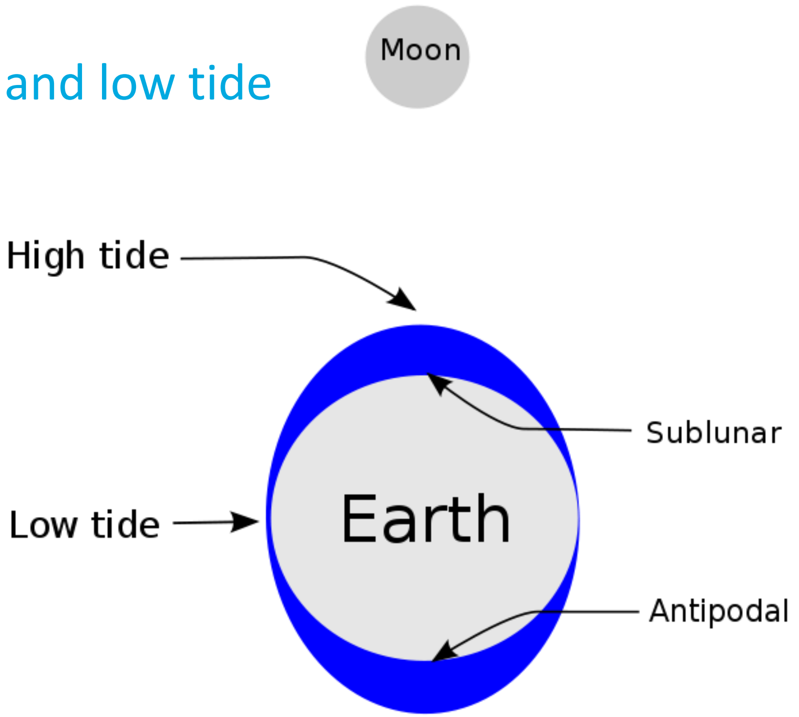
GNSS Technology for the Determination of Real-Time Tidal Information

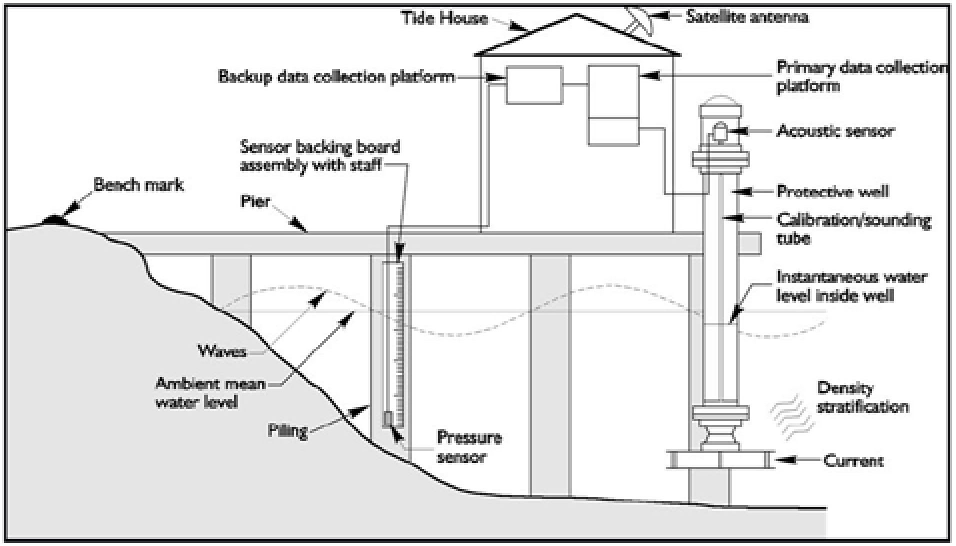
- Tides are very long-period waves that move through the oceans in response to forces exerted by the moon and sun
  - Gravitational forces of the moon and sun create areas of high and low water on the earth's surface
  - As the earth rotates the location of high and low tide changes
  - The moon has the greatest effect on the water compared with the sun due to it's proximity to the earth



C-Nav
POSITIONING SOLUTIONS

Onshore Tide Gauge Instrumentation

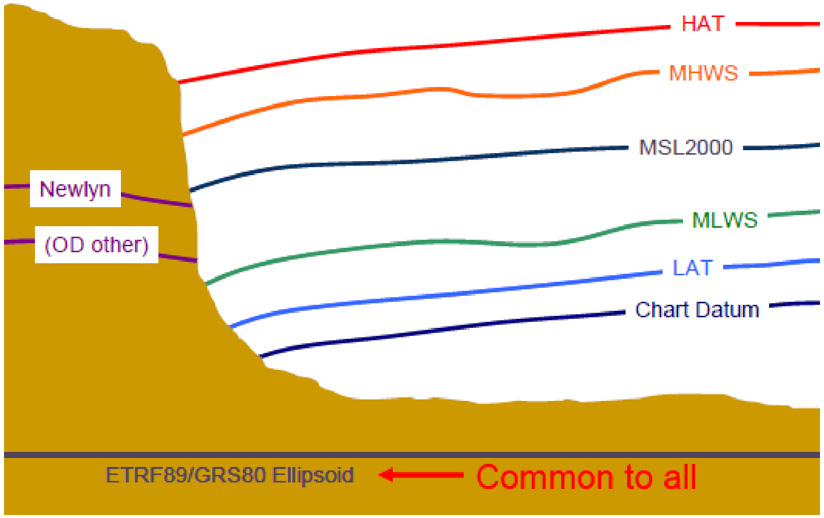
- Tide poles or tide staffs
- Mechanical Float and Stilling Well gauges (self-recording)
- Pressure gauges (bubbler gauges)
- Acoustic gauges
- Radar gauges



Offshore Tide Gauge Instrumentation

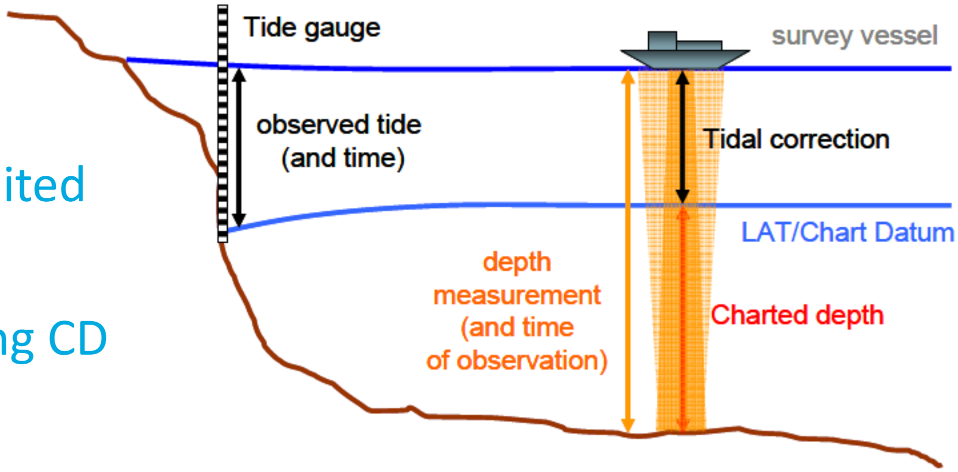
- Pressure sensor (not requiring a fixed datum)
  - Easiest use offshore
  - Robustness and validity of measured tide
  - Any acquisition problems only highlighted after recovery
  - High risk of loss of the instrument
- Tide gauges used indirectly through tidal predictions
  - Can’t account for local 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

- 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)

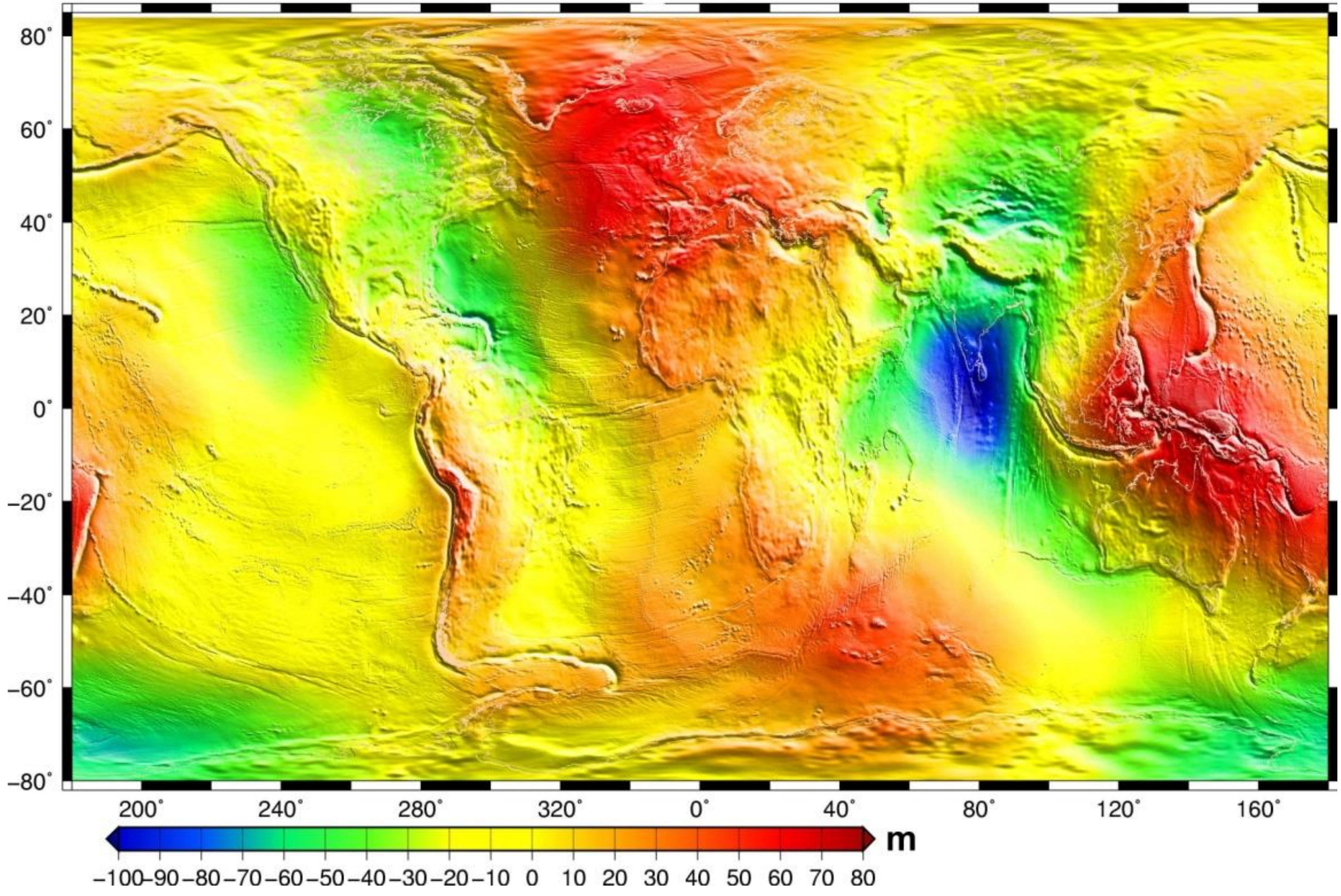


Sea Level from Space

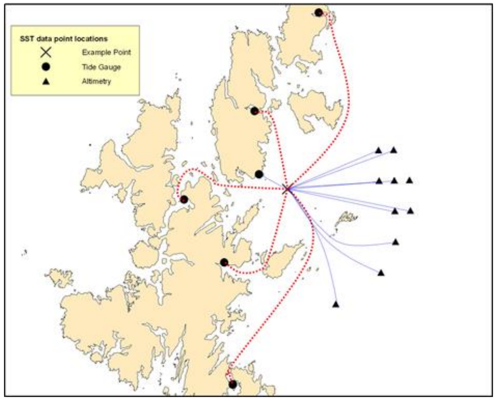
- Using satellites, we can measure sea level over almost the entire ocean
- Two kinds of measurement are needed to determine sea level
  - Position of sea surface (radar altimetry using two way travel time and precise tracking of the satellite)
  - Accurate measurements of the Earth's gravity field or height associated with Gravity to find the position of a level surface known as the geoid

MSS/MSL

- 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 in to 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 +2m


80°
60°
40°
20°
0°
−20°
−40°
−60°
−80°
200°
240°
280°
320°
0°
40°
80°
120°
160°
m
−100 −90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50 60 70 80

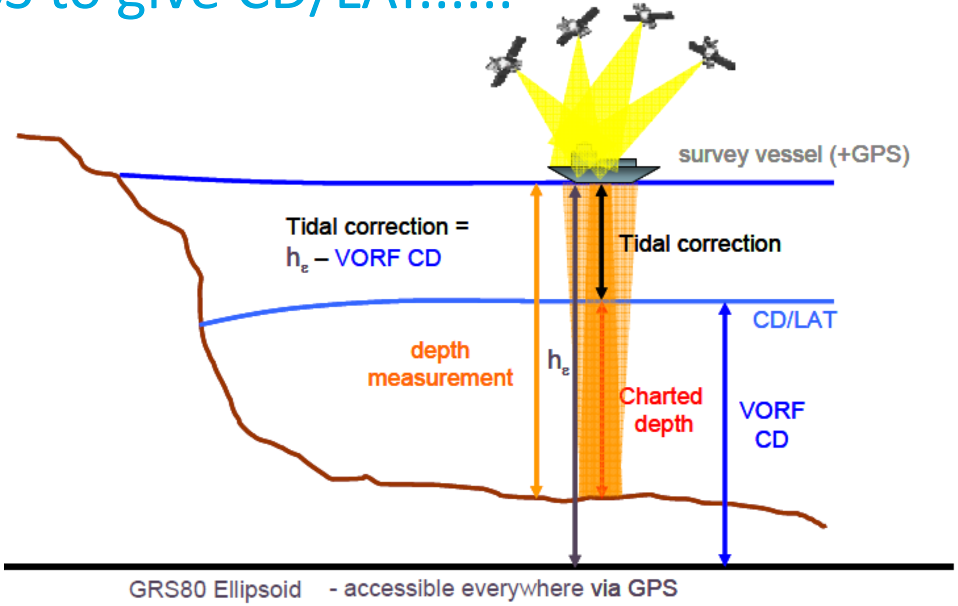
- Offshore reference frames represented as a continuous surface relative to ETRF89 (GRS80)
  - Use GNSS to precisely determine ellipsoidal height of each tide gauge
  - Tide gauge observations used to derive ellipsoidal height of MSL at tide gauge
  - Satellite altimetry measures MSL of open oceans from 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



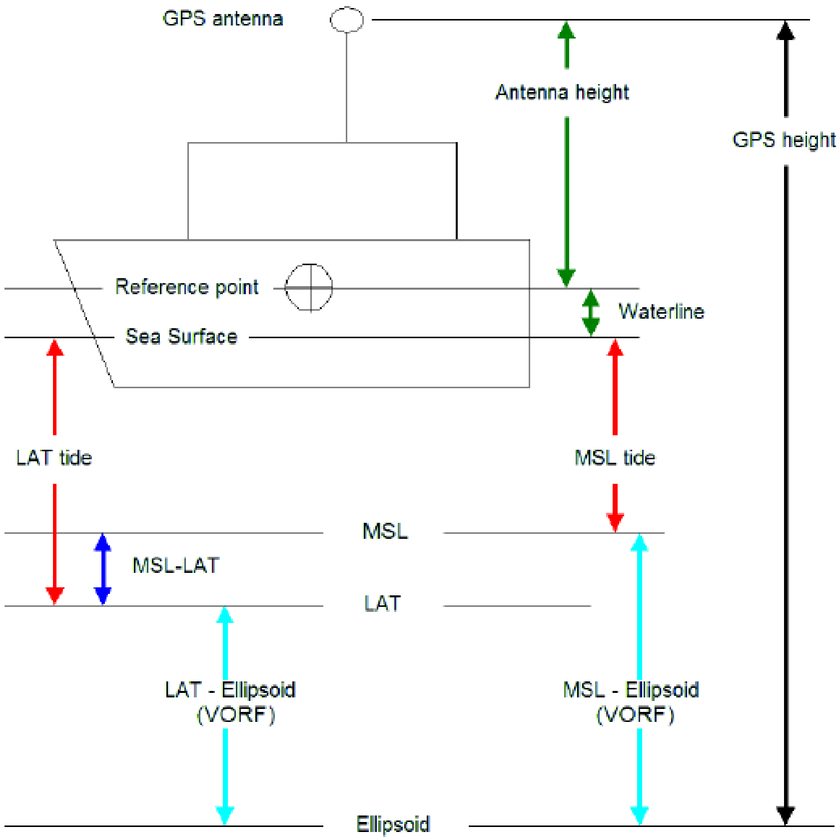
- Survey vessel equipped with GNSS delivers ellipsoidal height at an accuracy ~10cm (1σ)
- GNSS enables calculation of the ellipsoidal height of the echo sounder (h_ε) (assuming corrections for offsets and attitude)
- Lat/Long used to query VORF/MSS to give CD/LAT......

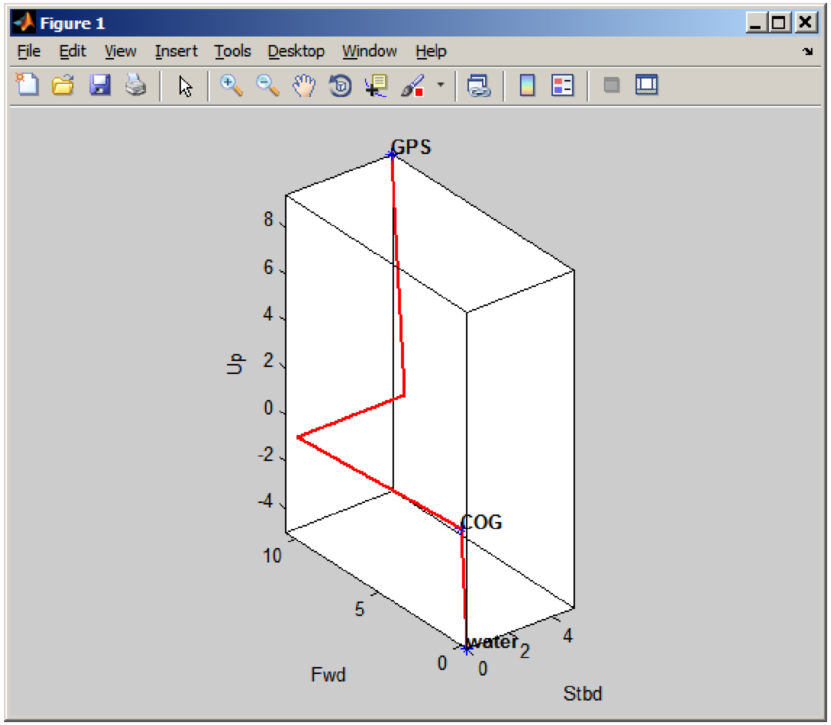
$$\Delta tide = h_\varepsilon - h_{VORF\ MSL}$$

- 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)



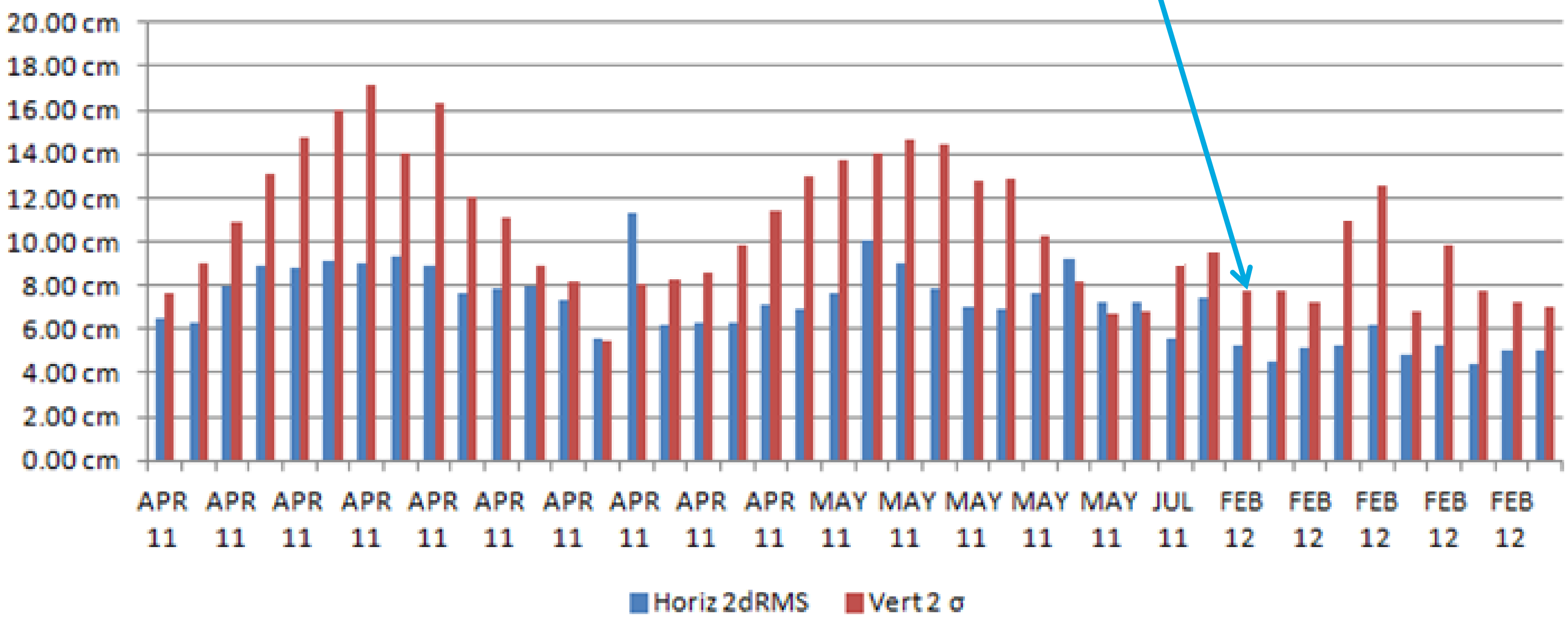
Relating Antenna Height to Sea Surface





Advances in C-Nav PPP

- Correctors for GLONASS constellation (C2)
- Improved GNSS PPP algorithms (*iCORE*)
- GPS & GLONASS improved convergence time



C-Nav C2 Vertical Performance

- 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)

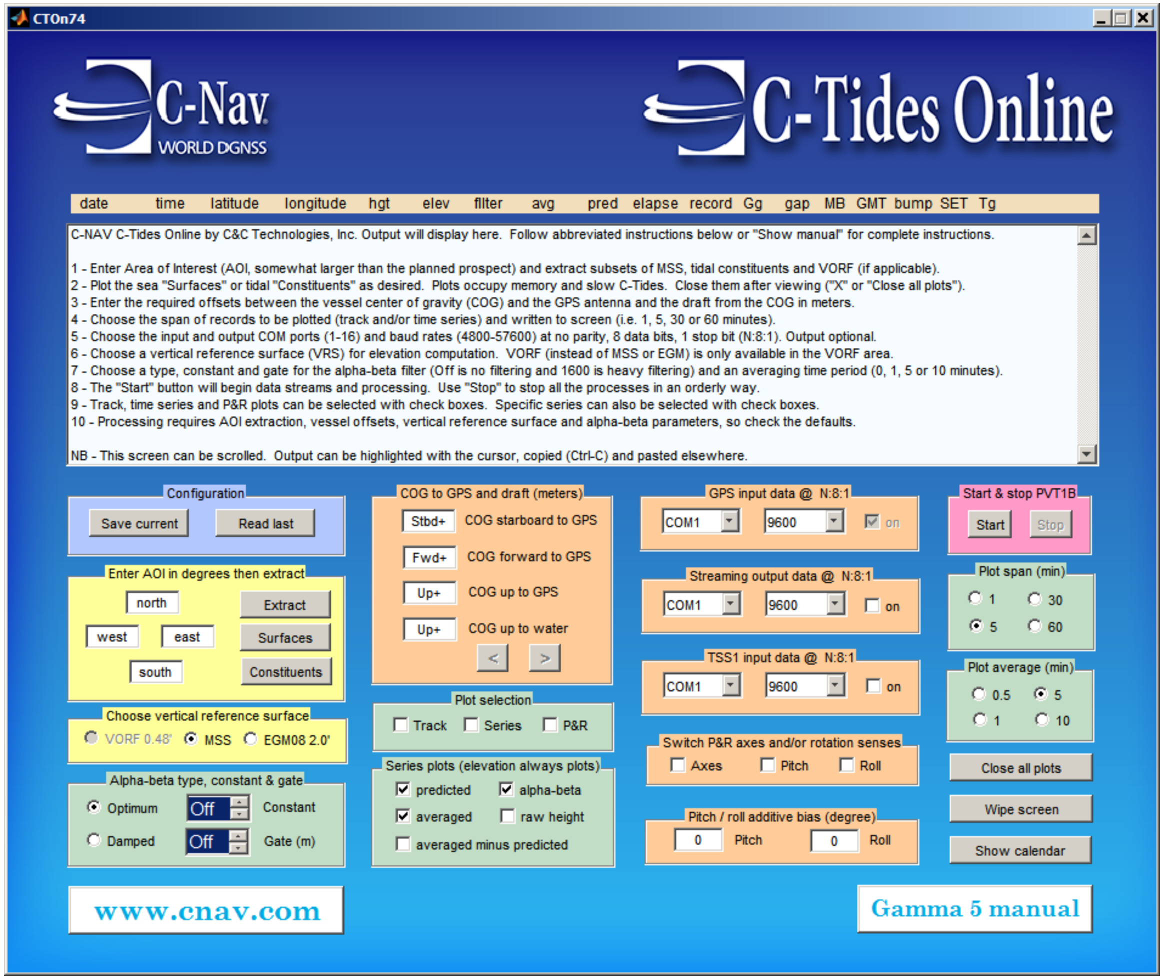
Station: CRCS Singapore	Observed Mean Position
Latitude: 1.330909528 Longitude: 103.951987028 Height: 51.597	Latitude: 1.330909442 Longitude: 103.951987105 Height: 51.601

Horizontal Statistics (meters)	Vertical Statistics (meters)
Minimum deviation: 0.000 Maximum deviation: 0.087 2dRMS: 0.051 Mean: 0.026 Standard Deviation: 0.026	Minimum deviation : -0.265 Maximum deviation : : 0.185 2 σ: 0.101 Mean: 0.004 Standard Deviation: 0.056

Station CRCS Kalvåg	Observed Mean Position
Latitude: 61.767820250 Longitude: 4.879132750 Height: 62.873	Latitude: 61.767820158 Longitude: 4.879132926 Height: 62.898

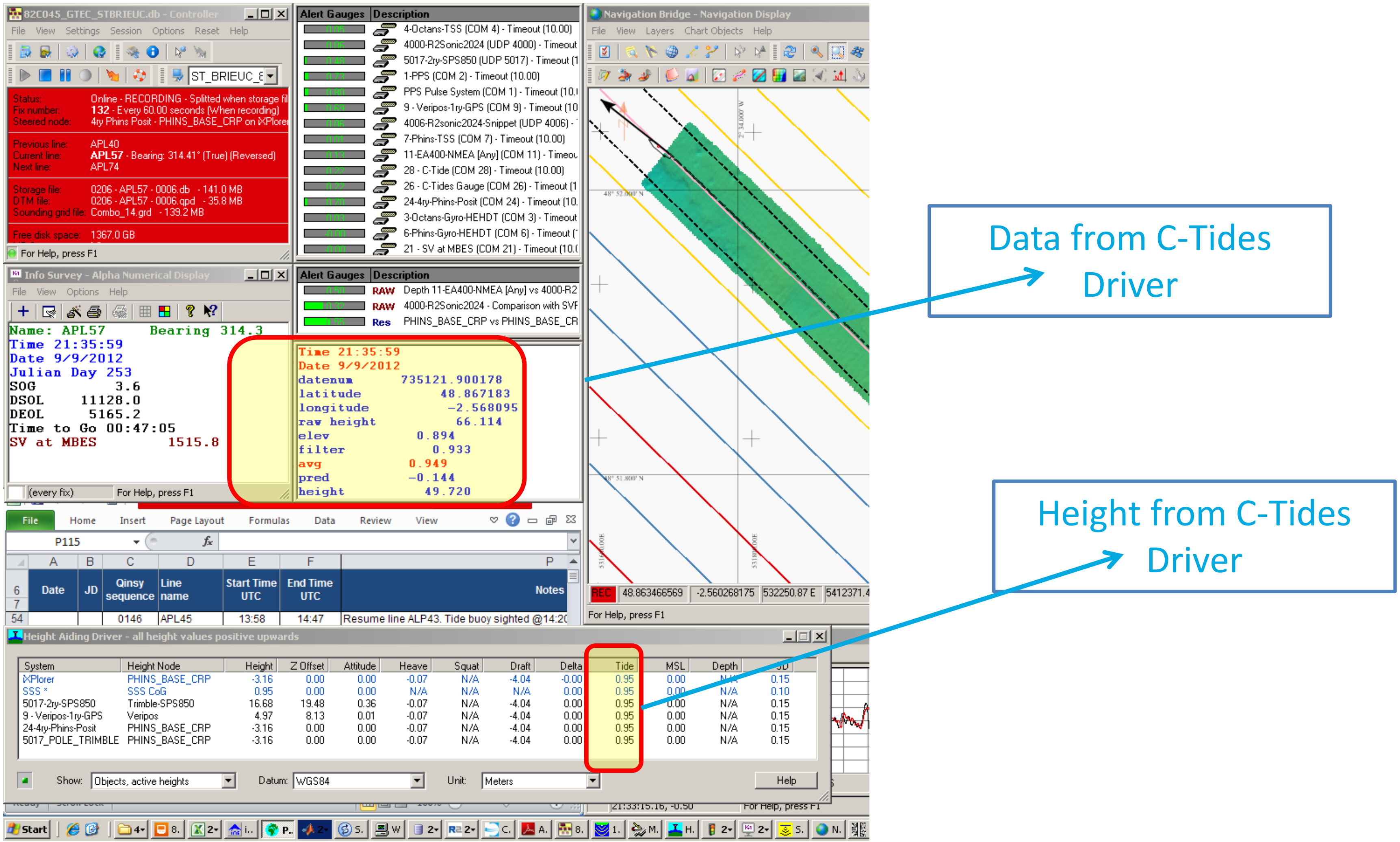
Horizontal Statistics (meters)	Vertical Statistics (meters)
Minimum deviation: 0.000 Maximum deviation: 0.112 2dRMS: 0.065 Mean: 0.032 Standard Deviation: 0.033	Minimum deviation : -0.138 Maximum deviation : 0.182 2σ: 0.094 Mean: 0.025 Standard Deviation: 0.042

C-Tides Online



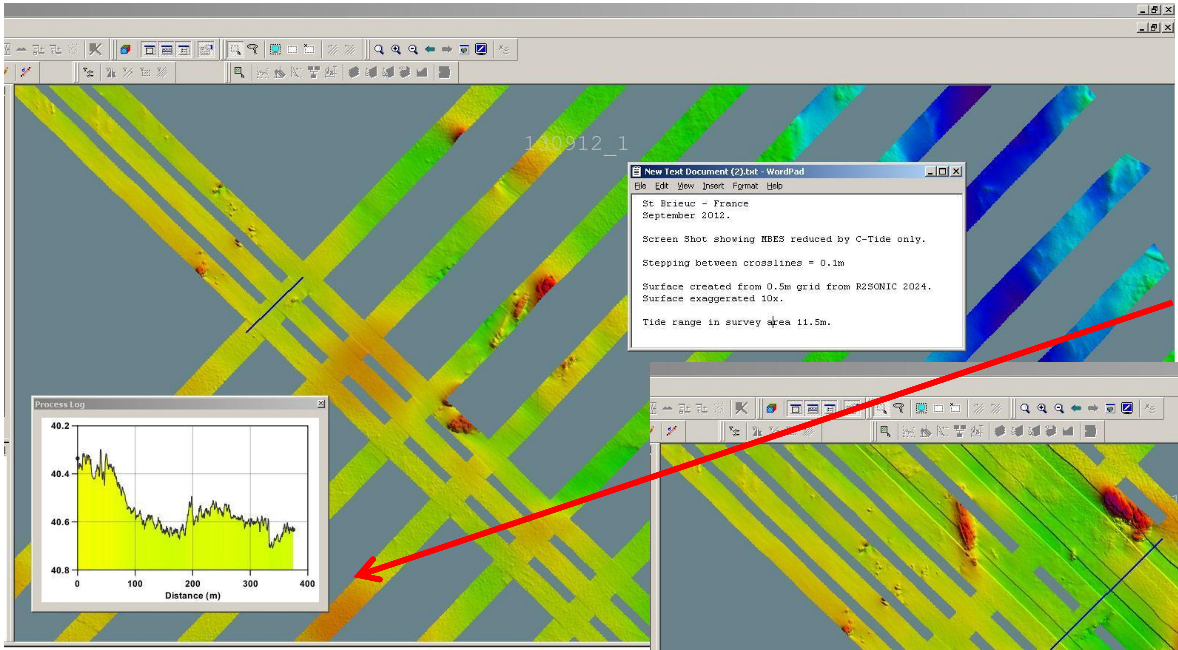
- Stream and process C-Nav3050 PVT1B data
- Instantaneous Tide relative to to MSS (Global), VORF MSL (UK), or EGM08
- Real-time tide output not dependent on 39-hour time delayed estimate
- Real-time attitude input
- Allows for tidal reduction (antenna offsets, draft changes) at any point in operation
- Output formats: time series plots, RS232 streams, ASCII log files, or difference contours

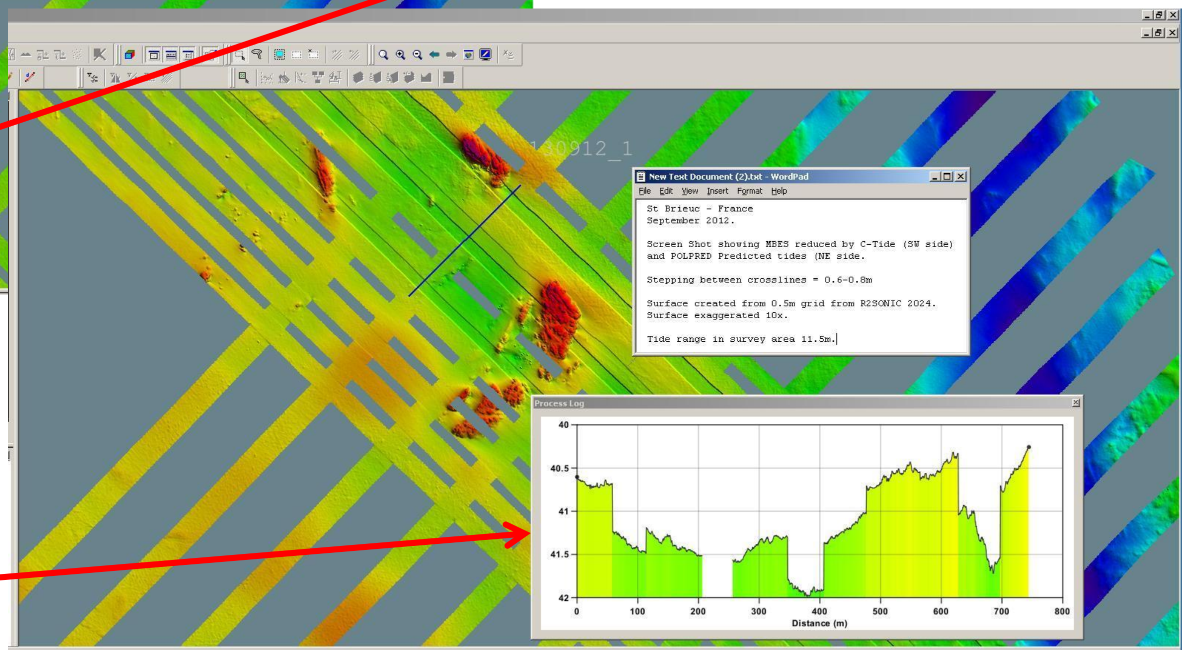
Real Time Bathymetry Reduction using C-Tides Online



Real Time Bathymetry Reduction using C-Tides Online

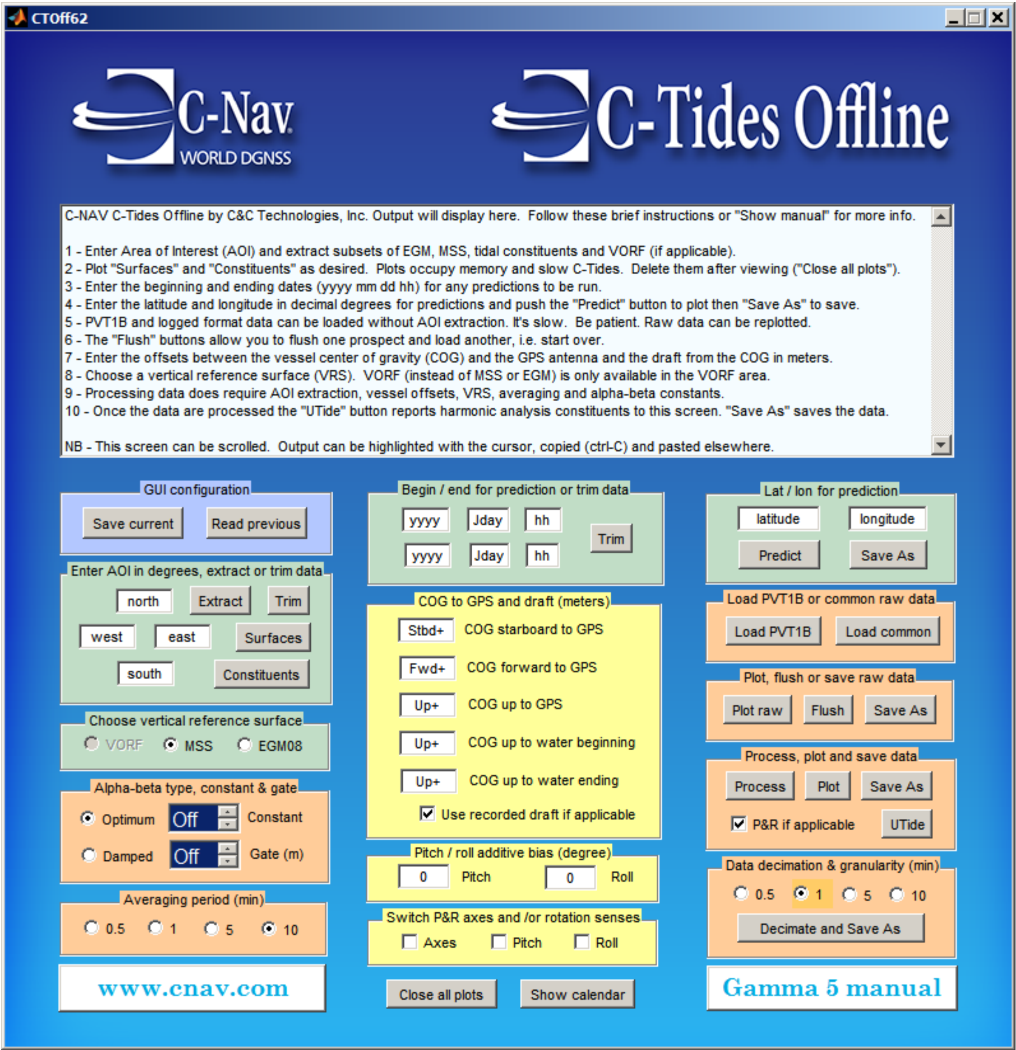
- MBES data reduced using C-Tides
- Cross section across overlapping swath lines
- Stepping ~ 10cm





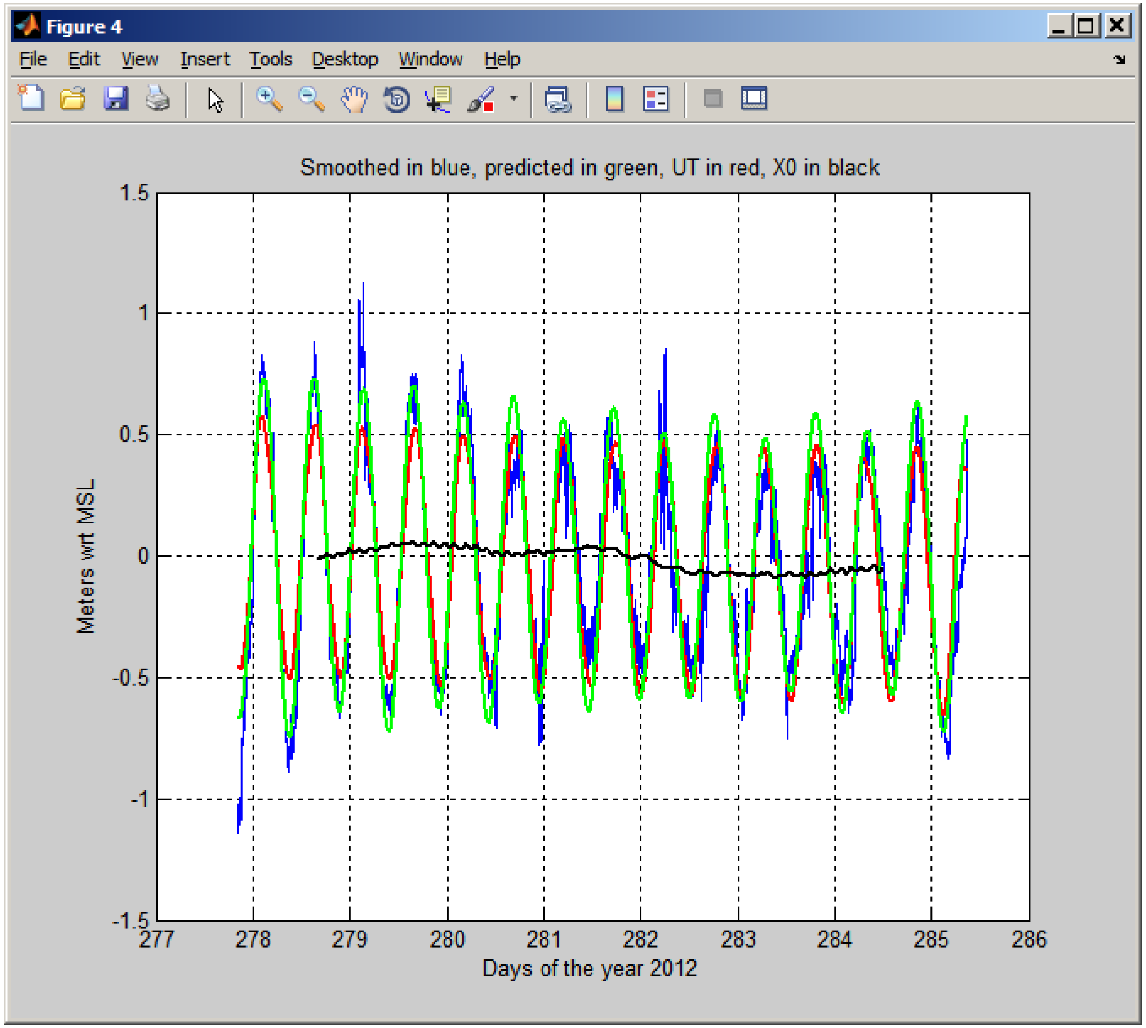
- MBES data reduced using C-Tides and POLPRED
- Stepping up to 1m

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

C-Tides Offline



C-Nav®

POSITIONING SOLUTIONS