OCEANPAL®, A GNSS-REFLECTION COASTAL INSTRUMENT TO MONITOR TIDE AND SEA-STATE

S. Dunne, F. Soulat, M. Caparrini, O. Germain, E. Farrès, X. Barroso+ and G. Ruffini

Starlab Barcelona S.L.
+Universitat Autònoma de Barcelona

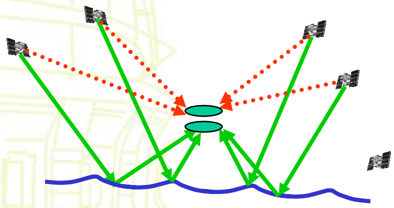
Oceans'05
22nd June 2005, Brest

Contents

- The GNSS-Reflection concept
- Instrument overview
- Applications
  - Coastal altimetry
  - Coastal sea-state
- Conclusions

The GNSS-R concept (1/2)

- GNSS-R: Global Navigation Satellite System – Reflections
- A Bistatic radar technique to monitor a reflective surface, e.g. the sea-surface
- A passive receiver picks up the direct and sea-surface reflected signals emitted by opportunity sources
- Sources are: GPS + Augmentation Systems (now) + GALILEO (future).

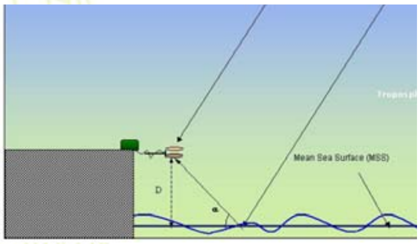


The GNSS-R concept (2/2)

- GNSS-R products
  - Surface Altimetry (SSH)
  - Surface Roughness (ocean wind) and wave height
  - Surface Dielectric Properties (salinity, pollution, soil moisture)
  - Surface Motion (orbital velocity, large scale currents)
- GNSS-R winning themes:
  - Coverage. By 2008, GPS and Galileo plus augmentation system (EGNOS/WAAS) will provide more than 50 sources
  - High quality signals: self-calibrating, dual frequency, long-term availability and stability
  - Inexpensive: dry, passive, off-the-shelf
  - Rain immune (L-band)

Oceanpal, a coastal implementation of GNSS-R

- Altimetry/sea-state
- A dry, cost-effective instrument
- Resolution: few tenth of meters
- Range from the coast: from meters to few hundredth of meters
- Possible deployment:
  - Port
  - Off-shore platforms
  - Cliffs, lighthouse, etc.



System overview

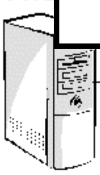
ORFU
Oceanpal
Radio Frequency Un

- A pair of L-band antennas
  - right/left CP
  - 7dB gain
- Mast, LNAs and cabling

OAR
Oceanpal
Antenna Rig

- Stores (temporally) the RAW data
- Data Processing and storage
  - L0 : complex waveforms
  - L1 : field coherence time, direct/reflected lapses
  - L2 : geophysical products (SWH and H)

OWL



- Yuma files. Download from internet, upload to ODMU
- L2 data (XML). Download from ODMU, store to MySQL database
- User remote access to the L2 database

Coastal Altimetry Algorithm (1/2)

- Phase Altimetry possible on calm-water surface (e.g. inside a harbour)
- Use of the interferometric field *I(t),* the ratio of the reflected *R(t)* and the direct *D(t)* signals (eliminates the navigation message and all errors common to both signals)
- Fundamental equation:

$$\Phi_p(t) = 2k\ h(t)\sin\varepsilon_p(t) + \theta(t)$$

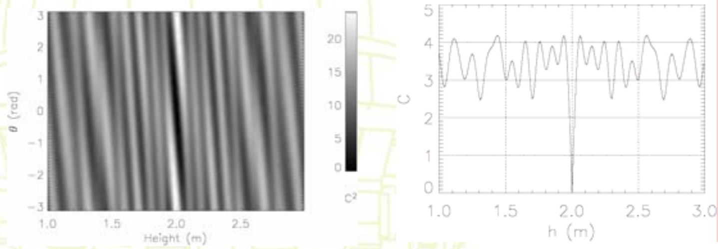
- $\theta(t)$: System bias
- $\varepsilon_p(t)$: Sat elevation
- $h(t)$: Height
- p: Index of PRN
- Φ: Phase of I

Coastal Altimetry Algorithm (2/2)

- System bias assumed constant during the take
- Non-linear cost function:

$$C(h,\theta) = \sum_{p,t}\left|e^{i\tilde{\phi}_p(t)} - e^{i\phi_p(t)}\right|$$

- Difficult to minimize jointly for *h* and *θ* due to *2π phase* wrapping ambiguities (here 6 PRNs from 15 to 78 deg)

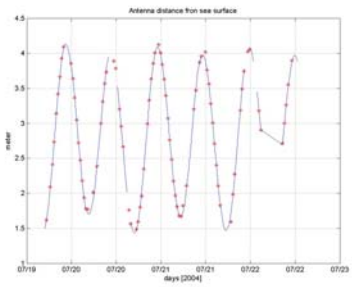


Coastal Altimetry Campaign (1/2)

- Port of Villagarcía (Galicia, Spain) in July 2004
- Three days of measurement
- Collaboration with Puertos del Estado
- Ground truth: Radar tide gauge
- Tide of 2.5 m approx

Coastal Altimetry Campaign (2/2)

- One take of 2 mn every 30 mn
- Optimization initialized by a tide model
- Prior automatic quality check of the data: 25% rejected because affected by multipath
- Error vs. ground truth: 3.1 cm RMS



Coastal Sea-state Algorithm

Interferometric field

Coherence time τ_I

EM model

Sea-surface

Coherence time τ_z

Height std: $SWH = 4.\sigma_z$

Sea-surface model

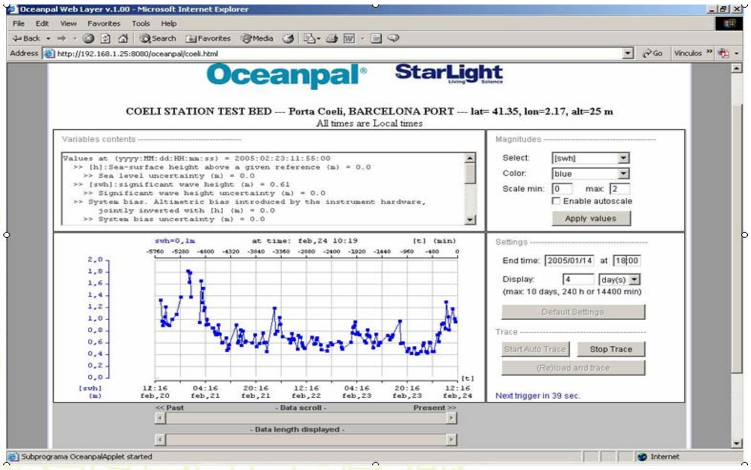
Semi-empirical model
(on-site calibration)

$SWH = f(\tau_I, \ldots)$

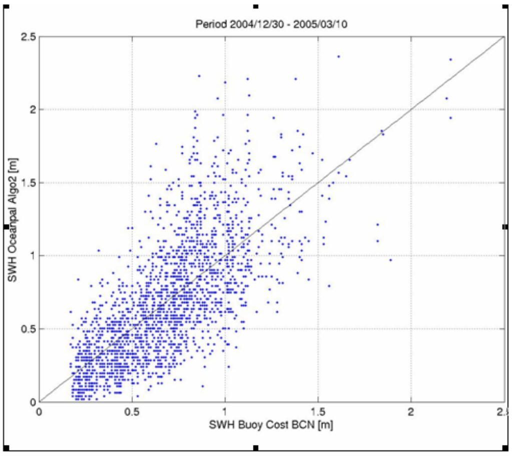
Coastal Sea-State Test Bed (1/3)

- Port of Barcelona
- Three months of measurement
- Collaboration with Barcelona Port Authority, Environmental Monitoring Department
- Ground truth: TRIAXYS buoy, 10 miles from site
  - Served for the calibration phase (linear relationship between SWH and MWP)
- One take of 1 mn every 15 mn

Coastal Sea-State Test Bed (2/3)



Coastal Sea-State Test Bed (3/3)



RMS error: 18 cm

Conclusions & Perspectives

- Oceanpal, a GNSS-R instrument for coastal sea-surface monitoring with two initial applications:
  - tide measurements inside a harbour
  - sea-state in open sea
- Two campaigns have demonstrated precisions of
  - 3 cm for the tide measurements
  - 18 cm for the *SWH* measurements
- Code altimetry (rough-surface) to be implemented soon
- More challenging products: current, salinity

Beyond the coast…

- GNSS-R not only coastal ! Airborne and spaceborne implementations exist as well.
- Visit our website to learn more !!

www.starlab.es

Software overview (ODMU)

- Conductor module
  - manages DAQ
  - launches data processing modules
  - manages communications with OWL to put L2 data and get YUMA files.
- Starlight module
  - Determine visible satellites given visibility mask, YUMA file, and approx time/position
  - Initialize tracking for each visible satellite
  - Track the signal on direct channel, drive the reflected channel
  - Decode the navigation message to get precise SOW (fedback)
  - Packs L0 data to NetCDF and store to disk
  - Processes further to L1 and L2 data, store to disk

Coastal Sea-state Algorithm (2 / 3)

Ref: Soulat *et al.*, *Geophys. Res. Lett.*, Vol. 31, 2004

Autocorrelation of the interferometric field:

$$\Gamma(\Delta t) \approx A(\sigma_z, l_z, \varepsilon, G_r) \cdot e^{-4k^2\sigma_z^2 \frac{\Delta t^2}{2\tau_z^2} \sin^2 \varepsilon}$$

$$\Rightarrow \quad \tau_I = \frac{\tau_z}{2k\sigma_z \sin\varepsilon} = \frac{\lambda}{\pi \sin\varepsilon} \frac{\tau_z}{SWH}$$

To first order, τ_I is inverse-proportional to the surface “effective velocity” σ_z / τ_z

Coastal Sea-state Algorithm (3 / 3)

Further, a linear relationship is assumed between σ_z and τ_z

So that finally:

$$SWH = SWH_0 + \frac{\alpha}{k\tau_I \sin\varepsilon - \beta}$$

Semi-empirical model where the coefficients SWH_0, α, β must be calibrated on site.