

Present-Day Land and Sea Level Changes around South Georgia Island: Results from Precise Levelling, GNSS, Tide Gauge and Satellite Altimetry Measurements

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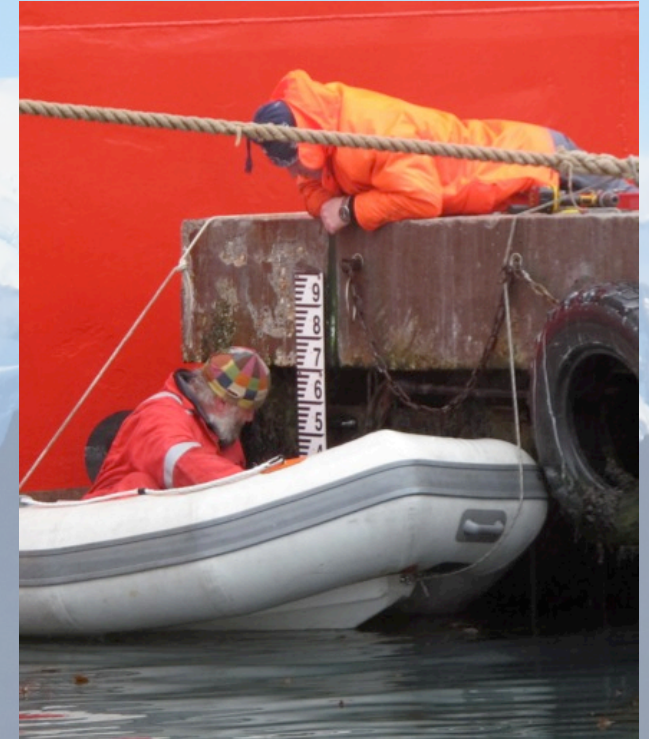
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Overview

- UK South Atlantic Tide Gauge Network
- GNSS Installations
- Benchmark Network
- Results
 - GNSS Height Time Series
 - Sea Level Observations
- Conclusions



Tide board installation at King Edward Point (KEP) Research Station, South Georgia Island in 2014.

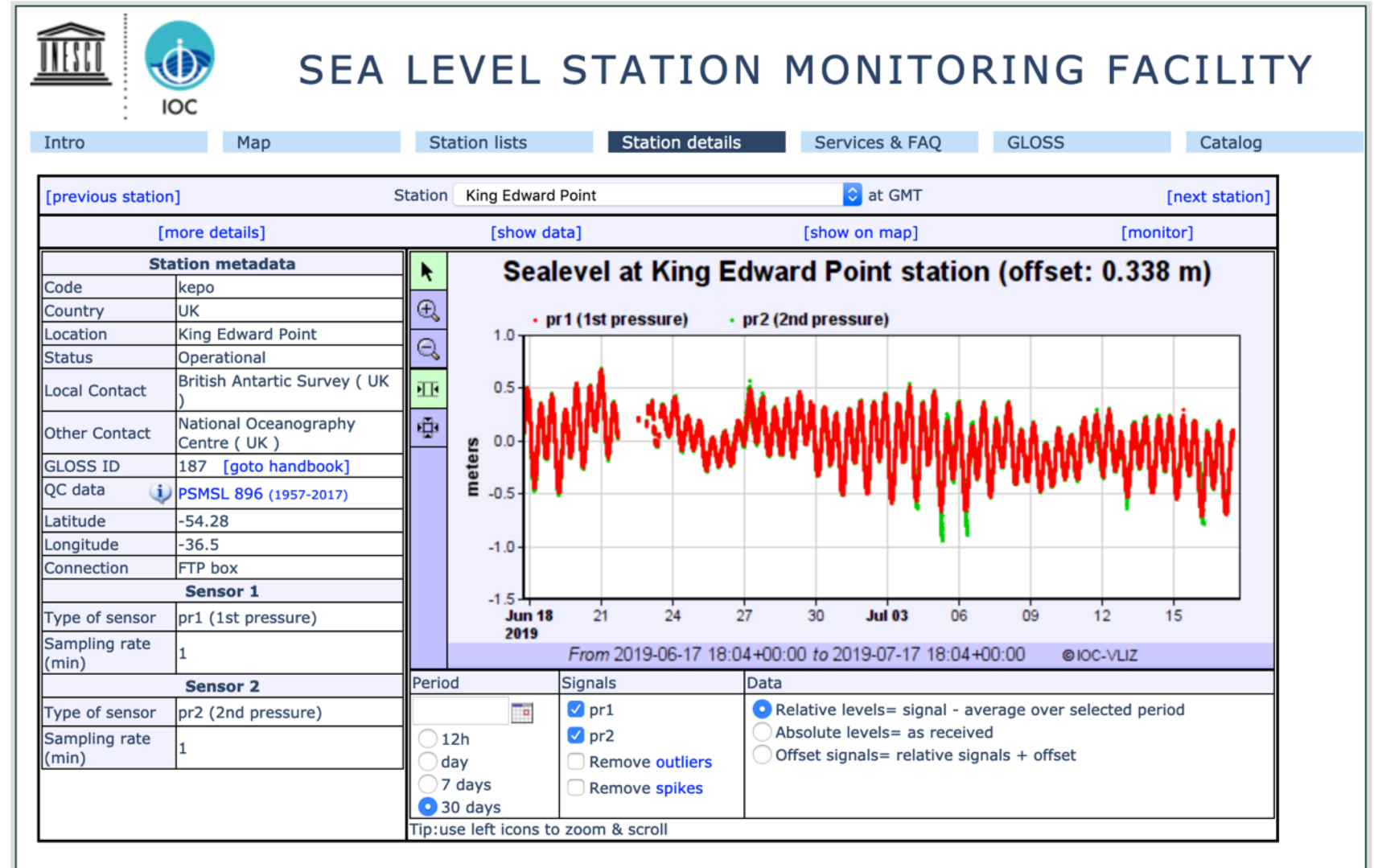
UK South Atlantic Tide Gauge Network

- Established since 1985
- British Overseas Territories (BOTs) and Antarctica
- Affords long sea level records from an under-sampled region
- Used for:
 - Monitoring ACC variability
 - ‘Ground truthing’ satellite altimetry
 - Understanding climate variability on various timescales incl. longer term changes
 - Design and testing of tide gauge (TG) equipment for remote and hostile locations

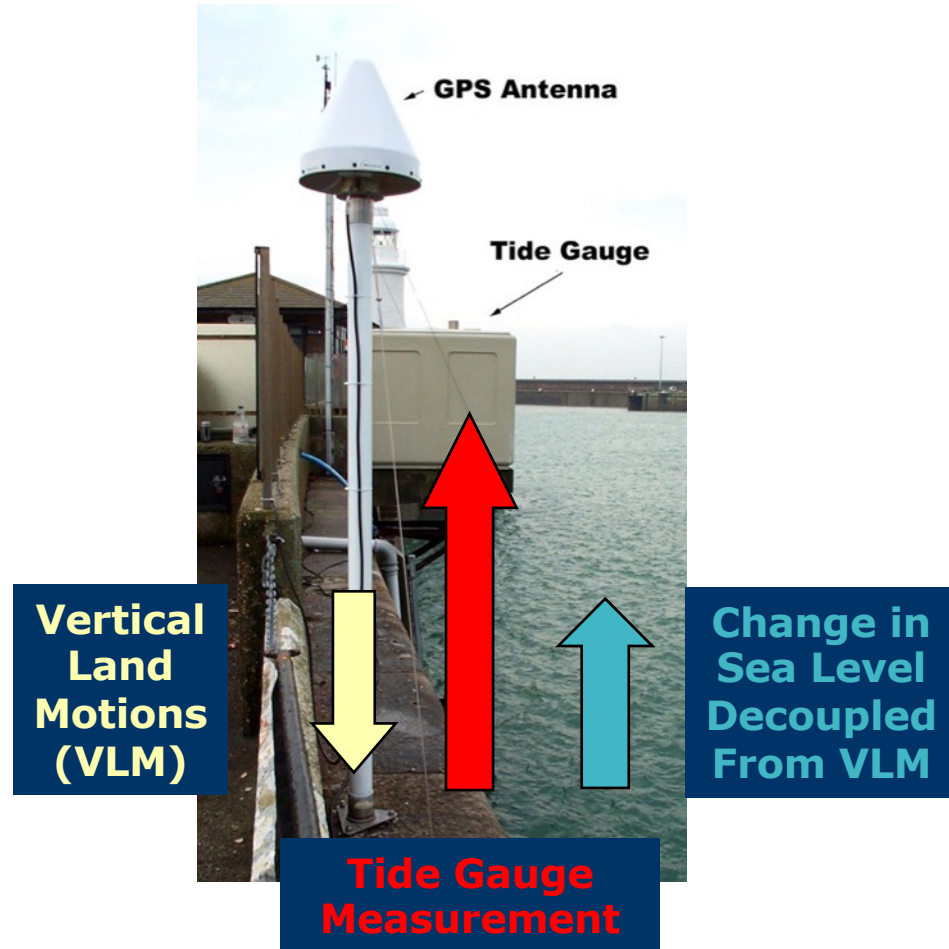


KEP Tide Gauge History

- Early tide gauge data 1957-1959
- New tide gauge since 2008
- Right hand shows the recent TG data at the IOC Sea Level Station Monitoring Facility



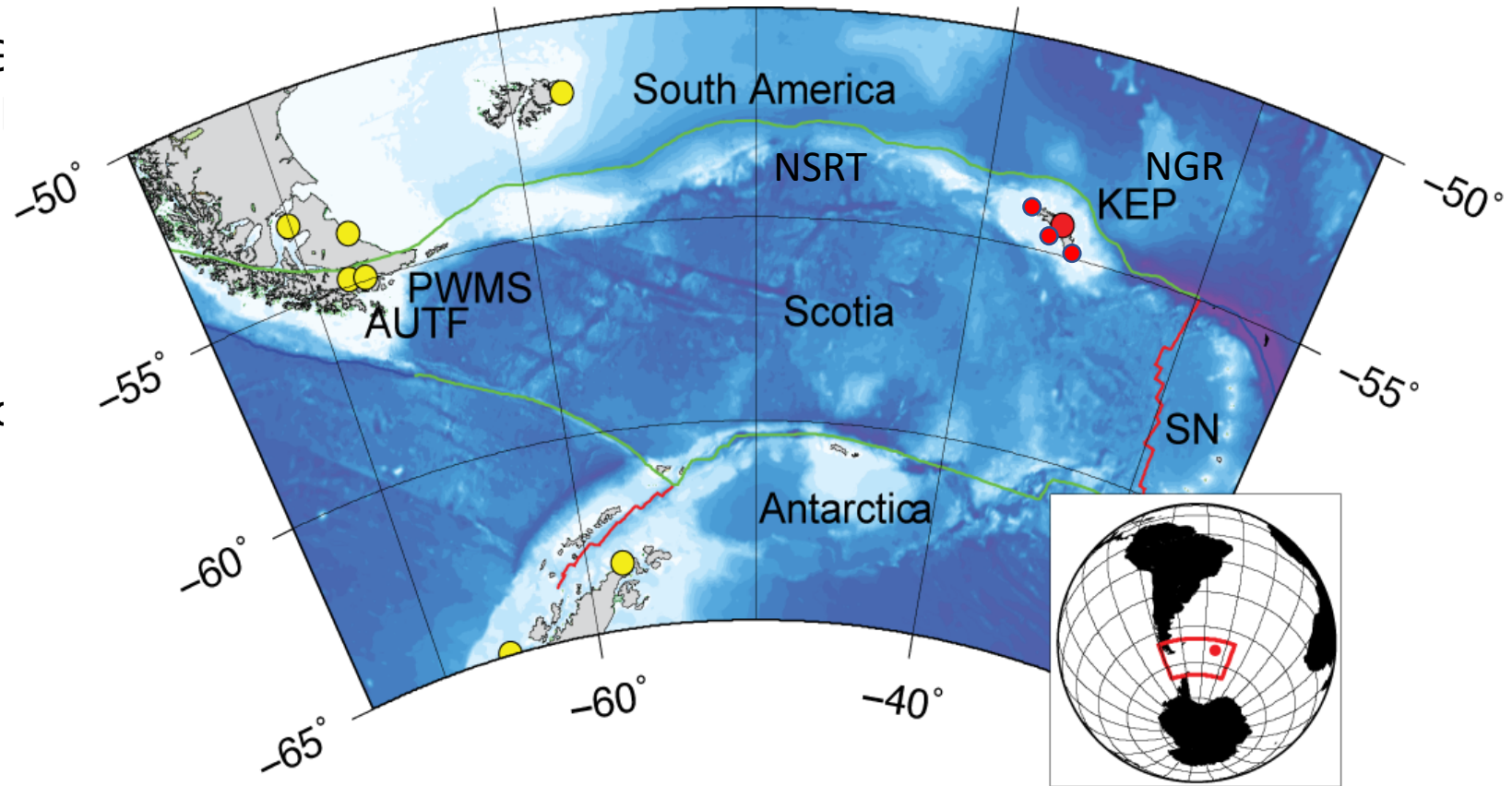
Why monitor Vertical Land Motions at Tide Gauges ?



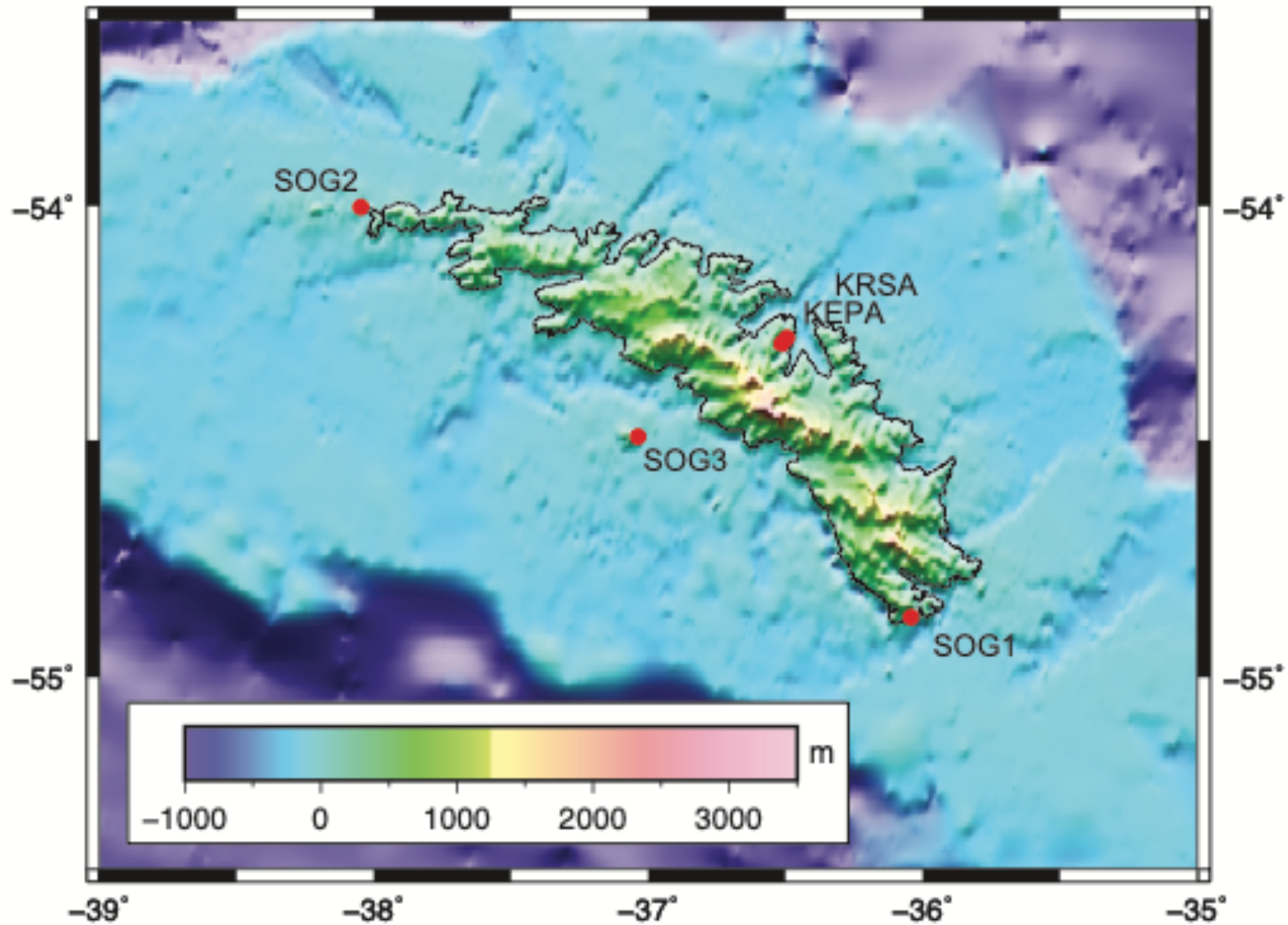
- Tide gauges (TG) measure local sea level
- Vertical land motions (VLM) are determined from CGPS and AG at or close to the tide gauge
- The change in sea level de-coupled from VLM can be inferred

Tectonic Plates and Continuous GNSS Stations

- Location of South Georgia (SG) Island and tectonic plates in the South Atlantic Ocean
- Transforms/fracture zones (green), ridges (red) and trenches (blue)
- continuous GNSS stations (red and yellow circles)
- King Edward Point (KEP)
- NSRT: North Scotia Ridge Transform, NGR: Northeast Georgia Rise, SN: the South Sandwich plate



South Georgia GNSS Network



Presented on July 25, 2019 at the 13th ISAES, July 22-26, 2019, Incheon, Republic of Korea

The continuous GNSS Stations KEPA and KRSA



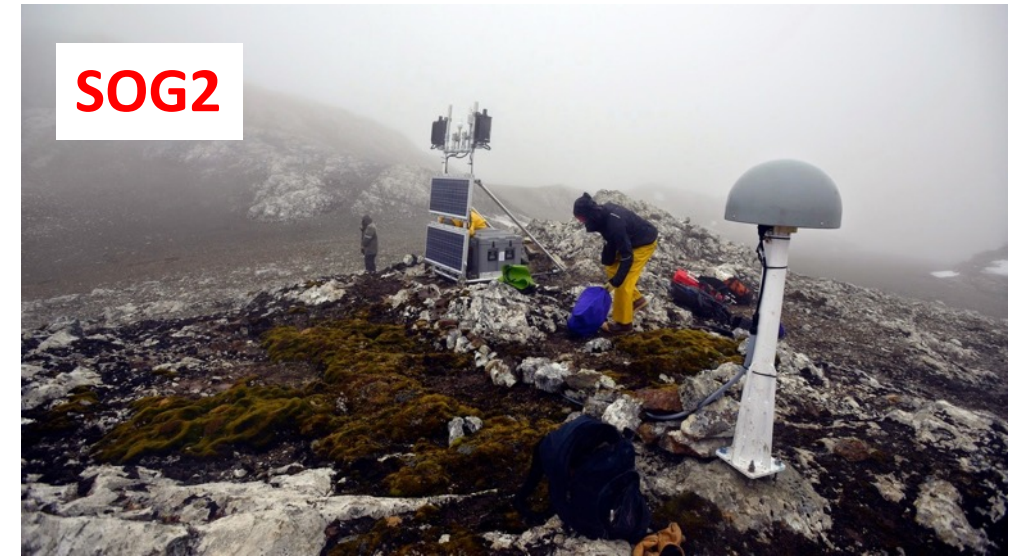
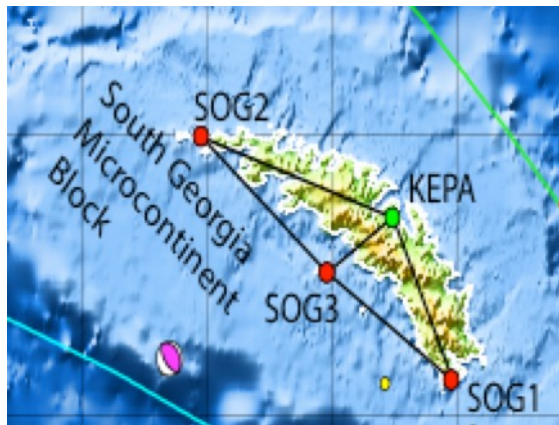
GNSS antenna and mast with unobstructed sky view on top of Brown Mt. Solar power system, enclosures with batteries and electronics, structural frame, radio antenna and weather station in 30m distance to mast. Antenna location on bedrock.



GNSS antenna and mast with obstructed sky due to Mt. Duse. Mains power and communications to KEP radio room in 120 m distance. Many problems since early 2017 with not all data having been recoverable. Antenna location on concrete monument in gravel beds.

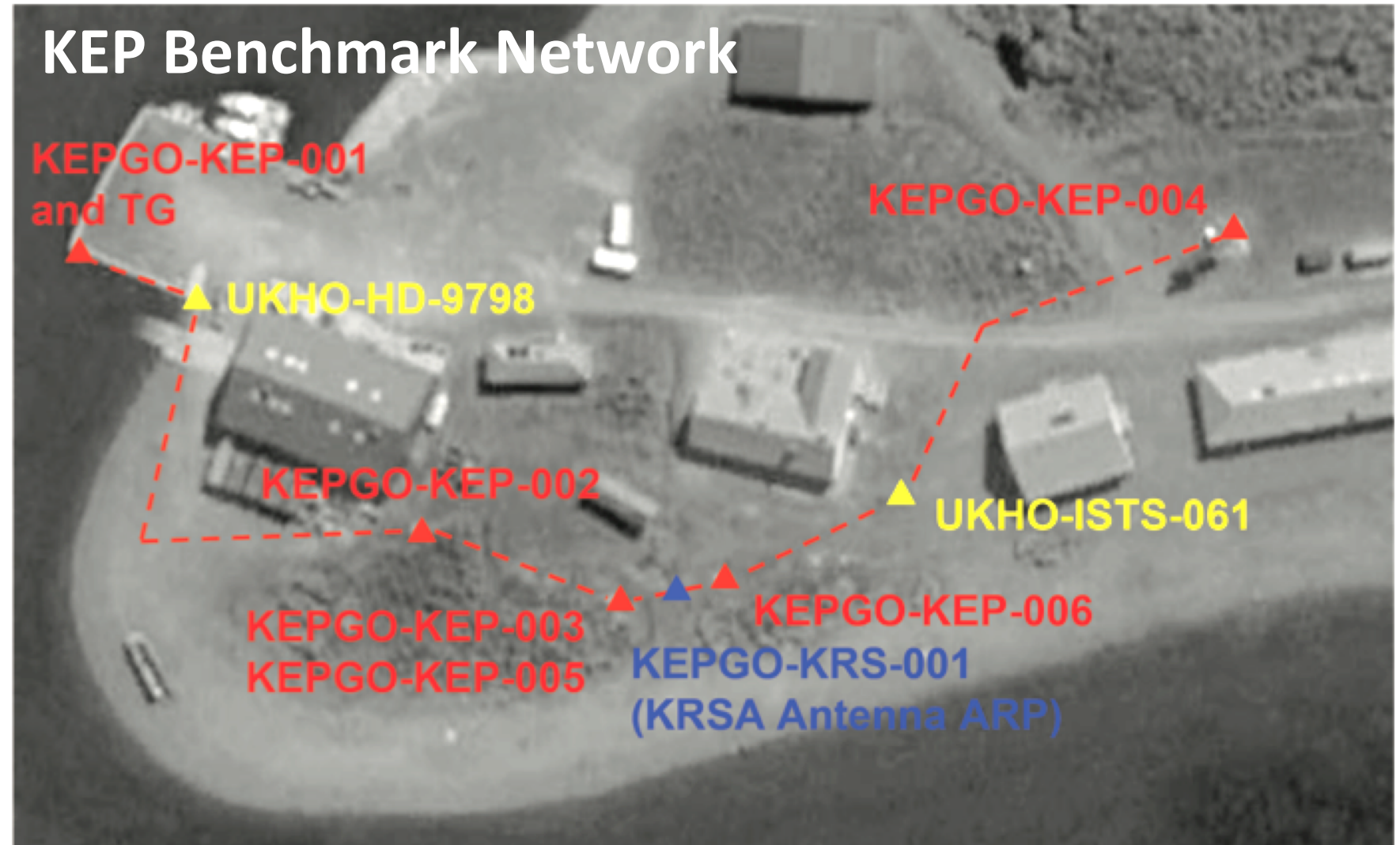
Other GNSS Installations

- Consortium of the University of Texas at Austin and Memphis University
- NSF Project
- Installed 3 stations in late 2014
- At periphery of main island



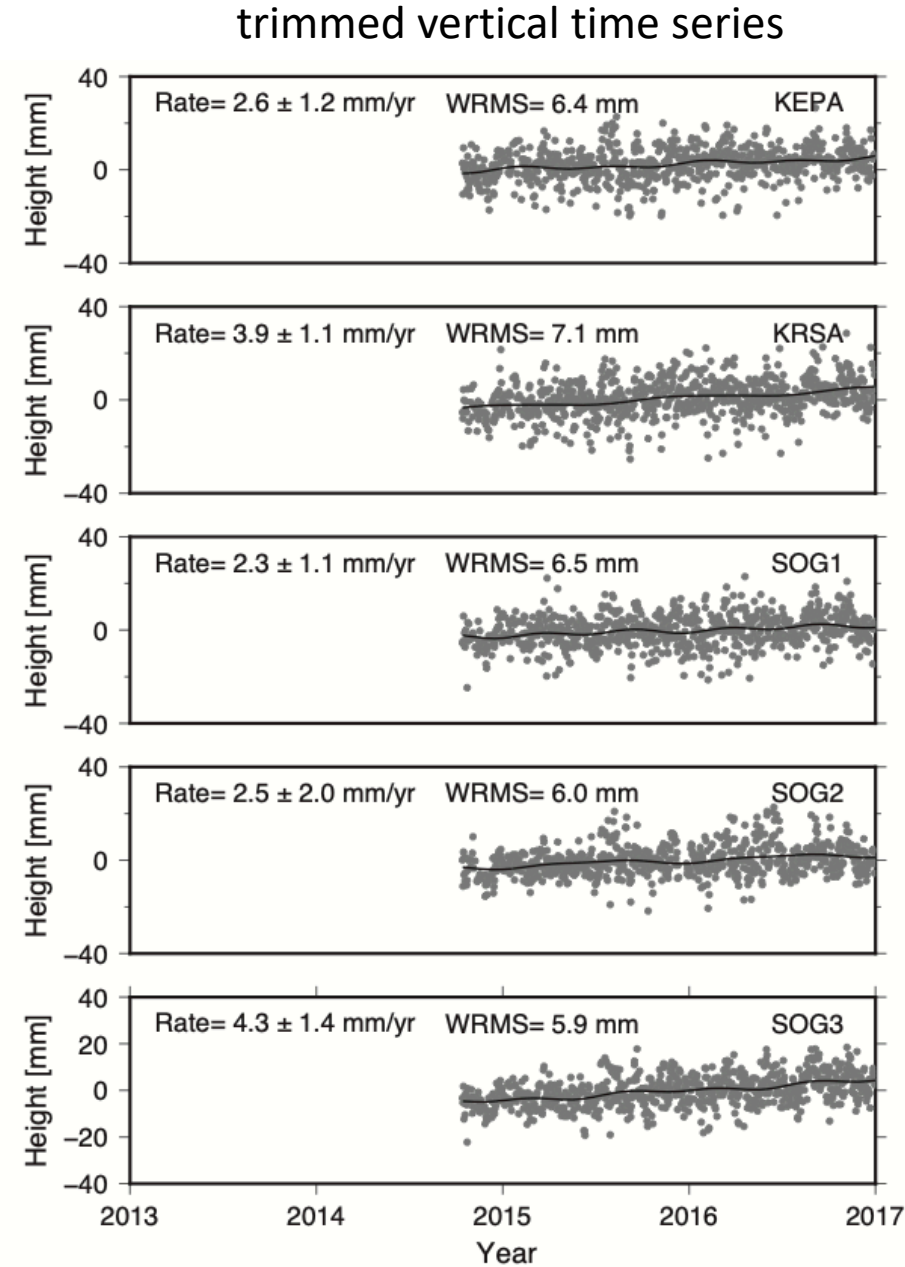
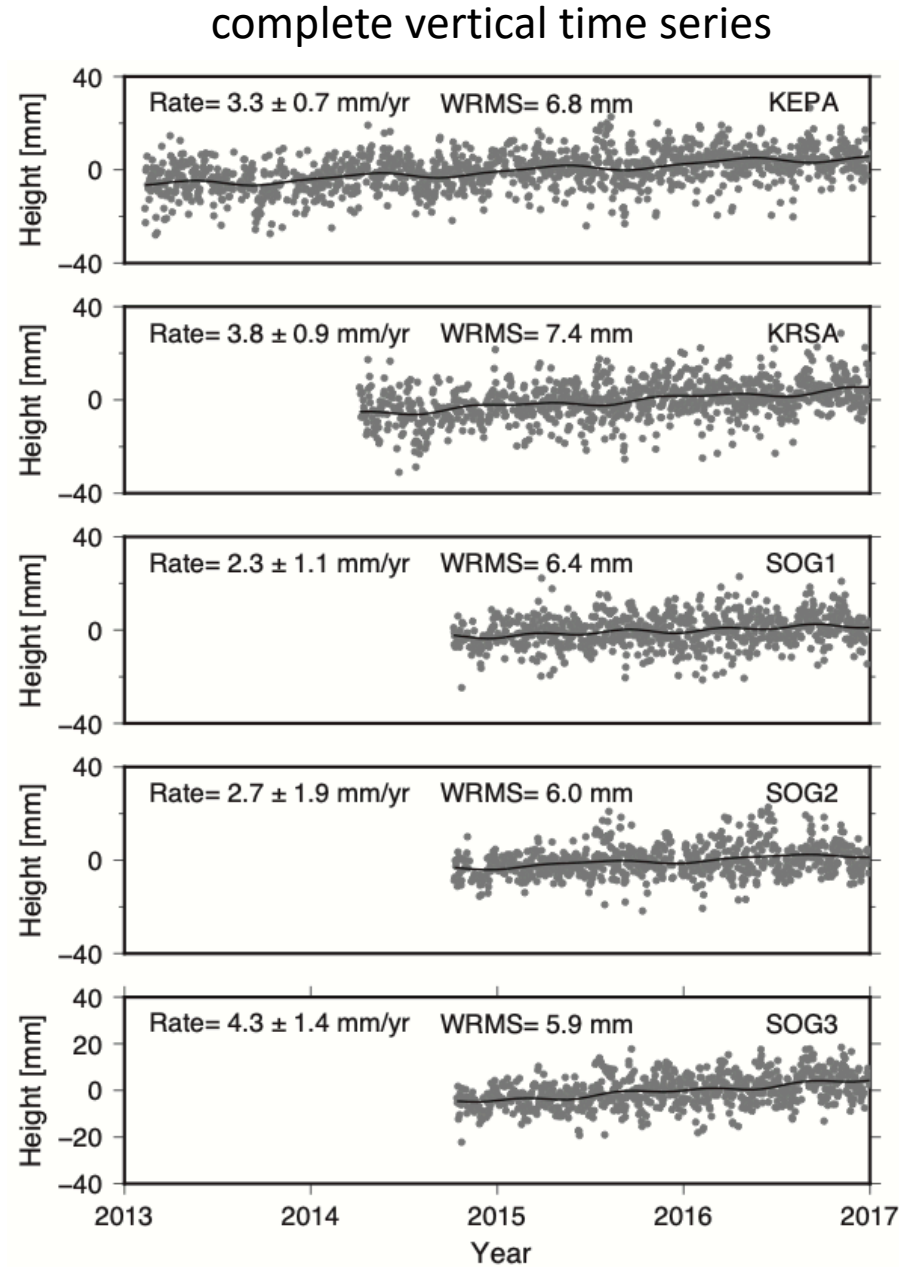
Benchmark Networks

- Two Benchmark networks were established: on Brown Mountain and at KEP
- At KEP to provide geodetic reference for the tide gauge and tie it to the GNSS station KRSA
- On Brown Mt. enable a tie if monument of KEPA gets destroyed by severe weather



Previous GNSS Results (<2017)

- Based on global Bernese GNSS Software DD solution (IGS Repro 2 Standards)
- Indicate general uplift of SG
- As expected, some vertical rate changes due to time series length



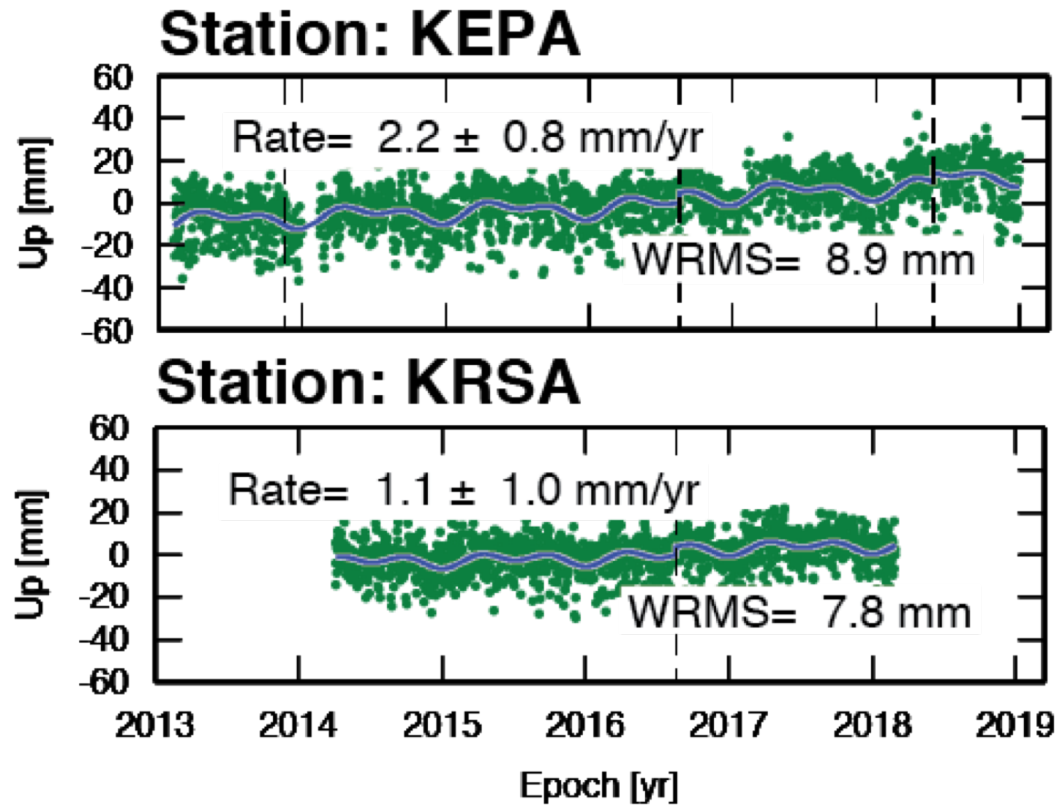
Updated GPS Solution

- Based on PRIDE Software and follow IGS repro2 strategy
 - Elevation angle cut off: 3 degrees
 - Weighting: Elevation-dependent data weighting
 - A priori hydrostatic delay, Vienna Mapping functions
 - Satellite orbit and clocks products by IGS
 - Solid Earth tides, Ocean tides, pole tides, relativistic effects IERS Conventions 2003
- Estimated parameters
 - Station coordinates
 - Receiver clocks
 - 2-hour zenith tropospheric delays
 - 12-hour horizontal tropospheric gradients
 - Integer phase ambiguities

PRIDE Software

- Developed and maintained by The PRIDE Lab at the GNSS Research Center of Wuhan University
- Open source software
- Follows Precise Point Positioning (PPP) strategy with integer ambiguity resolution (AR)
- The implementation of the AR, needs external phase bias products derived from a global network solution

What do the latest GNSS Results show?

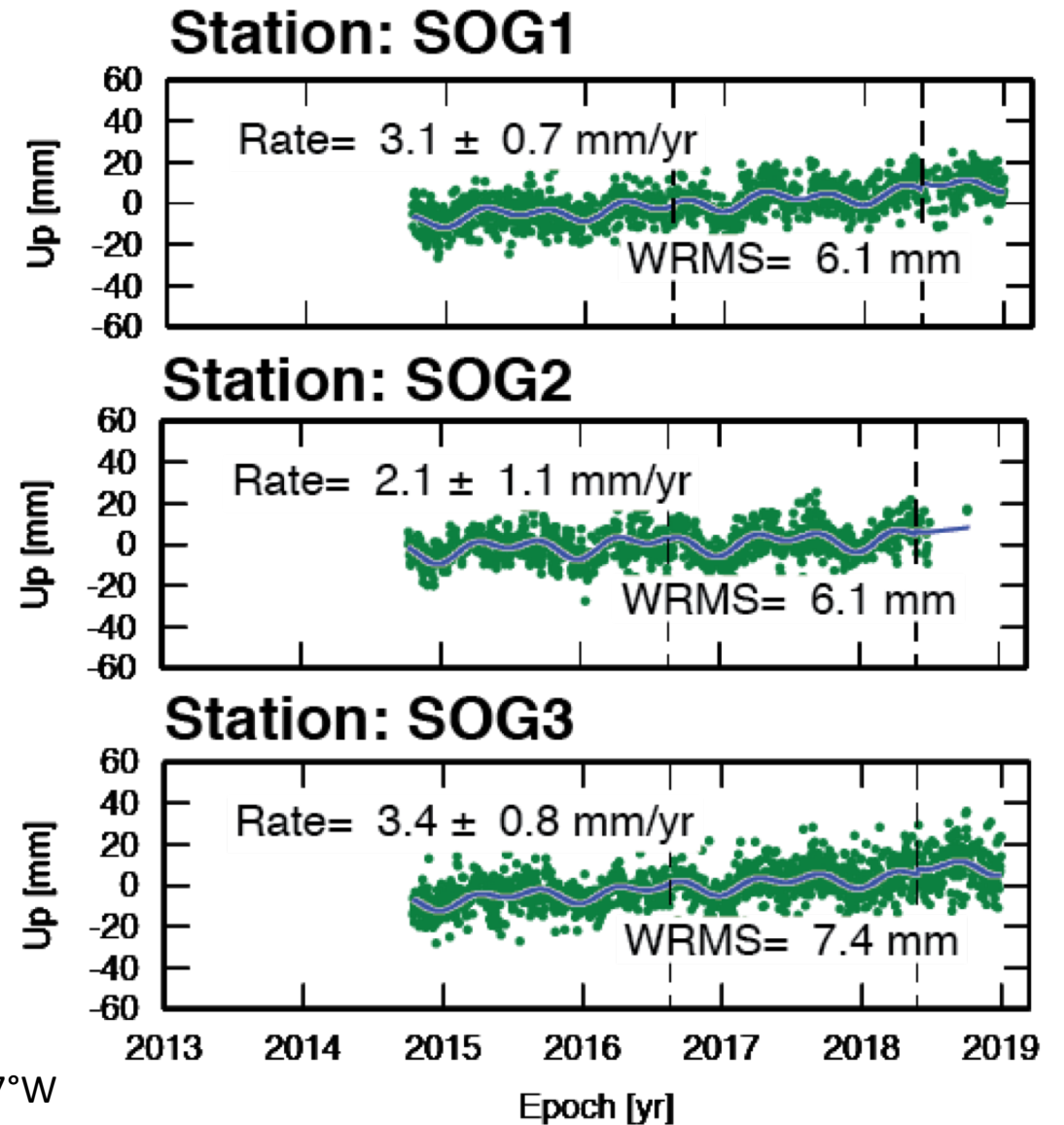


Offsets:

Nov 13, 2013: M7.7 Scotia Sea EQ, 60.274°S 46.401°W

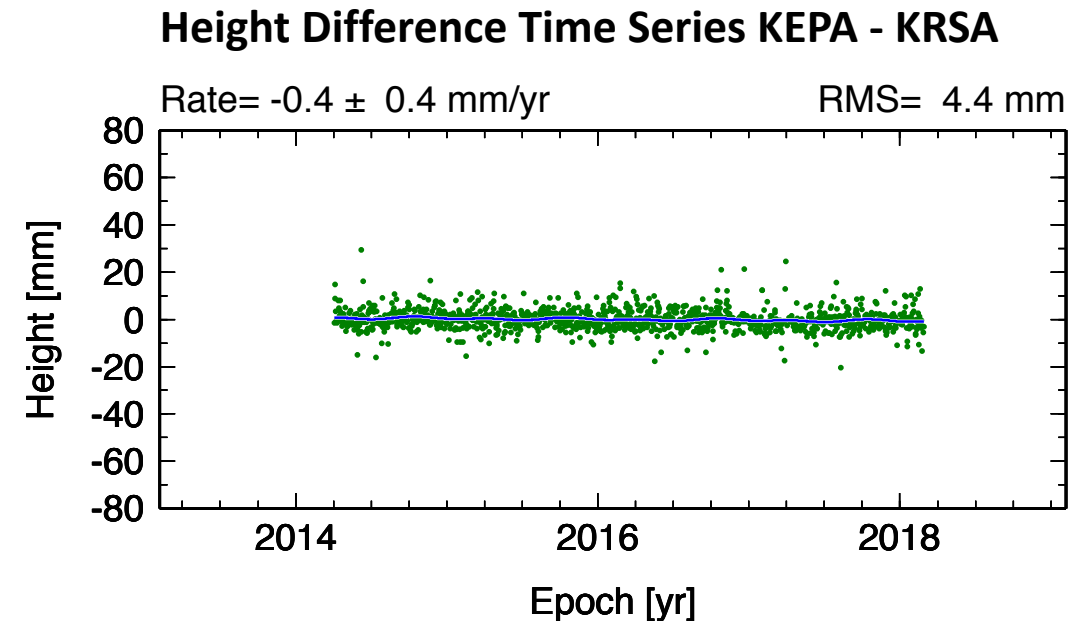
Aug 19, 2016: M7.4 South Georgia Island Region EQ, 55.285°S 31.877°W

May 27, 2018: Reference Frame Change ITRF2008 to ITRF2014



Is the rate difference due to the different time spans for KEPA and KRSA?

- Using Dual-CGPS Station Analysis (Teferle et al., 2002) investigate relative motion KEPA to KRSA
- The vertical rate difference from the “absolute” results is -1.1 ± 1.3 mm/yr
- The vertical rate difference from the “relative” results is -0.4 ± 0.4 mm/yr
- Judging by the $1-\sigma$ uncertainties the rate differences may indicate some relative vertical motion but they are statistically not significant



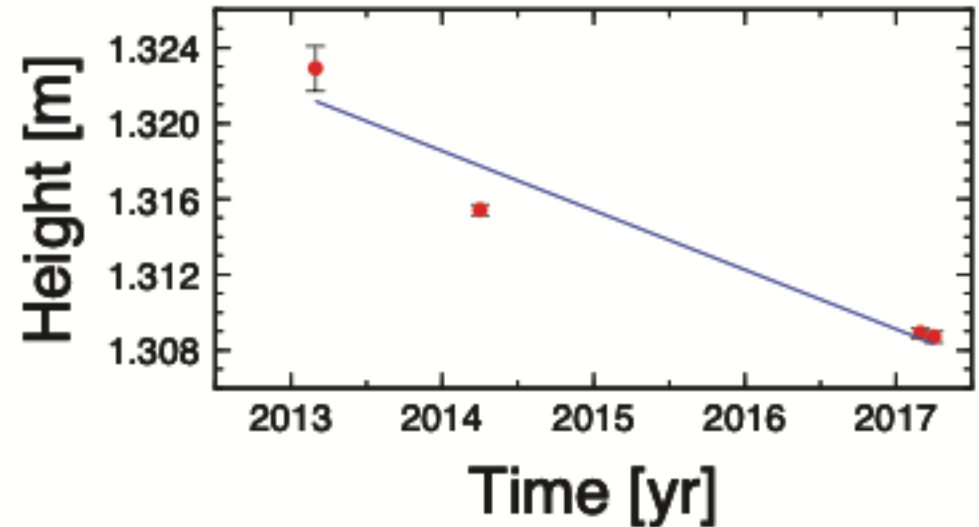
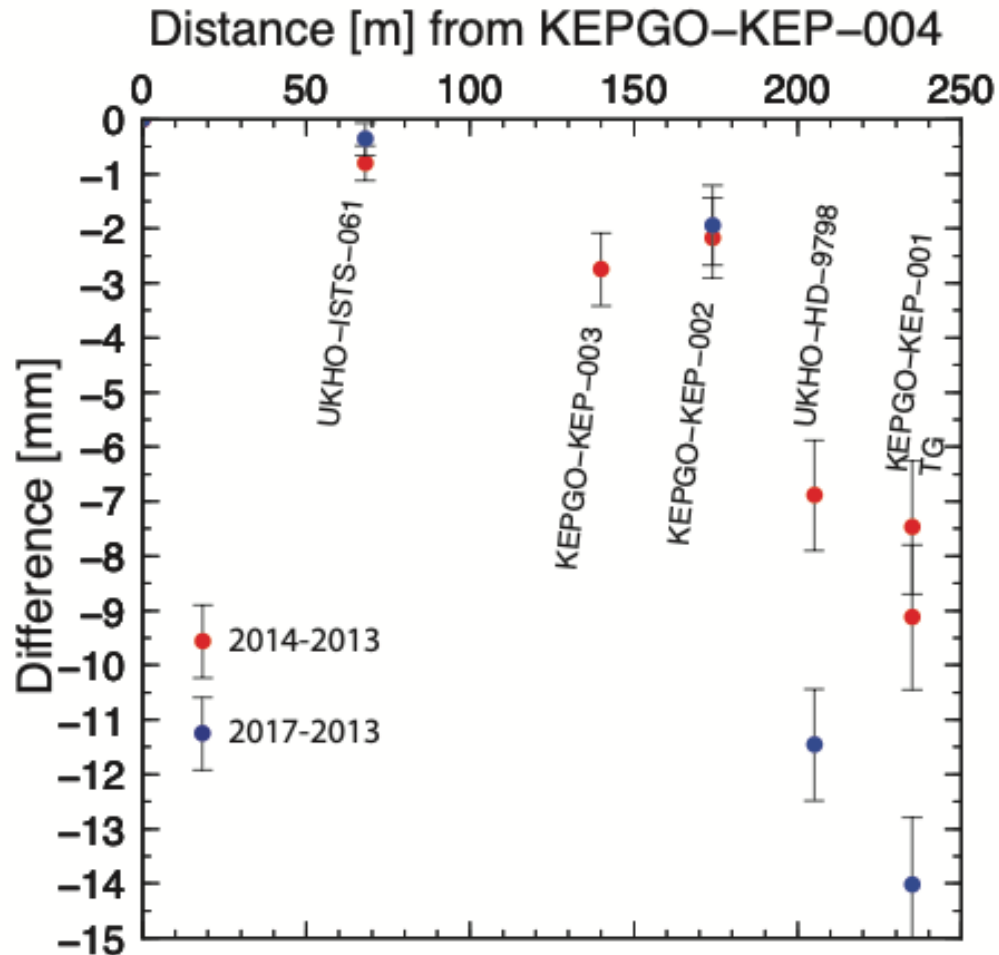
For any technical questions:
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What do the Precise Levelling Results show?

- Starting from KEPGO-KEP-004 towards the tide gauge (TG) we have stability up to KEPGEO-KEP-002
- UKHO-HD-9798 and the tide gauge, tide board and KEPGEO-KEP-001 are subsiding
- Subsidence can be computed to be between 2.9 to 3.6 mm/yr

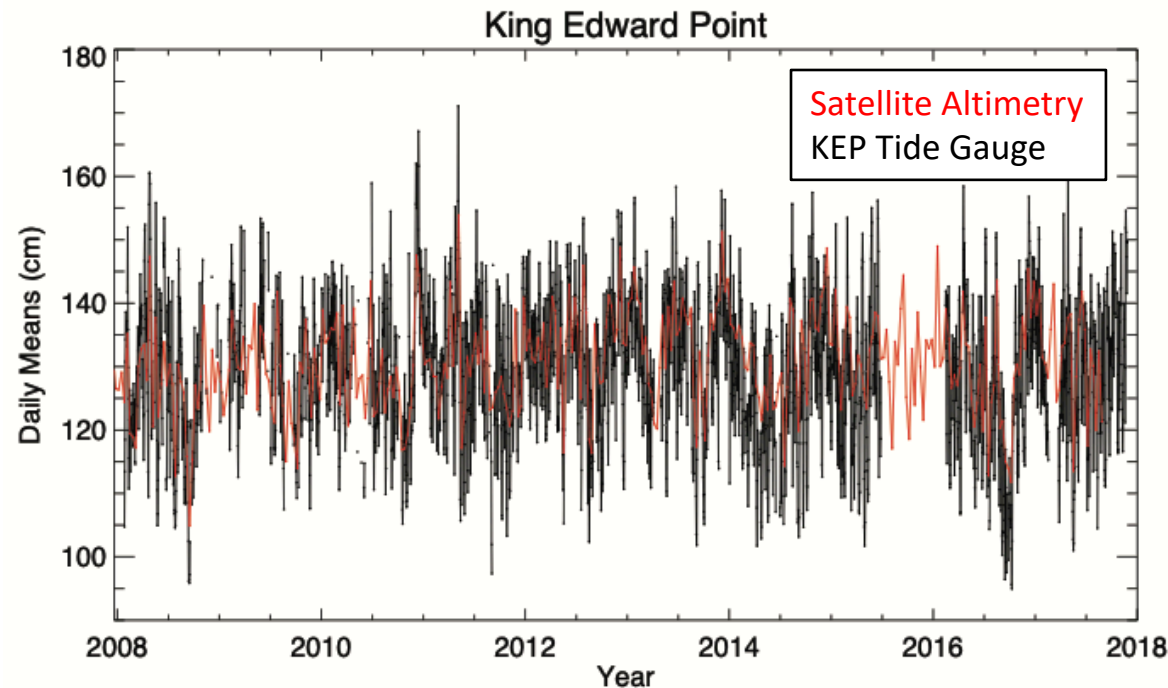
Benchmark	Distance [m] from KEPGO-KEP-004	Campaign 2013		Campaign 2014		Campaign 2017a		Campaign 2017b	
		Height [m]	SD [m]	Height [m]	SD [m]	Height [m]	SD [m]	Height [m]	SD [m]
KEPGO-KEP-004	0	3,7600		3,7600		3,7600		3,7600	
UKHO-ISTS-061	68	3,0757	0,0003	3,0749	0,0001	3,0753	0,0001	3,0753	0,0001
KEPGO-KEP-003	140	2,7704	0,0006	2,7676	0,0002				
KEPGO-KEP-002	174	2,8145	0,0007	2,8124	0,0002	2,8126	0,0002	2,8128	0,0002
UKHO-HD-9798	205	1,3465	0,0010	1,3396	0,0003	1,3350	0,0003	1,3349	0,0003
KEPGO-KEP-001	235	1,3229	0,0012	1,3154	0,0003	1,3089	0,0003	1,3087	0,0003
Tide Board	235			1,1531	0,0003	1,1469	0,0003	1,1466	0,0003
TG	235	0,6560	0,0012	0,6469	0,0005				

What is the TG Subsidence Rate?

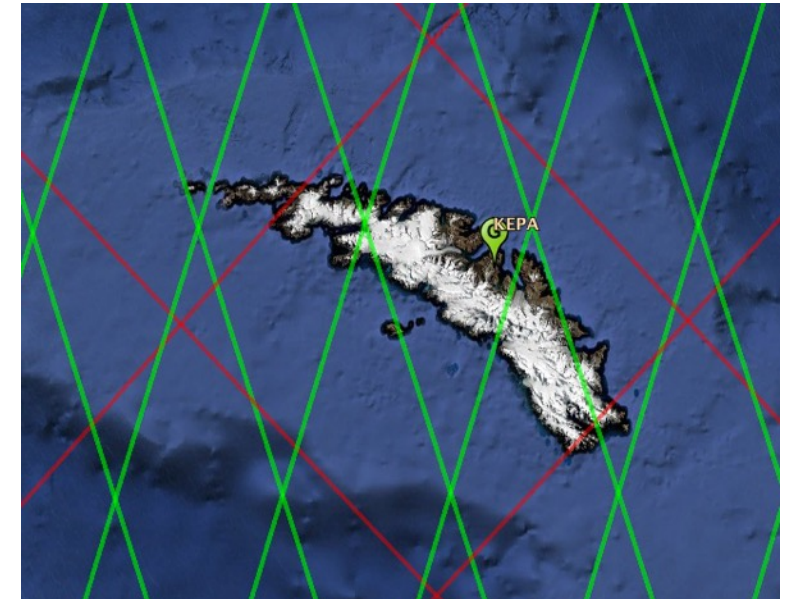


Height changes at TG from 2013 to early 2017. Over the 4 years the tide gauge subsided by 1.4 cm, which indicates an average subsidence rate of 3.6 mm/yr.

What do the Sea Level Time Series Show?



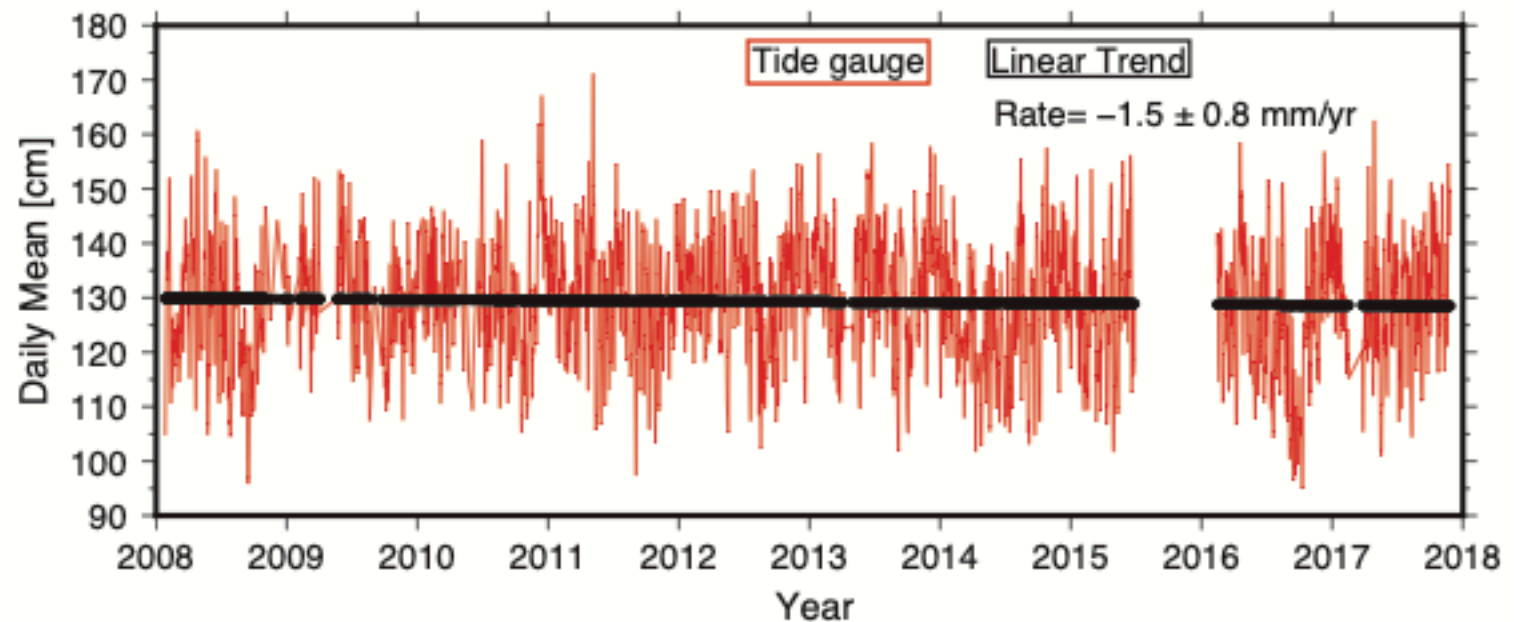
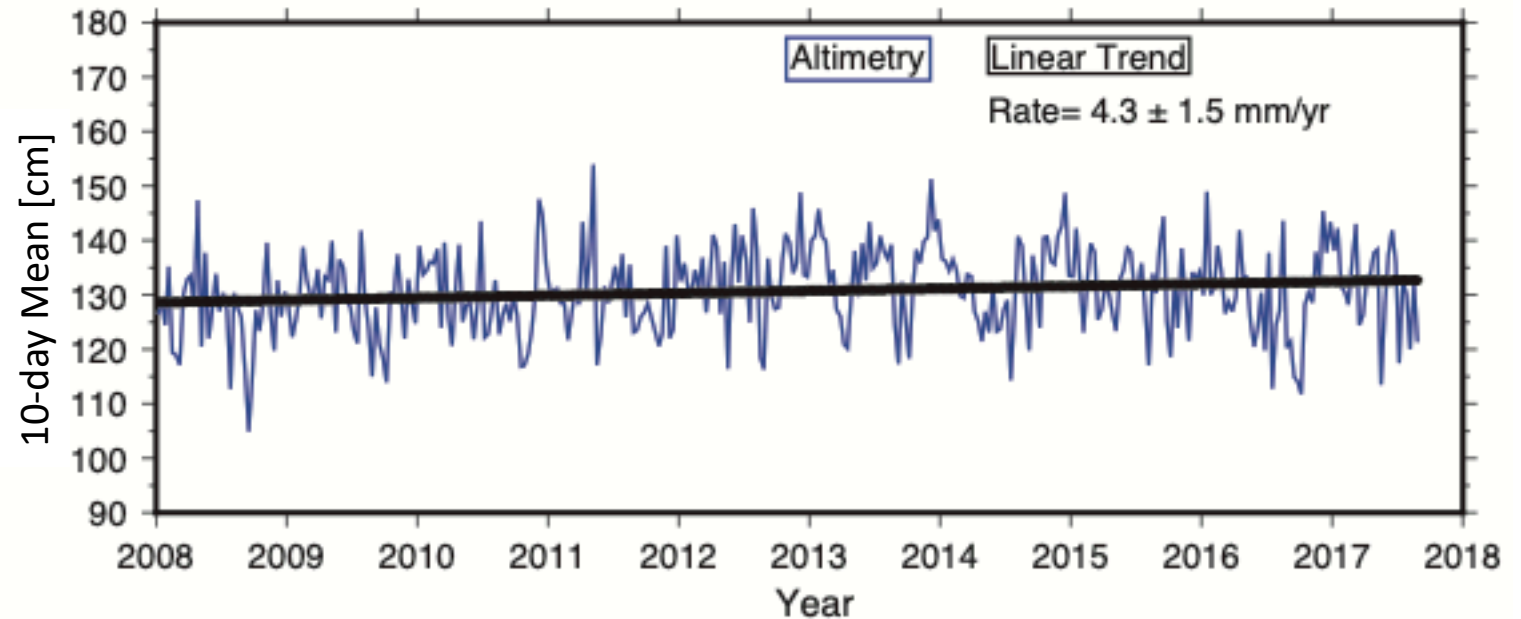
Sea level data for King Edward Point from daily mean tide gauge records (black line) and 10-day average satellite altimeter data (red line). Several data gaps in the tide gauge record are visible. The satellite altimeter data was provided by Brian Beckley and Xu Yang of NASA and was derived from the NASA MEaSUREs v4.2 data set of merged TOPEX/JASON/OSTM altimetry. No inverted barometer (IB) and dynamic atmospheric correction (DAC) combined correction were applied to the data.



KEP tide gauge and satellite altimetry mission ground tracks for TOPEX/POSEIDON/- JASON (red lines) and Sentinel-3 (green lines - for future reference)

A closer look at Sea Level ?

- Rate difference in the sea level records of 5.8 ± 1.7 mm/yr (2008-2018)
- SL fall indicated by the TG would be in line with land uplift, but what about subsidence at TG?
- Local TG subsidence needs a larger regional uplift than indicated
- More investigations are needed



What about the RRS Sir David Attenborough ?

- New Royal Research Ship (RRS) owned by UK Natural Environment Research Council (NERC)
- Substantially larger vessel than the RRS James Clark Ross and RRS Ernest Shackleton which currently serve KEP
- Vessel requires a new KEP jetty
- New KEP tide gauge will be installed



Conclusions

- We have updated the GNSS results since 2018
- The picture of uplift over South Georgia Island of 2-3 mm/yr continues while local subsidence of ~3 mm/yr at the tide gauge is indicated
- 2008-2018 altimeter and TG sea level rates differ substantially and cannot be explained by observed uplift/subsidence processes
- No new levelling information is available for 2018 or 2019, but
- in the Austral Summer 2019/2020 works on a new jetty will start and a new tide gauge will be installed
- This highlights once more the importance of the levelling information connecting the tide gauge and the GNSS station and new campaigns will be necessary in the future



Thank you for your attention!

- Acknowledgments

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