GNSS Reflections for Spaceborne Ocean Monitoring

GAMBLE Final Workshop
Arles, 17th November 2003
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- GNSS-R for ocean remote sensing
- A GNSS-R spaceborne altimetric mission
  - User requirements
  - Mission and sensor
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GNSS-R concept

• GNSS-R: **Global Navigation Satellite System - Reflections**
• Bistatic radar for reflective surface monitoring (mainly ocean)
Sensitivity / Potential products

- Surface Topography (SSH)
- Surface Roughness (mainly directional mean-square slope [DMSS], also SWH)
- Surface Dielectric Properties (salinity, pollution, soil moisture)
- Surface Motion (orbital velocity, large scale currents)
- Atmosphere (ionospheric electron content, surface pressure and/or tropospheric WV)
Winning themes

- Coverage, potential time/space resolution. By 2008, GPS and Galileo plus augmentation system (EGNOS/WAAS) will provide more than 50 sources
- Rain immune: L-band
- High quality signals: self-calibrating, dual frequency, long-term availability and stability
- Inexpensive: passive, off-the-shelf technology

... and pains [in altimetry]

- Poor altimetric precision
  - Long pulses (C/A code = 300 m, P code = 30 m)
  - Low SNR from space
- Higher sensitivity to antenna pattern
  - since not so much “pulse-limited”
Niche / Synergies

- Offers co-located altimetric/speculometric measurements over large swath and with high spatio-temporal sampling
  - Science (ocean modelling, climate, AO coupling and fluxes)
  - Operational (mesoscale and coastal altimetry, sea state/winds for ship routing and off-shore mining, pollution monitoring)
- Radar altimeters (Jason, ENVISAT, ...)
  - Mesoscale aspects
  - MSL definition; supporting “tie-up”
- L-band radiometry (SMOS/Aquarius)
  - Data source for L-band sea-roughness in salinity retrieval
A GNSS-R altimetric space mission

- **PETREL**, an Earth Explorer Opportunity Mission submitted in January 2002 did not pass: technical maturity, lack of experimental demonstration mentioned as main causes
- Next target is 2005!
- Work presented here was carried out under ESA study PARIS-Gamma Phase 1 (TRP ETP 137.A). Acknowledgement to partners for their contributions (EADS-Astrium, CLS and Ifremer)
User requirements

- Global coverage with samplings below **100 km and 10 days** offer a clear niche for future missions (as discussed later, they would require up to six RAs, especially for V mapping)
- Mesoscale Altimetric Signals (SHA) are of the order **5-30 cm**
- Long term availability and stability are required
- All weather measurements a plus
- Collocated h and dmss a plus

**Sensor precision requirement:**

100 km, 5 cm $\rightarrow$ $\sim$20 cm after 1 second (@7 km/s)
Altimetric error budget (1/2)

Altimetric precision
\[ \sigma_h = \frac{\sigma_r}{2 \sin \gamma} \]

Ranging precision, mainly depends on the reflected delay precision
Sat elevation (best @ nadir)

Reflected delay precision
\[ \sigma_{dR} \approx 0.22 \frac{\tau_{chip}}{SNR_v} \]

300 m for C/A code

Altimetric precision requirement translates into \( SNR_v \) (gain)
Altimetric error budget (2/2)

Requirement: one-shot SNRv around 5
At 500 km altitude, this translates into a 27 dB antenna gain

NB: This result was obtained in two equivalent manners:
• absolute: building a SNR budget
• relative: scaling the result of [Lowe et al., 2000], the unique reference for spaceborne GPS-R SNR value

<table>
<thead>
<tr>
<th></th>
<th>After 1 shot</th>
<th>After 1 s (7 km)</th>
<th>After 3 s (20 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR voltage</td>
<td>5</td>
<td>170</td>
<td>290</td>
</tr>
<tr>
<td>Reflected delay error</td>
<td>15 m</td>
<td>0.40 m</td>
<td>0.23 m</td>
</tr>
<tr>
<td>Ranging error</td>
<td>16 m</td>
<td>0.43 m</td>
<td>0.25 m</td>
</tr>
<tr>
<td>Altimetric error (Nadir / 45°)</td>
<td>8 / 12 m</td>
<td>0.21 / 0.31 m</td>
<td>0.12 / 0.17 m</td>
</tr>
</tbody>
</table>
Sampling density

GPS
5-day repeat
60° FoV

Courtesy EADS Astrium Ltd
Sampling density

GPS, Galileo and Inmarsat
5-day repeat
60° FoV

Courtesy EADS Astrium Ltd
Sampling density

GPS, Galileo and Inmarsat
5-day repeat
100° FoV

Courtesy EADS Astrium Ltd
Average number of Specular Points

- With 9 Visible: 27.57%
- With 8 Visible: 19.48%
- With 10 Visible: 23.24%
- With 11 Visible: 0.35%
- With 12 Visible: 12.57%
- With 13 Visible: 1.72%
- With 14 Visible: 0.47%
- With 5 Visible: 2.58%
- With 6 Visible: 8.09%
- With 7 Visible: 2.35%
- With 4 Visible: 0.01%
- With 3 Visible: 0.00%
- With 2 Visible: 0.00%
- With 1 Visible: 0.00%

Courtesy EADS Astrium Ltd

GPS, Galileo
90° FoV
Mission & Sensor Baseline

- Orbit:
  - 500 km altitude
  - Sun-synchronous, polar inclination
  - 5-day repeat (trade-off coverage / sampling)

- Antenna:
  - 27 dBi gain
  - 90° to 100° Field Of View
  - 8 to 12 Beams

- Frequencies
  - L1/L2 for ionosphere correction
  - L2/L5 for wide-laning

- Available signals: GPS, Galileo and Inmarsat

- Tropospheric delay: wet delay corrected through on-board radiometer or future NWP (TBD)

- Ionospheric error: exploit coherence scales and dual frequency to estimate and correct it out.
Scientific impact

- **Goal:** quantify the contribution of GNSS-R for the mapping of ocean mesoscale variability using the Los Alamos North Atlantic model.
- Model sea level fields are subsampled to simulate the typical space/time sampling of GNSS-R altimeter systems.
- A realistic measurement noise is added to these simulated measurements.
- Simulated measurements are used to reconstruct the initial model reference fields.
- This is achieved using a space/time objective mapping technique that takes into account the GNSS-R measurement noise characteristics and an a priori information on the space and time scales of ocean signals.
Simulated Sea Level Anomaly
RMS sea level mapping error

Jason-1 + ENVISAT

Jason-1 + ENVISAT + GNSS-R
RMS (Jason-1 + ENVISAT)

RMS (Jason-1 + ENVISAT + GNSS-R)
Conclusions

- User requirements: global coverage, measuring 5 cm signals with 100 km, 10 days sampling
- Sensor requirement: 20-30 cm altimetric precision after 1 second
- 500 km altitude, sun-synchronous, polar inclination, 5-day repeat orbit
- 27dB gain, 100° FOV antenna
- Simulations have shown a very positive scientific impact:
  - GNSS-R + Jason-1 + ENVISAT will improve the sea level mapping compared to Jason-1 + ENVISAT by a factor of 2 to 4
  - GNSS-R should allow a mapping of the mesoscale variability in high eddy variability regions better than Jason-1 + ENVISAT.
  - The dense and high frequency sampling offered by GNSS-R is likely to compensate for the large noise level in large eddy variability regions
Future work

• PARIS-Gamma Phase-2 will yield more airborne data for analysis
• Validate the SNR model from airborne data, and, if necessary, to upgrade it
• Further simulations to ascertain the nature and impact of atmospheric errors on the error budget
• Depending on previous points, a reanalysis of the scientific impact
Thank you for your attention...

More... See the SWT poster on: GNSS-R altimetry airborne experiment