Water Level Measurement and Tidal Datum Transfer Using High Rate GPS Buoys

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Introduction

Importance of Tidal Datums:
• Reference for navigation charts (CD) and
• Height datums (MSL)
• Coastal cadastral boundaries (MHWS and MHW)

Research Problem:
• Traditional tidal datum methods/equipment have limitations:
  - Accuracy
  - Efficiency
  - Cost
• Two general methods:
  1. Levelling – Terrestrial/GPS
  2. Tidal Datum Transfer Procedures
• GPS buoy technology offers unproven potential
Water Level Measurement and Tidal Datum Transfer Using High Rate GPS Buoys

Previous Research
- Ability to measure water levels <1 cm proven
- But – little previous research investigating the viability of using light weight GPS buoys to transfer tidal datums

Research Objectives
- **Primary:** To verify the ability of a high rate GPS buoy to measure sea levels compared to a tide gauge
  - To determine the precision of the GPS buoy measurements relative to the tide gauge
  - To determine the accuracy able to be achieved by examining the bias between these two systems
- **Secondary:** To demonstrate the accuracy that a tidal datum can be transferred using the sea levels estimated from GPS buoys.

Introduction
- **Location**
  - Existing tide gauges
  - ≈ 11km apart
- **Tangible Benefits:**
  - Easy data collection
  - Coastal cadastral boundaries
    - Increasing pressure on coastal development
    - Rising sea levels
  - Efficient tidal datum transfer

![Map showing locations of Dunedin Wharf and Port Chalmers]
GPS Buoy Designs

• 3 common types:
  1. Lightweight wave rider
     • Antenna only
     • Tethered
  2. Autonomous lightweight wave rider
     – Houses receiver, antenna, battery
  3. Autonomous, large scale
     – E.g. Tsunami monitoring

GPS Buoy Construction

• Considerations
  – Water proof
  – Antenna height above water
  – Tethering
Water Level Measurement and Tidal Datum Transfer Using High Rate GPS Buoys

Antenna Height Offset
- Tank filled with fresh water
- Spirit levelling with lightweight measuring rod
- Measurement between
  - Top of Antenna + Water Level BM
  - Repeat measurement before and after deployments
- Result: 0.264 ± 0.002 m

GPS Buoy Deployments
- Simultaneous locations
  - Port Chalmers + Dunedin Wharf
  - Existing tide gauges
  - ≈ 11km apart
- Observation Parameters:
  - Sampling Frequency
    - 5 second epochs
  - Period – approx 4 days
  - Weather – Extremes
- GPS Processing
  - Outlier Removal
Water Level Measurement and Tidal Datum Transfer Using High Rate GPS Buoys

Port of Dunedin

GPS Buoy

GPS Reference Station

Tide Gauge Stilling Well

Port Chalmers

GPS Buoy Location

GPS Reference Station

Tide Gauge Stilling Well

Tide Board

General Direction of Cross-Channel Gradient

Water Level Measurement and Tidal Datum Transfer Using High Rate GPS Buoys
GPS Buoy Sea Surface Heights

- Unfiltered time series
Data Analysis

Verification of the GPS buoy sea surface heights

- Clean Data
- Filtering 10 minute filter length
-\[ \text{Difference} \ TG - \text{GPS Buoy} = TG_{\text{SSH}} - GPS_{\text{Buoy}} \]

Results:
- Height Precision
- Bias

Tide Gauge – GPS Buoy Comparison

<table>
<thead>
<tr>
<th>Date/Time (NZST)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25/05/2007</td>
<td>0.00</td>
</tr>
<tr>
<td>25/05/2007</td>
<td>1.00</td>
</tr>
<tr>
<td>26/05/2007</td>
<td>2.00</td>
</tr>
<tr>
<td>27/05/2007</td>
<td>3.00</td>
</tr>
<tr>
<td>28/05/2007</td>
<td>4.00</td>
</tr>
<tr>
<td>29/05/2007</td>
<td>5.00</td>
</tr>
<tr>
<td>30/05/2007</td>
<td>6.00</td>
</tr>
</tbody>
</table>

Residuals (m)

(TG-estimated SSH (10min) relative to CD)
GPS Buoy – Tide Gauge Precision

<table>
<thead>
<tr>
<th>Deployment</th>
<th>Sampling Rate</th>
<th>Observation Period</th>
<th>$\text{rms } 1 \sigma$ (mm)</th>
<th>$\text{rms } 95%$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunedin Wharf 1</td>
<td>1 sec</td>
<td>~ 24 hours</td>
<td>±17</td>
<td>±33</td>
</tr>
<tr>
<td>Dunedin Wharf 2</td>
<td>5 sec</td>
<td>~ 4 days</td>
<td>±23</td>
<td>±43</td>
</tr>
<tr>
<td>Port Chalmers 2</td>
<td>5 sec</td>
<td>~ 3.75 days</td>
<td>±24</td>
<td>±47</td>
</tr>
</tbody>
</table>

- **Measurement precision:** ~ ±2 cm level
- **Comparison to Previous Research:**
  - ~ ±1 cm higher
  - Reason unknown, but could be due to a rough sea state

Geodetic to Chart Datum Offsets

<table>
<thead>
<tr>
<th>Sampling rate:</th>
<th>Dunedin Wharf 1</th>
<th>Dunedin Wharf 2</th>
<th>Port Chalmers 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1 sec)</td>
<td>4.322</td>
<td>4.322</td>
<td>4.450</td>
</tr>
<tr>
<td>(5 sec)</td>
<td>4.309</td>
<td>4.319</td>
<td>4.443</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chart datum to ellipsoid offset</th>
<th>Known Datum Offsets (m)</th>
<th>Measured Datum Offsets (m)</th>
<th>Difference (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denoted</td>
<td>4.322</td>
<td>4.309</td>
<td>+0.013</td>
</tr>
<tr>
<td></td>
<td>4.322</td>
<td>4.319</td>
<td>+0.003</td>
</tr>
<tr>
<td></td>
<td>4.450</td>
<td>4.443</td>
<td>+0.007</td>
</tr>
</tbody>
</table>
Data Analysis

Tidal Datum Transfer

- Range Ratio Method used
  - “Ratio between the known, long-term tidal range and the observed tidal range is the same at both the control and subordinate stations”

- High/Low point determination:
  - Polynomial curves fitted to unfiltered GPS heights
  - Observation Period: 3 days

\[
\text{Ratio: } \frac{\text{MHWS}}{\text{ml}} = \frac{\text{MR}}{\text{mr}}
\]

MHWS datum

- **Comparison of the MHWS datum transferred to nearby BM**

<table>
<thead>
<tr>
<th>Control to Subordinate Stations</th>
<th>Dunedin to Port Chalmers</th>
<th>Port Chalmers to Dunedin</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHWS datum transferred (m above CD)</td>
<td>2.153</td>
<td>2.170</td>
</tr>
<tr>
<td>Long-term MHWS datum (m above CD) (LINZ, 2007)</td>
<td>2.144</td>
<td>2.184</td>
</tr>
<tr>
<td><strong>Difference:</strong></td>
<td><strong>-0.009</strong></td>
<td><strong>+0.006</strong></td>
</tr>
</tbody>
</table>

- Comparison to datum transfer study using these tide gauges:
  - Mean difference: 10 ± 21 mm
  - Similar level of accuracy
Implication of Results

• Use in Determining Coastal Cadastral Boundaries
  – Particular estuarine areas with high value land

• Perceived Advantages:
  – **Efficient datum connections** between the GPS buoy and benchmark
    • Eliminates the need for levelling to the tide gauge/staff
  – **Efficiency and time saved in data collection**
    • No manual observations required.
  – **Existing GPS equipment** as owned by a typical surveying firm can be used in combination with **cheap readily available materials** for buoy construction.
  – **Potential for increased accuracy** in the datum transferred because of higher frequency observations
    • (maximised by deploying a GPS buoy at both control and subordinate locations)

Conclusion

Objectives

• **Primary**: Verification of a high rate GPS buoy to measure sea levels
  – Precision: ± 2 cm level
  – Bias: < 1 cm

• **Secondary**: Demonstration of tidal datum accuracy
  • Residuals: @ 1cm level

Overall Conclusion

• Only one factor in the tidal datum transfer process BUT:
  GPS buoys can be used successfully to transfer tidal datums and provide a good estimate of the datum relative to a control tide gauge site
Thanks