SAA Mitigation

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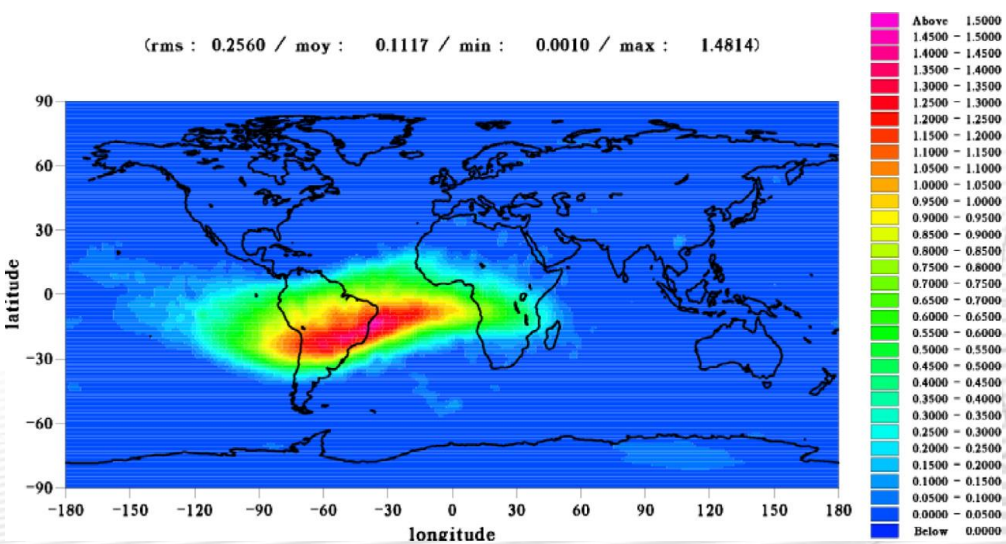
South Altantic Anomaly (SAA)

- The South Atlantic Anomaly (SAA) is an area where the Earth's inner Van Allen radiation belt comes closest to the Earth's surface, dipping down to an altitude of 200 kilometres. This leads to an increased flux of energetic particles in this region and exposes orbiting satellites to higher-than-usual levels of radiation. The SAA is the near-Earth region where the Earth's magnetic field is weakest relative to an idealized Earth-centered dipole field. The increased radiation perturbs the crystal quartz oscillators that are the heart of the DORIS system, causing short-term and long-term changes in the frequency behavior.

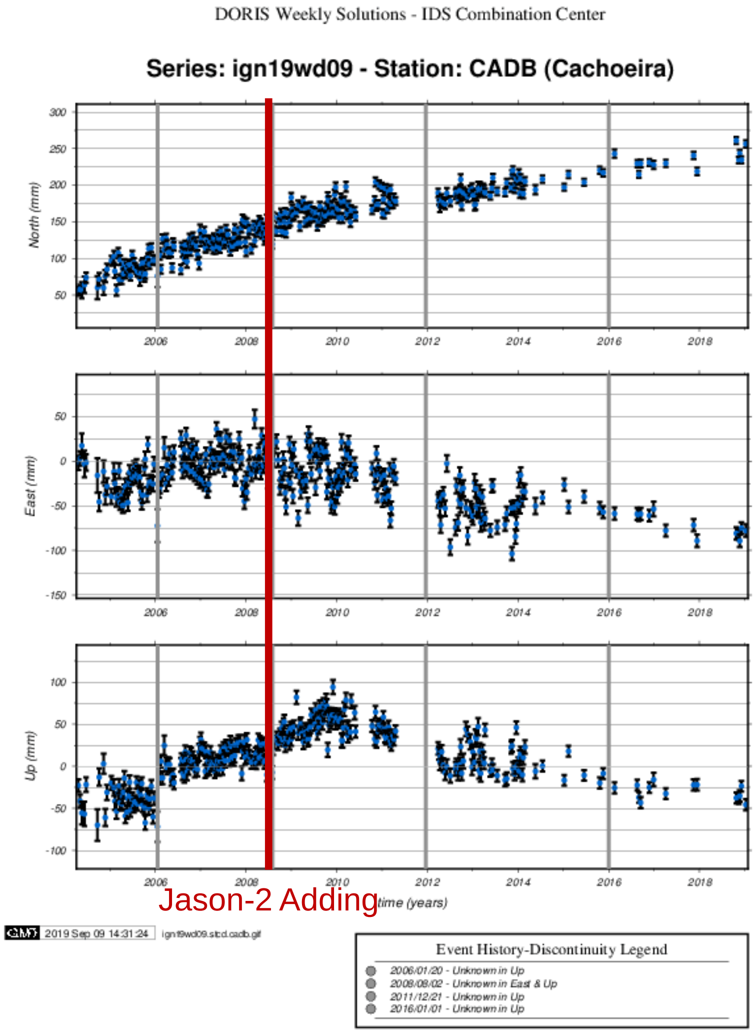


Plot of the DORIS derived relative dose exposure in 2002–2005 at 1300 km altitude (dimensionless units). Credit: Lemoine et Capdeville 2006.

DORIS & South Altantic Anomaly

- An anomalous behaviour of the DORIS ultra-stable oscillator (USO) on-board Jason-1 was first pointed out by Willis et al. (2003, 2004), who showed that the positioning of the DORIS stations located in the area of the South Atlantic Anomaly (SAA) was drifting away from the true position, either given by the ITRF2000.

- The error for these contaminated stations can exceed 40 times the standard positioning error of the other stations.



DORIS & South Altantic Anomaly

- **How to solve or account for the DORIS USO frequency shift?**
- So far, the IDS has tried four solutions:
  1) Do not include the DORIS missions sensitive to the SAA ➔ degrade performances of Helmert parameters and EOPs (cf. Moreaux et al, 2016).
  2) Develop a data correction model

  Jason-1 from Lemoine and Capdeville 2006;

  SPOT-5 from Capdeville, Štěpánek, Hecker and Lemoine 2016;

  Jason-2 from Belli et al. 2018; Belli & Exertier 2018.

  3) **<u>Rename the SAA stations in the normal equation while estimating the station positions.</u>**
  4) Obelix strategy: exhibit before launch the DORIS USO to the proton flux. But contrary to Obelix, the effect is not for always (Jason-2).

Study

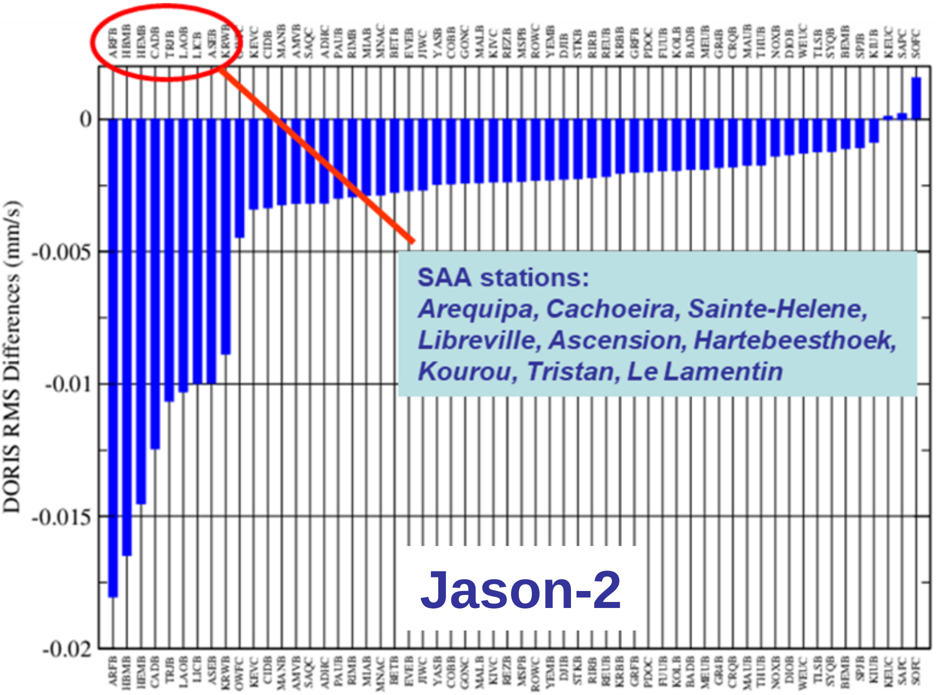
- **Analyze the impact in terms of Helmert parameters, EOPs and station positioning of the SAA mitigation strategies.**
- **References = series without any DORIS satellite sensitive to the SAA.**

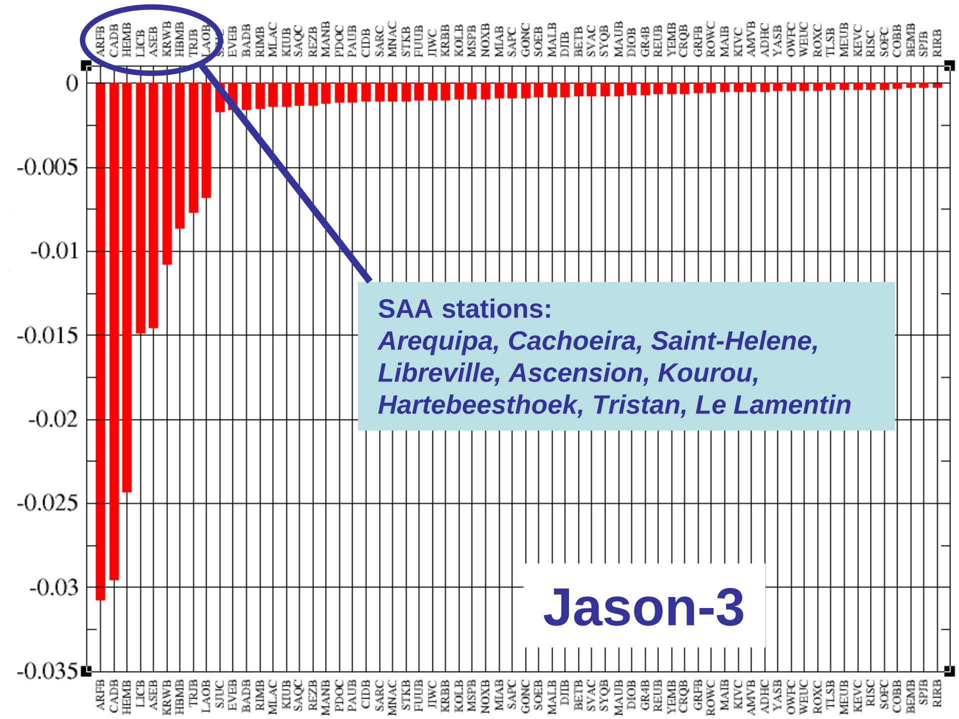
- **Series:**
  - grg 41 = current operational series including all the satellites, Jason-2 & 3 SAA strategy applied.
  - *grg 60 = grg 41 with new gravity, mean pole and FES2014 models.*
  - *grg 61 = grg60 without Jason-2 & 3*
  - *grg 62 = grg 60 with Jason-2 & 3 without any SAA strategy*
  - ➔ **grg 61 vs grg 60: impact of adding Jason-2 & 3 with SAA strategy**
  - ➔ **grg 62 vs grg 60: impact of adding Jason-2 & 3 without any SAA strategy**

  - gsc 31 = current baseline operational series: itrf2014 stations, Jason-3 SAA Strategy applied.
  - *gsc 32 = gsc 31 with update for strategy of estimating troposphere and range-rate biases.*
  - *gsc 33 = gsc 32 with Jason-2 SAA strategy applied.*
  - *gsc 34 = gsc 32 excluding Jason-2 & 3*
  - ➔ **gsc 34 vs gsc 33: impact of adding Jason-2 & 3 with SAA strategy**

GRG – DORIS data residuals

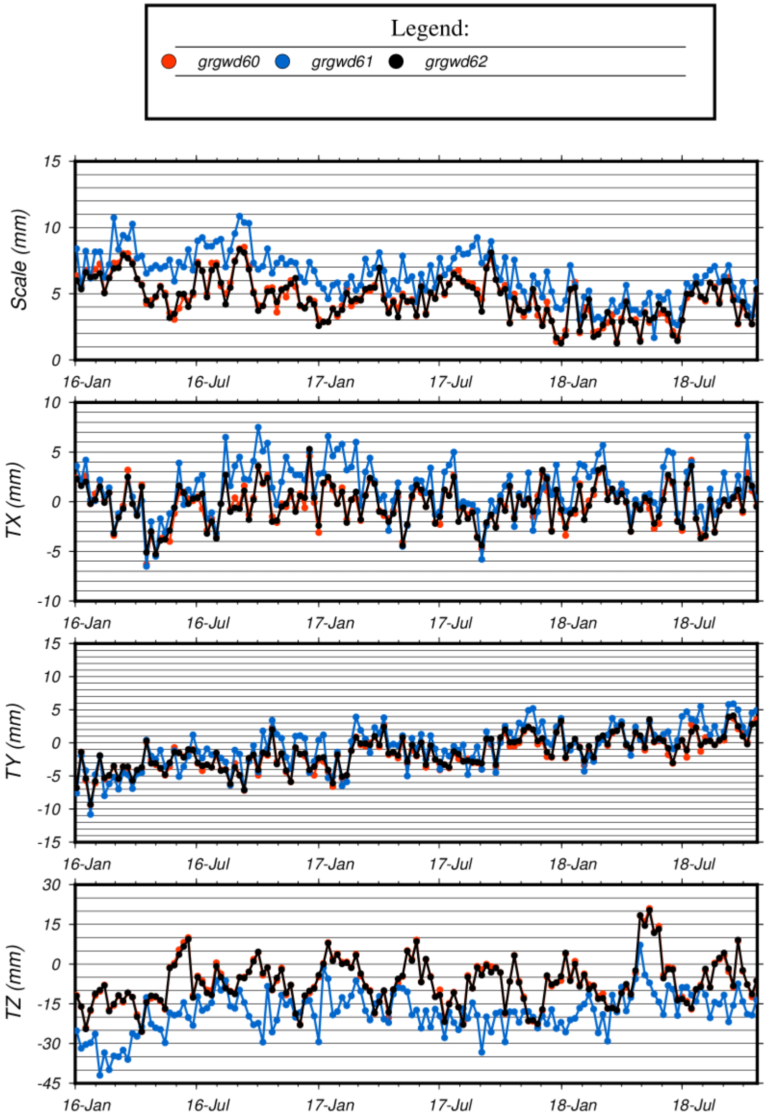
DORIS RMS of fit differences per station





- *The DORIS residuals are lower when we apply the strategy of Bias+Drift adjusting frequency per pass for SAA stations.*
- *The impact is significant for SAA stations, the number of measurements is higher.*
- *For Jason-3, the level of DORIS RMS residuals is slightly higher compared to Jason-2, explained by its higher sensitivity to the SAA.*

GRG – Helmert Parameters wrt DPOD2014 v4



Time period: 2016.0-2019.0

mean / std	grg 60	grg 61	grg 62
Scale [mm]	4.74 ± 1.37	6.41 ± 1.42	4.66 ± 1.35
Tx [mm]	-0.28 ± 1.98	1.23 ± 2.63	-0.26 ± 1.96
Ty [mm]	-1.61 ± 1.89	-0.60 ± 2.44	-1.43 ± 1.81
Tz [mm]	-6.89 ± 8.56	-18.28 ± 7.09	-7.06 ± 8.39

- Similar performances for grg 60 and grg 62

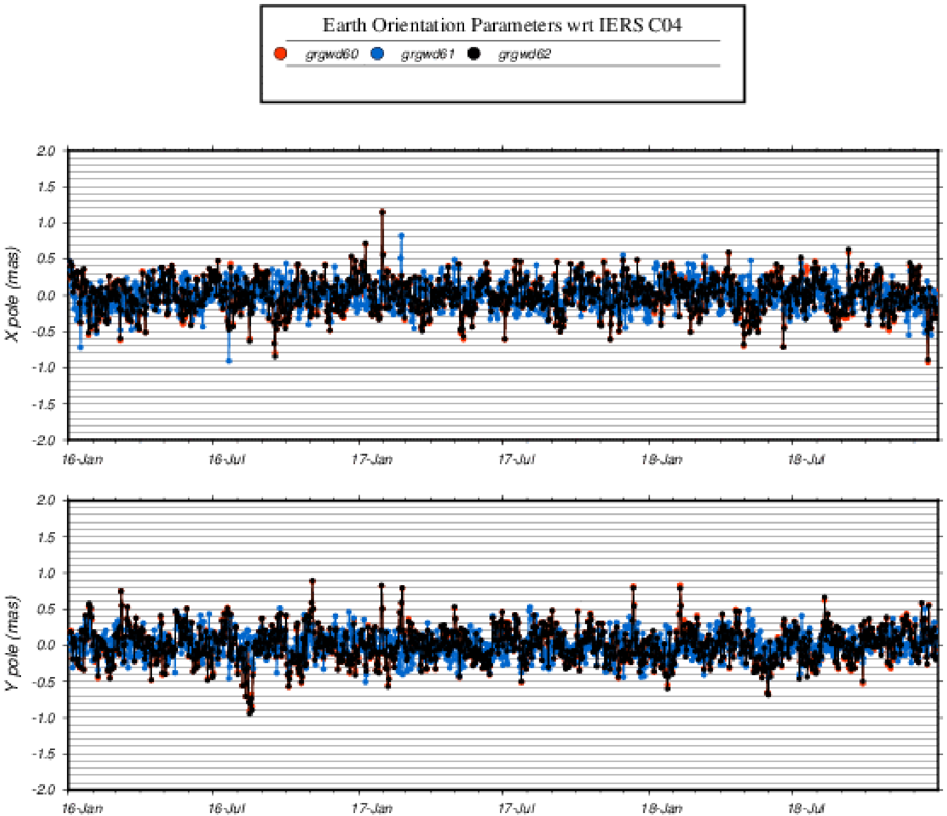
➔ Partial validation of the SAA strategy.

- Including Jason- 2 & 3

➔ Decrease the scale offset by 1.7mm

➔ Increase the stability of the parameters by reducing the stds.

GRG – EOPs differences wrt IERS C04

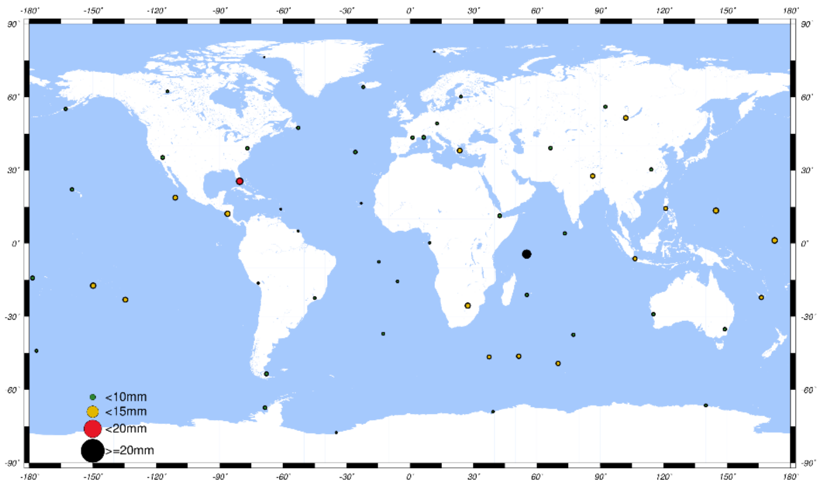


AC	serie	# days	X pole (mas)			Y pole (mas)		
			trend	mean	std	trend	mean	std
grg	60	1093	0.024	-0.001	0.228	0.000	0.000	0.230
grg	61	1093	0.021	-0.000	0.182	-0.040	0.000	0.172
grg	62	1091	0.022	-0.001	0.228	0.000	0.000	0.234

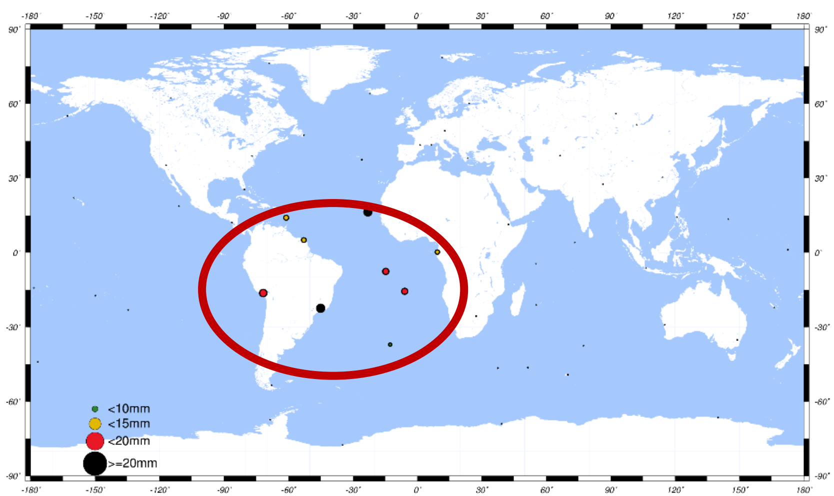
- Similar performances of grg 60 in X and Y in terms of std.
- grg 61 performs the best in terms of std with a reduction in both X and Y by 20-25% !!!

GRG – RMS of weekly station position differences

grg 61 vs grg 60



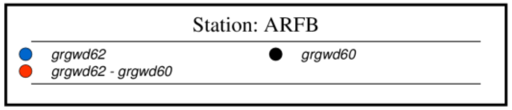
grg 62 vs grg 60



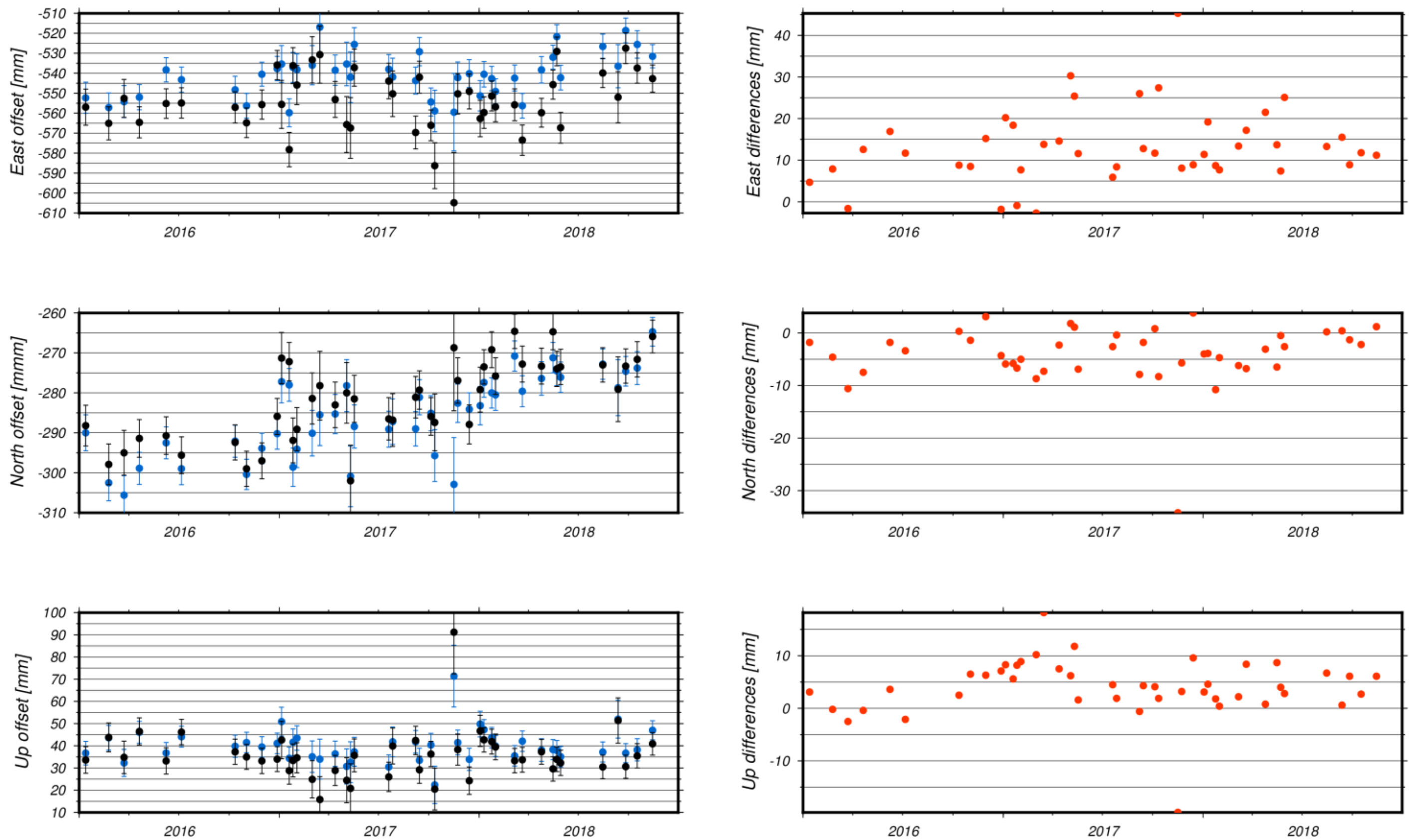
- GRG 62 vs GRG 60 ➔ SAA stations.
- GRG 61 vs GRG 60: no geographical pattern, small differences on the SAA stations
  ➔ partial validation of the SAA mitigation strategy.

GRG – Example: Arequipa

Impact of adding Jason-2 & 3 without any SAA mitigation strategy

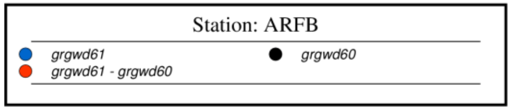


		days	min	max	mean	std
1990001-2099365	E diff.	44	-2.700	45.300	13.223	9.034
1990001-2099365	N diff.	44	-34.200	3.800	-4.200	5.841
1990001-2099365	U diff.	44	-19.800	18.200	4.057	5.415

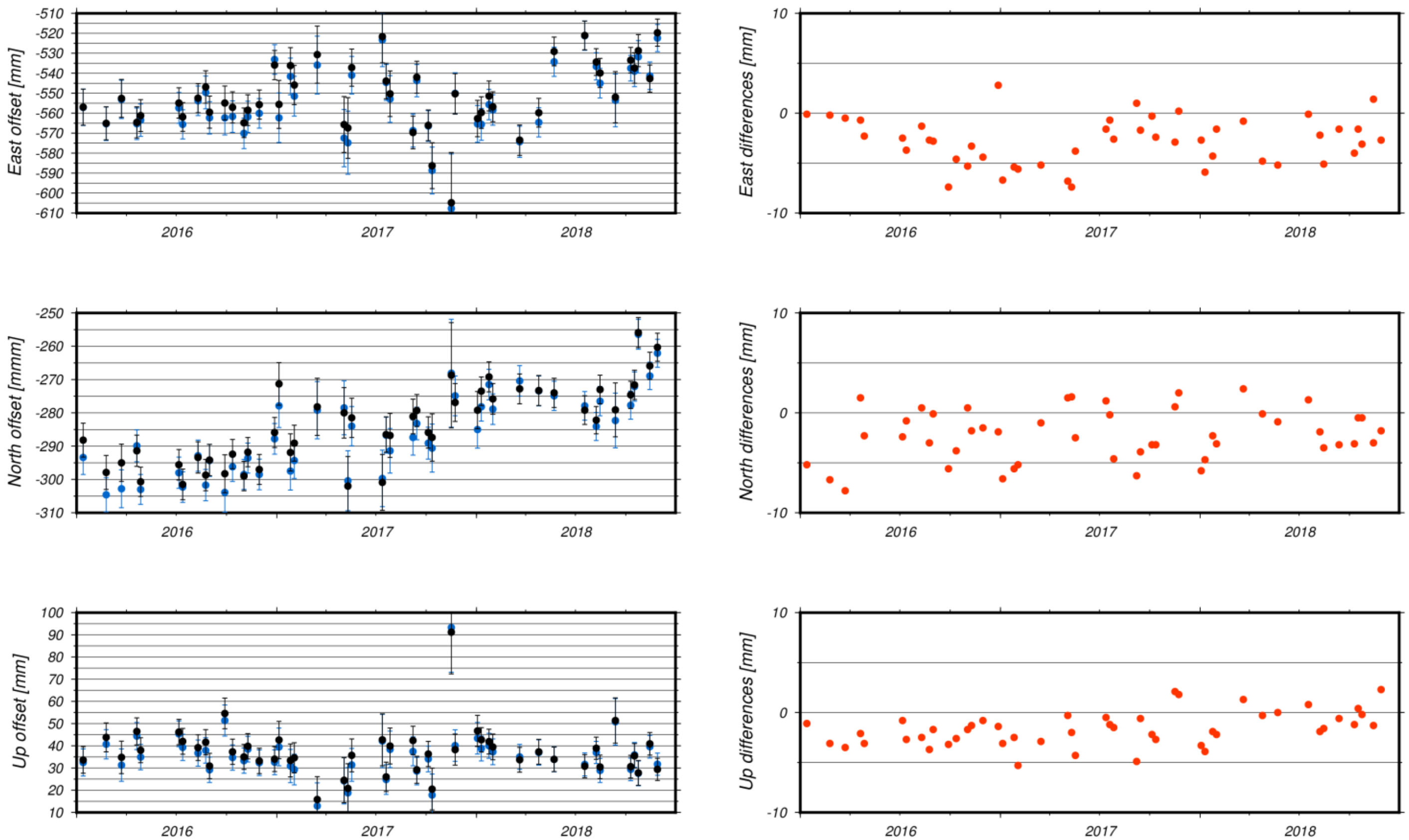


GRG – Example: Arequipa

Impact of adding Jason-2 & 3 with a SAA mitigation strategy



		days	min	max	mean	std
1990001-2099365	E diff.	48	-7.400	2.800	-2.817	2.373
1990001-2099365	N diff.	48	-7.800	2.400	-2.219	2.603
1990001-2099365	U diff.	48	-5.300	2.300	-1.646	1.708



GRG – Example: Kourou

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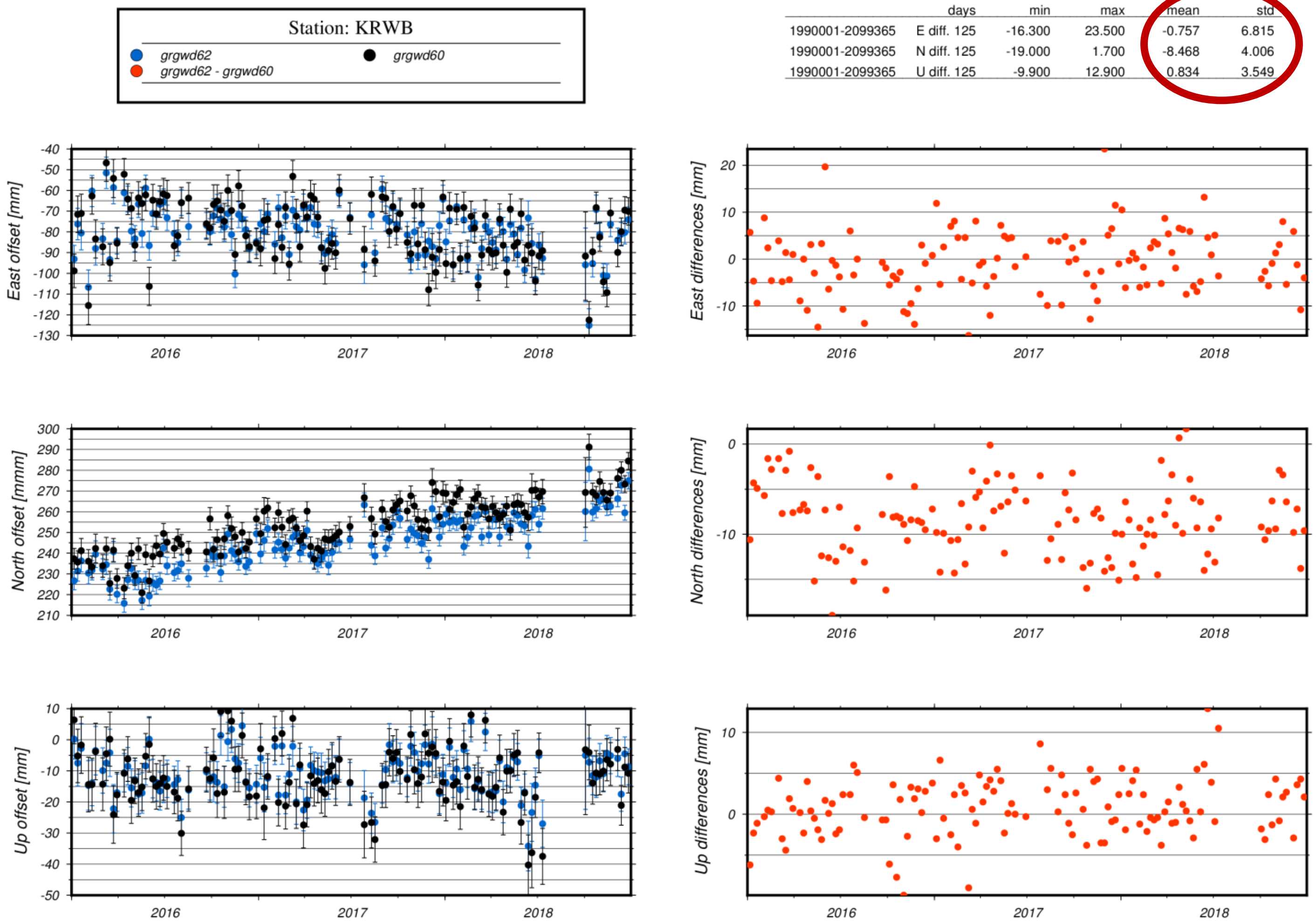
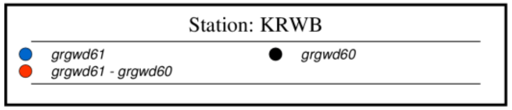
Impact of adding Jason-2 & 3 without any SAA mitigation strategy

		days	min	max	mean	std
1990001-2099365	E diff.	125	-16.300	23.500	-0.757	6.815
1990001-2099365	N diff.	125	-19.000	1.700	-8.468	4.006
1990001-2099365	U diff.	125	-9.900	12.900	0.834	3.549

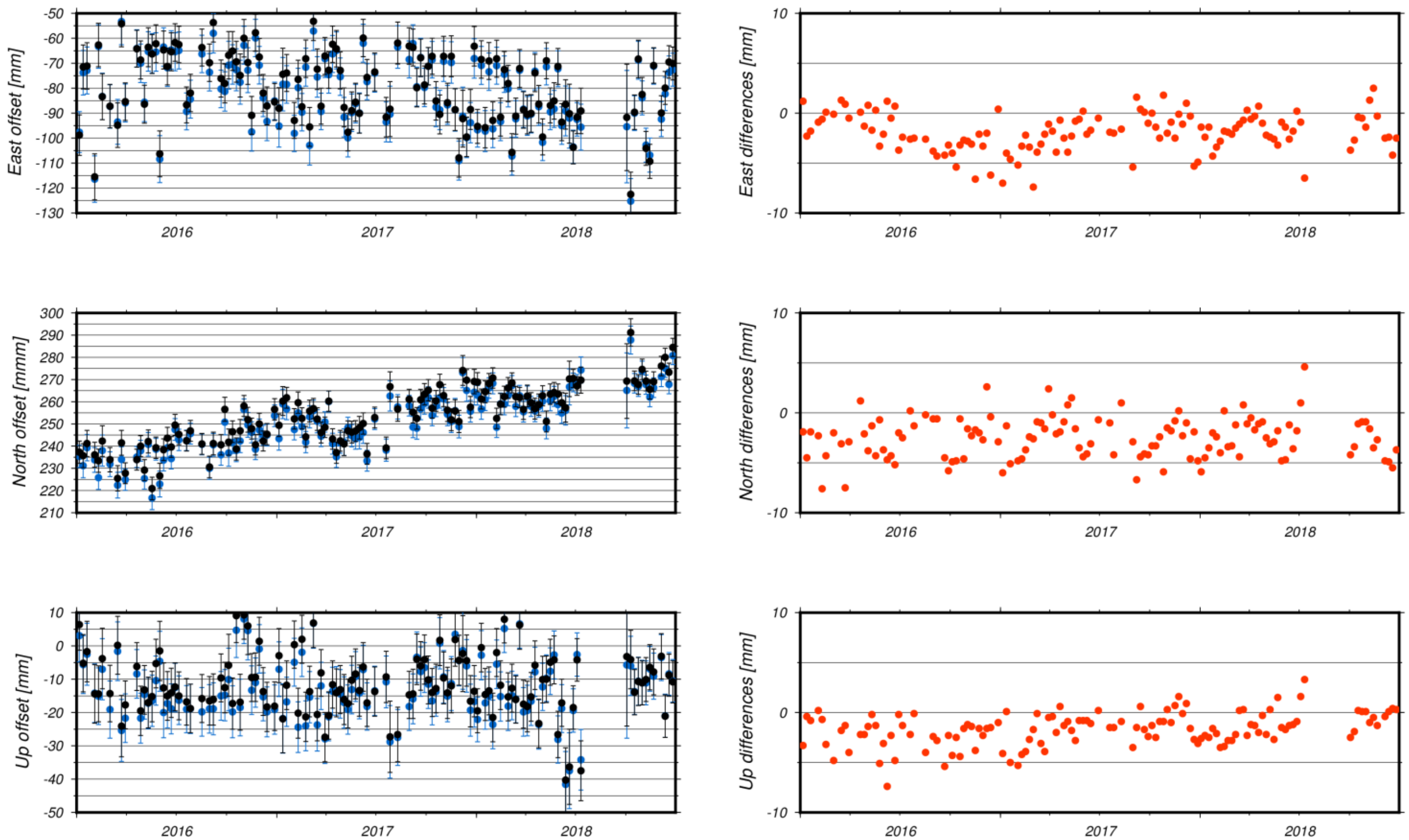


GRG – Example: Kourou

Impact of adding Jason-2 & 3 with a SAA mitigation strategy

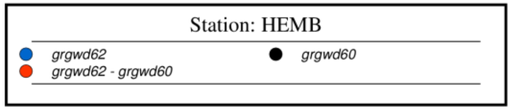


		days	min	max	mean	std
1990001-2099365	E diff.	126	-7.400	2.500	-1.917	1.941
1990001-2099365	N diff.	126	-7.600	4.600	-2.529	2.085
1990001-2099365	U diff.	126	-7.400	3.300	-1.674	1.671

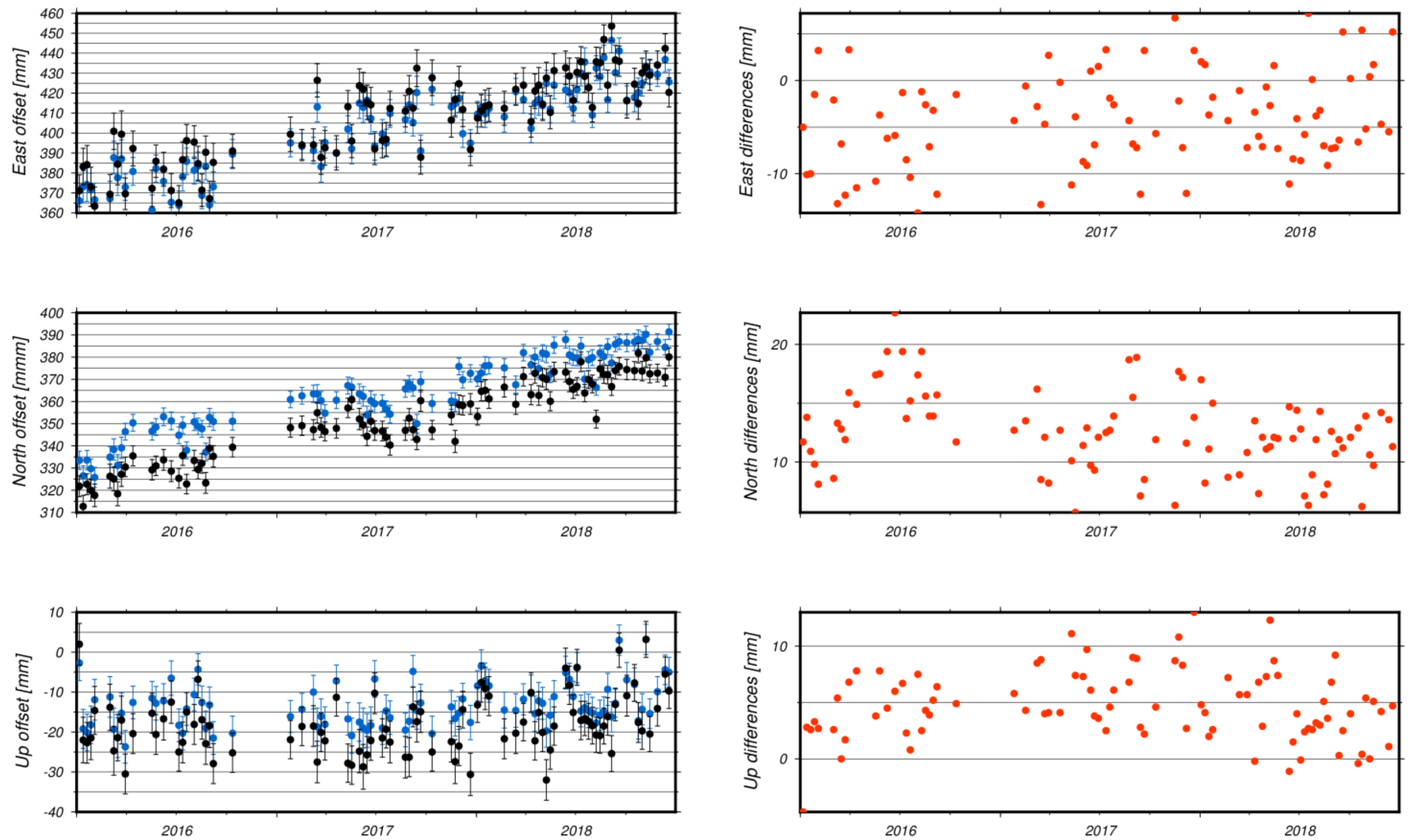


GRG – Example: Saint Helena

Impact of adding Jason-2 & 3 without any SAA mitigation strategy



		days	min	max	mean	std
1990001-2099365	E diff.	91	-14.200	7.200	-4.173	5.046
1990001-2099365	N diff.	91	5.700	22.700	12.458	3.462
1990001-2099365	U diff.	91	-4.700	13.000	4.667	3.122



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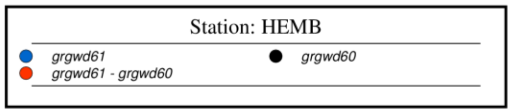
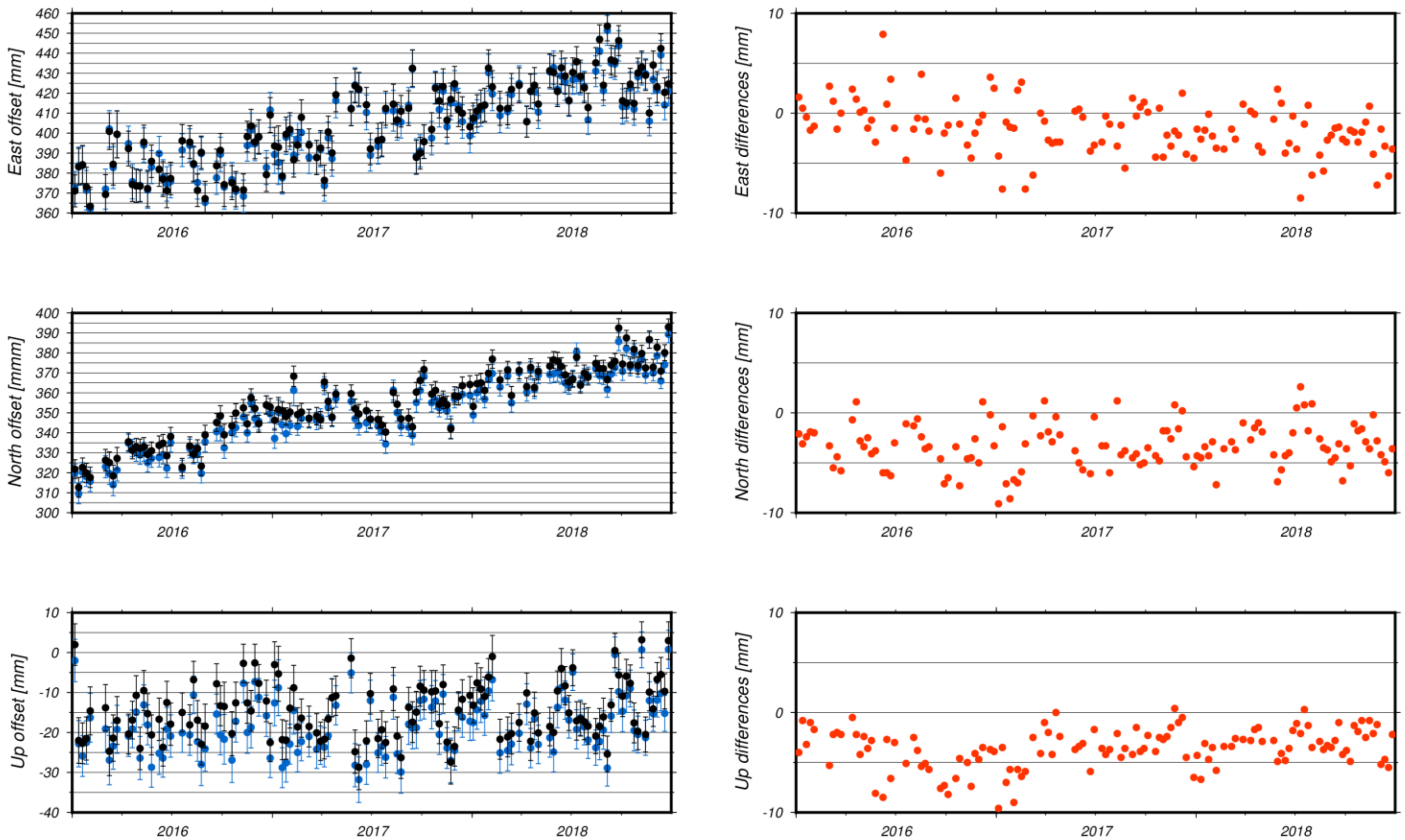
GRG – Example: Saint Helena

Impact of adding Jason-2 & 3 with a SAA mitigation strategy



		days	min	max	mean	std
1990001-2099365	E diff.	124	-8.500	7.900	-1.563	2.614
1990001-2099365	N diff.	124	-9.100	2.600	-3.340	2.250
1990001-2099365	U diff.	124	-9.600	0.400	-3.608	2.012

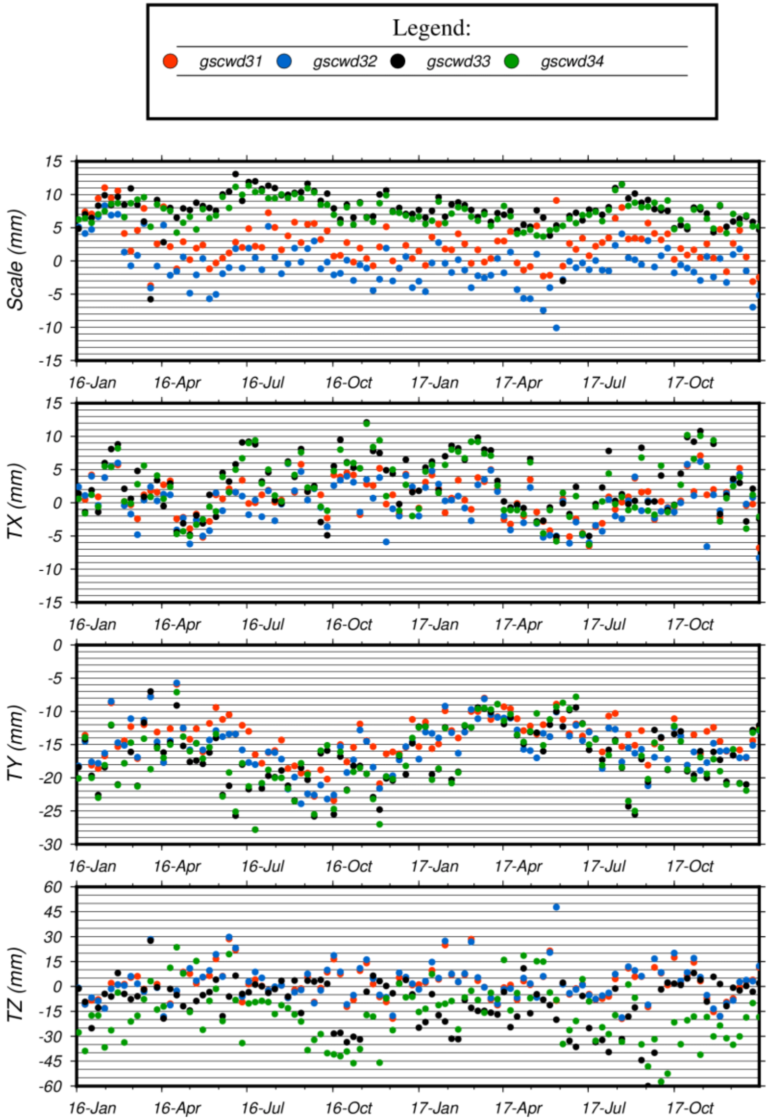


GRG Conclusions

- **The SAA mitigation strategy on Jason-2 & 3 significantly reduces the impact of the SAA on the positions on the stations in the SAA region (Arequipa, Cachoiera, Kourou, Libreville, Saint Helena, Santiago).**

- **Adding Jason-2 & 3 improves the stability of the Helmert parameters as well as the EOP performances.**

GSC – Helmert Parameters wrt DPOD2014 v4



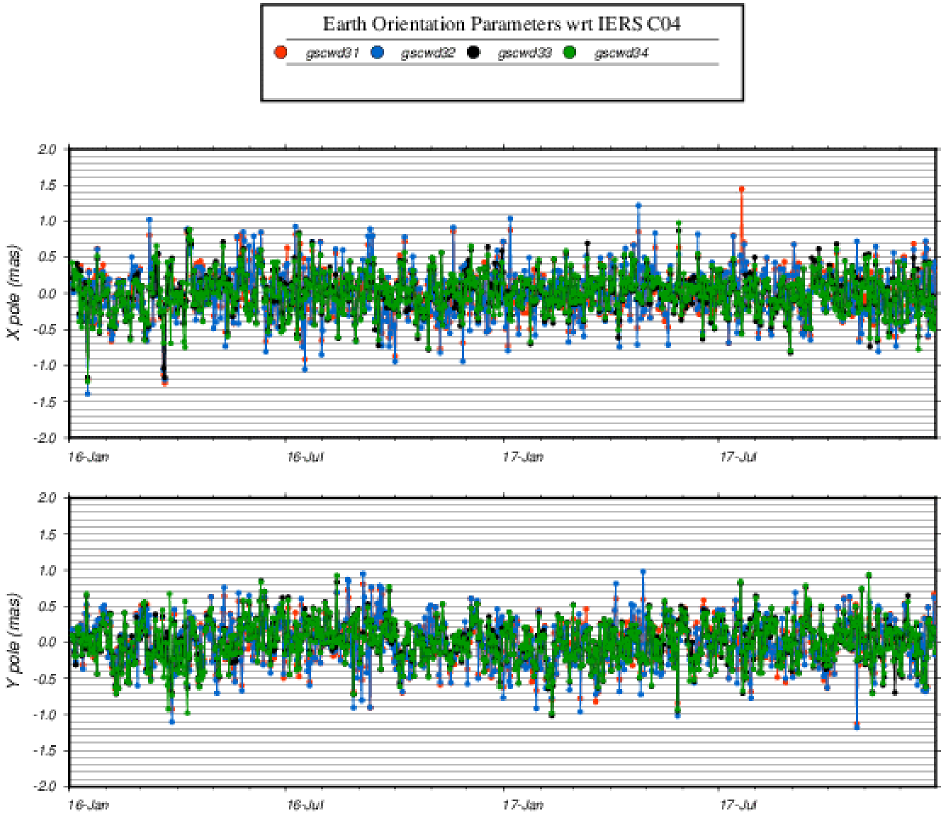
Time period: 2016.0-2018.0

	gsc 31	gsc 32	gsc 33	gsc 34
Scale	2.63 ± 2.88	-0.57 ± 3.01	7.69 ± 2.54	7.32 ± 1.81
Tx	0.72 ± 2.94	-0.08 ± 3.22	2.88 ± 4.27	2.37 ± 4.25
Ty	-14.12 ± 3.19	-15.37 ± 3.51	-16.90 ± 4.35	-16.87 ± 4.43
Tz	1.36 ± 10.00	2.67 ± 11.17	-9.82 ± 14.01	-17.11 ± 16.54

- Similar performances of gsc 33 and gsc 34
➔ partial validation of the SAA mitigation strategy.

- gsc 33 vs gsc 32: Jason-2 SAA strategy
➔ scale increase by nearly 7 mm !!!

GSC– EOPs differences wrt IERS C04



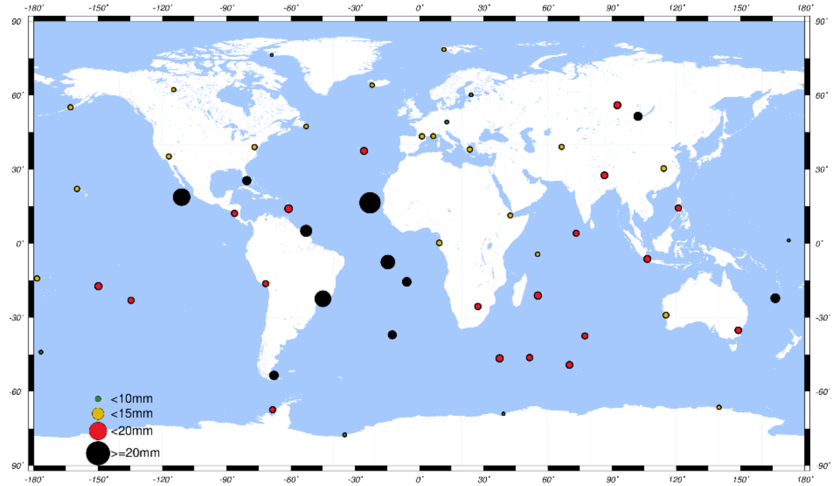
AC	serie	# days	X pole (mas)			Y pole (mas)		
			trend	mean	std	trend	mean	std
gsc	31	721	0.010	0.001	0.327	0.010	-0.001	0.303
gsc	32	726	0.016	0.000	0.352	0.000	-0.001	0.327
gsc	33	728	0.067	-0.000	0.286	-0.030	-0.000	0.289
gsc	34	728	0.023	-0.001	0.281	-0.030	-0.000	0.296

gsc 33 performs

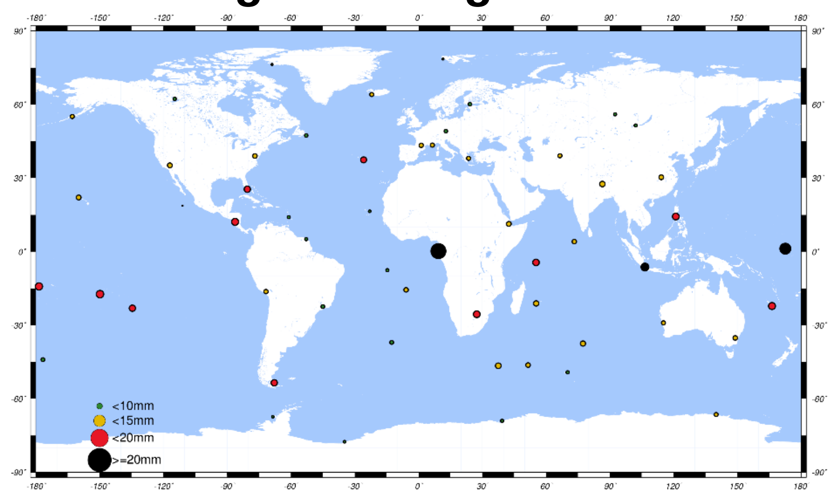
- better than gsc 31 and 32,
- as well as gsc 34,
- With same performances in X and Y.

GSC series – RMS of weekly station position differences

gsc 33 vs gsc 32



gsc 34 vs gsc 33



- GSC 33 vs GSC 32 ➔ SAA stations.
- GSC 34 vs GSC 33: no geographical pattern, small differences on the SAA stations excepted for Libreville
  ➔ partial validation of the SAA mitigation strategy.

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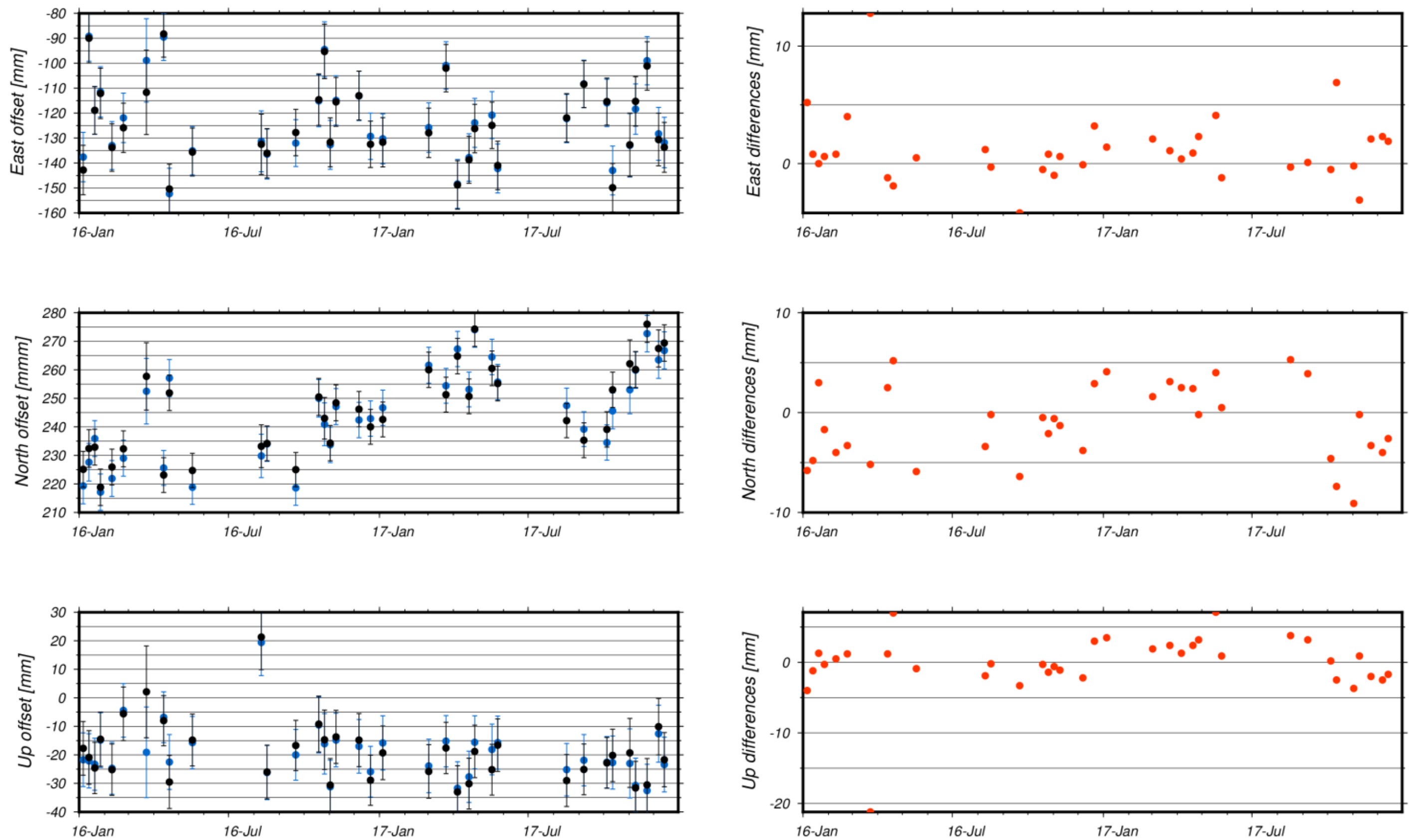
GSC 34 vs 33 – Example: Cachoiera

Impact of adding Jason-2 & 3 with a SAA mitigation strategy

Station: CADB

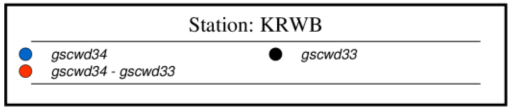
gscwd34 gscwd33
gscwd34 - gscwd33

		days	min	max	mean	std
1990001-2099365	E diff.	36	-4.200	12.800	1.156	2.930
1990001-2099365	N diff.	36	-9.100	5.300	-1.094	3.864
1990001-2099365	U diff.	36	-21.200	7.100	-0.167	4.478

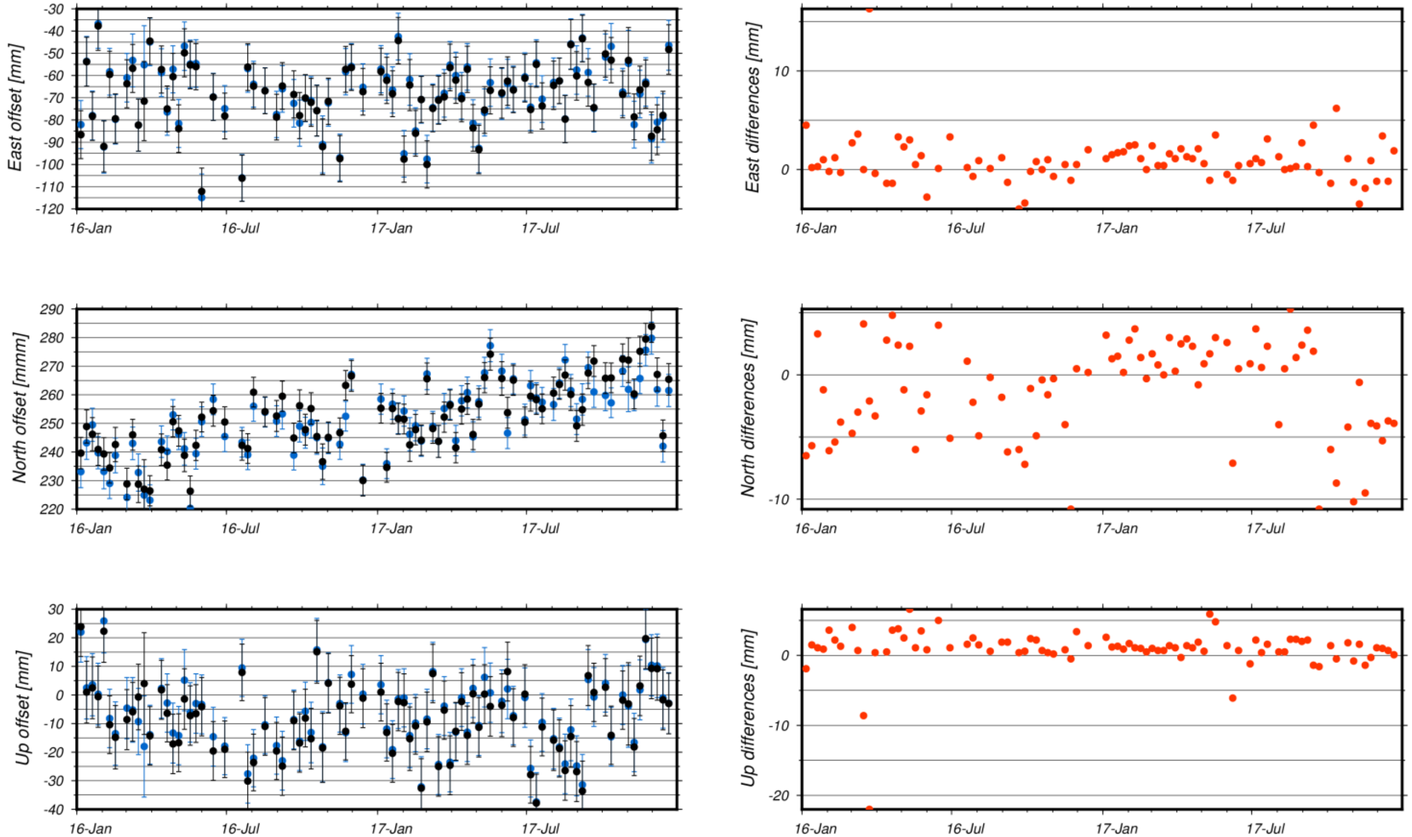


GSC 34 vs 33 – Example: Kourou

Impact of adding Jason-2 & 3 with a SAA mitigation strategy



		days	min	max	mean	std
1990001-2099365	E diff.	85	-4.000	16.300	0.904	2.461
1990001-2099365	N diff.	85	-10.800	5.300	-1.281	3.940
1990001-2099365	U diff.	85	-22.000	6.600	0.880	3.221



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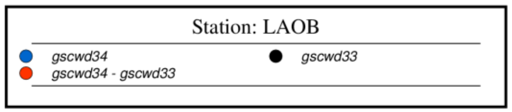
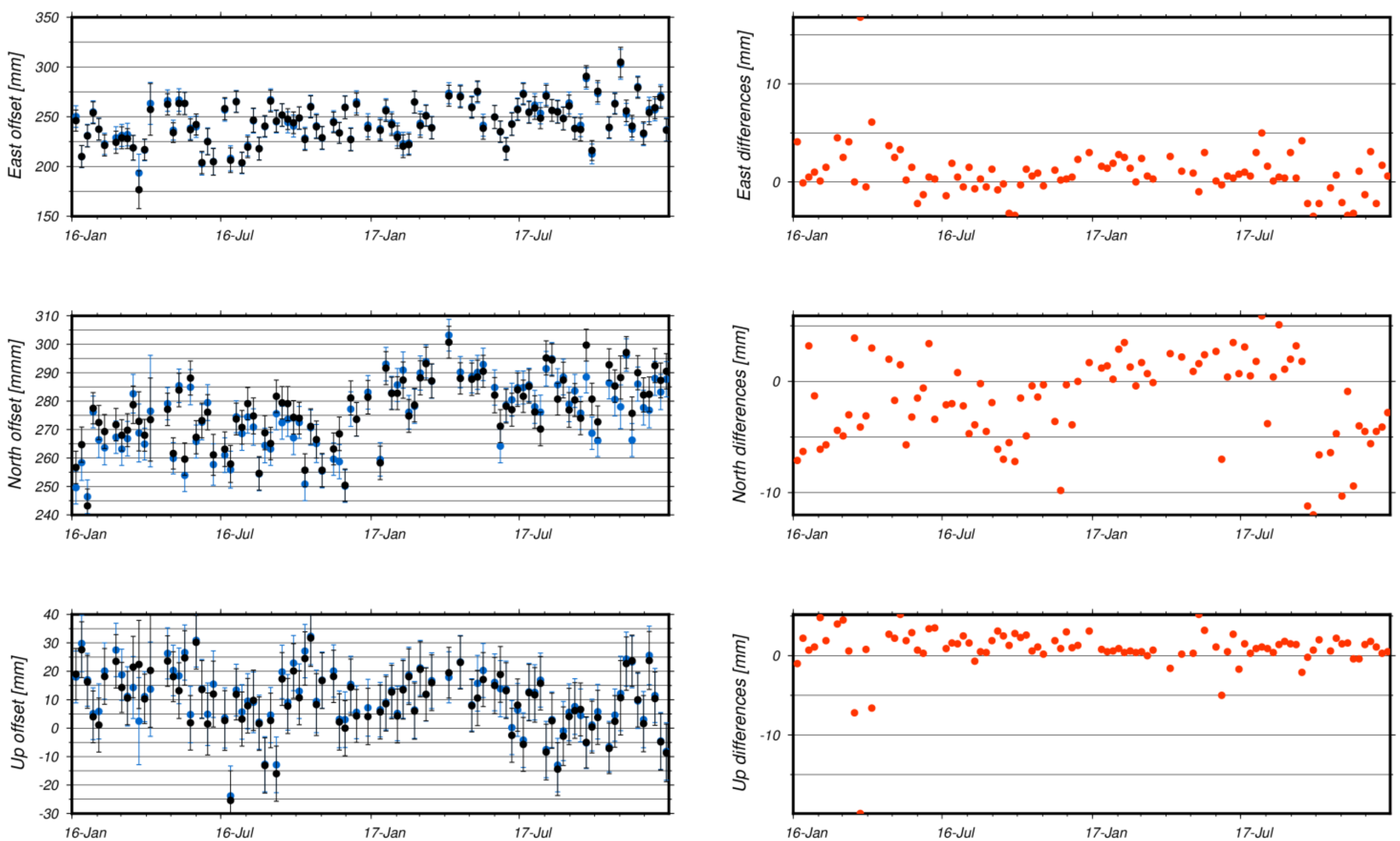
GSC 34 vs 33 – Example: Le Lamentin

Impact of adding Jason-2 & 3 with a SAA mitigation strategy



		days	min	max	mean	std
1990001-2099365	E diff.	91	-3.500	16.800	0.911	2.551
1990001-2099365	N diff.	91	-12.000	5.900	-1.754	3.918
1990001-2099365	U diff.	91	-19.900	5.200	0.865	2.934



GSC Conclusions

- **The SAA mitigation strategy on Jason-2 & 3 (gsc 33) has similar performances cpmpared to the solution without Jason-2 & 3 (gsc 34).**

- **GSC 33 shows a scale:**
  - **Offset of nearly 7mm vs solution wo Jason-2 SAA strategy.**

Open Issues

- **Which SAA strategy for Jason-1 and Spot-5?**
  - **Data correction model**
  - **Station renaming**
  - **Both**

- **Jason-1 in between end of Topex and start of Jason-2?**

- **Jason-2: Belli model?**

- **IDS CC is curious to get series from 2007 to 2010 to see the impact on the coordinate time series of the SAA stations.**