GNSS Technology for the Determination of Real-Time Tidal Information
Tides are very long-period waves that move through the oceans in response to forces exerted by the moon and sun.

- Gravitational forces of the moon and sun create areas of high and low water on the earth’s surface.
- As the earth rotates, the location of high and low tide changes.
- The moon has the greatest effect on the water compared with the sun due to its proximity to the earth.
Onshore Tide Gauge Instrumentation

- Tide poles or tide staffs
- Mechanical Float and Stilling Well gauges (self-recording)
- Pressure gauges (bubbler gauges)
- Acoustic gauges
- Radar gauges
Offshore Tide Gauge Instrumentation

• Pressure sensor (not requiring a fixed datum)
  – Easiest use offshore
  – Robustness and validity of measured tide
  – Any acquisition problems only highlighted after recovery
  – High risk of loss of the instrument

• Tide gauges used indirectly through tidal predictions
  – Can’t account for local environment (surge, atmosphere)

• Tidal prediction software (e.g. POLPRED)
  – Can’t account for local environment (surge, atmosphere)
  – Only access regional portions of predicted tides per license
  – Easy to operate
Vertical Levels

- **HAT/LAT** – the highest and lowest levels respectively which can be predicted under average meteorological conditions.
- **MHWS/MLWS** – the average of the height of two successive high waters during those periods of 24 hrs (approx. once per fortnight).
- **MSL** – the average level of the sea surface over a long period, normally 19 years.
- **CD** – often defined as by the LAT observed over a certain time period. A common outcome from a survey is a chart showing depth of water below Chart Datum. The chart seeks to express the minimum depth of water available to the mariner for the purposes of navigation.
Conventional Bathymetric Processing

- Tidal correction must be applied to reduce the soundings to CD
- Coastal tide gauge and co-tidal charts
  - Co-tidal chart to correct the observed coastal tide variations for change in phase and amplitude of tide between the station and the survey vessel
- Drawbacks
  - Synchronised operations
  - Latency (two observation sets married together)
  - Accuracy (co-tidal charts have a limited resolution, paper product)
  - Inconsistency (survey practices using CD are poorly defined)
• Using satellites, we can measure sea level over almost the entire ocean
• Two kinds of measurement are needed to determine sea level
  – Position of sea surface (radar altimetry using two way travel time and precise tracking of the satellite)
  – Accurate measurements of the Earth’s gravity field or height associated with Gravity to find the position of a level surface known as the geoid
• Relationship between local vertical levels (CD, LAT or MSL) and the ellipsoid (GNSS)
• Two kinds of surface models can be used worldwide
  – **Geoid** – equipotential surface of the Earth’s gravity field tending to coincide with MSL. Coincidence is exact if the oceans and the atmosphere were in a complete state of equilibrium
  – **MSS** – derived from altimetry, the height of the free surface of the oceans. Average level of ellipsoid corresponding to observation period of the model.
    • Altimetry values only valid a respectable distance from the coast ~10km
    • Integrate Geoid models into the calculations
    • Affected by currents, wind and atmosphere – Dynamic Ocean Topography (DOT)
    • DOT mathematically corresponds to the difference between the Geoid and the MSS
    • Globally, changes in DOT are generally between -2 m and +2 m
Offshore reference frames represented as a continuous surface relative to ETRF89 (GRS80)

- Use GNSS to precisely determine ellipsoidal height of each tide gauge
- Tide gauge observations used to derive ellipsoidal height of MSL at tide gauge
- Satellite altimetry measures MSL of open oceans from space >> ellipsoidal height of MSL at tide gauge AND in open oceans now known
- Geoid to derive DOT (MSL – Geoid) >> use DOT to interpolate between open ocean and tide gauge >> gives continuous MSL surface
- Use tidal modelling to derive other surfaces
- 17 times denser than either the MSS or EGM08 surfaces
Survey vessel equipped with GNSS delivers ellipsoidal height at an accuracy \( \sim 10\text{cm} \) (1\( \sigma \)).

GNSS enables calculation of the ellipsoidal height of the echo sounder \( h_\varepsilon \) (assuming corrections for offsets and attitude).

Lat/Long used to query VORF/MSS to give CD/LAT......

\[
\Delta \text{tide} = h_\varepsilon - h_{\text{VORF MSL}}
\]

Gains:
- No reliance on tide gauges
- Consistency (all contractors using same reduction methods)
- QC (error budget controlled by GNSS and bathymetry – both user based)
- Speed (data available on board the ship)
Relating Antenna Height to Sea Surface
• Correctors for GLONASS constellation (C2)
• Improved GNSS PPP algorithms (iCORE)
• GPS & GLONASS improved convergence time
C-Nav C2 vertical accuracy is significantly more precise than the legacy C1 (GPS only service).

- Upgrade included implementation of proprietary network of C-Nav3050 equipped reference stations
  - Improved modelling using homogeneous network of receivers
- New PPP algorithms
- 10.3 cm ± 2.4 cm (2σ)

### Station CRCS Singapore

<table>
<thead>
<tr>
<th></th>
<th>Latitude</th>
<th>Longitude</th>
<th>Height</th>
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</thead>
<tbody>
<tr>
<td>Observed</td>
<td>1.33090942</td>
<td>103.951987105</td>
<td>51.601</td>
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### Station CRCS Kalvåg

<table>
<thead>
<tr>
<th></th>
<th>Latitude</th>
<th>Longitude</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>61.767820250</td>
<td>4.879132750</td>
<td>62.873</td>
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### Horizontal Statistics (meters)

<table>
<thead>
<tr>
<th>Station: CRCS Singapore</th>
<th>Vertical Statistics (meters)</th>
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</thead>
<tbody>
<tr>
<td>Minimum deviation: 0.000</td>
<td>Minimum deviation: -0.285</td>
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<tr>
<td>Maximum deviation: 0.087</td>
<td>Maximum deviation: 0.185</td>
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<tr>
<td>2dRMS: 0.051</td>
<td>2σ: 0.101</td>
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<tr>
<td>Mean: 0.026</td>
<td>Mean: 0.004</td>
</tr>
<tr>
<td>Standard Deviation: 0.026</td>
<td>Standard Deviation: 0.056</td>
</tr>
</tbody>
</table>

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</thead>
<tbody>
<tr>
<td>Minimum deviation: 0.000</td>
<td>Minimum deviation: -0.138</td>
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<tr>
<td>Maximum deviation: 0.112</td>
<td>Maximum deviation: 0.182</td>
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<tr>
<td>2dRMS: 0.065</td>
<td>2σ: 0.094</td>
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<tr>
<td>Mean: 0.032</td>
<td>Mean: 0.025</td>
</tr>
<tr>
<td>Standard Deviation: 0.033</td>
<td>Standard Deviation: 0.042</td>
</tr>
</tbody>
</table>
Stream and process C-Nav3050 PVT1B data

Instantaneous Tide relative to MSS (Global), VORF MSL (UK), or EGM08

Real-time tide output not dependent on 39-hour time delayed estimate

Real-time attitude input

Allows for tidal reduction (antenna offsets, draft changes) at any point in operation

Output formats: time series plots, RS232 streams, ASCII log files, or difference contours
Real Time Bathymetry Reduction using C-Tides Online

Data from C-Tides Driver

Height from C-Tides Driver
Real Time Bathymetry Reduction using C-Tides Online

- MBES data reduced using C-Tides
- Cross section across overlapping swath lines
- Stepping ~ 10cm

- MBES data reduced using C-Tides and POLPRED
- Stepping up to 1m

www.cnav.com
C-Tides Offline

- Process C-Nav3050 recorded binary data or C-Tides Online data
- Processed tide relative to MSS (Global), VORF MSL (UK) or EGM08
- Allows for tidal reduction (antenna offsets, draft and squat)
- Tidal predictions for any Area of Interest in any time period
- Doodson X0 filter derived MSS estimate
- Tidal harmonic analysis using GNSS data to derive tide constituents using UTide
Figure 4
Smoothed in blue, predicted in green, UT in red, X0 in black.

Days of the year 2012

Meters w.r.t MSL