Five years of gravity measurement at Onsala Space Observatory: The absolute scale

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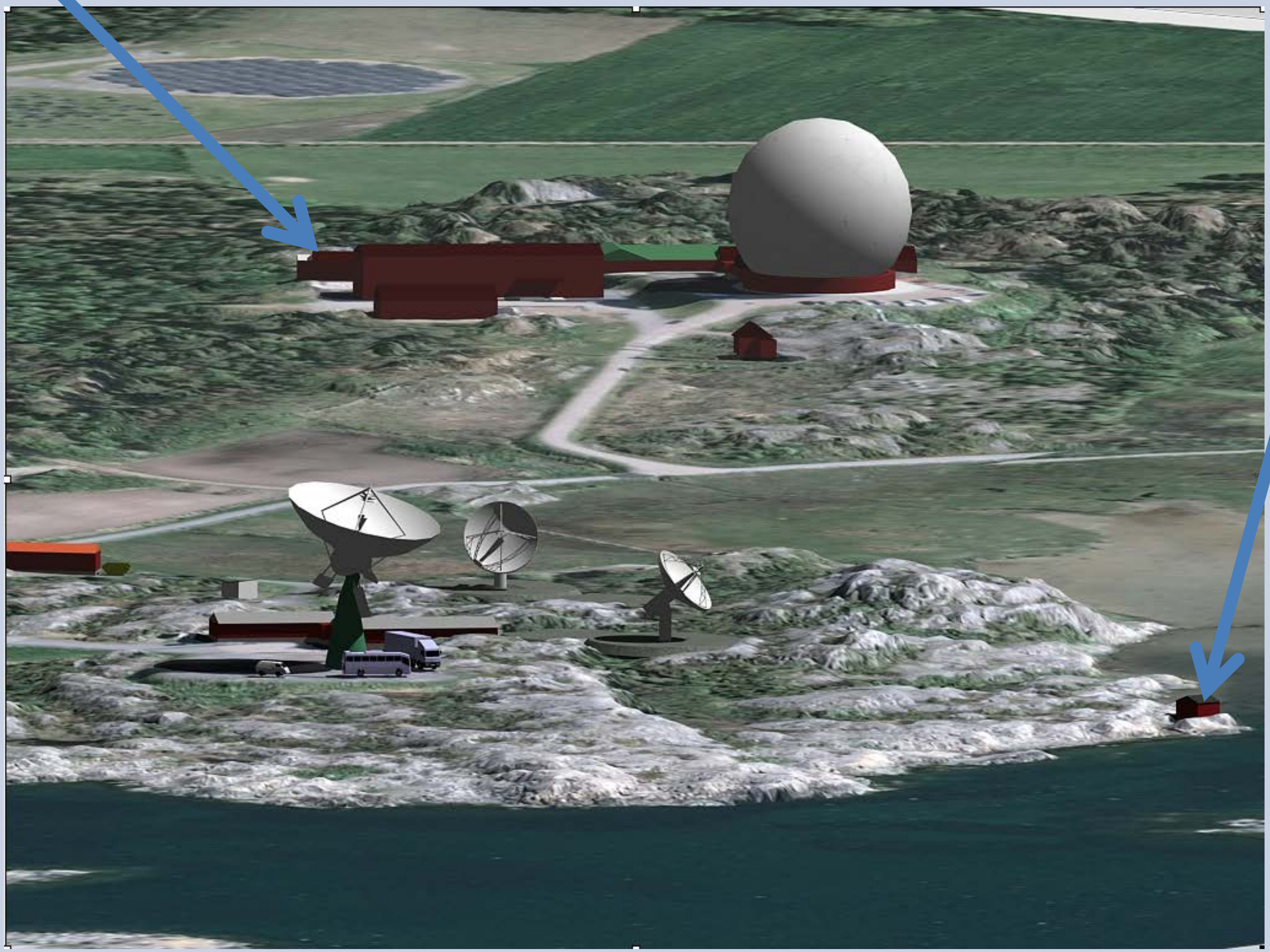
The gravimetry lab

at Onsala Space Observatory

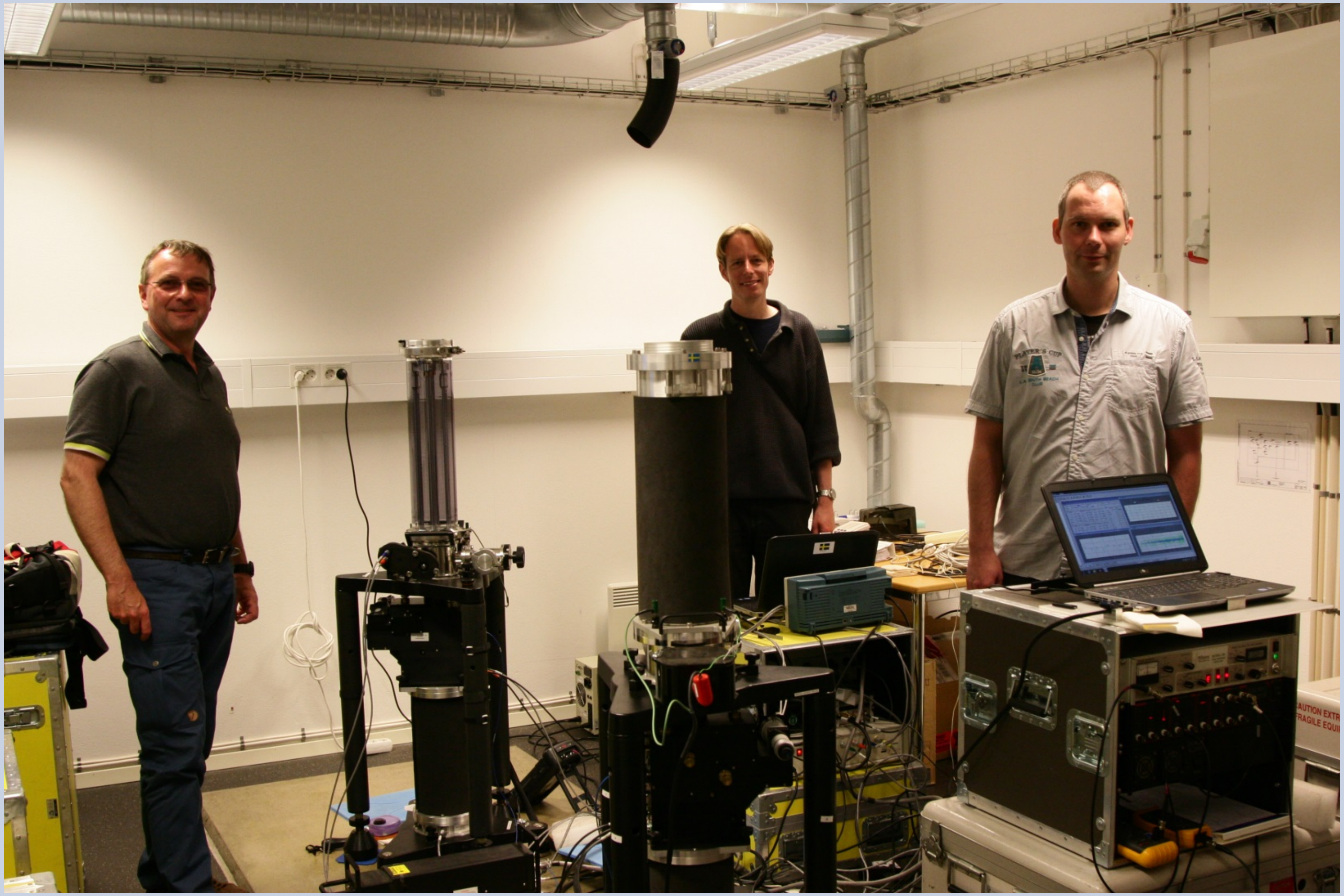


Tide gauges:
Bubble
Radar
GNSS


GPS-antenn
barometer
reglerad pump
samlingsbassäng för
yt- och grundvatten


kylhuvud
GWR INSTRUMENTS, INC
kärl med
flytande helium
uy
ux
*

The parallel campaign May 2014



Ludger Timmen FG5X 220 FG5 233 Andreas Engfeldt Manuel Schilling

Content

- **The limitations of the geophysical models in g-software**
  - Atmosphere and seasonal perturbations
  - Ocean loading: nontidal, non-static, non-stationary
- **FG5 absolute gravimeters**
  - Drift on the Project time-scale
- **The limitations of SCG-measurements**
  - Drift
- **The *Atmacs* atmospheric attraction and loading model**
  - Non-static effects from short to long time-scale
- **Reduction of AG-measurements by SCG-data**
  - At the Drop-level

- **AG reduction of observations by models**
  - The standard method, geophyscial models:
    - Polar motion, tides, ocean loading, atmosphere, …
- **AG … by direct application of SCG-observations**
  - **Sensitivity that AG and SCG have in common:**
    - Polar motion, tides, ocean loading, atmosphere, hydrosphere
- **Data, no model:**
    - No need to assume stationarity,
    - SCG drift needs a model though

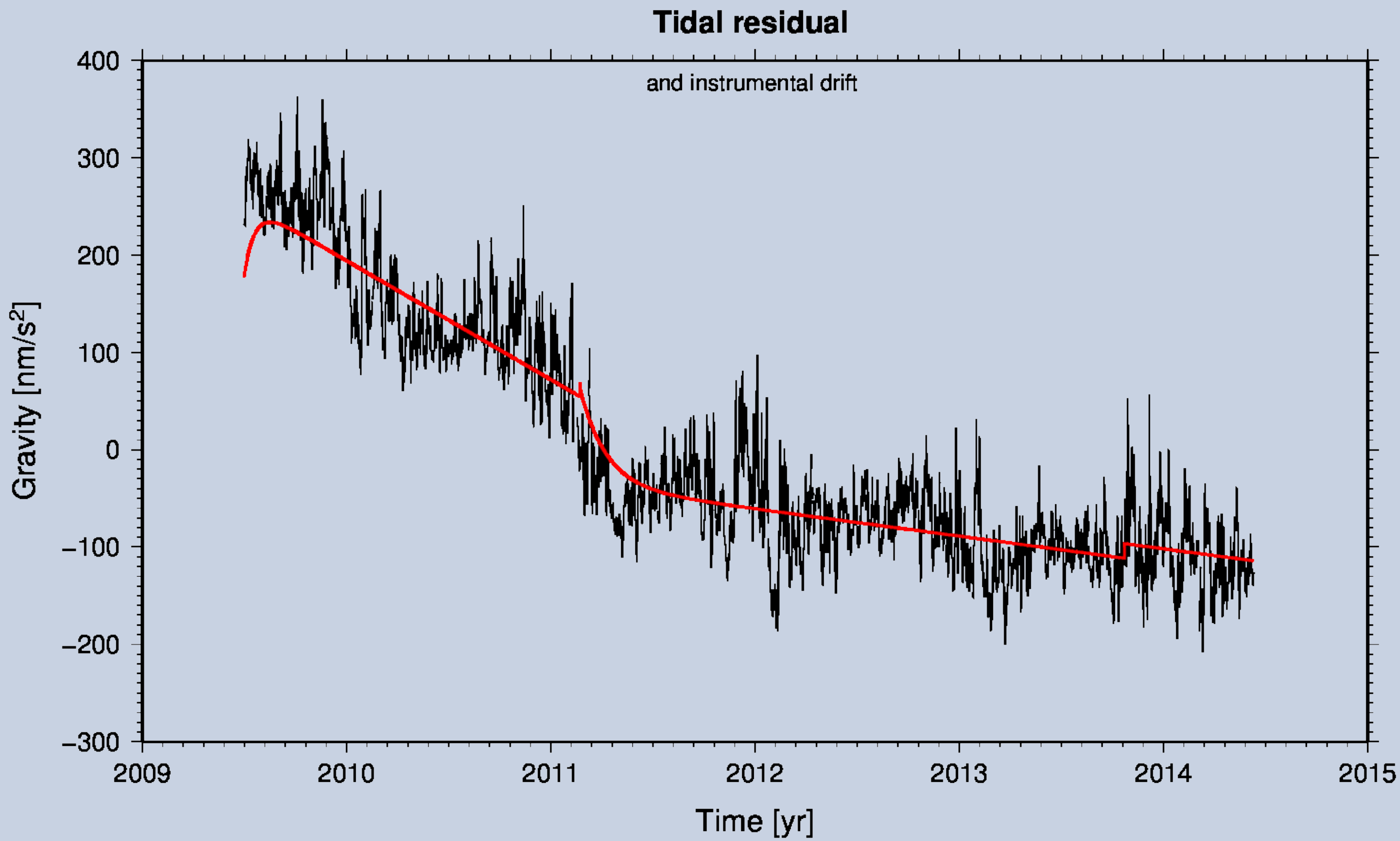
- **First I will show that we ”understand” the SCG record down to the 2 nm/s^2 level**
  - To first order: a complex, stationary model
    - Tides, polar motion, sea level, atmosphere (two shades of Atmacs)
  - Additional dynamics ”explained” by stochastic models (Wiener filtering) = ”non-static”

- Tides: Empirical tide coefficients in which we can identify known effects (tides, ocean tide loading) but also find effects yet to be identified

- **Cannot address AG instrumental limitations**
- **Devote efforts to SCG instrumental limitations, primarily DRIFT**
- **The challenges of a wide-band signal**
  - 1-second sampling at the front-end of processing
  - 1-hour averages, a compromise
    - atmosphere model Atmacs (3 h) => spectral fill-in local barometer (not so simple as it may sound)
    - sea-level data Ringhals (1 h) => decimate OSO tide gauge data
  - 1-day averages (nice data, not too useful) => testing Atmacs at long periods
- By the way:

Atmacs: Atmospheric Attraction Computation Service

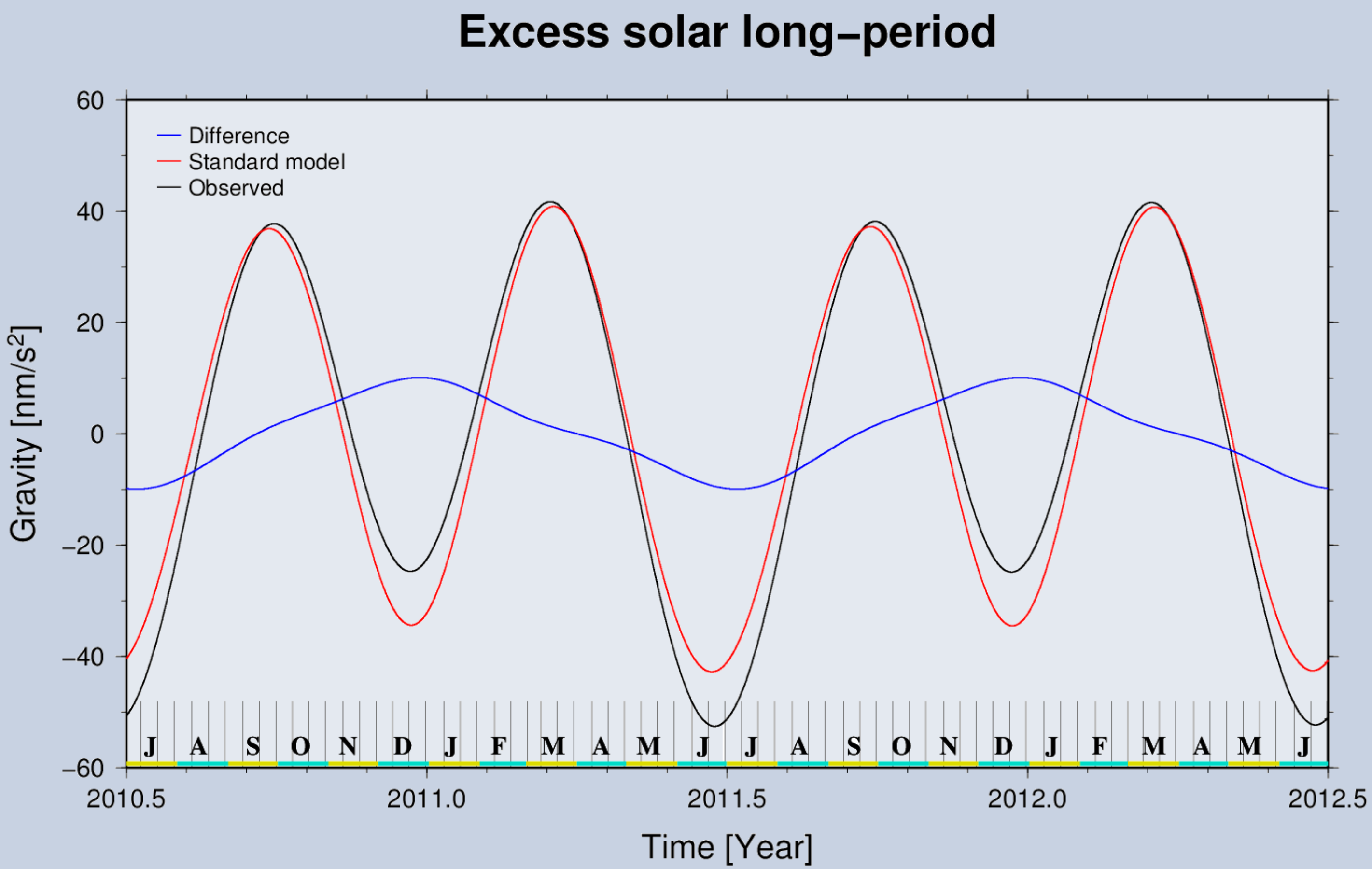
http://atmacs.bkg.bund.de



Is this difference, Tide-residual minus drift, a reliable prediction for AG?

Notice:
long-term excursions are neither exactly annual
(S_a tide coeff. took this effect away)
nor related to Polar Motion (that’s in the model too).

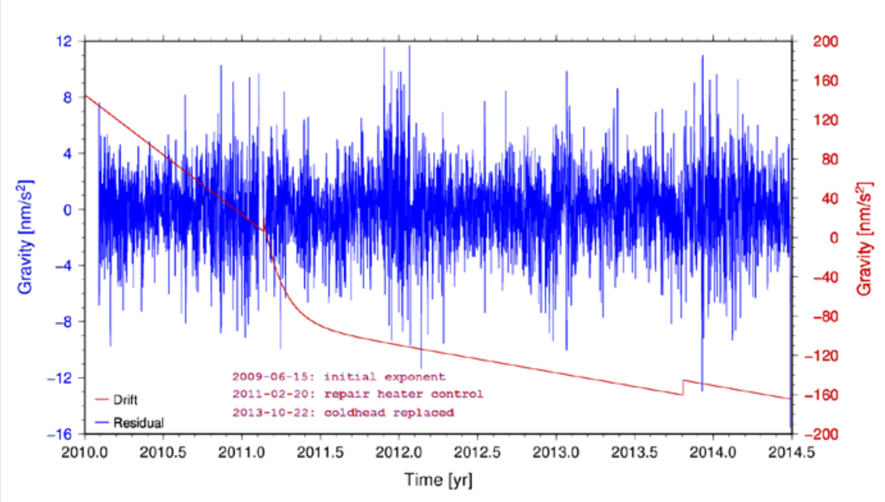
Long-period, annual, seasonal

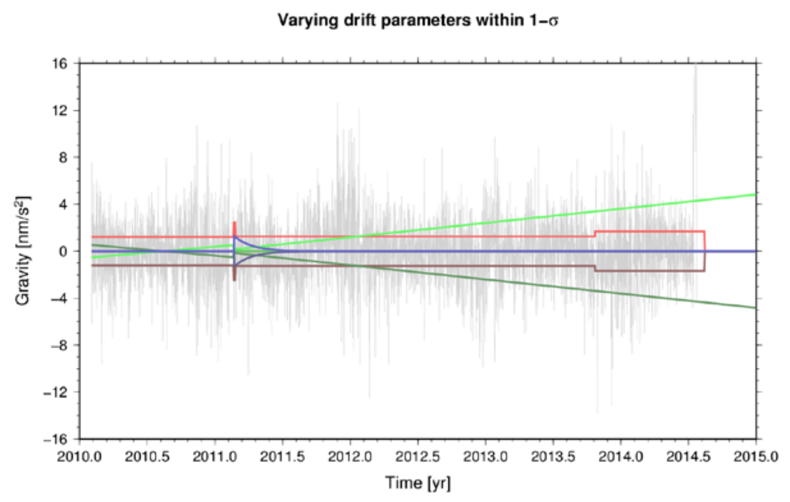


See the poster on this. A short summary …

Some findings

- **The annual tide at OSO is 2 × the solar gravity**
- This observation is ≈ **independent of** using
  either 1-hour data with spectral whitening
  or 1-day data without
- … while the admittance coefficients for Atmacs regional+local and global change substantially (a matter of best fit at daily periods vs at very-long periods.
- The perturbation peaks low-to-high: early January to mid June.
  See the poster
- Presently we don’t know the origin (while we are ignorant of ground water level, hydrology, biomass…
  (a ground water monitor below the lab is on the way))
- The SCG will ”know” (beware an unknown instrumental effect – hmm)





Assuming that we can determine drift components (slopes, biases, exponentials) at the 5 nm/s^2 level, we could try to take the rest of the SCG observations at face value.

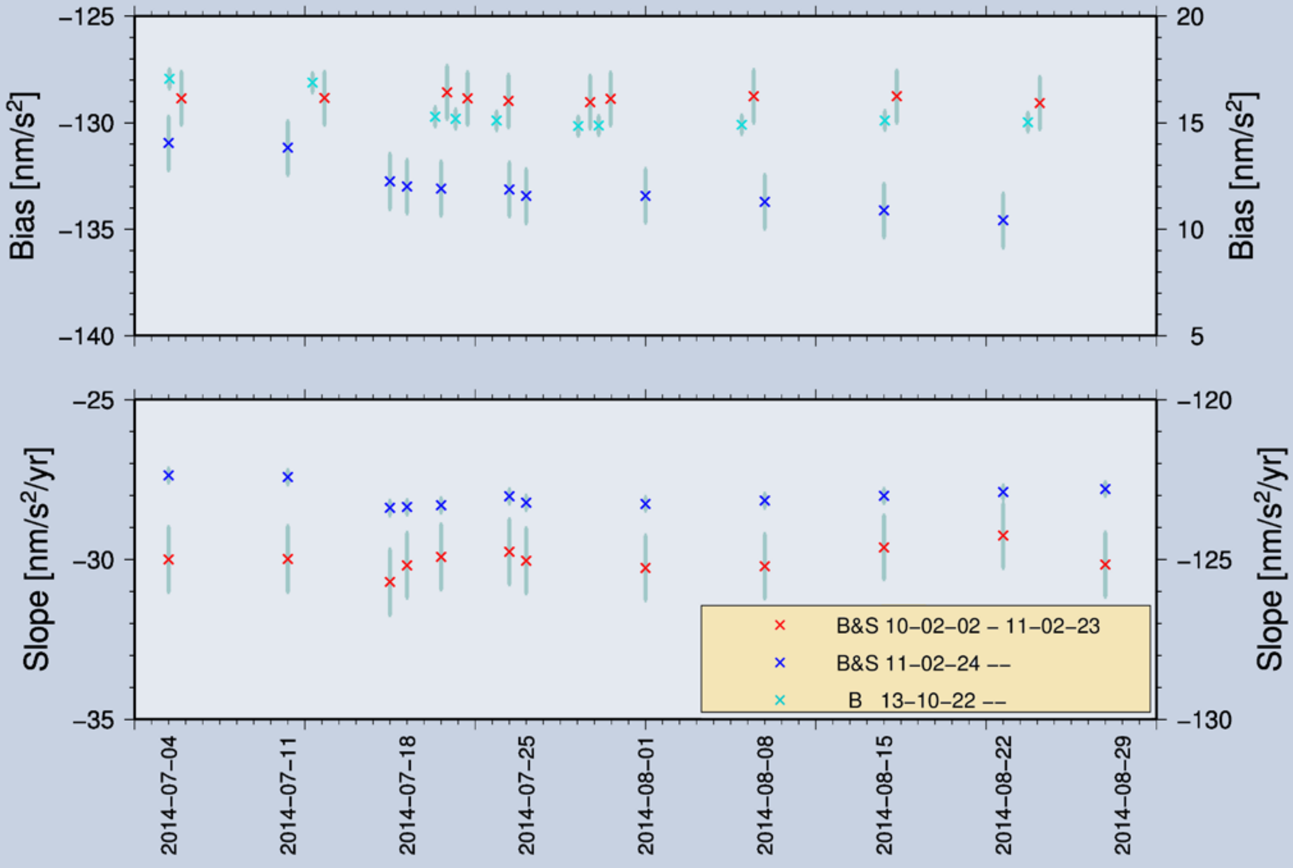
The residual RMS in the extended solution: 2.27 nm/s^2
In the standard solution (no Wiener filters): 7.05 nm/s^2

The residual RMS in the extended solution is

2.27 nm/s^2 ! ! !

from 40,000 hours of data

Drift parameters - robustness

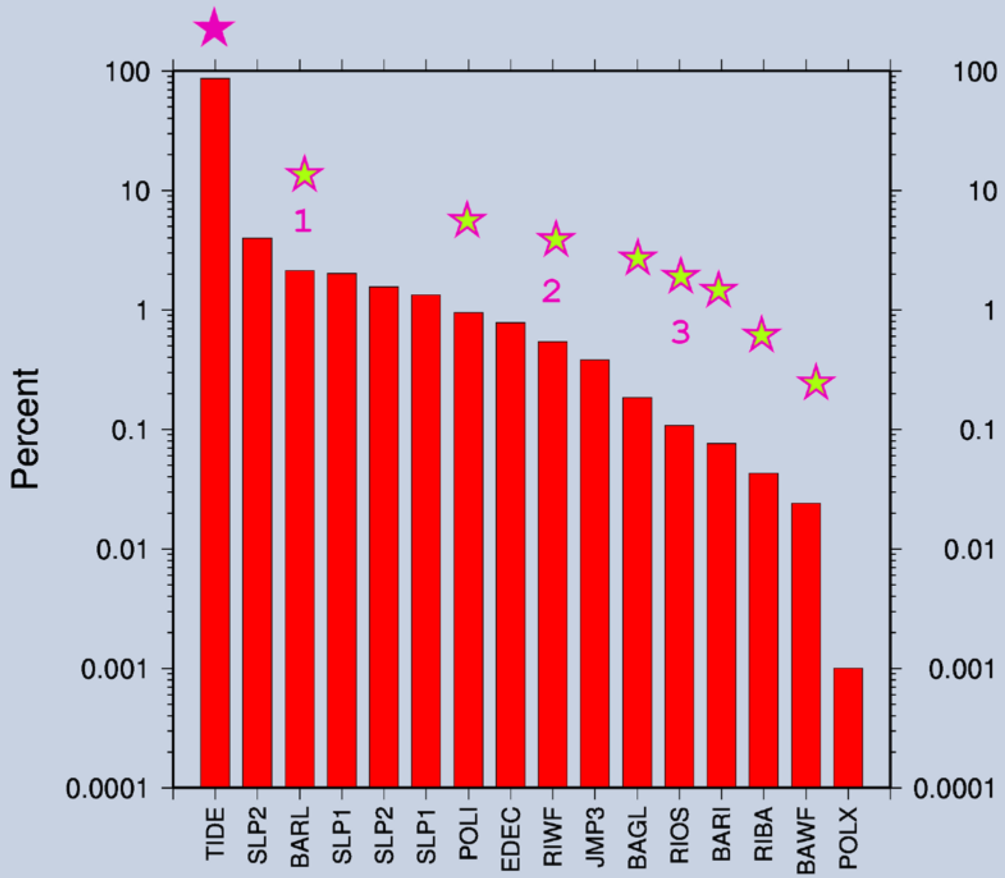


Since May 2014 we produce a standard solution every week. (In July the setup was changed):

Atmacs R+L
Atmacs Glob
Ringhals+OSO Sea level
Polar motion
63 tide wave groups
6 drift parameters
(5 shown here)

Recent change B&S:
2014-08-28 affects biases

We must keep an eye on the drift parameters.
So far they spread wider than the standard deviation.



Signal budget by percent of total RMS:

”TIDE” = all wavegroups (Tamura 1982 model)

★ ancillary observations in least-squares fit

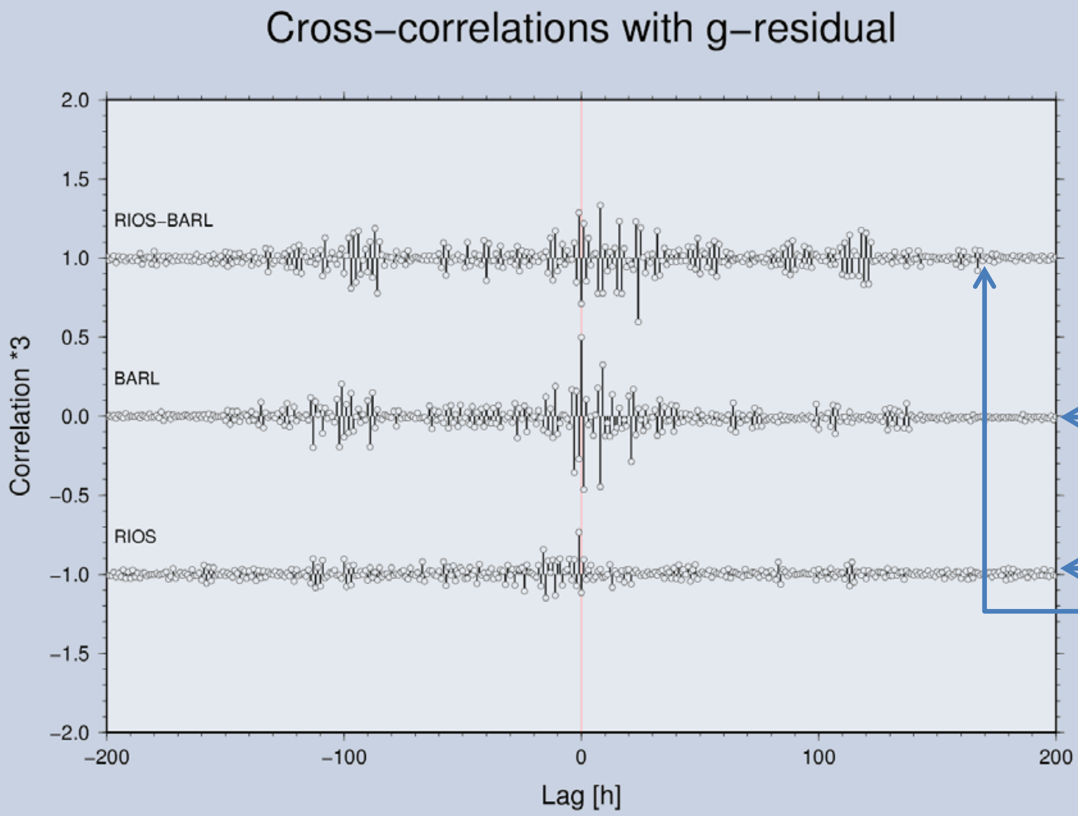
The rest are drift terms

Comments: ★ 1 – Regional+Local atmosphere model from *Atmacs,* not surprisingly most important after tides

★ 2 – Tide gauge (mostly from Ringhals, lately from OSO) Wiener-filtered **”dynamic admittance”** (although a stationary concept) – **more important than:**

★ 3 – Tide gauge: **the static admittance** **!**

Now I have to explain…



After a least-squares fit with single admittance coefficients for Atmacs-R+L and tide gauge,

$GR := g - tides - a\ AT - t\ TG$

off-centre cross correlation is found between these time series:

$\{ GR \mid AT \}$ $\{ GR \mid TG \}$

and between the pair

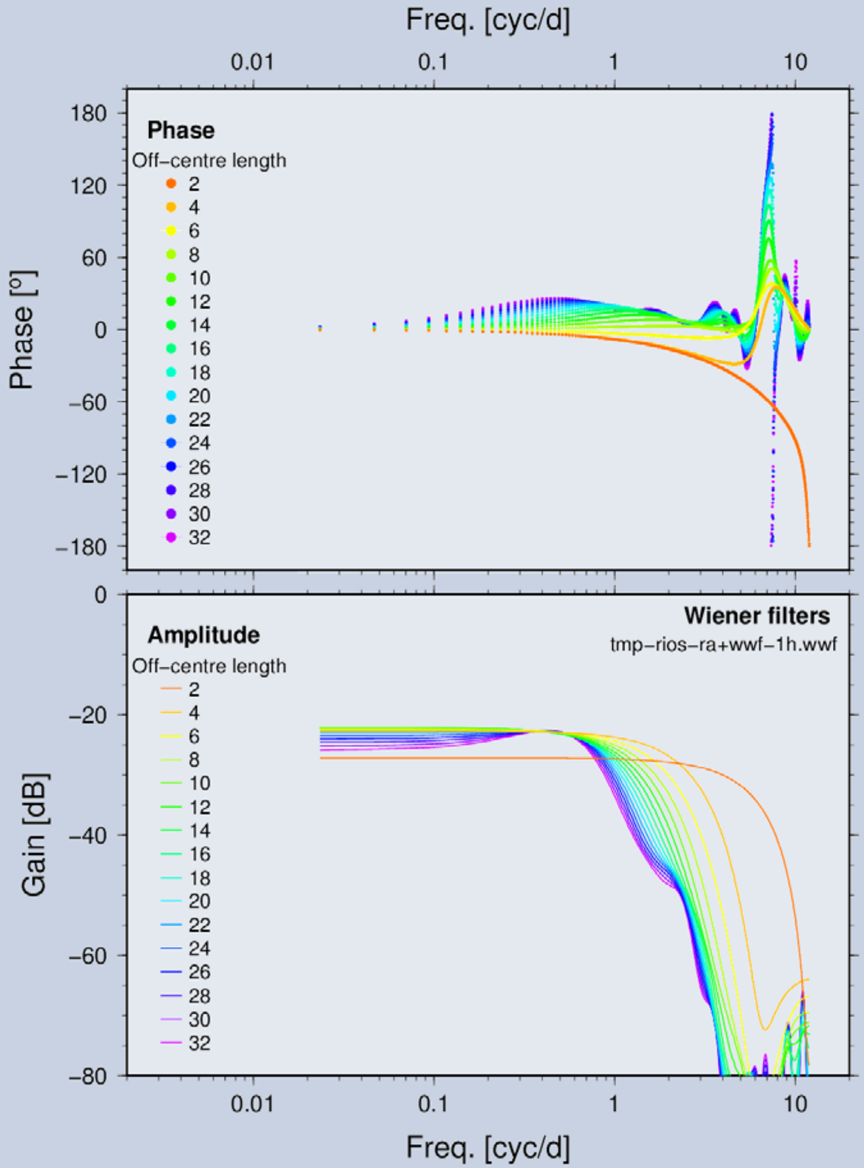
$\{ TG - \alpha\ AT \mid AT - \tau\ TG \}$

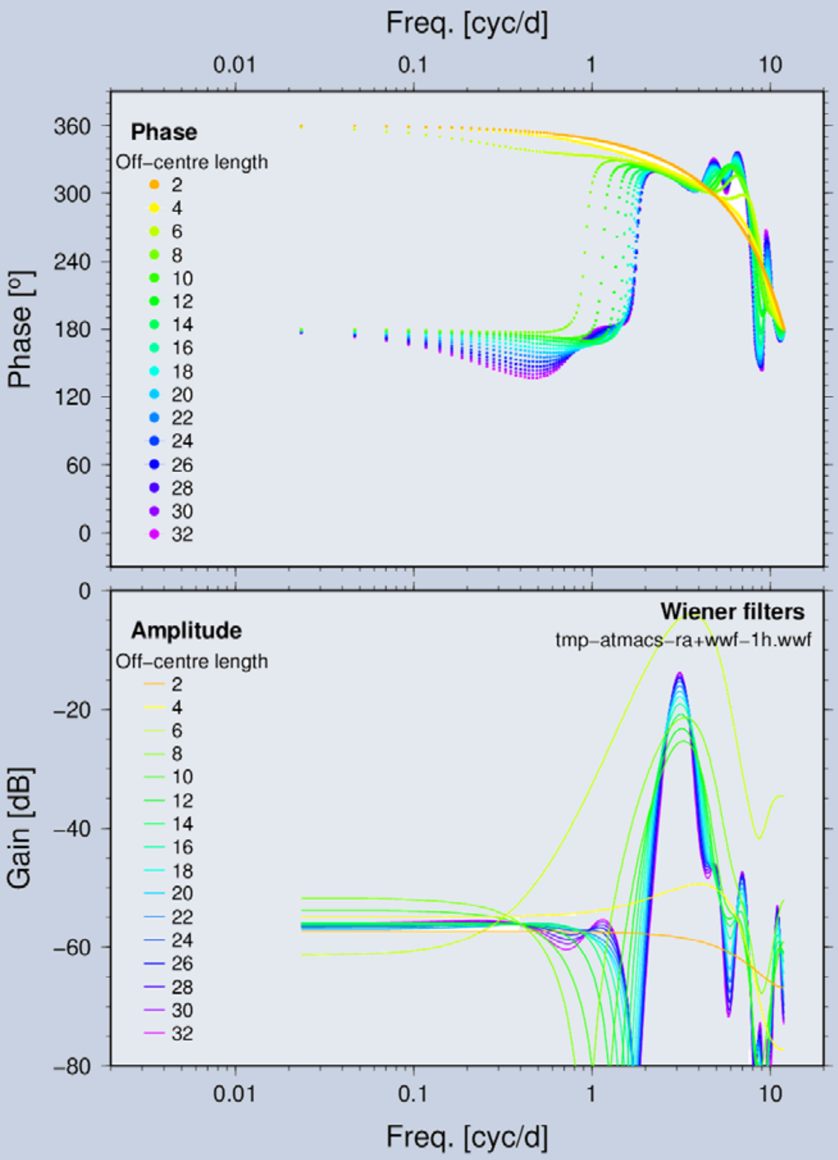
(over-simplified, sorry)

<= this information is the basis for the Wiener filters:

$Wf = \mathscr{F}^{-1}\{ Cohc \cdot XY^* / |Y|^2 \} \cdot w$

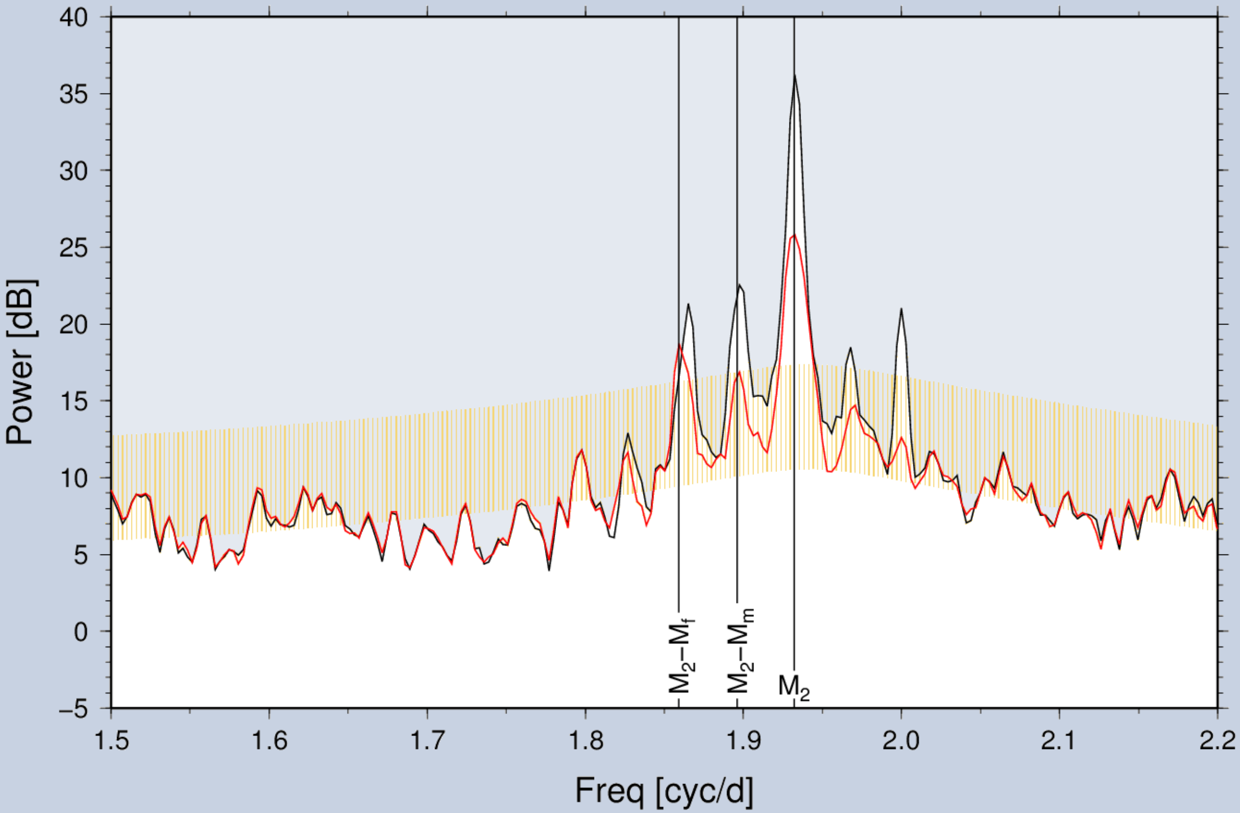
with a window for tapering off at large lag (noise suppression)
and the coherence spectrum as a multiplier (selecting common features)





{ *GR* | *TG* } tide gauge <- **Wiener filter gain spectra** -> { *GR* | *AT* } Atmacs R&L

Nonstationary M_2 found in the power spectrum

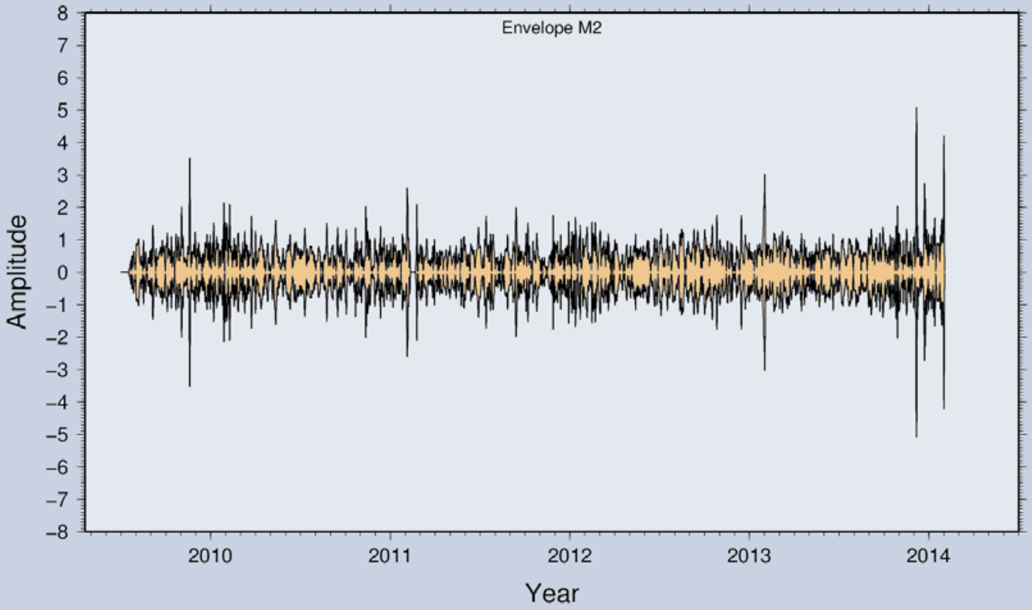


Ringhals tide gauge:

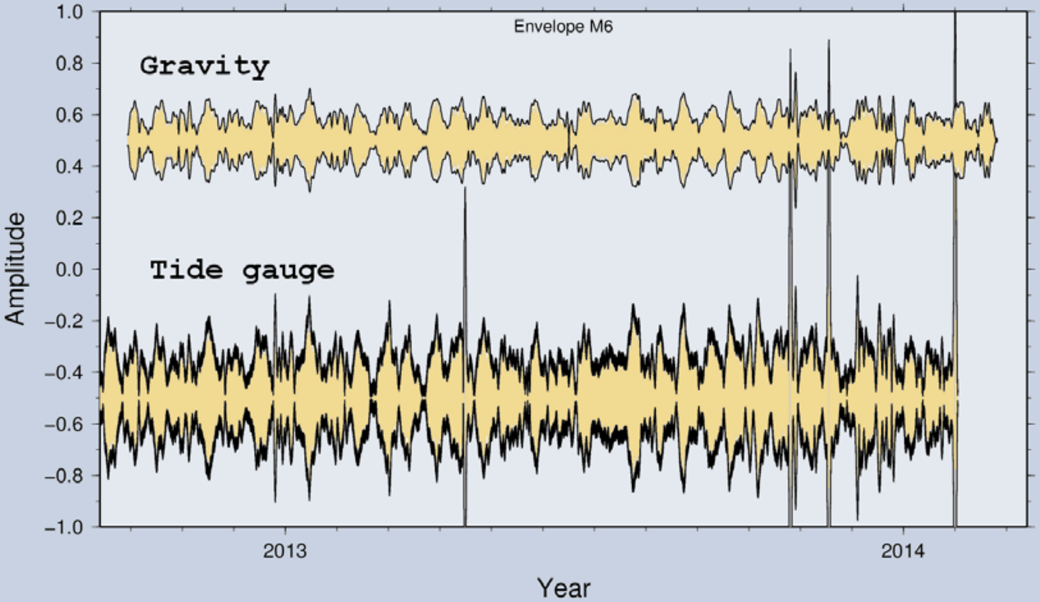
Black:
Unreduced for tides.

Red:
After reduction of the tide wave groups in the least-squares procedure, the signal vanishes only in the whole-span mean.

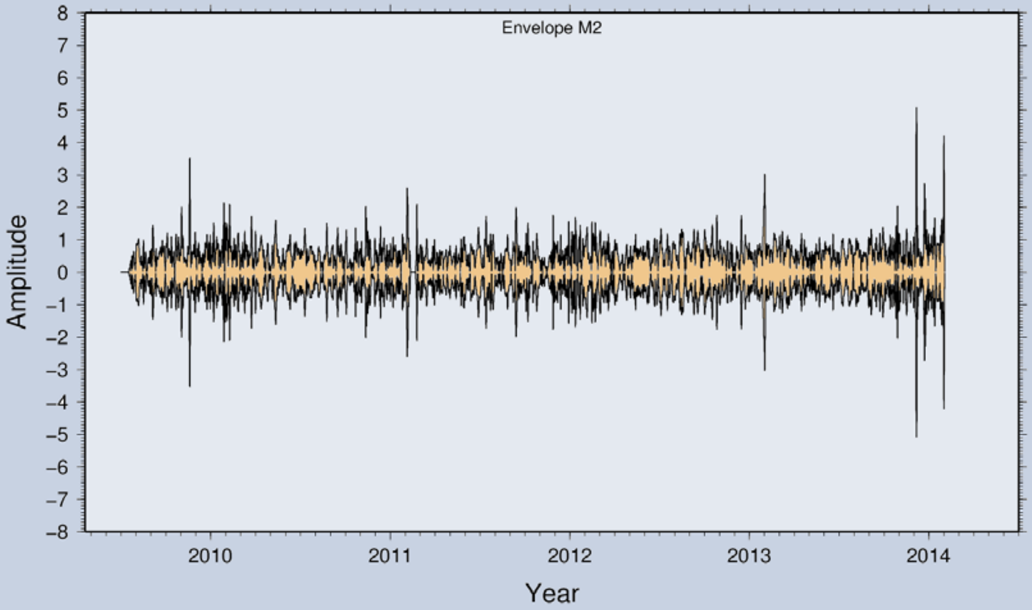
A power spectrum (Fourier-tr of ACV) using a finite window (e.g. ± lag 2048) detects time-limited excursions of amplitude and/or phase.
We find intermodulation products at beat frequencies with the (oh so small) long-period waves (this is probably not the mechanism behind; I can try explain but it'll be lengthy).

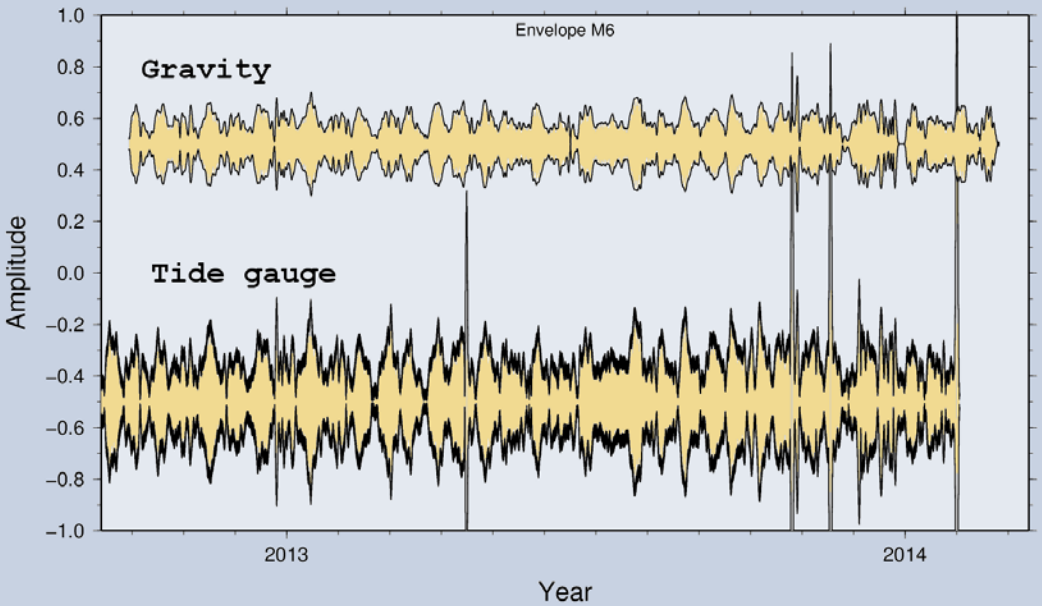


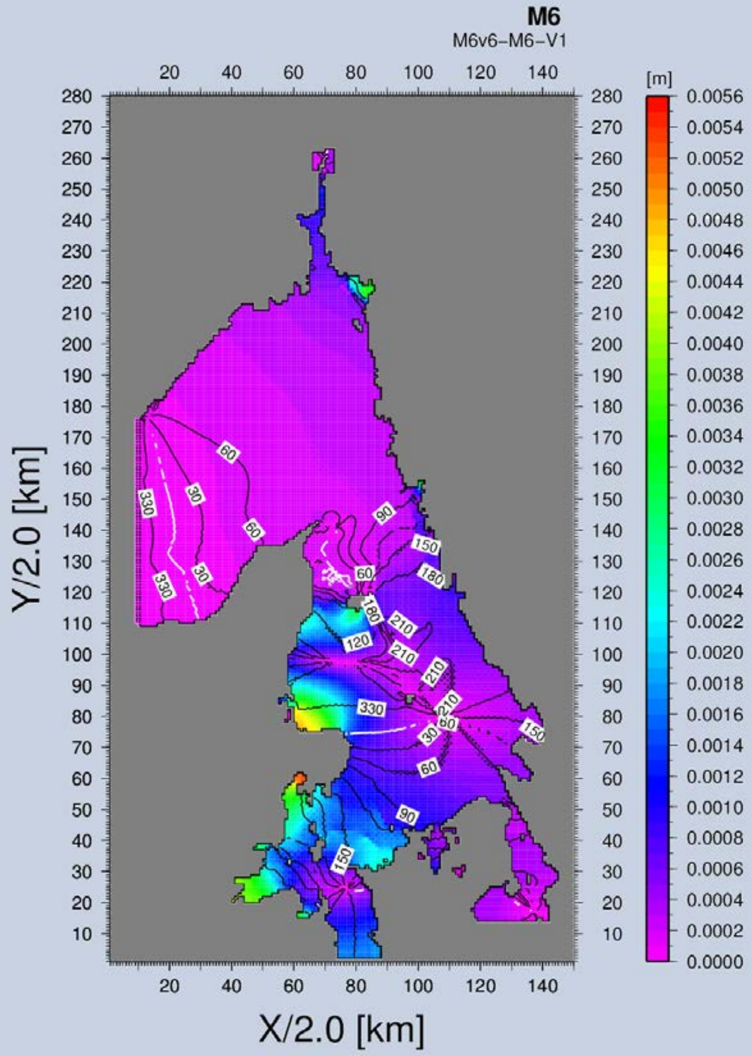
The gravimeter's M_2 ”organ pipe”



M6 – band (a nonlinear tide)
Shows temporal correlation of amplitudes (envelope) between tide gauge and gravity


Envelope M2
Amplitude
Year
2010
2011
2012
2013
2014


Envelope M6
Gravity
Tide gauge
Amplitude
Year
2013
2014

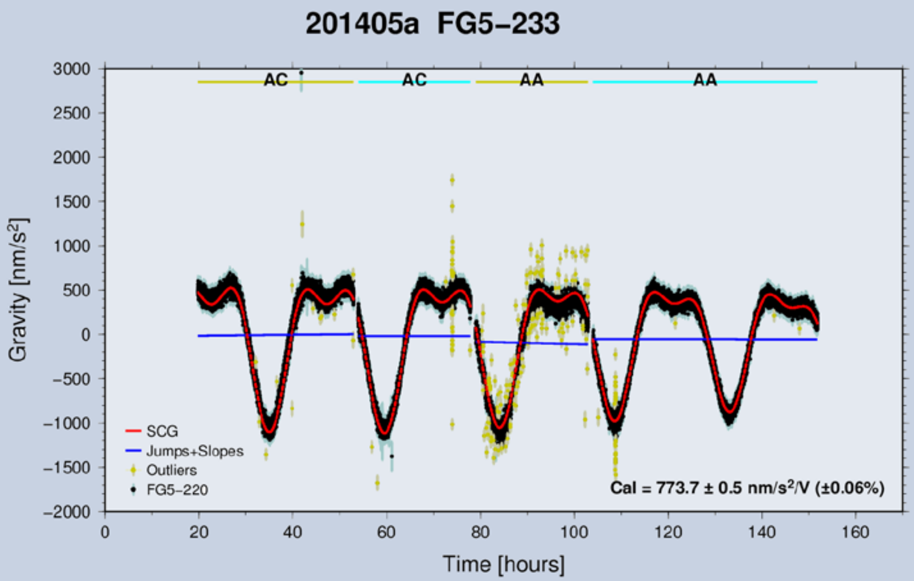

M6
M6v6–M6–V1
[m]
Y/2.0 [km]
X/2.0 [km]

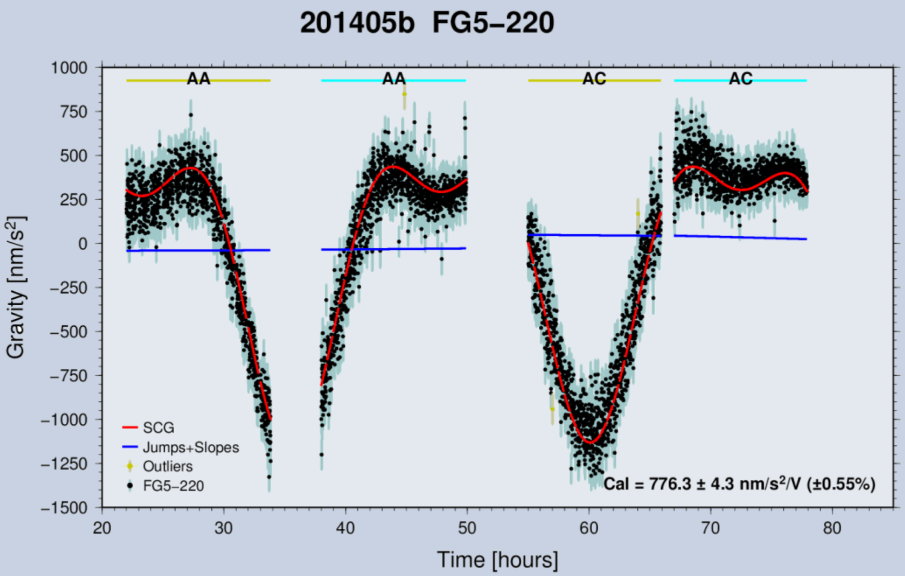
Thus the decision to reduce AG data with SCG data, no models involved

… except the SCG drift. More precisely: no **deterministic** model

- **Showing example from most recent campaign May 2014**
- **Parallel FG5x-220 (IfE) and FG5-233 (LM)**

- **Estimating**
  - **Calibration factor** for SCG for whole campaign (but instruments apart)
  - **Bias and slope** parameters for each ”project” (placement)
- **Using**
  - a-priori weights from AG drop files





Least-squares solution, task is **SCG-calibration**

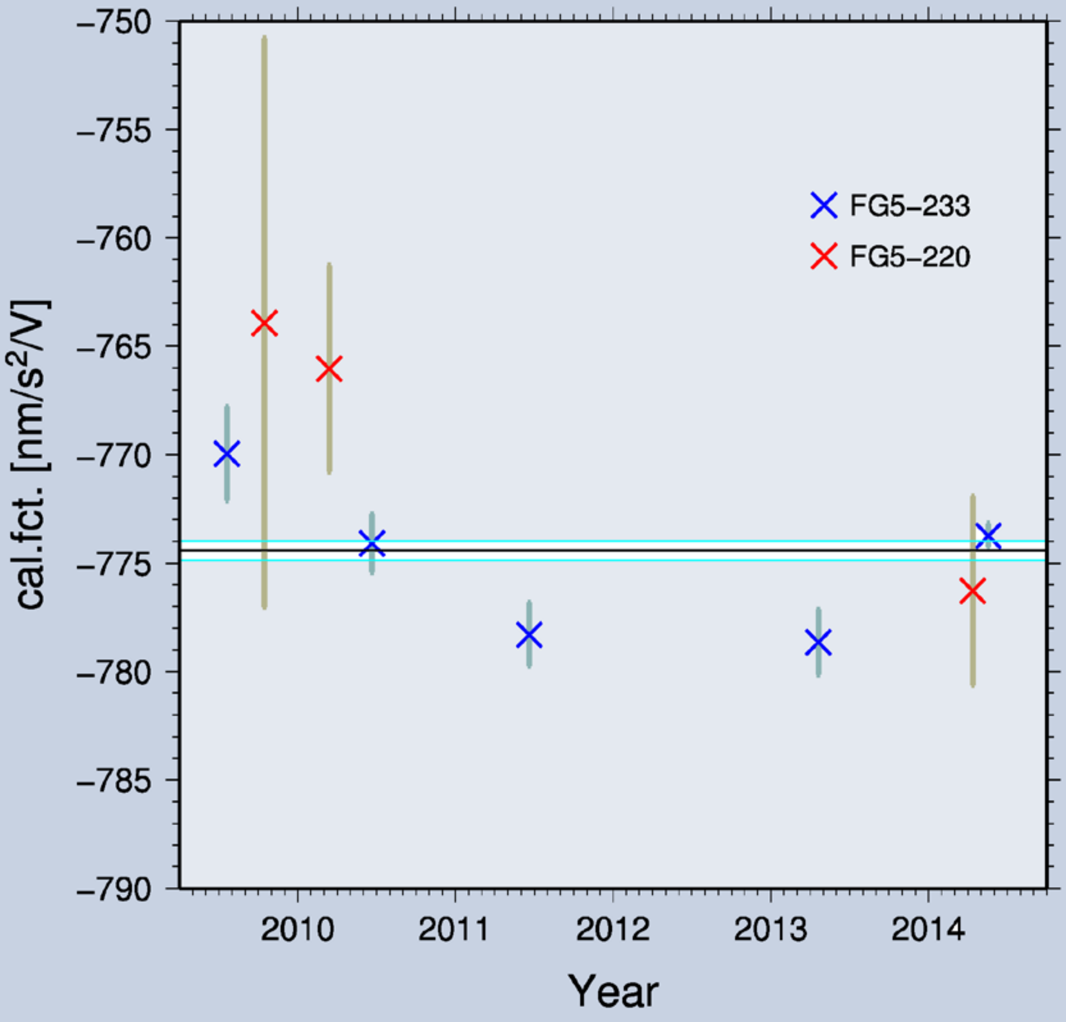
Shown:

$AG - slope - bias - Acm$ AG's campaign-mean

$SCG[\mathrm{V}] \cdot cal[\mathrm{nm/s^2/V}] - Scm$ SCG's campaign-mean

Outliers as yellow error bars, accepted: light-blue

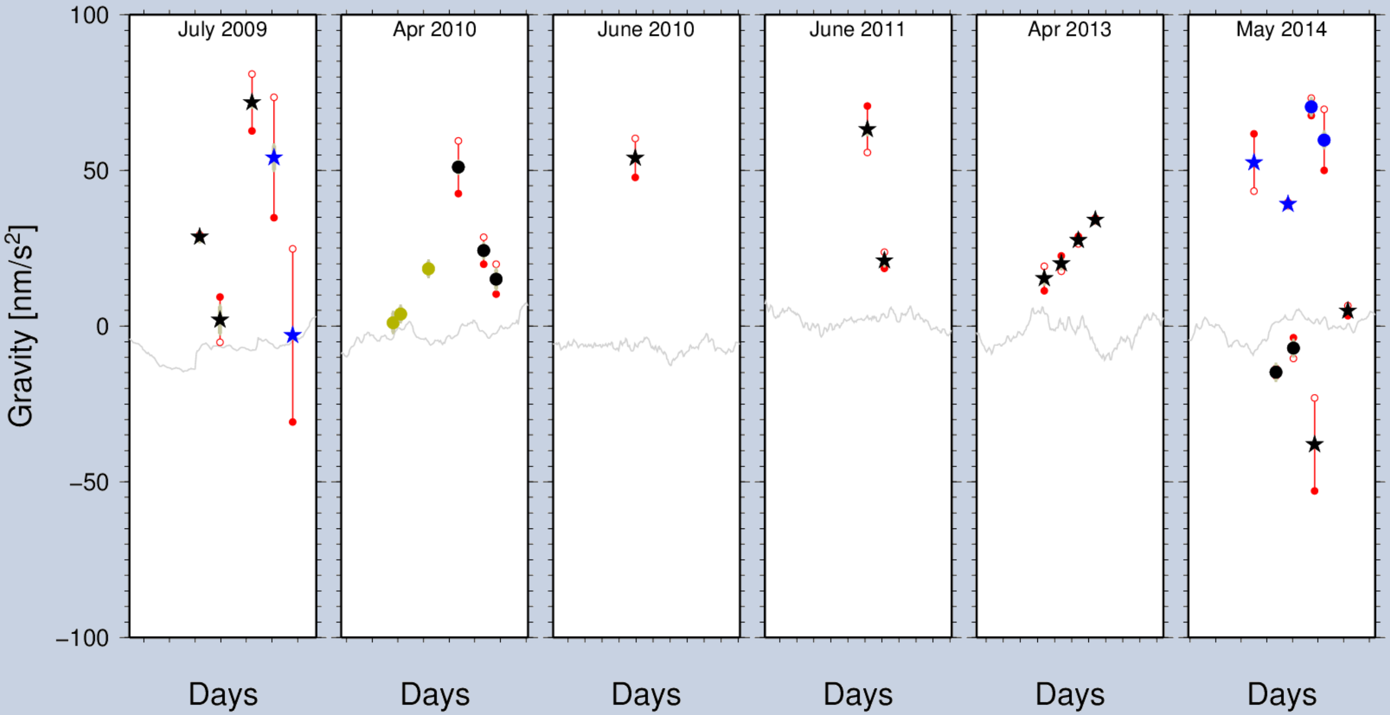
where *cal* has been determined here.



The SCG's calibration factor from AG parallel recording

All campaigns

A-posteriori uncertainties (stdev) are shown



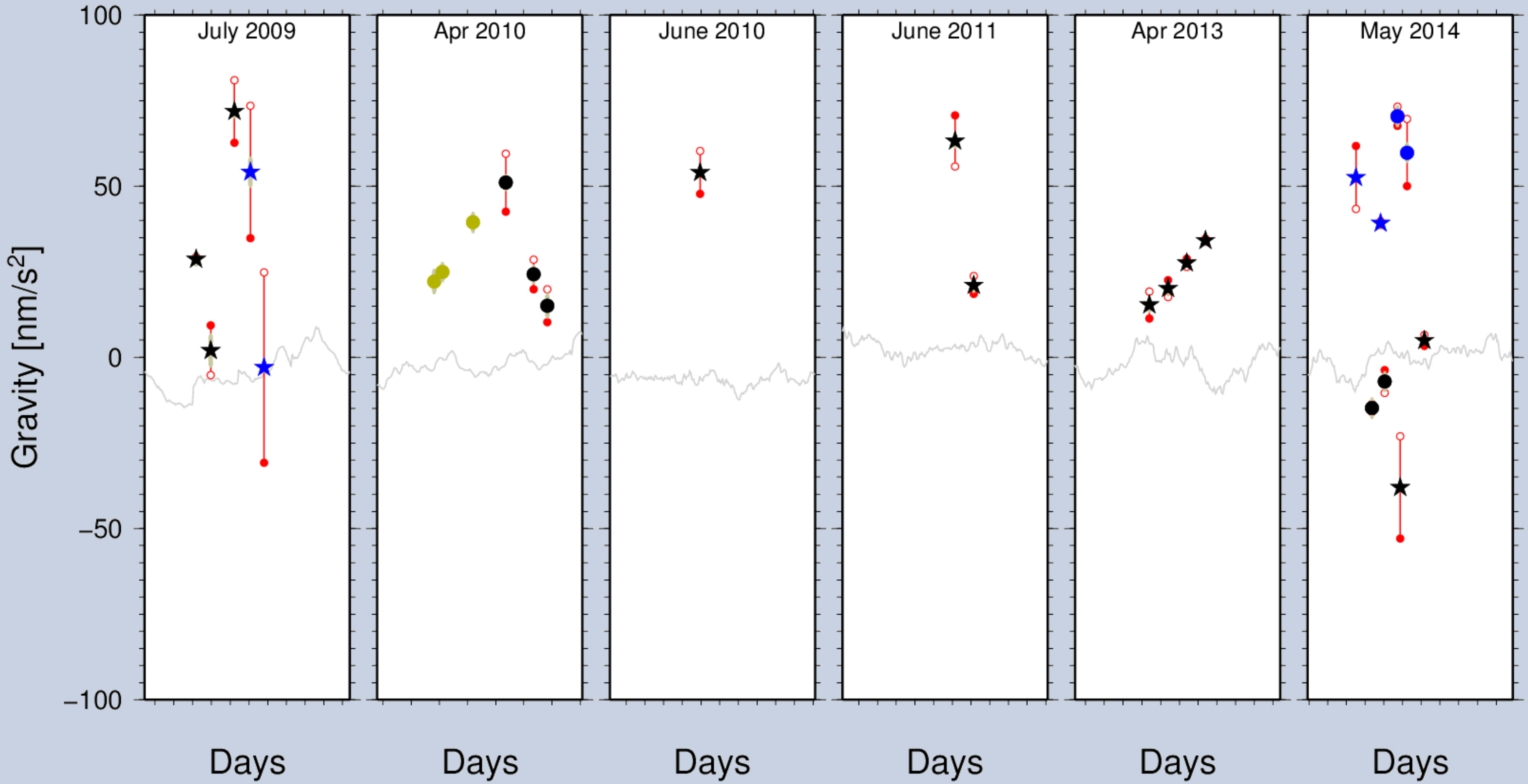
Shown:
AG – (*SCG* – *drift*)
– *slope*

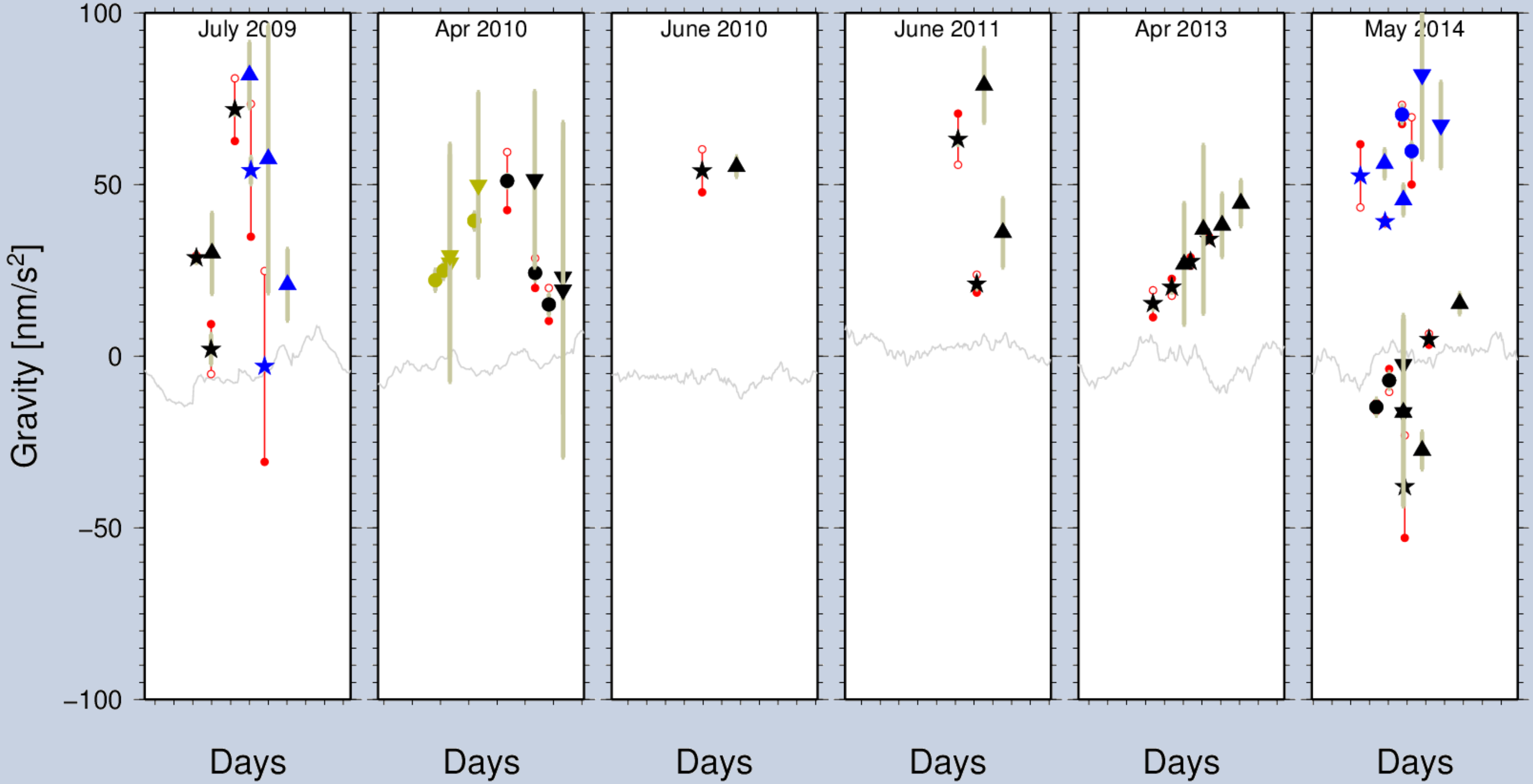
(but not – *bias*)

Also shown (gray):
SCG – *gXM*
eXtended Model

Monuments: yellow = AS (old) blue = AC black = AA (main)
Instruments: asterisk = FG5-233 (LM) circle = FG5-220 (IfE)
Estimated slopes: red barbells, filled = from, open = to

We've discussed campaign July 2009, monuments correctly identified in drop files? Project 3 on AC and 5 on AA? – well…
Scatter would not decrease if we took the start of the project as unaffected by the slopes (filled barbells).


July 2009
Apr 2010
June 2010
June 2011
Apr 2013
May 2014
Gravity [nm/s^2]
100
50
0
−50
−100
Days
Days
Days
Days
Days
Days



Triangles: Weighted means, standard g-software (-like) solution

Conclusions

- We by-passed a range of models normally employed in AG observation reduction
  - Tides, atmosphere, ocean loading, pole tide
- and instead use SCG observations at the drop level
- We found drift during AG projects, slopes that occasionally exceed their standard deviations
- There are components in the SCG records which are either difficult to model (site-dependent) or have a nonstationary character. Atmosphere and annual/seasonal periodics; sea-level at temporal scale from 1 day to ~week
- Some excursions from exxpected values (campaigns 2010, 2011) could not be reduced. No miracle cure (there is a greater number of items in the gravimeter's error budgets than a parallel recording SCG can address).

See the poster

The Superconducting Gravimeter at Onsala Space Observatory

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http://holt.oso.chalmers.se/hgs/4me/ag2014/Poster_NKG2014_SCG-Onsala.pptx