IAG/GGOS Inter-comparison Campaign on SNR-based GNSS Reflectometry for Sea Level Monitoring

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GNSS+R 2017 Workshop
May 23-25, 2017, Ann Arbor, MI USA
Outline

• Part I: IAG/GGOS Working Group

• Part II: SNR-based GNSS-R

• Part III: Inter-comparison campaign

• Part IV: Future work
International Association of Geodesy (IAG) Global Geodetic Observing System (GGOS)

Services: IGS, PSMSL, etc.

Targets:
• Water storage
• Sea level
• Ground deformation
• Atmospheric sounding
IAG/GGOS Working Group 4.3.9

• Created at the end of 2015
• Focus on *geodetic* GNSS-R:
  – Geodetic instrumentation for GNSS-R data collection
    • E.g., existing ground networks, including historical data
  – GNSS-R environ. estimates to aid in geodetic positioning
    • E.g., hydrologic loading (subsidence/uplift)
• Members from 11 countries:
  – BRA CHN FRA DEU JPN LUX ESP SWE CHE GBR USA
• Liaisons with:
  – Permanent Service for Mean Sea Level
  – IEEE Geosciences and Remote Sensing Society
GNSS Multipath Reflectometry

• 1 clean replica for 1+1 paths
• Coherent reflections
  - Low-noise interferometric phase:
  \[ \sigma_{\phi_i}^2 = \sigma_{\phi_d}^2 + \sigma_{\phi_r}^2 - 2\sigma_{\phi_d}\sigma_{\phi_r}\rho_{\phi_d\phi_r} \]
  - Wave superposition:
  \[ P \propto P_d + P_r + 2\sqrt{P_d}\sqrt{P_r}\cos\phi_i \]
• Main observables: SNR
  - Then a.k.a. Interference-Pattern Technique or Interferometric Reflectometry (not iGNSS-R or zero replica)
  - Also feasible: carrier-phase & pseudorange ("MP")
Interferometric phase model

\[ \phi_i = \phi_r - \phi_d = \phi_I + \phi_X + \cdots \]  
(no clocks, iono, etc.)

Surface geometry:

\[ \phi_I = k\tau_i = k_z H \]
\[ \tau_i = 2H \sin e \]
\[ k_z = k \sin e \]
\[ k = 2\pi/\lambda \]

Material composition & Antenna radiation pattern:

\[ \phi_X = \text{arg}(X^R + X^L) \]
\[ X^R = R^S\sqrt{G_r^R} \exp(1\Phi_r^R) \]
\[ X^L = R^X\sqrt{G_r^L} \exp(1\Phi_r^L) \]

Reflector height retrieval:

Unwrapped & ambiguity fixed:  Scaled interferometric Doppler:

\[ H' \approx \frac{\phi_i'}{k_z} \]
\[ H = \frac{\partial \phi_i}{\partial k_z} = \frac{\dot{\phi}_i}{k_z} = \frac{\Delta \omega_i}{k \dot{e} \cos e} \]
Environmental targets

- Multiple targets feasible:
  - Sea level
  - Snow depth
  - Soil moisture

- Chosen target: **sea level**
  - More levelled surface
    - Contrary to snow depth
  - Little dependence on antenna gain/phase pattern
    - Contrary to soil moisture
  - Large phase change
    - Esp. for high antennas
  - Homogenous composition and negligible vertical stratification

- Several independent demonstrations worldwide
Coastal sea level altimetry

- Sea level rising globally with regional variability
- GPS: vertical land motion control near tide gauges
Inter-comparison campaign

- Start: end of 2016
- Goal: to validate state-of-art retrieval algorithms
- Participation: 5 teams (SWE LUX DEU FRA GBR)
- Initial site: Onsala, Sweden (courtesy Chalmers U.)
  - Colocated tide gauge
Input observations

• **Antenna:** Leica AT504 GG
• **Receiver:** Leica GRX1200 GG
• **GNSS period & rate:** 1 yr, 1 Hz
  – **8 GB** in daily RINEX v.2 files
• **GNSS constellations:** GPS & GLONASS
• **SNR signals:**
  – GPS: L1-C/A, L2-P(Y) – no L2-C(SLX)
  – GLONASS L1-C, L2-P
  – Missing (RINEX-v3 only): GPS L1-P(Y), GLO L1-P, L2-C.
• **Tide gauge sampling interval:** 1 min.
Retrieval settings

1) Elevation angle mask (oscillations): 1° - 14.5°
2) Azimuthal mask (land/sea): 70° - 260° clockwise
3) GNSS signals utilized: all 4 and GPS-L1-C/A only.
4) Retrieval sampling interval: 1 min, 20 min, etc.
5) Retrieval smoothing period: none, 6 h, etc.
6) Basic observation group: none, 8° chunks, etc.
7) Multi-signal combination: SNR or reflector height
8) Vertical velocity correction: yes, no (negligible).
9) Tropospheric correction: no.

Next: a couple of representative solutions.
Tide gauge vs. GPS L1-C/A: Sea level time series

Group (a)

Group (b)
Tide gauge vs. GPS L1-C/A: Sea level time series
Tide gauge vs. GPS L1-C/A: Scatterplots

Group (a)

Group (b)
Tide gauge vs. GPS L1-C/A: Error (GPS-minus-TG) time series

Group (a)

Group (b)
Tide gauge vs. GPS L1-C/A: van de Casteele test

Group (a)

Group (b)

(diferente scales)
Summary statistics

Single signal (GPS L1-C/A):

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<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
<td>c</td>
<td></td>
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<tr>
<td>Correlation coeff.</td>
<td>0.99</td>
<td>0.99</td>
<td>0.95</td>
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<tr>
<td>RMSE (m)</td>
<td>0.02</td>
<td>0.03</td>
<td>0.08</td>
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<tr>
<td>Regression slope</td>
<td>1.01</td>
<td>1.00</td>
<td>1.08</td>
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Multi-signal (dual-freq. GPS/GLO)

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<tbody>
<tr>
<td></td>
<td>a</td>
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<td>d</td>
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<td>Correlation coeff.</td>
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<td>RMSE (m)</td>
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<td>Regression slope</td>
<td>1.04</td>
<td>0.98</td>
<td>0.42</td>
<td>0.29</td>
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</tbody>
</table>

* not available; ** to be checked

Conclusions:
- Very high correlation
- Centimeter-level error
- Few-percent slope bias
Ongoing and future work

- Tidal constituents
- Time-frequency analysis
  - Wavelets, coherence
- Systematic effects
  - Regression slope deviating from 1:1
- Submit for publication
- Neglected effects
  - Tropospheric delay
  - EM bias

- Second and third sites:
  - Larger tidal range
  - Greater elevation
    - Separation of antenna above sea surface
- Synthetic SNR observations
  - Using end-to-end simulator
- Adopt RINEX v.3?
  - Non-ambiguous signals:
    - S1: S1C, S1P, S1W, S1Y
    - S2: S2C, S2S, S2L, S2X, S2P, S2W, S2Y
Further tasks of WG 4.3.9

- Additional open data
  - For research reproducibility
  - Three-parts:
    - Input measurements
    - Output retrievals
    - In situ data
- Extend IGS Site Guidelines
  - Make GNSS sites more useful for GNSS-R
- New liaisons:
  - IGS-TIGA: Tide Gauge Benchmark Monitoring Project
  - IOC-GLOSS: Global Sea Level Observing System
- Vision: a combined international GNSS-R data product for coastal sea level altimetry
  - Inspiration: IGS weighted average satellite ephemeris
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