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Vertical Land Movements and Sea Level Changes on South Georgia, South Atlantic Ocean: Results from 7 Years of Geodetic and Oceanographic Observations on a Remote Island

F.N. Teferle[1], A. Hunegnaw[1], A. Hibbert[2],

S.D.P. Williams[2] , P.L. Woodworth[2], I.W.D. Dalziel[3],

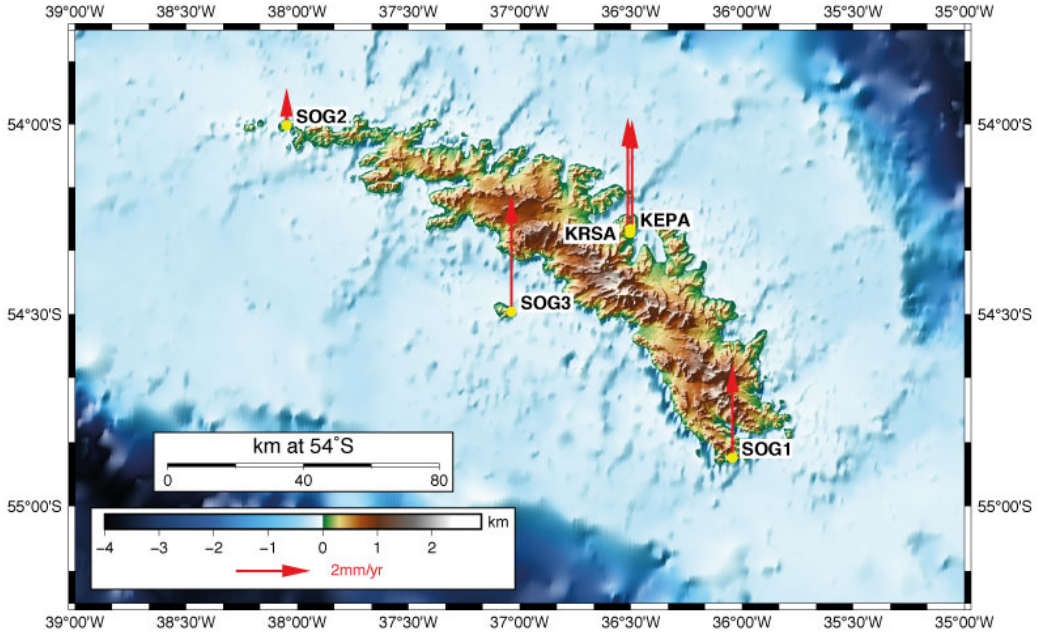
R. Smalley[4] and L. Lawver[3]

[1]*University of Luxembourg, Geodesy and Geospatial Engineering, Department of Engineering, Luxembourg*

[2]*National Oceanography Centre, Liverpool, United Kingdom*

[3]*University of Texas at Austin, Jackson School of Geosciences, USA*

[4]*University of Memphis, Center for Earthquake Research and Information, USA*



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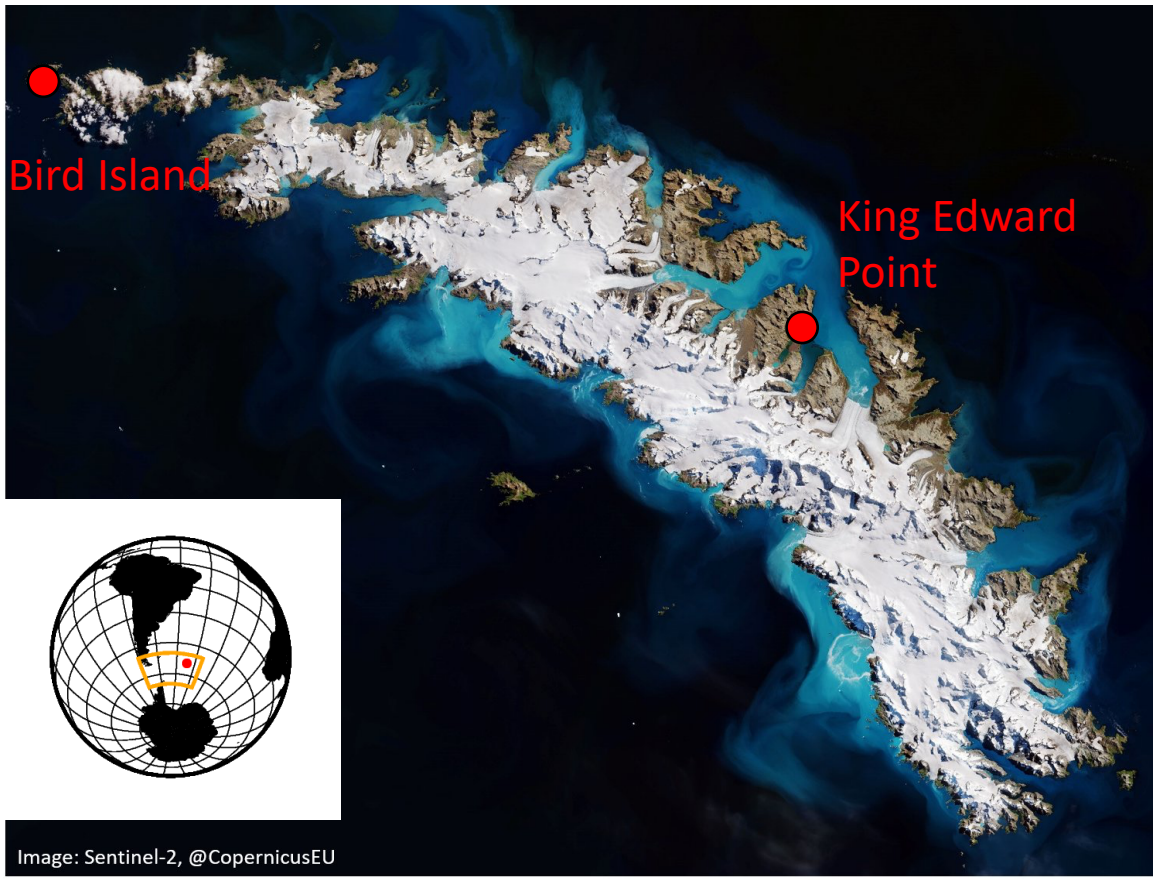
Session Date and Time: Wednesday, 16 December 2020, 05:30 – 06:30 PST (UTC -8)
Session Number and Title: G022: The Global Geodetic Observing System: Resilient Infrastructure for Sustainable Scientific Activities

UK South Atlantic Tide Gauge (TG) Network

- Established since 1985
- British Overseas Territories (BOTs) and Antarctica
- Affords long sea level records from an under-sampled region
- Used for:
  - Monitoring Antarctic Circumpolar Current (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
- GNSS @ TG to provide vertical land movement corrections for MSL!

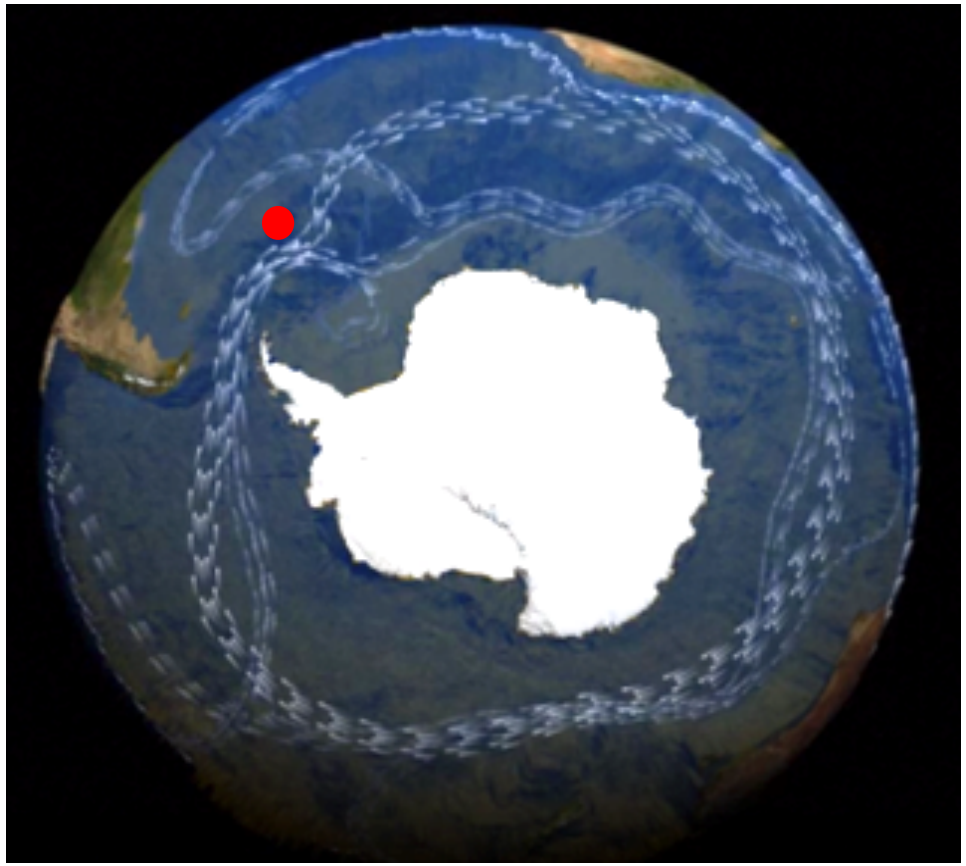
South Georgia is a subantarctic island between the South Atlantic and Southern Ocean, which is largely covered by glaciers with only its northeast coastal areas being snow-free during the Austral summer.

- Size approximately 170 km x 45 km
- Uninhabited expect for personnel at two research stations:
  - King Edward Point (KEP)
  - Bird Island
- Marine environment is extremely rich in nutrients and supports incredible and uniq biodiversity



South Georgia provides an outpost in a largely under-sampled region of the globe that is of critical importance to the global climatic system.

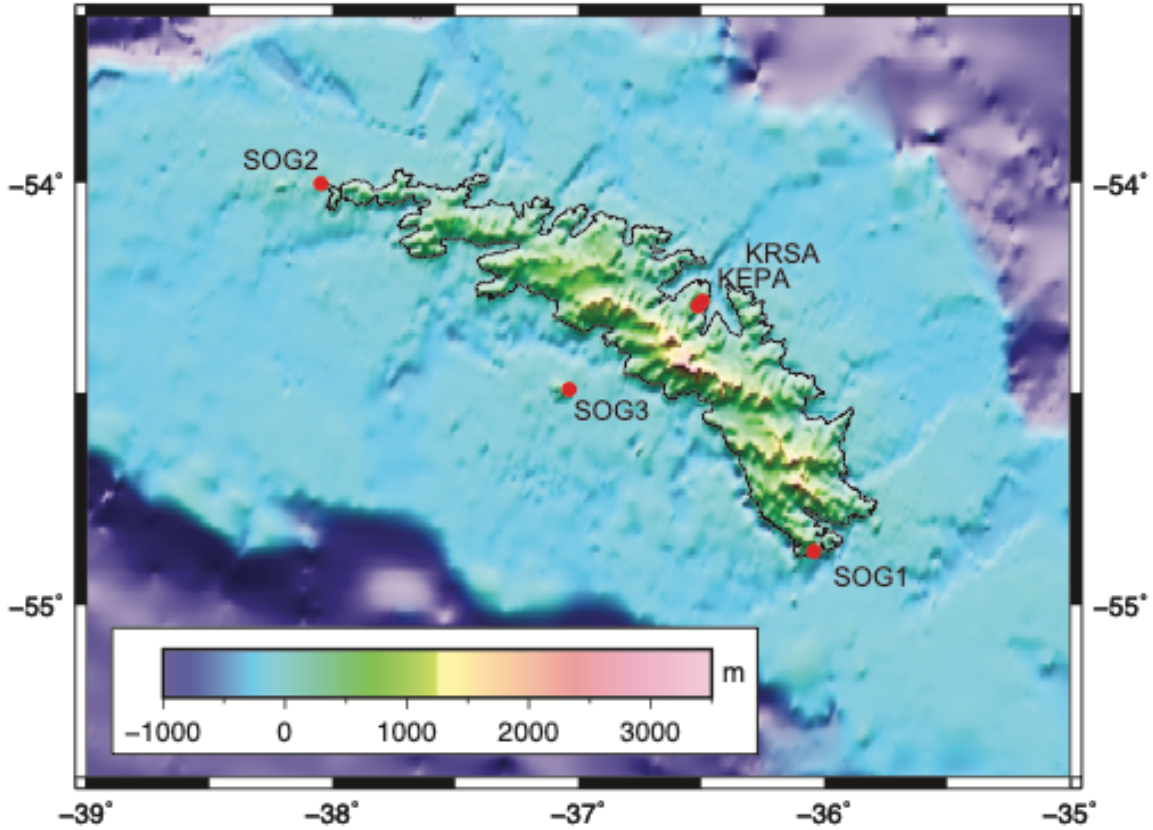
- Zone of the **westerly winds**, which affect regional weather and climate (see poster presentation Erkihune et al., session G010-12)
- Barrier to the **Antarctic Circumpolar Current (ACC)**, which is a driver of the global thermohaline circulation and, thus, of the global climate
- Associated with the ACC is the **Antarctic Convergence**, where colder Antarctic and warmer sub-Antarctic water masses meet. This results in an upwelling of nutrients, which in turn, stimulates biodiversity



Wikipedia (2020)

South Georgia GNSS network and KEP tide gauge used in this study of vertical land movements and sea level changes.

South Georgia GNSS Network



King Edward Point (KEP) Research Station

The continuous GNSS Stations KEPA and KRSA

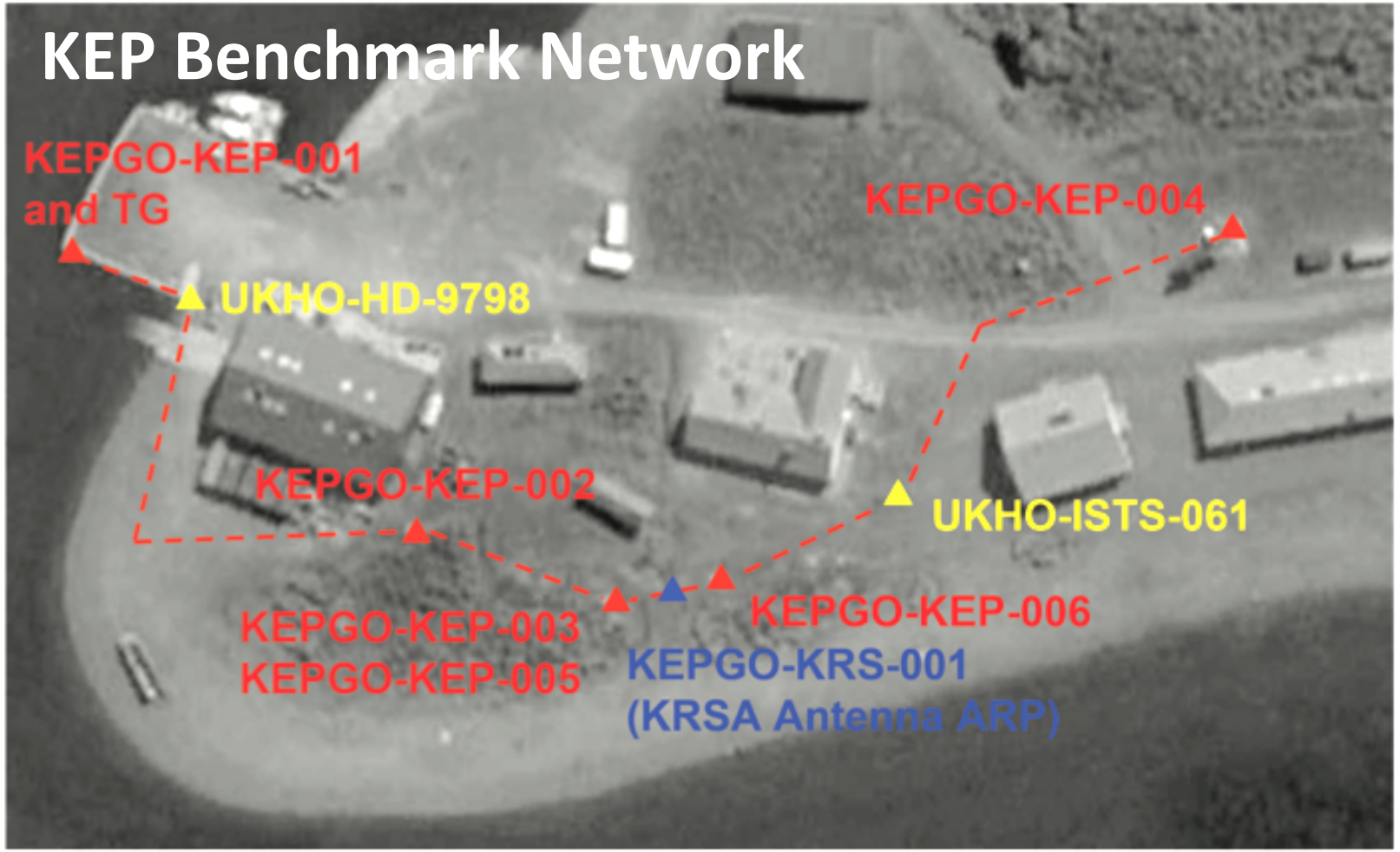
GNSS antenna and mast with unobstructed sky view on top of Brown Mt. Solar power system, enclosures with batteries and electronics, structural frame, radio antenna and weather station in 30m distance to mast. Antenna location on bedrock but some multipath from reflective rock surface below antenna.

Whale vertebrae

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.

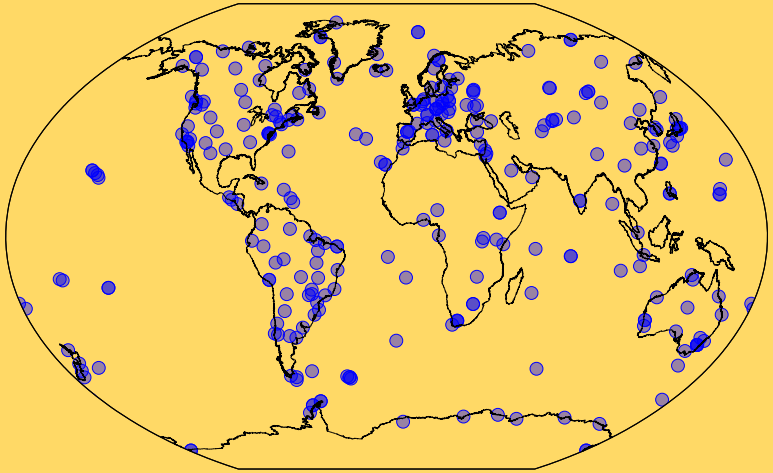
Benchmark networks geodetically link the sensors together for long-term monitoring, especially important for the tide gauge and GNSS.

- 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



Our updated GPS solution (ULVLM2020) follows largely the 3rd IGS reprocessing campaign strategy.

- Based on Bernese GNSS Software v5.2 (Release Feb 2020)
- DD network processing strategy
- CODE satellite and ERP products
- IERS Conventions 2010
- ITRF2014
- …

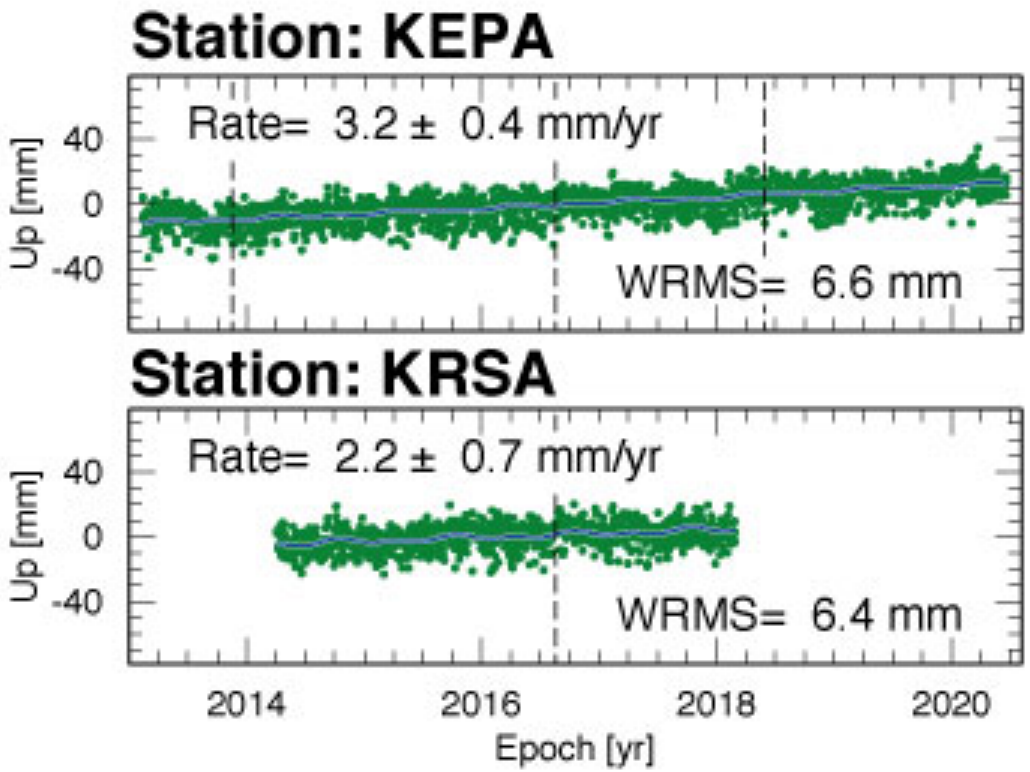


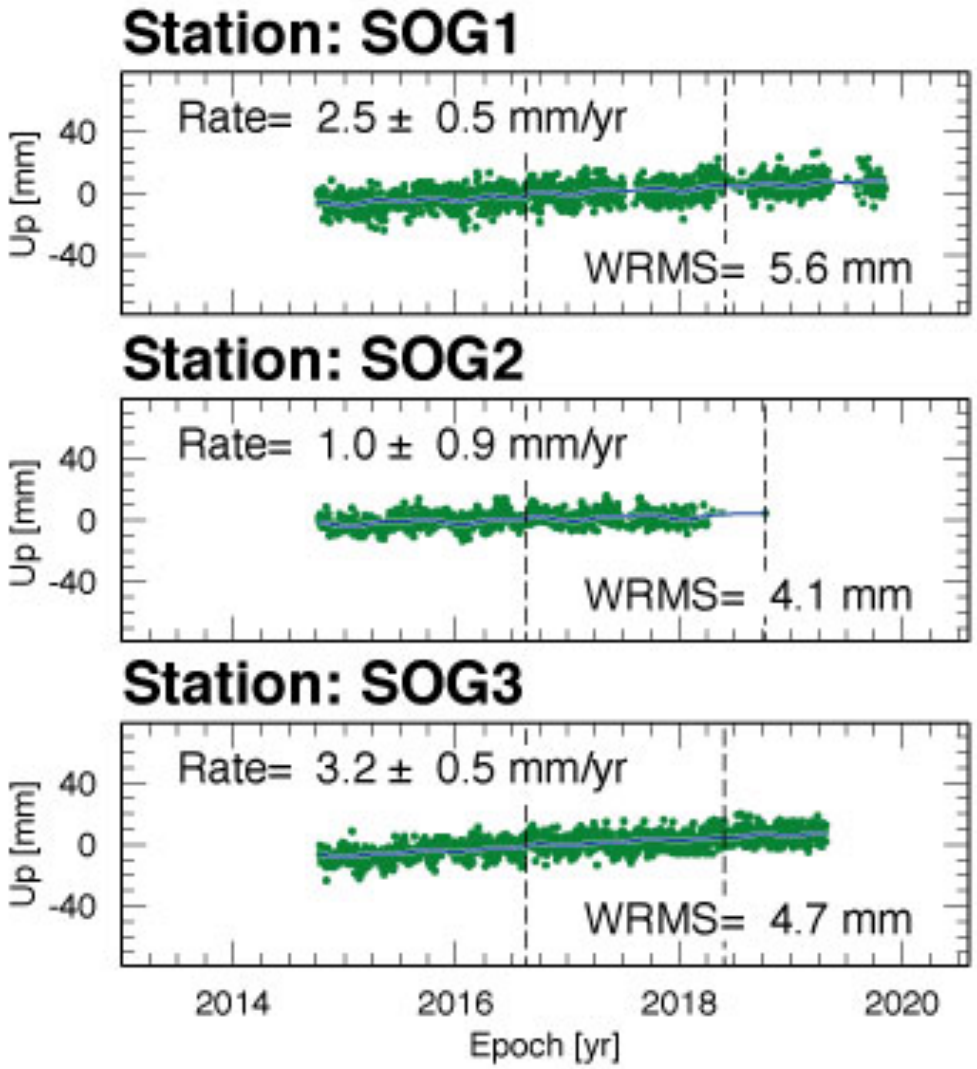
RF network, consisting of ~300 IGS stations

- Estimated parameters include
  - Coordinates and receiver clocks
  - Ambiguities
  - Troposphere
  - …

- Time series analysis using Hector software v1.6
- Stochastic characterization using white + power-law noise model

The GNSS time series are of varying quality and length due to instrument issues. All show uplift but KEPA provides the most complete data set, yet it has the largest WRMS.

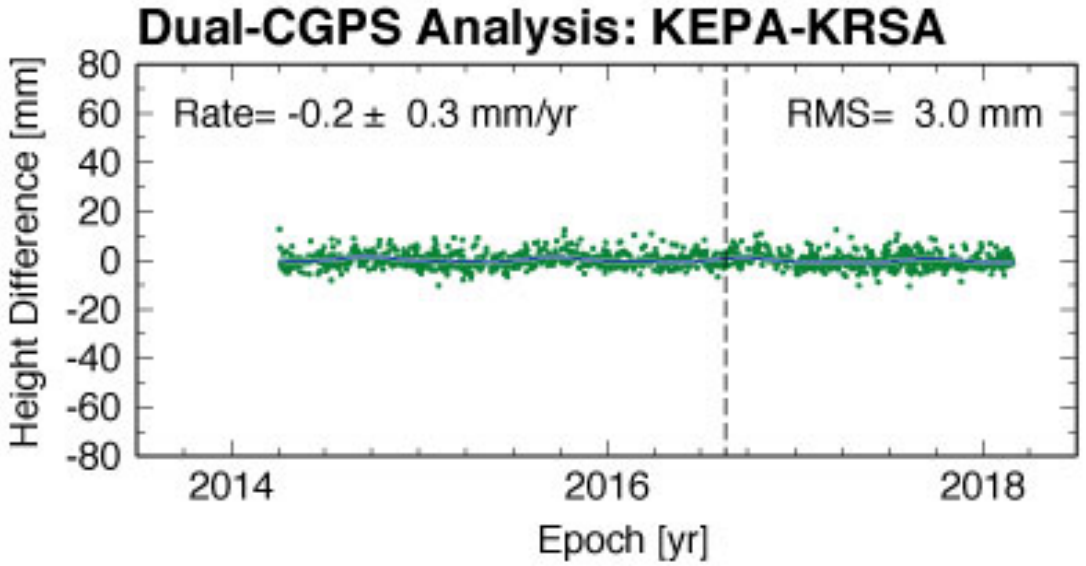




Offsets:
Nov 13, 2013: M7.7 Scotia Sea EQ, 60.274°S 46.401°W
Aug 19, 2016: M7.4 South Georgia Island Region EQ, 55.285°S 31.877°W
May 27, 2018: Reference Frame Change ITRF2008 to ITRF2014

The vertical rate difference from the dual-CGPS analysis KEPA-KRSA suggests stability at KRSA and uplift of 3.0 ± 0.5 mm/yr.

- Using Dual-CGPS Station Analysis (Teferle et al., 2002) to investigate relative motion KEPA to KRSA
- The vertical rate difference from the "absolute" results is -1.0 ± 0.8 mm/yr
- The vertical rate difference from the dual-CGPS "relative" results is -0.2 ± 0.3 mm/yr
- The "relative" results suggest stable ground at KRSA
- Hence KRSA may be rising by 3.0 ± 0.5 mm/yr using a construct of rates.



Stability at KRSA is confirmed by the levelling results...

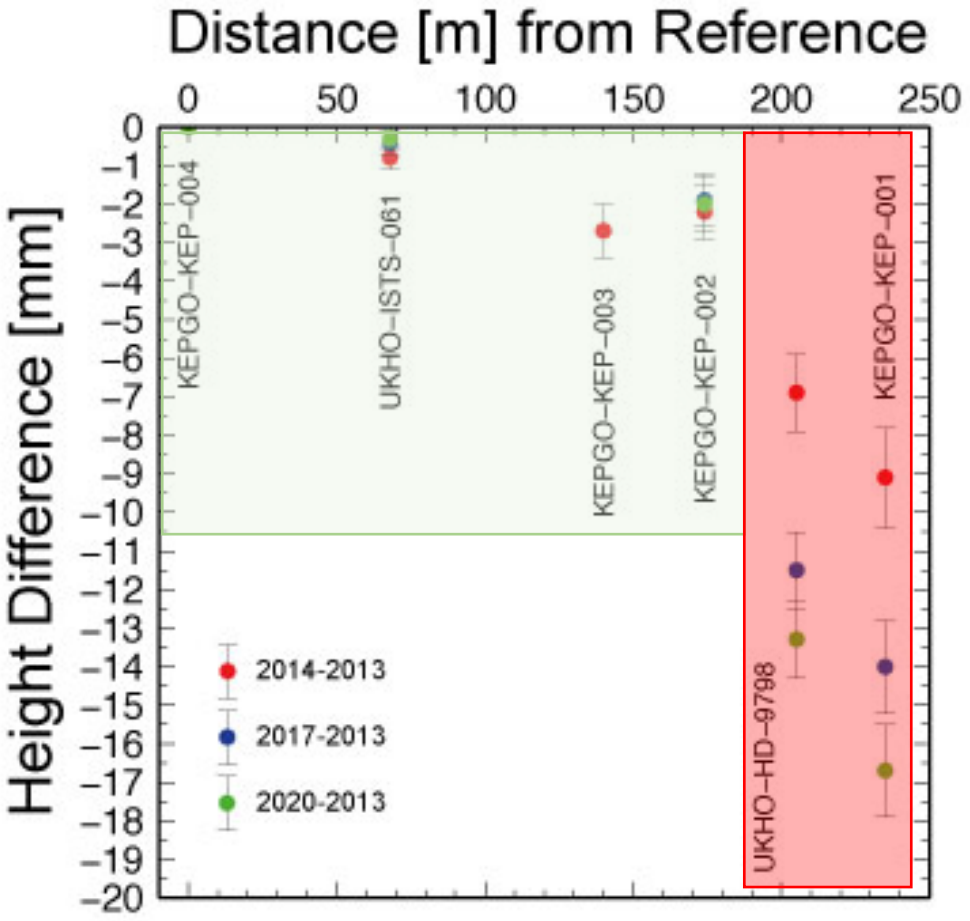
The 5 levelling campaigns between the KEP BMs during 2013-2020 reveal continued subsidence of the KEP wharf and TG BM (KEPGO-KEP-001).

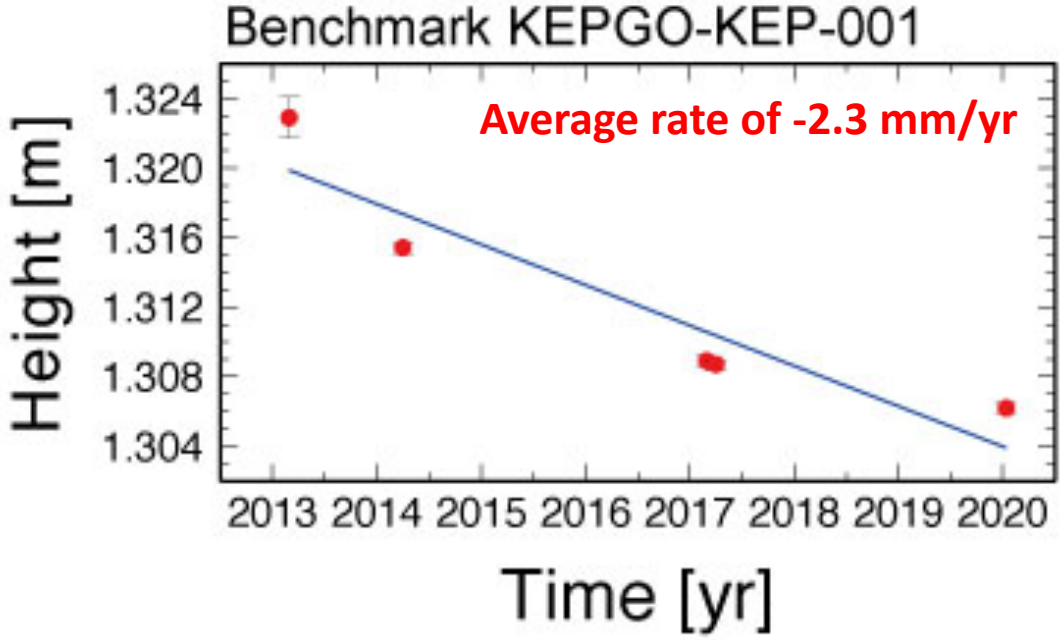
Benchmark	Distance [m] from Start	Campaigns 2013 Height [m]	2014 Height [m]	2017a Height [m]	2017b Height [m]	2020 Height [m]
KEPGO-KEP-004	0	3.7600	3.7600	3.7600	3.7600	3.7600
UKHO-ISTS-061	68	3.0757	3.0749	3.0753	3.0753	3.0754
KEPGO-KEP-006	97	3.4000	3.4008	3.4007	3.4007	3.4007
KEPGO-KEP-003	115	2.7704	2.7676	-	-	-
KEPGO-KEP-005	115	2.7693	2.7701	2.7700	2.7699	2.7696
KEPGO-KEP-002	174	2.8145	2.8125	2.8126	2.8128	2.8125
UKHO-HD-9798	205	1.3465	1.3396	1.3350	1.3349	1.3332
KEPGO-KEP-001	235	1.3229	1.3154	1.3089	1.3087	1.3062
Tide Board	236		1.1531	1.1469	1.1466	1.1447
Tide Gauge	236	0.6560	0.6469	-	-	-

Stable Ground

Subsidence

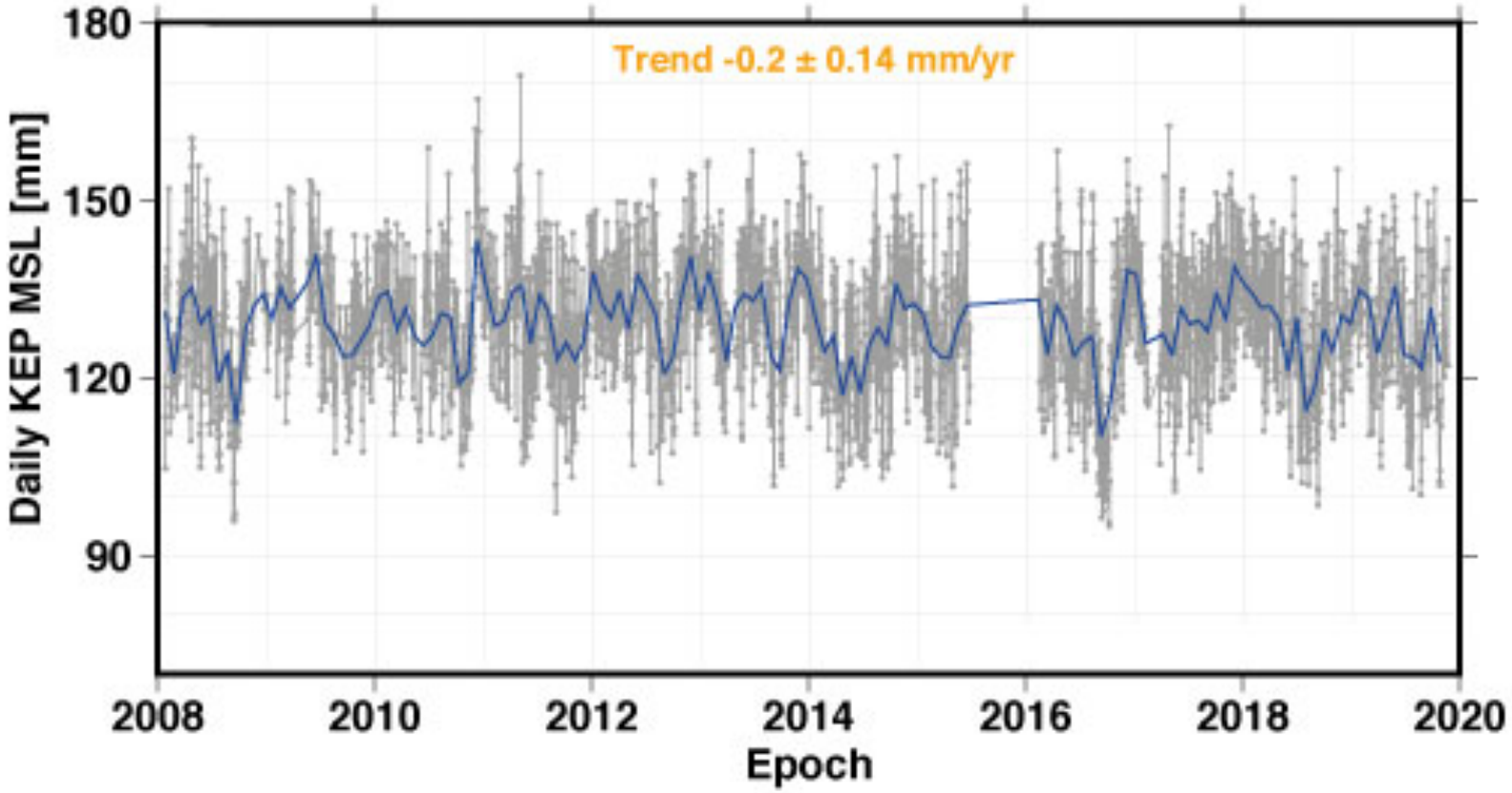
Between 2013-2020 the TG BM subsided in total by 1.67 cm at an average rate of 2.3 mm/yr.





The TGBM (KEPGO-KEP-001) subsided by 1.67 cm over the past 7 years but we don't know when this started. We fitted a linear rate, but it could easily be approximated by an exponential decay.

The daily MSL record for the KEP TG shows no significant sea level trend for 2008-2020…

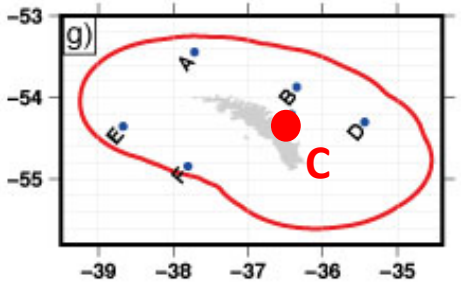


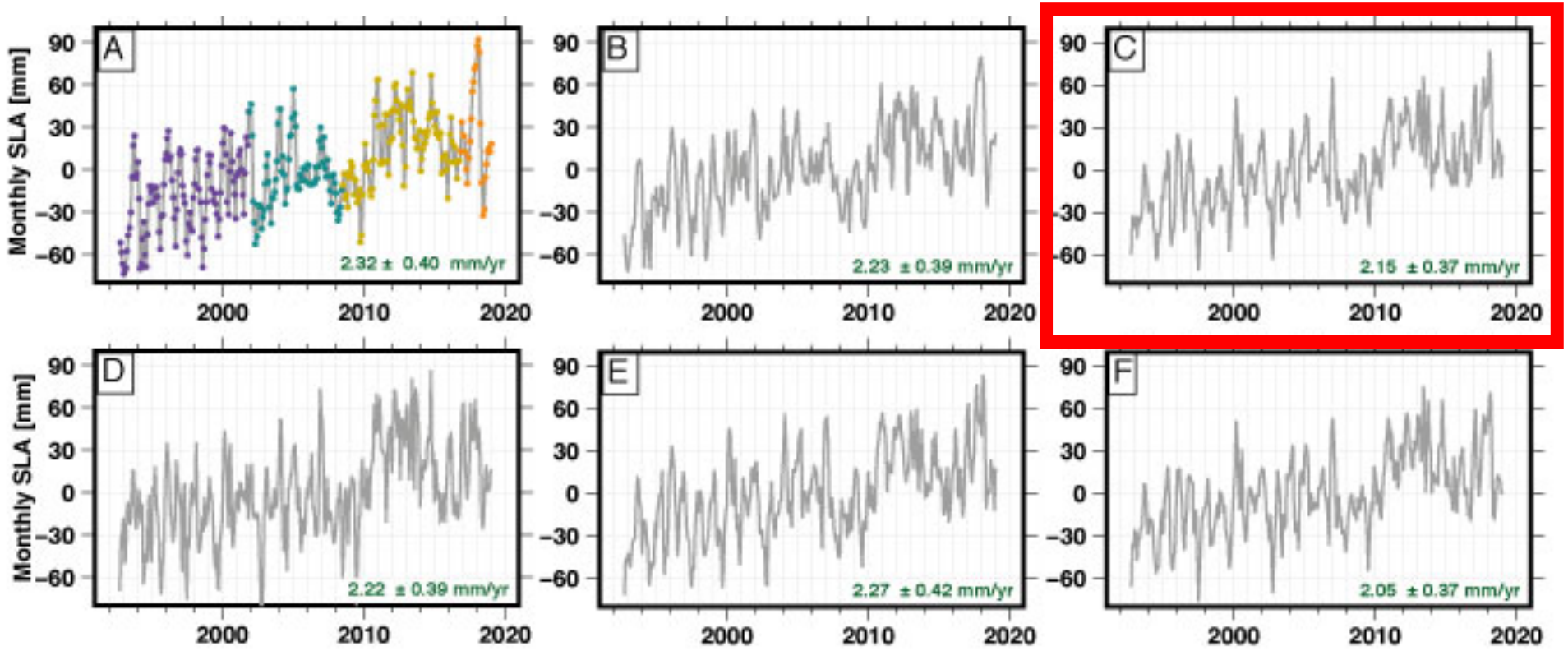
…but we know that the area at KEP is rising by 3.2 mm/yr and 3.0 mm/yr as indicated by KEPA and KRSA, respectively, while the KEP wharf and the TG are subsiding by on average 2.3 mm/yr.

We can use the sea level anomaly (SLA) product from NASA's sea level MEaSUREs Programme to compare to the KEP MSL record.

Monthly SLA from satellite altimetry around South Georgia for 10/1992 – 01/2019 show high consistency in their variations and trends.

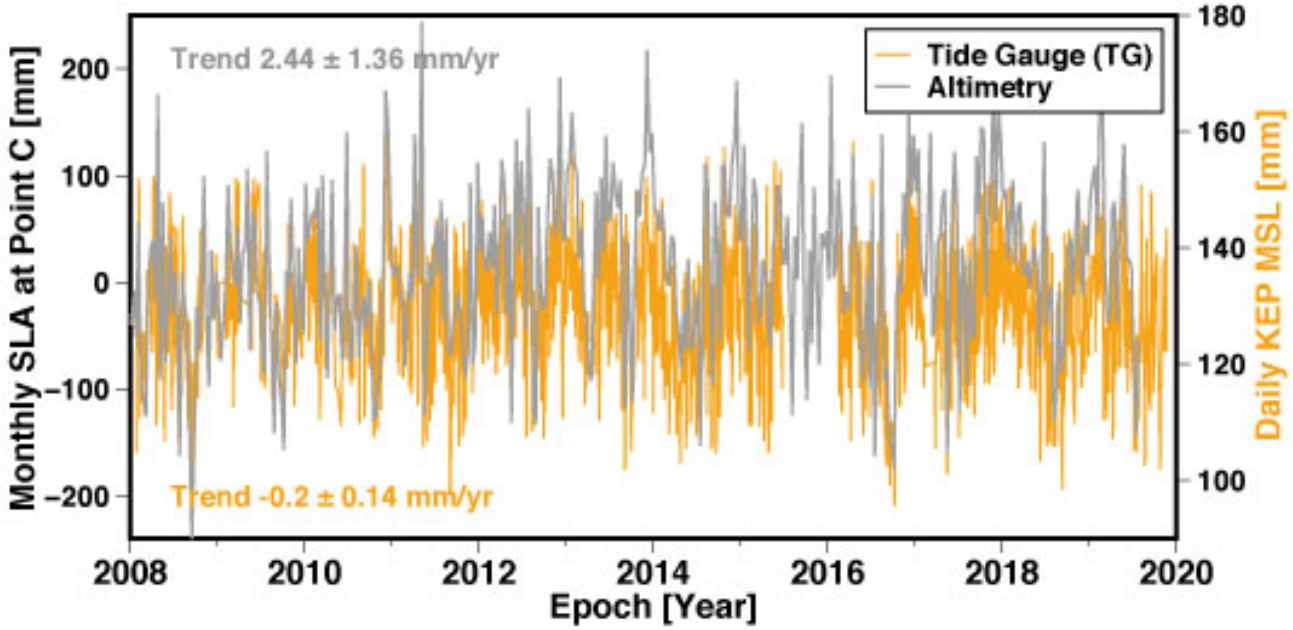
NASA MEaSUREs v4.2 data set of merged TOPEX/ JASON-1, -2 and -3 satellite altimetry

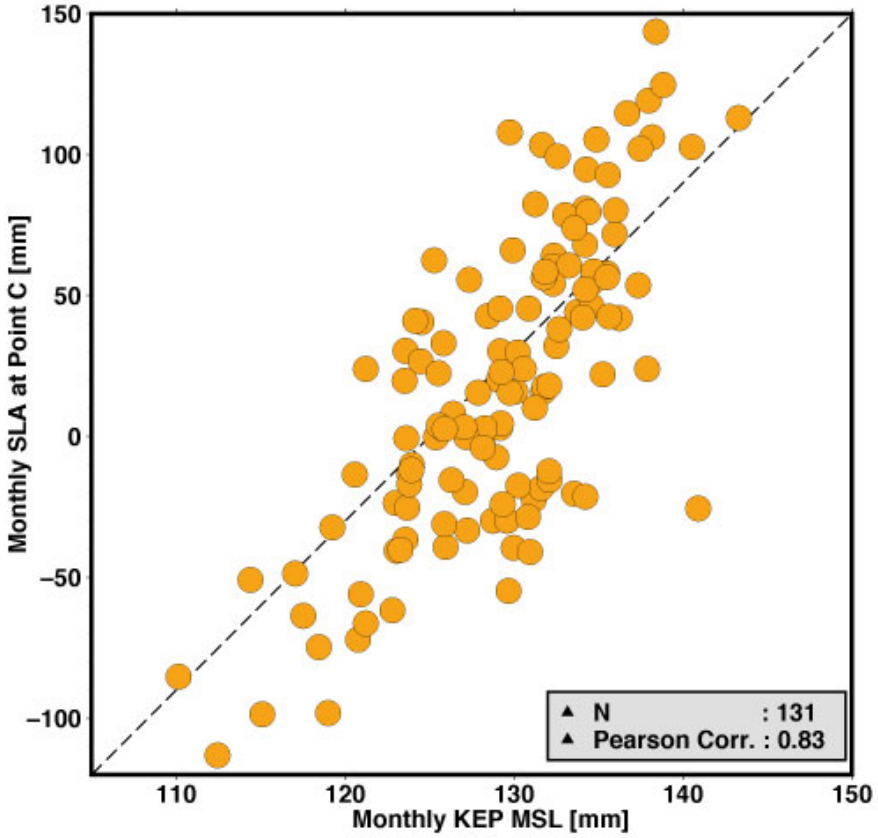




Monthly SLA for point C (off Cumberland Bay, 55.5°S, 36.5°W) shows good agreement with the other time series, i.e. it is representative of the satellite altimetry measurements from further offshore.

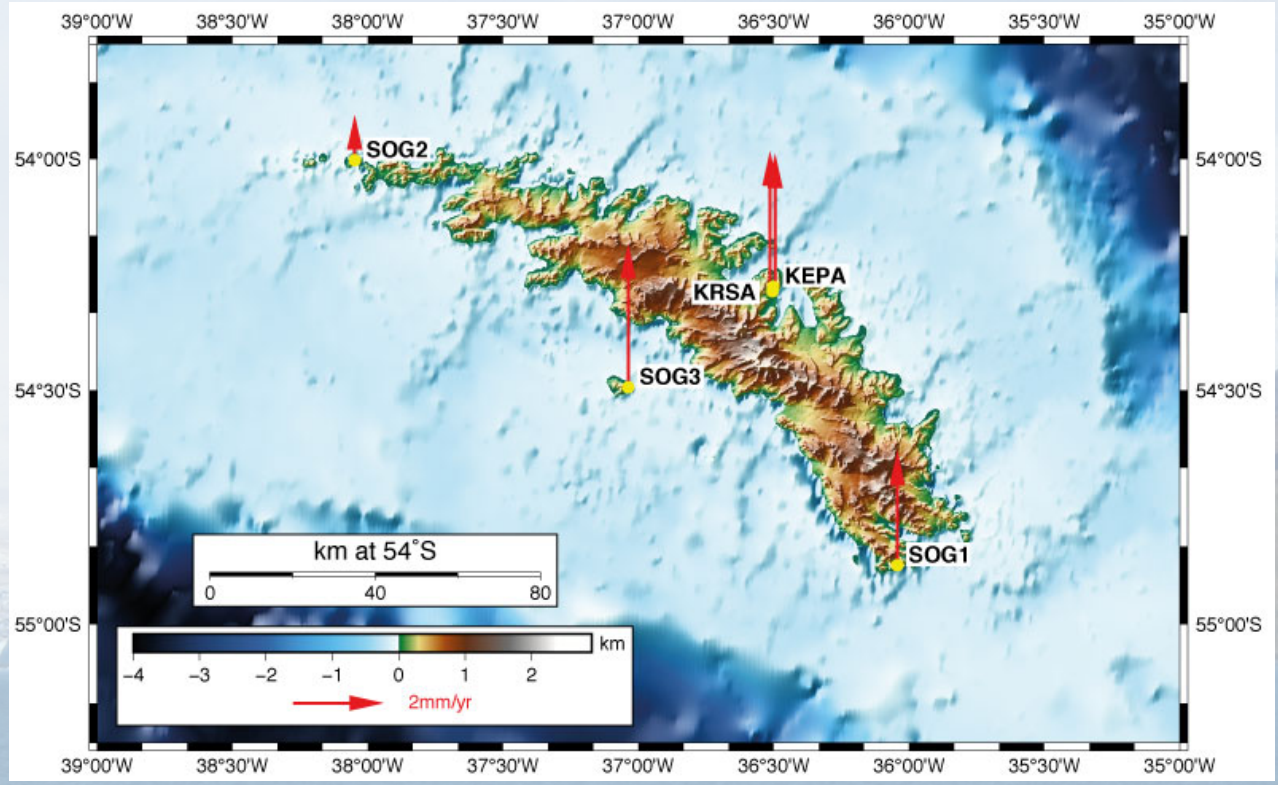
The sea level observations from satellite altimetry at location C and the KEP TG for 2008-2020 show high consistency with a correlation between the monthly averages of 0.83.





In conclusion, our analysis shows that South Georgia is rising, with local subsidence at the KEP tide gauge. There is good agreement between KEP MSL and SLA derived from satellite altimetry.

- We have updated the GNSS results since 2019 and added further levelling results for 2020
- The picture of South Georgia VLM of 2-3 mm/yr continues while local subsidence of 2.3 mm/yr at the tide gauge is confirmed by levelling
- 2008-2020 SLA and MSL rate differences improve but cannot fully be explained by current VLM estimates
- We note the importance of the levelling information for connecting the TG and GNSS observations



Thank you for your attention!