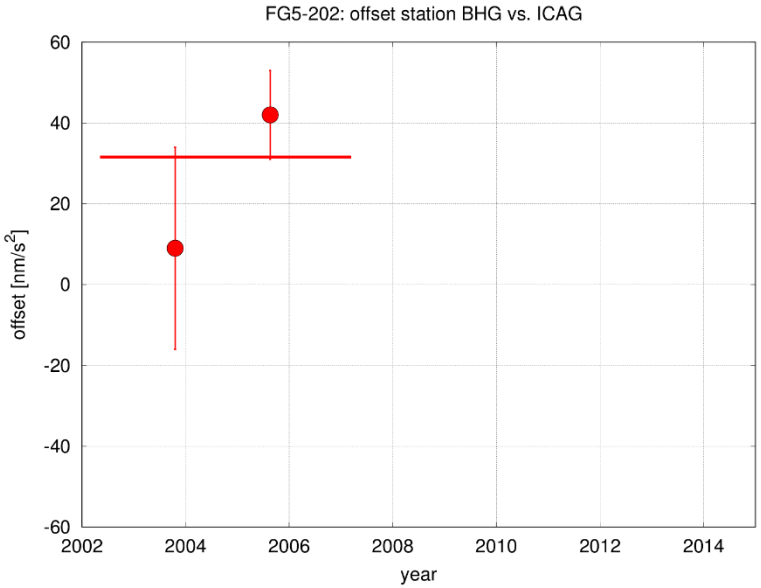


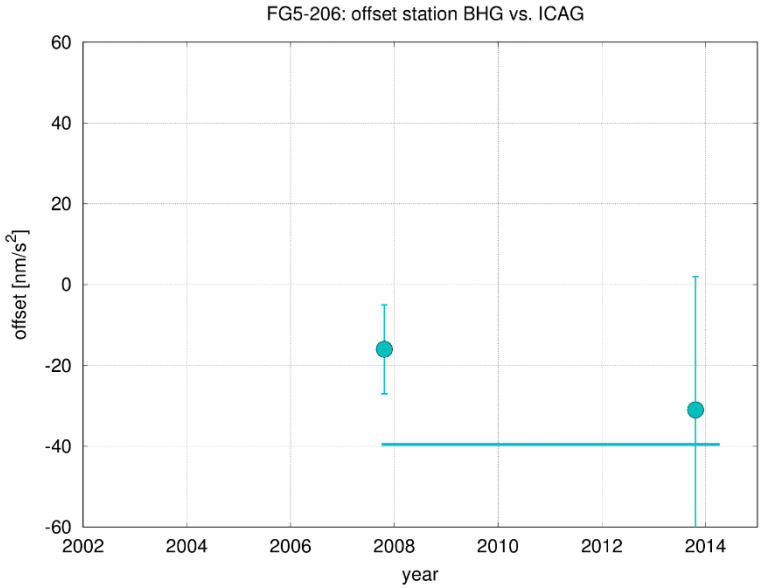
Bad Homburg vs. ICAG/ECAG 2002-2014

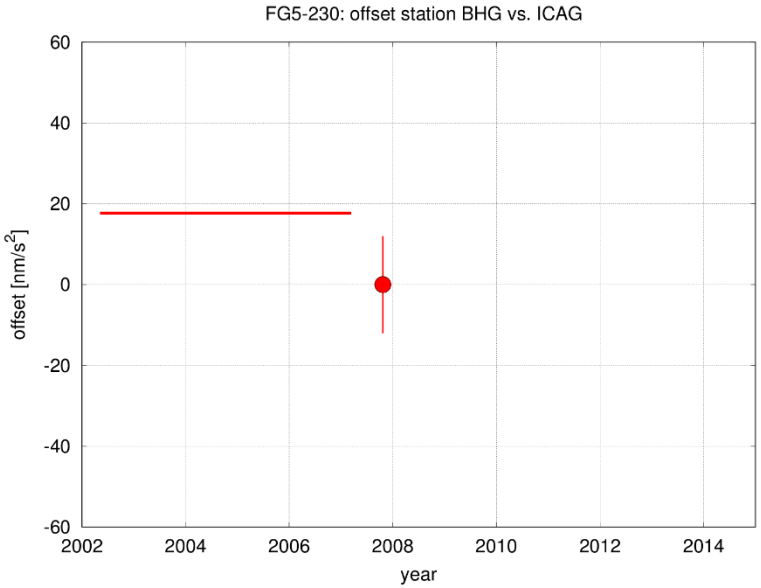


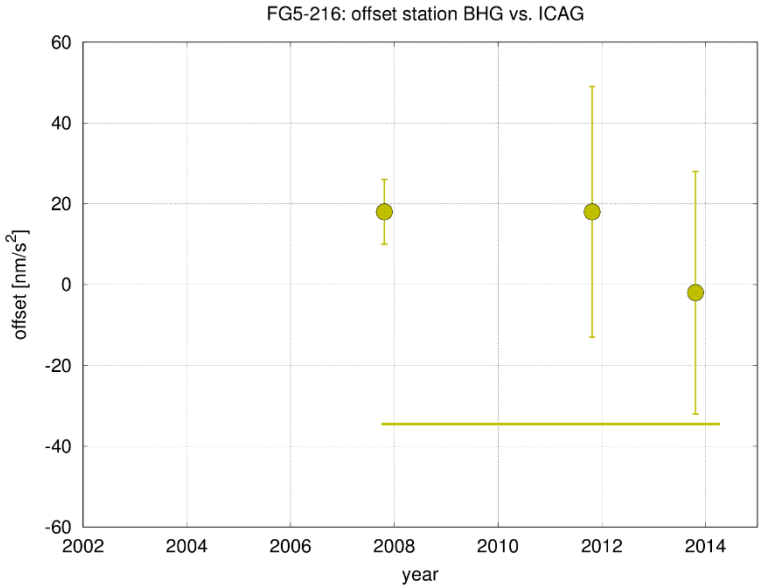
Marker: ICAG / Lines: level changes for predefined periods from combination with SG

Bad Homburg vs. ICAG/ECAG 2002-2014









Marker: ICAG / Lines: level changes for predefined periods from combination with SG

Bad Homburg vs. ICAG/ECAG 2002-2014

- Two periods:

  a) SG030:
  05/2002 – 03/2007

  b) SG044
  10/2007 – 04/2014

- Bias to ICAG's:
  a) +9 nm/s^2
  b) -23 nm/s^2
- Difference of CRF between epochs a) and b): ~ 30 nm/s^2
- Transition SG030 → SG044 close to maintenance of FG5-101/ FG5-301

Grey shaded values excluded!
*WAL 2013: preliminary results

Station	AG	Regional Comparison				International Comparison				Diff Offset	Offset regional shifted
BHG SG030	FG5-101	05//2002	12//2003	-20	0	BIPM	07//2001	23	23	-43	-28
		12//2003	04//2005	24	1	BIPM	07//2001	23	23	1	15
		04//2005	03//2007	-18	2	BIPM	09//2005	-25	15	7	-27
	FG5-202	05//2002	03//2007	32	2	WAL	11//2003	9	25	23	23
		05//2002	03//2007	32	2	BIPM	09//2005	42	11	-10	23
	FG5-215	05//2002	03//2007	5	1	WAL	11//2003	9	23	-5	-4
		05//2002	03//2007	5	1	BIPM	09//2005	0	6	5	-4
	FG5-220	05//2002	04//2005	17	3	WAL	11//2003	-16	23	33	8
		04//2005	03//2007	-3	3	WAL	11//2003	-16	23	13	-12
	FG5-226	05//2002	03//2007	-37	2	WAL	11//2007	-34	12	-3	-45
	FG5-230	05//2002	03//2007	18	2	WAL	11//2007	0	12	18	9
	FG5-301	11//2002	11//2003	3	1	WAL	11//2003	-13	23	16	-6
		11//2003	11//2004	-6	1	WAL	11//2003	-13	23	7	-14
		11//2004	11//2005	15	3	WAL	11//2003	-13	23	28	6
		11//2005	10//2006	-4	2	WAL	11//2003	-13	23	9	-13
		10//2006	03//2007	6	2	WAL	11//2003	-13	23	19	-2
		05//2002	03//2007			Mean offset difference				9	
						RMS				12	
BHG SG044	FG5-101	10//2007	03//2012	-6	0	WAL	11//2007	22	9	-28	16
		10//2007	03//2012	-6	0	BIPM	09//2009	5	11	-11	16
		03//2012	02//2014	0	0	None					22
		02//2014	04//2014	18	1	None					41
	FG5-206	10//2007	04//2014	-40	1	WAL	11//2007	-16	11	-24	-17
		10//2007	04//2014	-40	1	WAL *	11//2013	-31	33	-9	-17
	FG5-216	10//2007	04//2014	-35	1	WAL	11//2007	18	8	-53	-12
		10//2007	04//2014	-35	1	WAL	11//2011	18	31	-53	-12
		10//2007	04//2014	-35	1	WAL *	11//2013	-2	30	-33	-12
	FG5-220	10//2007	09//2012	-11	1	WAL	11//2007	25	11	-36	12
		10//2007	09//2012	-11	1	BIPM	09//2009	17	14	-28	12
		10//2007	09//2012	-11	1	WAL	11//2011	18	32	-29	12
		09//2012	04//2014	64	1	WAL	11//2013	23	31	41	86
	FG5-301	10//2007	10//2010	-21	1	WAL	11//2003	-13	23	-8	1
		10//2010	04//2014	-9	0	WAL	11//2011	-30	29	21	13
		10//2010	04//2014	-9	0	WAL *	11//2013	-19	29	10	13
		10//2007	04//2014			Mean offset difference				-23	
						RMS				22	

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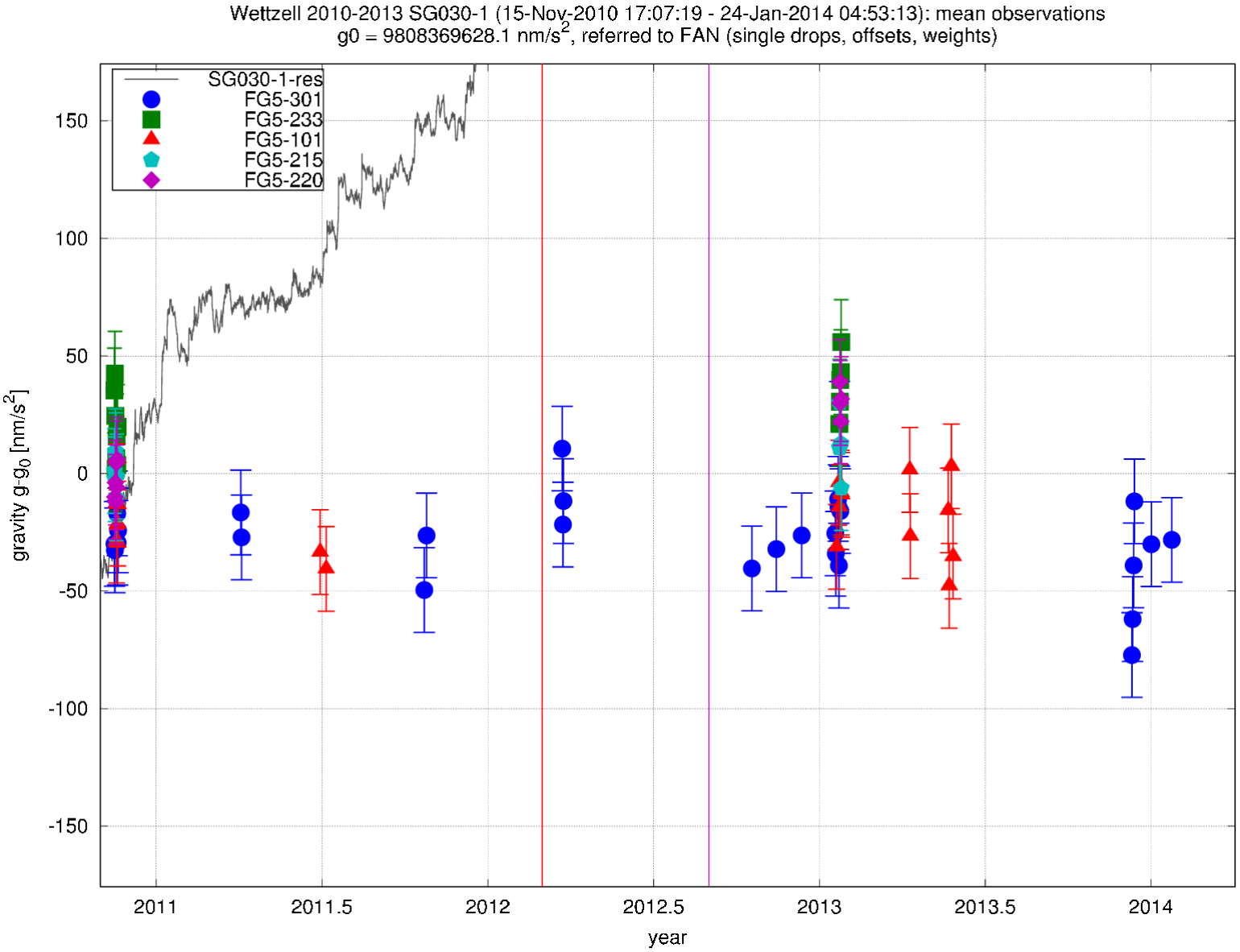
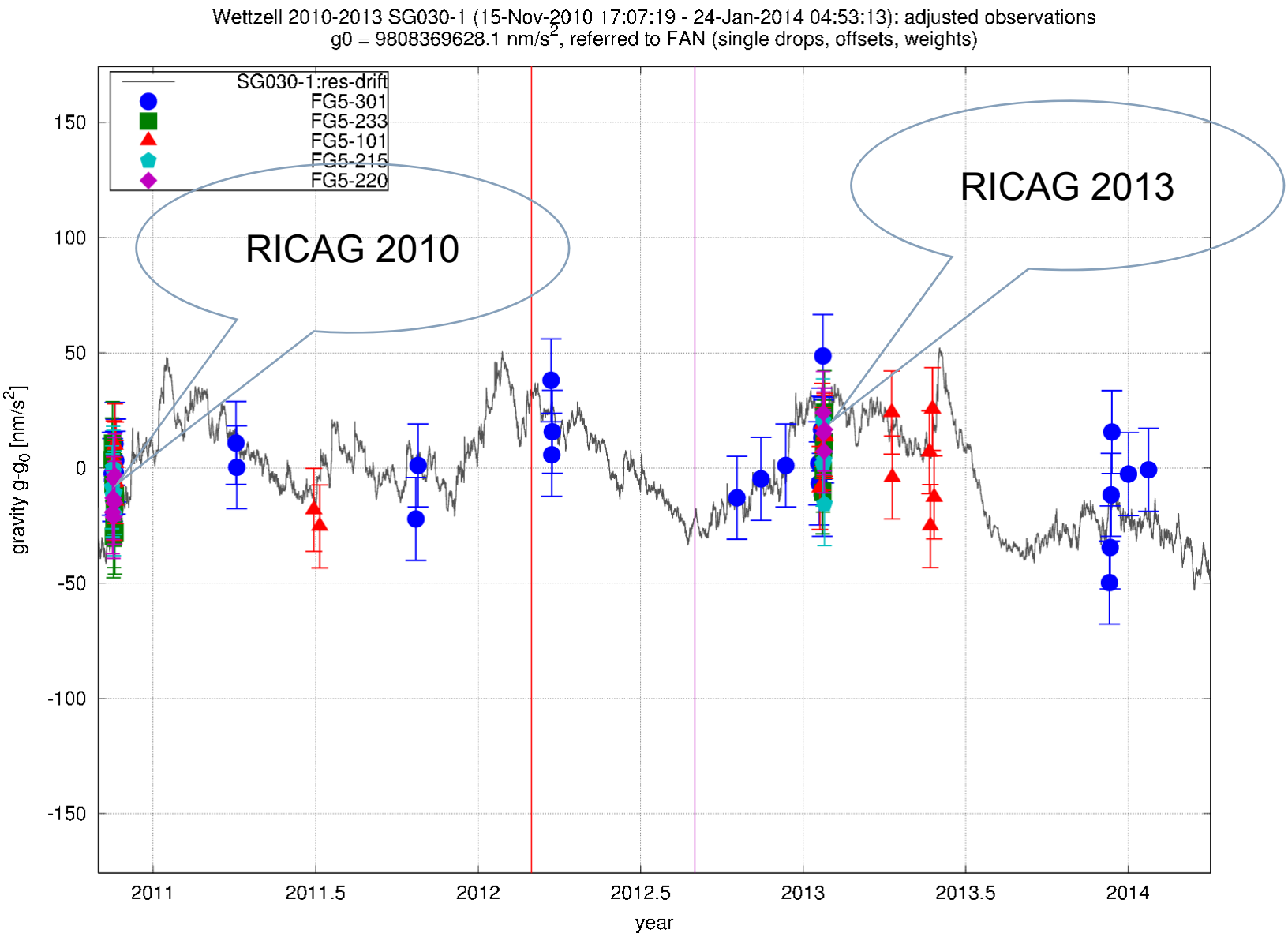
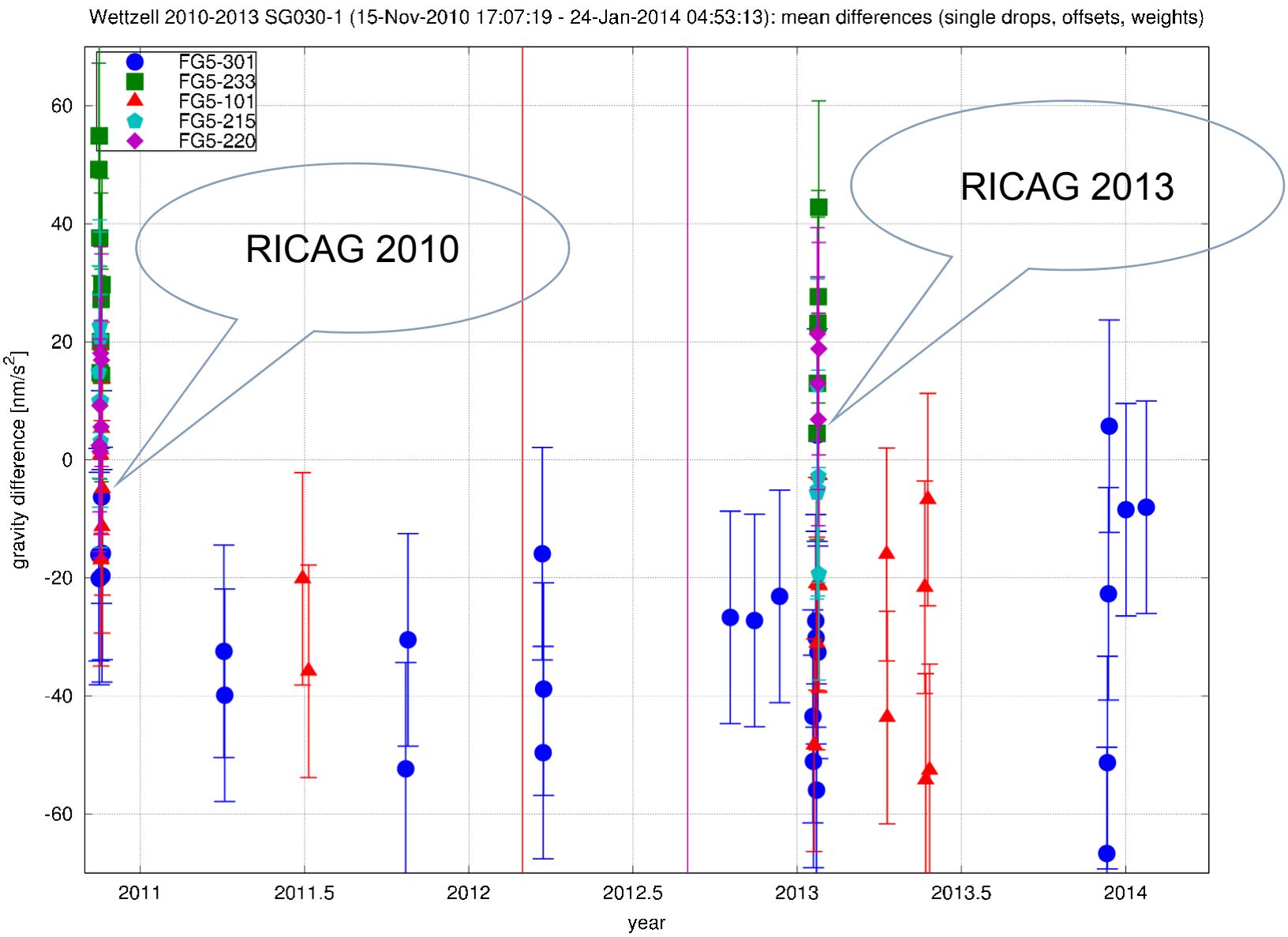
Wettzell 2010-2014: FG5 / SG030



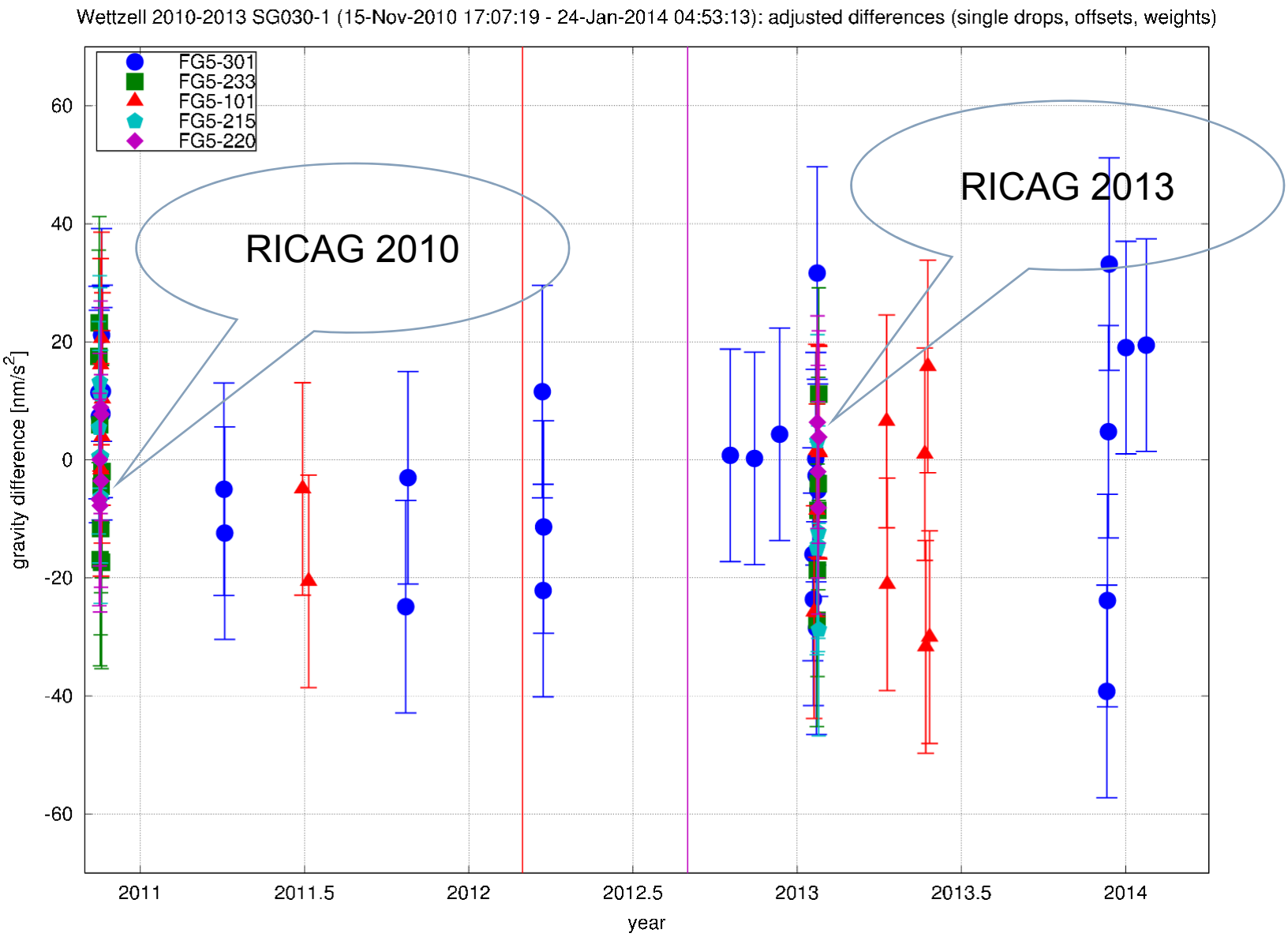
Wettzell 2010-2014: FG5 / SG030



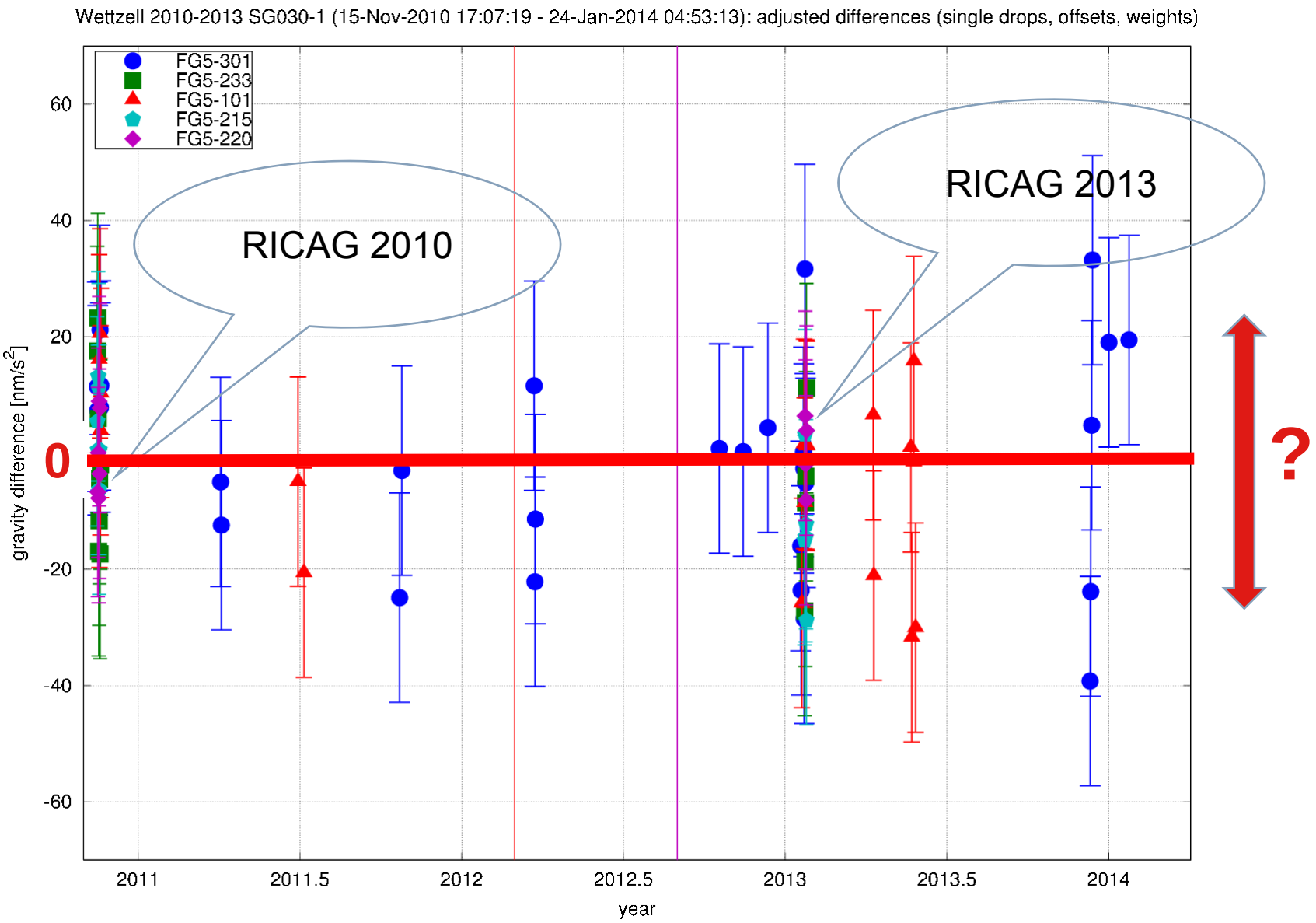
Wettzell 2010-2014: AG - SG



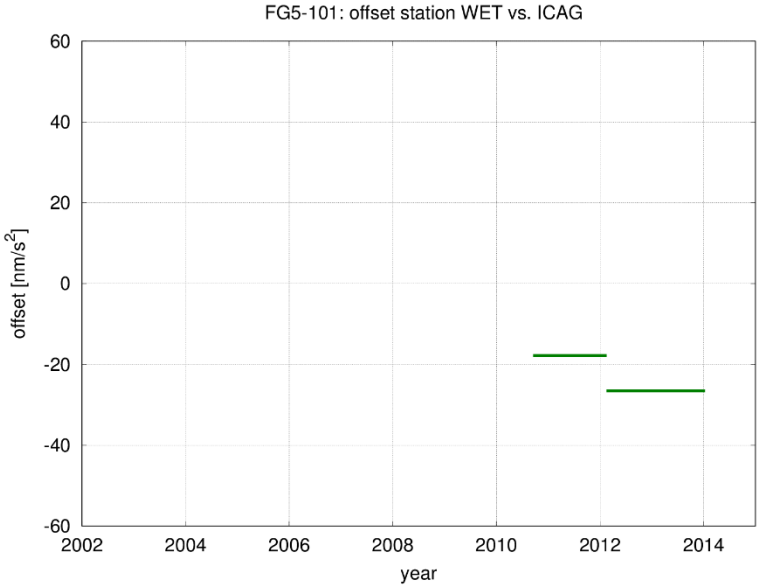
Wettzell 2010-2014: AG - SG - offsets

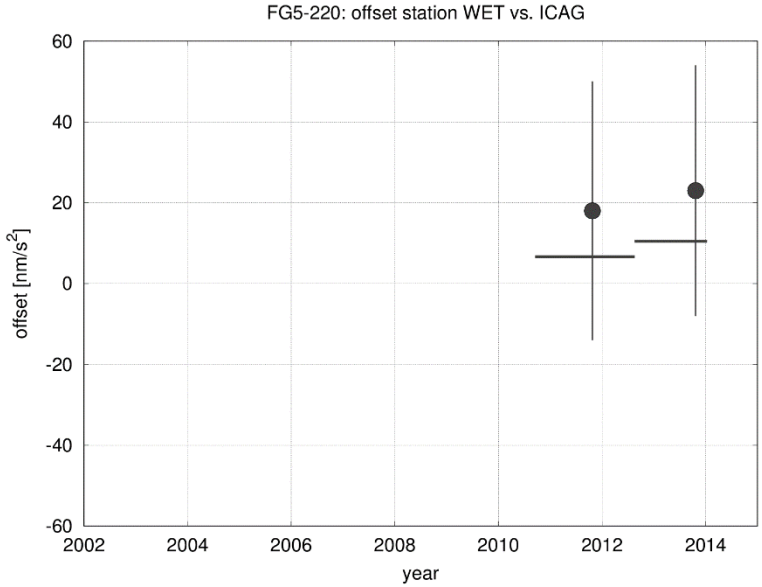


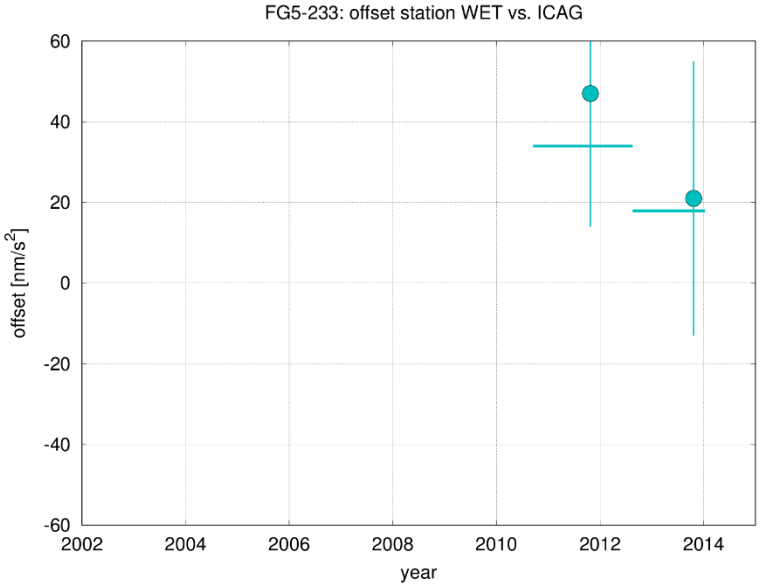
Wettzell 2010-2014: AG - SG - offsets

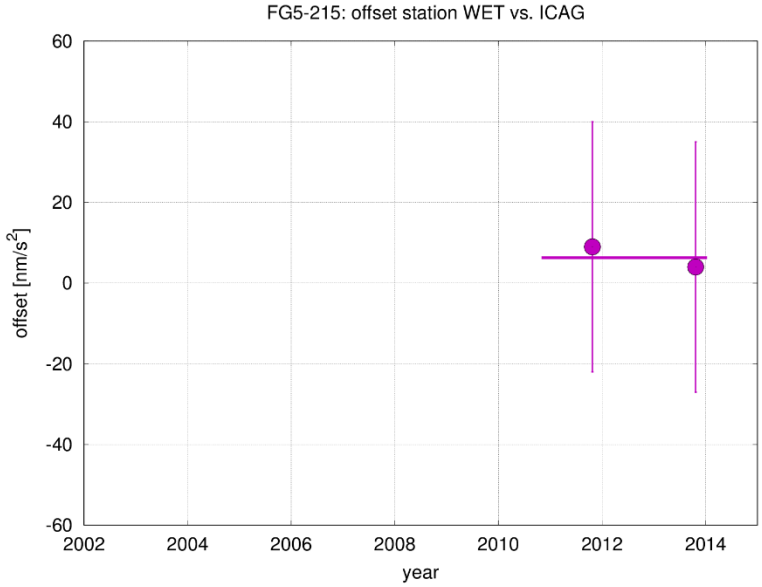


Wettzell vs. ICAG/ECAG: 2010-2014



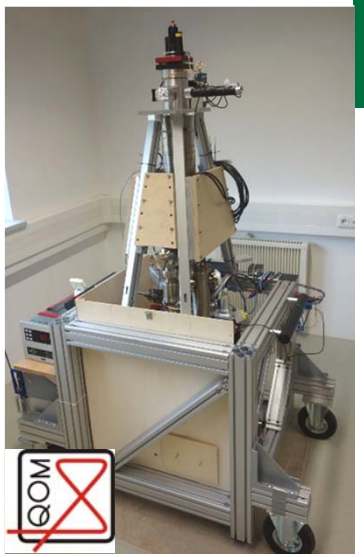






Marker: ICAG / Lines: level changes for predefined periods from combination with SG

Wettzell vs. ICAG/ECAG: 2010-2014



- Mean level matches well to the results of ICAG/ECAG
- Bias of only -7 nm/s^2 detected and applied to SG reference.
- Mean absolute value for epoch [27-Oct-2013 - 07-Nov-2013]:

  g_FA@125 = 9808369623 ± 18 nm/s^2

  → comparison reference value for GAIN

Station	AG	Regional Comparison				International Comparison				Diff Offset	Offset regional shifted
WET SG030	FG5-101	10//2010	03//2012	-18	0	None					-11
		03//2012	01//2014	-27	1	None					-20
	FG5-215	11//2010	01//2014	6	1	WAL	11//2011	9	31	-3	13
		11//2010	01//2014	6	1	WAL*	11//2013	4	31	2	13
	FG5-220	10//2010	09//2012	7	1	WAL	11//2011	18	32	-11	13
		09//2012	01//2014	10	1	WAL*	11//2013	23	31	-13	17
	FG5-233	10//2010	09//2012	34	1	WAL	11//2011	47	33	-13	41
		09//2012	01//2014	18	1	WAL*	11//2013	21	34	-3	25
	FG5-301	10//2010	01//2014	-31	0	WAL	11//2011	-30	29	-1	-24
		10//2010	01//2014	-31	0	WAL*	11//2013	-19	29	-12	-24
		10//2010	01//2014					Mean offset difference		-7	
								RMS		6	

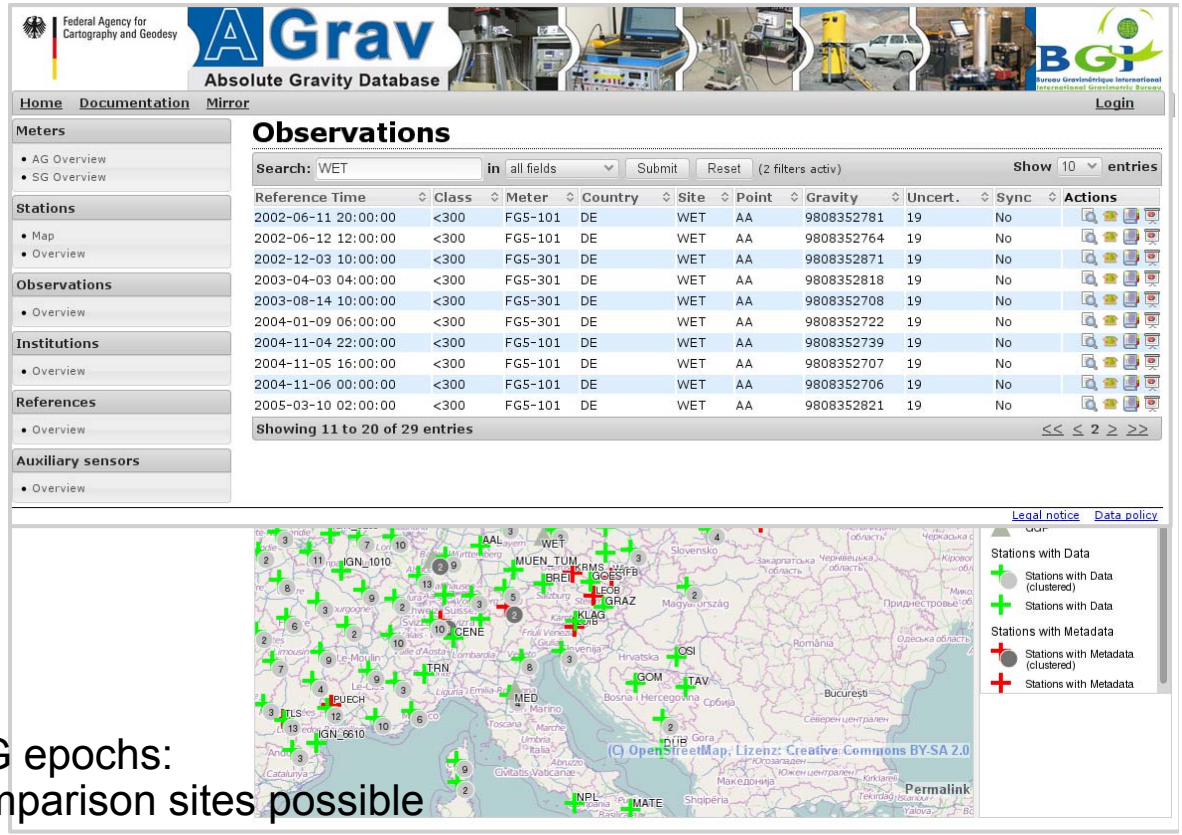
*WAL 2013: preliminary results

Conclusions

- Reproducibility of repeated AG observations can be checked against a continuous comparison reference function (CRF) from SG time series,
- Systematic deviations (‘offsets’) are compatible with results from international comparisons, if a bias is applied,
- Other AG’s can be compared to a CRF at any time, site-by-site AG measurements are optional,
- Bias determination at regional comparison sites serves as a component in the realization of a global gravity references system,
- By this, AG’s not part of ICAG’s can be traced back to the level of international (key) comparisons.

The AGrav: A future registry for comparisons

- Status (2014/09/05):
  49 Meters
  1086 AG stations
  3208 AG observations
- Comparison sites already included
- Key comparison DB at BIPM: Results of ‘Pilot study’ not included
- AGrav: Include results of Key comparisons and PS and regional comparisons
- By linking of RICAG and ICAG epochs:
  Bias estimates at regional comparison sites possible
- Link to SG time series from GGP may provide comparison reference function over time at SG stations



Thank you for your kind attention!

We thank these teams for their measurements at stations Bad Homburg and Wettzell:

EOST - Université de Strasbourg, France
IfE - Universität Hannover, Institut für Erdmessung, Germany
LMV - Lantmäteriet, Sweden
QOM - Humboldt-Universität zu Berlin
ROB - Royal Observatory of Belgium
UL - University of Luxembourg
UMB - University of Environmental and Life Sciences, Norway
VUGTK - Geodetic Observatory of Pecny, Czech Republic
WUT - Warsaw University of Technology, Poland

Participants of the 1st RICAG Wettzell 2010

Contact:

Federal Agency for Cartography and Geodesy (BKG)
National Reference Systems Gravity
- Branch Office Leipzig -
Karl-Rothe-Straße 10-14, 04105 Leipzig, Germany

Hartmut Wziontek
hartmut.wziontek@bkg.bund.de
www.bkg.bund.de
Tel. +49 (0) 341 56 34 - 256