# THE GPS REFLECTOMETER INSTRUMENT FOR PAU: ARCHITECTURE AND APPLICATIONS OVERVIEW

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# 0. Outline

- Introduction
- GPS Reflectometer Instrument for PAU (griPAU):
  - Principle of operation
  - Instrument architecture
- Field experiments conducted and results
- Conclusions

# 1. Introduction (1/2)

- Key issue: Accurate knowledge of Sea Surface Salinity (SSS).
- Ocean brightness temperature at L-band depends on SSS, SST, θ and sea roughness.
- Sea surface roughness at L-band is not well parameterized with any of the currently available parameters such as WS or SWH.

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- Reflectometry using GNSS signals proposed to achieve sea-state determination.
- Passive Advanced Unit project (2003 proposed to ESF, awarded in 2004) aims at demonstrating the use GNSS-R data to correct radiometric measurements for sea-state effect.
- More studies needed to obtain a meaningful parameter usable for scientific objectives.

# 1. Introduction (2/2)

- GNSS-R stands as a new field to explore:
  - Field experiments to be undertaken.
  - New GNSS-R receivers have to be designed.
  - Scientific requirements not yet well established.

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New instruments have to be designed to have
an optimum performance

# 2. GPS Reflectometer Instrument for PAU (griPAU)

## 2.1. Principle of operation (1/2):

- Delay-Doppler Map can be interpreted as the scattered power distribution over a surface: contains information of the surface and the geometry.

- griPAU works at the GPS L1 frequency and uses the public C/A codes.

- DDM are computed correlating the received reflected GPS signal with a local replica of the PRN code shifted in time delay and Doppler offset:

$$DDM(\tau, f_D) = \int_0^{T_i} s(t)a(t+\tau)\exp\left(-j2\pi\left(f_{L1}+f_D\right)t\right)dt$$

$$\overline{\left|DDM(\tau, f_D)\right|^2} = \frac{1}{N}\sum_N \left|DDM(\tau, f_D)\right|^2$$

$T_i$ : Coherent integration time.

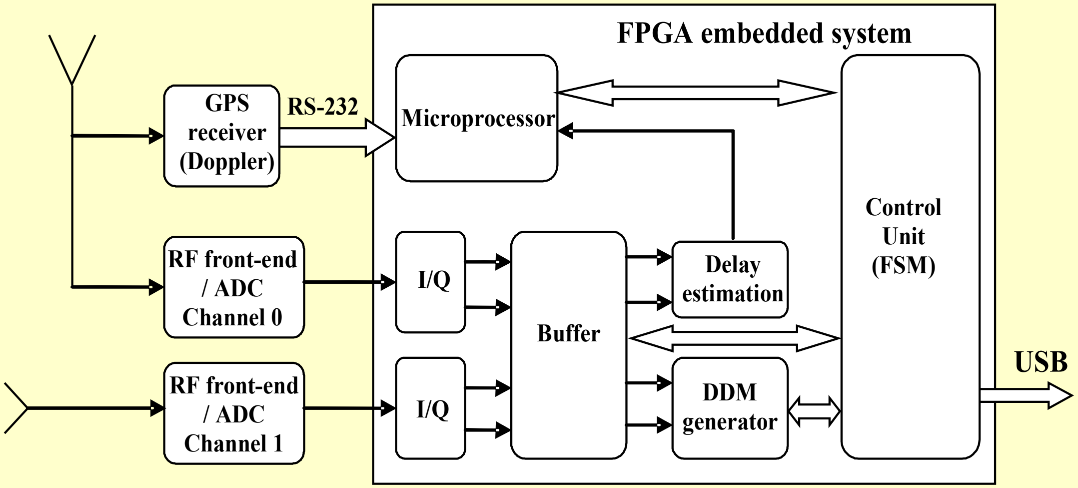
$N\cdot T_i$ : Incoherent integration time.

## 2.1. Principle of operation (2/2):

- griPAU performance:
  - Real time complex DDMs every 1 ms (6.14 MBps throughput via USB link).
  - High resolution DDMs: 24x32 points (768 real-time complex correlations).
  - Configurable delay-Doppler resolutions, typically 0.09 chips and 200 Hz.
  - Configurable coherent/incoherent integration available.
- Automatic tracking of the specular reflection point to avoid antenna pattern modulation.

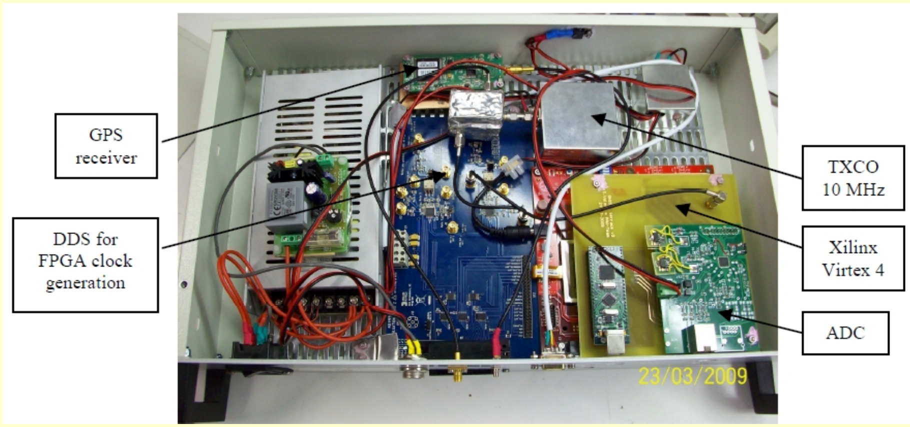
# 2.2. Instrument architecture (1/3):

- System overview:




- DDM generator:
  - Generates two sets of signals:
    - Demodulating tones
    - Shifted replicas of C/A code
  - Computes all cross-products and accumulates them to implement correlation.
  - Re-sampling techniques are used.

- Resources optimization:
  - Hardware reuse techniques.
  - Optimal frequency plan.
  - Optimal filters design.

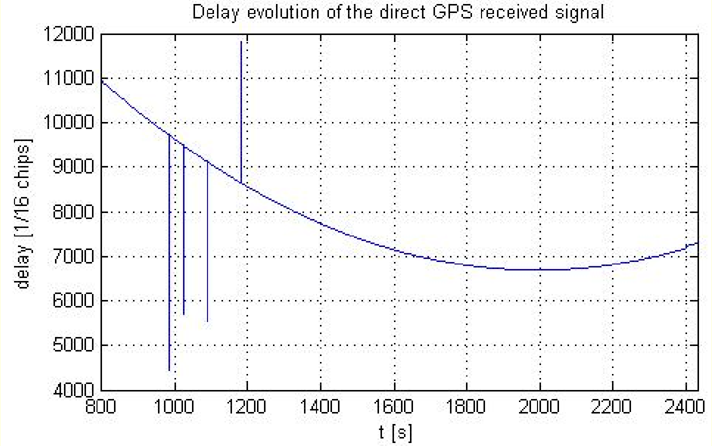


## 2.2. Instrument architecture (2/3):

- Direct signal delay estimation:
  - Circular correlation algorithm:

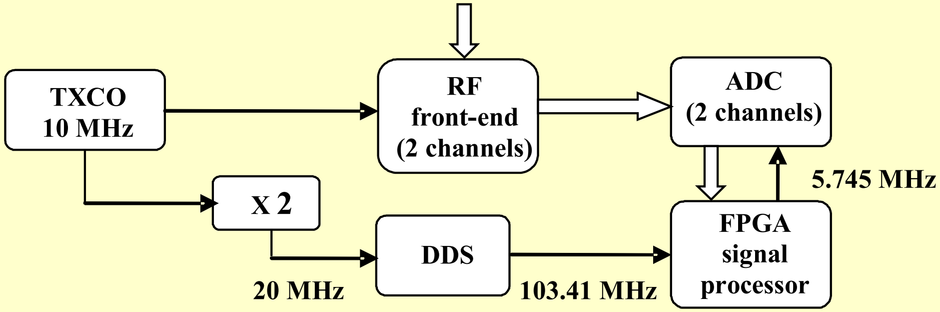
$$R_{x,ca} = IFFT(FFT(x) \cdot IFFT(ca))$$

- I/Q components of the direct signal are processed to avoid fading and a RHCP antenna is used to minimize multi-path.
- High estimation rate achieved:
  - 1 estimation / 5 ms.
  - Ability to work in dynamic scenarios.
- Very low error rate (below 1‰):



# 2.2. Instrument architecture (3/3):

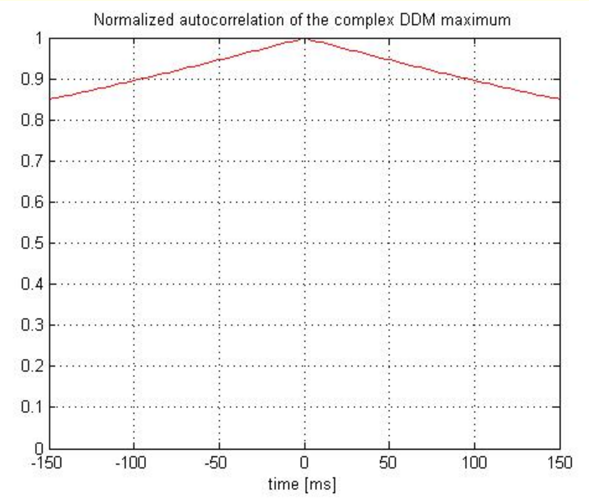
- Design stress on strict clock policy to ensure phase coherence:




- A single high-stable (0.01 ppm) clock reference is used to improve stability.

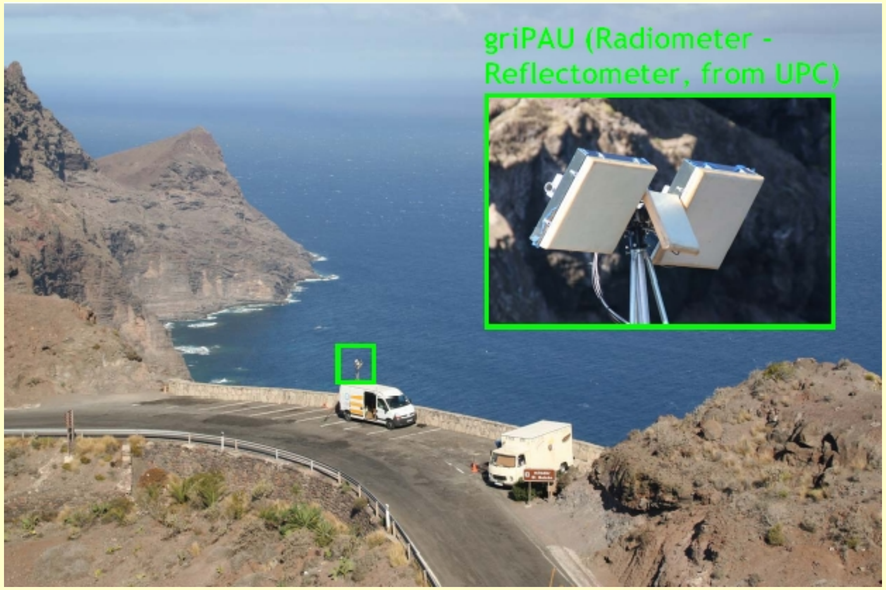
- System stability evaluated injecting a highly coherent synthetic GPS signal:

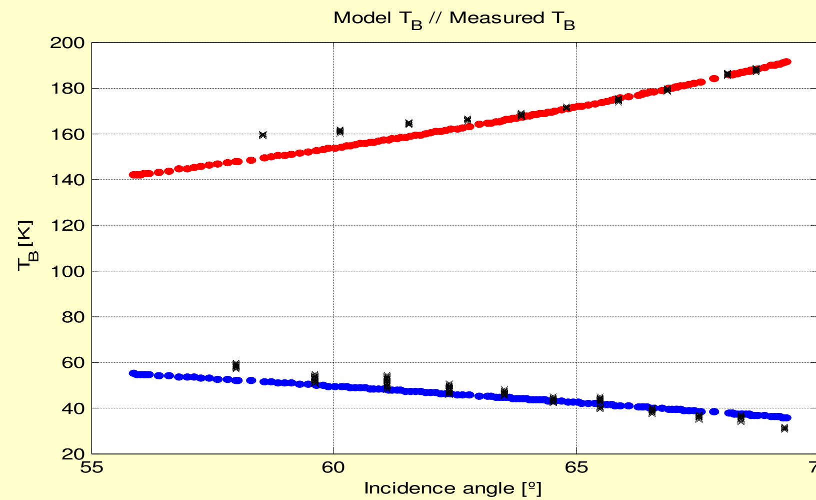
Decorrelation time of griPAU ≈100ms @90%, much higher than the sea correlation time.

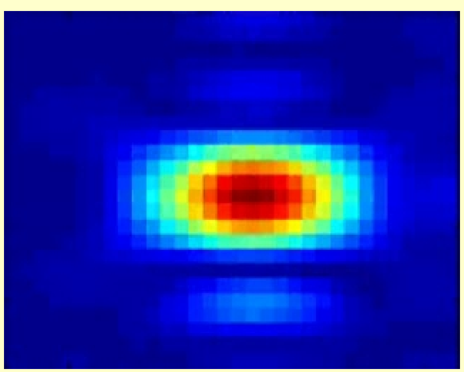


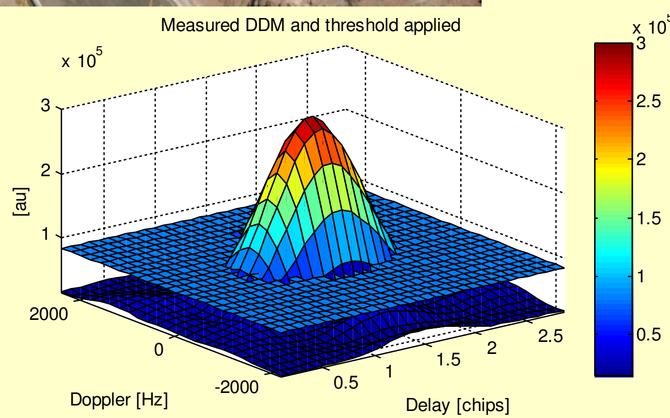
# 3. Conducted field experiments and results (1/5)

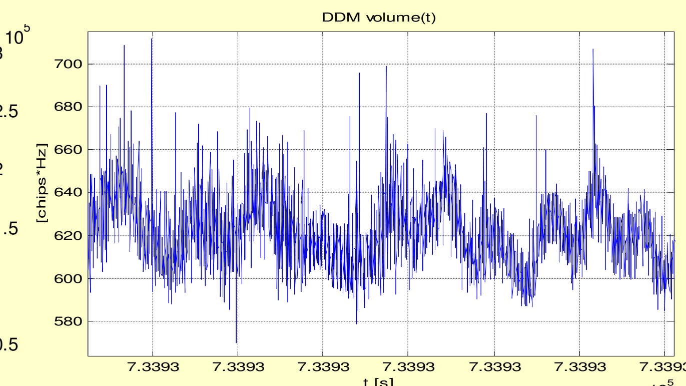
- Advanced L-BAnd emissiviTy and Reflectivity Observations of the Sea Surface (ALBATROSS 2009) Canary Islands, Spain



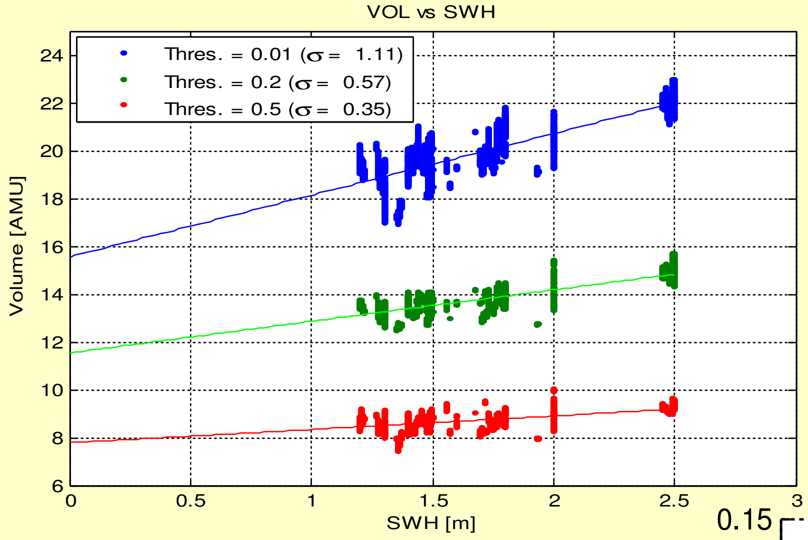



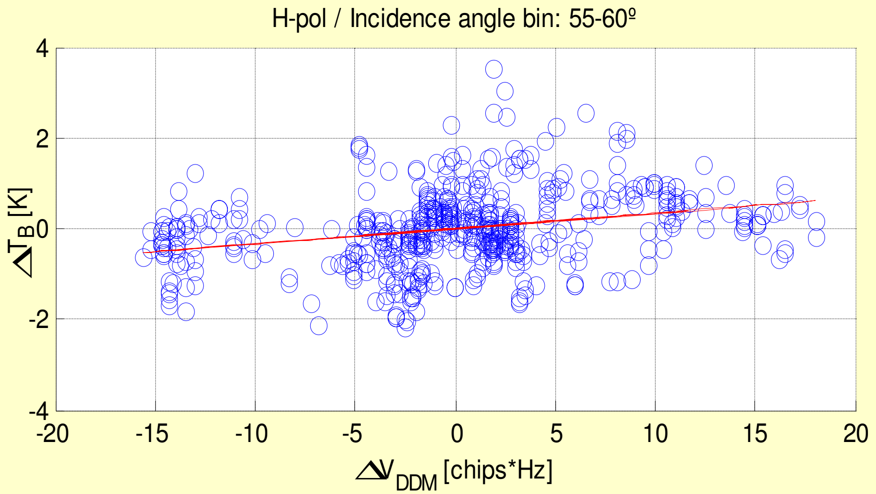



1-s averaged DDM volume time series

Direct relationship among sea-state and a GNSS-R observable




Direct relationship among ocean brightness temperature variations and GNSS-R observables

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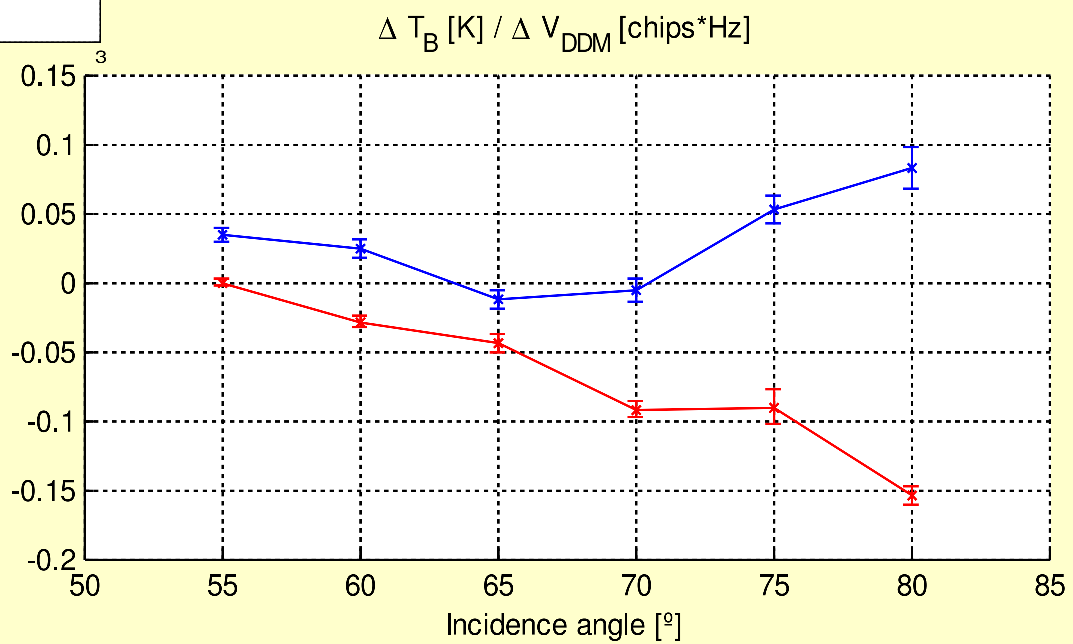
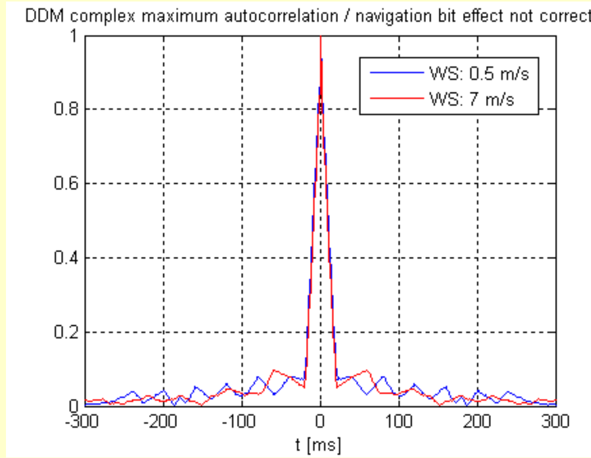
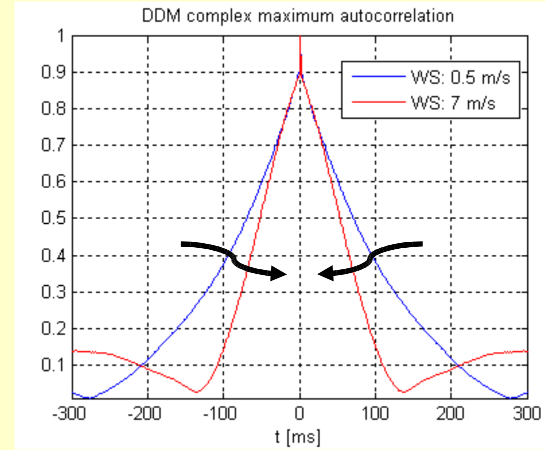
✓ Main goal of the project achieved

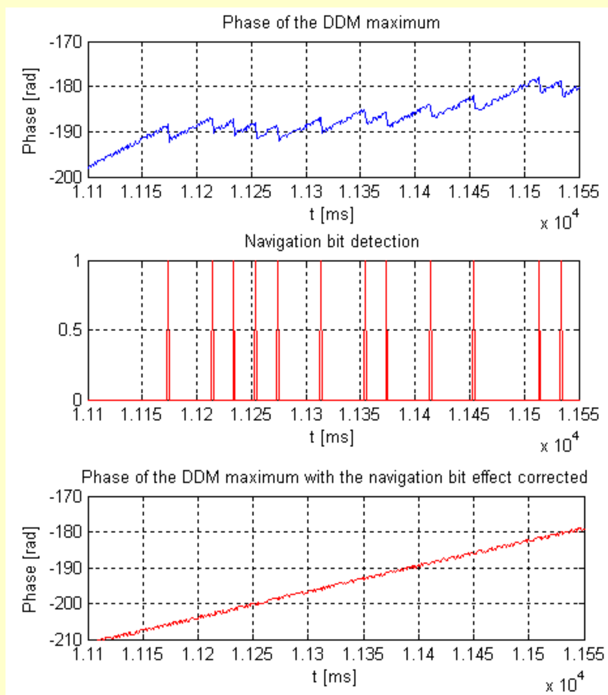


GNSS-R coherent measurements used to retrieve the ocean correlation time



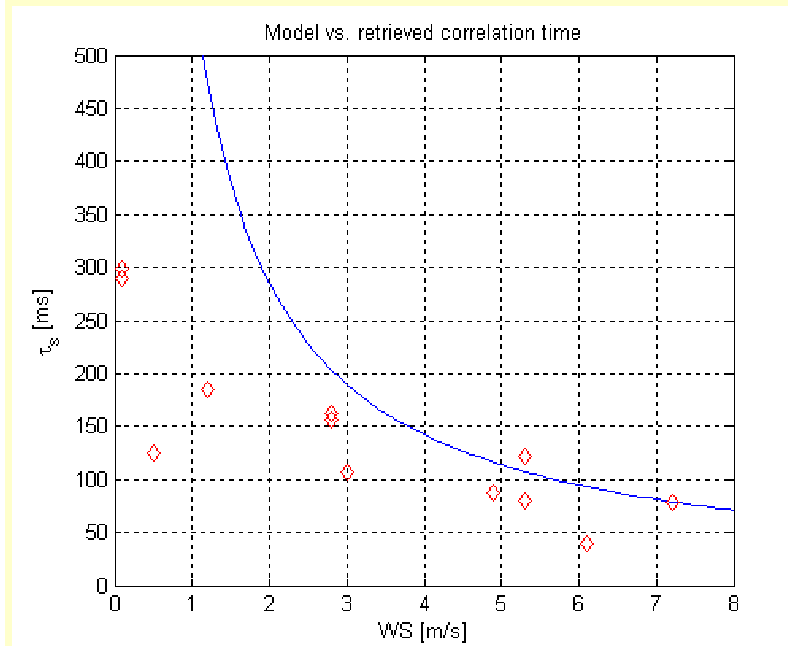




ACF function of the complex DDM maximum studied



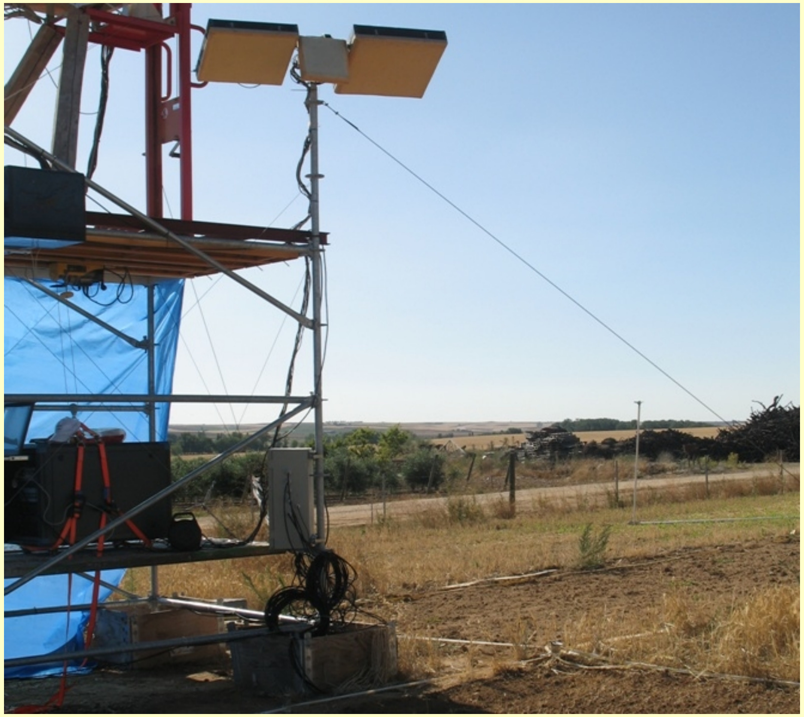

Model used:

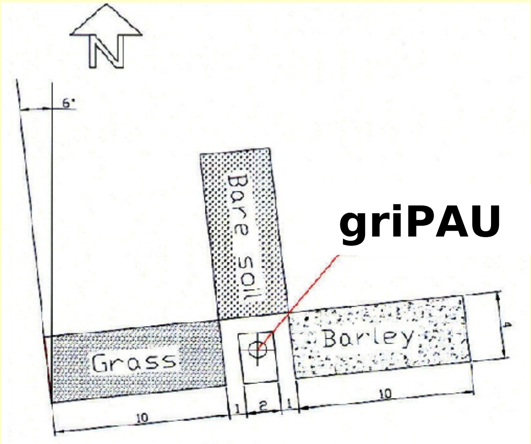
Frasier and Camps, TGRS 2001



# 3. Conducted field experiments and results (4/5)

- GPS and RAdiometric Joint Observations (GRAJO) Salamanca, Spain






Reflection can be considered quasi-specular

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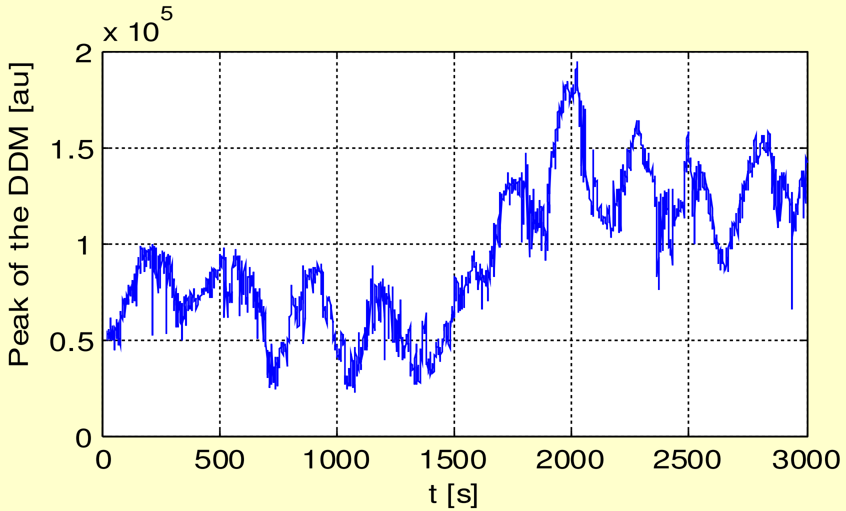
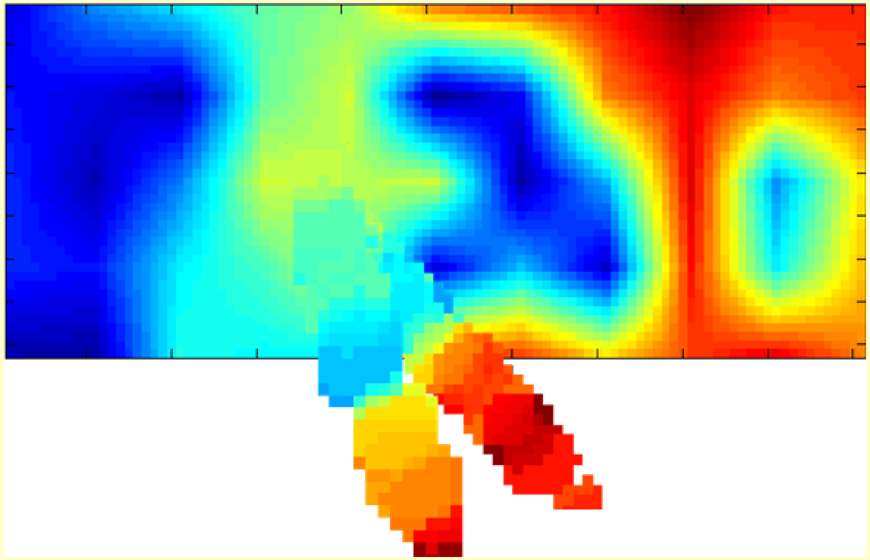
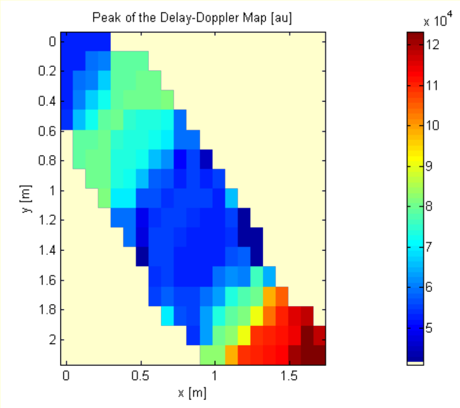
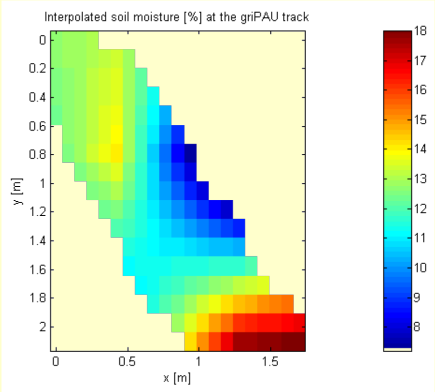
DDM peak evolution studied along the satellite tracks








DDM peak evolution along the satellite tracks compared to SM in-situ measurements

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Good agreement achieved

As reflection is quasi-specular, negligible info is added by full DDM

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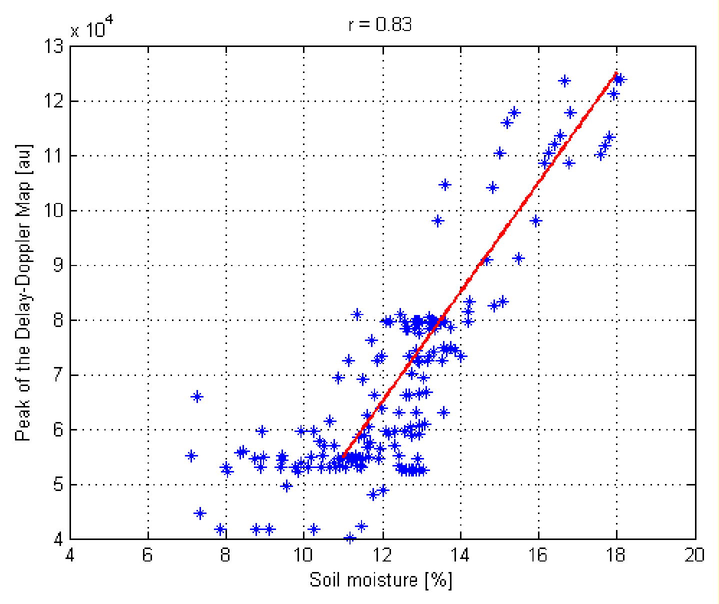
Power-based techniques such as IPT* more suitable for SM retrieval

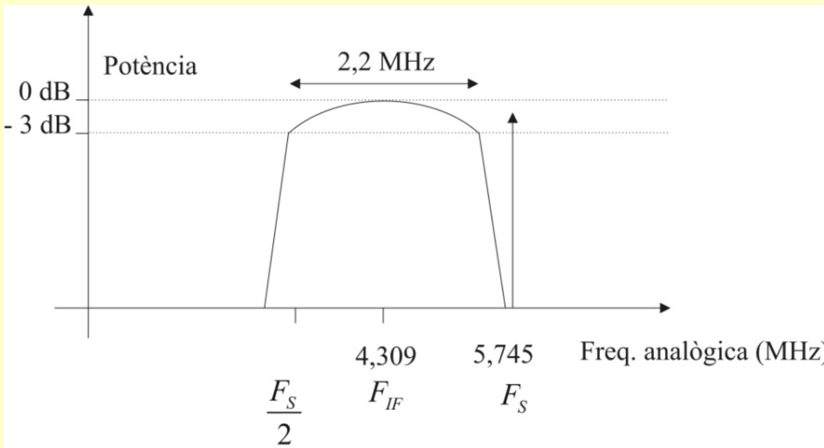


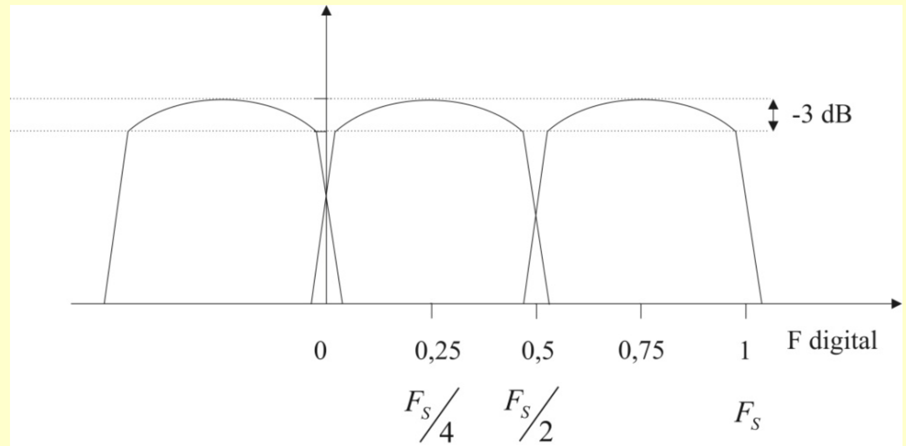

*Poster session: “Land retrievals: the SMIGOL-reflectometer and the interference pattern technique”

# 4. Conclusions

- GNSS-R is an emerging remote sensing technique with a high potential, especially for ocean applications.
- The PAU project has proposed using GNSS-R to correct measured L-band brightness temperature for the sea-state effect.
- The griPAU instrument has been designed and implemented end-to-end.
- griPAU is a real time GNSS-R receiver that computes the DDM equation obtaining one high resolution complex DDM per ms.
- The design process has involved advanced digital design techniques so as to achieve an appropriate synchronism and a good stability.
- griPAU has been successfully used in two field experiments over ocean (sea state determination) and land (soil moisture retrieval).
- A simplified version is being developed to fly on-board the INTA's μSAT plattform.

# Thank you for your attention



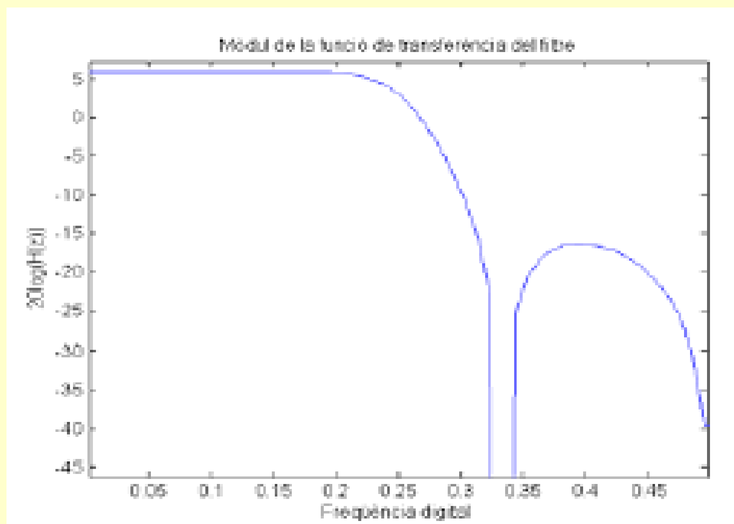



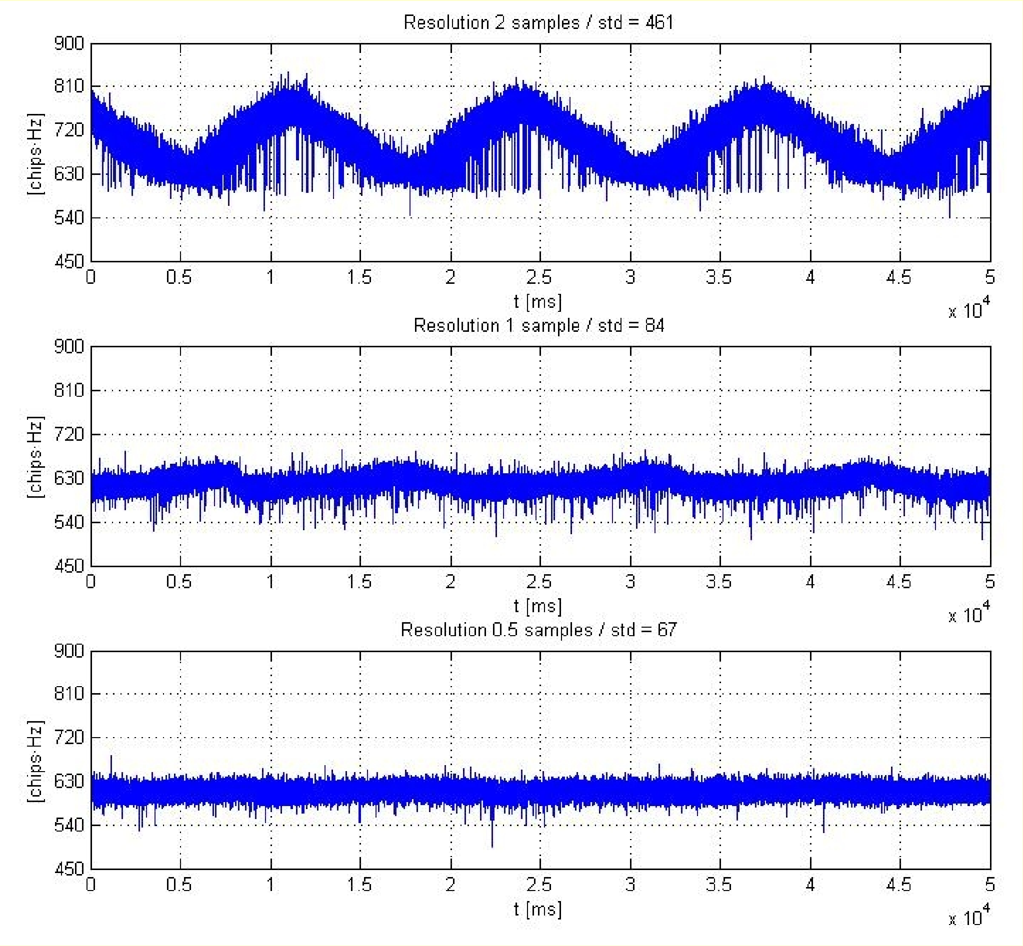

$$\cos(F_{digital} 2\pi n) = \cos(\frac{\pi}{2} n) = 1,0,-1,0,\ldots$$

$$-\sin(F_{digital} 2\pi n) = -\sin(\frac{\pi}{2} n) = 0,-1,0,1..$$

- Implemented low-pass IIR digital filter:
  - Power-of-2 coefficients makes multiply and division become simple right and left bit shifts

$$H(z) = \frac{2^{-1} + z^{-1} + z^{-2} + 2^{-1}z^{-3}}{1 + 2^{-1}z^{-2}}.$$




Resolution 2 samples / std = 461
Resolution 1 sample / std = 84
Resolution 0.5 samples / std = 67
[chips·Hz]
t [ms]
x 10^4
900
810
720
630
540
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0
0.5
1
1.5
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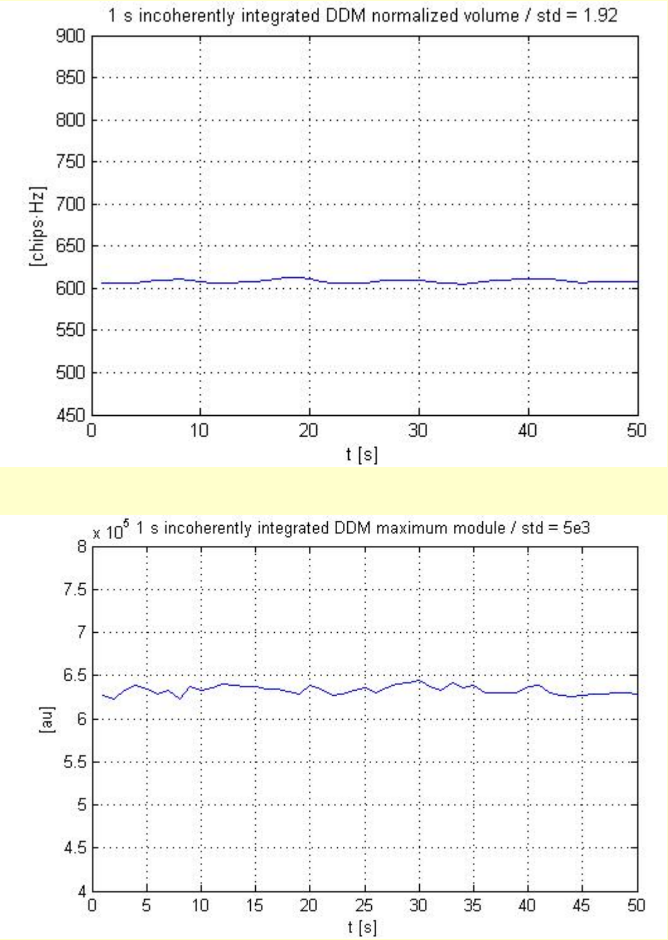
3.5
4
4.5
5


1 s incoherently integrated DDM normalized volume / std = 1.92
[chips·Hz]
t [s]
x 10^5 1 s incoherently integrated DDM maximum module / std = 5e3
[au]
t [s]