Monitoring long term Vertical Land Movement at North Shields Tide Gauge

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1. Introduction

- Changes in mean sea level (MSL), provide key indications of climate change
- Sea level is measured using tide gauges with respect to benchmarks on land which were traditionally assumed to be stable
- However, vertical land movement (VLM, typically up to a few mm/yr) may occur at tide gauges due to geophysical processes such as post glacial rebound, or local instability, leading to erroneous changes in MSL unless appropriate corrections are applied [1]
- Continuously operating Global Positioning System (CGPS) receivers have been used to attempt to measure such VLM at tide gauges since the mid-to-late 1990s
- This project focuses on monitoring VLM at the North Shields tide gauge, where a CGPS receiver was installed in 1997
- Due to a number of practical reasons, the receiver was relocated along with the tide gauge itself in 2009 approximately 500 metres downstream

2. Aims

- The aims of this research project were therefore:

1. Assessing VLM at the old tide gauge during 1998-2009 and post relocation of the tide gauge, during 2009-2014 using GPS analysis
2. Assessing the stability of land in the vicinity of the old and new tide gauge locations using levelling technique
3. Ascertaining whether the new tide gauge is more stable than the old tide gauge

3. Methods

GPS Processing

- The old and new tide gauges are shown in Figure 1a (NSTG and NSLG respectively)
- GPS processing and analysis were carried out using GAMIT scientific software
- Receivers at both tide gauge locations were coordinated relative to another simultaneously-observing receiver near Morpeth (MORP with fixed ITRF08 coordinates) by calculating baseline vectors MORP-NSTG and MORP-NSLG
- MORP is an International GNSS Service reference station sited directly on bedrock, approximately 27 km northwest of the area in question (Figure 1b)
- Daily baseline components (East, North, Up) were computed for the receiver located at the old tide gauge (NSTG) for the period of 1998.5 – 2009.9 and similarly for the receiver at the new tide gauge (NSLG) during the period of 2009.9 – 2014.6 using predominantly 24 h observation sessions
- The 'Up' baseline component of both receivers (which represents the change in height from MORP to NSTG/NSLG) was plotted against time to detect any trends

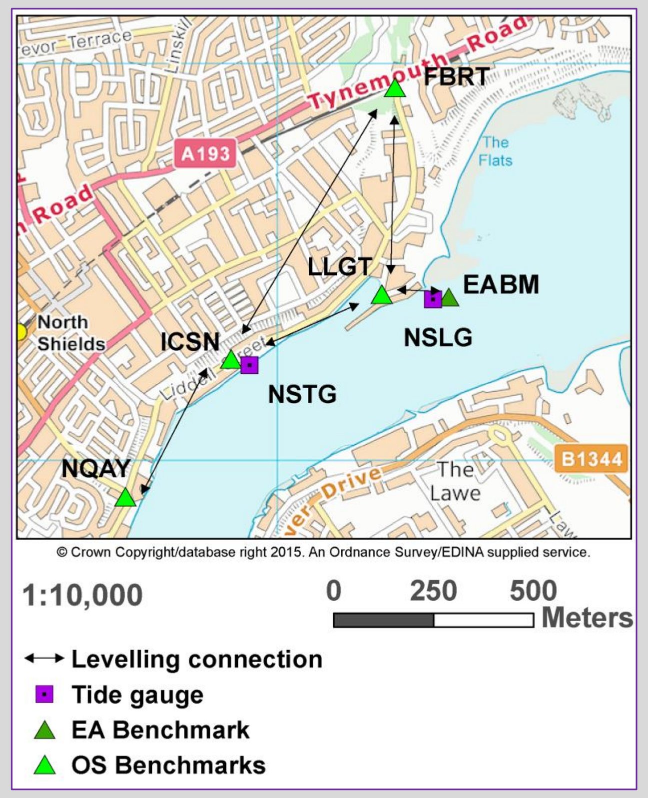

Figure 1a. Levelling campaign 2015

Levelling

- Levelling observations were made to a number of benchmarks shown in Figure 1a
- This technique determines the change in height from one benchmark to another
- Changes in height (or relative heights) between benchmarks determined in 2015 were compared to historical values published by Ordnance Survey to identify any change
- Previous levelling connections (ICSN to LLGT and LLGT to EABM) (Figure 1a) made by CEG Geomatics staff in 2008, 2009 and 2010 were also used for analysis
- Trends in relative height of benchmarks closest to the old and new tide gauge locations (benchmarks ICSN and EABM respectively) were inspected

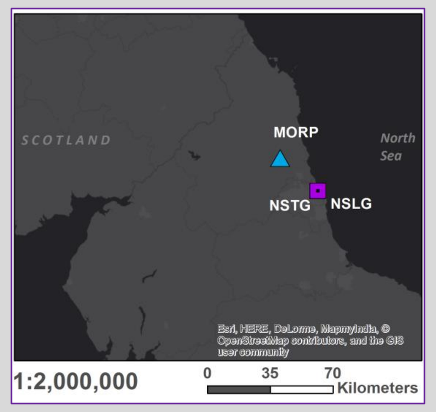

Figure 1b. MORP reference station

4. Results/ Discussion

GPS Analysis

- NSTG height time series has rather large inherent noise (30 mm on average) during 1998.5 - 2007.4 period (Figure 2a)
- It is suspected that the increased noise is caused by a combination of restricted view of satellites at NSTG and error propagation from the receiver at MORP
- A slight reduction of noise can be seen after 2007.9, most likely due to hardware upgrades at MORP
- The time series also has a number of gaps due to observation data being unavailable either from MORP or NSTG receivers
- Linear trend fitted through the time series indicates that NSTG is subsiding at 1.2 ± 13.6 mm/yr relative to MORP
- A significant reduction of noise (now 10 mm on average) in the NSLG height time series (Figure 2b) can be observed due to a more optimal location of NSLG receiver and further hardware upgrades at both MORP and NSLG sites
- Linear regression model shows a rise of NSLG of 0.8 ± 5.7 mm/yr relative to MORP
- Clearly, the trend for NSTG is less accurate and biased due to the unfiltered noise of the time series

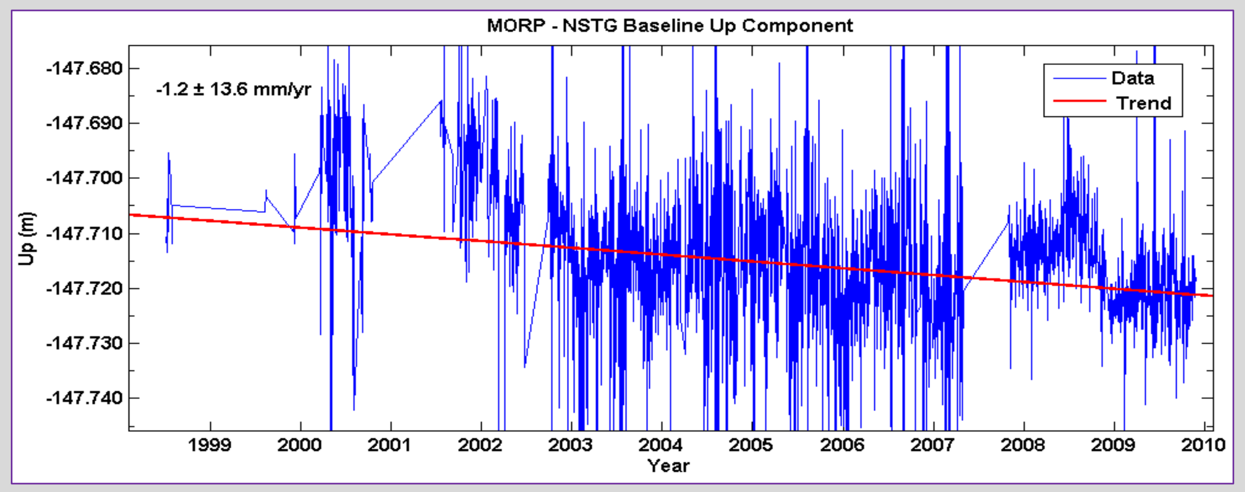

Figure 2a. Relative height from MORP to the old tide gauge (NSTG) during 1998 - 2009 .9

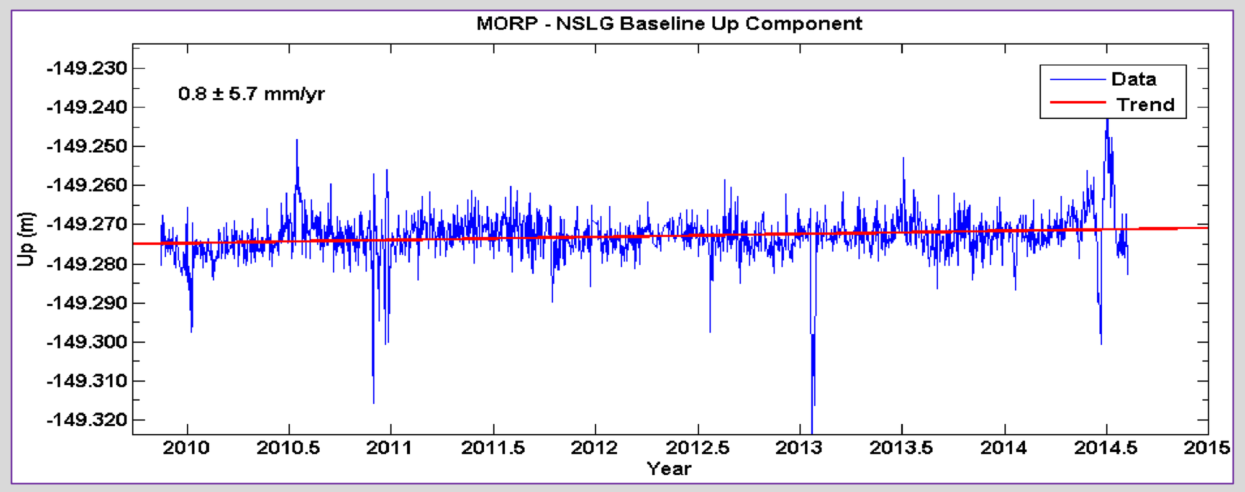

Figure 2b. Relative height from MORP to the new tide gauge (NSLG) during 2009.9 – 2014.6

5. Results / Discussion (continued)

Levelling

- Figures 3 a, b, c, d and e depict relative heights between benchmarks
- Change in height from ICSN to FBRT (Figure 3a) decreased by 4.8 mm during 1996-2015 suggesting ICSN is rising at 0.3 ± 0.7 mm/yr relative to FBRT
- Relative height from LLGT to FBRT (Figure 3b) decreased by 5.3 mm over 1991-2015 period, indicating a rise of LLGT of 0.2 ± 0.7 mm/yr
- Relative height between ICSN and LLGT (Figure 3c) did not change significantly (0.5 mm) over the 1996-2015 period meaning ICSN and LLGT are stable relative to each other
- An apparent rise of 0.4 ± 0.7 mm of EABM relative to LLGT can be seen from Figure 3d which is in close agreement with the trend derived from MORP-NSLG relative height time series (0.8 ± 5.7 mm/yr)
- The height difference from ICSN to NQAY (Figure 3e) however, suggests that either ICSN is subsiding at 0.7 ± 0.7 mm/yr or NQAY is rising relative to ICSN or it is the combination of both
- Little weight was attached to the relative height between ICSN and NQAY however, due to the old verification date of the latter benchmark (NQAY, 1962)

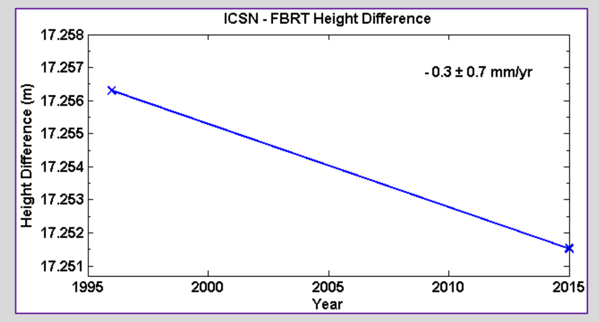

Figure 3a. ICSN-FBRT Relative height

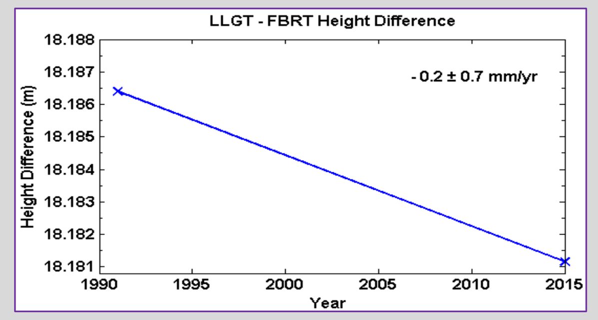

Figure 3b. LLGT-FBRT Relative height

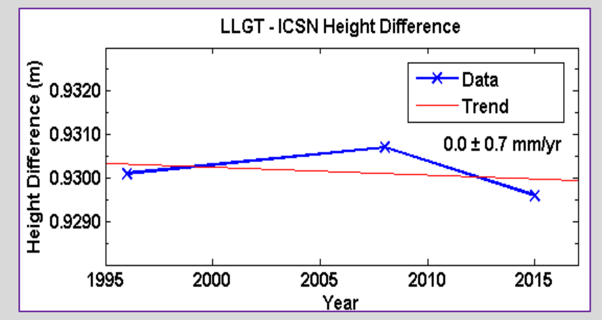

Figure 3c. LLGT-ICSN Relative height

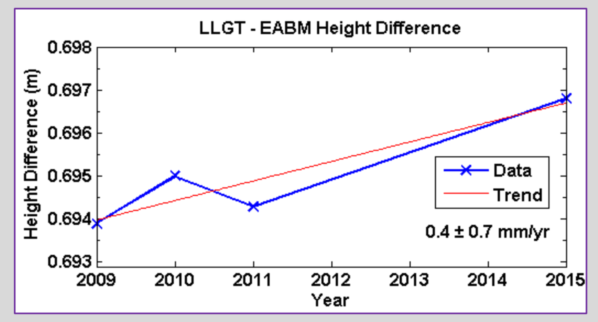

Figure 3d. LLGT-EABM Relative height

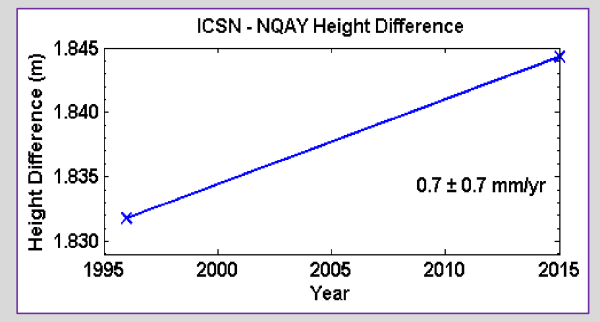

Figure 3e. ICSN-NQAY Relative height

6. Conclusions

- According to levelling, the old and new tide gauge locations can be considered as stable relative to each other as they appear to be rising at similar rates with respect to an inland benchmark FBRT (0.3 ± 0.7 mm/yr and 0.4 ± 0.7 mm/yr respectively)
- GPS-derived VLM of 0.8 ± 5.7 mm/yr at the new tide gauge during the 2009.9-2014.6 period is within a close agreement with the levelling-derived trend of 0.4 ± 0.7 mm/yr (2009-2015)
- GPS-derived VLM (-1.2 ± 13.6 mm/yr) at the old tide gauge however, contradicts with levelling-derived trend of 0.3 ± 0.7 mm/yr; it is therefore preferred to determine vertical position of the old and new tide gauges using an additional, independent GPS approach (Precise Point Positioning) to confirm GPS-derived results

Reference: [1] Blewitt, G. and Sanli, U. (2001) *Geocentric sea level trend using GPS and >100-year tide gauge record on a postglacial rebound nodal line*, Journal of Geophysical Research, VOL. 106, NO. B1, p.713

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