

Observation aéroportée par réflectométrie GNSS et Positionnement par la phase

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GT GNSS & positionnement, 16 octobre 2024

PLATEFORME RADAR GNSS, LIDAR, SONAR ACOUSTIQUE



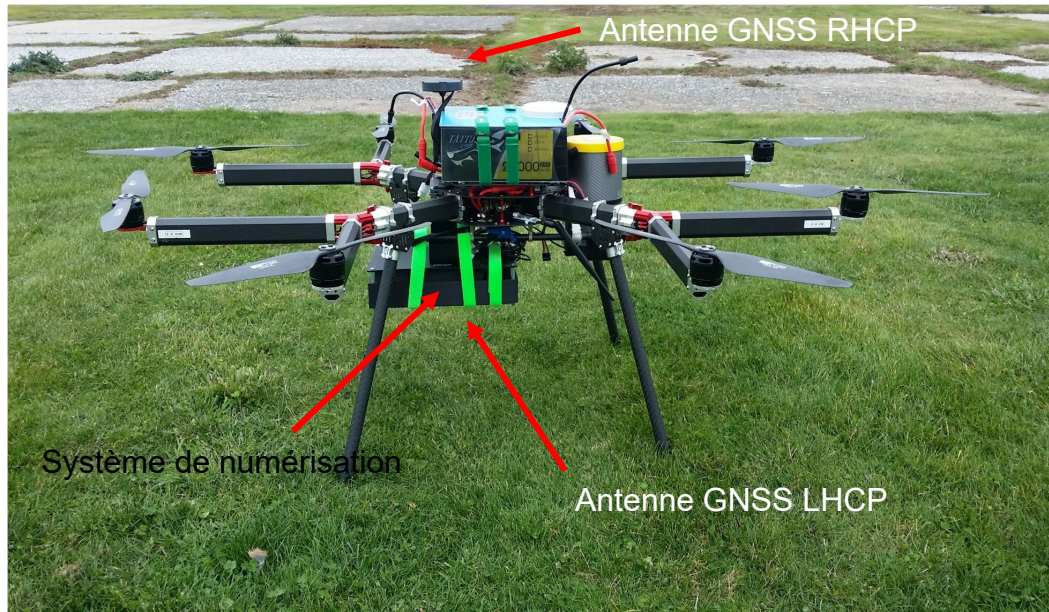
Laboratoire sur le site de Calais

Salle de manipulation
de la plateforme au
Laboratoire

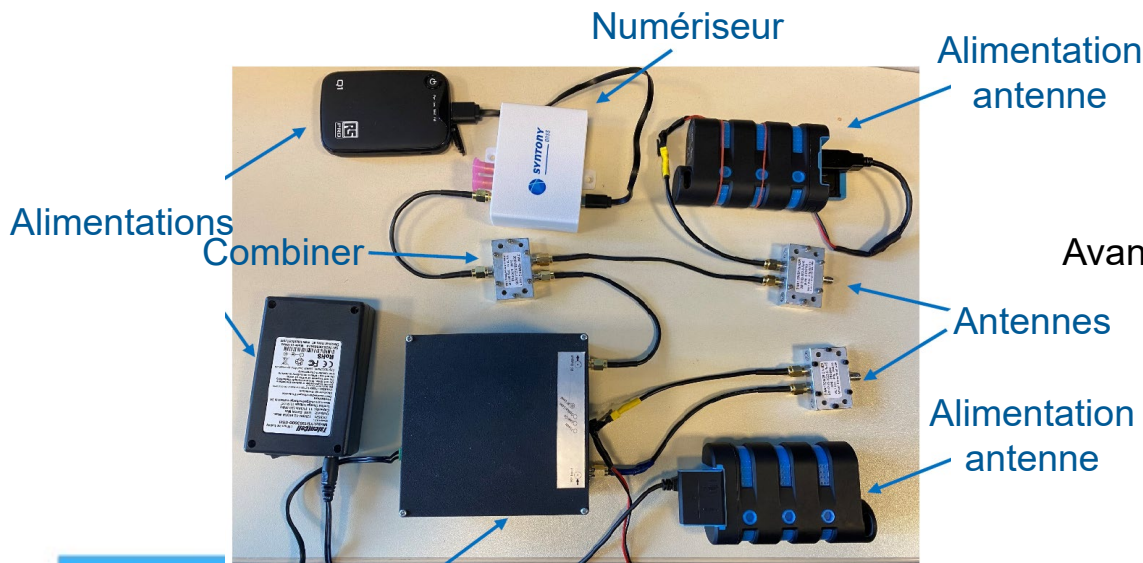
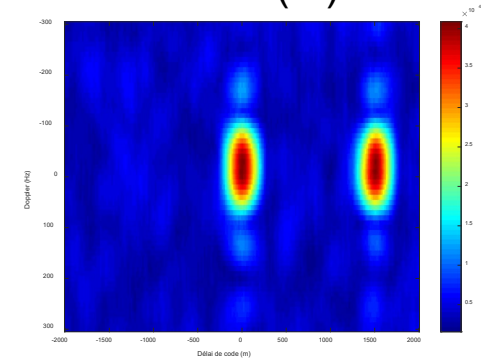
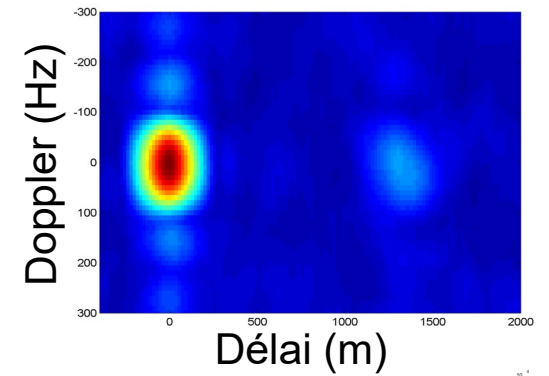
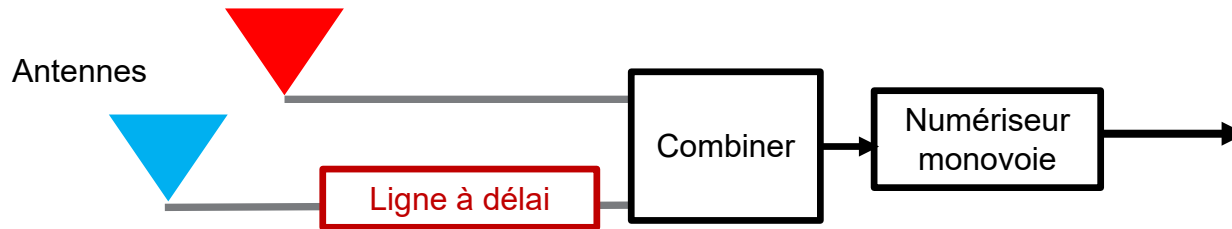


Salle de manipulation
de la plateforme à
l'EILCO

EQUIPEMENTS



FRONT END DU RADAR GNSS



Fibre optique

Avantages :

- Numérisation synchronisée des signaux
- Diminue la quantité de données à stocker et traiter
- 25^e6 ech/s, traitement hors ligne
- Bibliothèque récepteur radio logiciel

ALTIMÉTRIE PAR LE CODE

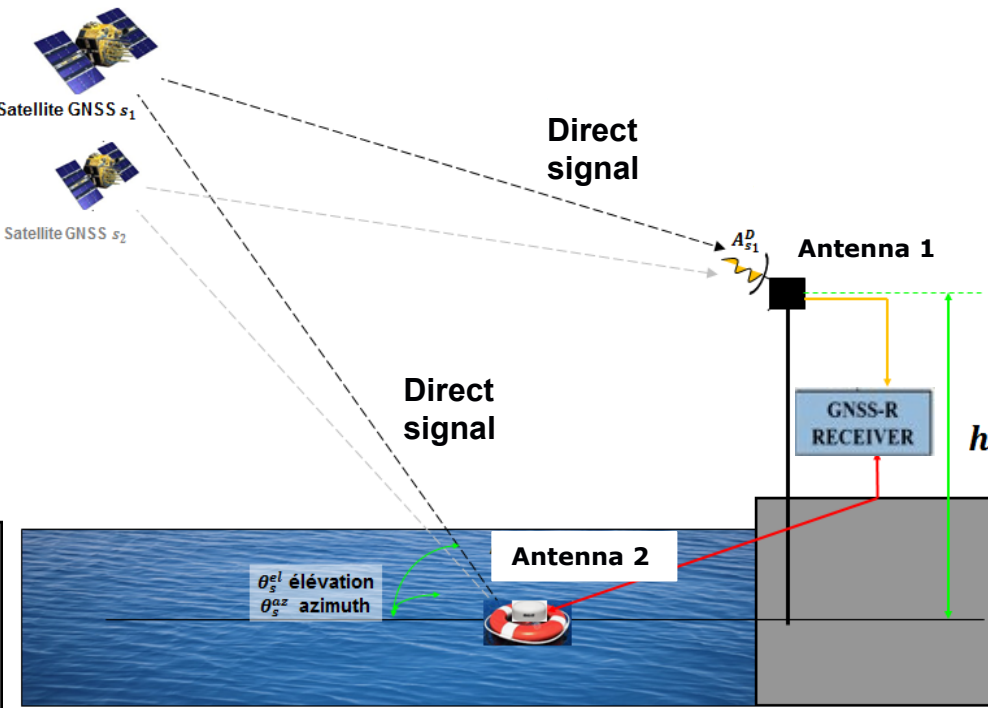
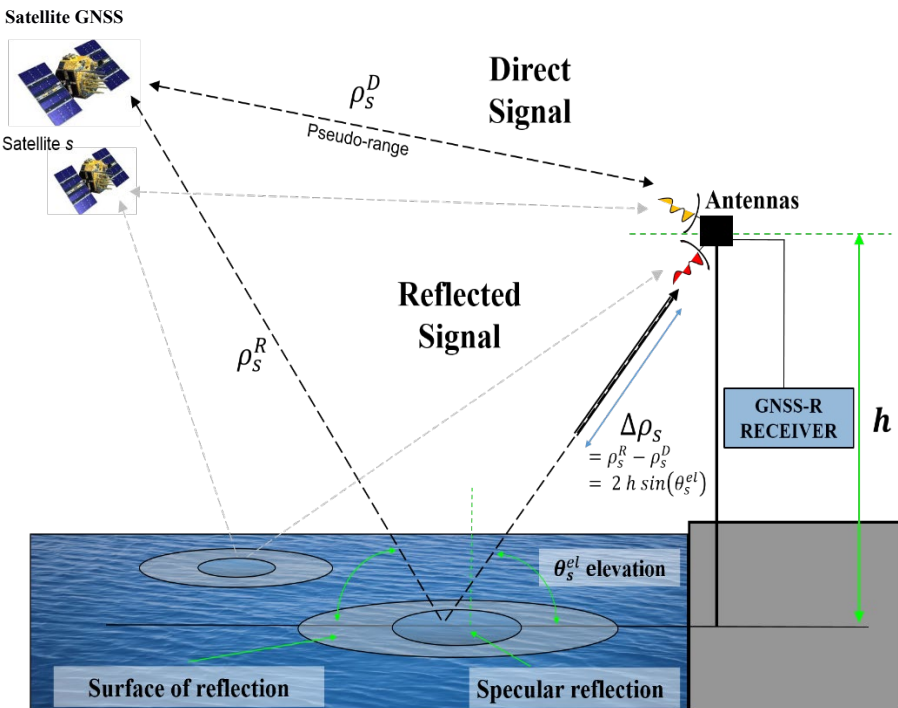
J-C KUCWAJ, G. STIENNE, S. REBOUL, J. -B. CHOQUEL, M. BENJELLOUN, **Accurate pseudo-range estimation by means of code and phase delay integration : Application to GNSS-R Altimetry**, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (JSTARS), 9(10), pp. 4854-4864, 2016.

M.A. RIBOT, J-C KUCWAJ, C. BOTTERON, S. REBOUL, G. STIENNE, J. LECLERE, J. -B. CHOQUEL, P.-A. FARINE, M. BENJELLOUN, **Normalized GNSS Interference Pattern Technique for Altimetry**, Sensors, 14, pp. 10234-10257, 2014. Article réalisé en collaboration avec l'EPFL.

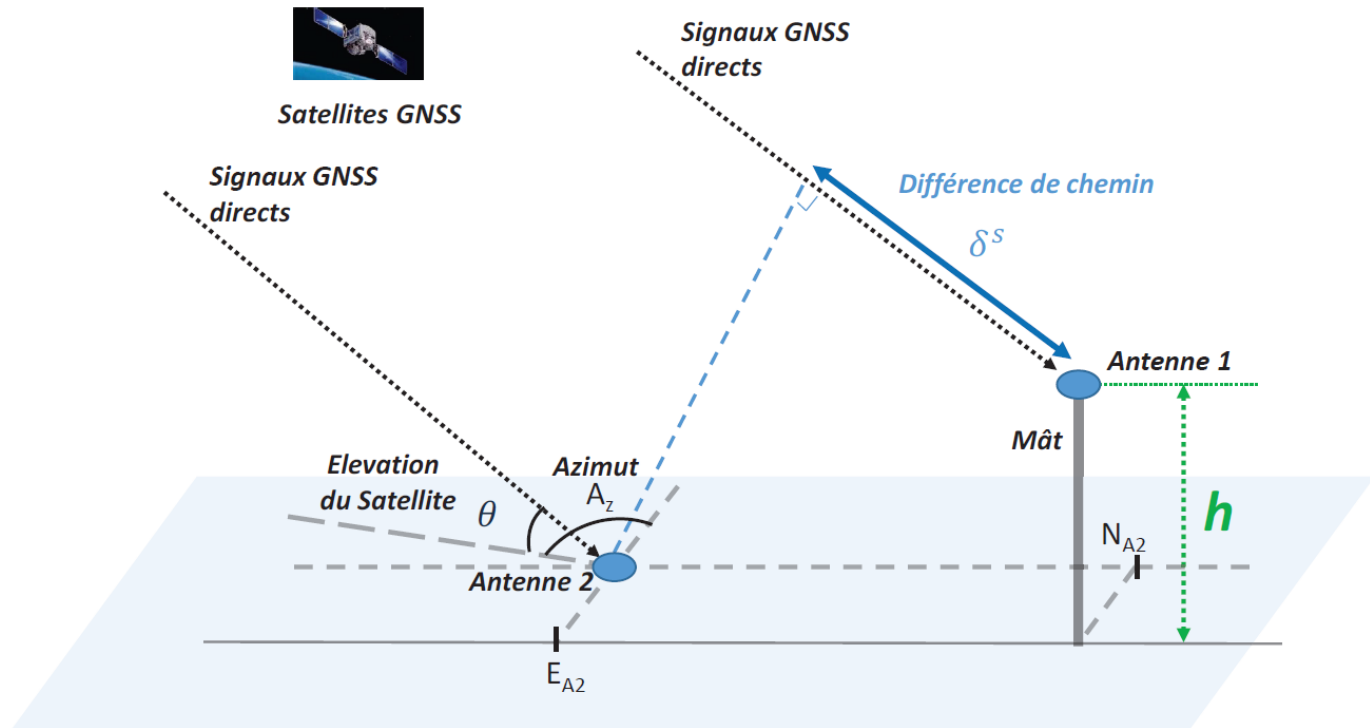
ALTIMÉTRIE PAR LA PHASE

Reflectometry approach

Buoy approach



POSITIONNEMENT PRÉCIS I

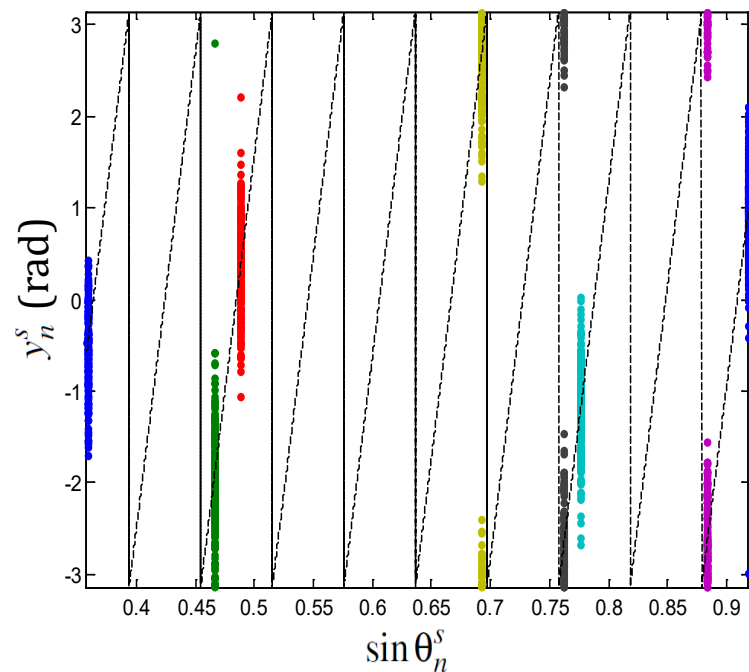
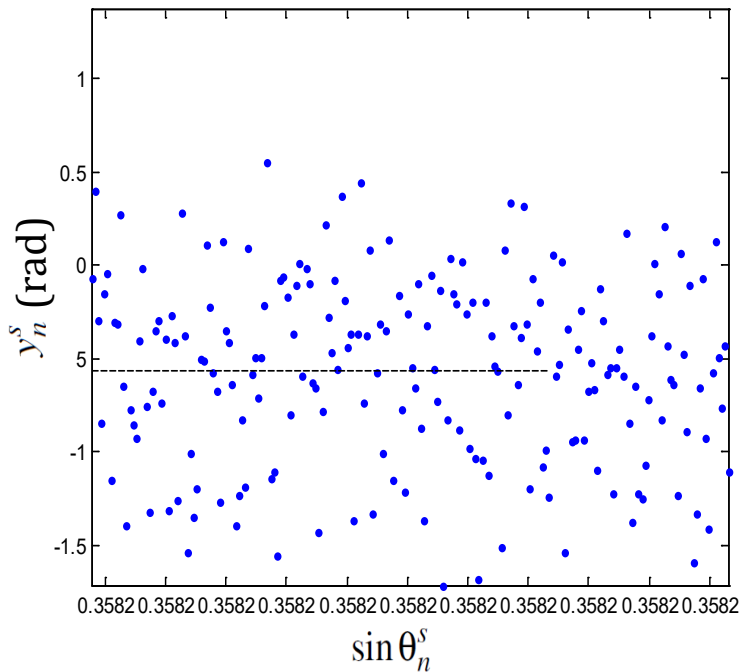


$$\delta_n^s = (N_{A2} \cos \theta_n^s \cos A_{z_n^s} + E_{A2} \cos \theta_n^s \sin A_{z_n^s} - h \sin \theta_n^s) + \xi_n^s$$

$$y_n^s = \left[\frac{2\pi}{\lambda} (N_{A2} \cos \theta_n^s \cos A_{z_n^s} + E_{A2} \cos \theta_n^s \sin A_{z_n^s} - h \sin \theta_n^s) + \xi_n^s \right] \text{mod}(2\pi)$$

POSITIONNEMENT PRÉCIS II

$$y_n^s = \left[\frac{2\pi}{\lambda} (\cancel{N_{AZ} \cos \theta_n^s \cos Az_n^s} + \cancel{E_{AZ} \cos \theta_n^s \sin Az_n^s} - h \sin \theta_n^s) + \xi_n^s \right] \text{mod}(2\pi)$$



POSITIONNEMENT PRÉCIS III

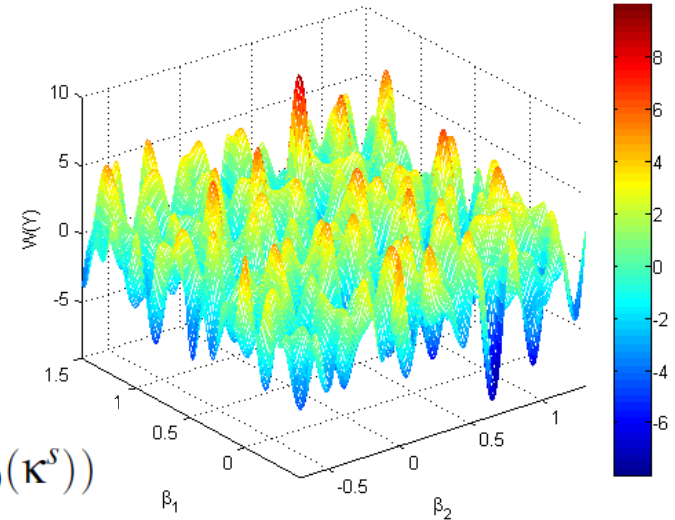
Modèle : $y_n^s = (\alpha + \sum_j \beta_j x_n^{j,s} + \xi_n^s) \bmod (2\pi)$

Approche du maximum de vraisemblance :

$$L(Y) = \prod_{s=1}^S \prod_{n=1}^N \frac{1}{2\pi I_0(\kappa^s)} \exp(\kappa^s \cos(y_n^s - (\alpha + \sum_j \beta_j x_n^{j,s})))$$

Paramètre de concentration

$$\ln(L(Y)) = \underbrace{\sum_{s=1}^S \sum_{n=1}^N \kappa^s \cos(y_n^s - (\alpha + \sum_j \beta_j x_n^{j,s}))}_{W(Y)} - N \sum_{s=1}^S \ln(2\pi I_0(\kappa^s))$$



Initialisation : Grid Search

Par annulation de la dérivée de $\ln(L(Y))$, on trouve les estimées :

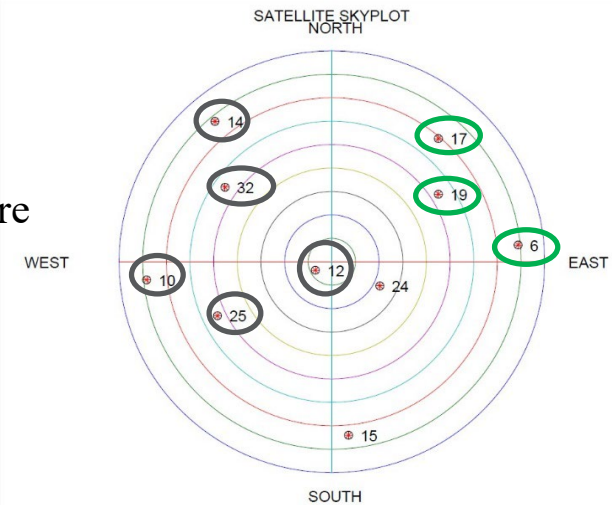
$$\hat{\kappa}^s = A^{-1} \left(\frac{\sum_{n=1}^N \cos(y_n^s - (\alpha + \sum_j \beta_j x_n^{j,s}))}{N} \right) \quad \hat{\alpha} = \text{atan2} \left(\frac{\sum_{s=1}^S \sum_{n=1}^N \kappa^s \sin(y_n^s - \sum_j \beta_j x_n^{j,s})}{\sum_{s=1}^S \sum_{n=1}^N \kappa^s \cos(y_n^s - \sum_j \beta_j x_n^{j,s})} \right)$$

$[\hat{\beta}_1, \dots, \hat{\beta}_P]$ sont obtenues par descente de gradient.

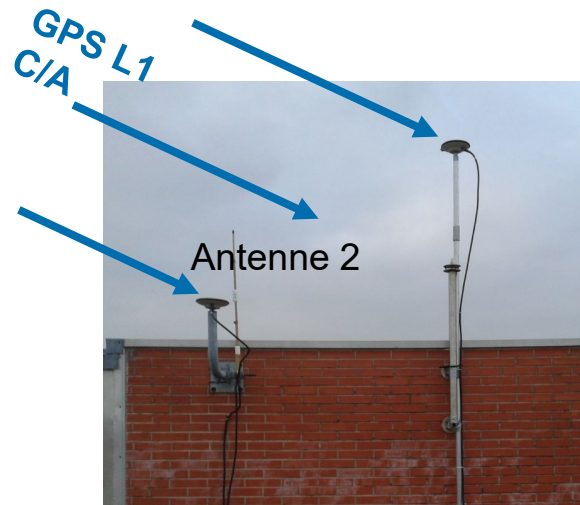
POSITIONNEMENT PRÉCIS IV

Constellation de satellites	C/N_0 (dB.Hz)	Intégration time (ms)	$CRLB(\hat{N}_{A2})$ (cm)	$STD(\hat{N}_{A2})$ (cm)	$CRLB(\hat{E}_{A2})$ (cm)	$STD(\hat{E}_{A2})$ (cm)	$CRLB(\hat{h})$ (cm)	$STD(\hat{h})$ (cm)
Côté Nord-Est	40	100	0.26	0.27	0.13	0.14	0.36	0.36
	35	180	0.37	0.37	0.19	0.19	0.52	0.53
	30	500	0.37	0.40	0.19	0.20	0.51	0.53
Côté Ouest	40	17	0.27	0.28	0.22	0.22	0.25	0.25
	35	25	0.43	0.44	0.35	0.35	0.40	0.40
	30	60	0.45	0.49	0.38	0.42	0.43	0.46
Quatre cadrans	40	9	0.21	0.21	0.16	0.16	0.19	0.19
	35	11	0.37	0.37	0.28	0.29	0.33	0.33
	30	15	0.53	0.58	0.41	0.43	0.48	0.51

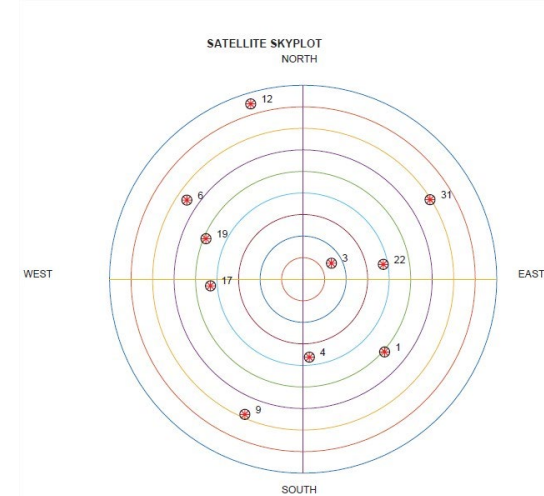
- Plus le bruit est important plus le temps d'intégration augmente
- Plus on a de satellites visibles moins le temps d'intégration nécessaire est important



POSITIONNEMENT PRÉCIS IV



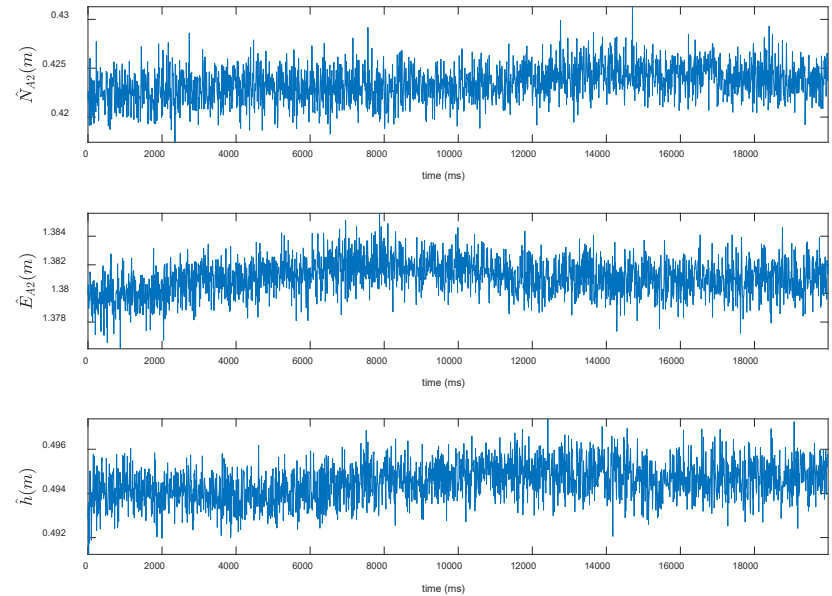
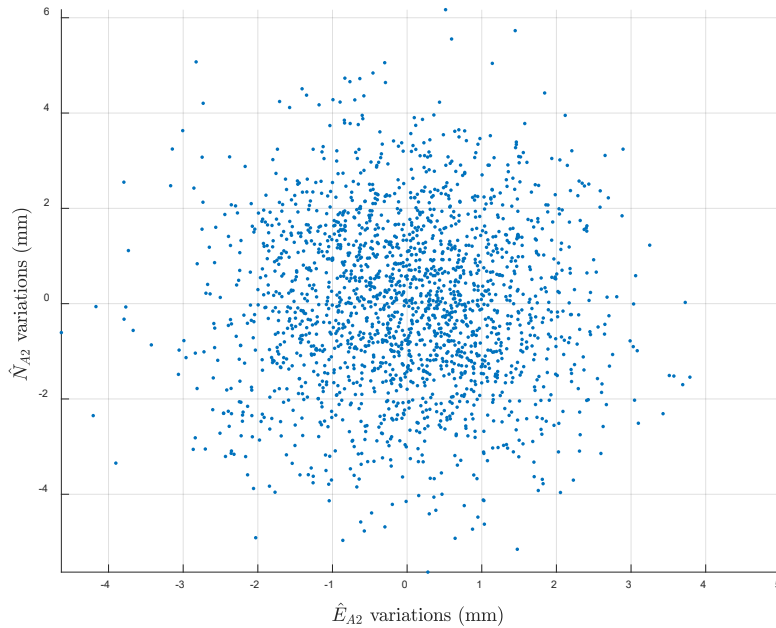
- 10 satellites utilisés, 20s de signal
- Temps d'intégration : 9 ms
soit 22222 points



Positions recherchées : $N_{A_2}=42.01\text{cm}$, $E_{A_2}=138.78\text{cm}$, $h=49.69\text{cm}$
(estimation GNSS RTK)

PRN	1	3	4	6	9	12	17	19	22	31
A_z (°)	133.63	65.32	173.26	-55.34	-155.95	-19.99	-99.59	-72.51	81.45	54.17
θ^s (°)	35.53	71.15	57.78	28.16	25.49	5.30	45.68	42.02	48.59	20.41
C/N_0 (dB Hz)	47.63	53.07	49.67	46.01	46.26	43.32	49.97	49.60	50.33	47.26

POSITIONNEMENT PRÉCIS IV



Paramètre	Moyenne (cm)	Ecart-type (mm)
\hat{N}_{A2}	42.35	1.77
\hat{E}_{A2}	138.10	1.24
\hat{h}	49.45	0.86

Positions recherchées :

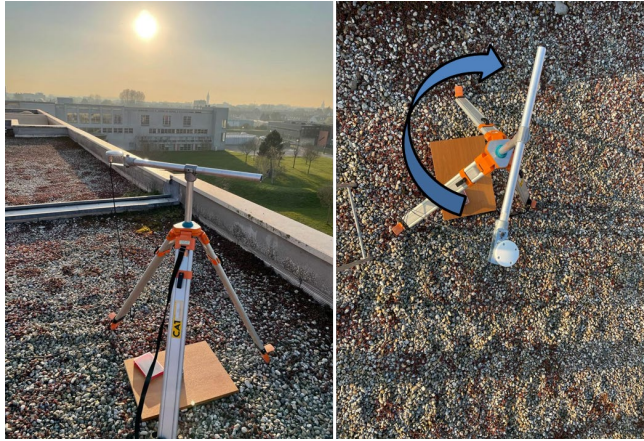
$N_{A2}=42.01\text{cm}$, $E_{A2}=138.78\text{cm}$, $h=49.69\text{cm}$

POSITIONNEMENT PRÉCIS IV

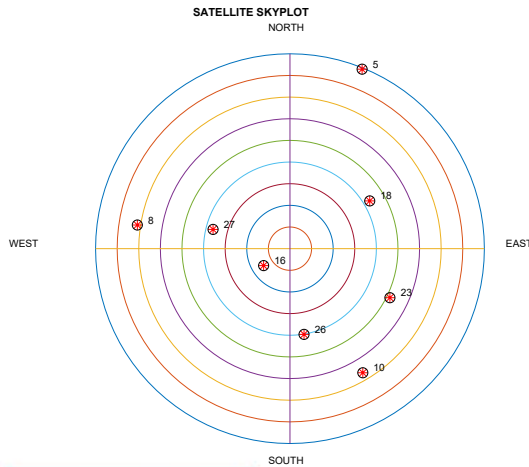
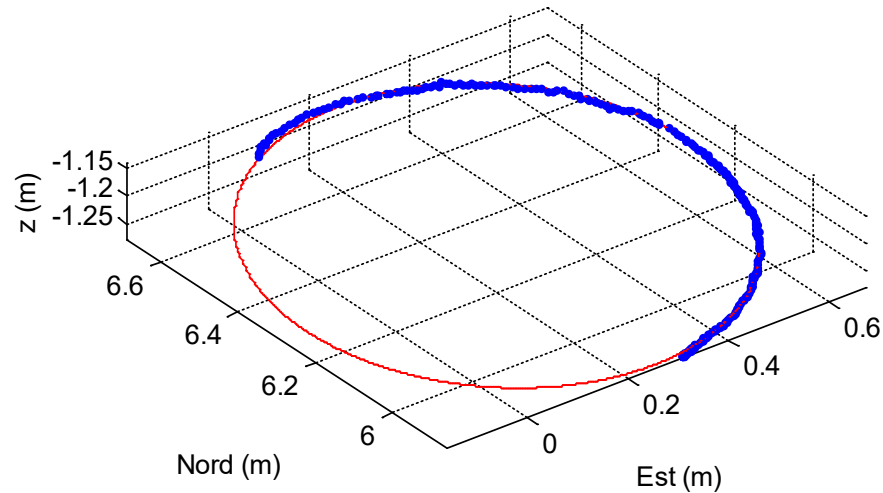
- Signaux acquis chaque jour pendant 9 jours
- 10 satellites utilisés
- Temps d'intégration : 9 ms

Jour du Mois	03	04	07	08	10	11	12	14	17
Temps (UTC)	13h12	13h15	13h14	13h12	13h11	13h12	13h10	13h13	13h15
$\hat{N}_{A2}(cm)$	43.17	42.88	43.29	42.41	43.28	42.49	43.24	42.17	43.03
$\hat{E}_{A2}(cm)$	138.66	137.88	138.62	137.79	138.56	138.46	138.49	138.00	138.30
$\hat{h}(cm)$	49.17	49.10	49.18	49.35	49.28	49.29	49.24	49.28	49.30
	\hat{N}_{A2}			\hat{E}_{A2}			\hat{h}		
Moyenne (cm)	42.89			138.31			49.25		
Ecart-type (mm)	4.20			3.30			0.80		

POSITIONNEMENT PRÉCIS IV

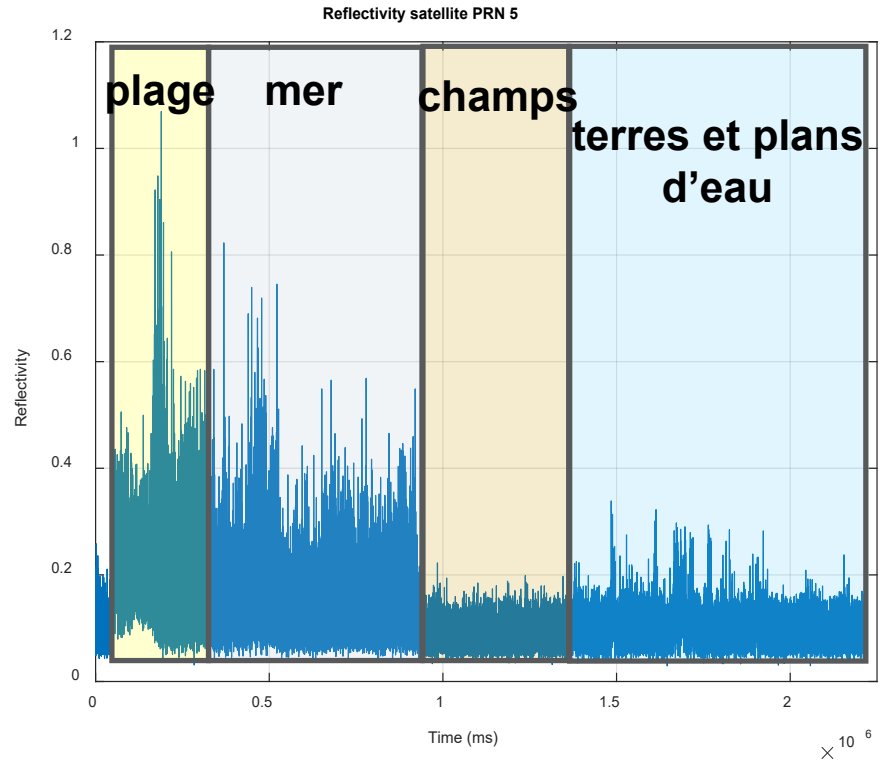
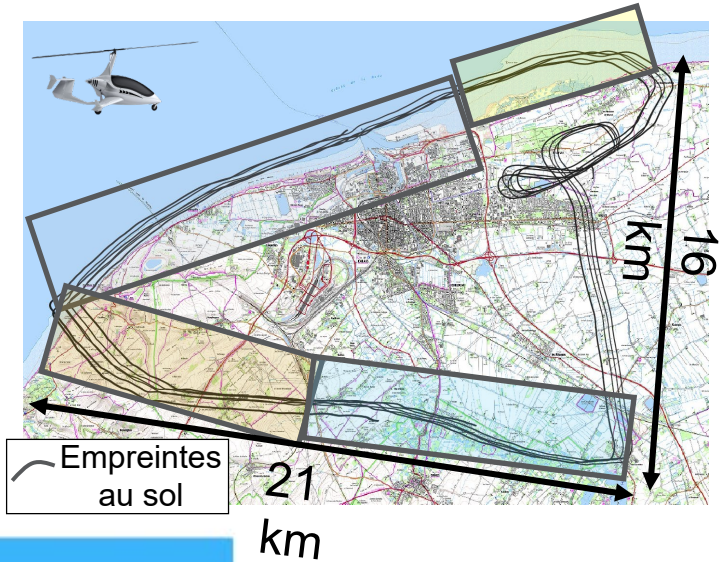
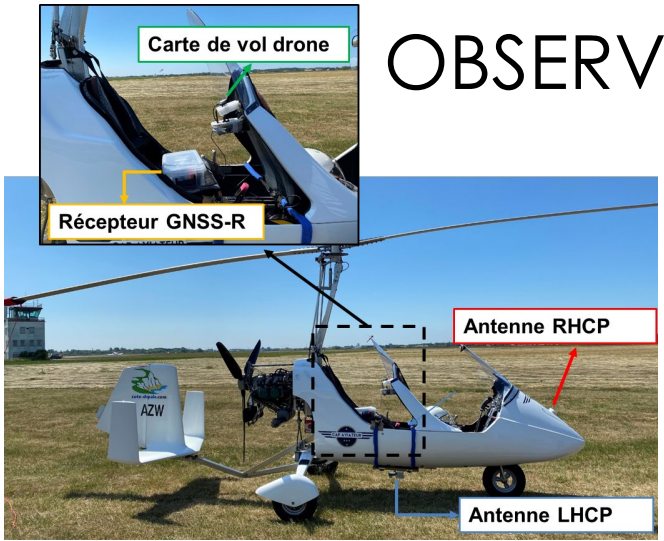


- 7 satellites utilisés, 5s de signal
- Temps d'intégration : 9 ms

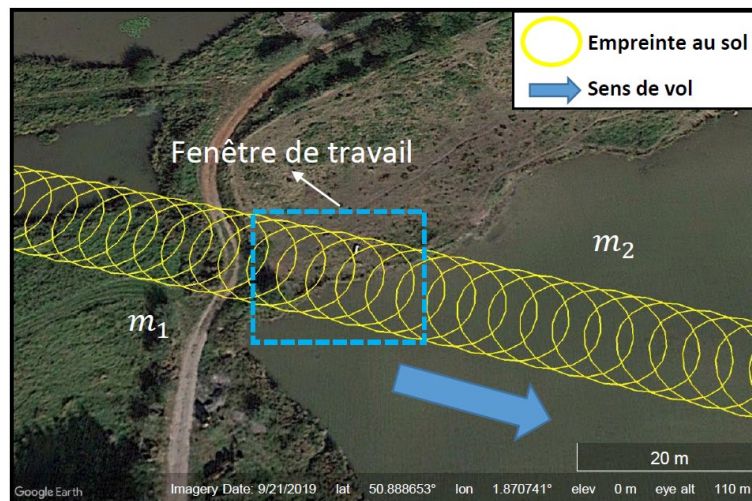
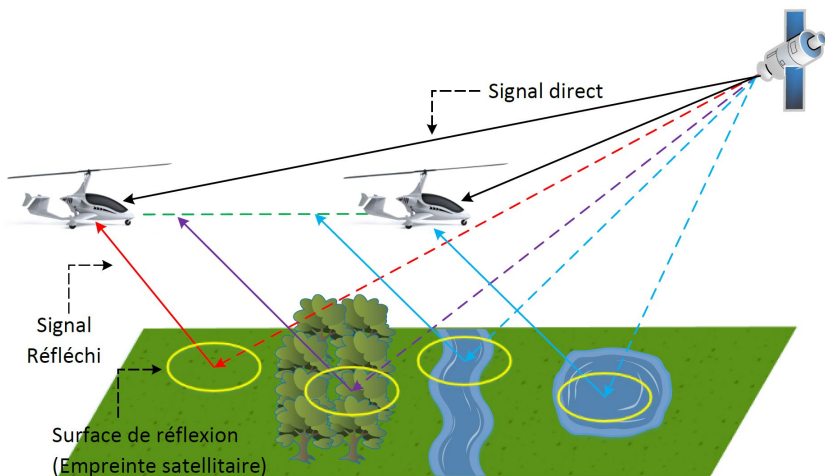


- Mesure in-situ : 42 cm
- Rayon du cercle : 41,58 cm
- Précision: 8,09 mm

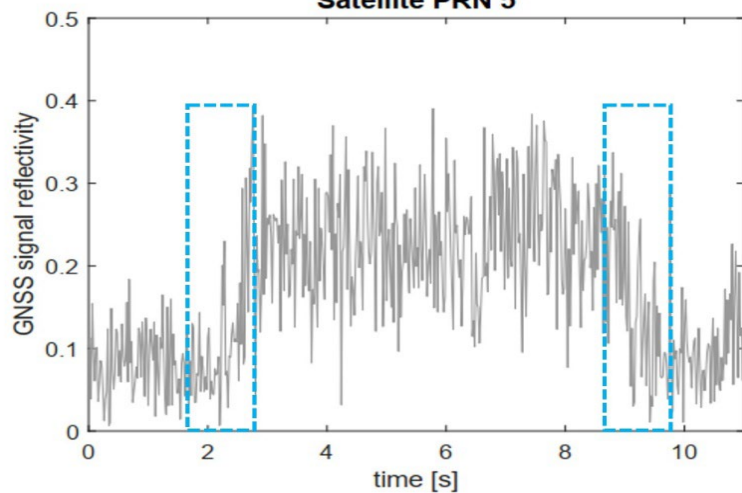
OBSERVATION RADAR GNSSR



OBSERVATION RADAR GNSSR



Satellite PRN 5



Problématiques :

- Transition lente : CUSUM
- Bruit multiplicatif : loi Log-gamma

OBSERVATION RADAR GNSSR

Réflexivité GNSS-R : modèle statistique

Mesure de réflectivité GNSS-R

$$R = \frac{T_r}{E(T_d)} = \frac{\frac{1}{N} \sum_{i=1}^N (I_r^2(0) + Q_r^2(0))}{a^2 + 2\sigma^2}$$

$$E(R) = \frac{E(T_r)}{E(T_d)} = \frac{2\sigma_r^2}{a^2 + 2\sigma^2} = \lambda$$

$$R(N, \lambda) \sim \text{Gamma}(N, \lambda/N)$$

$$V(R) = \frac{\lambda^2}{N}$$

Bruit de speckle multiplicatif

Log-transformation homomorphique

$$W(N, \lambda) = \log(R(N, \lambda))$$

$$E(W) = \Psi(N) + \log\left(\frac{\lambda}{N}\right)$$

$$V(W) = \Psi^{(1)}(N)$$

Digamma

Trigamma

OBSERVATION RADAR GNSSR

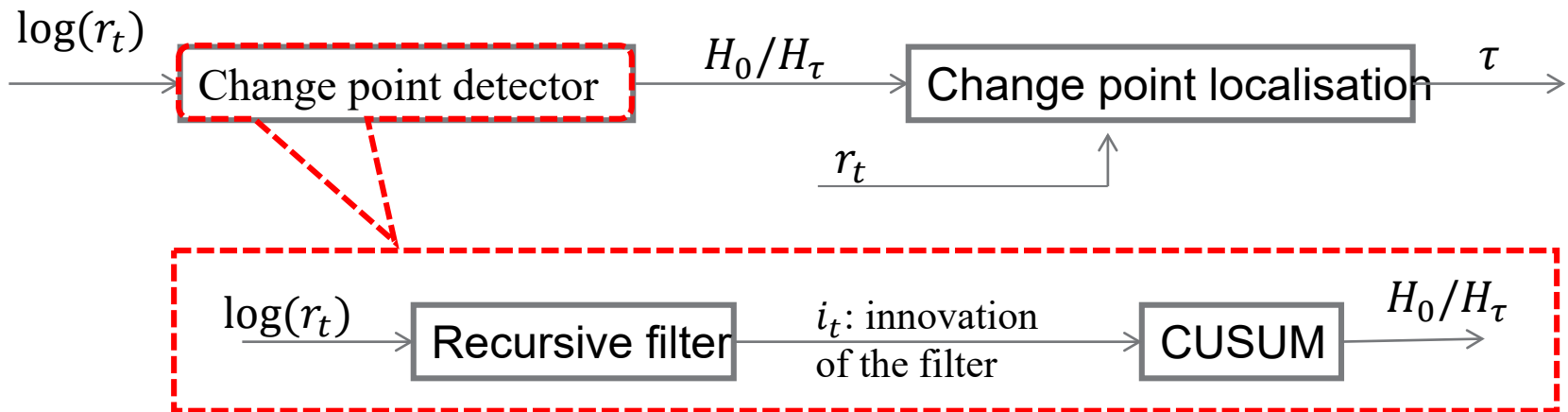
Change Point Analysis

Detection & Localization Approach

$$H_0 : R_t \sim \text{Gamma}(N, \lambda_0/N) \sim \forall t \in \{1, \dots, n\}$$

$$H_\tau : R_t \sim \text{Gamma}(N, \lambda_0/N) \sim \forall t \in \{1, \dots, \tau\}$$

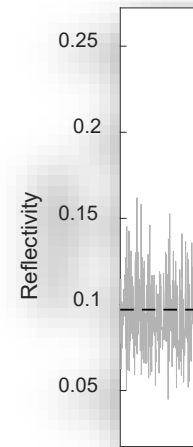
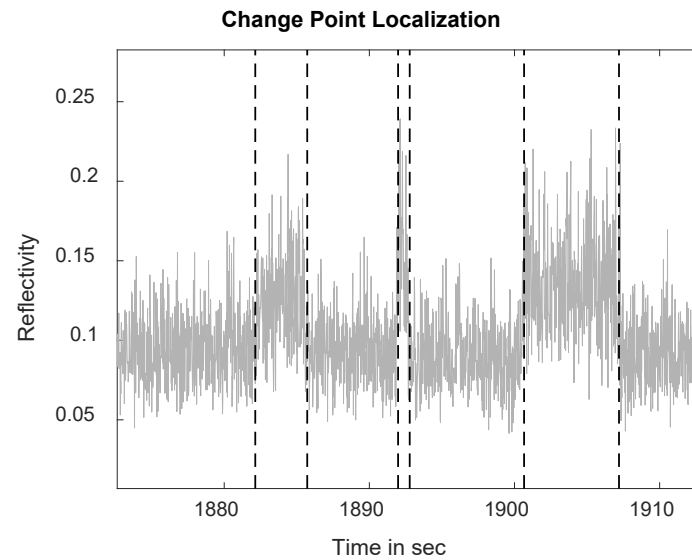
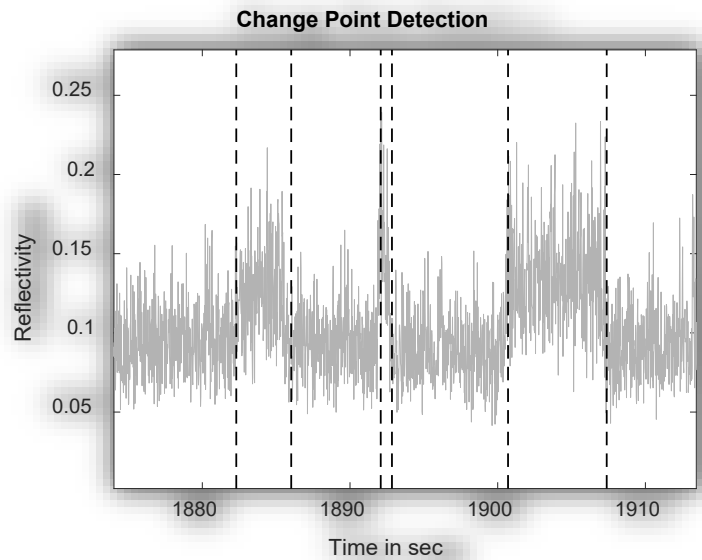
$$: R_t \sim \text{Gamma}(N, \lambda_1/N) \sim \forall t \in \{\tau + 1, \dots, n\}$$



As we use the Homomorphic transformation of the reflectivity :

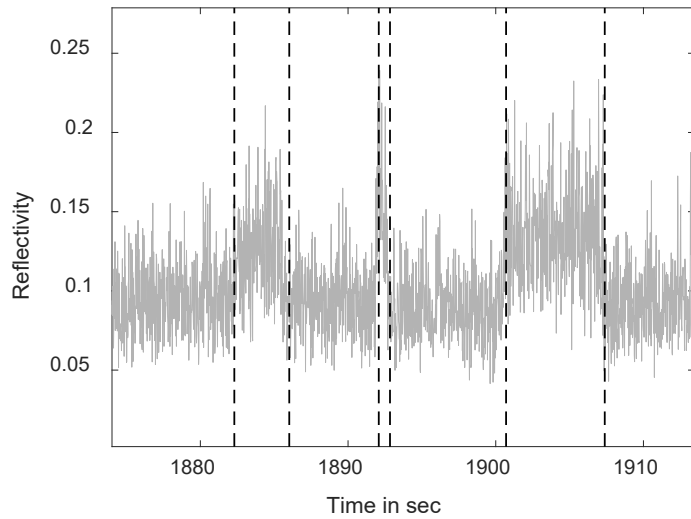
- Change point detection is defined with one threshold according to a false alarm rate.
- This threshold is for all signals of reflectivity processed with N values

Change Point Analysis

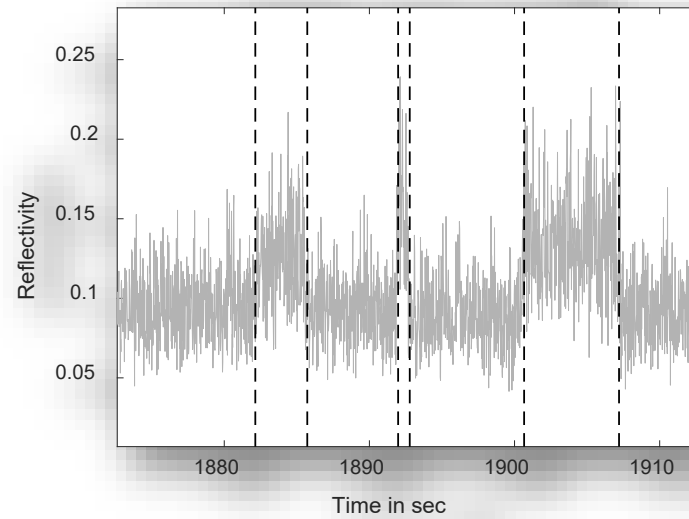


Change Point Analysis

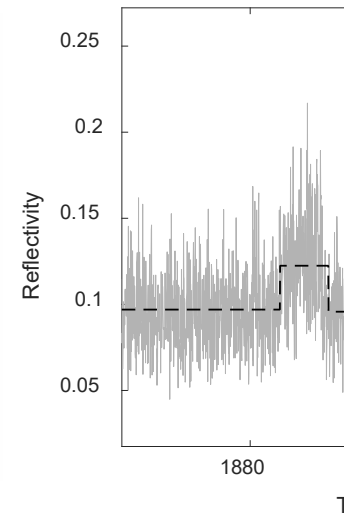
Change Point Detection



Change Point Localization

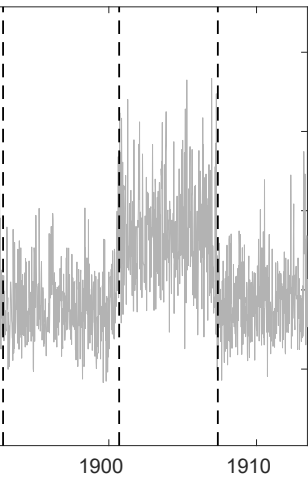


Se

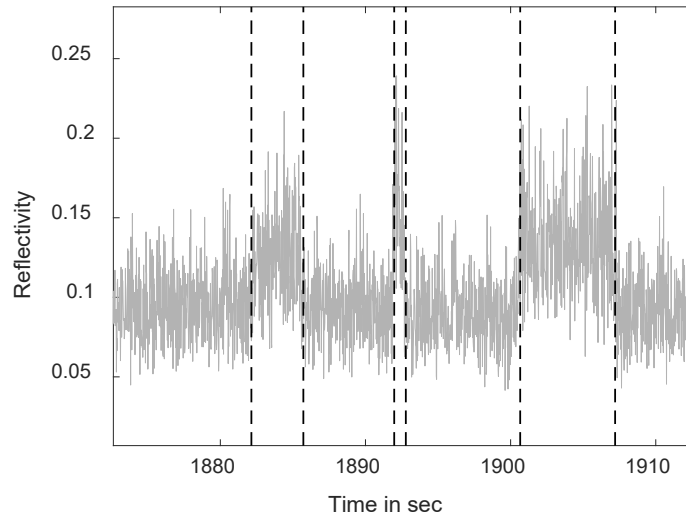


Change Point Analysis

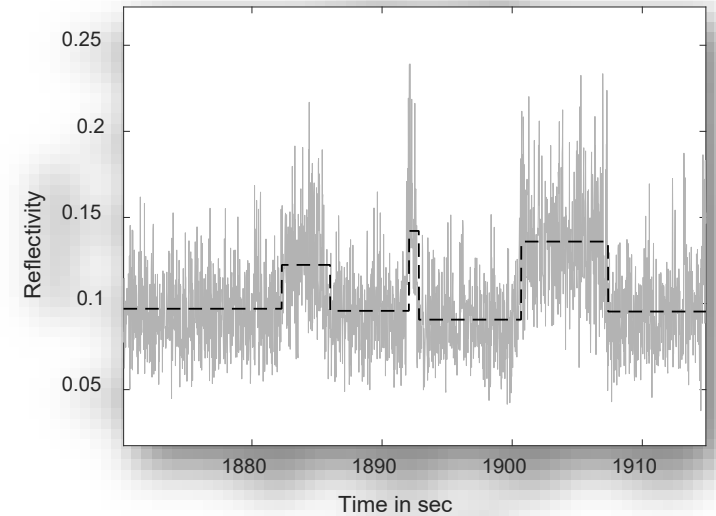
Detection



Change Point Localization



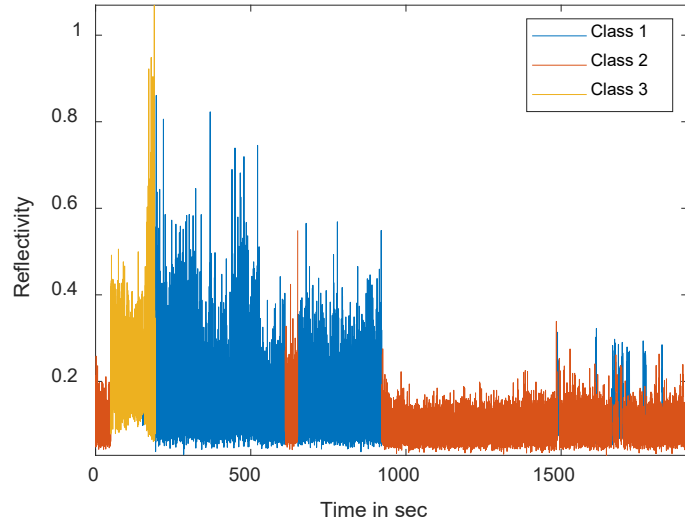
Segmentation



OBSERVATION RADAR GNSSR

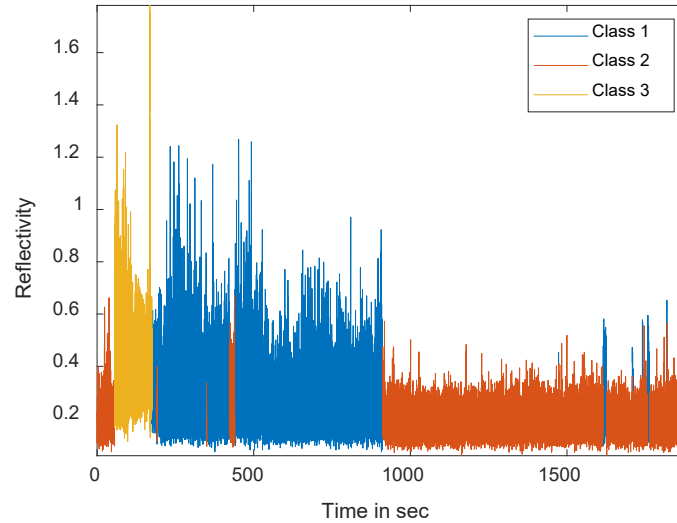
Clustering K-means

Signal Classification for PRN 5



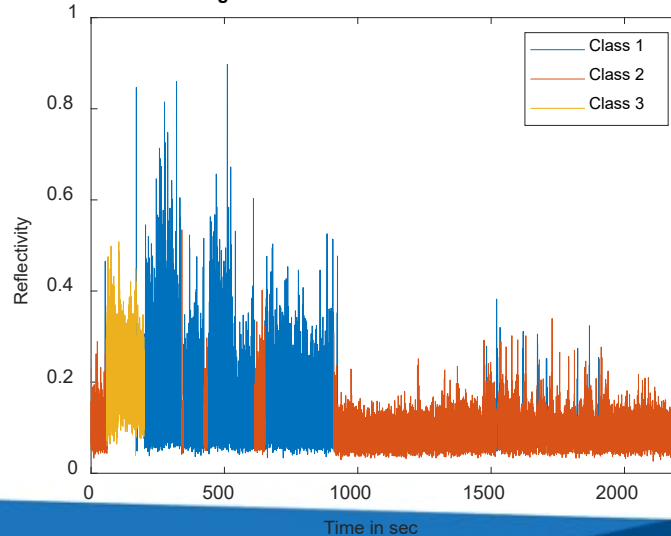
PRN 7 (élévation 64°)

Signal Classification for PRN 7



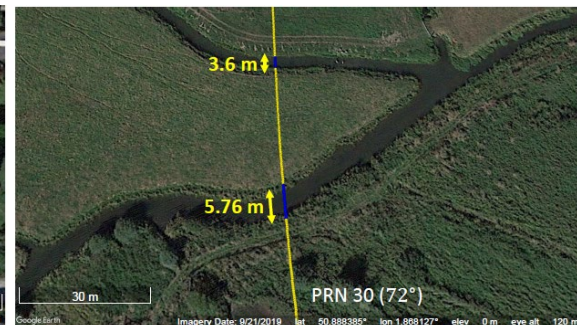
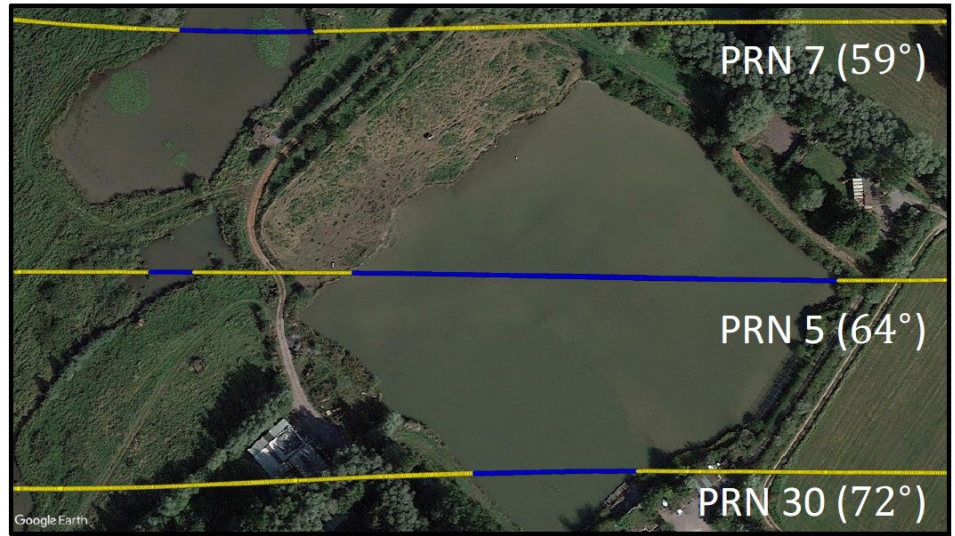
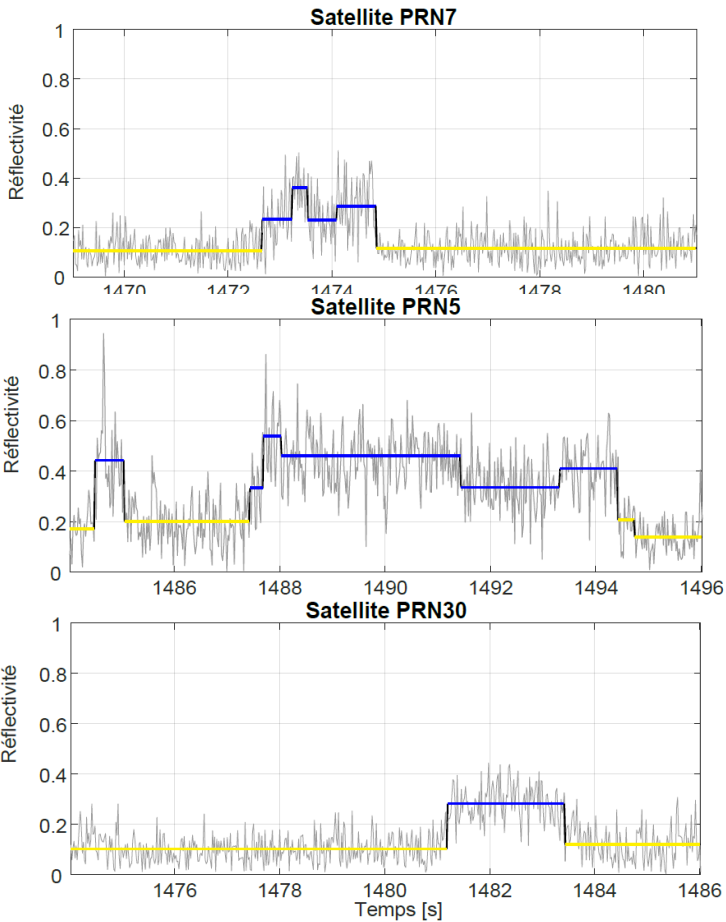
PRN 7 (élévation 59°)

Signal Classification for PRN 30



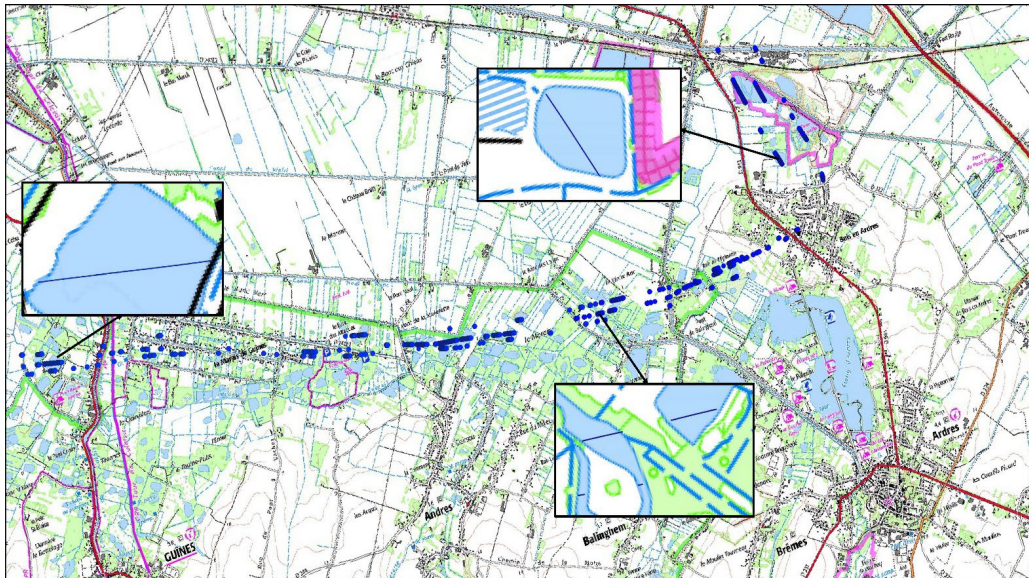
PRN 30 (élévation 72°)

OBSERVATION RADAR GNSSR



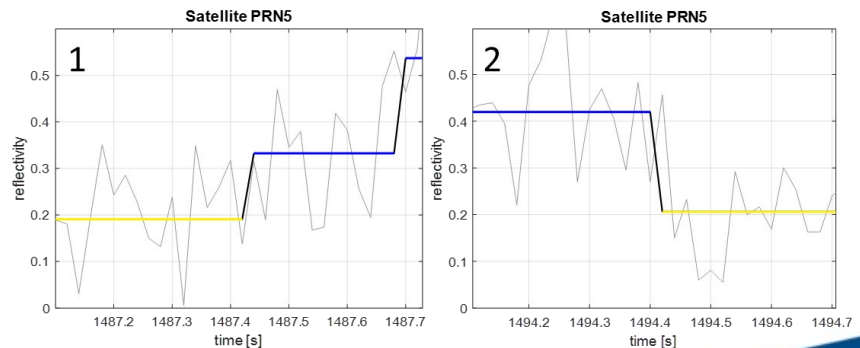
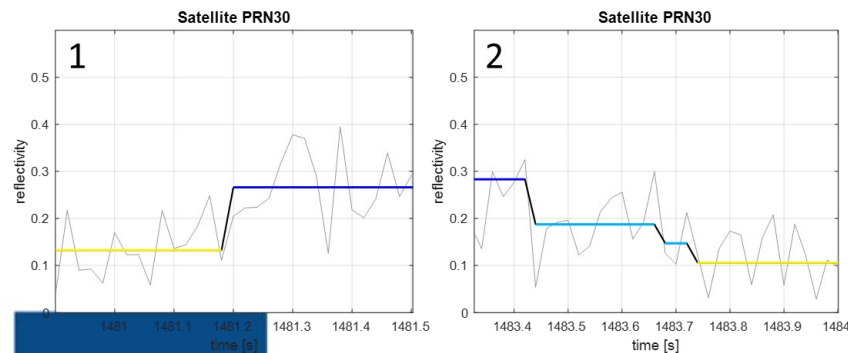
Water Body Detection

IGN maps provide up-to-date map schemes that clearly show the actual locations of the water body surfaces at the day of the experimentation.



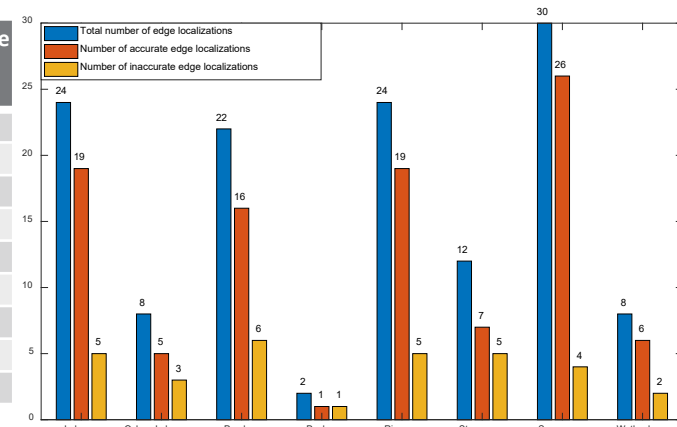
Water body	Number of surfaces using IGN maps	% of detection using our radar technique
Lakes/ Large Swamps	20	100%
Ponds/Swamps/Wetlands	17	94%
Rivers/Canals	4	100%
Streams/Brooks	6	83%
Total	47	96%

Water Body Edge Localization



Quantitative Analysis

Waterbody	Number of Detections	Accurate Edge Localizations	Mean Distance Localization Error (in meters)	Localization Difference Standard Deviation (in meters)
Lake	12	79.2%	0.59	0.69
Oxbow Lake	4	62.5%	1.86	1.47
Pond	11	72.7%	0.68	0.73
Pool	1	50.0%	0.82	0.41
River	12	79.2%	0.63	0.93
Stream/Brook	6	58.3%	1.75	1.38
Swamp	15	86.7%	0.36	0.50
Wetland	4	75.0%	0.99	1.12
Total	65	76.2%	0.96	0.90



PRN 5 (Elevation =65°, Azimuth= 280°)			
Waterbody	Number of Detections	Reflectivity - Mean	Reflectivity - Std
Lake	6	0.35	0.10
Oxbow Lake	1	0.37	0.12
Pond	6	0.32	0.10
Pool	1	0.30	0.11
River	4	0.28	0.08
Stream/Brook	2	0.24	0.09
Swamp	6	0.29	0.08
Wetland	1	0.27	0.11
Total	27	0.30	0.10

PRN 7 (Elevation =57°, Azimuth= 70°)			
Waterbody	Number of Detections	Reflectivity - Mean	Reflectivity - Std
Lake	2	0.28	0.10
Oxbow Lake	1	0.20	0.10
Pond	3	0.27	0.10
Pool	0	NA	NA
River	4	0.23	0.09
Stream\Brook	2	0.19	0.06
Swamp	5	0.26	0.09
Wetland	0	NA	NA
Total	16	0.24	0.09

PRN 30 (Elevation =73°, Azimuth= 145°)			
Waterbody	Number of Detections	Reflectivity - Mean	Reflectivity - Std
Lake	4	0.27	0.08
Oxbow Lake	2	0.24	0.09
Pond	2	0.30	0.10
Pool	0	NA	NA
River	4	0.27	0.09
Stream/Brook	2	0.21	0.06
Swamp	4	0.29	0.09
Wetland	3	0.25	0.10
Total	21	0.26	0.09

MERCI