The Effect of Vertical Land Movement Data Sets on Estimates of Sea Level Rise around the UK

F. N. Teferle(1), R. M. Bingley(1), S. D. P. Williams(2), S. L. Bradley(3), G. A. Milne(3), P. L. Woodworth(2), and I. Shennan(4)

1) Institute of Engineering Surveying and Space Geodesy, University of Nottingham, UK
2) Proudman Oceanographic Laboratory, UK
3) Department of Earth Sciences, Durham University, UK
4) Department of Geography, Durham University, UK

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Overview

• Background and Motivation
• Updated mean sea level (MSL) trends for the UK
  – Woodworth et al. (2008) and PSMSL (2007)
• Data sets of vertical land movement (VLM) estimates for the UK
  – From measurements:
    • Geological evidence (Shennan and Horton, 2002)
    • Geodetic evidence from a combination of absolute gravity (AG) and continuous
      GPS (CGPS) measurements (update from Teferle et al., 2006)
  – From geodynamic models of the glacial isostatic adjustment (GIA) process:
    • Global GIA model ICE4G-VM2 (Peltier, 2001)
    • “Revised” GIA model for the British Isles (Bradley et al., 2008)
• Comparison of VLM estimates for the UK
• Effects on Average Changes of Sea Level around the UK
• Conclusions
Background and Motivation

- Sea level change is an important topic in the United Kingdom (UK) due to
  - Many low-lying areas along the North Sea coast
  - Subsidence in the London area and along the Thames Estuary
- Several studies of changes in sea level around Great Britain and the UK
  - Using tide gauges (TG) with PSMSL revised local reference (RLR) records and mean sea level (MSL) trends
  - Woodworth et al. (1999)
    - MSL trends for TG at Aberdeen, North Shields, Sheerness, Newlyn and Liverpool
    - Vertical land movement (VLM) estimates from geology (Shennan, 1989)
    - Regional average of sea level change around of Great Britain of 1.0 mm/yr
  - Teferle et al. (2006)
    - MSL trends for TG at Aberdeen, Lowestoft, Sheerness, Newlyn, Liverpool and Brest (France)
    - VLM estimates from a combination of absolute gravity and continuous GPS
    - Regional average of sea level change around of Great Britain of $1.1 \pm 0.7$ mm/yr, but this varies between 0.6 and 1.9 mm/yr depending on the sub-set of TG used
    - These UK estimates fit within the range of 0.7 to 1.8 mm/yr of global averages of sea level change (e.g. Church et al., 2001; Douglas, 2001; Wöppelmann et al., 2007)
- Motivation for this study:
  - Recently updated MSL trends for UK TG
  - New sets of estimates of vertical land movements for the UK
**MSL trends for UK PSMSL RLR TGs**

<table>
<thead>
<tr>
<th>Station</th>
<th>No. Years</th>
<th>Range</th>
<th>Trend and St. Err.</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[mm/yr]</td>
<td></td>
<td>[mm]</td>
</tr>
<tr>
<td>Lerwick</td>
<td>38</td>
<td>1957 - 2005</td>
<td>-0.68 +/- 0.34</td>
<td>28.5</td>
</tr>
<tr>
<td>Wick</td>
<td>34</td>
<td>1965 - 2006</td>
<td>1.55 +/- 0.43</td>
<td>30.8</td>
</tr>
<tr>
<td>Aberdeen Composite</td>
<td>96</td>
<td>1901 - 2006</td>
<td>0.87 +/- 0.10</td>
<td>28.6</td>
</tr>
<tr>
<td>Rosyth</td>
<td>27</td>
<td>1964 - 1993</td>
<td>1.99 +/- 0.92</td>
<td>41.1</td>
</tr>
<tr>
<td>Dunbar</td>
<td>37</td>
<td>1914 - 1950</td>
<td>0.47 +/- 0.31</td>
<td>20.5</td>
</tr>
<tr>
<td>North Shields</td>
<td>84</td>
<td>1901 - 2006</td>
<td>1.92 +/- 0.12</td>
<td>32.6</td>
</tr>
<tr>
<td>Lowestoft</td>
<td>44</td>
<td>1956 - 2006</td>
<td>2.57 +/- 0.33</td>
<td>31.7</td>
</tr>
<tr>
<td>Southend</td>
<td>44</td>
<td>1933 - 1983</td>
<td>1.22 +/- 0.24</td>
<td>24.1</td>
</tr>
<tr>
<td>Tilbury</td>
<td>22</td>
<td>1961 - 1983</td>
<td>1.58 +/- 0.91</td>
<td>28.5</td>
</tr>
<tr>
<td>Sheerness</td>
<td>58</td>
<td>1901 - 2006</td>
<td>2.23 +/- 0.13</td>
<td>34.0</td>
</tr>
<tr>
<td>Dover</td>
<td>37</td>
<td>1961 - 2006</td>
<td>2.18 +/- 0.26</td>
<td>22.1</td>
</tr>
<tr>
<td>Portsmouth</td>
<td>34</td>
<td>1962 - 2005</td>
<td>1.58 +/- 0.44</td>
<td>32.5</td>
</tr>
<tr>
<td>Newlyn</td>
<td>89</td>
<td>1916 - 2006</td>
<td>1.70 +/- 0.10</td>
<td>25.0</td>
</tr>
<tr>
<td>Liverpool Composite</td>
<td>69</td>
<td>1901 - 2004</td>
<td>1.60 +/- 0.17</td>
<td>40.8</td>
</tr>
<tr>
<td>Douglas</td>
<td>31</td>
<td>1938 - 1977</td>
<td>0.26 +/- 0.70</td>
<td>39.6</td>
</tr>
<tr>
<td>Portpatrick</td>
<td>31</td>
<td>1968 - 2004</td>
<td>1.95 +/- 0.44</td>
<td>25.9</td>
</tr>
<tr>
<td>Millport</td>
<td>20</td>
<td>1969 - 2006</td>
<td>1.20 +/- 0.53</td>
<td>28.0</td>
</tr>
<tr>
<td>Stotomoy</td>
<td>18</td>
<td>1977 - 2006</td>
<td>2.22 +/- 0.90</td>
<td>33.9</td>
</tr>
</tbody>
</table>

(Woodworth et al., 2008; PSMSL, 2007)
VLM from Geological Evidence: GEOL

- General pattern of VLM:
  - Uplift of Scotland and Northern England
  - Subsidence in Wales, Central and Southern England
- Geological evidence from:
  - >1250 radiocarbon dated samples that constrain relative sea levels in Great Britain over the past 16,000 yr
  - Shennan & Horton (2002), Shennan et al. (2006a, b)
VLM from Geodetic Evidence: CGPS and AG

45 CGPS stations processed including 11 CGPS@TG stations and long period OSGB and Met Office stations in BIGF (1997-2005)

Absolute Gravity (AG) measurements (1995-2006) as a complementary (and independent) technique to CGPS
VLM from Geodetic Evidence (2)

- Two independent CGPS processing streams as outlined in Teferle et al. (2006, 2007)
- Combination of AG and CGPS vertical station velocities to obtain AG-aligned CGPS estimates of vertical station velocity (Teferle et al., 2006)
Global GIA Model: GIA1

- ICE4G-VM2 model (Peltier, 2001)
  - Global GIA model that fits US east-coast and UK geological data sets well without focus on UK area (Peltier et al., 2002)
- Ice model
  - ICE4G (Peltier, 1994; 1996)
- Earth model:
  - 1D, spherically symmetric, self gravitating, linear Maxwell viscoelastic rheology
  - VM2 viscosity profile
  - Lithosphere – 120km

Inferred from Peltier (2001)
A “Revised” GIA Model for the British Isles: GIA2

- **Ice model:**
  - Global Background model (Basset et al., 2005)
  - Regional Model (Shennan et al., 2002)
  - Terrain correction
  - Rapid glaciation begin at 34k yr BP with no isostatic equilibrium at Last Glacial Maximum

- **Earth model:**
  - 1D, spherically symmetric, self gravitating, linear Maxwell viscoelastic rheology
  - Lower mantle - 4*10^22 Pa s - (Basset et al., 2005)
  - Upper mantle - 5*10^20 Pa s - (Peltier et al., 2002)
  - Lithosphere – 71km (10^43 Pa s) – (Shennan et al., 2006)
VLM Estimates for Selected TG Stations

Uncertainties are 1-σ
MSL trends vs. Negative Emergence/Submergence Rate

GEOL

AGCGPS1

GIA1

AGCGPS2

GIA2
TG Selections for Tests

- We investigate several subsets and the complete selection of TG and estimate an average change in sea level around the UK for these.
- The selection is mainly restricted by the number of CGPS stations close to or at the TG.
  - Not all TG in the PSMSL RLR data base can be used for which geological evidence was used in previous studies.
- We can separate four sets:
  - Set 1: TG with long records and adjacent CGPS@TG station.
  - Set 2: TG with adjacent CGPS@TG station.
  - Set 3: TG with no CGPS@TG station, but with nearby non-TG CGPS station.
  - Set 4: TG with adjacent CGPS@TG and TG with nearby non-TG CGPS stations (combination of the above).
- A special case for the geodetic evidence from AG and CGPS only:
  - TG with long records and adjacent CGPS@TG station but using the AG-aligned CGPS estimate of vertical station velocity from a nearby CGPS station.
Estimated Average Changes in Sea Level around the UK for different VLM Data Sets and TG Selections
Estimated Average Changes in Sea Level (2)

- Estimates based on geological and geodetic evidence agree well

<table>
<thead>
<tr>
<th></th>
<th>GEOL</th>
<th>AGCGPS1</th>
<th>AGCGPS2</th>
<th>GIA1</th>
<th>GIA2</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set1</td>
<td>1.31</td>
<td>1.33</td>
<td>1.73</td>
<td>1.93</td>
<td>0.90</td>
<td>1.44</td>
<td>0.40</td>
</tr>
<tr>
<td>Set2</td>
<td>1.35</td>
<td>1.29</td>
<td>1.49</td>
<td>1.93</td>
<td>0.90</td>
<td>1.39</td>
<td>0.37</td>
</tr>
<tr>
<td>Set3</td>
<td>1.25</td>
<td>1.18</td>
<td>1.14</td>
<td>1.32</td>
<td>0.64</td>
<td>1.11</td>
<td>0.27</td>
</tr>
<tr>
<td>Set4</td>
<td>1.31</td>
<td>1.24</td>
<td>1.34</td>
<td>1.77</td>
<td>0.84</td>
<td>1.30</td>
<td>0.33</td>
</tr>
<tr>
<td>Mean</td>
<td>1.31</td>
<td>1.26</td>
<td>1.43</td>
<td>1.74</td>
<td>0.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>0.04</td>
<td>0.06</td>
<td>0.25</td>
<td>0.29</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Effect of Using “nearby” Geodetic Evidence for Correcting TG records for VLM

- AG-aligned CGPS estimates of VLM for CGPS@TG stations in North Shields, Sheerness, Newlyn and Liverpool are replaced by the estimates for CGPS stations in Newcastle, Barking, Camborne and Daresbury

<table>
<thead>
<tr>
<th>CGPS@TG Station</th>
<th>Replacement CGPS Station</th>
<th>AGCGPS1 dV [mm/yr]</th>
<th>AGCGPS2 dV [mm/yr]</th>
<th>Distance [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Shields</td>
<td>Newcastle</td>
<td>-0.72</td>
<td>-0.63</td>
<td>12</td>
</tr>
<tr>
<td>Sheerness</td>
<td>Barking</td>
<td>0.65</td>
<td>0.43</td>
<td>45</td>
</tr>
<tr>
<td>Newlyn</td>
<td>Camborne</td>
<td>0.07</td>
<td>0.90</td>
<td>20</td>
</tr>
<tr>
<td>Liverpool*</td>
<td>Daresbury</td>
<td>0.10</td>
<td>0.60</td>
<td>28</td>
</tr>
</tbody>
</table>
Conclusions

- We have presented
  - Recent MSL trend estimates for UK tide gauges in the PSMSL RLR data base
  - Updated and recent estimates for VLM from geological and geodetic evidence
  - Predictions of VLM from a global and a “revised” (for the British Isles) GIA model
- We show that the estimate for an average change in sea level around the UK seems to be
  - Unaffected by the TG selection when using VLM estimates from geological evidence
  - Largely unaffected by the TG selection when using VLM estimates from geodetic evidence
  - Affected by the TG selection when using VLM predictions from a global GIA model
  - Less affected by the TG selection when using VLM predictions from a revised GIA model specific for the British Isles
- We show that the estimate for an average change in sea level around the UK seems to be dependent on the VLM data set used to correct the TG records:
  - 1.26 to 1.43 mm/yr (VLM estimates from geological and geodetic evidence)
  - 1.7 ± 0.3 mm/yr (VLM predictions from the global GIA model)
  - 0.8 ± 0.1 mm/yr (VLM predictions from the revised GIA model specific to the British Isles)
- Our results for testing the effect of using VLM estimates from CGPS station within 45km of a tide gauge are inconclusive, but suggest an effect of <0.5mm/yr on the estimated average change in sea level around the UK
  - This is inline with the findings of Snay et al. (2007)
Thank you!

Tomorrow: EGU2008-A-07948; Poster Area: Halls X/Y
Teferle, F. N.; Bingley, R. M.; Williams, S. D.
Geodetic Monitoring of UK Tide Gauges in the Permanent Service for Mean Sea Level Revised Local Reference Data Base
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