

Monitoring the vertical motion of the UK using GPS and absolute gravity

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NTSLF-Challenger Symposium
Sea level rise and coastal flooding –
understanding the risk

Royal Society, London, 2-3 November 2009

Acknowledgements

- The work reported on in this presentation was carried out jointly by the University of Nottingham and Proudman Oceanographic Laboratory and funded:
 - by a NERC SOFI small research grant for “The Creation of a Map of Current Vertical Land Movements in the UK based on an Optimal Combination of Absolute Gravity and Continuous GPS” (NE/F012179/1);
 - by an Environment Agency contract for “Measuring Changes in Land and Sea Levels around the coast of Great Britain” (contract 22869); and
 - as part of the development of products (such as coordinate time series, CGPS station velocities and maps) to be made available through the NERC British Isles continuous GNSS Facility (BIGF) (R8/H10/59).

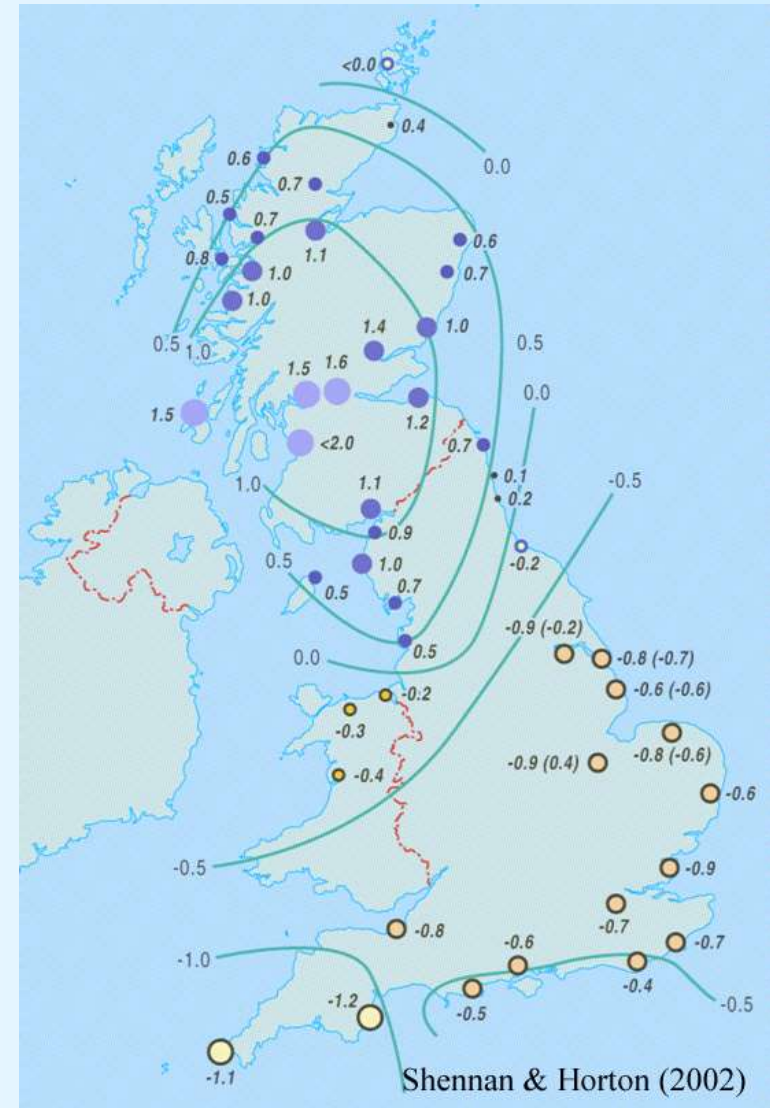


Overview

- Holocene land level changes in Great Britain/British Isles
- Current vertical motions of the UK
 - Continuous GPS (CGPS)
 - Absolute gravity (AG)
- Comparison of AG-aligned CGPS and Holocene land level changes
- Changes in sea level (decoupled from changes in land level) around the coast of Great Britain
 - CGPS and AG at or close to Tide Gauges (TGs)
- Conclusions

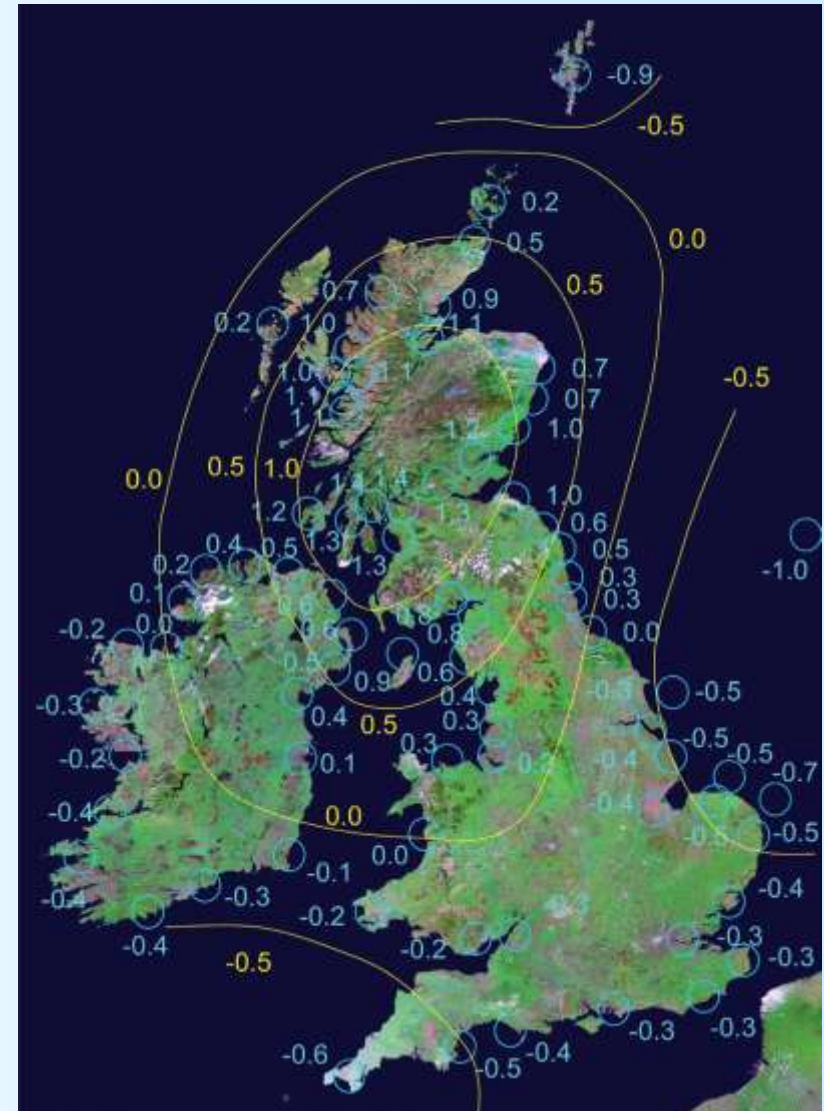
Holocene land level changes in Great Britain

- General pattern:
 - Uplift in Scotland and North of England
 - Subsidence in Wales, Central England and South of England
- Based on geological evidence:
 - >1250 radiocarbon dated samples constrain relative sea levels over past 16,000 years
 - Shennan and Horton (2002) then Shennan et al. (2006)
 - Dominant signal from glacial isostatic adjustment (GIA)



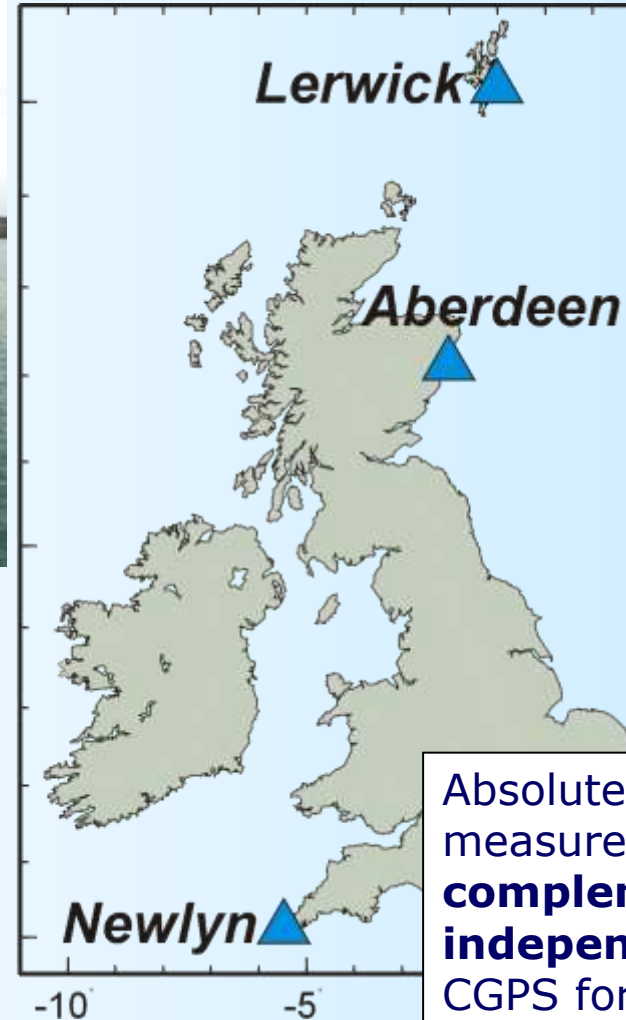
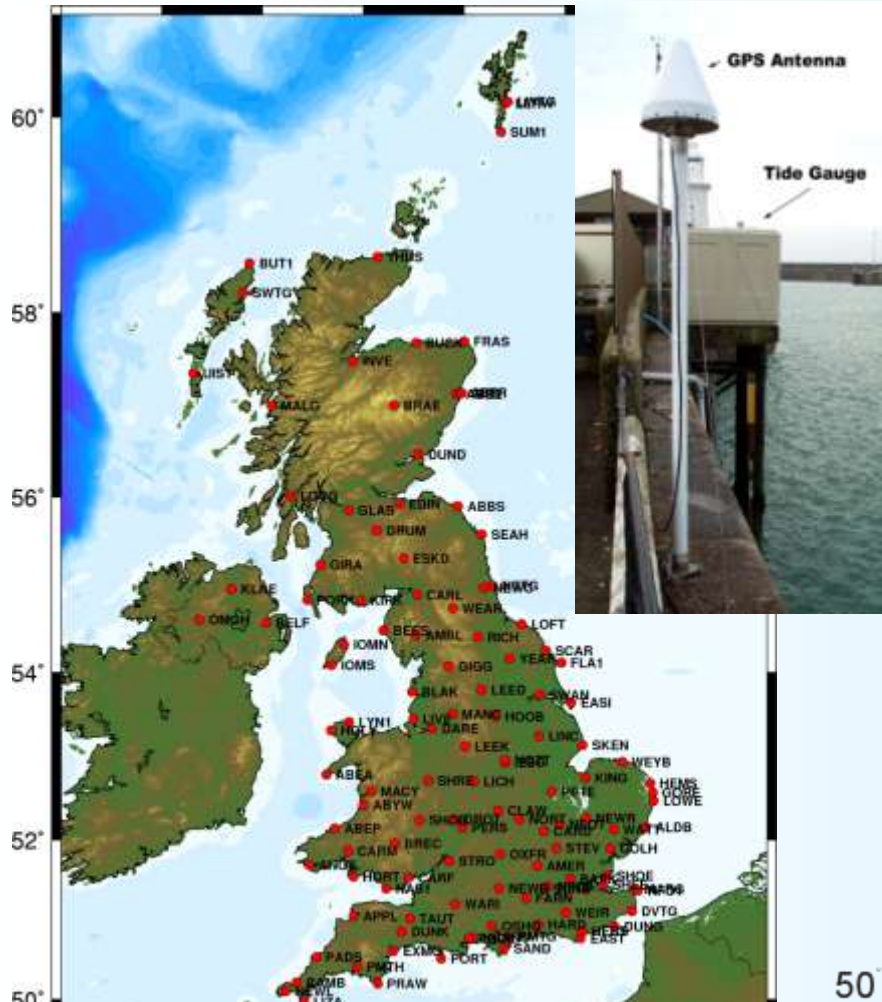
Holocene land level changes in British Isles

- General pattern:
 - Subsidence on Shetland
 - Uplift in Scotland, Northern Ireland, North of Ireland and North of England
 - Subsidence in Southern Ireland, Wales, Central England and South of England
 - Less uplift in Scotland and less subsidence in southwest England than Shennan and Horton (2002) due to
 - (1) the availability of more data to test models;
 - (2) model improvements;
 - (3) calculating late Holocene rates for the past 1 ka rather than 4 ka; and
 - (4) greater consideration of sediment consolidation



Shennan et al. (2009)

UK CGPS and AG Stations

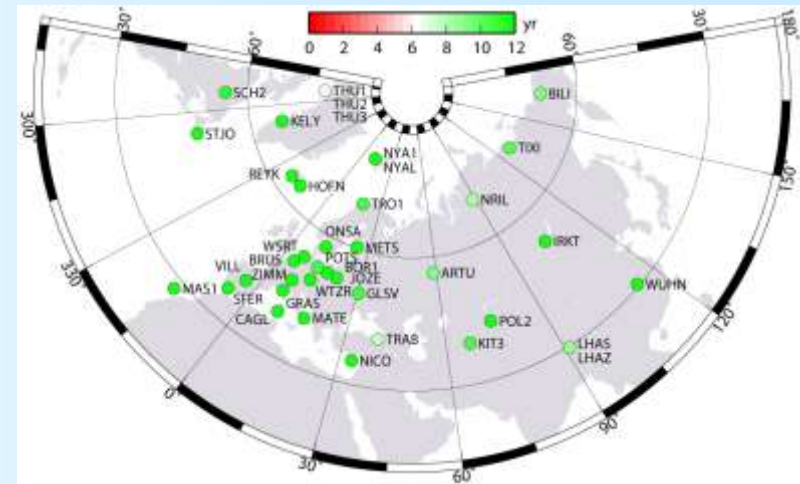


127 CGPS stations processed with at least 2.5 years of data within BIGF

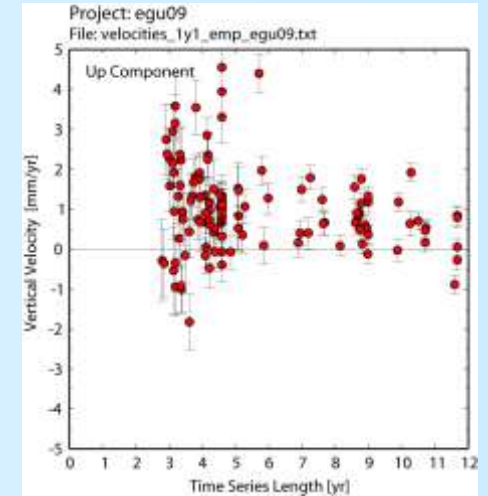
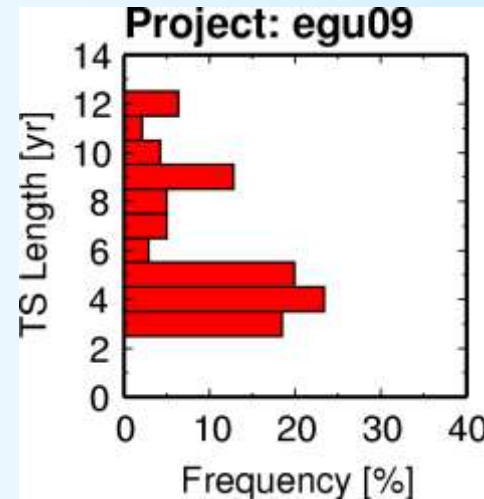
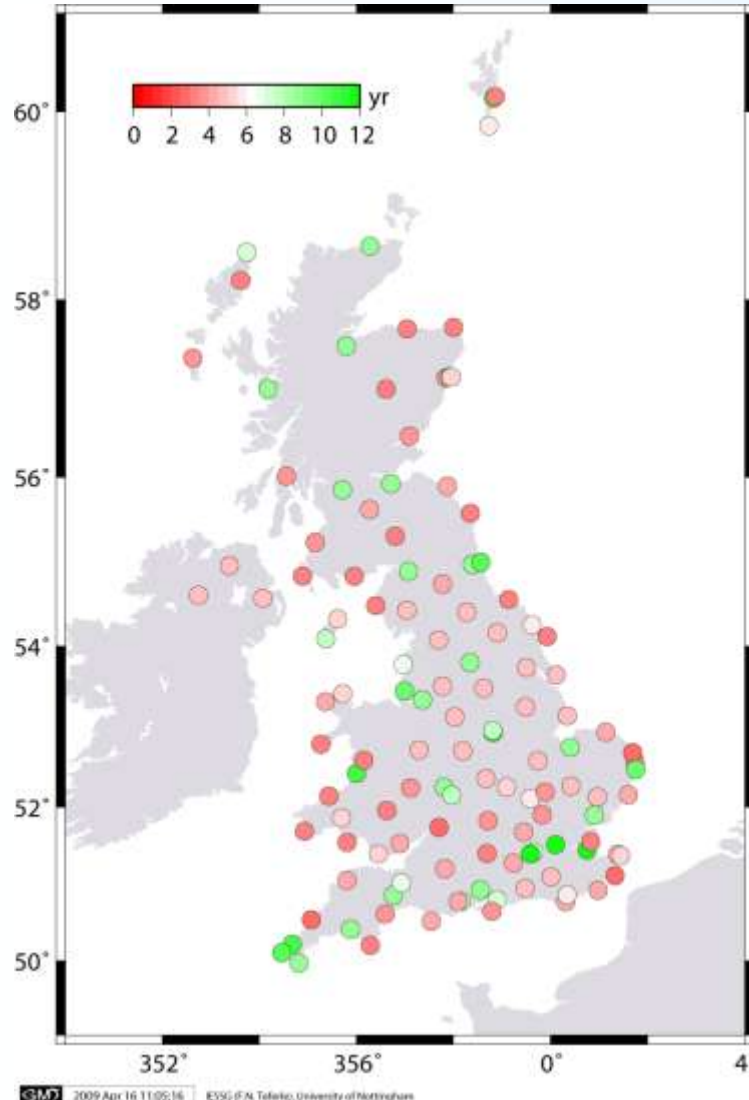
Absolute Gravity (AG) measurement as a **complementary** (and **independent**) technique to CGPS for monitoring vertical motion

Re-processing of the UK CGPS data set

- Bernese GPS Software v5.0 (Dach et al., 2007) used
 - Models for absolute satellite and receiver antenna phase centres
 - Modified internally to allow use of GMF (Boehm et al., 2006)
- Consistent GPS satellite orbit and EOP products used from 1997 to 2008:
 - 1997:001 to 2006:112, re-analysed PDR (Steigenberger et al., 2006)
 - 2006:309 to 2008:366, new IGS final
- Ambiguity resolution achieved
 - Following Steigenberger et al. (2006)
- Reference frame implementation
 - Using a semi-global network of approximately 50 IGS stations to align our daily position estimates, using a no-net rotation (no scale) minimum constraints approach, to ITRF2005



Final station selection: Length of time series

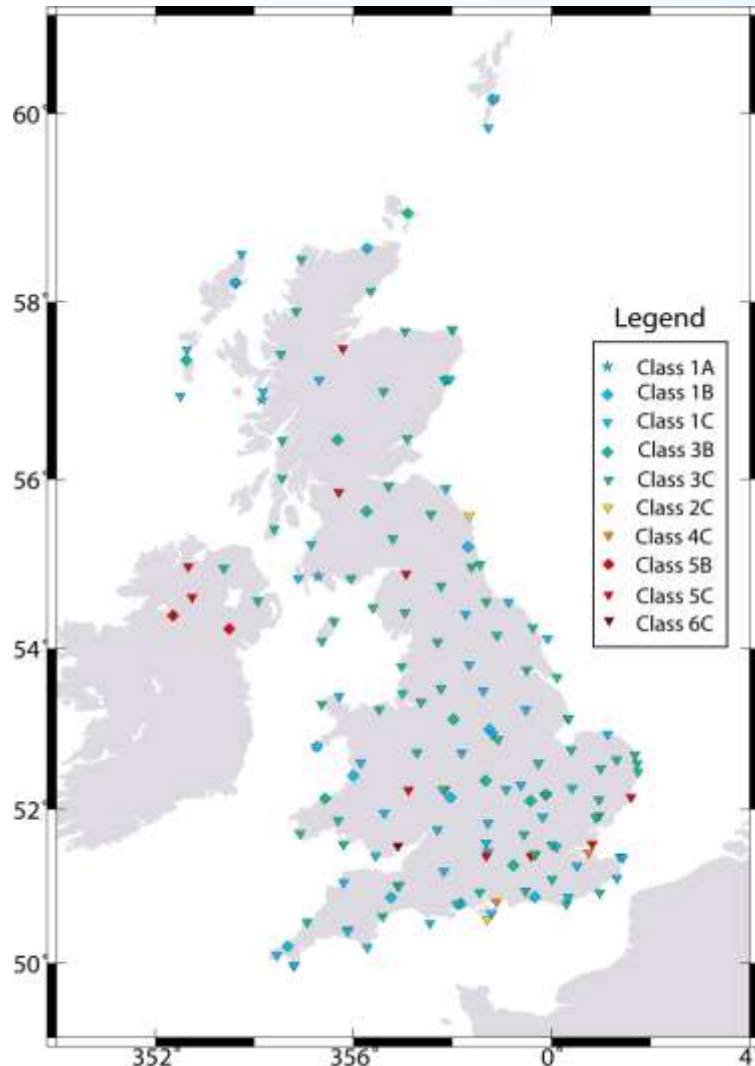


- Based on
 - Reliability of estimates of vertical station velocity (time series length)
 - 56/127 CGPS stations accepted as providing reliable estimates of vertical movement
 - 40 as direct estimates and 16 as dual-CGPS estimates

Final station selection: Classification by Site Suitability Rating

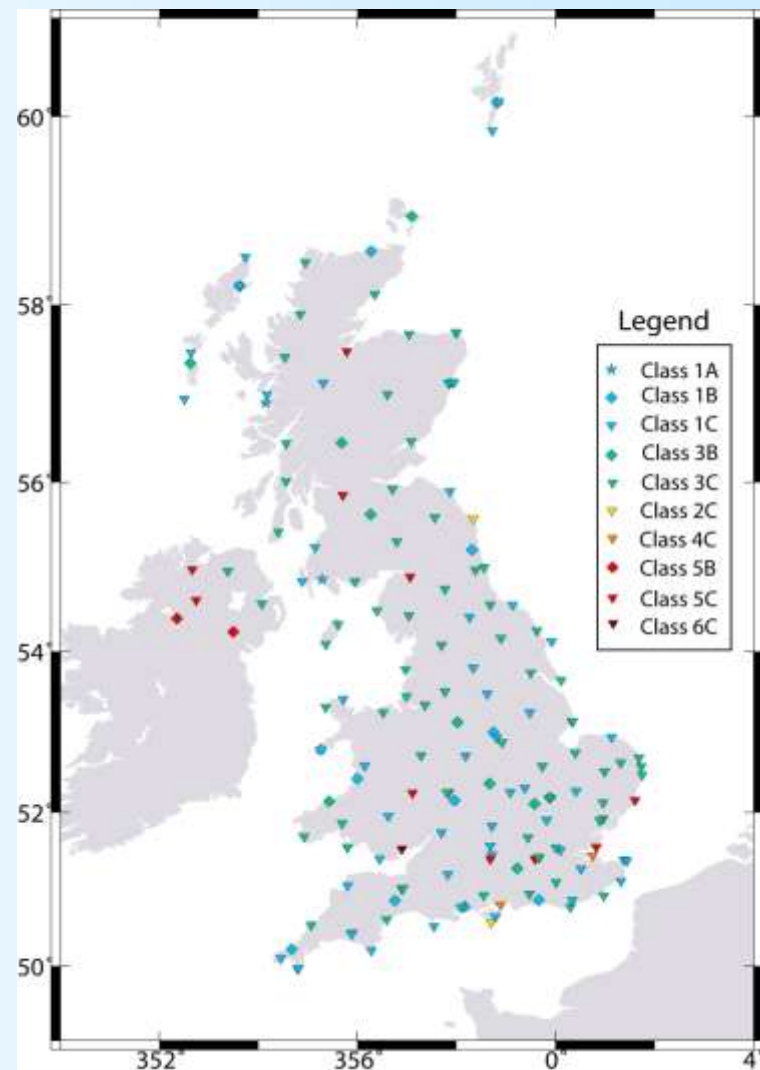
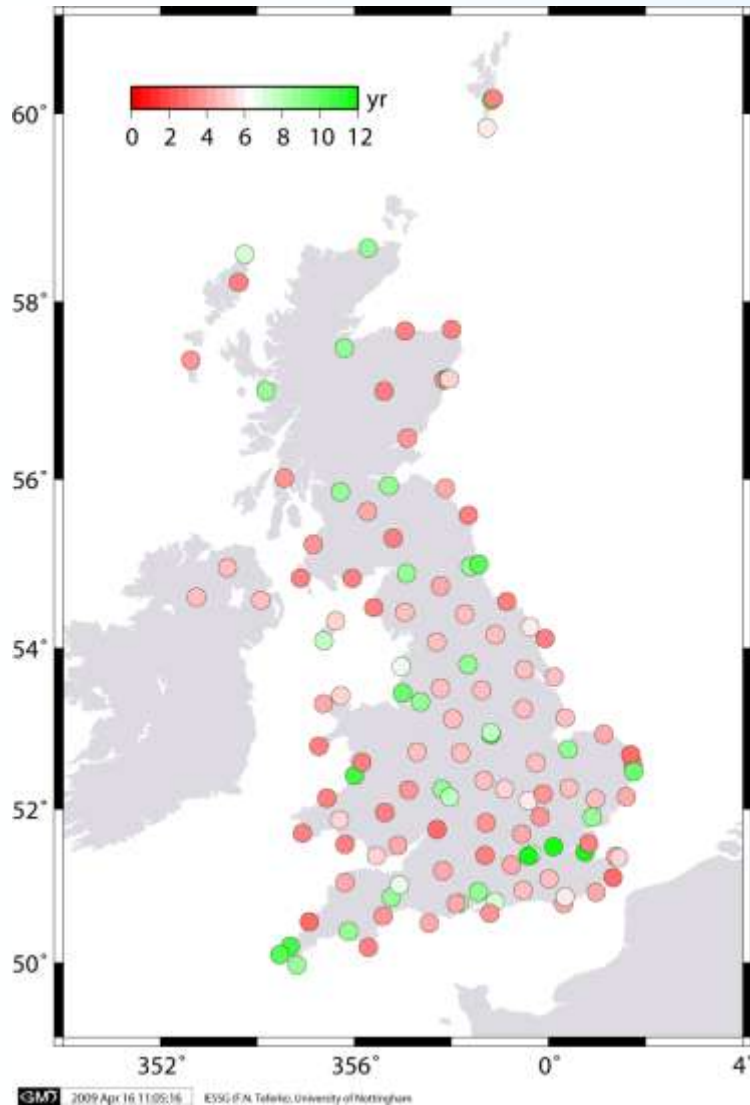
| | | | | | | | | | | |
|--|-----------------------------------|--|--|--|---|---|---|---|---|---|
| Geological / engineering setting of CGPS station | Connected directly to solid rock. | Connected to solid rock via a monolith, concrete block or concrete plinth. | Connected to solid rock via a building or structure which has no structural deformation. | Connected to solid rock via a building or structure which may have structural deformation. | Not connected to solid rock, but on a monolith, concrete block or concrete plinth that is on top of consolidated sediments. | Not connected to solid rock, but on a building or structure: that is on top of, or piled into, consolidated sediments; and which has no structural deformation. | Not connected to solid rock, but on a building or structure: that is on top of, or piled into, consolidated sediments; and which may have structural deformation. | Not connected to solid rock, but on a monolith, concrete block or concrete plinth that is on top of unconsolidated sediments. | Not connected to solid rock, but on a building or structure: that is on top of, or piled into, unconsolidated sediments; and which has no structural deformation. | Not connected to solid rock, but on a building or structure: that is on top of, or piled into, unconsolidated sediments; and which may have structural deformation. |
| Current vertical motion contributors | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment |
| | | | | | Natural compaction | Natural compaction | Natural compaction | Natural compaction | Natural compaction | Natural compaction |
| | | | | | | | | Man-made compaction | Man-made compaction | Man-made compaction |
| | | | | Structural deformation | | | Structural deformation | | | Structural deformation |
| Site Suitability Rating (SSR) | 1A | 1B | 1C | 2C | 3B | 3C | 4C | 5B | 5C | 6C |
| What is being measured? | VCM | VCM | VCM | VCM, if structural deformation can be assumed to be negligible, otherwise VSM | VLM | VLM | VLM, if structural deformation can be assumed to be negligible, otherwise VSM | VSM | VSM | VSM |

Final station selection: Site Suitability Rating

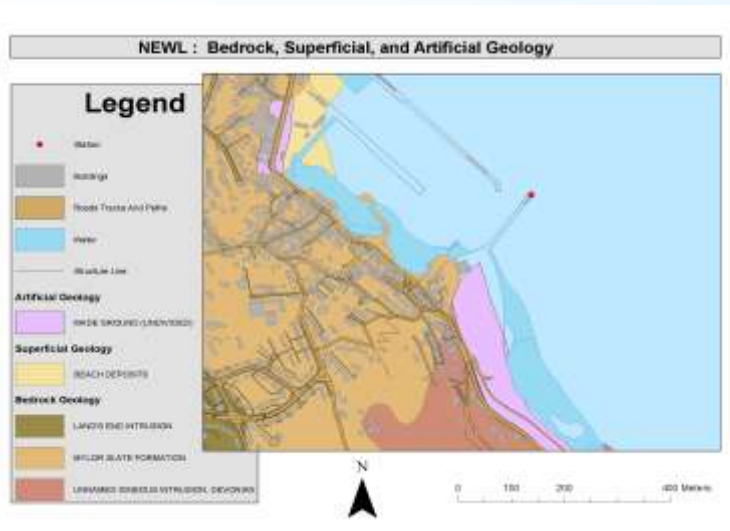


- Based on
- Reliability of estimates of vertical station velocity (time series length) **and**
- Classification through award of a Site Suitability Rating by considering local environment, monument type and foundation, and local site geology
- 46/127 CGPS stations accepted as providing reliable estimates of vertical land movement, due to GIA or a combination of GIA and natural compaction
 - 30 as direct estimates and 16 as dual-CGPS estimates

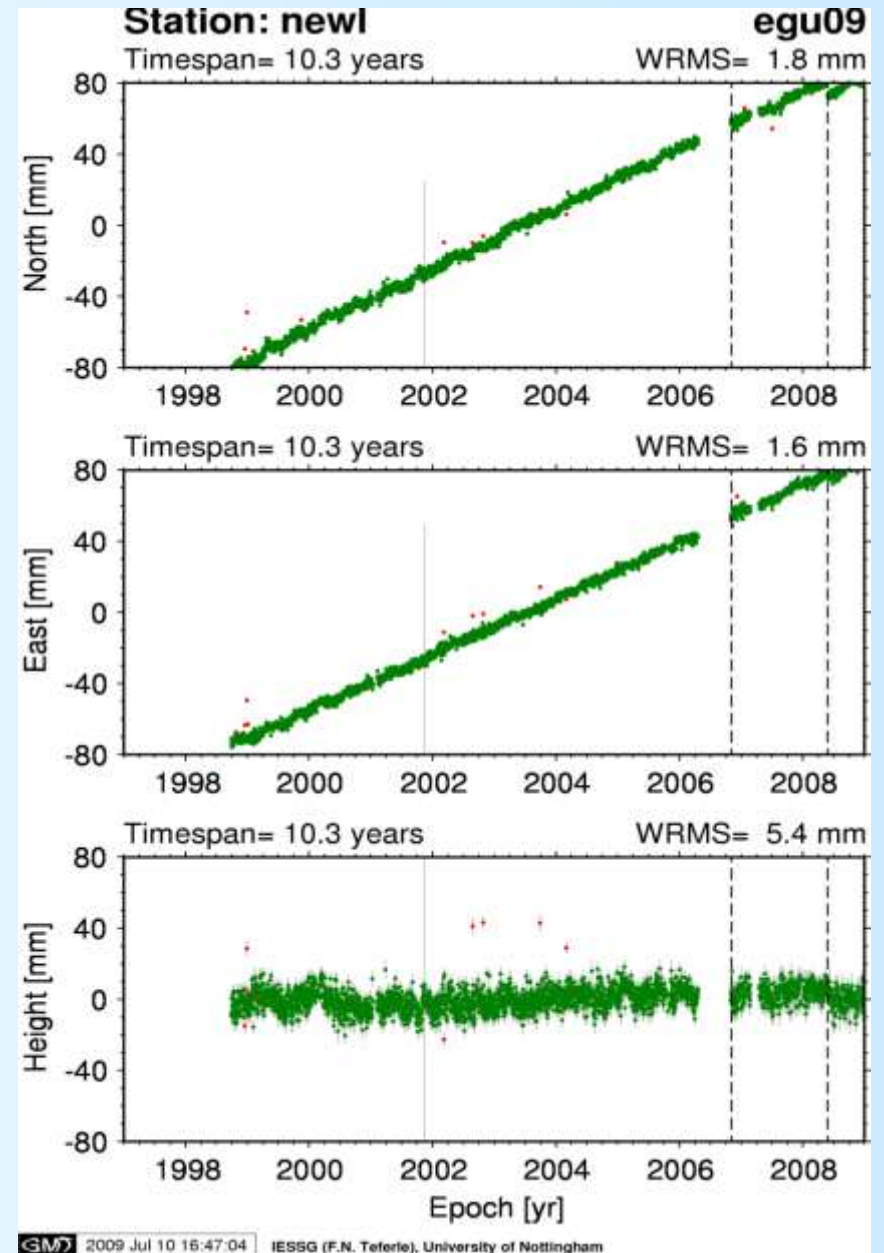
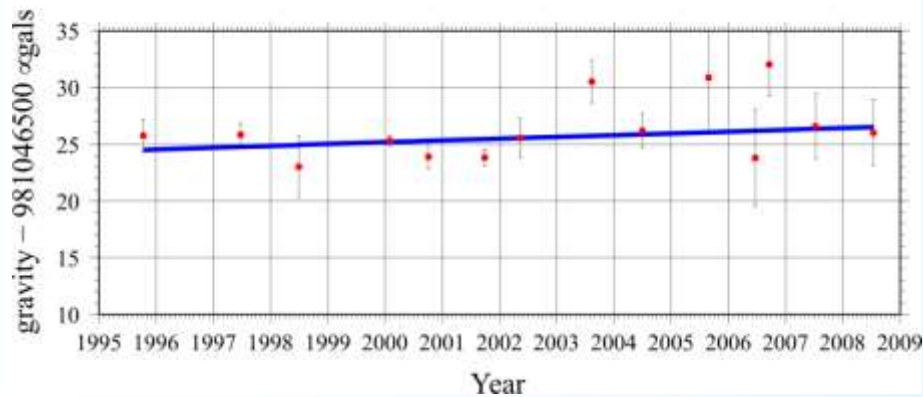
Final station selection



Newlyn

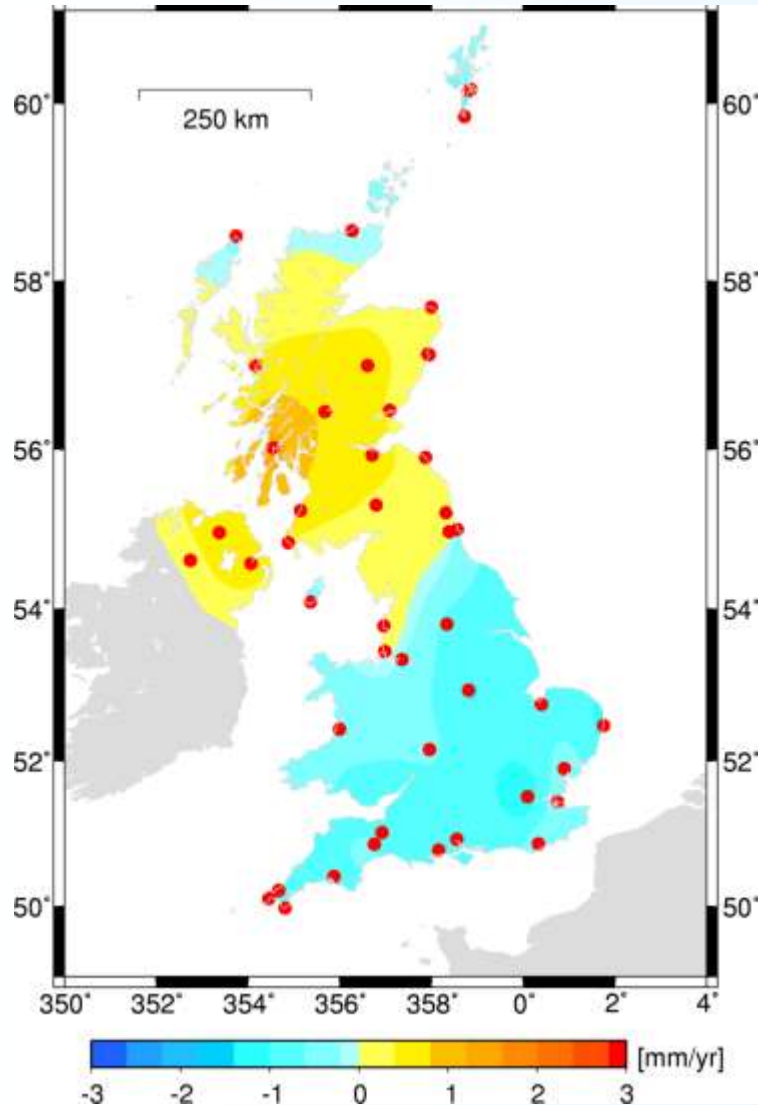


Newlyn (NEWL) Absolute Gravity

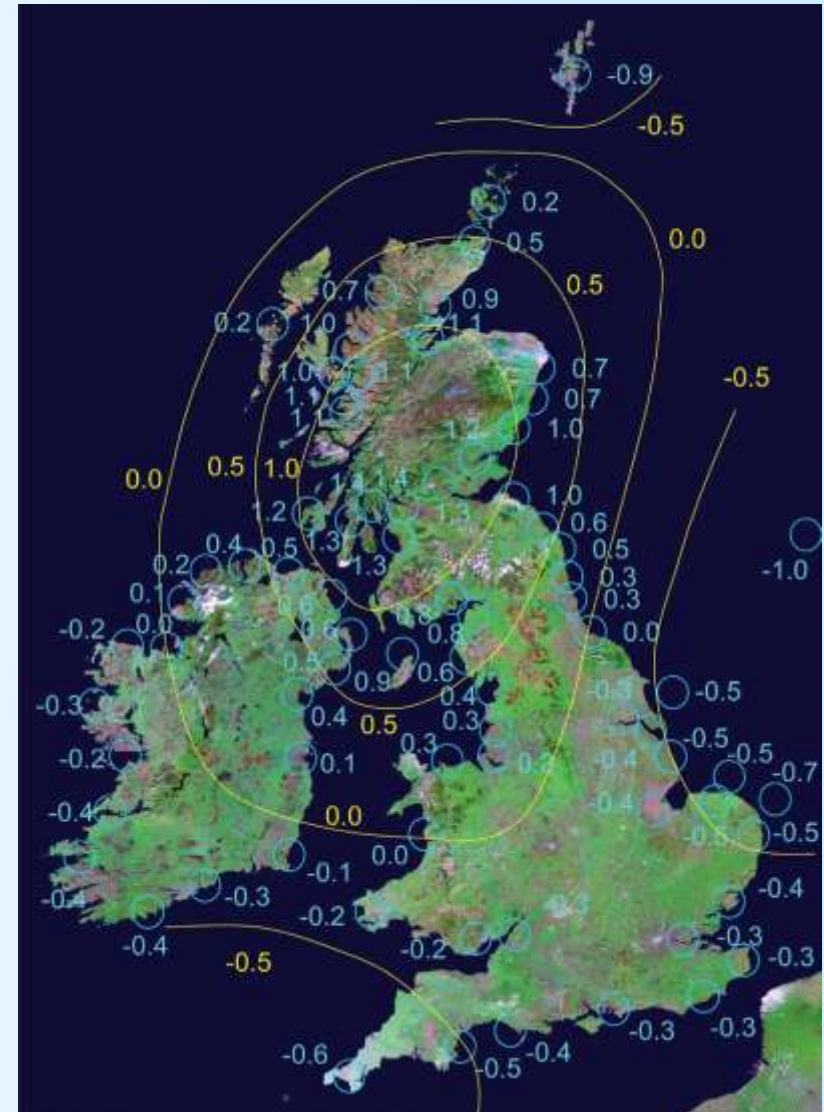


GM 2009 Jul 10 16:47:04 IESSG (F.N. Teferte), University of Nottingham

Comparison of current vertical motions and Holocene land level changes

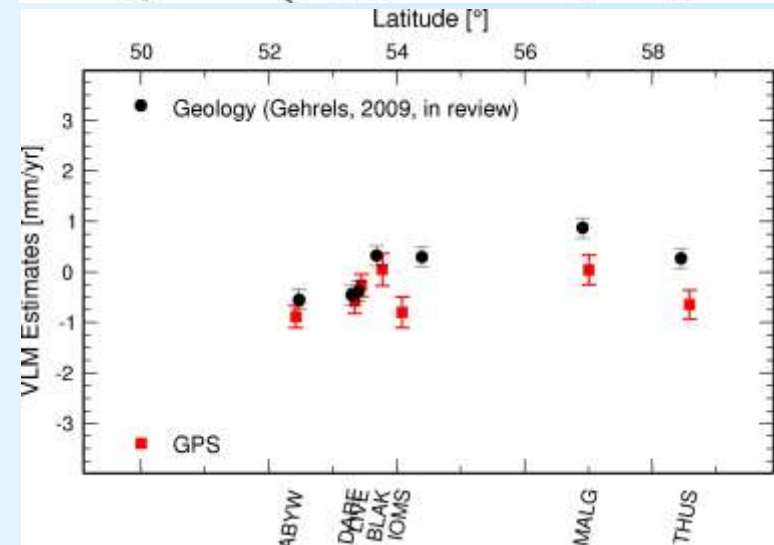
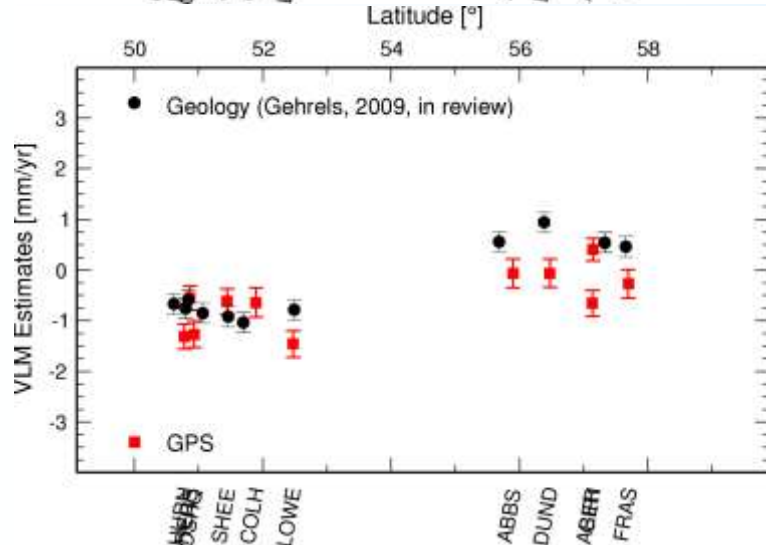
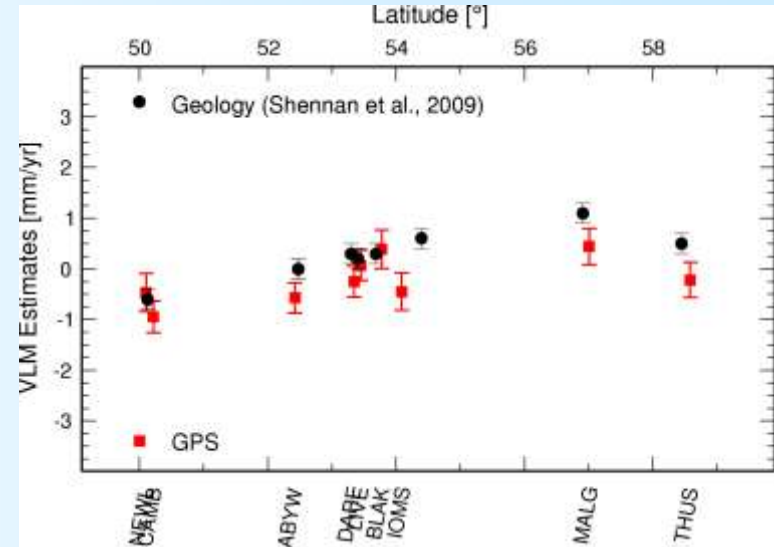
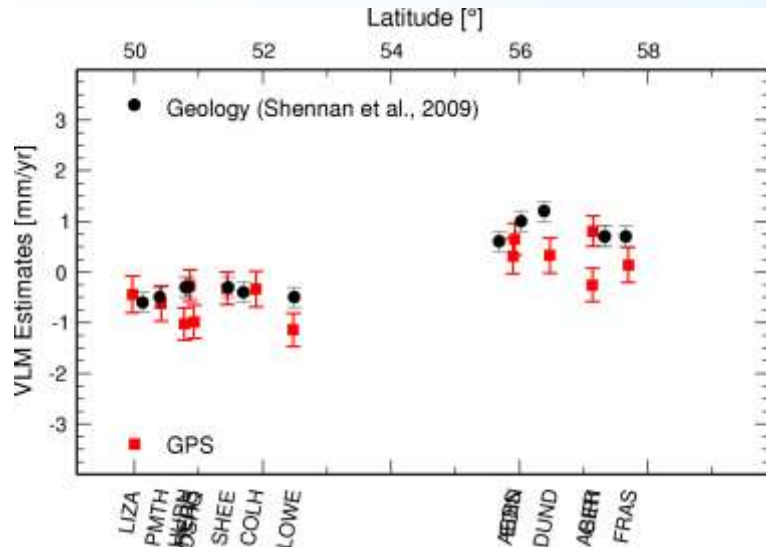


AG-aligned CGPS



Shennan et al. (2009)

Comparison of current vertical motions and Holocene land level changes



UK CGPS@TG Stations



Lerwick



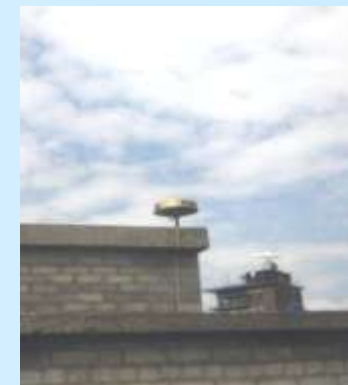
Aberdeen



North Shields



Lowestoft



Sheerness



Dover



Portsmouth



Newlyn



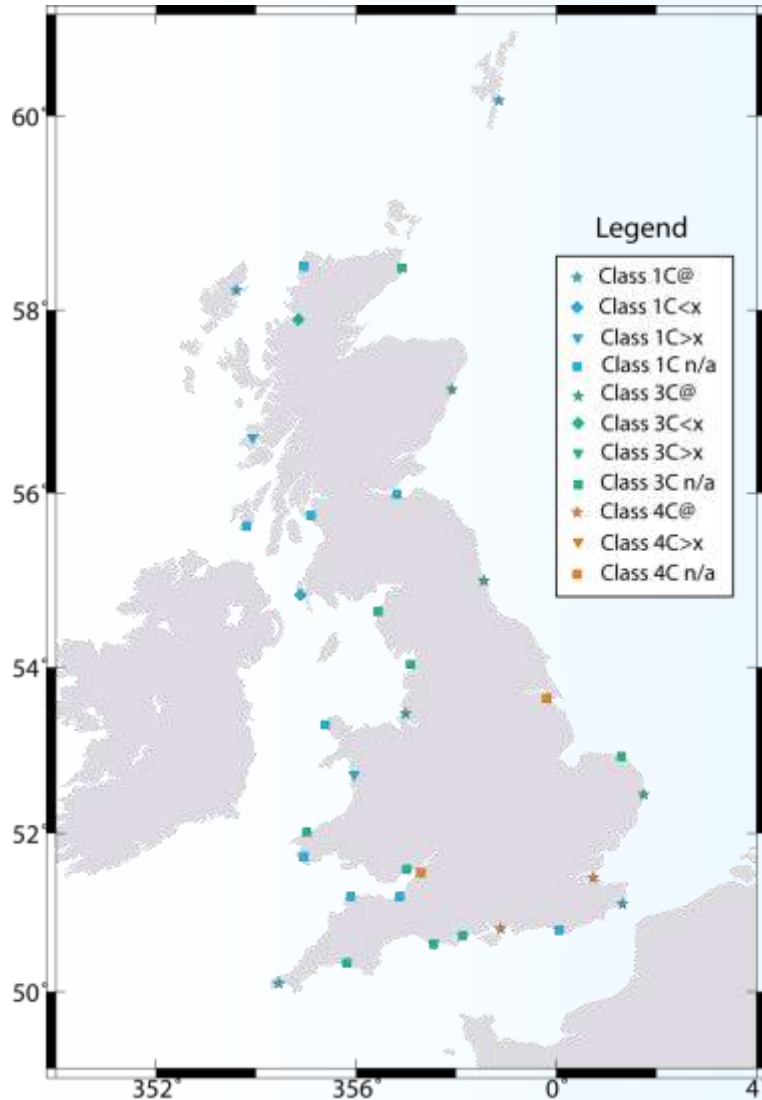
Liverpool



Stornoway

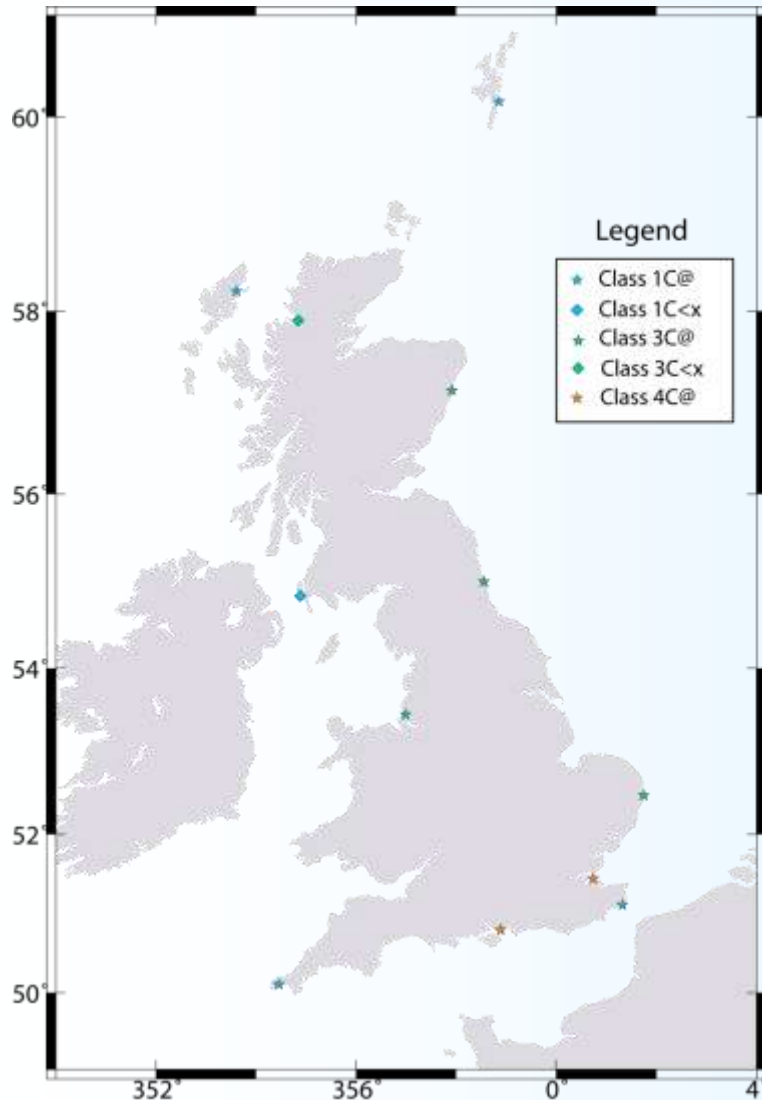
| | | | | | | | | | | |
|--|-----------------------------------|--|--|--|---|---|---|---|---|---|
| Geological / engineering setting of TG | Connected directly to solid rock. | Connected to solid rock via a monolith, concrete block or concrete plinth. | Connected to solid rock via a building or structure which has no structural deformation. | Connected to solid rock via a building or structure which may have structural deformation. | Not connected to solid rock, but on a monolith, concrete block or concrete plinth that is on top of consolidated sediments. | Not connected to solid rock, but on a building or structure: that is on top of, or piled into, consolidated sediments; and which has no structural deformation. | Not connected to solid rock, but on a building or structure: that is on top of, or piled into, consolidated sediments; and which may have structural deformation. | Not connected to solid rock, but on a monolith, concrete block or concrete plinth that is on top of unconsolidated sediments. | Not connected to solid rock, but on a building or structure: that is on top of, or piled into, unconsolidated sediments; and which has no structural deformation. | Not connected to solid rock, but on a building or structure: that is on top of, or piled into, unconsolidated sediments; and which may have structural deformation. |
| Current vertical motion contributors | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment | Glacio-isostatic adjustment |
| | | | | | Natural compaction | Natural compaction | Natural compaction | Natural compaction | Natural compaction | Natural compaction |
| | | | | | | | | Man-made compaction | Man-made compaction | Man-made compaction |
| | | | | Structural deformation | | | Structural deformation | | | Structural deformation |
| CGPS@TG | 1A @ | 1B @ | 1C @ | 2C @ | 3B @ | 3C @ | 4C @ | 5B @ | 5C @ | 6C @ |
| CGPS $\leq x$ km from TG and with the <u>same</u> geological/engineering setting and main current vertical movement contributors | 1A <x | 1B <x | 1C <x | 2C <x | 3B <x | 3C <x | 4C <x | 5B <x | 5C <x | 6C <x |
| CGPS $\geq x$ km from TG but with the <u>same</u> geological/engineering setting and main current vertical movement contributors | 1A >x | 1B >x | 1C >x | 2C >x | 3B >x | 3C >x | 4C >x | 5B >x | 5C >x | 6C >x |
| CGPS not at TG and with <u>different</u> geological/engineering setting and/or main current vertical movement contributors | 1A NA | 1B NA | 1C NA | 2C NA | 3B NA | 3C NA | 4C NA | 5B NA | 5C NA | 6C NA |

Final station selection



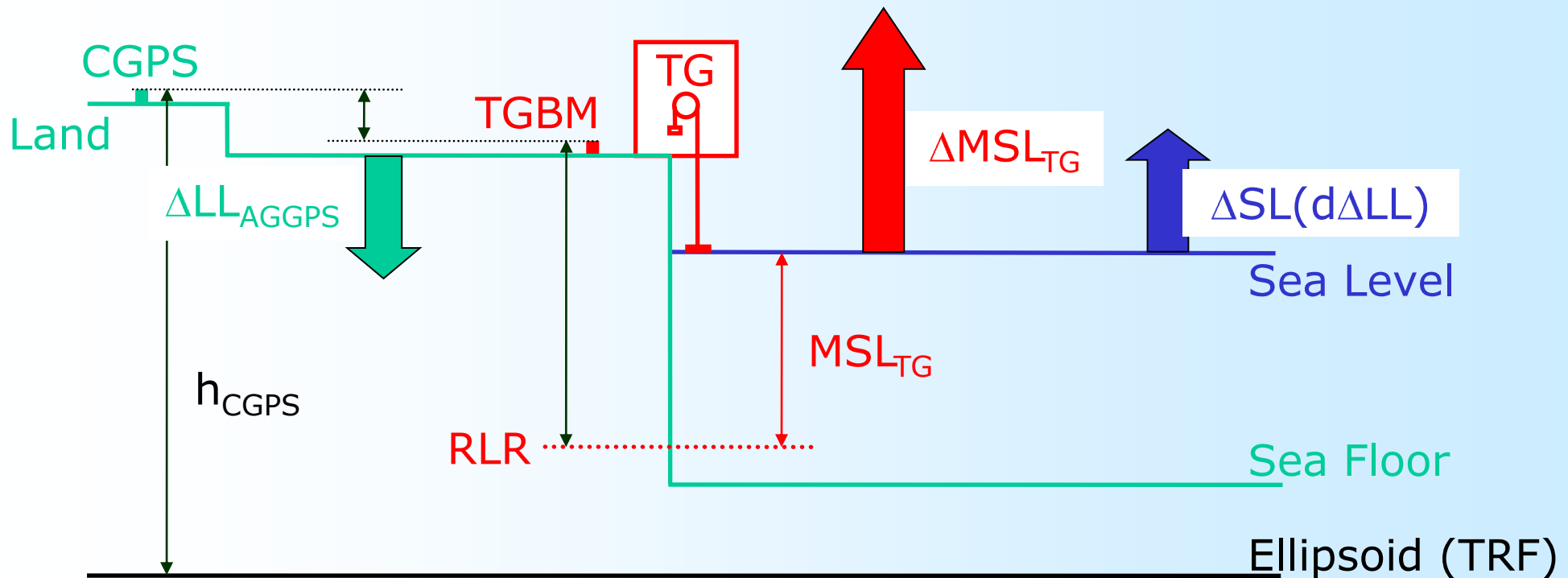
- Based on
- Reliability of estimates of **changes in mean sea level and vertical station velocity** (time series length)
- Classification through award of a **combined** Site Suitability Rating by considering local environment, monument type and foundation, and local site geology **at the tide gauge and the nearest CGPS station**

Final station selection



- Based on
- Reliability of estimates of **changes in mean sea level and vertical station velocity** (time series length)
- Classification through award of a **combined** Site Suitability Rating by considering local environment, monument type and foundation, and local site geology **at the tide gauge and the nearest CGPS station**
- 10/34 tide gauges accepted as providing reliable estimates of changes in sea level (decoupled from changes in land level)
 - **All CGPS@TG stations**

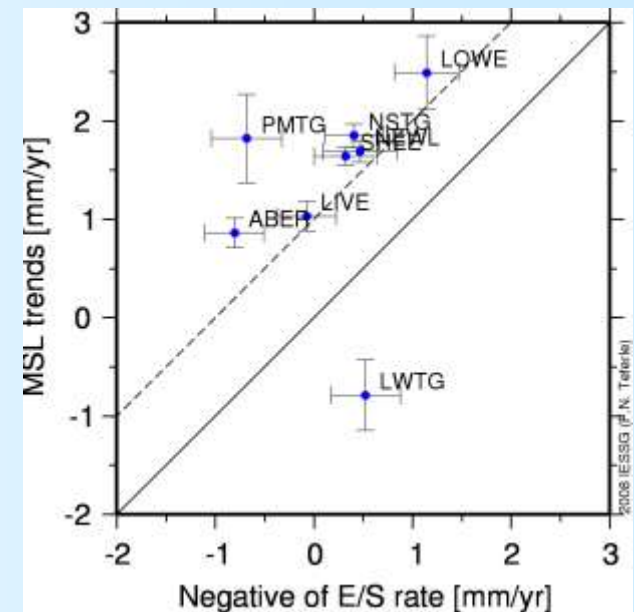
Changes in sea level (decoupled from changes in land level) around the coast of Great Britain



$$\Delta SL(d\Delta LL) = \underbrace{\Delta MS L_{TG}}_{\text{PSMSL}} + \underbrace{\Delta LL_{AGGPS}}_{\text{AG-aligned CGPS}}$$

Changes in sea level (decoupled from changes in land level) around the coast of Great Britain

| Station name | ID | $\Delta\text{MSL}_{\text{TG}}$ | $\Delta\text{LL}_{\text{AGGPS}}$ (mm/yr) | $\Delta\text{SL}(\text{d}\Delta\text{LL})$ |
|--------------------------------|------|--------------------------------|---|--|
| Lerwick | LERW | | -0.65 | |
| Lerwick | LWTG | -0.79* | -0.53 | -1.32* |
| Stornoway | SWTG | | | |
| Aberdeen | ABER | +0.86 | +0.80 | +1.66 |
| N. Shields | NSTG | +1.85 | -0.42 | +1.43 |
| Liverpool | LIVE | +1.03 | +0.06 | +1.09 |
| Lowestoft | LOWE | +2.49 | -1.15 | +1.34 |
| Sheerness | SHEE | +1.64 | -0.33 | +1.31 |
| Dover | DVTG | | | |
| Portsmouth | PMTG | +1.82 | +0.67? | +2.49? |
| Newlyn | NEWL | +1.69 | -0.48 | +1.21 |
| Mean (excluding LWTG and PMTG) | | | | +1.34 |



Notes:

- * = latest estimates suggesting spurious tide gauge record?
- ? = latest estimates suggesting recent local scale movements?

Conclusions

- We have derived a new map of current vertical motions in the UK
 - based on 2 AG stations and 46/127 CGPS stations, and a recent reprocessing that included data for the period from 1997 to 2008
 - including, for the first time, stations in Northern Ireland, to better define the westerly extent of uplift associated with the glacio-isostatic processes active in the region
 - which has similar (but not identical) characteristics to the 'geological map' of Holocene land level changes
 - which is available for use in any assessments of future changes in relative sea level for flood and coastal risk management in the UK

Conclusions

- We have derived new estimates for the changes in sea level (decoupled from changes in land level)
 - based on 2 AG stations and 6/10 CGPS@TG stations, and a recent reprocessing that included data for the period from 1997 to 2008
 - with an average for around the coast of Great Britain of +1.34mm/yr, when combining the current vertical motions from CGPS and AG, and changes in sea level for the past few decades/past century

Keep on monitoring...

- If we acquire more concurrent CGPS, AG and tide gauge data over the next 10 to 20 years it will be possible to compute an accurate estimate for any acceleration in the average change in sea level (decoupled from changes in land level) around the coast of Great Britain

