Wind & Waves Analysis of TechDemoSat-1 Observations

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Context

• Consequent GNSS-R database now available with the TechDemoSat-1 mission.

• Assessment of the **scatterometry** capability of spaceborne GNSS-R now possible.

• REGALO study framework:
  ✓ **REflectométrie GNSS pour les AppLications Océaniques**
  ✓ Under R&T CNES program
  ✓ CLS, IFREMER, C-SCIC/IEEC

• Objective: L1 data analysis w.r.t. the sea state. No specific attention on the wind inversion strategy.
Outline

• Power Waveform Analysis

• Case Studies

• Radar Cross Section
TDS-1 DDM Analysis
DDM sensitivity analysis

Objective is to relate the DDM shape features to the local sea state conditions.

Several types of delay waveforms
- Integrated over all Doppler bands (“LRM” WF)
- Zero-Doppler waveform (“SAR” WF)
- 1-sec and 10-sec averaged waveforms

Doppler waveform
- Range Integrated Power

Co-location with reference data
- Wind (ECMWF) and wave model (WW3)
- AMSR-2 and SMAP
Delay waveform analysis

- Leading Edge Slope (LES) and Trailing Edge Slope (TES).
LES & TES wind dependency

- Zero-Doppler LES and TES as a function of U10 and SWH.
- Sensitivity:
  - ✓ Slope unchanged with incidence angle
  - ✓ ~ 1dB/(m/s) at low winds
  - ✓ ~ 0.2dB/(m/s) at moderate to strong winds

![LES wind dependency](image1)

![TES wind dependency](image2)
Range Integrated Power (RIP)

**Method:** noise floor removal and integration of the power DDM over range bins. → Analysis of the Doppler signature.
Doppler width

- Bandwidth increases with sea state, as expected.
- No saturation for moderate and large incidence angles?
“Doppler” slope variance

- Relation to mss to be further investigated [Elfouhaily et al., 2002]

\[
\text{Equivalent Slope Variance} = \frac{\lambda^2 B^2}{(2V^2 \sin^2 \epsilon)}
\]

First attempt to derive the L-band slope variance from the Doppler width.

- Large error bars.
- To be compared to model.
- Good sensitivity at low winds only (see next slide)
Case Studies
Co-locations

For any datatake, we study the along-track joint variations of:

- Antenna gain and elevation angle

- TDS-1 power DDM:
  - Doppler integrated waveform (LRM delay waveform)
  - zero-Doppler Waveform (SAR delay waveform)
  - range integrated waveform (RIP)

- Waveform features: LES, TES and Doppler width

- Temporal evolution of Sigma0, reference U10 (AMSR-2) & SWH (WW3)
Analysis panel

Sigma0 = f(U10)  Sigma0 = f(SWH)

Wind Speed (AMVRJ) over time

Sigma0

SWH (AMVRJ) over time

Sigma0

Antenna gain

Position of the measure
Analysis panel

U10

Sigma0

Slope variance
Derivation of the TDS-1 NRCS
From SNR to Sigma0

\[ \Gamma(\tau, f) = \frac{1}{k\theta_E B_W} \frac{\lambda^2}{(4\pi)^3} P_t G_{PR} \frac{G_R G_T}{R_t^2 R_r^2} \sigma_0 \int_{F_{CZ}} \chi^2(\tau, f) dS \]

\[ \sigma_0 = k\theta_E B_W \frac{(4\pi)^3}{\lambda^2} \frac{1}{P_t G_t} \frac{1}{G_R} \frac{1}{G_{PR}} \frac{R_t^2 R_r^2}{A_0} \frac{\sin^2(\varepsilon)}{\sin^2(\varepsilon)} \Gamma \]

Surface area at \( \varepsilon = 90^\circ \)

Elevation angle
Sensitivity to wind and waves

**TechDemoSat-1**

Sigma0 (L band) as a function of U10 and SWH

**Jason-2**

Sigma0 (C Band) as a function of U10 and SWH
Sigma0 vs. wind

- 0.2 dB / (m/s) when 10 m/s < U10 < 20 m/s
- Need to further analyze the noise level for strong wind conditions
- Options for CYGNSS (?): along-track averaging (PRN level) or between simultaneous obs. (e.g., <30 min.)
Specific wind/wave conditions

Tentative of an explanation for these events:
- SWH relatively low compared to wind conditions (e.g., young seas)
- mss relatively small and Q factor is no more considered as high (OK up to C-band)
- mean squared curvature may “talk” when expanding the GO approx. to the 4th order:

$$\sigma_0 = \sigma_{GO,mss} \cdot C_{mss,mss}$$

$$C_{mss,mss} = 1 + \frac{mss}{4Q_2^2mss^2} \left[ \frac{Q_H^4}{Q_2^4mss^2} - 4 \frac{Q_H^2}{Q_2^2mss} + 2 \right]$$
**Mean Square Slope**

- \( \text{mss} = \frac{R(\theta)^2}{\Sigma_0} \)
- Good match with the L-band mss derived from the slope spectrum with a 3*\(\lambda\) cut-off [Elfouhaily, 1997]
Directionnality: preliminary analysis

- The mss is modified as the wind or wave direction changes w.r.t. the along-track line.
- Mean variation of 20%: if confirmed, wind direction should be part of the GMF inversion.
Lessons learned

• TDS-1 L1 observables show consistent behaviour, but no conclusions for strong sea state conditions yet:
  ✓ waves up to 7m and wind up to 24m/s could be analyzed only.

• BRCS sensitivity of ~0.2 dB/(m/s) in the range [10 - 20 m/s]
  ✓ in line with NOAA’s results [Soisuvarn et al., 2016].
  ✓ we need to assess noise behaviour

• Alternative derivations of the BRCS should be investigated (e.g., from Doppler) to get rid of calibration issues.

• BRCS is sensitive to wind, waves and direction with equivalent weights
  → A deep analysis is now required to derive 1) an appropriate GMF and 2) an inversion scheme strategy.