Ocean Monitoring Using L-Band Microwave Radiometry and GNSS-R Observations

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Outline

- Introduction
- The PAU Concept
- GNSS-R
- First Experimental Results
- Conclusions

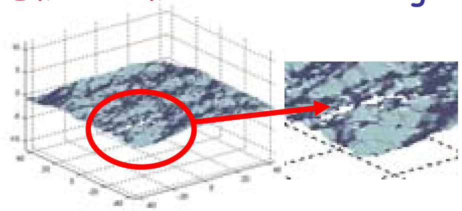
Introduction (i)

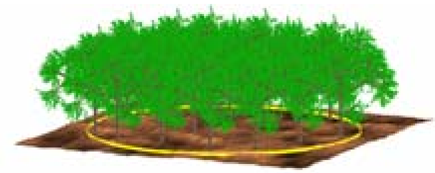
SMOS activities (1993-today)

1. **Instrument**: Analysis, performance, calibration, imaging...
→ Subsystem specificacions (EADS-CASA, MIER, YLINEN...)

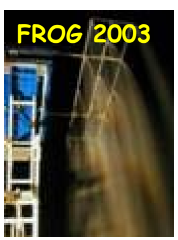
SEPS:
SMOS End-to-end
Performance Simulator

2. **Numerical Emission models**: sea and vegetation-covered land





3. **Field experiments**: sea and land emissivity



...

4. **Development of sea surface salinity and soil moisture retrieval algorithms from multi-angular radiometric measurements**

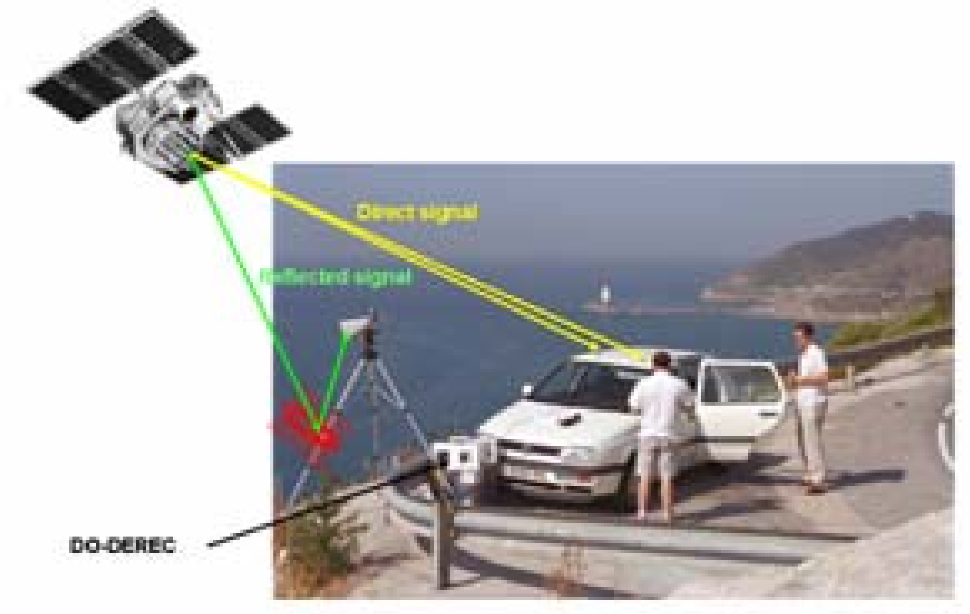
Collaboration with INDRA Espacio, GMV, DEIMOS Eng.

Introduction (ii)

- **GPS-reflectometry**

DODEREC (2001-2002): a GNSS-R instrument developed for IEEC

3 channel GPS-R with high speed data logger (20 MB/s during 60 min, or 40 MB/s during 15 s)



Introduction (iii)

- The brightness temperature of the sea surface depends on:
  - salinity
  - physical temperature
  - sea state + foam

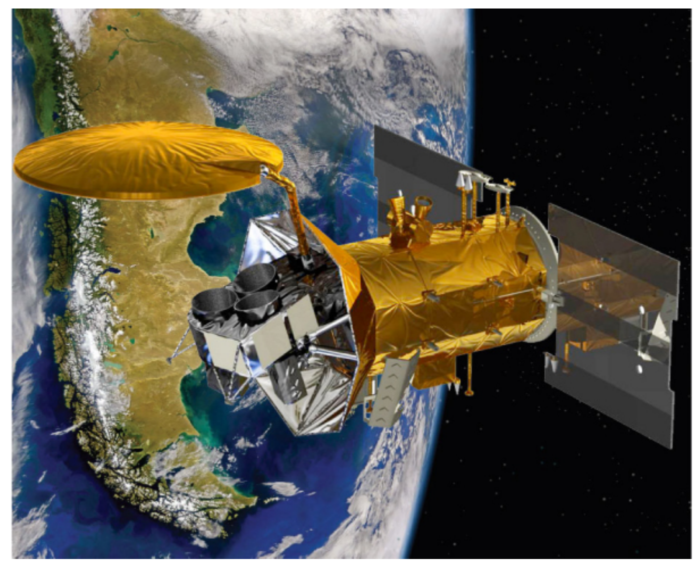
$$T_B^{sea}(\theta, pol) = \left[1 - \Gamma^{Fresnel}(\theta, \varepsilon_r, pol)\right] \cdot T_s + \Delta T_B(\theta, pol, parameter)$$

$$T_{B_{h,v}}^{Total} = F(U_{10}) \cdot T_{B_{h,v}}^{Foam} + \left[1 - F(U_{10})\right] \cdot T_{B_{h,v}}^{Sea} = T_{B_{h,v}}^{Sea} + F(U_{10})\left[T_{B_{h,v}}^{Foam} - T_{B_{h,v}}^{Sea}\right]$$

$\Rightarrow$ critical correction:

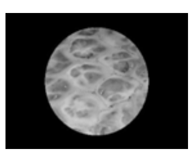
. SMOS: multi-angular information to estimate an effective wind speed

. AQUARIUS: L-band scatterometer



WISE/FROG Field campaigns (2000, 2001 and 2003)


UPC L-band AUtomatic RAdiometer

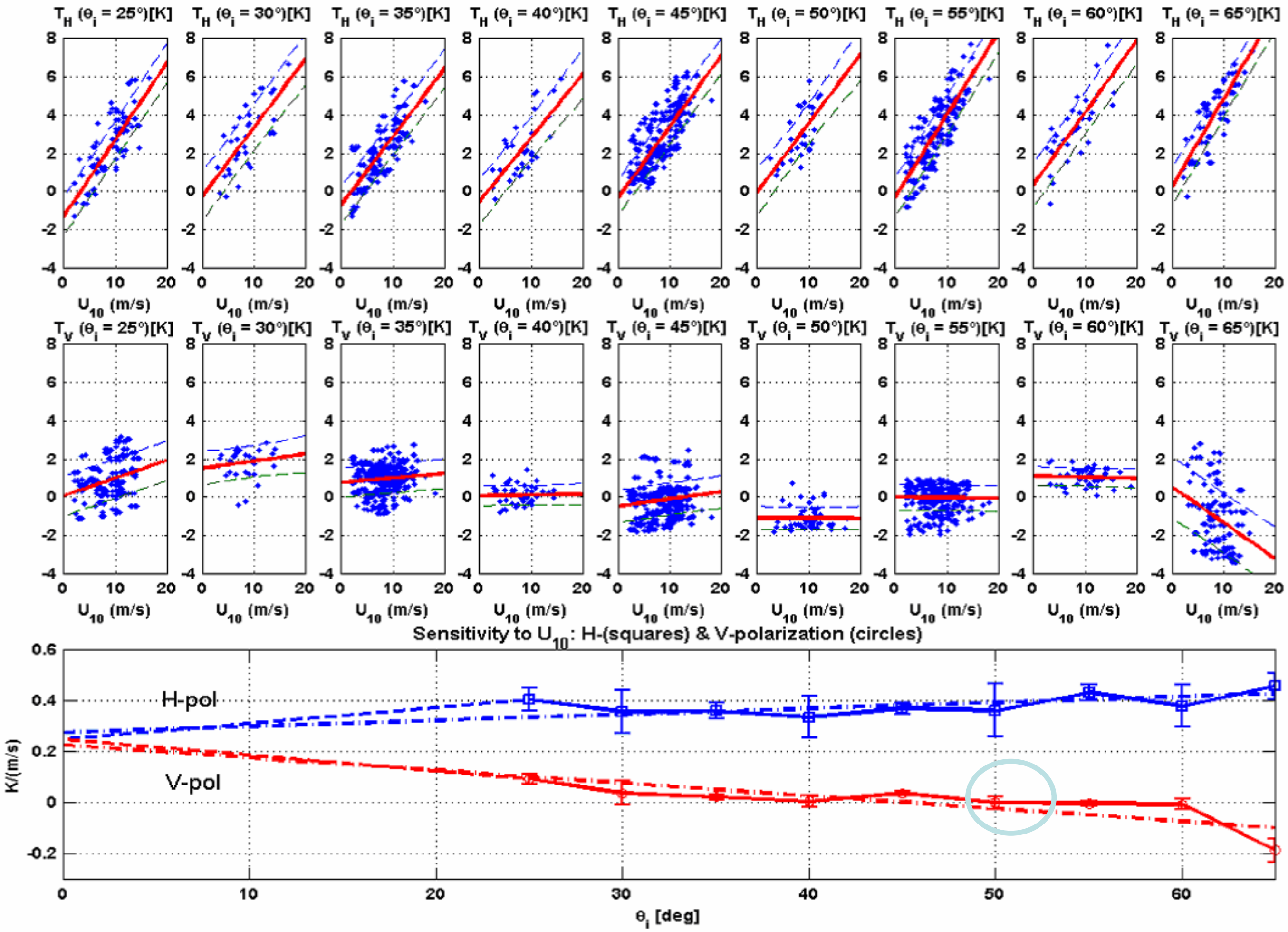



ICM EMS buoy


ICM Aandera CMB3280 buoy

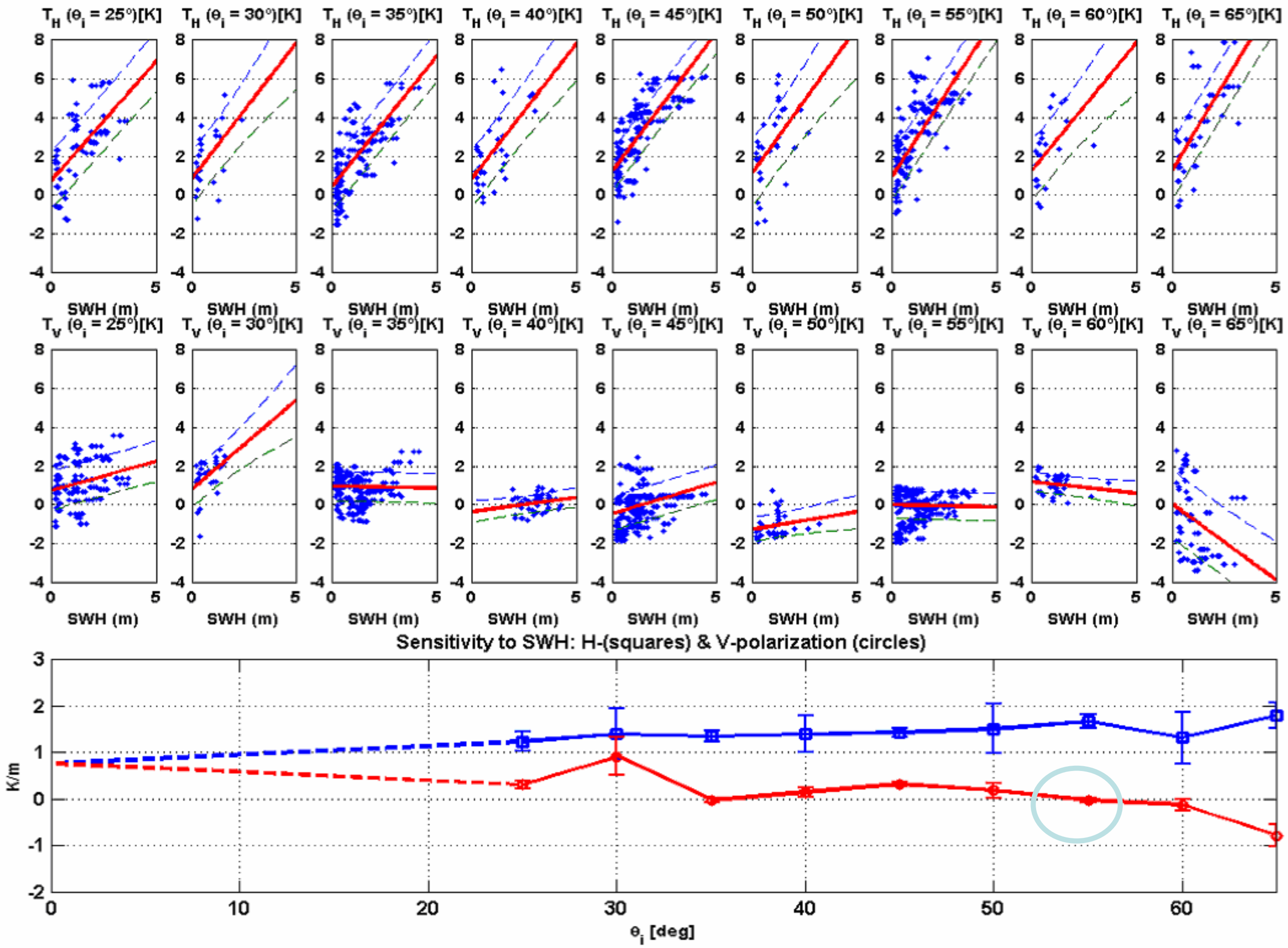

LODYC Clearwater & Datawell buoys

WISE 2001: T_B sensitivity to U_{10}



$$\begin{cases} \Delta T_h \approx 0.25 \cdot (1 + \theta / 94°) \cdot U_{10} \\ \Delta T_v \approx 0.24 \cdot (1 - \theta / 81°) \cdot U_{10} \end{cases}$$

WISE 2001: T_B sensitivity to SWH



$$\begin{cases} \Delta T_h \approx 1.09 \cdot (1 + \theta / 142°) \cdot SWH \\ \Delta T_v \approx 0.92 \cdot (1 - \theta / 51°) \cdot SWH \end{cases}$$

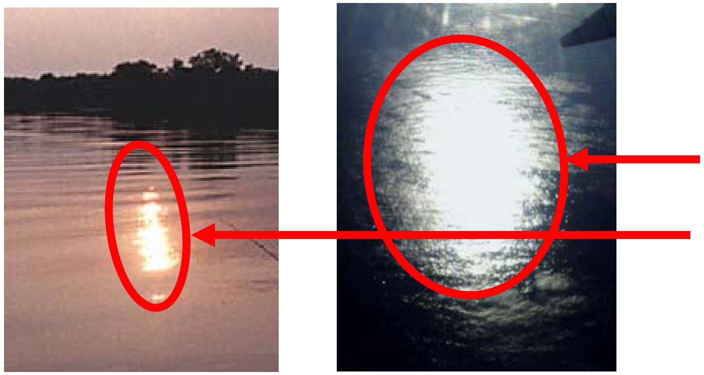
PAU Concept (i)

- **PAU = Passive Advanced Unit for ocean monitoring ⇒ potential solution to sea state pb.**
- **PAU concept proposed to ESF 2003, EURYI award 2004: March 2005-February 2010**

- **PAU = Combination in a single instrument 3 different sensors, taking advantage of experience gained in previous projects (SMOS, DODEREC...)**

  - **PAU-RAD:** New type of radiometer: pseudo-correlation ⇒ measure TB
    digital beamforming
    polarization synthesis

  - **PAU-GNSS/R:** GPS reflectometer ⇒ measure sea state (and altimetry)

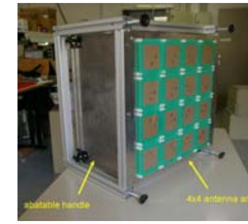


Sun glint over a (left) calm sea, and (right) roughned sea

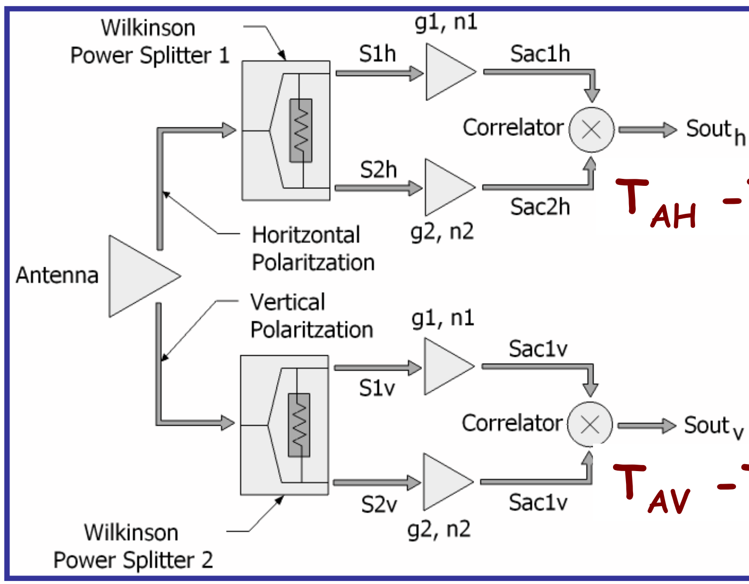
  - **PAU-IR:** IR radiometer ⇒ measure SST

PAU Concept (iii)

PAU-Real Aperture Main Characteristics

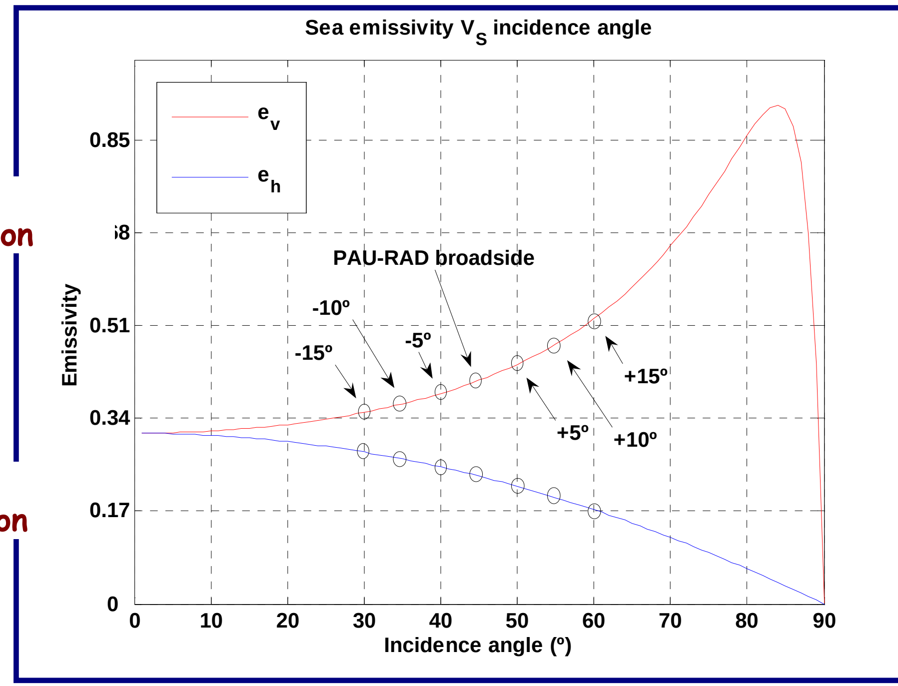


1. Architecture based on new kind of pseudo-correlation radiometer.
2. DBF 4x4 elements: square array with triangular illumination.
   Steering: ±15° (Δθ = 5°) ⇒ multi-angular observations without mechanical scan



T_{AH} - $T_{Wilkinson}$

T_{AV} - $T_{Wilkinson}$



PAU-RAD architecture diagram:

- Output proportional to T_{Ap}-$T_{Wilkinson}$
- No chopping ⇒ GPS signal can be tracked

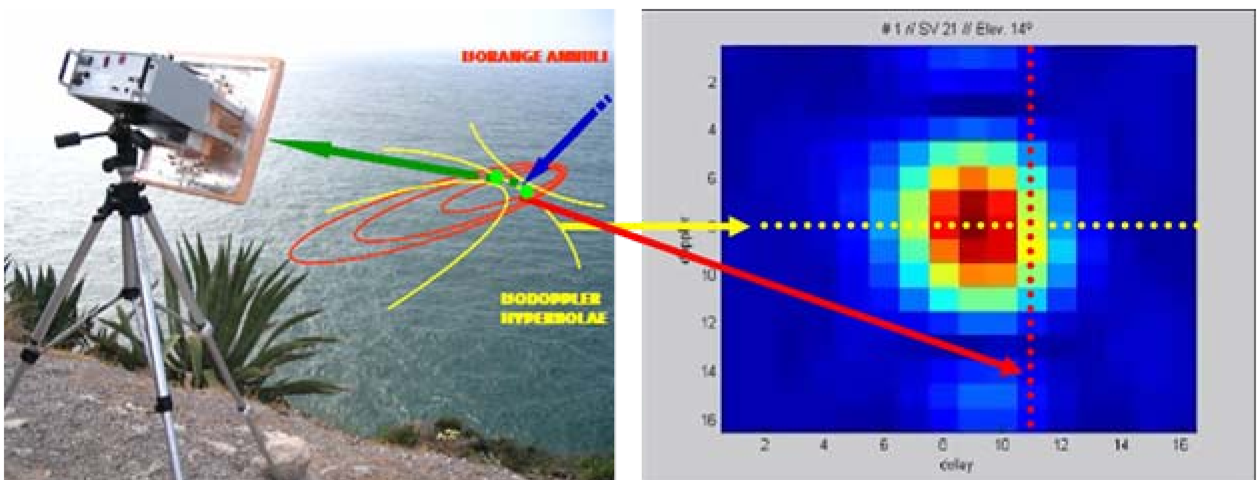
PAU Concept (iv)

- **What can a GNSS-R reflectometer measure?**

  - The most complete information is the **Delay Doppler Map (DDM)** or correlation of the received signal with a replica of the transmitted one at different time lags and Doppler shifts ⇒ mapping of space (x,y) coordinates into (τ, f_d)

$$Y(\delta\tau, \delta f_D) = \int_0^{T_i} s(t)a(t+\delta\tau)\exp(-j2\pi\cdot\delta f_D\cdot t)dt$$

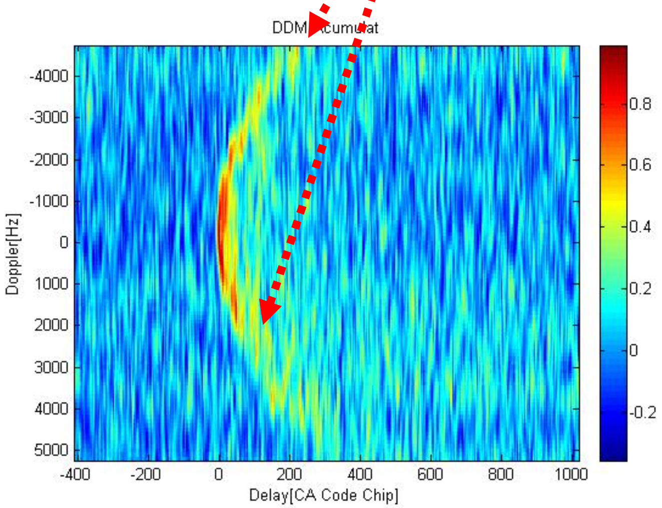
  - DDM cut for f_d=0 is usually called a **waveform** ⇒ most widely used observable



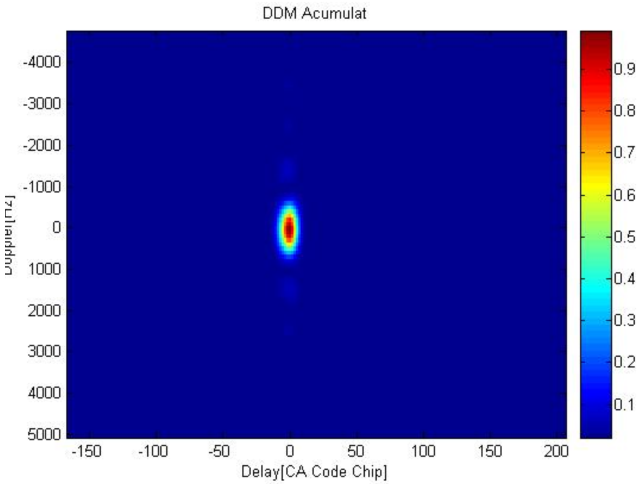
GNSS-R (ii)

- The "shape" of the DDM depends on:
- Surface where GNSS signals are scattered: sea, ice, land…
  - ⇒ dielectric properties, surface roughness, temporal variability…
- The relative movement of the GNSS transmitter and the receiver
- The DDM must be integrated (coherently and incoherently) to reduce noise

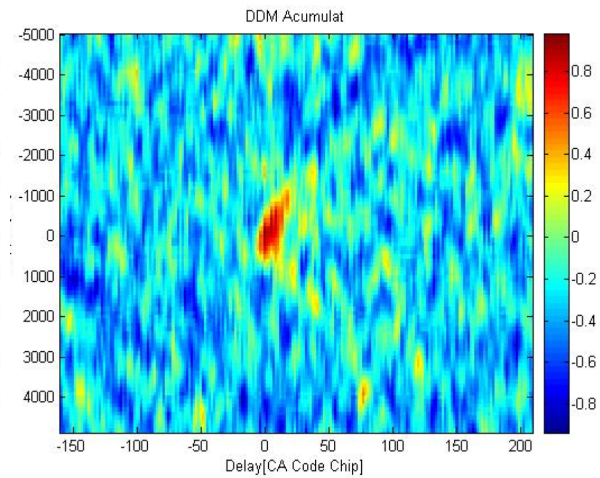
SAMPLE DATA FROM UK-DMC
(processed by UPC)



DDM τ_c = 1 ms, τ_i = 200 ms
SEA



DDM τ_c = 1 ms, τ_i = 200 ms
ICE



DDM τ_c = 1 ms, τ_i = 200 ms
LAND

First experimental results (i)

- 1st full real-time DDM generator (variable τ_c and τ_i from 1 ms…) in 2007
- gri-PAU: improved version for field campaigns
  = collocated radiometer + GNSS-Reflectometer
- Field experiments conducted so far with this new instrument over sea and land:

Advanced **L**-**BA**nd emissivi**T**y **R**eflectivity **O**bservations of the **S**ea **S**urface (**ALBATROSS** 2009)

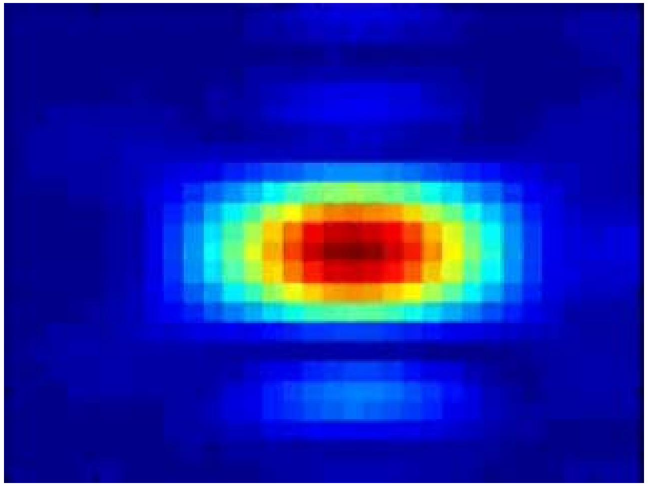
First experimental results (ii)

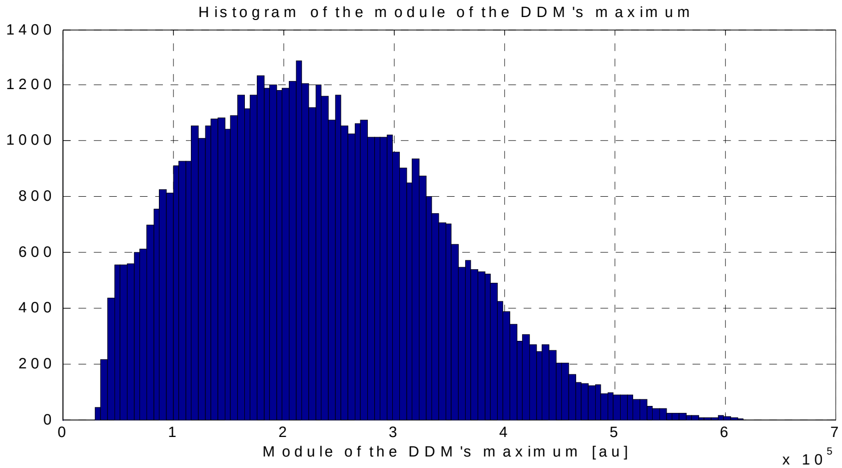
gri-PAU:

- **24x32 points (768 real-time complex correlations)**
- **Adjustable delay and Doppler steps.**
- **Typically: 0.09 chips, 200 Hz**

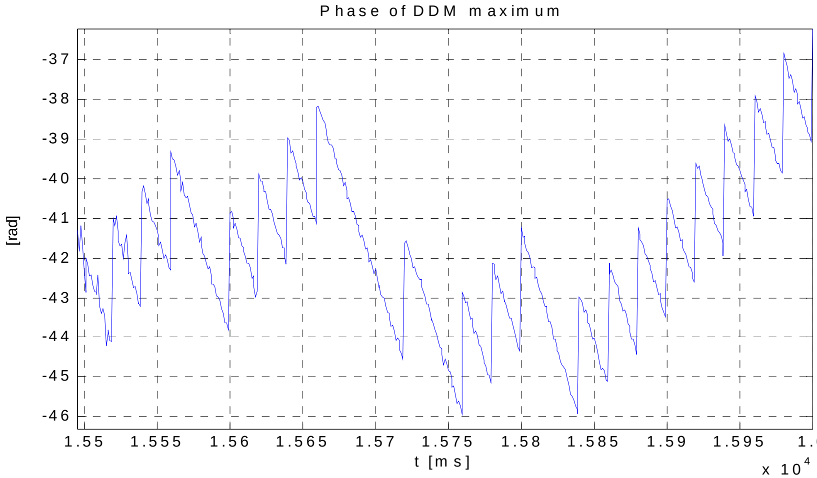
- Real capture over the ocean:

1 ms DDMs



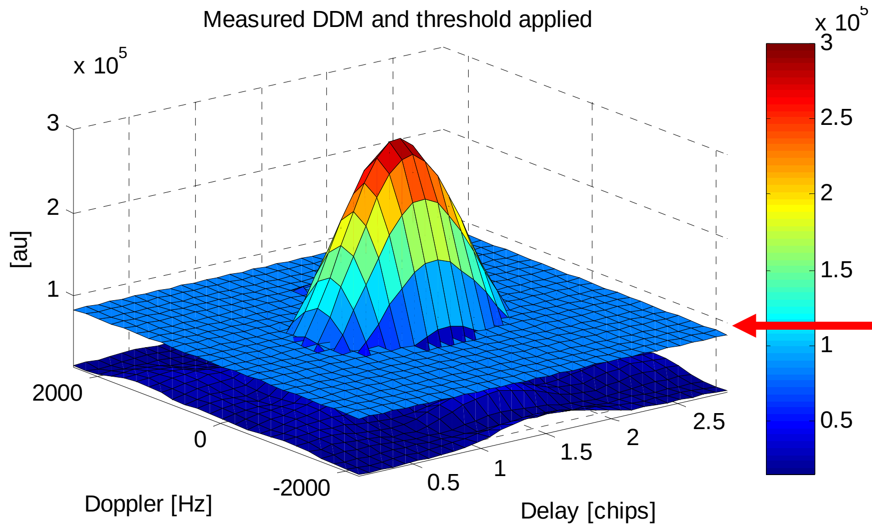


DDM's maximum module has approximately a Rice PDF as expected



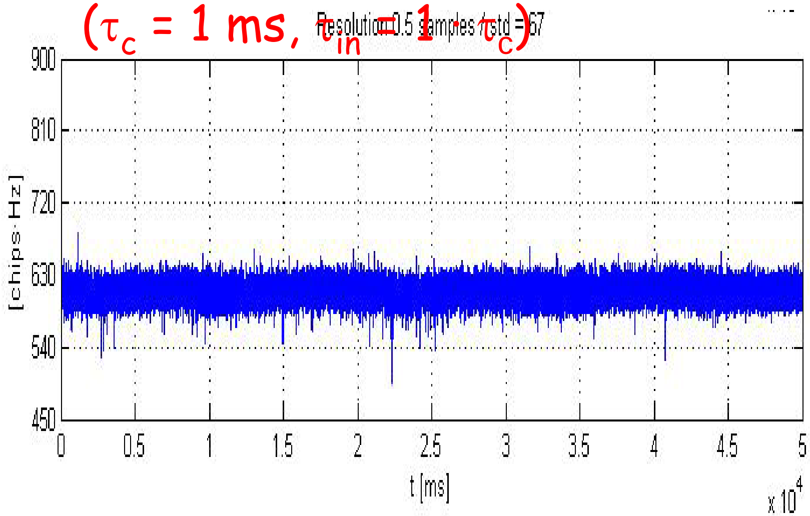
π rad phase jumps → Navigation bit detection with reflected signal

First experimental results (iii)

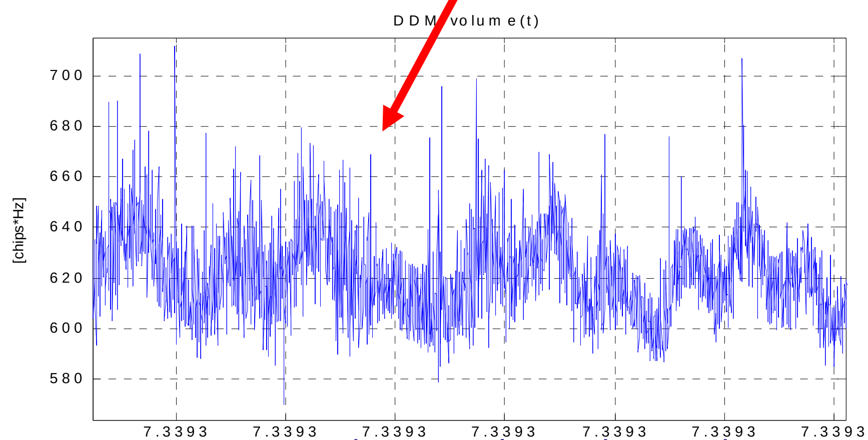


Noise threshold

DDM volume fluctuations due to noise
(τ_c = 1 ms, τ_{in} = 1 · τ_c)



DDM volume fluctuations follow ΔT_B fluctuations



1-s averaged DDM volume time series

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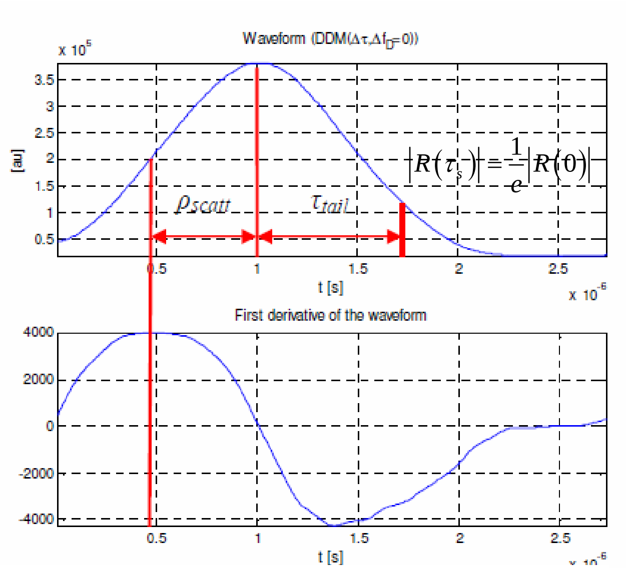
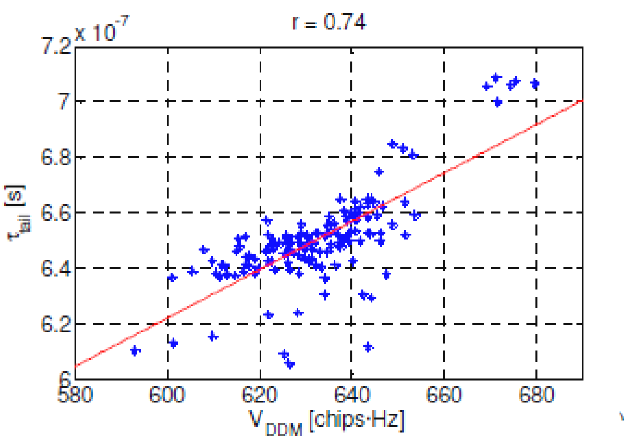
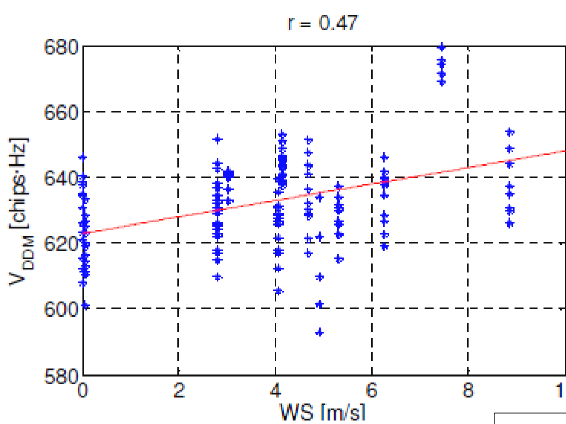
First experimental results (iv)

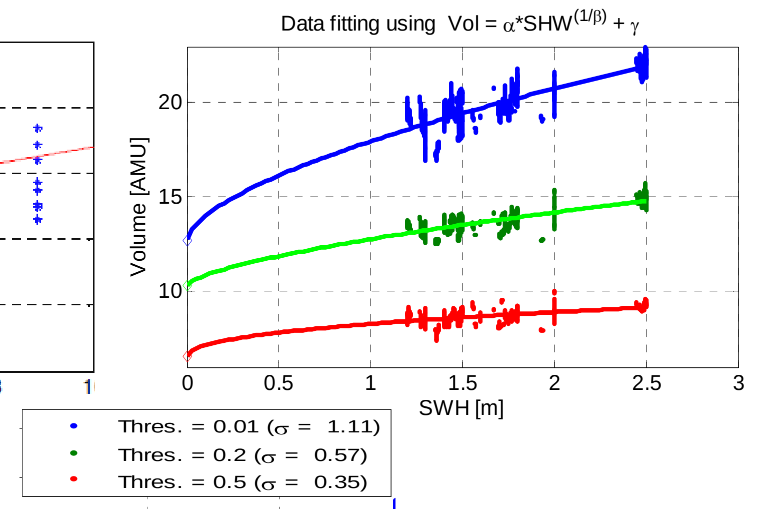


- No corrrelation found between scatterometric delay and DDM volume
- But high correlation between length of waveform tail and DDM volume
- Poorer correlations between DDM volume and WS or SWH

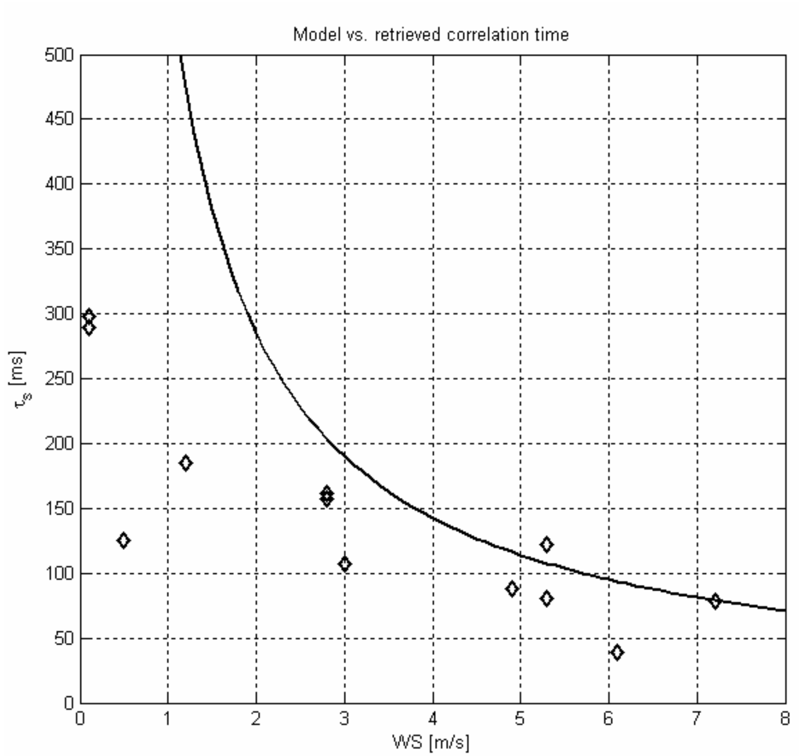
Note: results may improve at higher platform heights



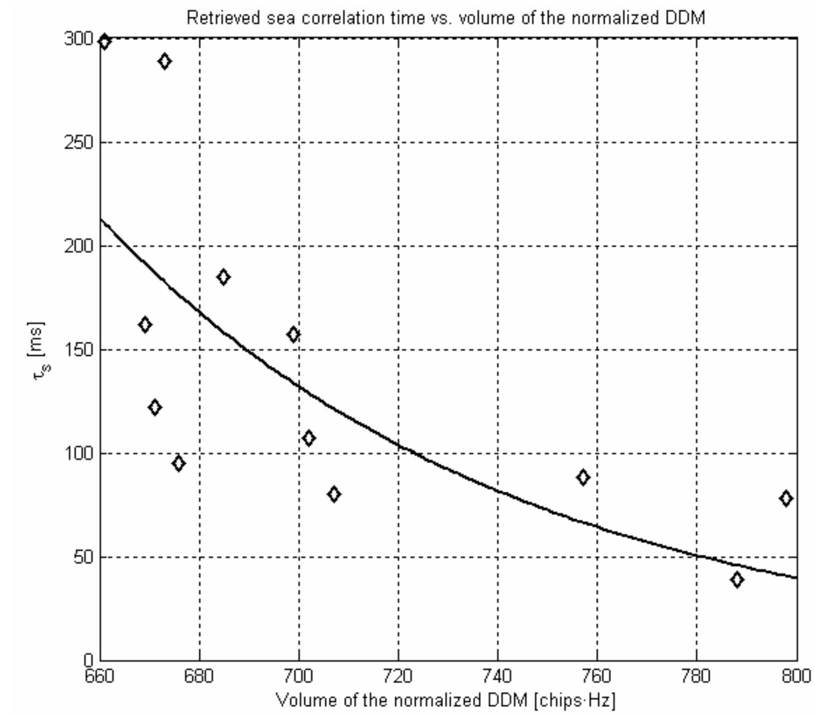




First experimental results (v)



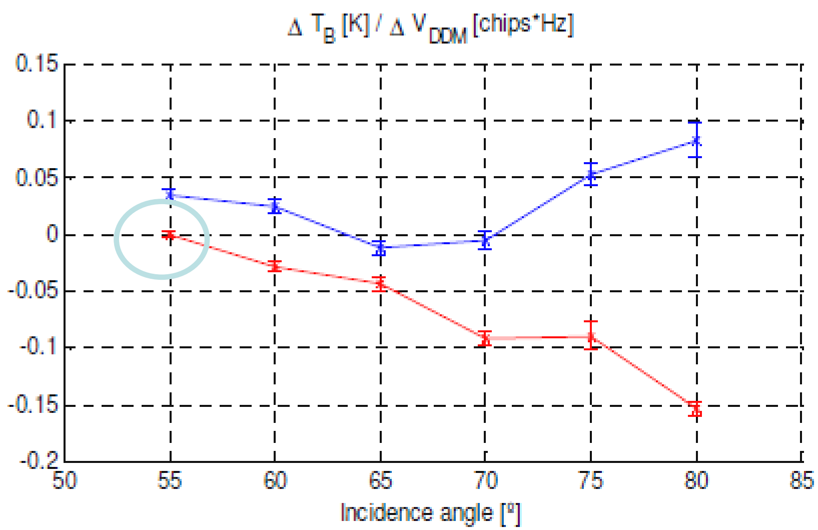
Sea correlation time (diamonds) & modeled correlation time (solid line) vs. wind speed



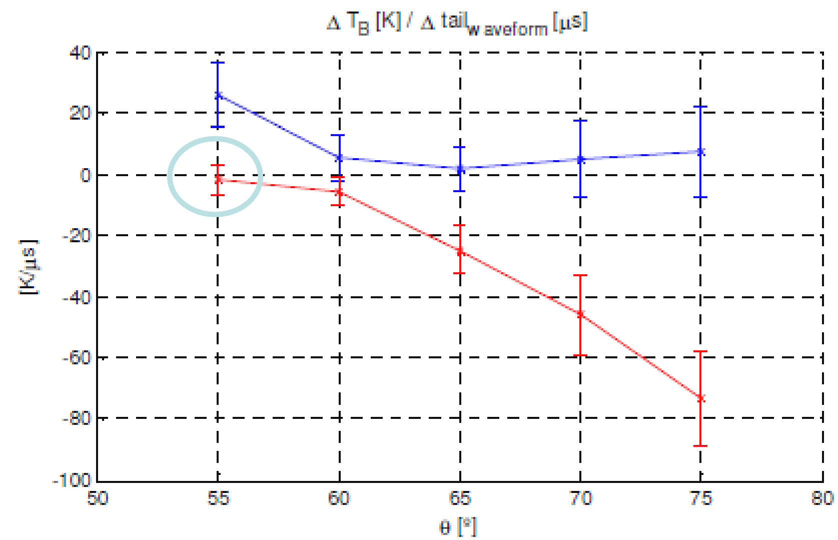
Correlation time (diamonds) and volume of normalized DDM. Solid line corresponds to exponential model fitted to data.

First experimental results (vi)

Direct relationship among ocean T_B variations and a GNSS-R observable:



T_B sensitivity to ΔDDM volume



T_B sensitivity to changes in $\Delta\tau_{tail}$

NO emission & scattering model

NO ocean surface model

Conclusions (i)

- GNSS-R is an emerging remote sensing technique which a high potential for ocean applications: altimetry + sea state determination + sea state correction in ΔT_B.

- PAU project proposed in 2003 to ESF and funded (2/2005-2/2010):

  Main goal = use GNSS-R to correct measured L-band brightness temperature for the sea-state effects.

  Technological demonstrator for SMOS follow on mission

- PAU and griPAU instruments designed and implemented.

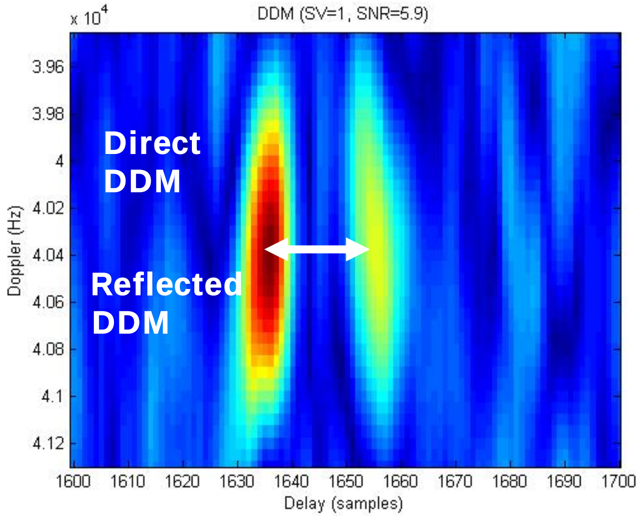
  griPAU is a real time GNSS-R receiver to compute the DDM every 1 ms in 24x32 points (768 real-time complex correlations), with configurable delay-Doppler resolutions, typically 0.09 chips and 200 Hz.

- griPAU has been successfully used in two field experiments over ocean and land (soil moisture & vegetation height), and over sea. First results over sea presented

Conclusions (ii)

- GNSS-Reflectometer in R/C small aircrafts:

Direct and reflected DDMs showing altimetric information ("classical" PARIS demonstration)



PAU-ORA: ALTIMETRIC & SM applications