

Analyse des vitesses verticales mesurées par couplage SENTINEL V ADCP / CTD durant la campagne FUMSECK

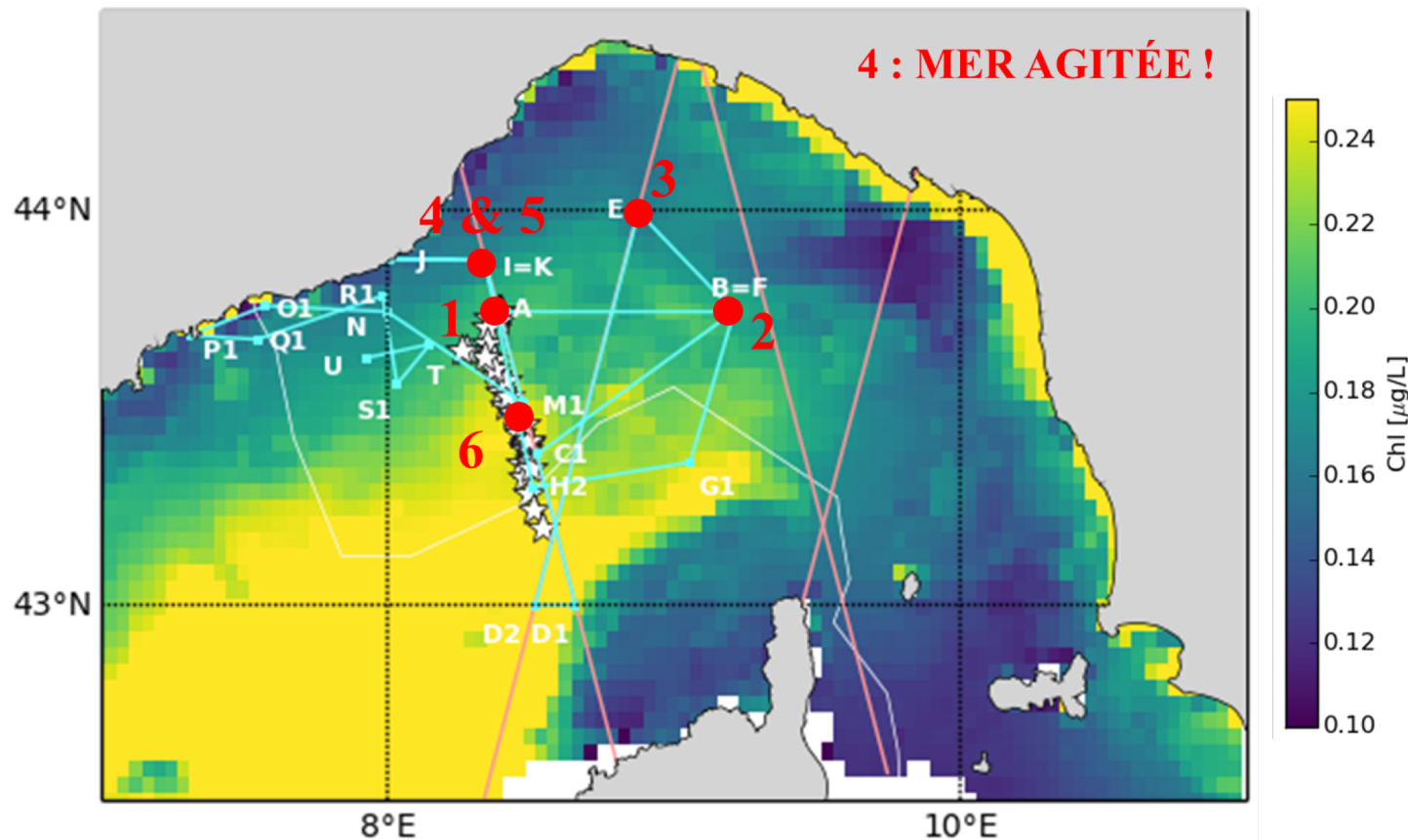
Caroline COMBY

Stage M1 Océanographie Physique et Biogéochimique – OSU Pythéas

20/05/2019 – 12/07/2019

Encadrement : **Barrillon, S.**, Petrenko, A., Doglioli, A., Fuda, J.-L.

Position des stations « Sentinel »



Conditions d'échantillonnage

- 6 stations (focus sur n°6)

- 3 phases d'acquisition

immersion fixe (10 m)
plongée (x3)
remontée (x3)

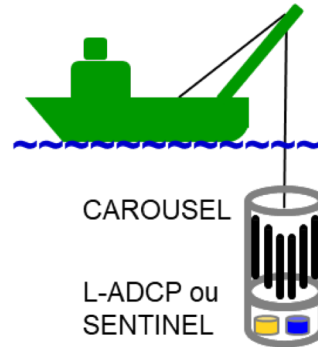
Récapitulatif du matériel utilisé et des données acquises

CTD

Acquisition haute fréquence
[24 Hz]

Précision dans la mesure
de la pression

Outil de
correction



ADCP (SENTINEL)

Acquisition basse fréquence [1 Hz]

ADCP 500 kHz → portée de la mesure ~40 m

Mesure de la vitesse verticale via un
5^{ème} faisceau (« *w from 5th beam* »)

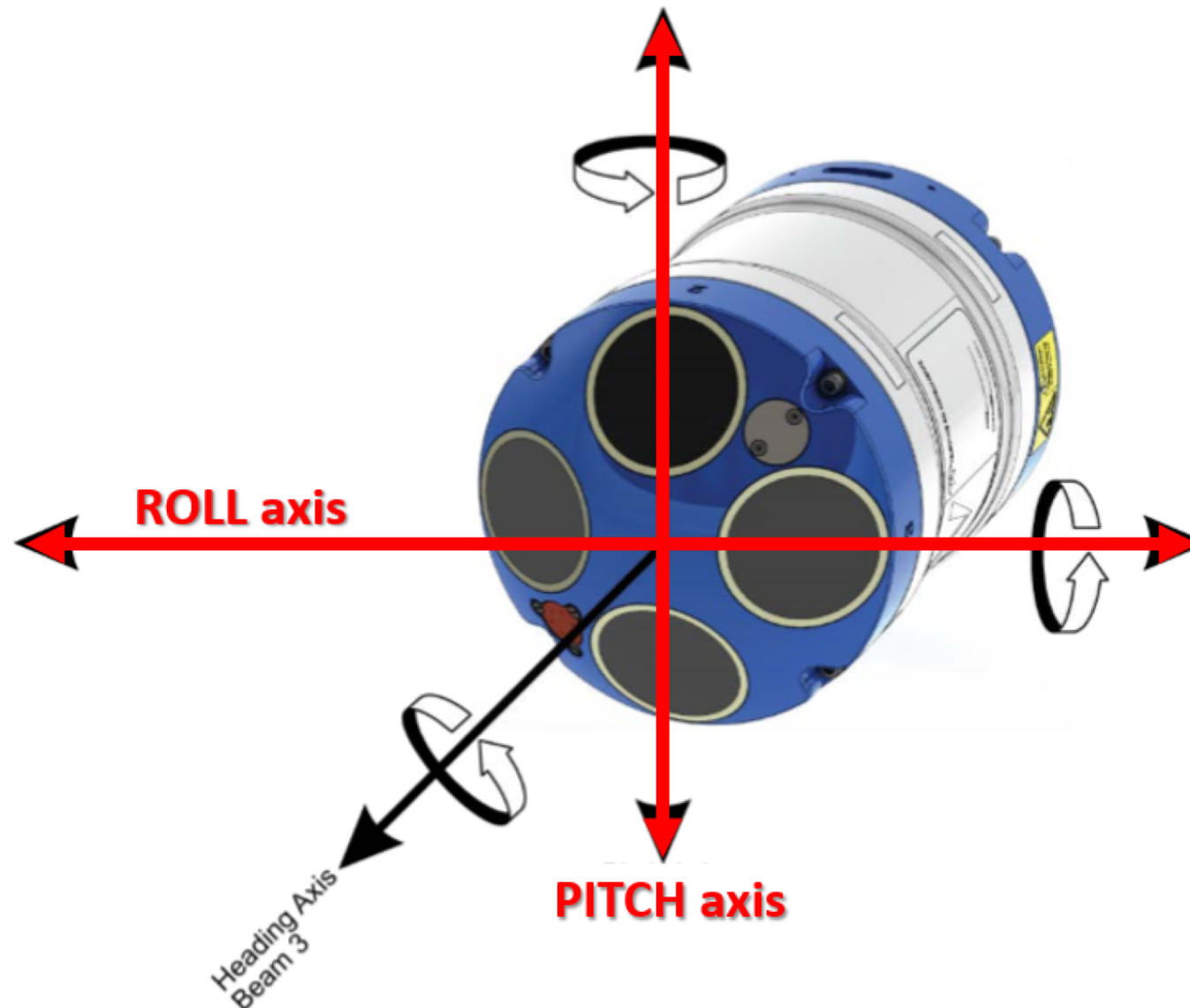
Estimation de la vitesse verticale via les
composantes horizontales (« *w from 4 beams* »)

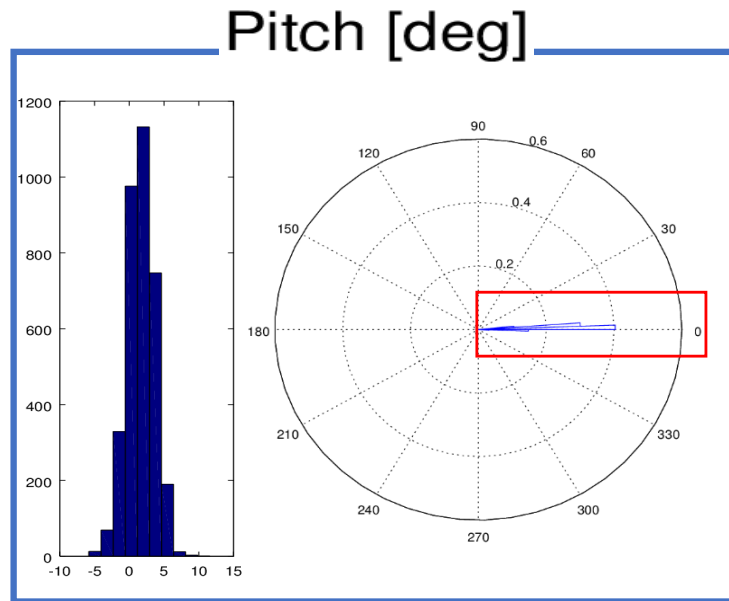
Outil de mesure



$$w_{\text{océan}} = w_{\text{mesurée}} - w_{\text{CTD}}$$

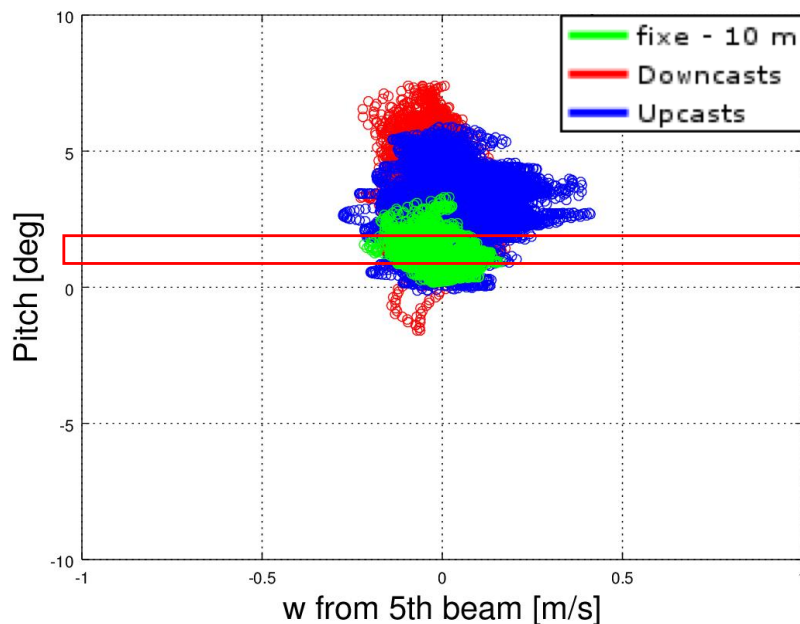
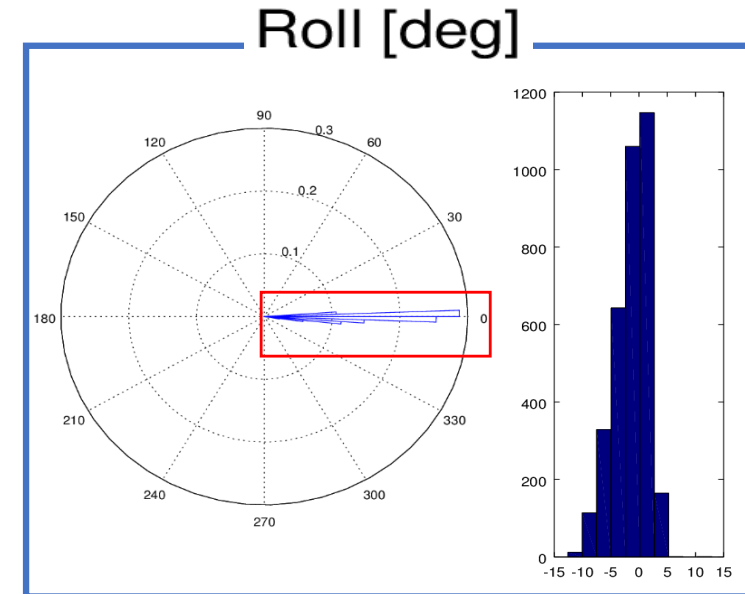
Étude du comportement des instruments



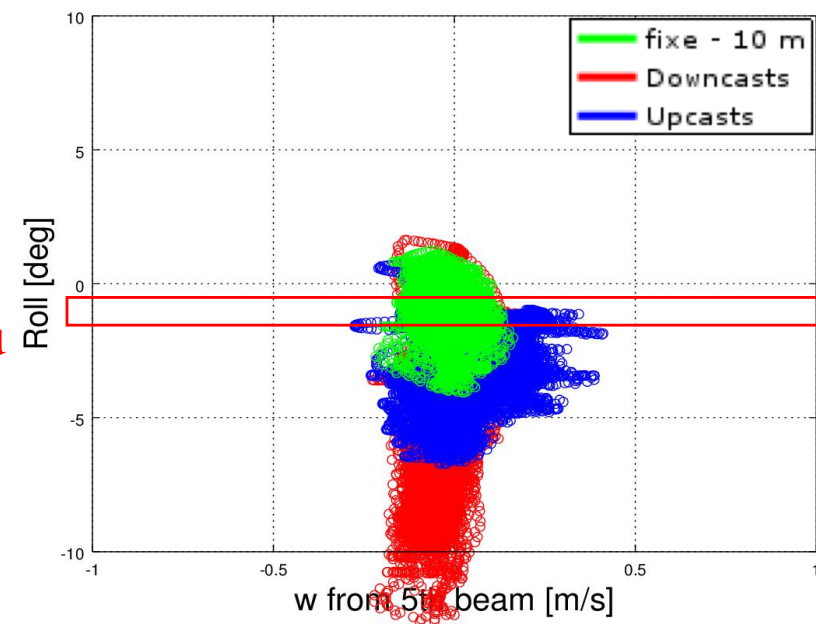


Angle d'orientation limité à environ 10°

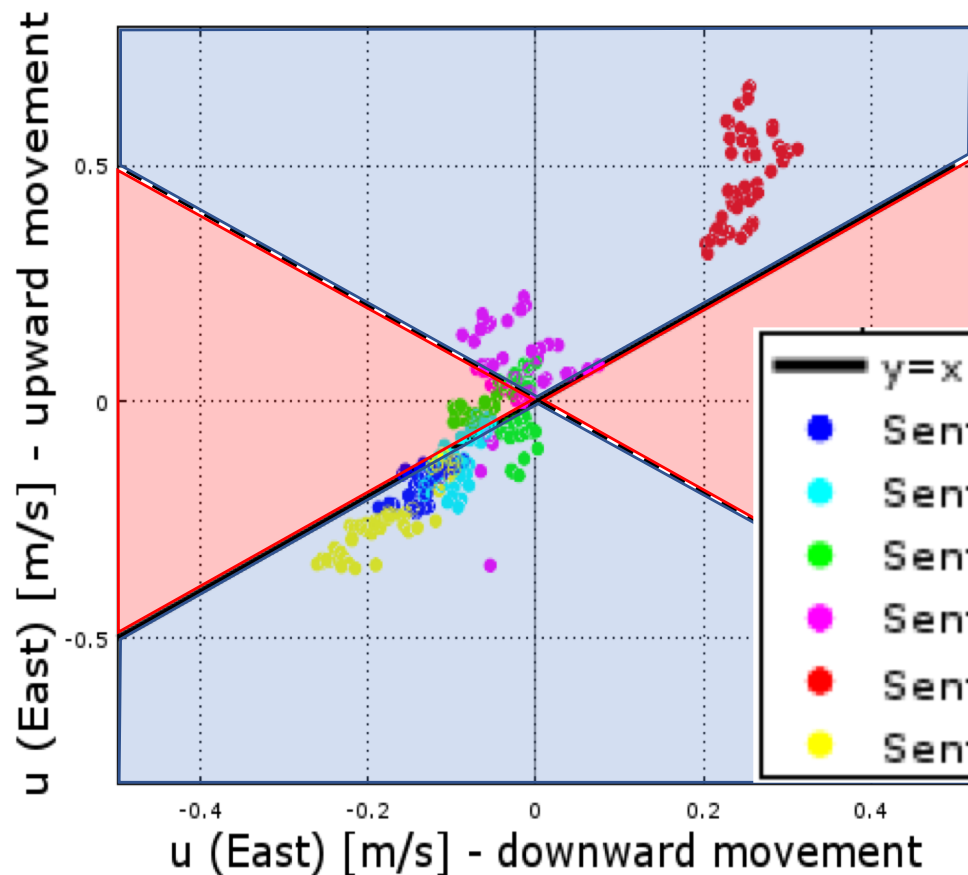
STATION 6



Pas de corrélation visible entre orientation du Sentinel et w mesurée



Upcast / Downcast et dérive du bateau



**Composante u
(positive vers l'Est)**

Dérive [km]

0.276

0.157

1.108

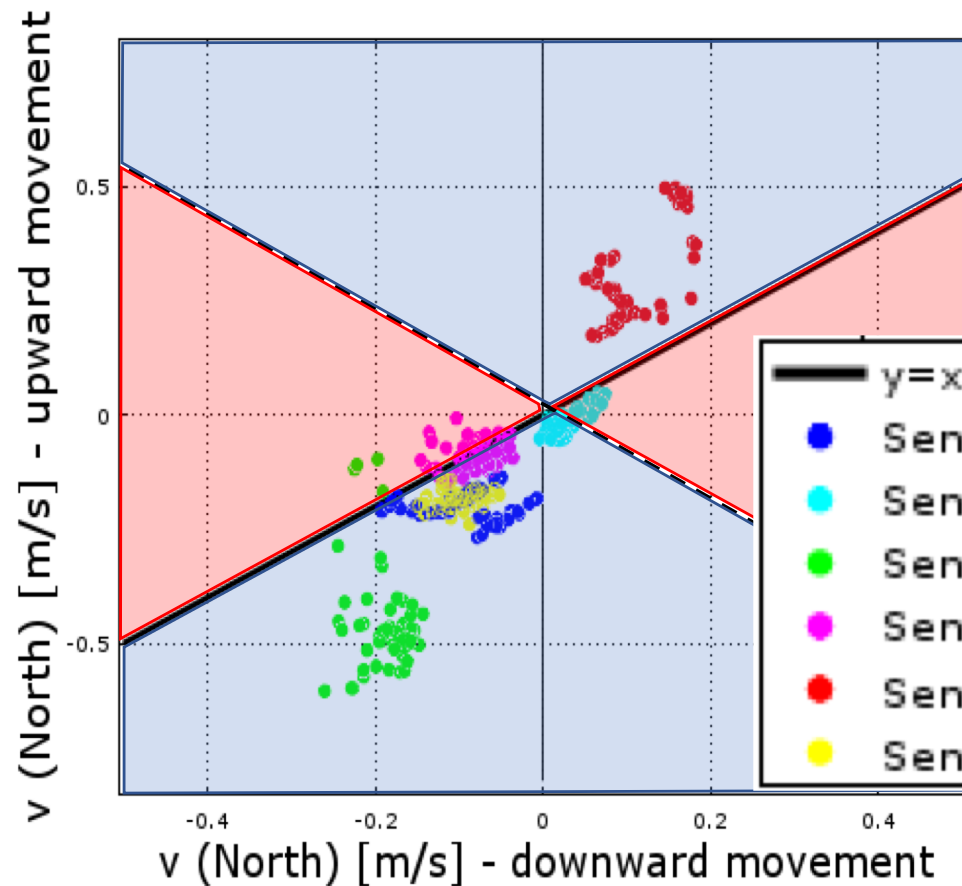
0.242

1.125

0.479

➡ **|Upcast| >> |Downcast|**

Upcast / Downcast et dérive du bateau



Composante v
(positive vers le Nord)

Dérive [km]

0.276

0.157

1.108

0.242

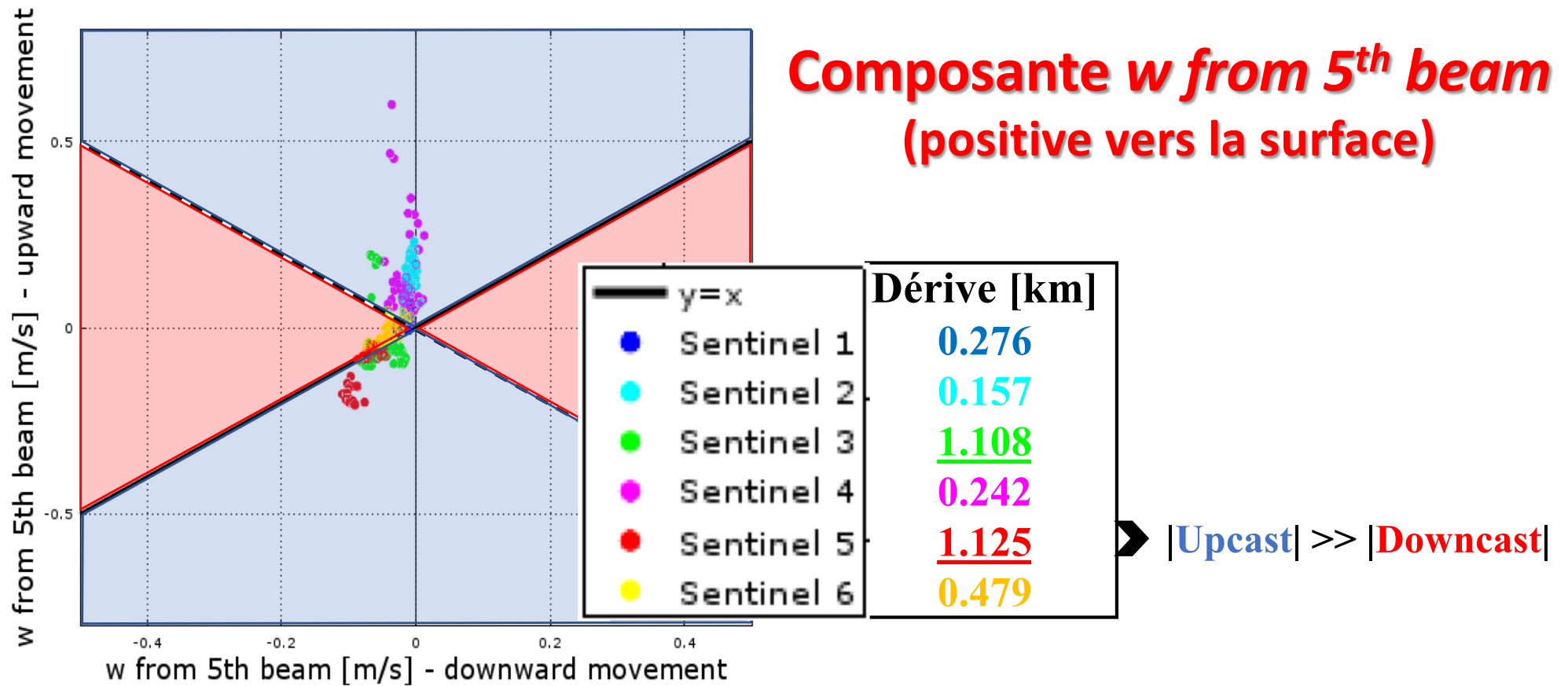
1.125

0.479

► |Upcast| >> |Downcast|

► |Upcast| >> |Downcast|

Upcast / Downcast et dérive du bateau



Principe de la correction

Utilisation des datasets Sentinel & CTD

Principe de base : $w_{\text{océan}} = w_{\text{mesurée}} - w_{\text{instruments}}$

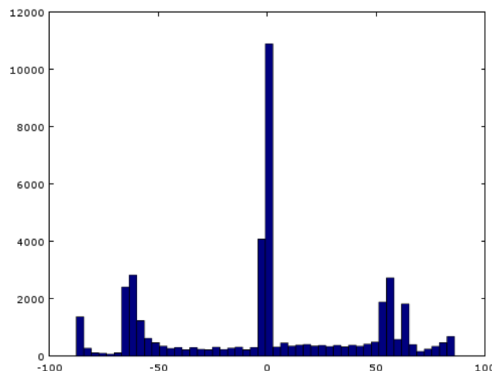
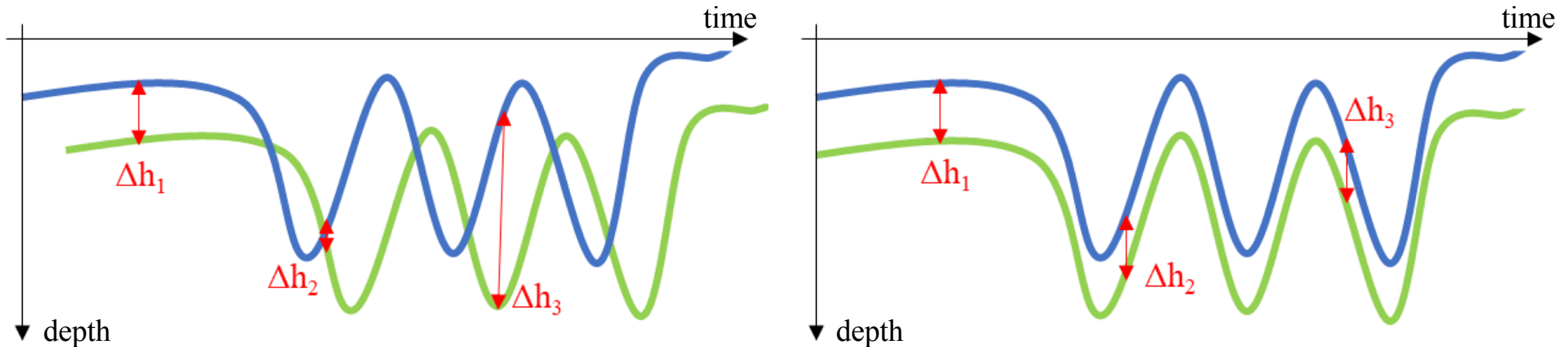
La séquence de données Sentinel (interpolée) est **calée automatiquement** sur celle de la CTD.

Les **vitesse**s calculées de la CTD sont **lissées** sur la période = 1 seconde

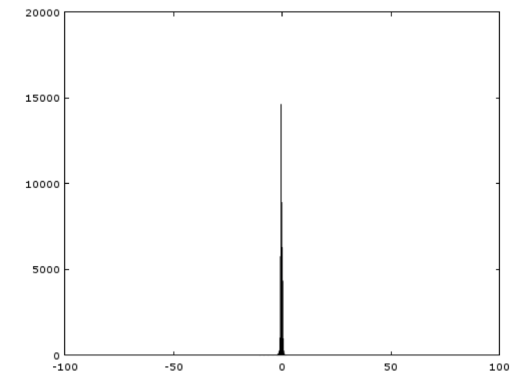
Les **mesures de w from 5th beam** et **w from 4 beams** sont **corrigées** de la part due au mouvement des instruments :

$$w_{\text{instruments}} = \frac{1}{\rho g} \frac{\partial p}{\partial t}$$

Ajustement automatique des datasets

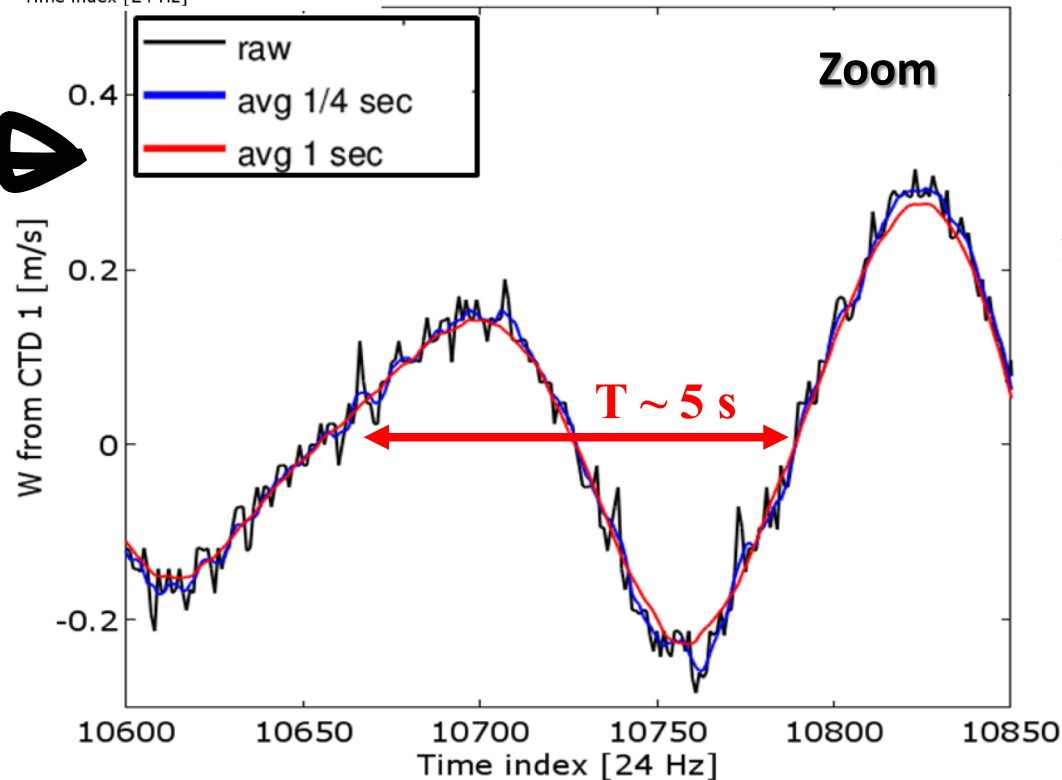
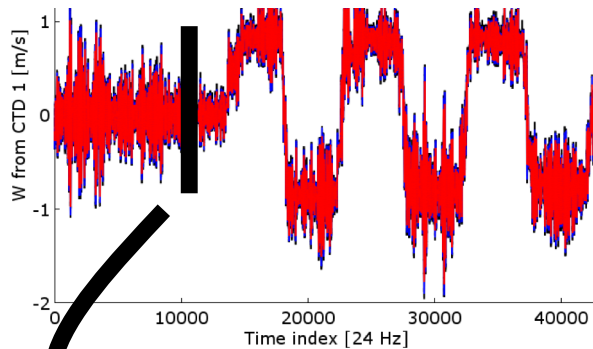


- Séquence **CTD** balayée par la séquence **SENTINEL**
- Différence de hauteur (Δh) pour chaque indice de temps
- Calcul : moyenne (μ) et écart-type (σ) de l'échantillon



σ minimum = index d'ajustement des séquences

Lissage des données haute fréquence



Raw data : échantillonnage 24 Hz
+ oscillation périodique + bruit

Principe du lissage appliqué :
moyenne mobile sur une fenêtre
de durée

→ **1/4 sec** : amplitude & bruit
conservés

→ **1 sec** : amplitude & bruit
réduits

Choix de la fenêtre sur 1 seconde :
Échantillonnage 24 Hz conservé + Bruit en grande partie éliminé

*Nettoyage des données adapté selon Thurnherr (2011)**

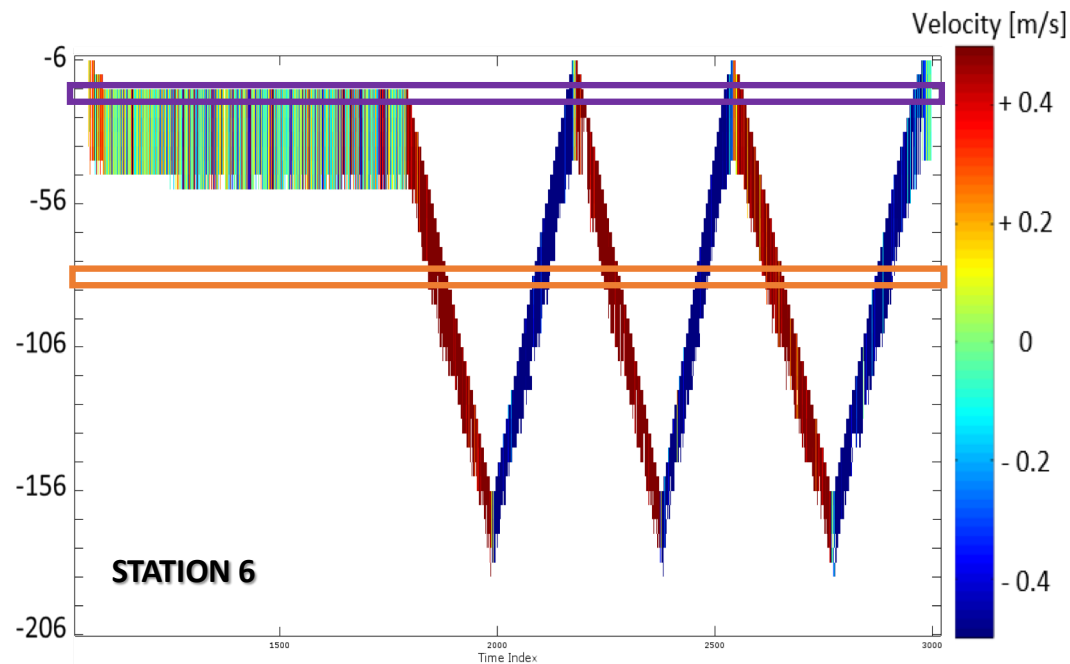
- **effectif** : nombre de mesures effectuées à une profondeur donnée (cellules de 5 m)
effectif < 10 → mesure non prise en compte
- « **tilts** » : mouvement de l'appareillage (*pitch, roll*) par rapport à la verticale (orientation Nord magnétique)
|tilts| > 10° → mesure non prise en compte
- « **error velocity** » : erreur sur la cohérence des estimations de w from 4 beams
error velocity > 0.1 m/s → mesure non prise en compte



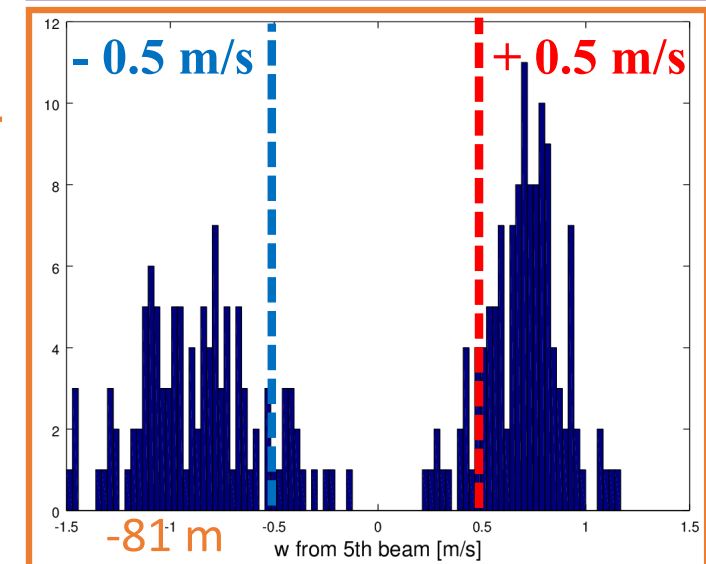
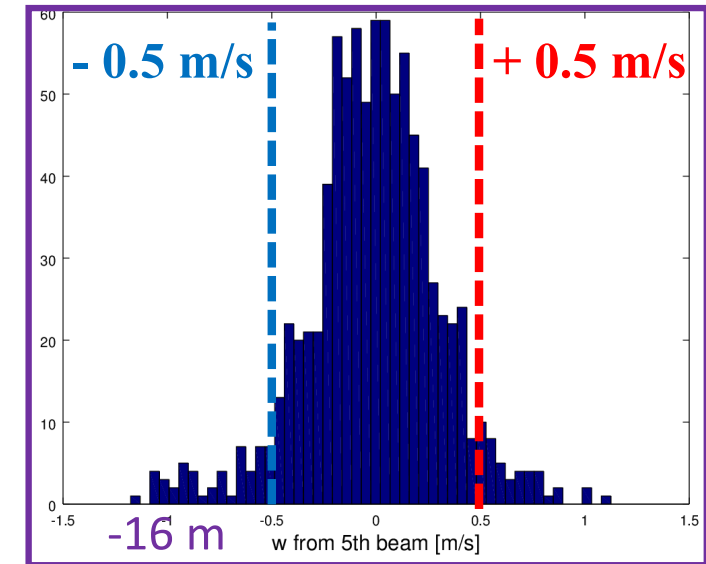
« **w corrected** » : mesure de w from 5th beam corrigée

w corrected > 0.1 m/s → mesure corrigée non prise en compte

* A. M. Thurnherr (2011). Vertical Velocity from LADCP Data. *Proceedings of the IEEE/OES/CWTM Tenth Working Conference on Current Measurement Technology*



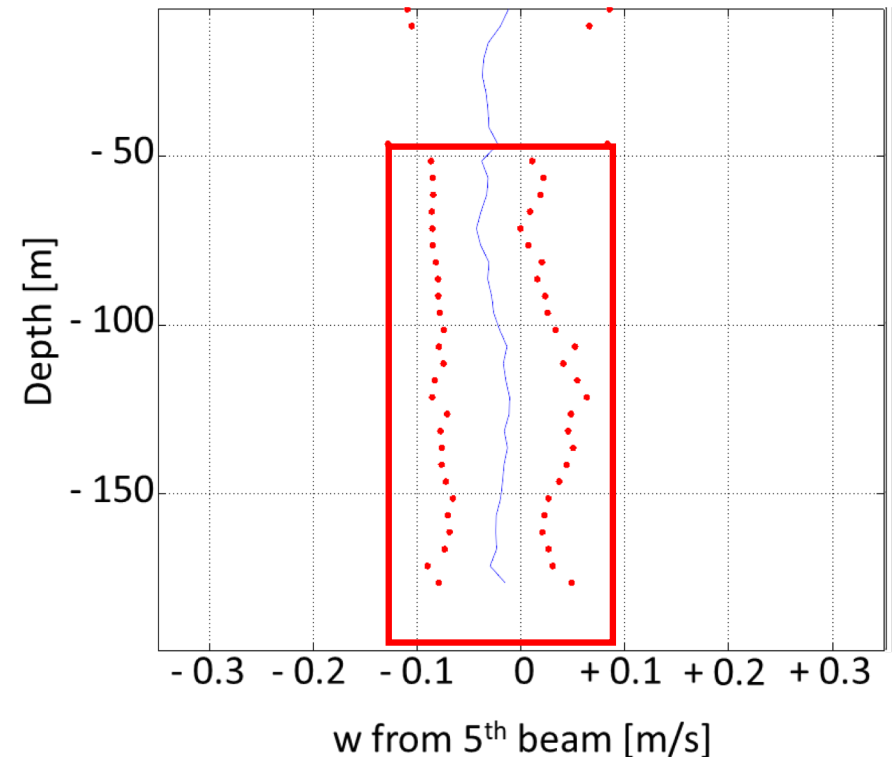
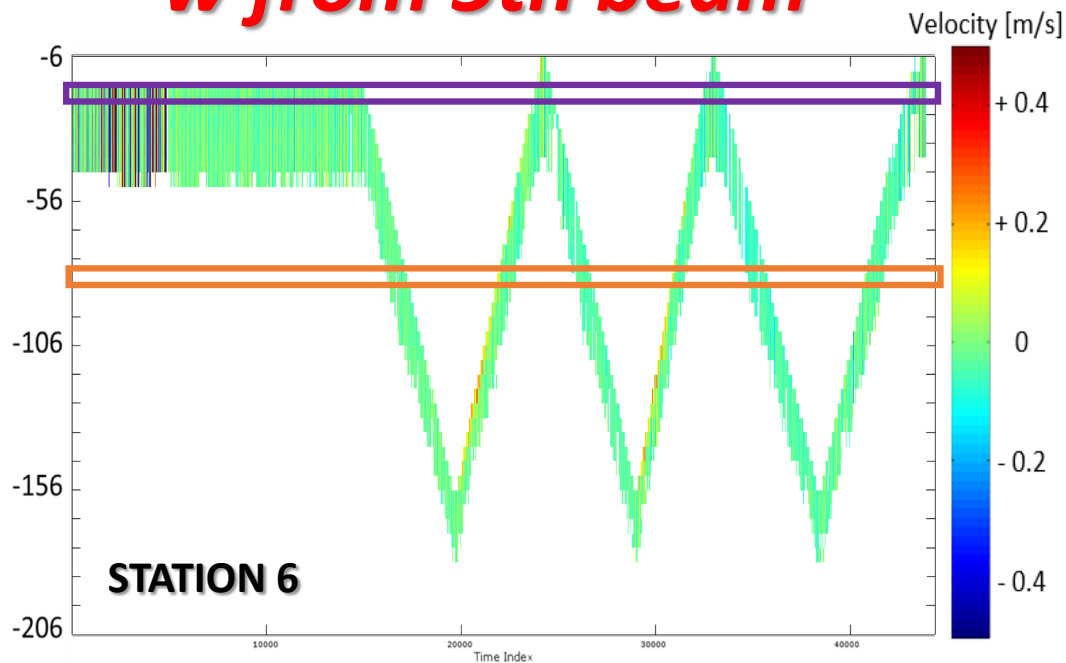
w raw data



Oscillations d'ordre
élevé
Effet de la houle +
autres
 $\pm 0.5 \text{ m/s}$

Oscillation d'ordre 0
Mouvement en
« yoyo » des
instruments
 $\pm 1 \text{ m/s}$

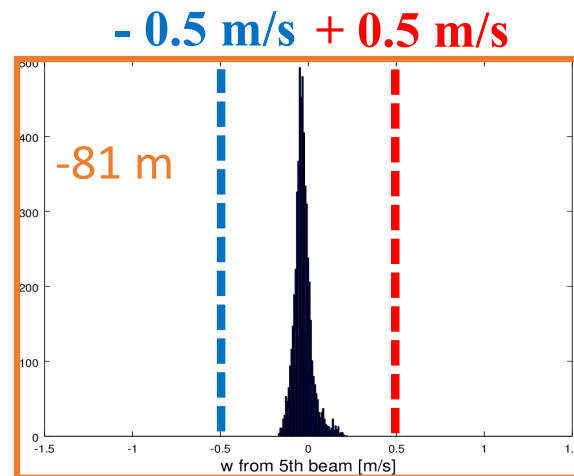
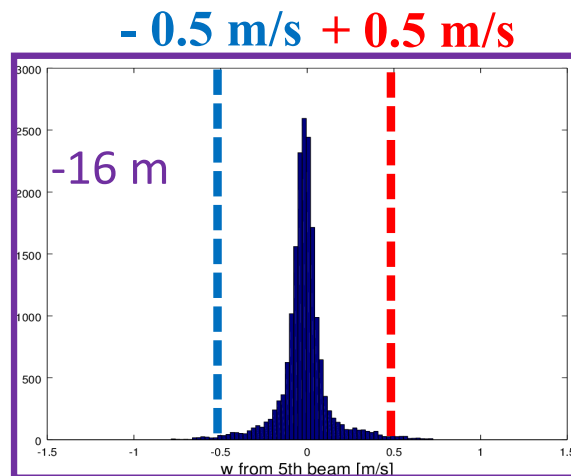
w from 5th beam



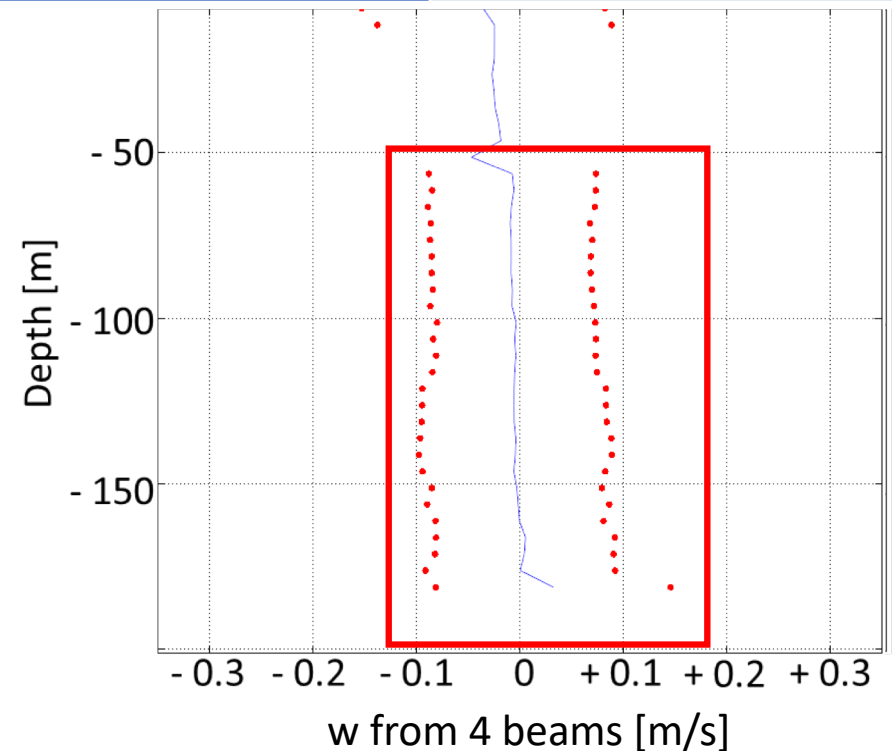
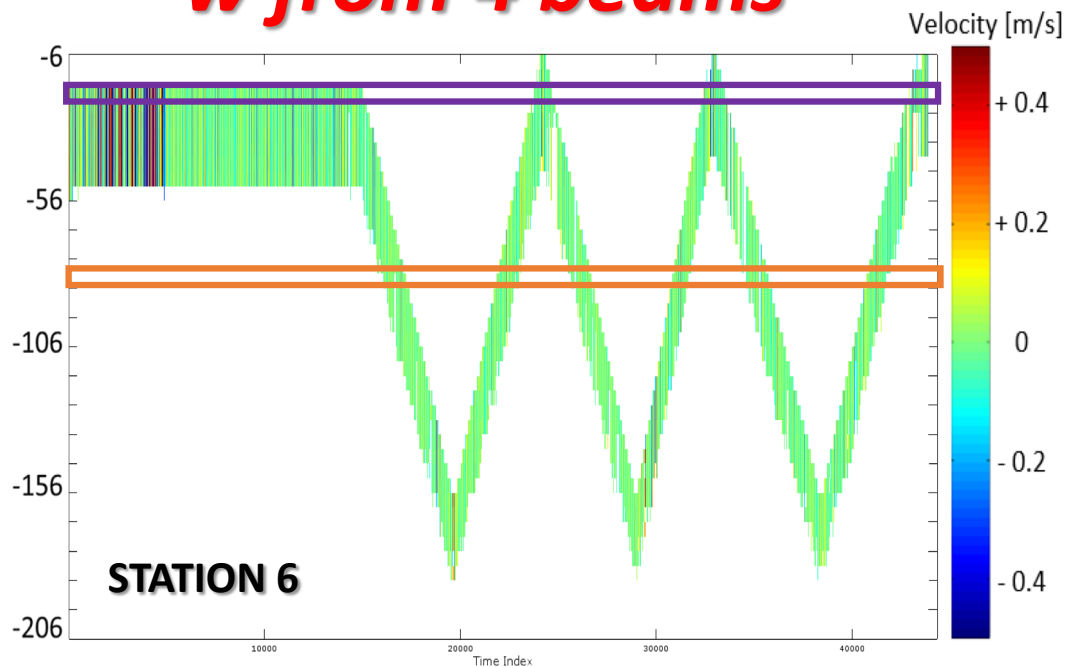
Sur la colonne d'eau 50-200 m

$$\mu = -0.024 \text{ m/s}$$

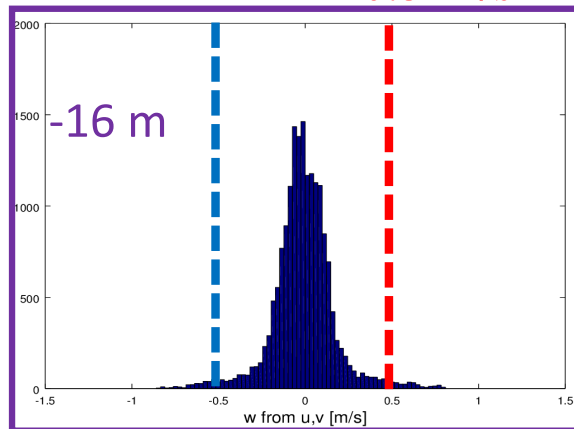
$$\sigma = 0.055 \text{ m/s}$$



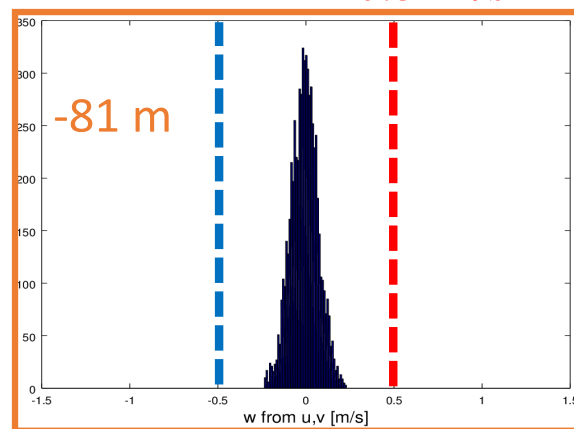
w from 4 beams



- 0.5 m/s + 0.5 m/s



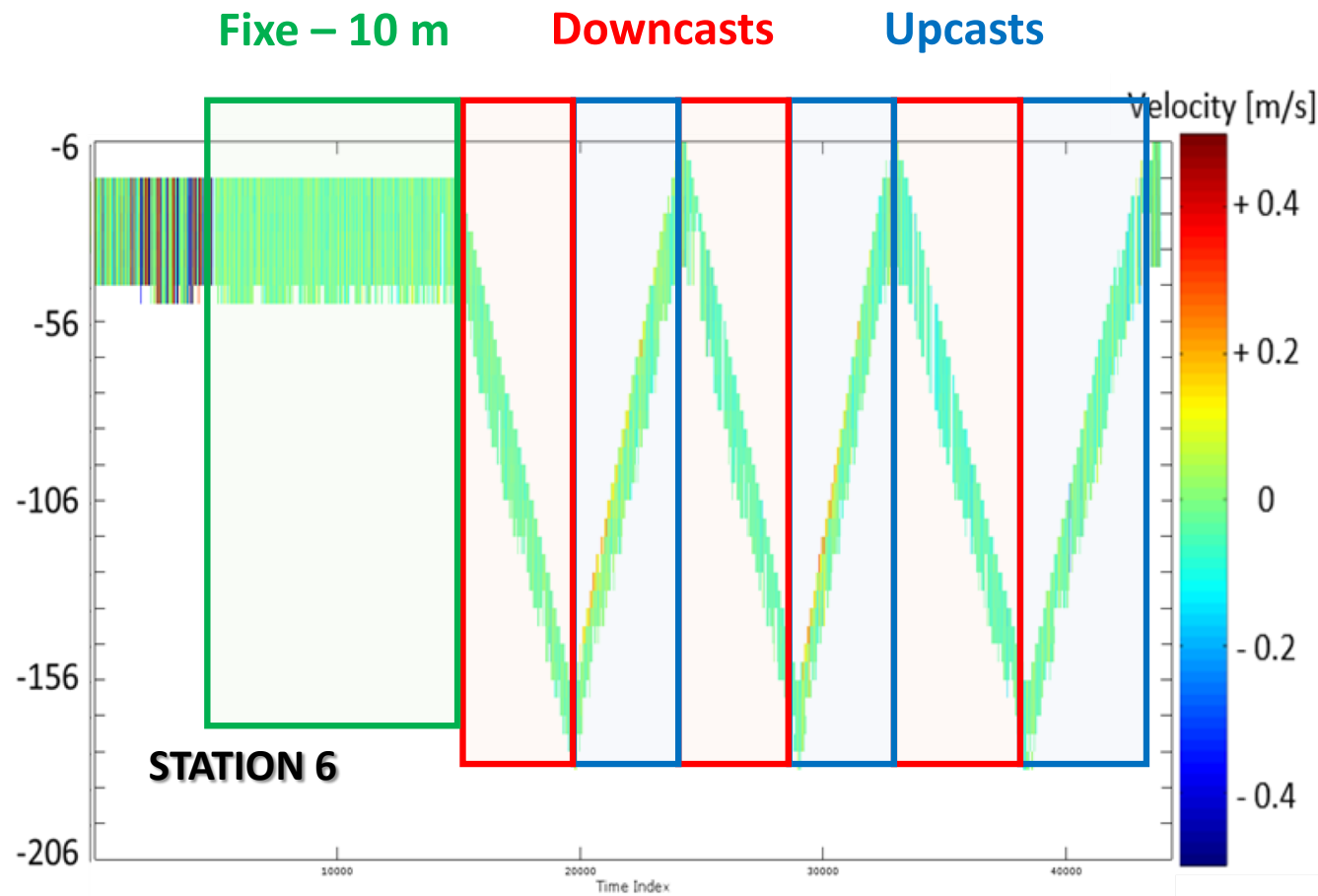
- 0.5 m/s + 0.5 m/s



Sur la colonne d'eau 50-200 m

$$\mu = -0.005 \text{ m/s}$$

$$\sigma = 0.106 \text{ m/s}$$

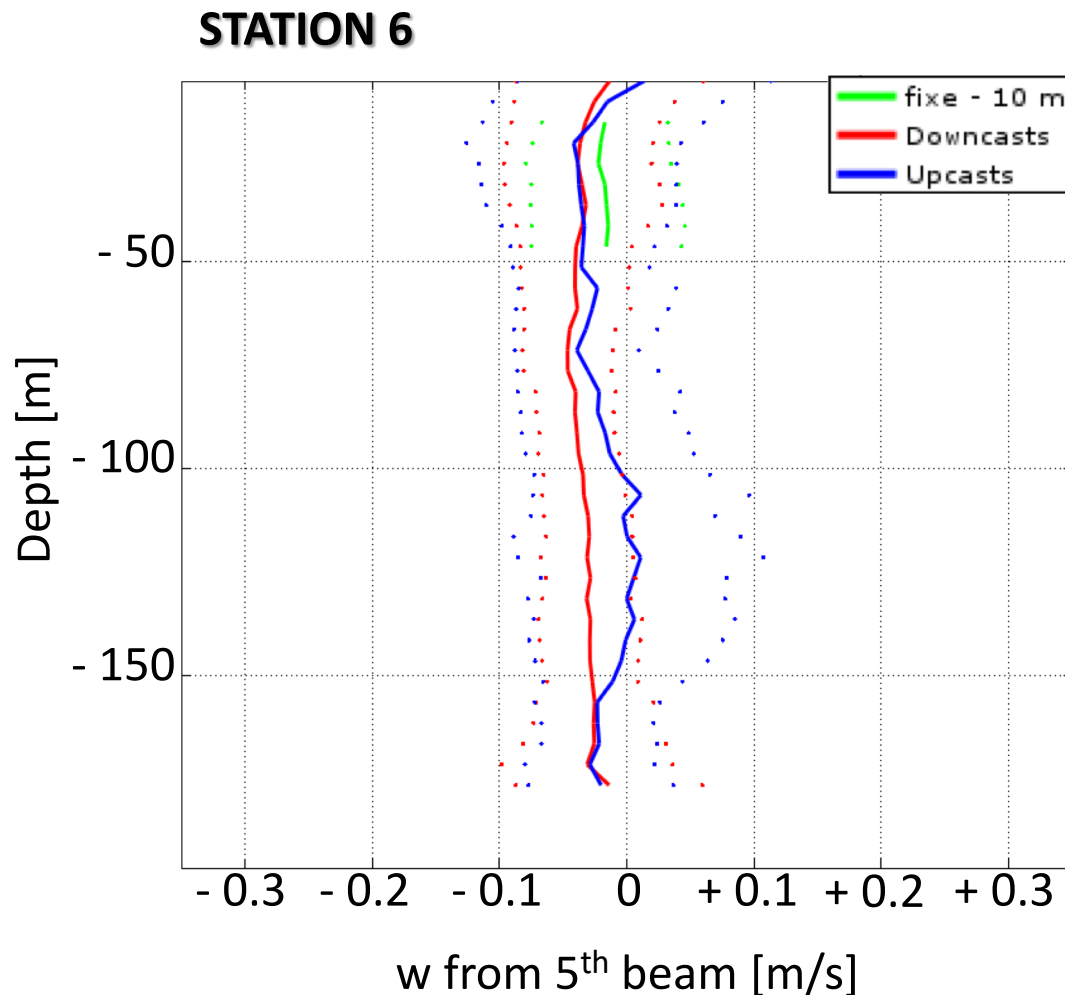


Variation de w
corrected entre la
plongée (*downcasts*)
et l'ascension
(*upcasts*) des
instruments



Étude différentielle
de w selon le
mouvement

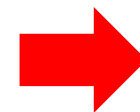
w from 5th beam



Upcasts : influence très probable
des courants horizontaux →
distribution **inhomogène** des
mesures sur la verticale

Downcasts : distribution **homogène**
des mesures sur la verticale

Downcasts sur la colonne d'eau

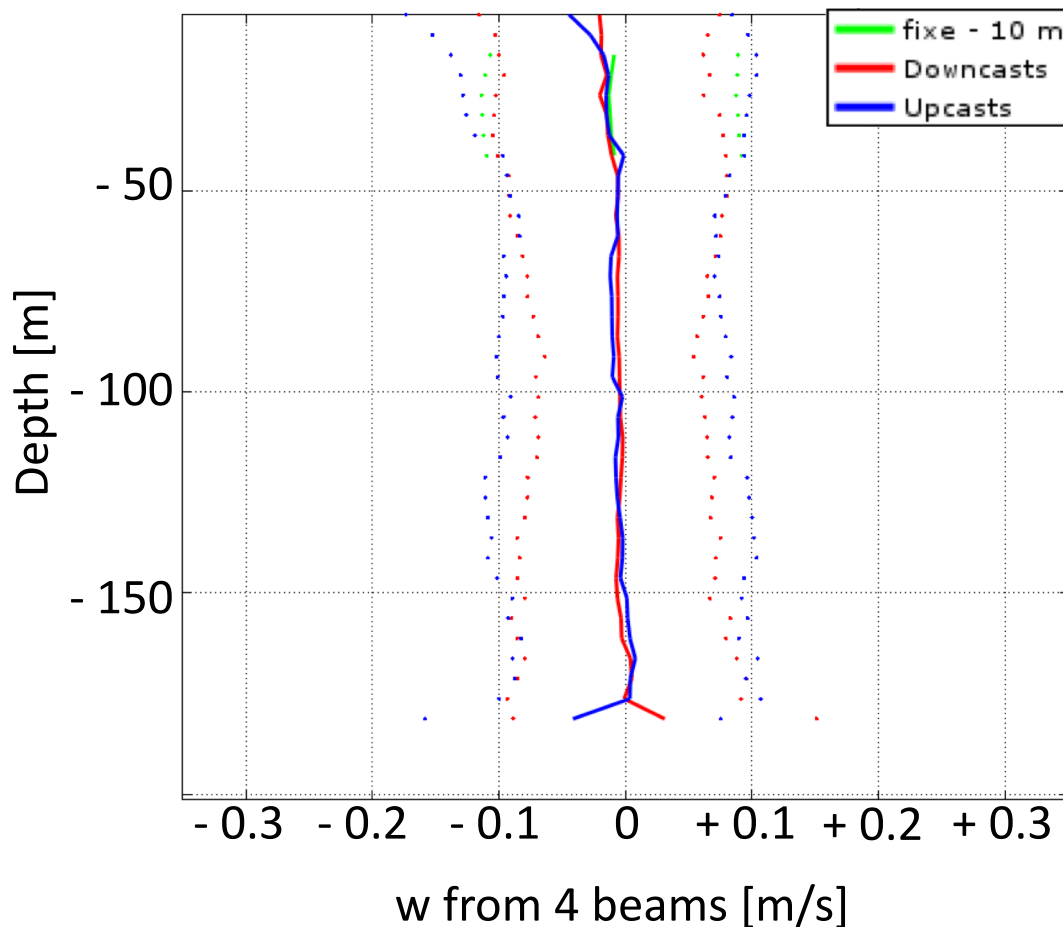


$$\mu = -0.033 \text{ m/s}$$

$$\sigma = 0.045 \text{ m/s}$$

w from 4 beams

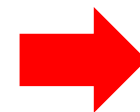
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Upcasts : distribution **homogène**
des mesures sur la verticale +
variations ponctuelles

Downcasts : distribution **homogène**
des mesures sur la verticale

Downcasts sur la colonne d'eau



$$\mu = -0.006 \text{ m/s}$$

$$\sigma = 0.079 \text{ m/s}$$

- Mesures de w par Sentinel V ADCP corrigées successivement par $\frac{1}{\rho g} \frac{\partial p}{\partial t}$
Sentinel puis **CTD** → réduction progressive des écart-types : **méthode optimale**
facteur 20
- Mesure de w *from 5th beam* : différence marquée entre les mesures *upcasts* et *downcasts*
→ étude différentielle des mesures avec la correction la plus affinée
 - *Downcasts* : distribution homogène des valeurs de w corrigées.
 - *Upcasts* : influence probable des courants horizontaux mais pas d'explication trouvée à l'étude du mouvement du Sentinel.
- Comparaison des mesures de w sur la colonne d'eau (*downcasts*) :
w from 4 beams → μ plus proches de 0 + moins bons σ
w from 5th beam → μ plus éloignées de 0 + meilleurs σ

- Tableau des données de w corrigée par $\frac{1}{\rho g} \frac{\partial p}{\partial t}$ (CTD) pour les mesures relevées en plongée (*downcasts*) :

w from 5th beam

SENTINEL	1	2	3	4	5	6
μ [m/s]	- 0.018	- 0.005	- 0.042	- 0.014	- 0.059	- 0.033
σ [m/s]	0.044	0.036	0.054	0.066	0.045	0.044

✗ Biais dans la mesure ?

✓ Écart-types les plus réduits

w from 4 beams

SENTINEL	1	2	3	4	5	6
μ [m/s]	- 0.001	0.002	- 0.013	- 0.013	- 0.011	- 0.006
σ [m/s]	0.070	0.054	0.111	0.156	0.090	0.079

✗ σ d'ordre de grandeur plus élevé

✓ w corrigées les plus réalistes

- À moyen-terme :

Upcasts plus intenses (5th beam) : **comprendre l'origine de cette surestimation.**

Comparaison avec les mesures de w par : L-ADCP, FF-ADCP, VVP, glider, ADCP de coque.

Comparaison avec MVP et équation oméga.

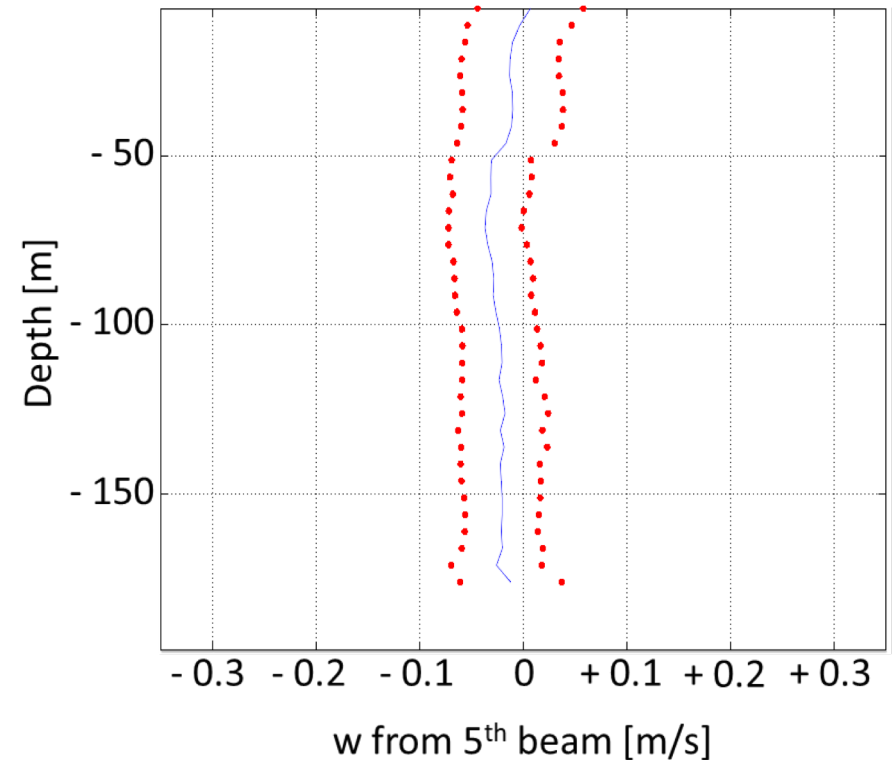
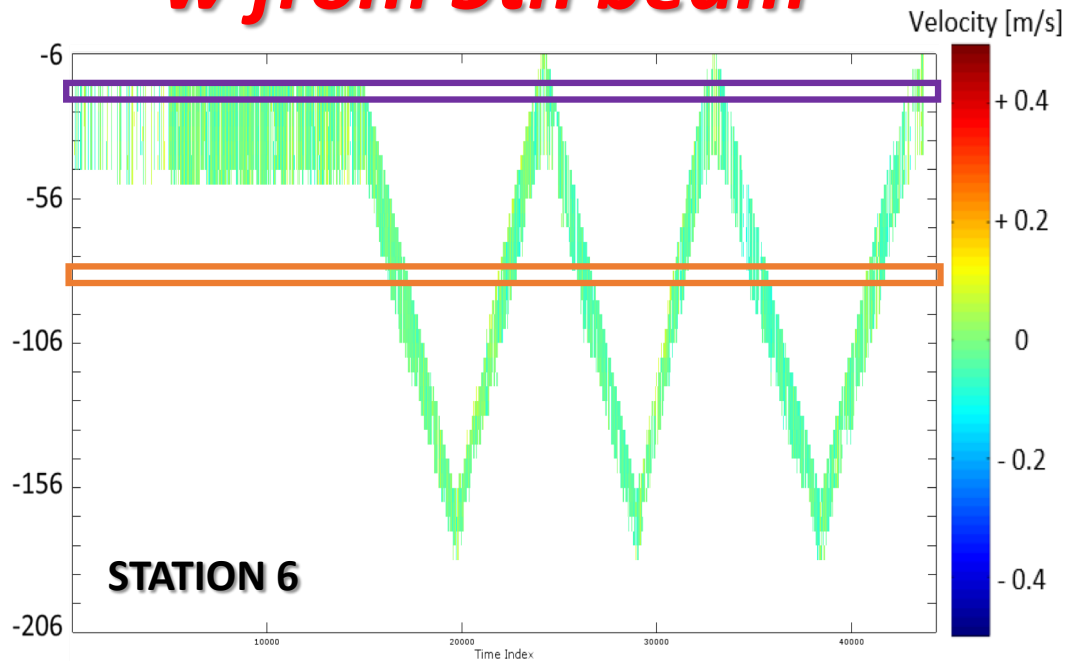
- À long-terme : mise en œuvre de la (des) meilleure(s) instrumentation(s) parmi FF-ADCP, L-ADCP, Sentinel V ADCP, VVP pour la mesure de la vitesse verticale lors de la campagne Gibraltar 2020 (SHOM).

Merci pour votre attention

Questions ?

Correction de w avec coupure des
 $w_{corrected} > 0.1 \text{ m/s}$

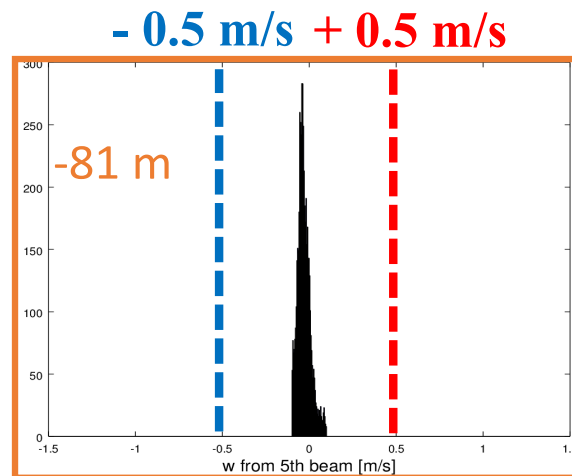
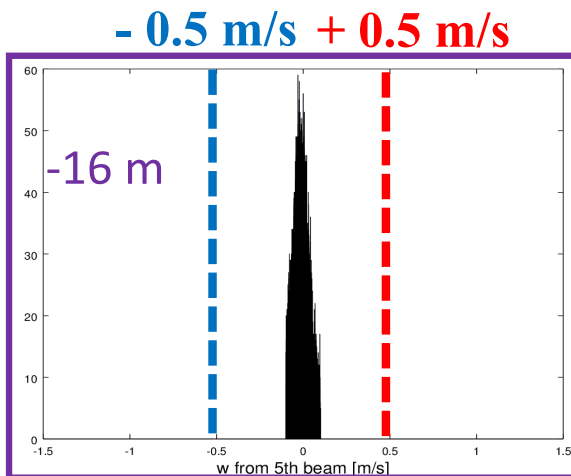
w from 5th beam



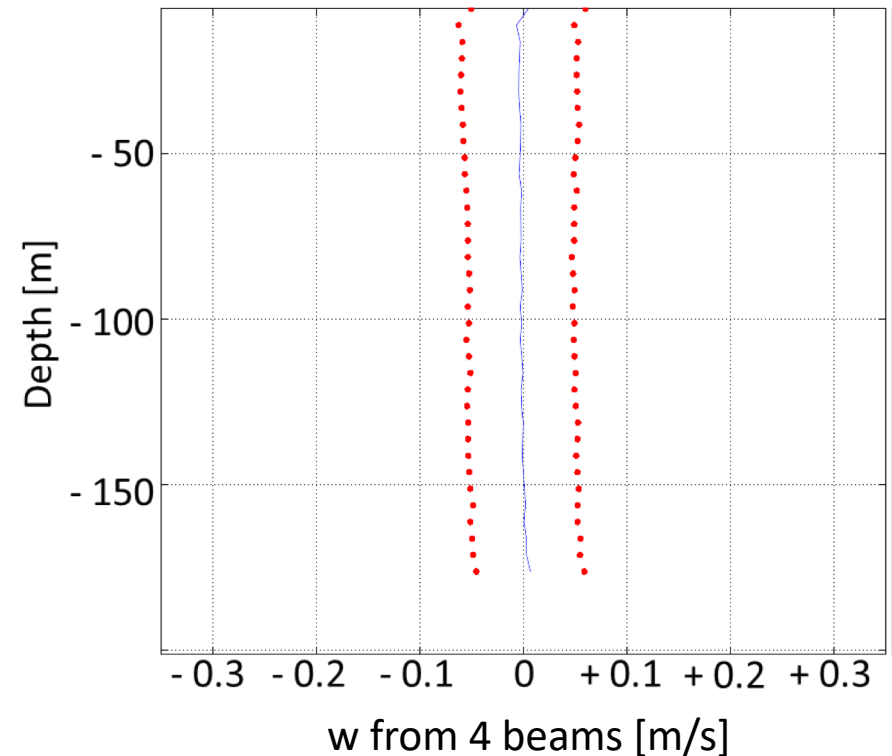
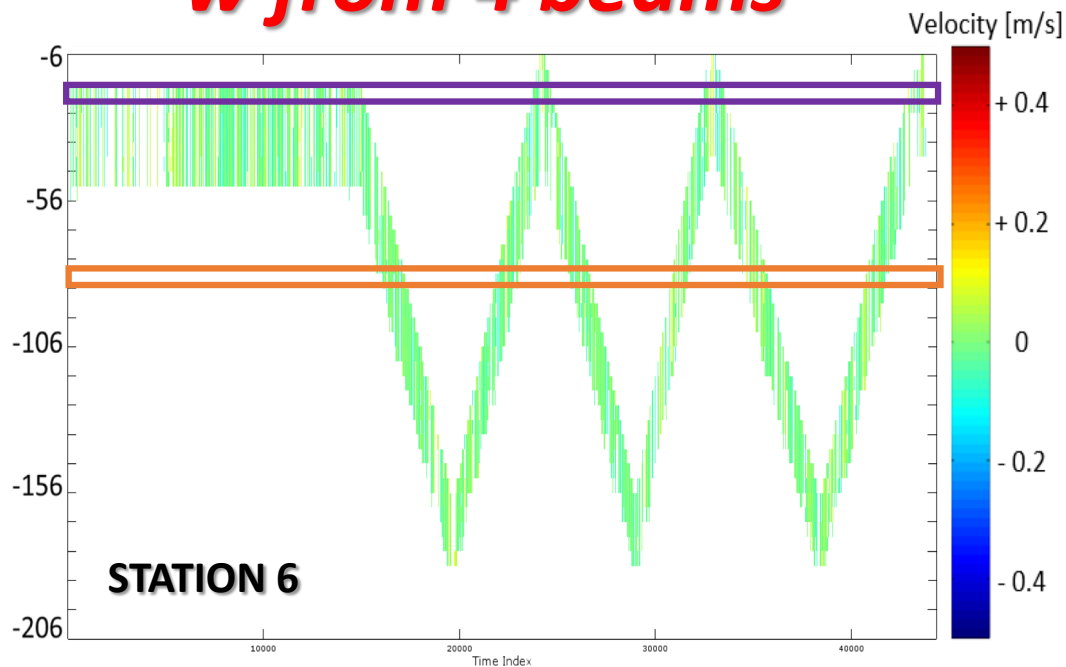
Sur la colonne d'eau

$$\mu = -0.021 \text{ m/s}$$

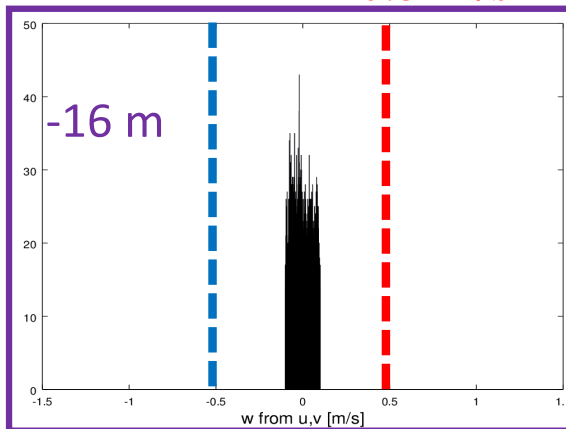
$$\sigma = 0.041 \text{ m/s}$$



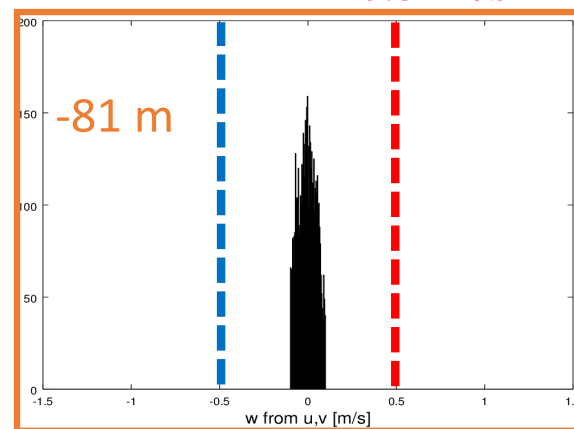
w from 4 beams



- 0.5 m/s + 0.5 m/s



- 0.5 m/s + 0.5 m/s



Sur la colonne d'eau

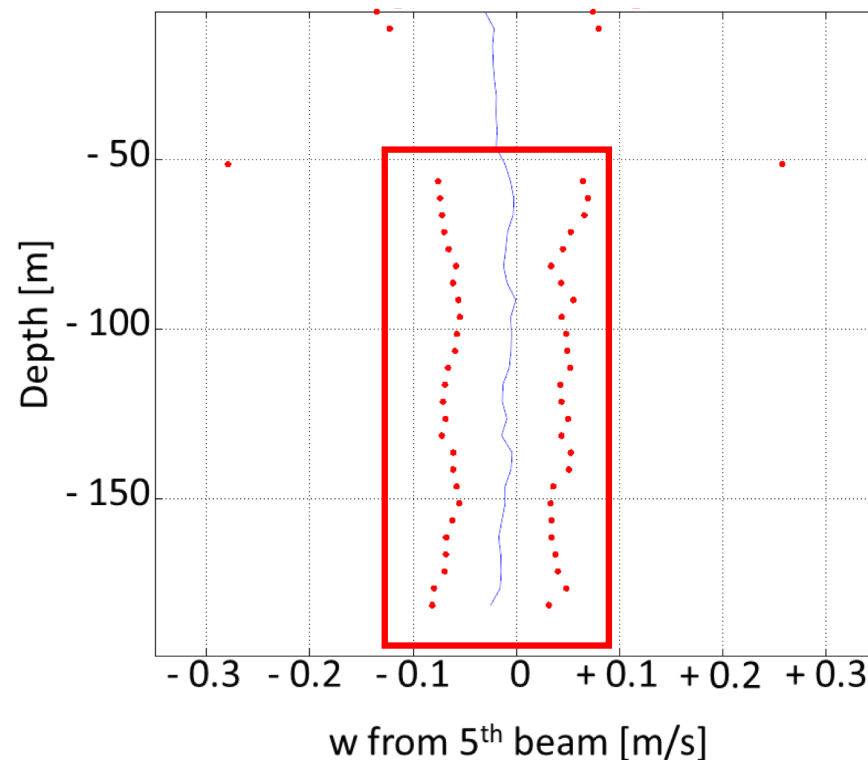
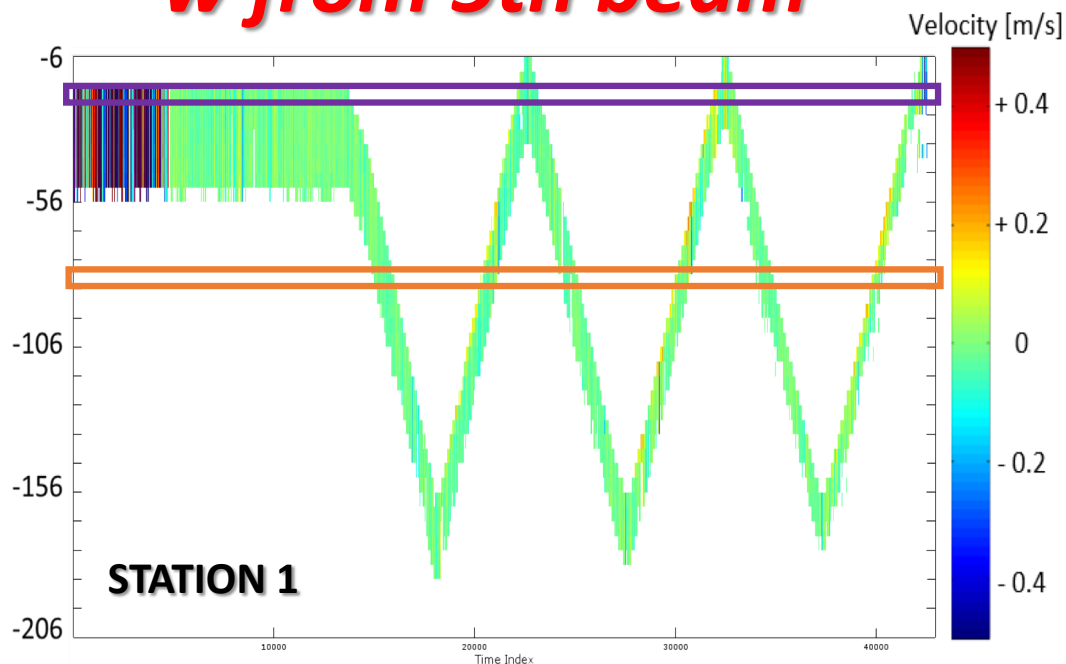
$$\mu = -0.0017 \text{ m/s}$$

$$\sigma = 0.0527 \text{ m/s}$$

w from 5th beam

Correction (CTD) pour chacune des stations

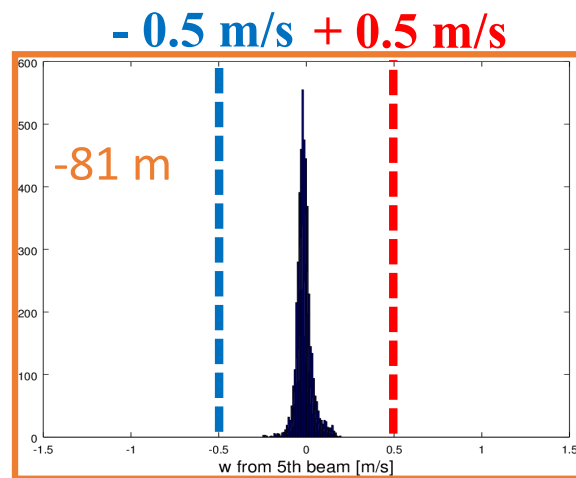
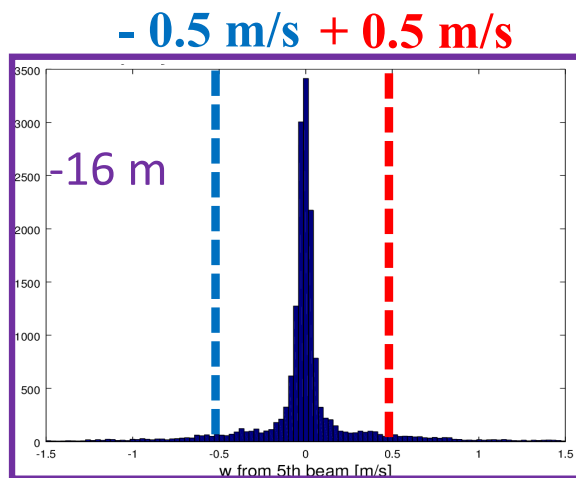
w from 5th beam



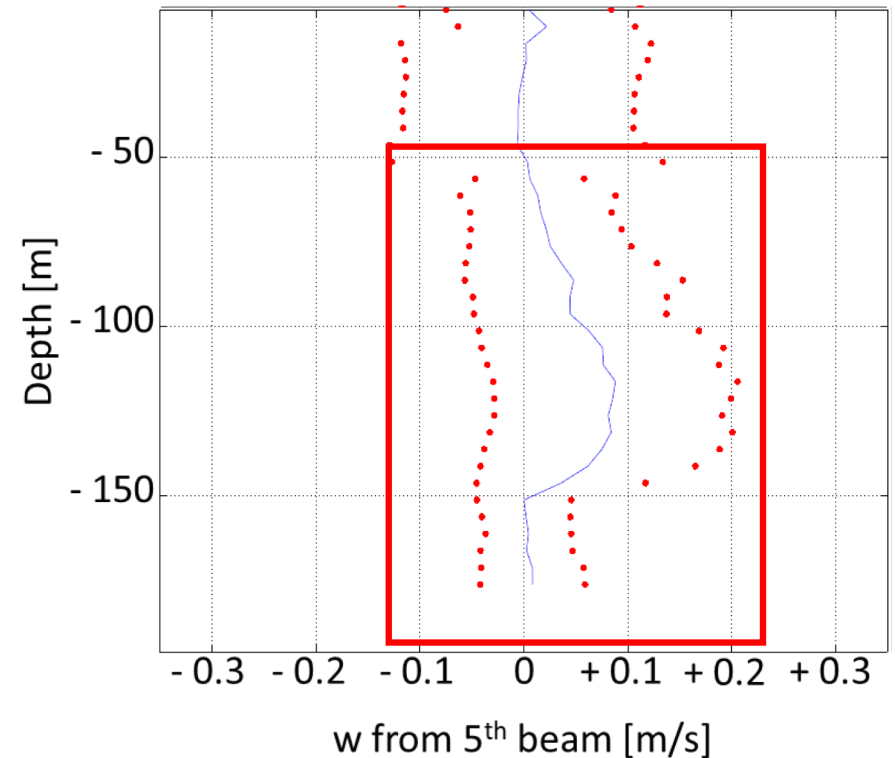
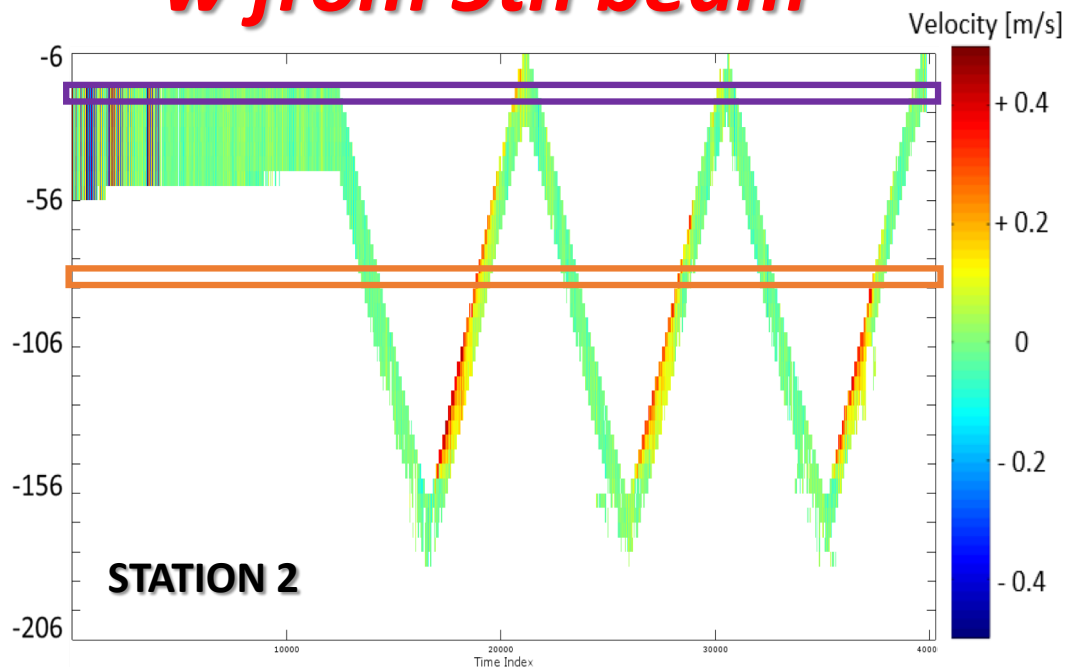
Sur la colonne d'eau 50-200 m

$$\mu = -0.010 \text{ m/s}$$

$$\sigma = 0.064 \text{ m/s}$$



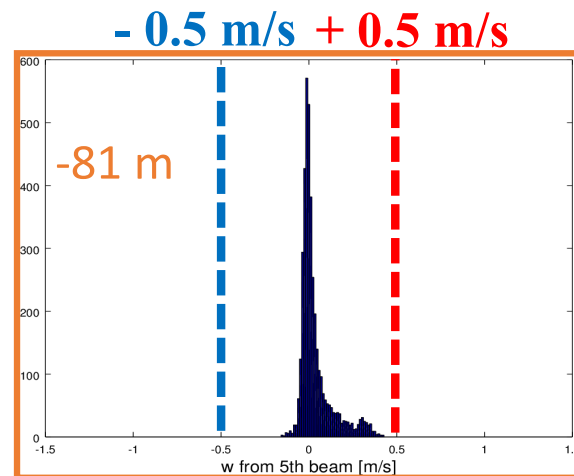
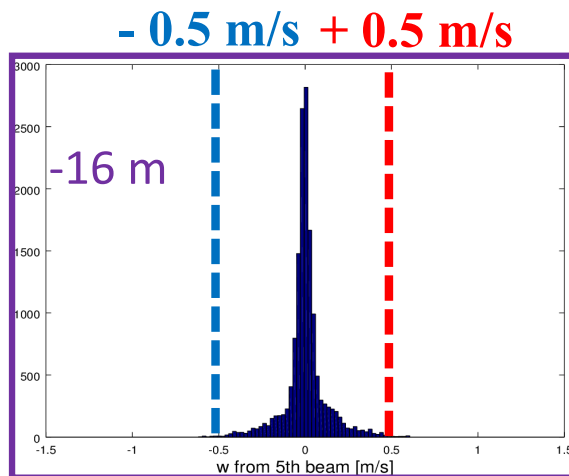
w from 5th beam



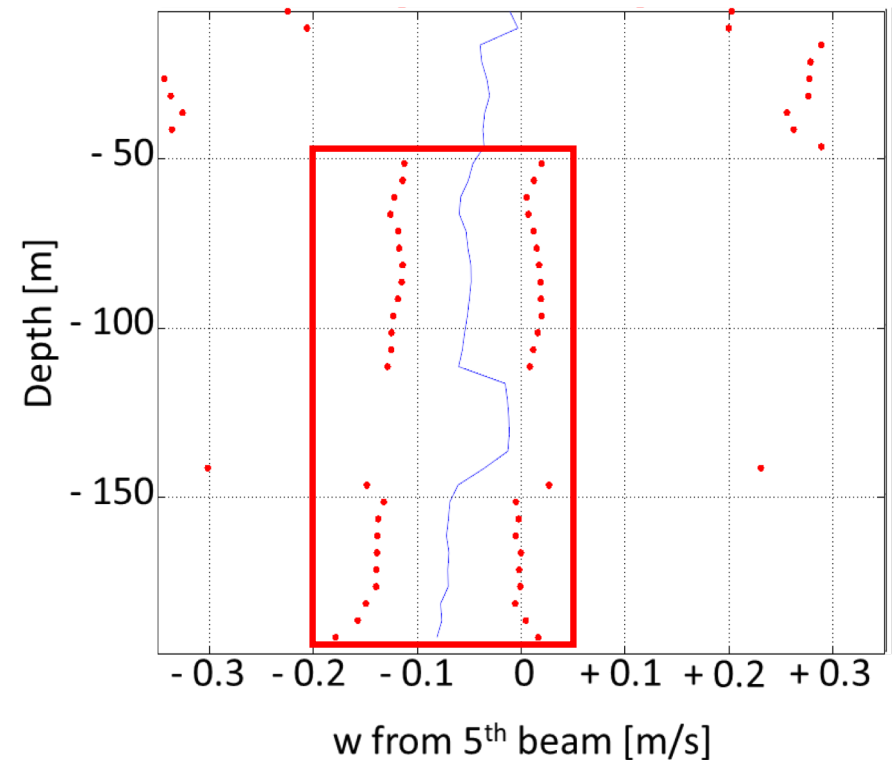
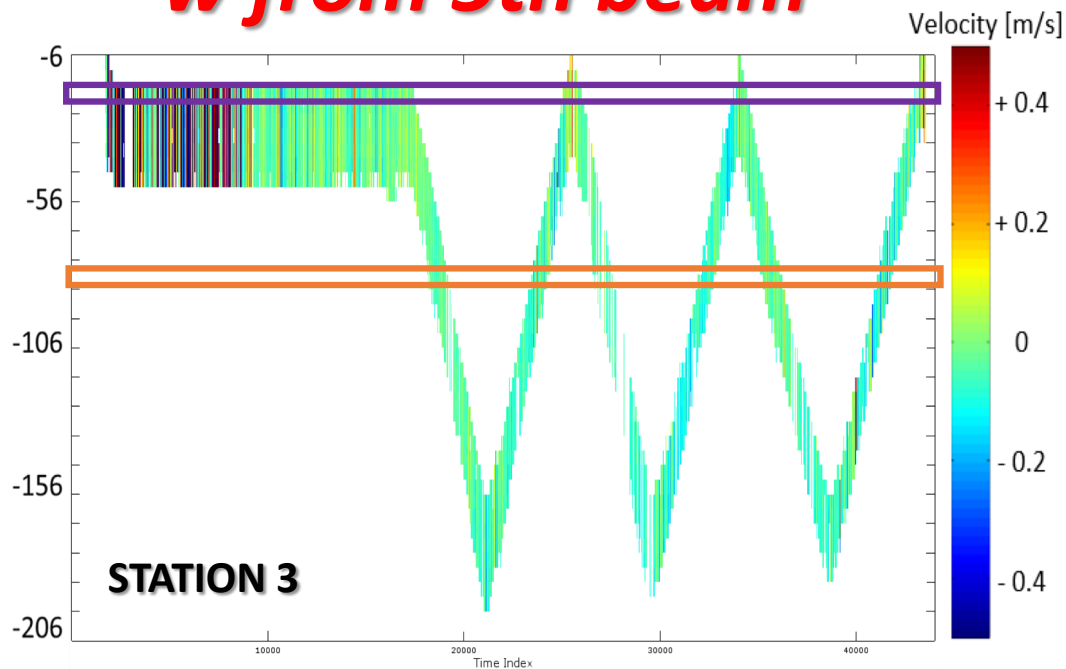
Sur la colonne d'eau 50-200 m

$$\mu = 0.039 \text{ m/s}$$

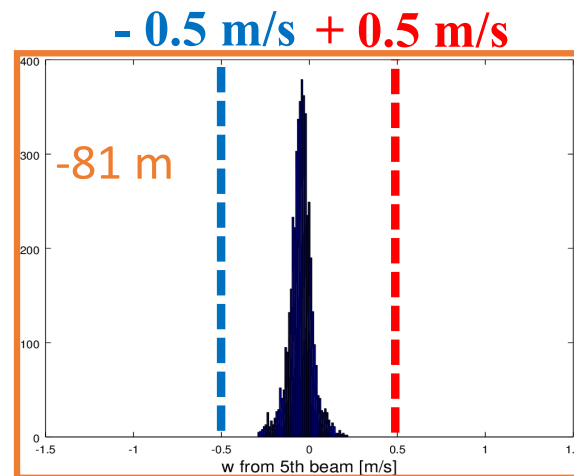
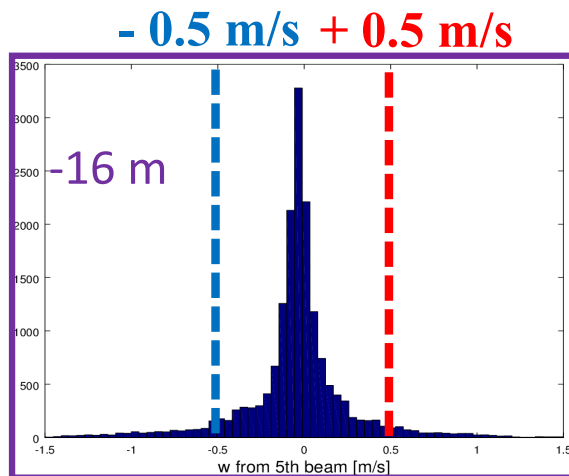
$$\sigma = 0.085 \text{ m/s}$$



w from 5th beam



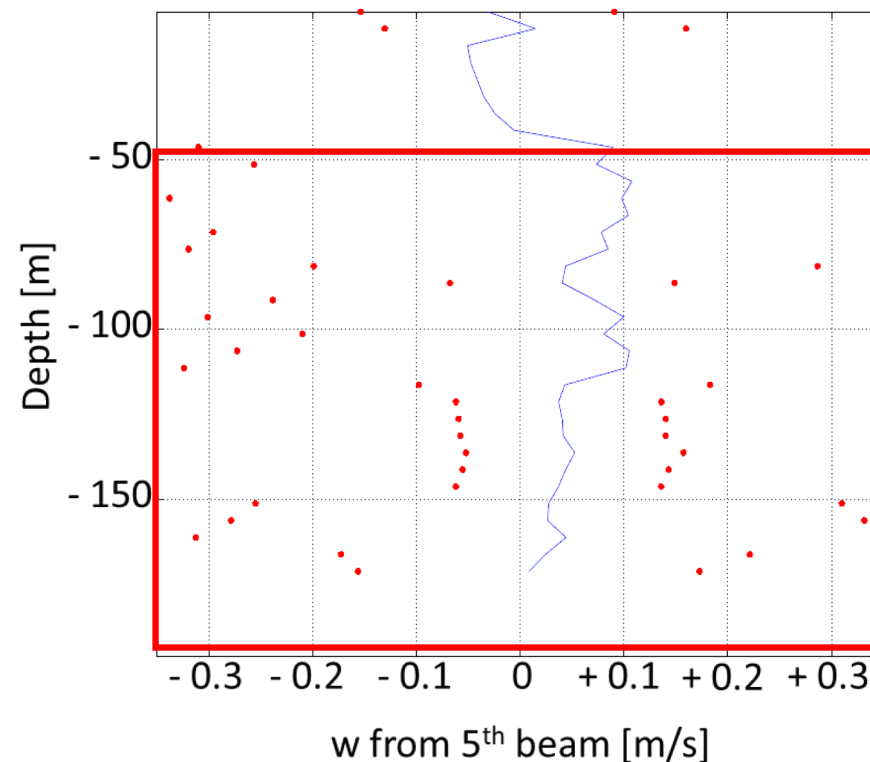
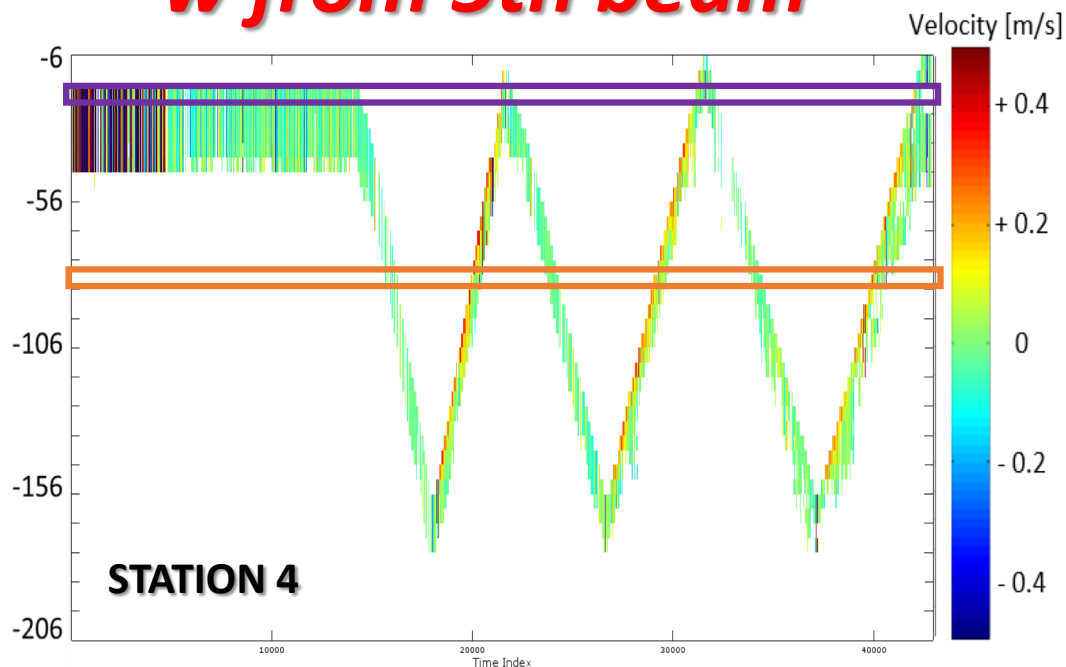
Sur la colonne d'eau 50-200 m



$$\mu = -0.052 \text{ m/s}$$

$$\sigma = 0.131 \text{ m/s}$$

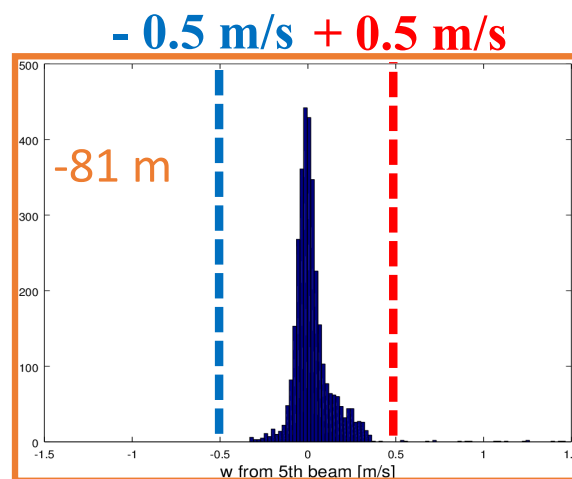
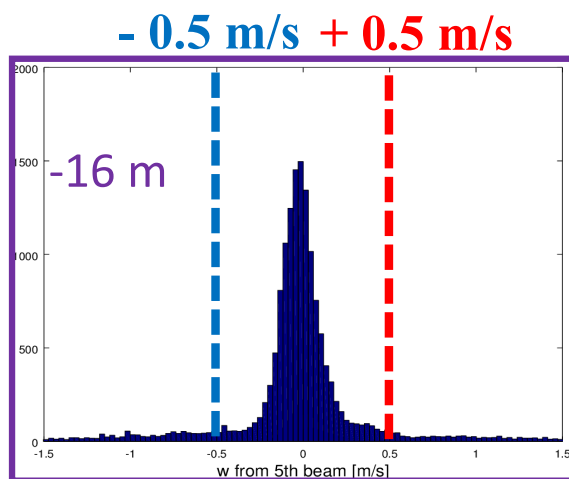
w from 5th beam



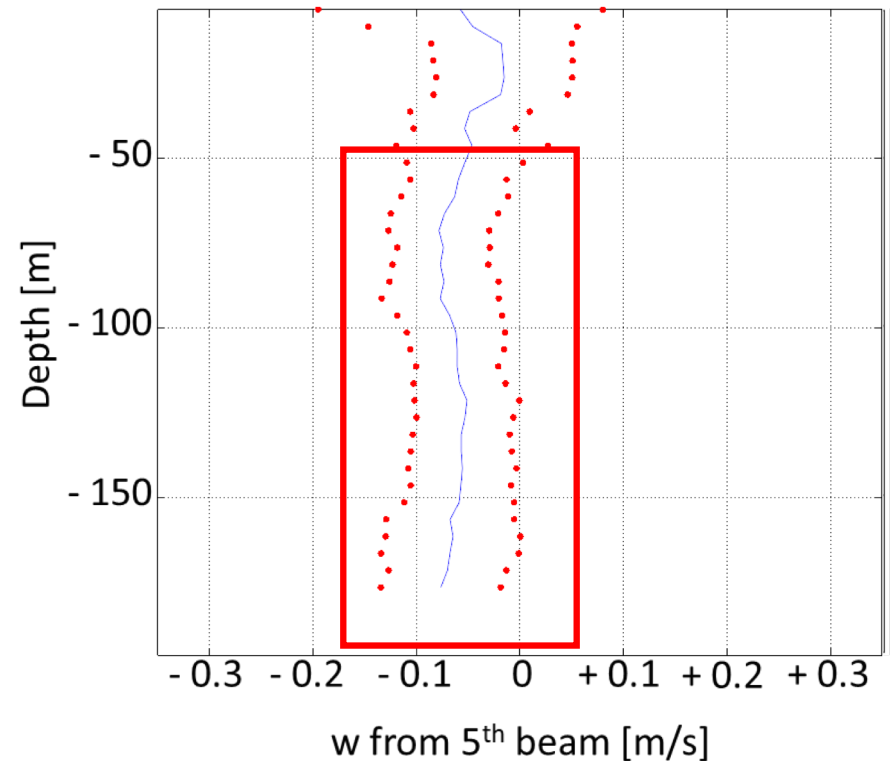
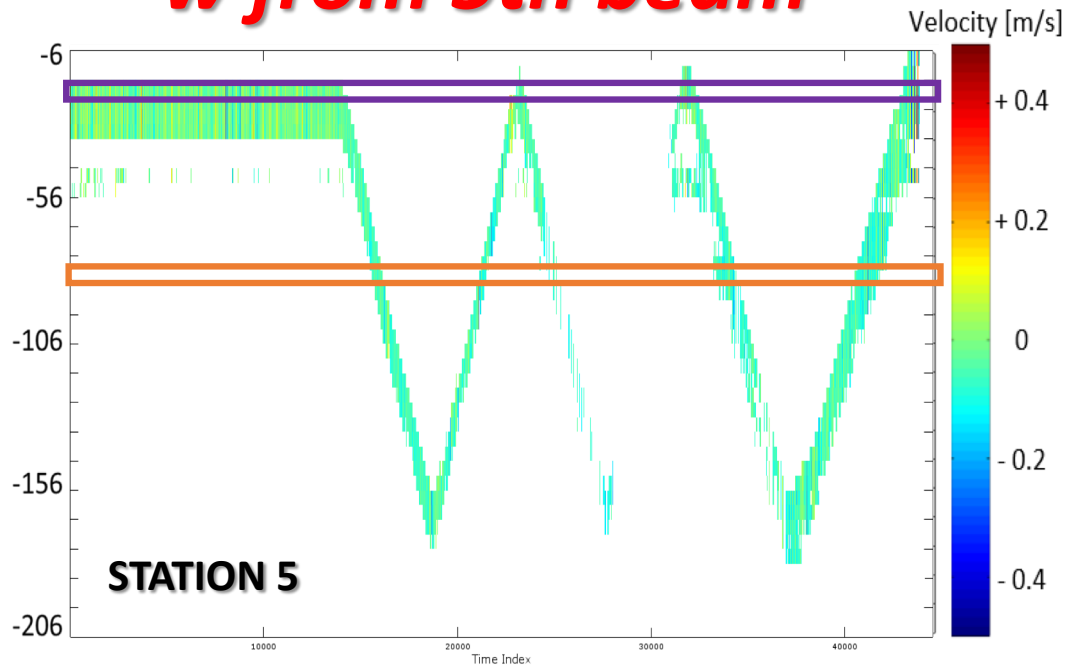
Sur la colonne d'eau 50-200 m

$$\mu = 0.061 \text{ m/s}$$

$$\sigma = 0.268 \text{ m/s}$$



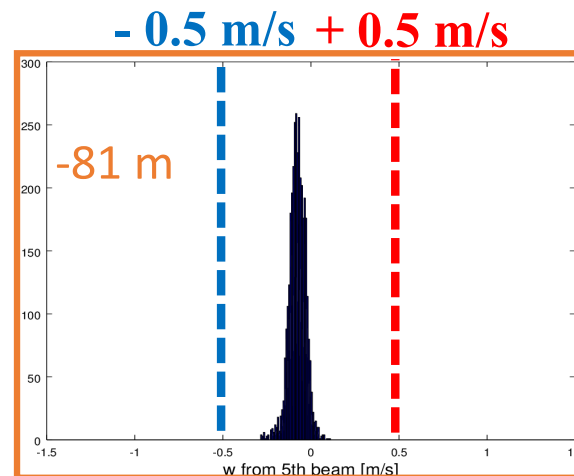
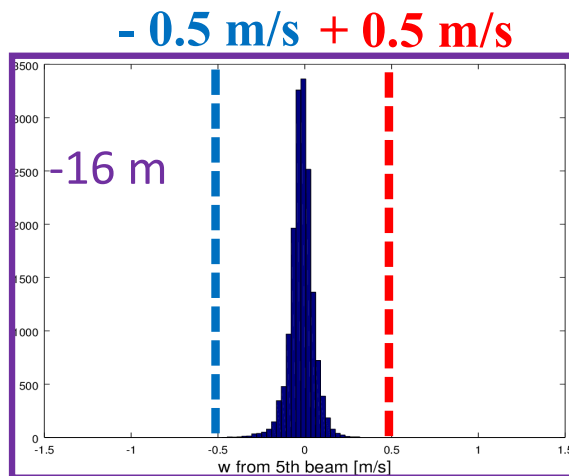
w from 5th beam



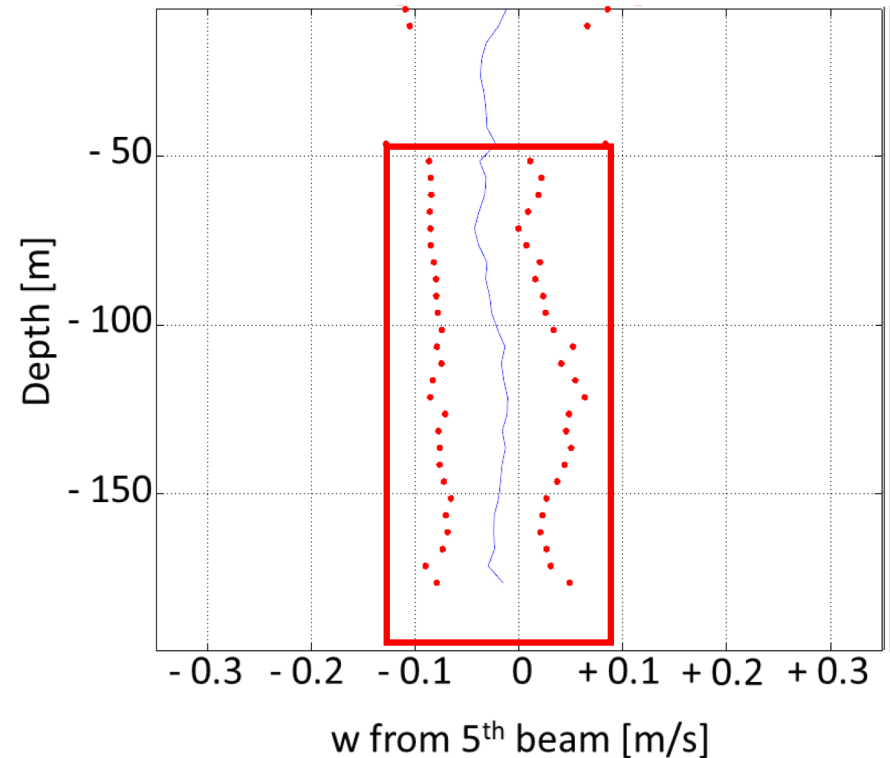
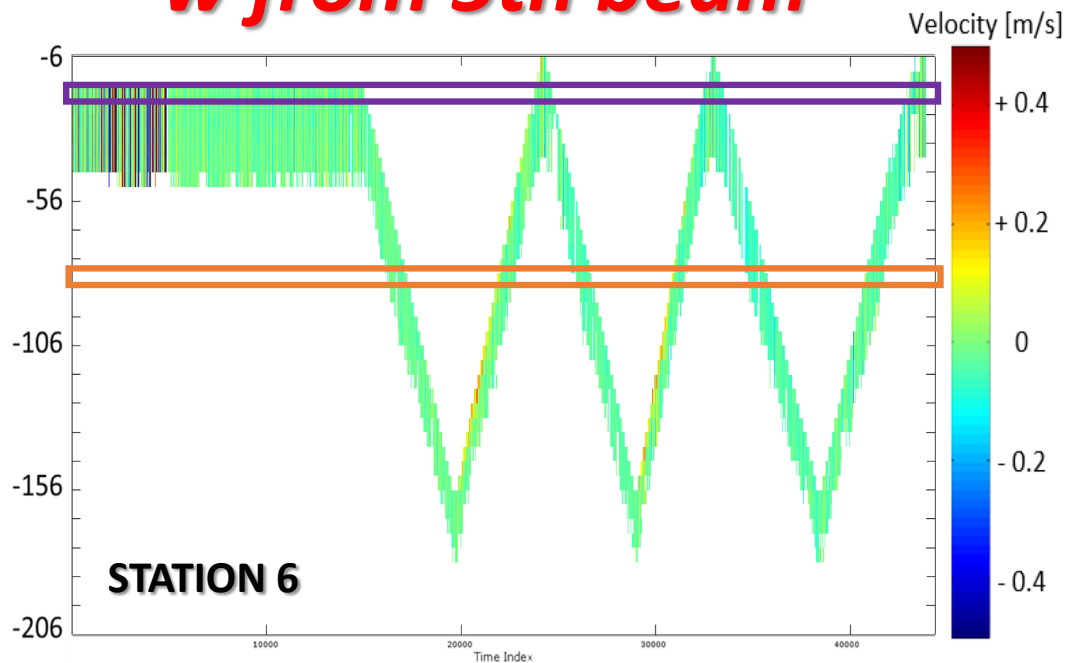
Sur la colonne d'eau 50-200 m

$$\mu = -0.064 \text{ m/s}$$

$$\sigma = 0.052 \text{ m/s}$$



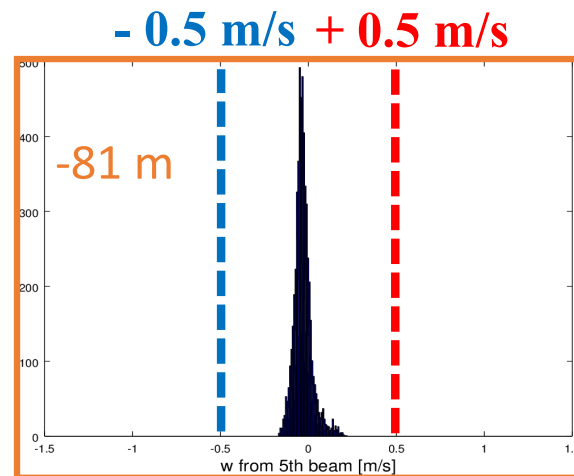
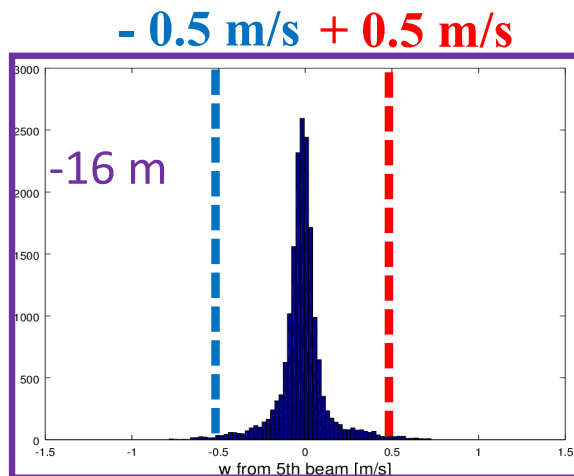
w from 5th beam



Sur la colonne d'eau 50-200 m

$$\mu = -0.024 \text{ m/s}$$

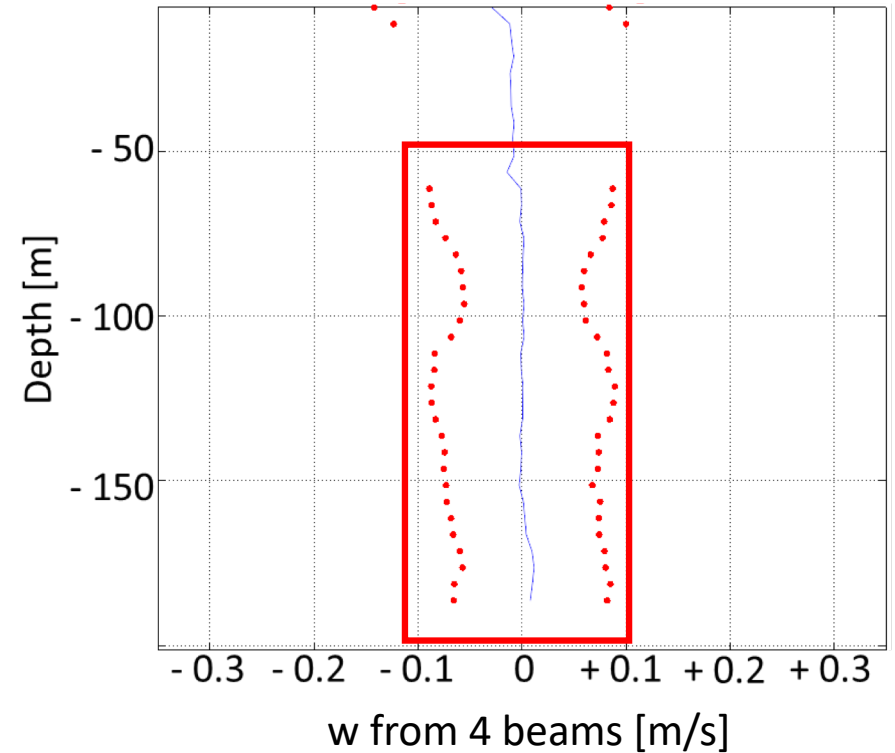
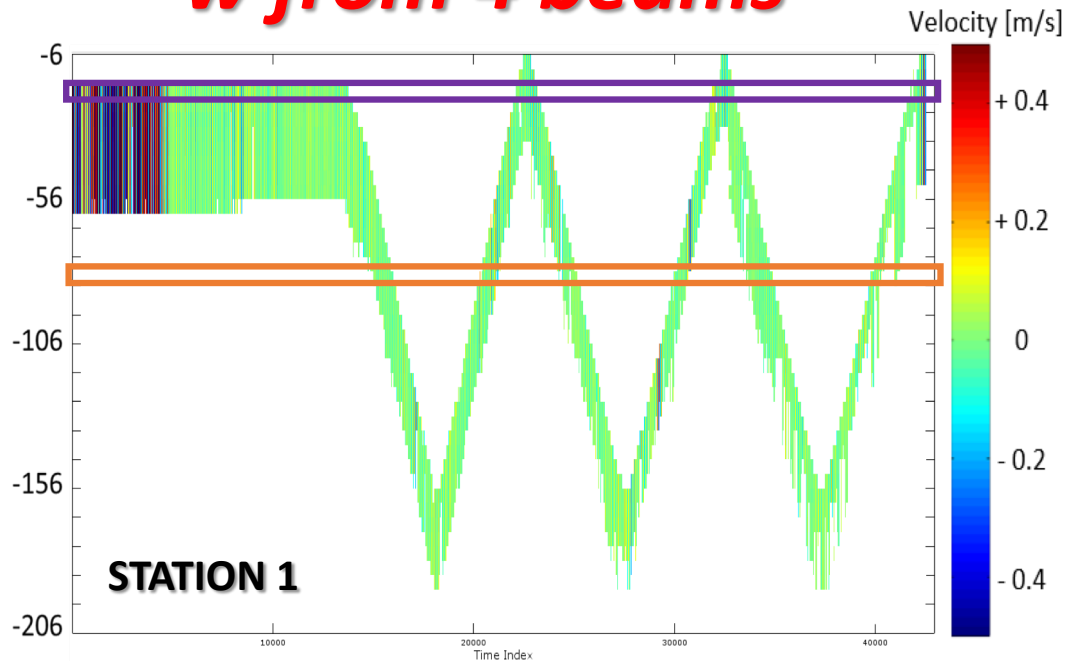
$$\sigma = 0.055 \text{ m/s}$$



w from 4 beams

Correction (CTD) pour chacune des stations

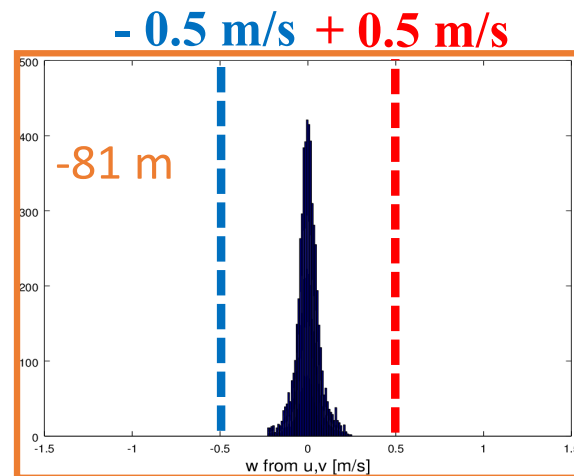
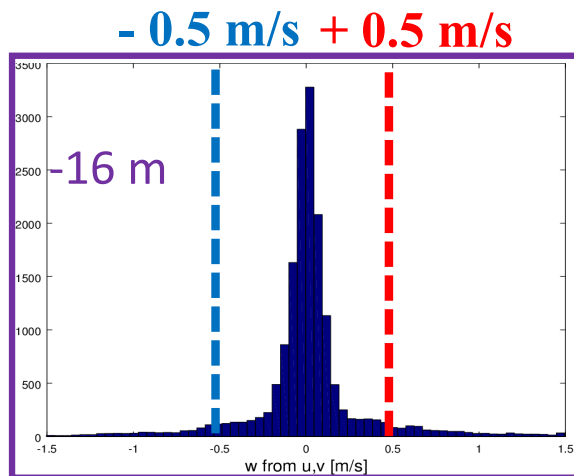
w from 4 beams



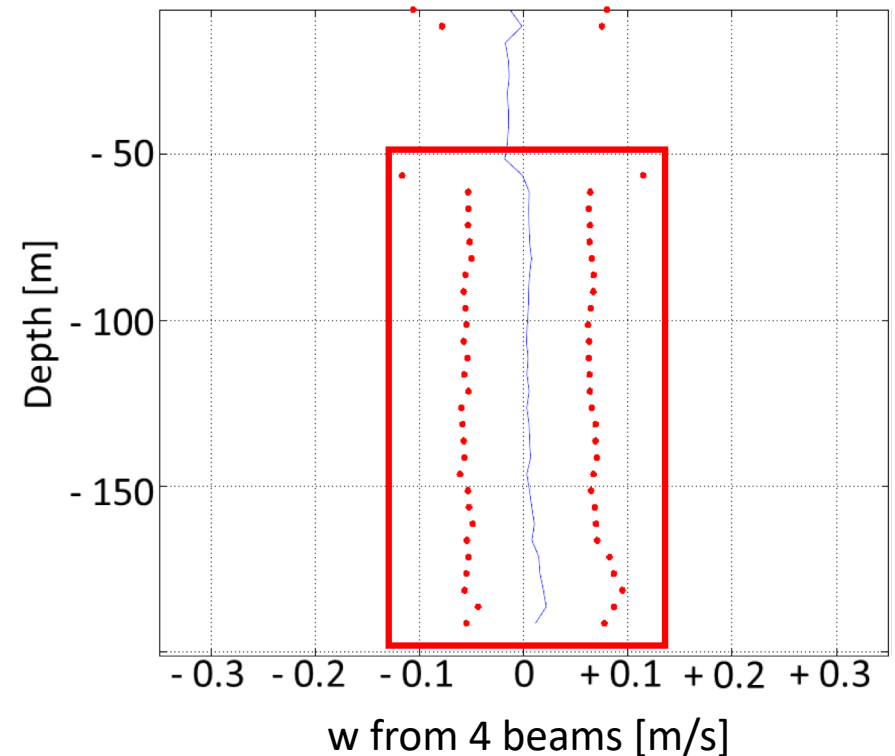
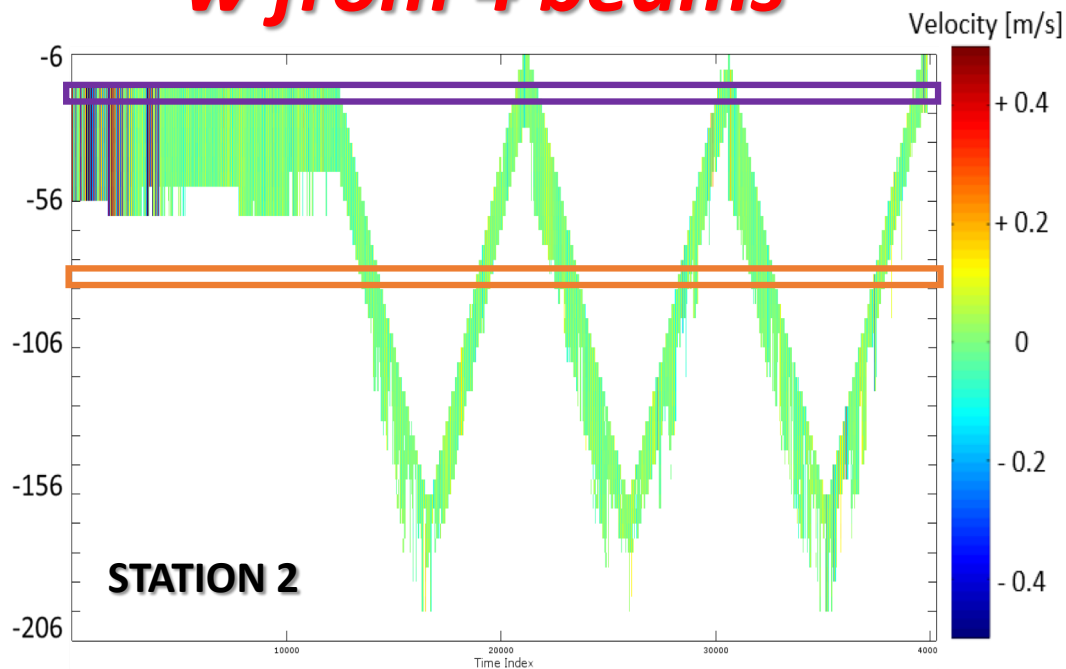
Sur la colonne d'eau 50-200 m

$$\mu = 0.001 \text{ m/s}$$

$$\sigma = 0.108 \text{ m/s}$$



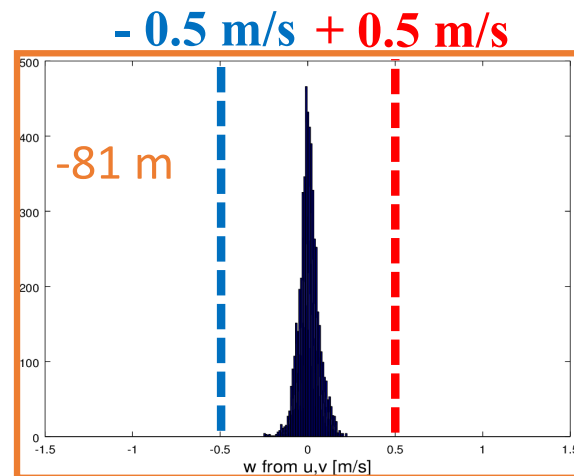
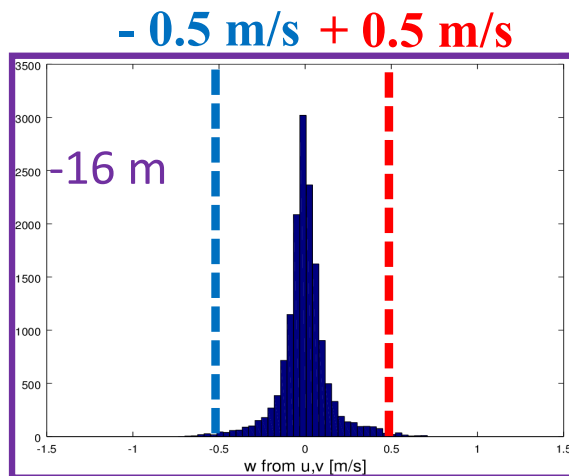
w from 4 beams



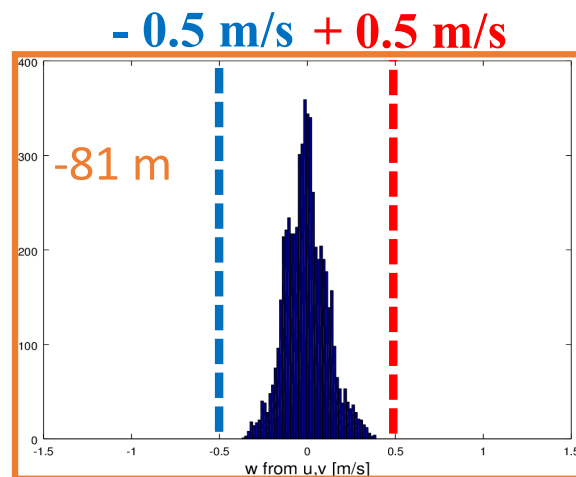
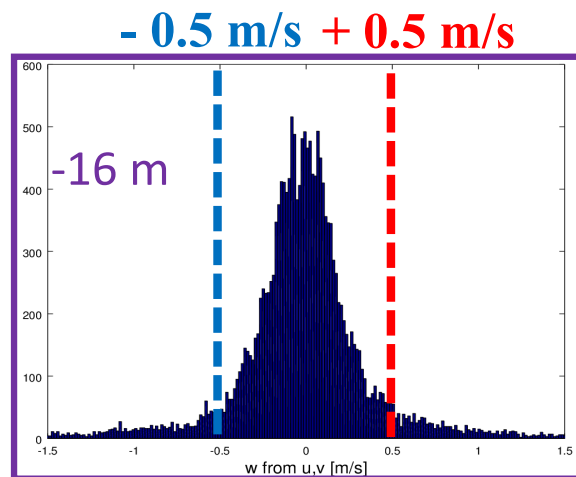
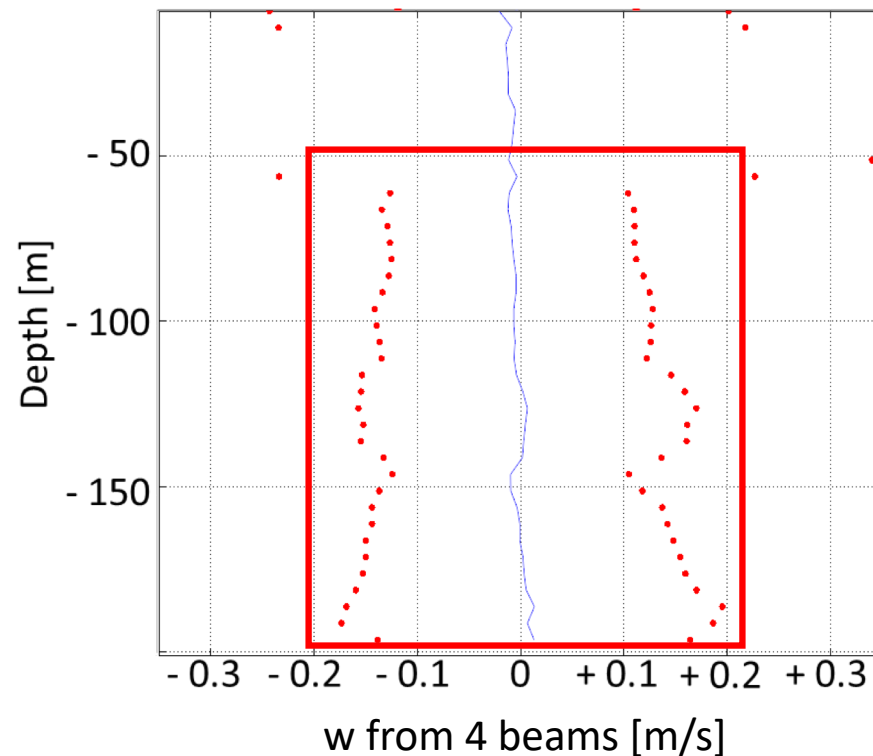
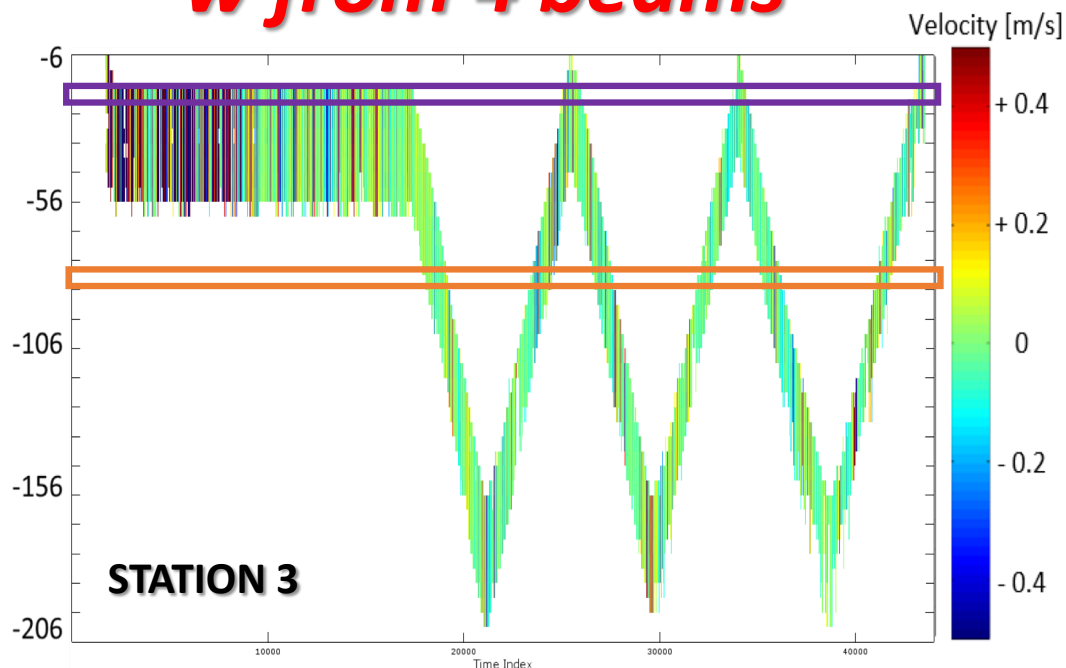
Sur la colonne d'eau 50-200 m

$$\mu = 0.006 \text{ m/s}$$

$$\sigma = 0.077 \text{ m/s}$$



w from 4 beams

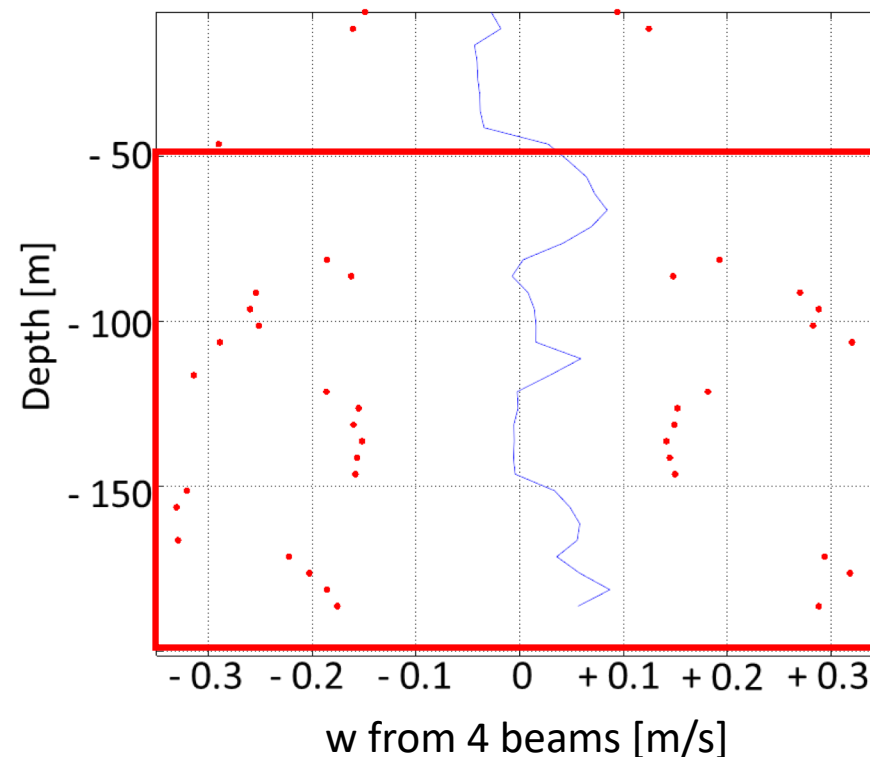
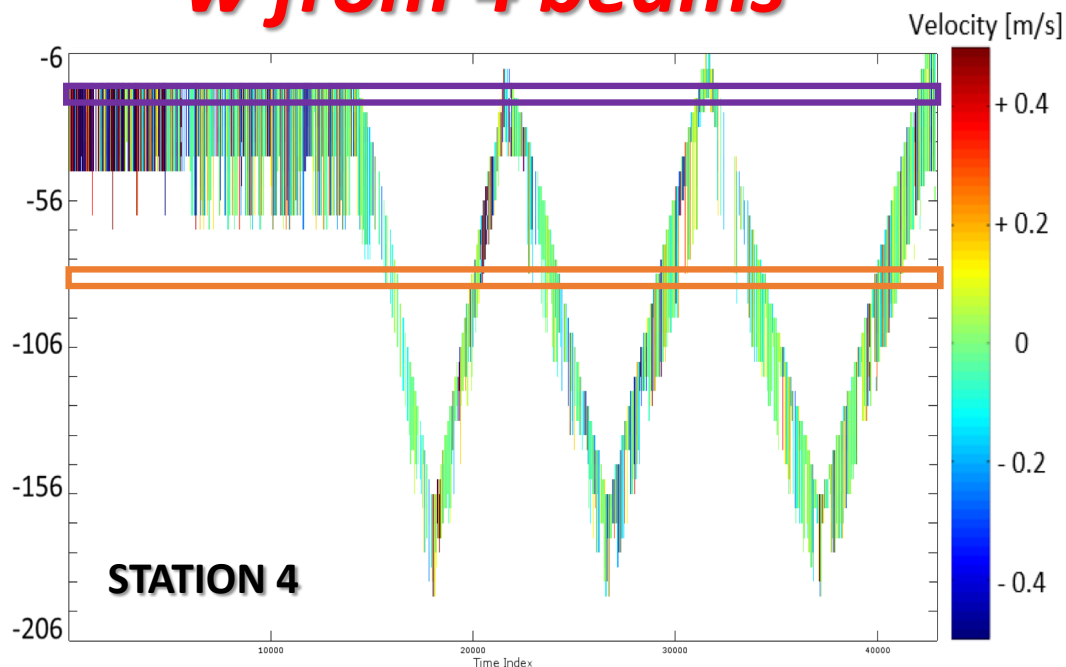


Sur la colonne d'eau 50-200 m

$$\mu = -0.010 \text{ m/s}$$

$$\sigma = 0.141 \text{ m/s}$$

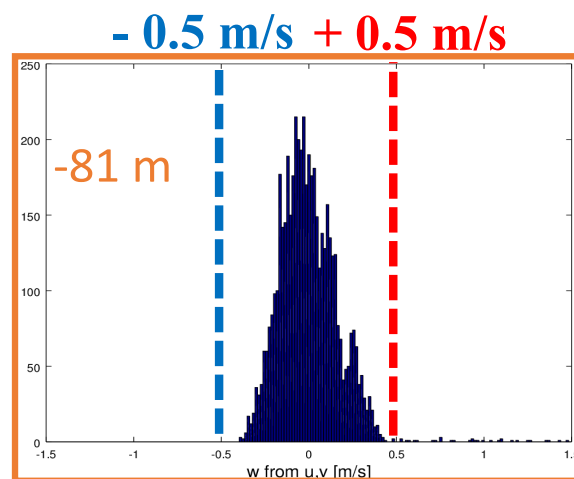
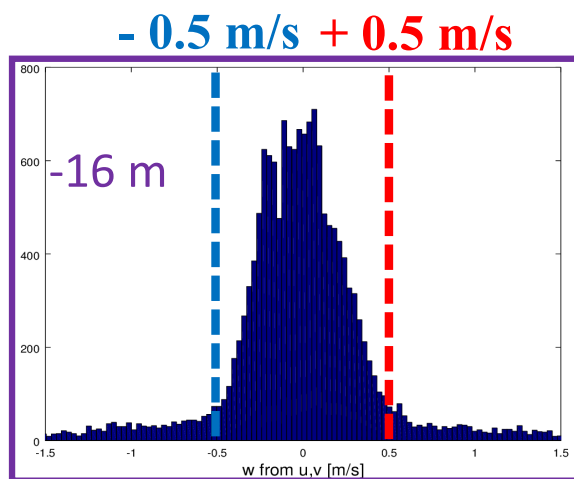
w from 4 beams



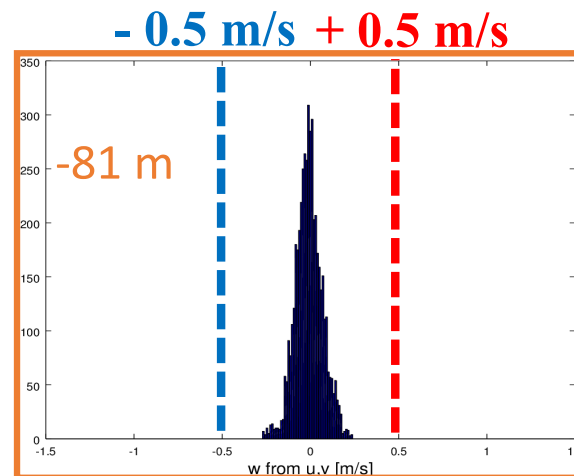
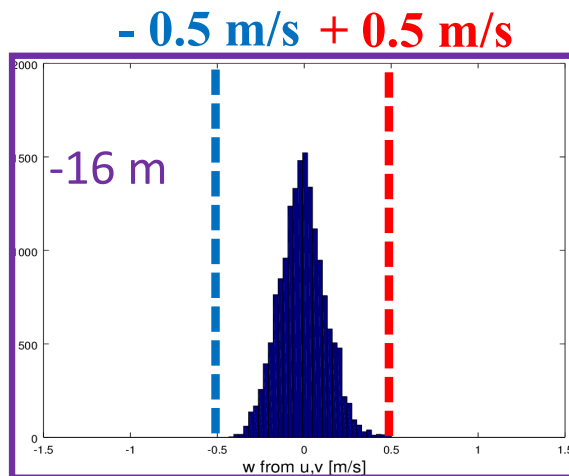
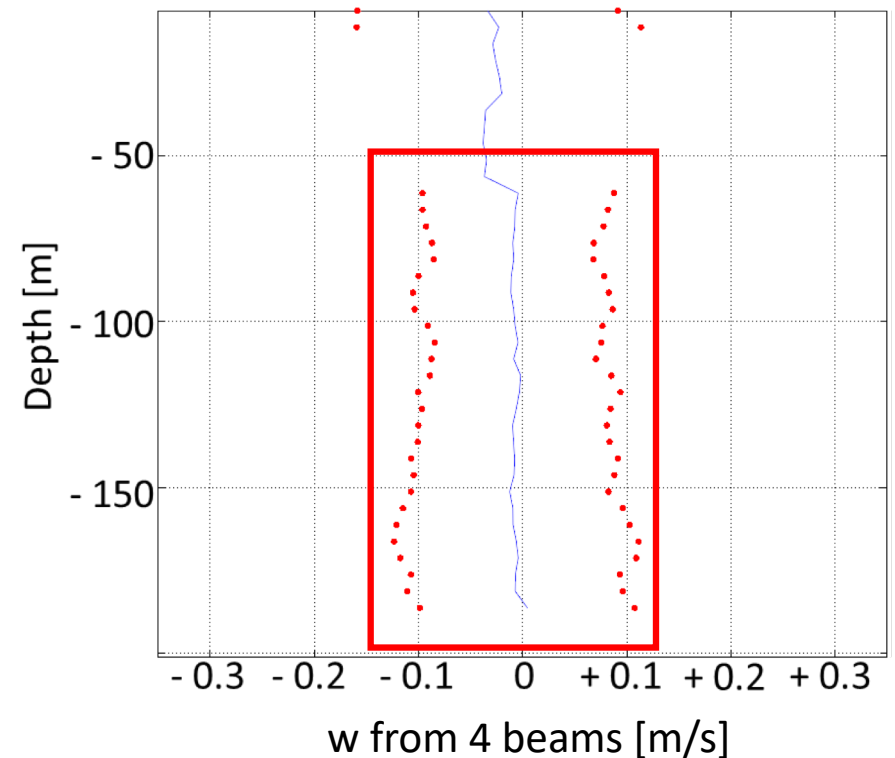
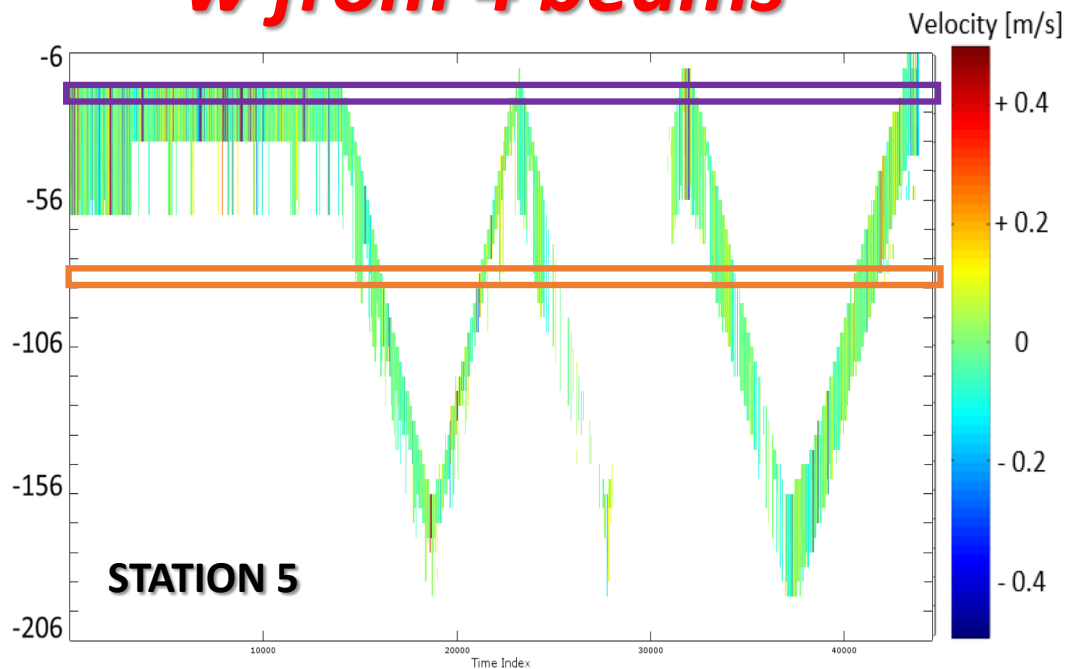
Sur la colonne d'eau 50-200 m

$$\mu = 0.033 \text{ m/s}$$

$$\sigma = 0.306 \text{ m/s}$$



w from 4 beams

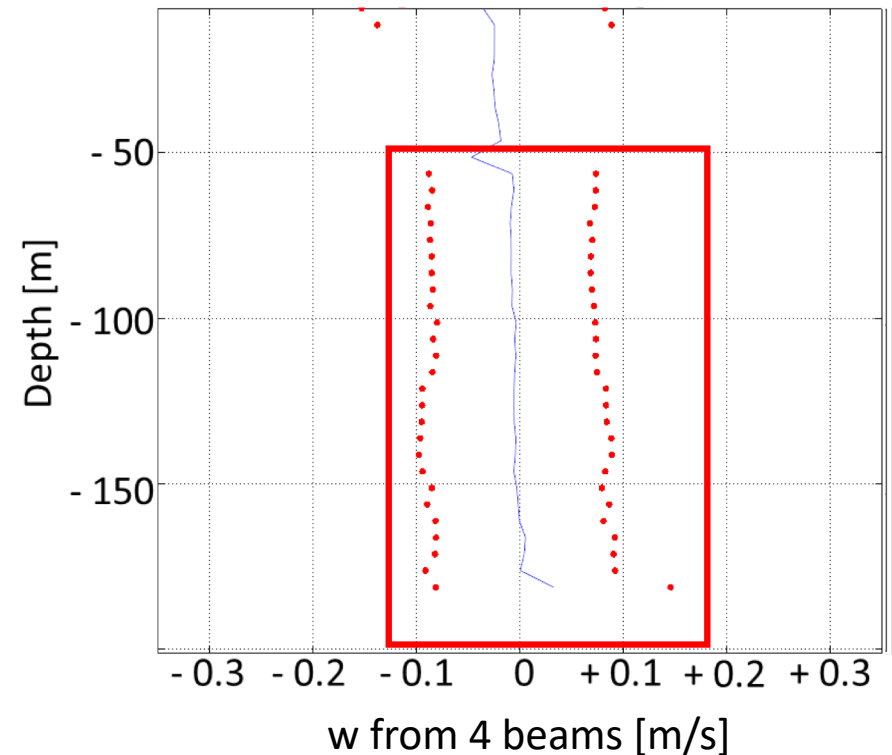
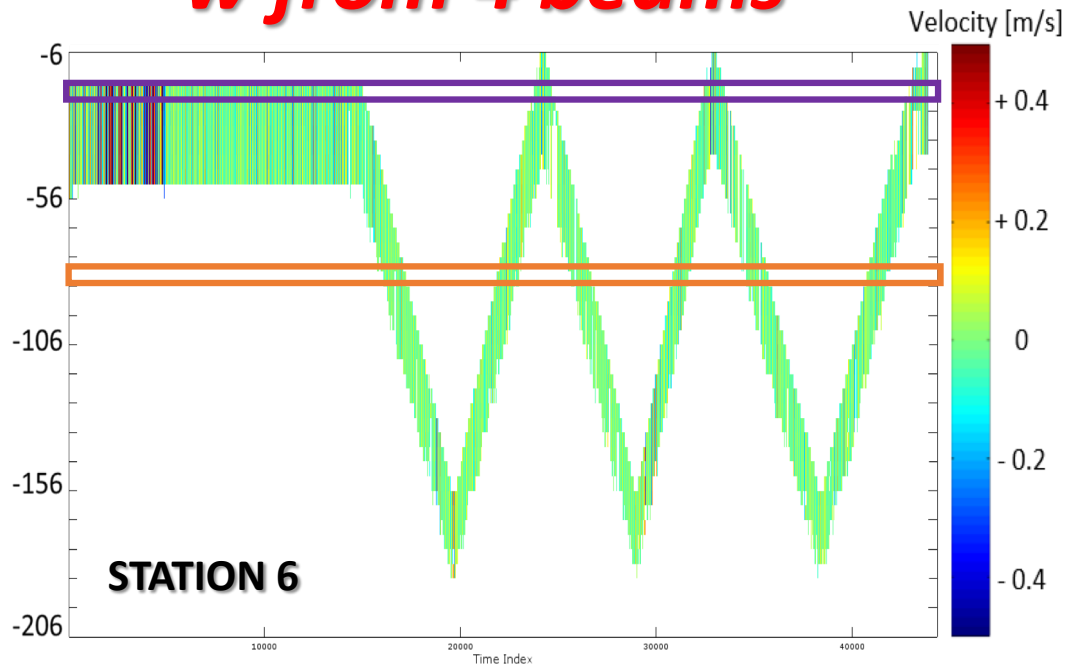


Sur la colonne d'eau 50-200 m

$$\mu = -0.009 \text{ m/s}$$

$$\sigma = 0.133 \text{ m/s}$$

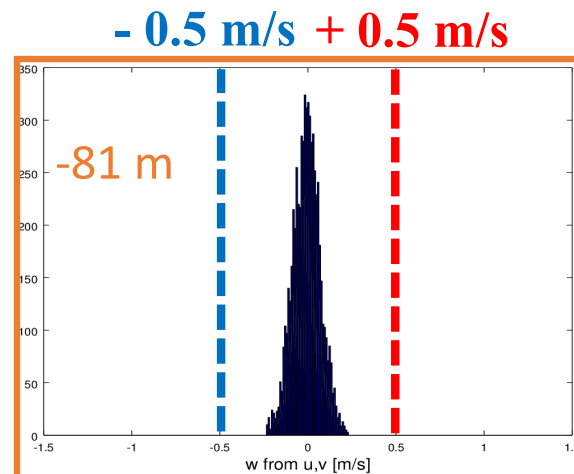
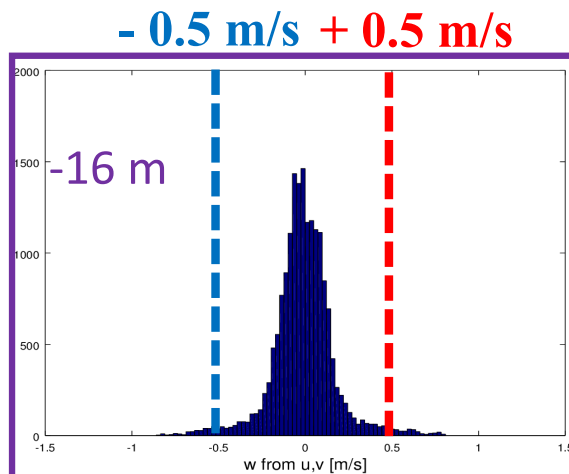
w from 4 beams



Sur la colonne d'eau 50-200 m

$$\mu = -0.005 \text{ m/s}$$

$$\sigma = 0.106 \text{ m/s}$$



Séparation des phases d'acquisition

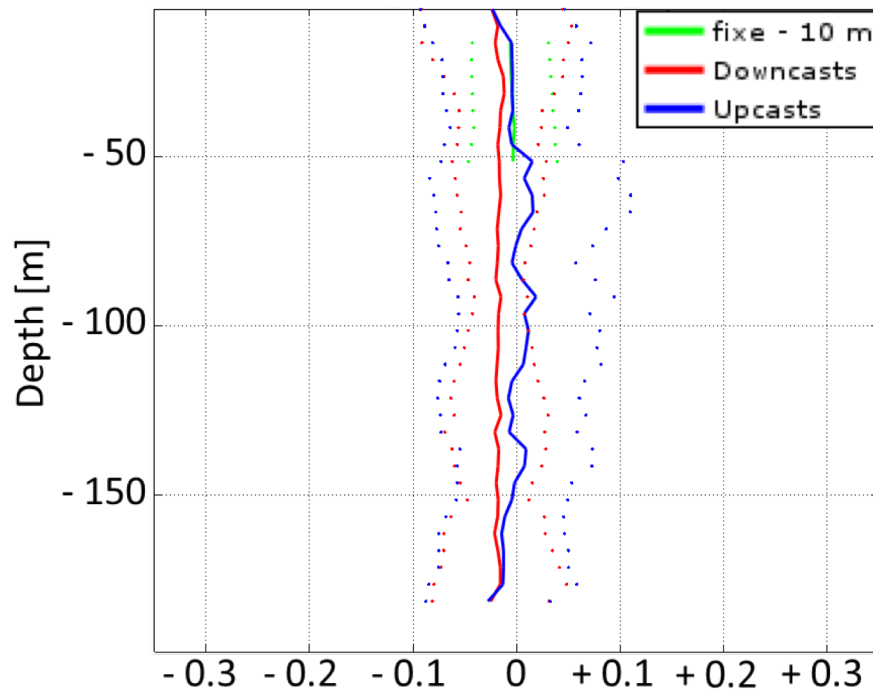
—

Comparaison des corrections (CTD)

w from 5th beam

STATION 1

w from 4 beams



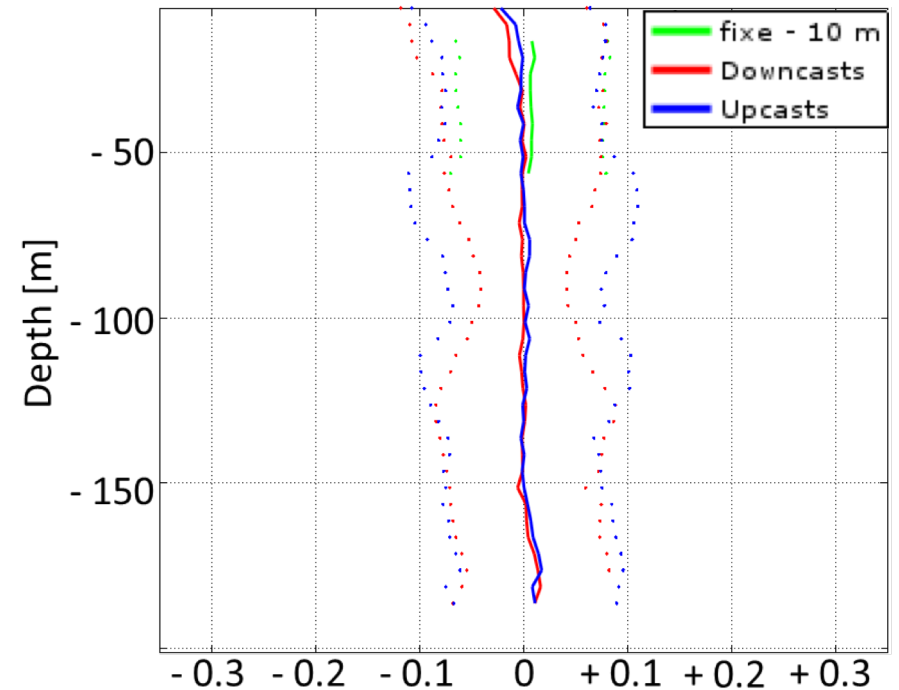
w from 5th beam [m/s]



Sur la colonne d'eau

$$\mu = -0.018 \text{ m/s}$$

$$\sigma = 0.044 \text{ m/s}$$



w from 4 beams [m/s]



Sur la colonne d'eau

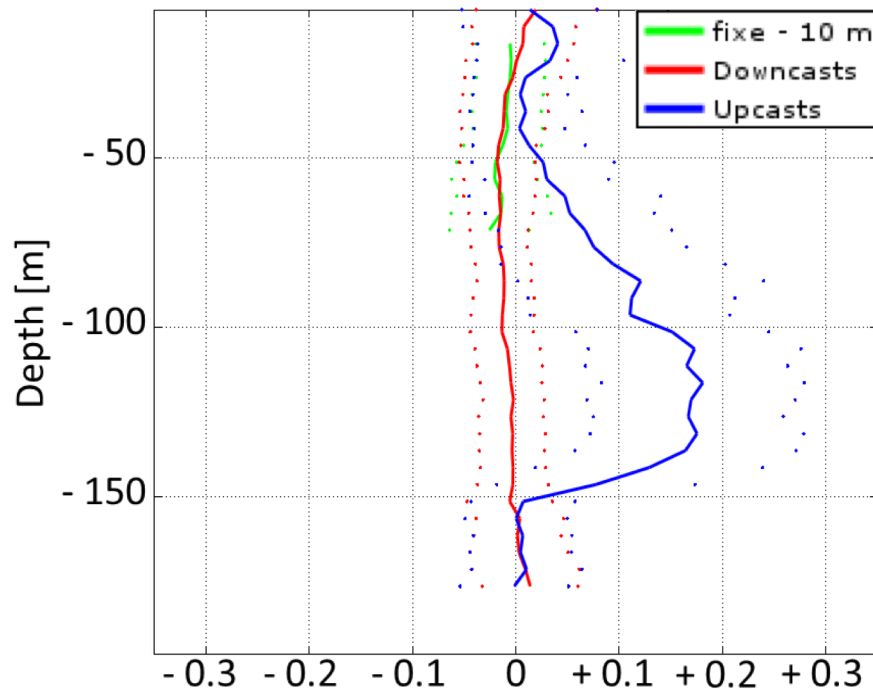
$$\mu = -0.001 \text{ m/s}$$

$$\sigma = 0.070 \text{ m/s}$$

w from 5th beam

STATION 2

w from 4 beams



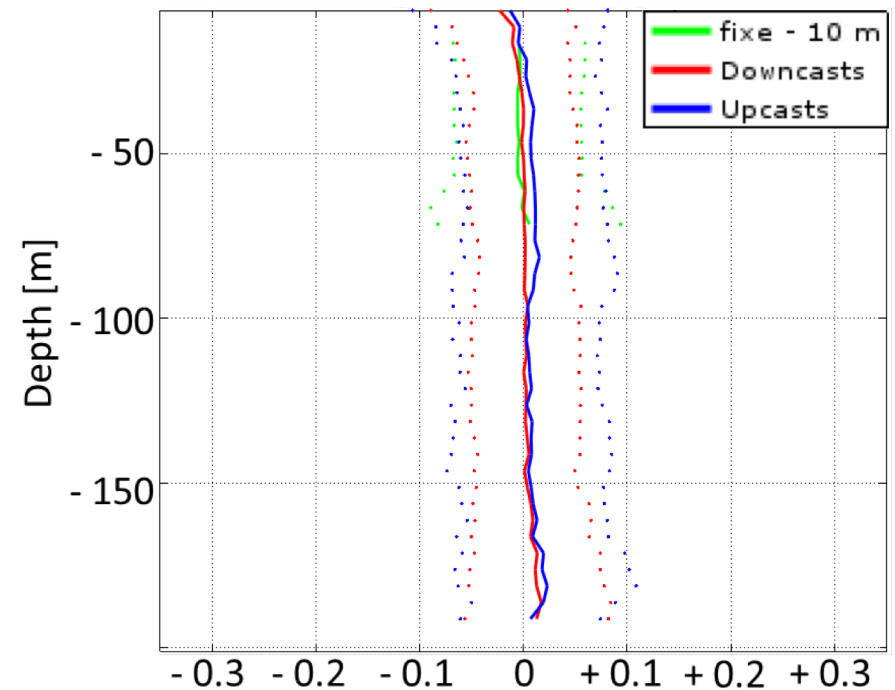
w from 5th beam [m/s]



Sur la colonne d'eau

$\mu = -0.005$ m/s

$\sigma = 0.036$ m/s



w from 4 beams [m/s]



Sur la colonne d'eau

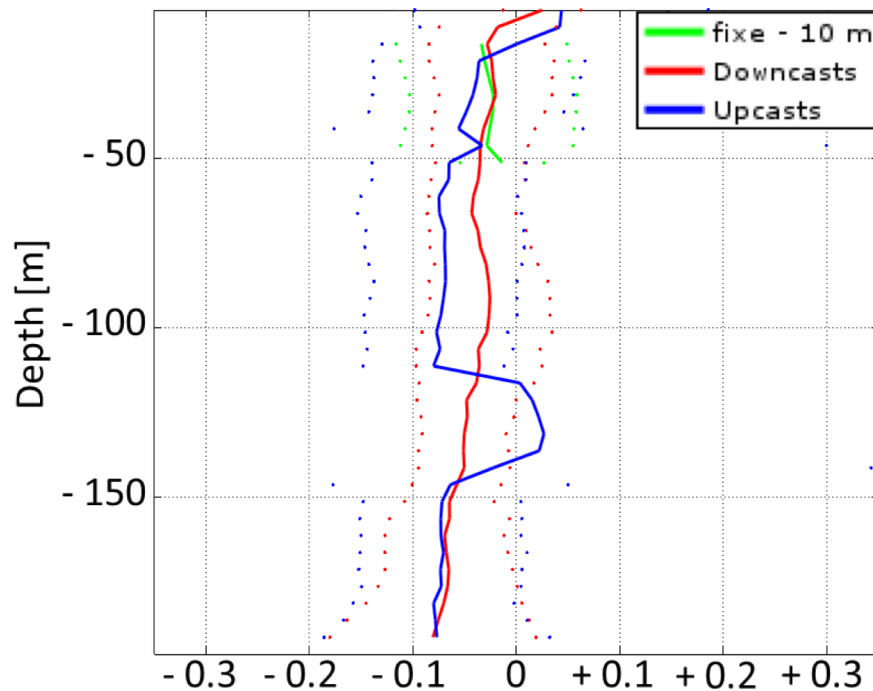
$\mu = 0.002$ m/s

$\sigma = 0.054$ m/s

w from 5th beam

STATION 3

w from 4 beams



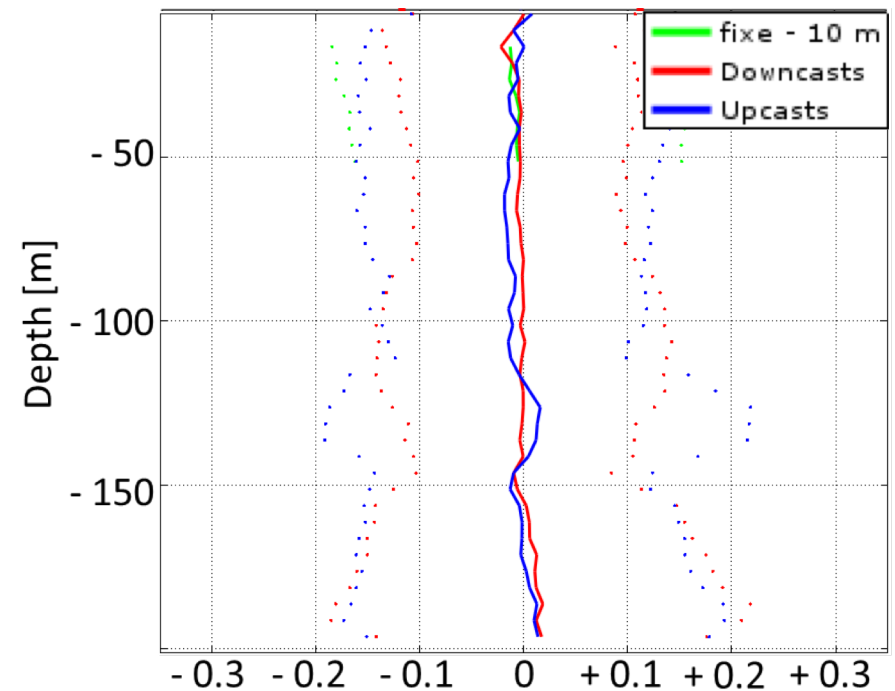
w from 5th beam [m/s]



Sur la colonne d'eau

$\mu = -0.042$ m/s

$\sigma = 0.054$ m/s



w from 4 beams [m/s]



Sur la colonne d'eau

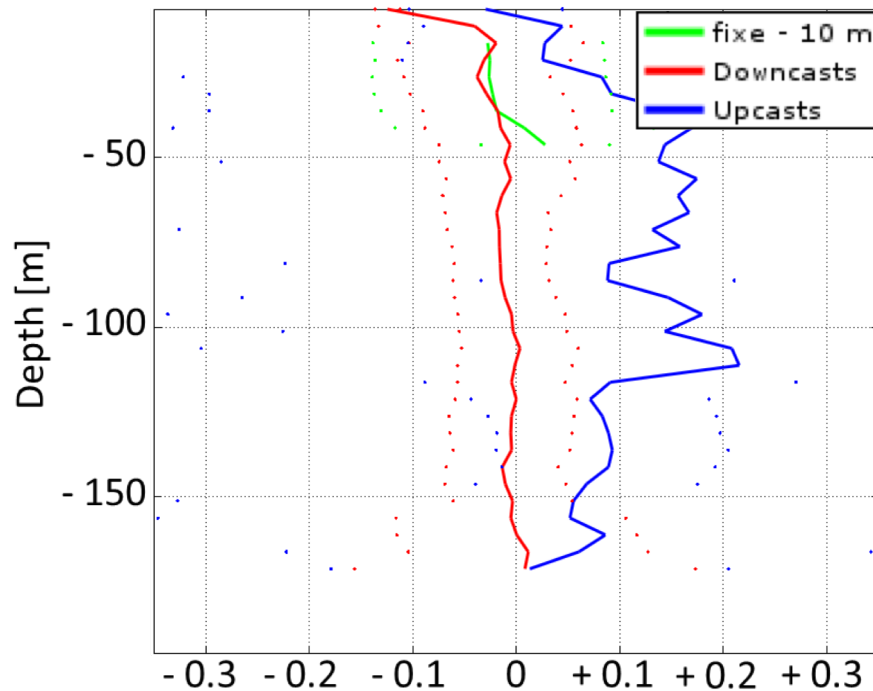
$\mu = -0.013$ m/s

$\sigma = 0.111$ m/s

w from 5th beam

STATION 4

w from 4 beams



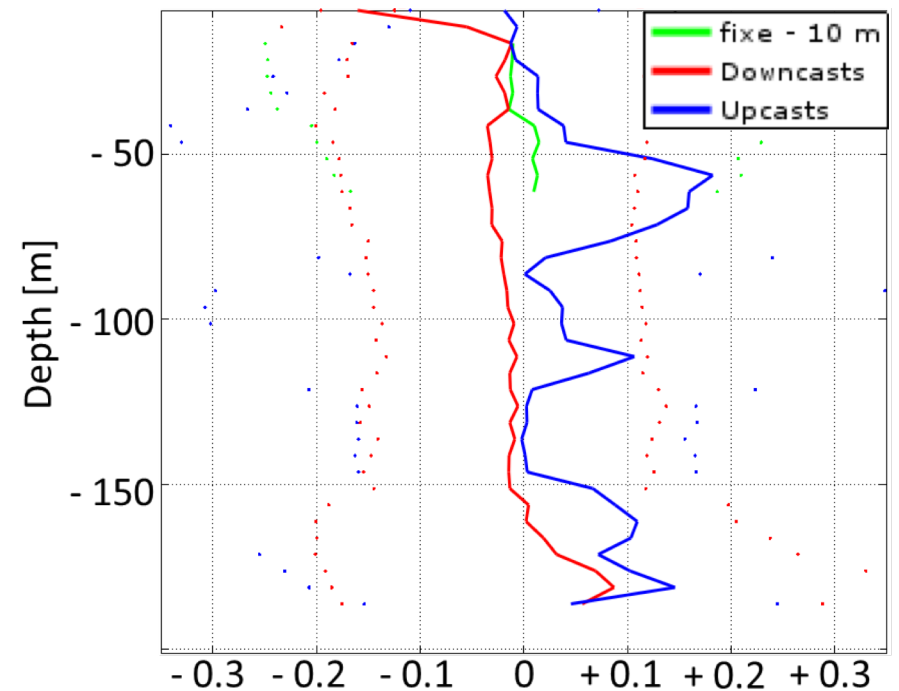
w from 5th beam [m/s]



Sur la colonne d'eau

$\mu = -0.014$ m/s

$\sigma = 0.066$ m/s



w from 4 beams [m/s]



Sur la colonne d'eau

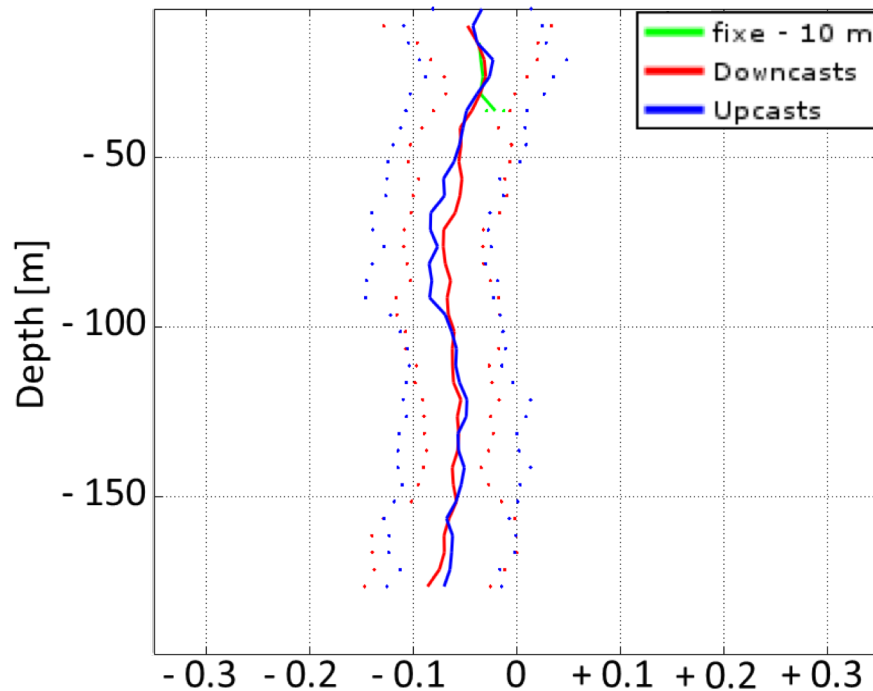
$\mu = -0.013$ m/s

$\sigma = 0.156$ m/s

w from 5th beam

STATION 5

w from 4 beams



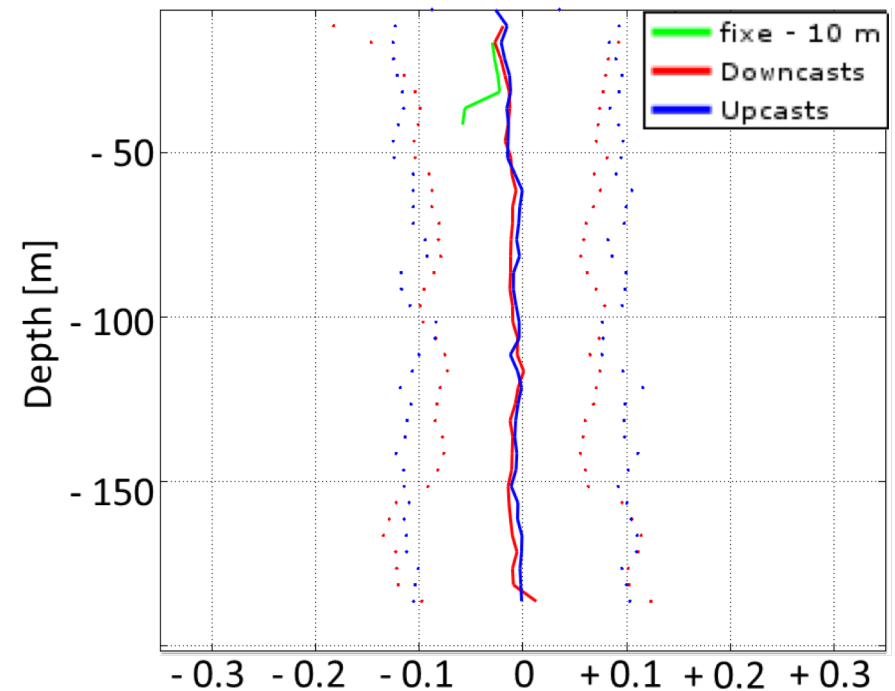
w from 5th beam [m/s]



Sur la colonne d'eau

$\mu = -0.059$ m/s

$\sigma = 0.045$ m/s



w from 4 beams [m/s]



Sur la colonne d'eau

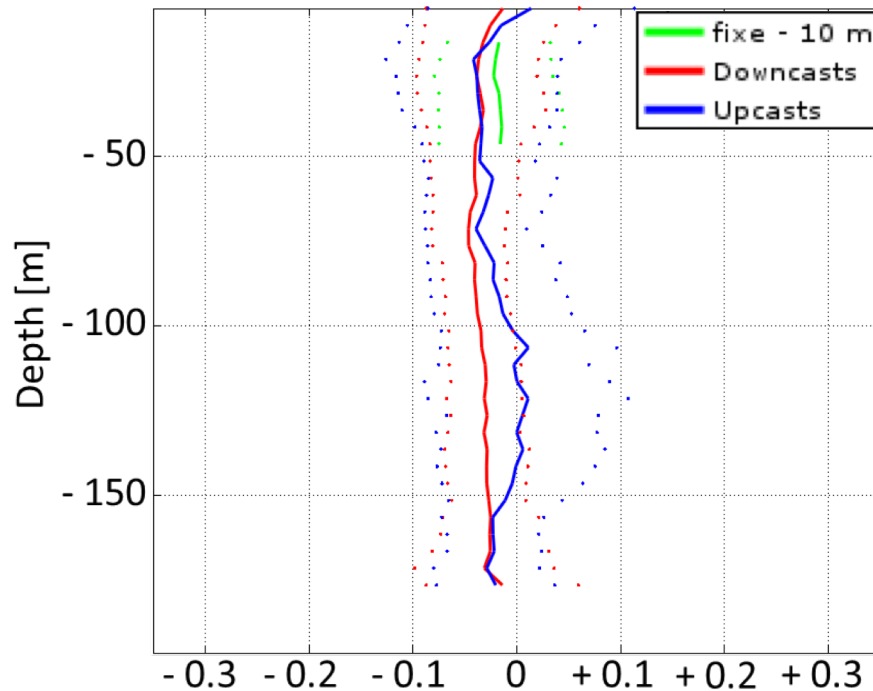
$\mu = -0.011$ m/s

$\sigma = 0.090$ m/s

w from 5th beam

STATION 6

w from 4 beams



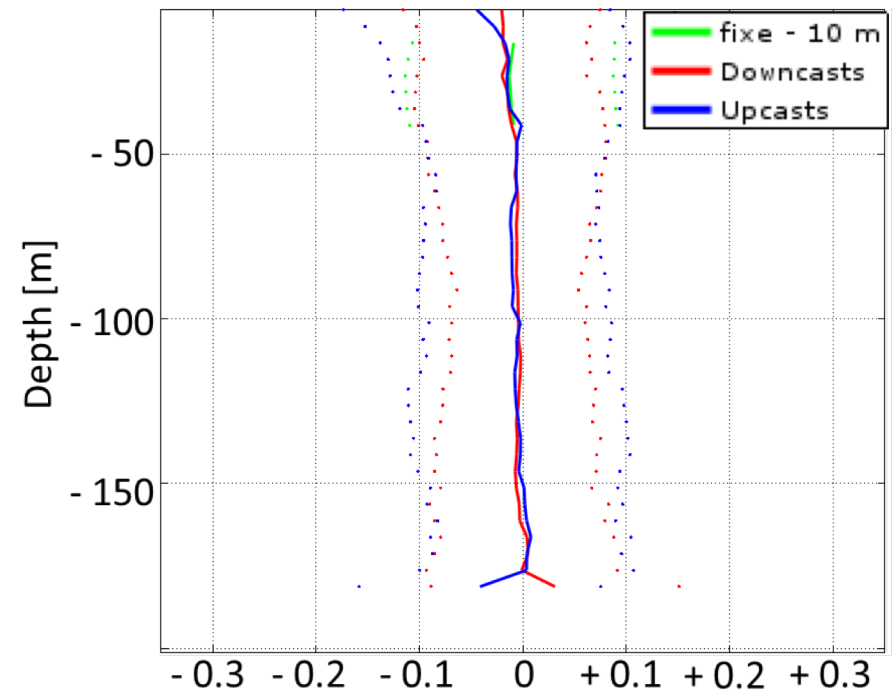
w from 5th beam [m/s]



Sur la colonne d'eau

$$\mu = -0.033 \text{ m/s}$$

$$\sigma = 0.044 \text{ m/s}$$



w from 4 beams [m/s]



Sur la colonne d'eau

$$\mu = -0.006 \text{ m/s}$$

$$\sigma = 0.079 \text{ m/s}$$

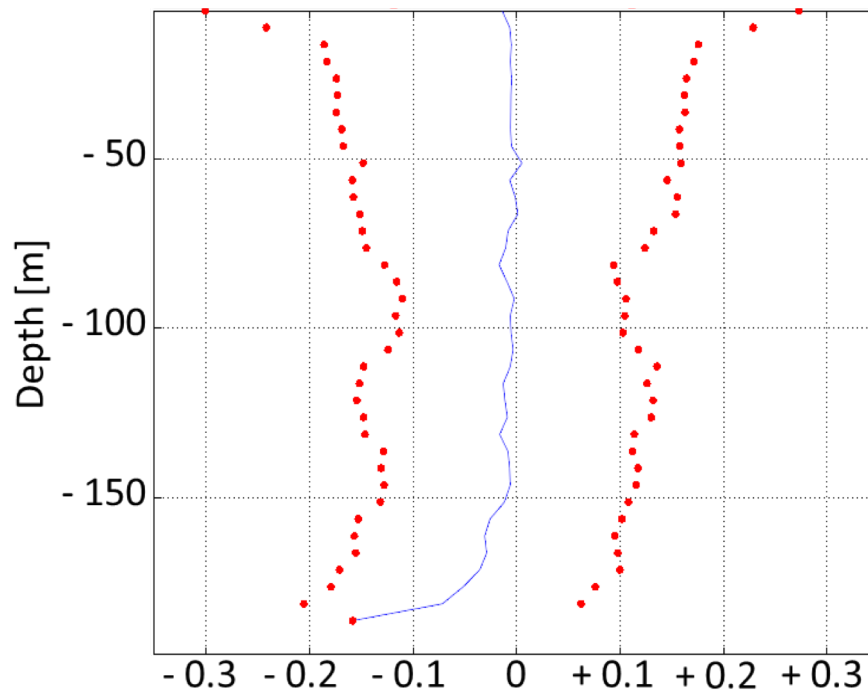
Comparaison des corrections

w_{Sentinel} VS. w_{CTD}

—

Dataset from 5th beam

w corrected (Sentinel)



w from 5th beam [m/s]

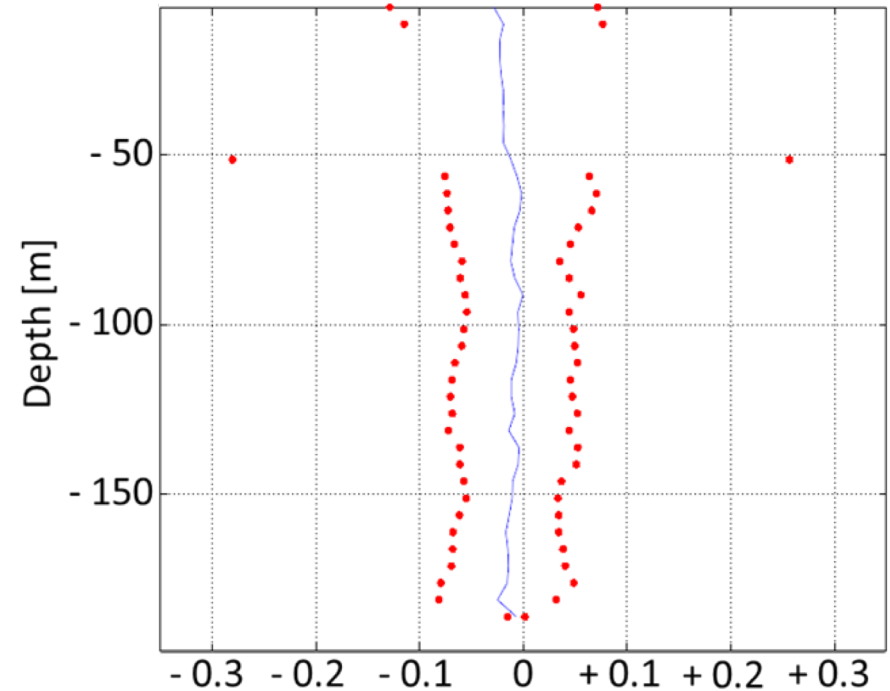


Sur la colonne d'eau

$$\mu = -0.017 \text{ m/s}$$

$$\sigma = 0.141 \text{ m/s}$$

w corrected (CTD)



w from 5th beam [m/s]



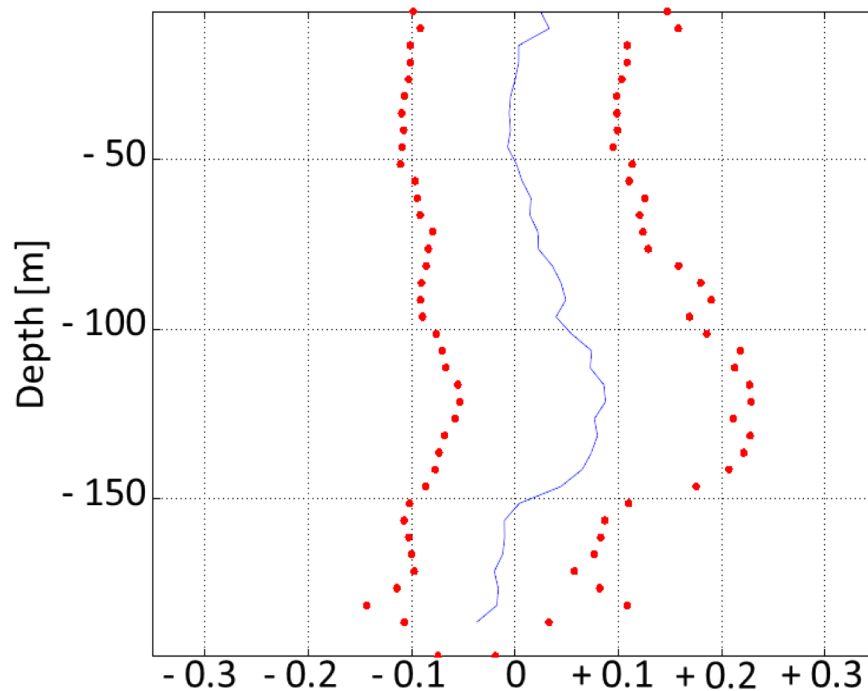
Sur la colonne d'eau

$$\mu = -0.013 \text{ m/s}$$

$$\sigma = 0.153 \text{ m/s}$$

STATION 1

w corrected (Sentinel)



w from 5th beam [m/s]

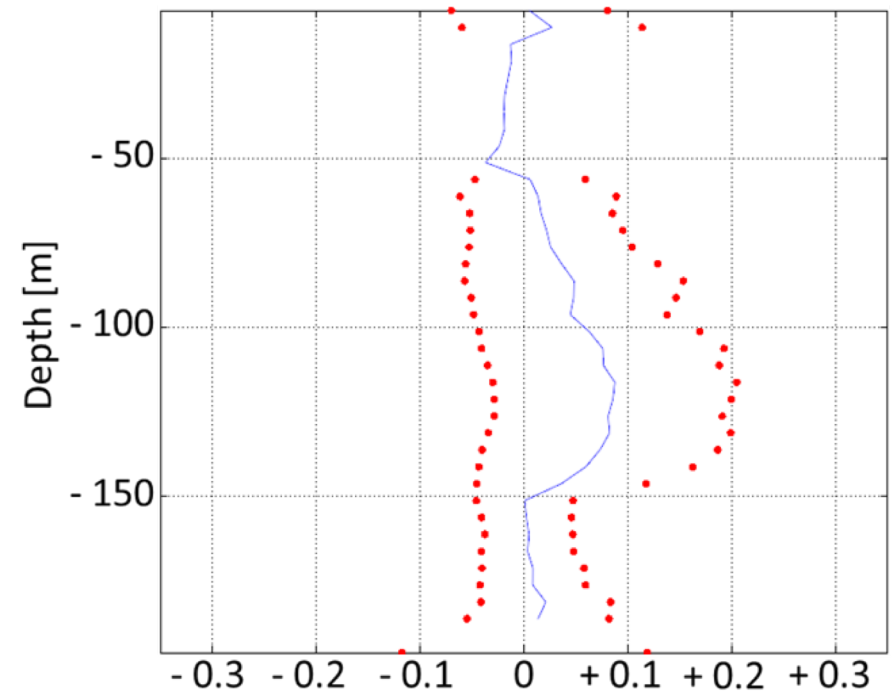


Sur la colonne d'eau

$\mu = 0.022 \text{ m/s}$

$\sigma = 0.114 \text{ m/s}$

w corrected (CTD)



w from 5th beam [m/s]



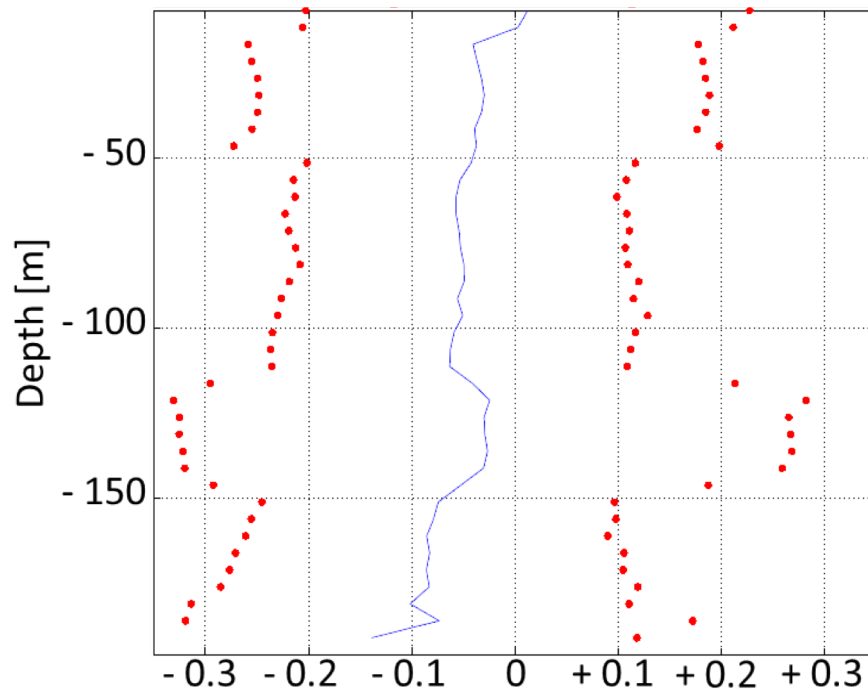
Sur la colonne d'eau

$\mu = 0.024 \text{ m/s}$

$\sigma = 0.157 \text{ m/s}$

STATION 2

w corrected (Sentinel)



w from 5th beam [m/s]

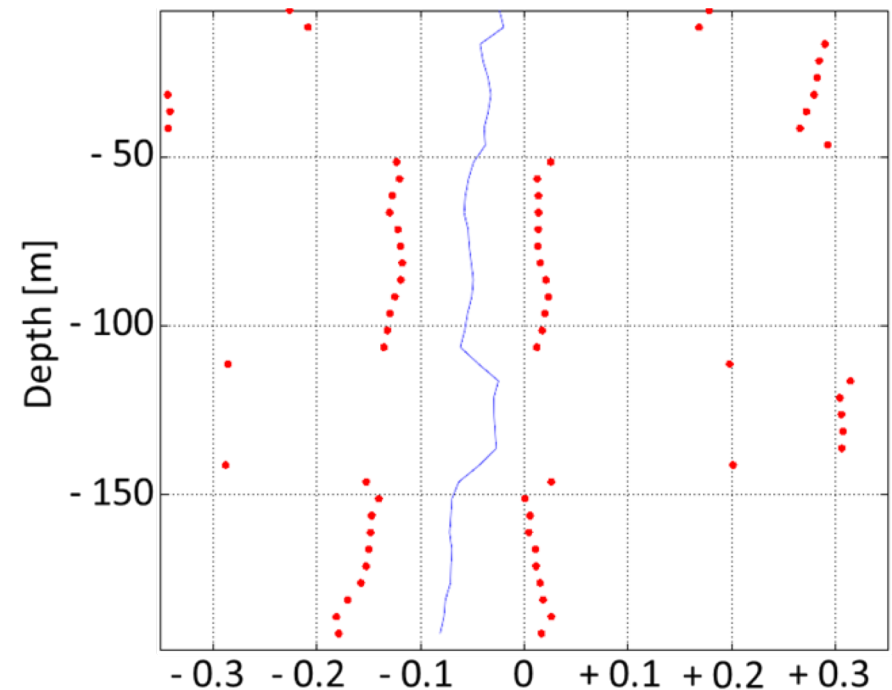


Sur la colonne d'eau

$$\mu = -0.052 \text{ m/s}$$

$$\sigma = 0.209 \text{ m/s}$$

w corrected (CTD)



w from 5th beam [m/s]



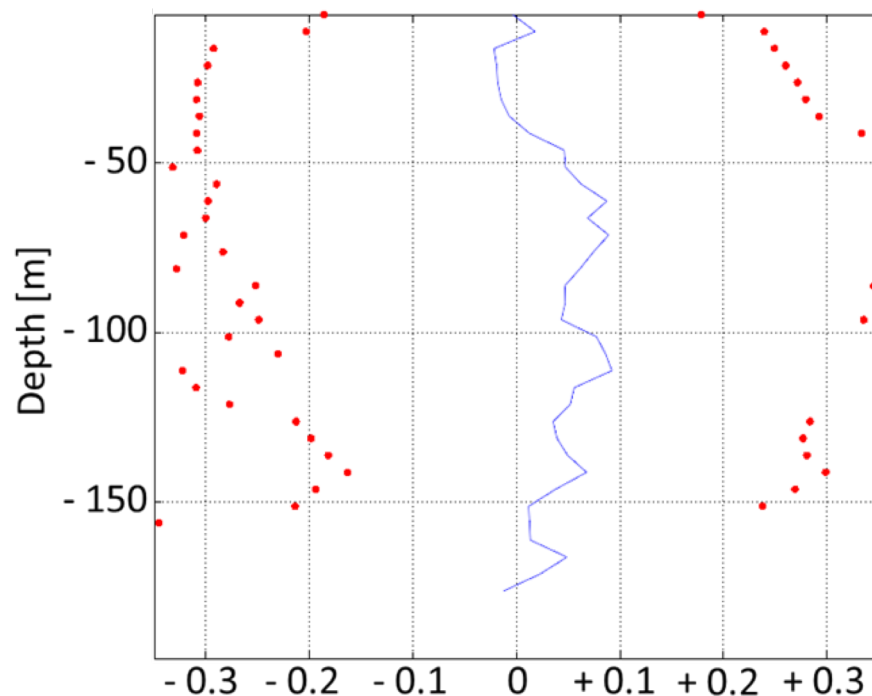
Sur la colonne d'eau

$$\mu = -0.050 \text{ m/s}$$

$$\sigma = 0.171 \text{ m/s}$$

STATION 3

w corrected (Sentinel)



w from 5th beam [m/s]

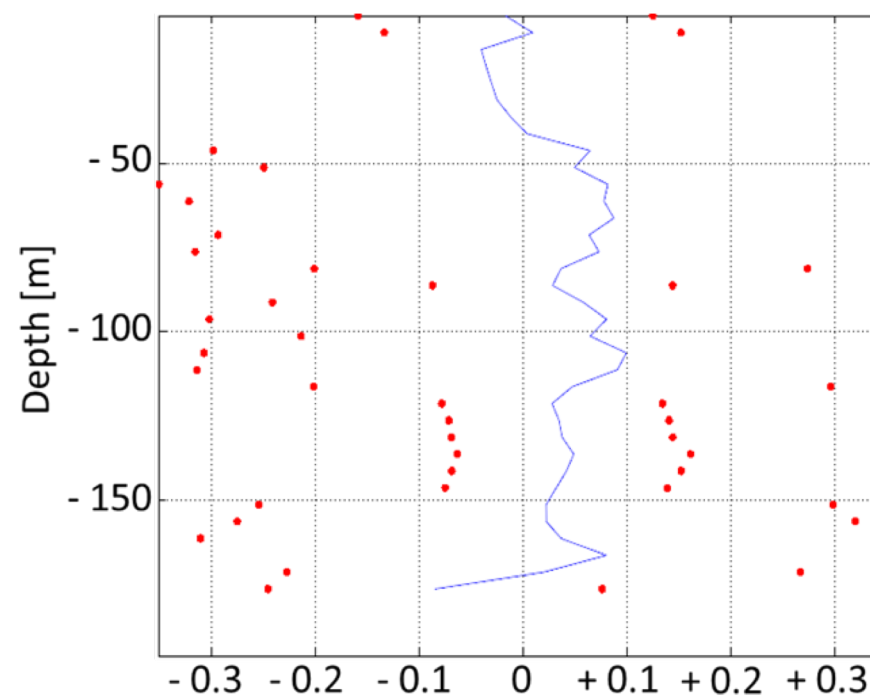


Sur la colonne d'eau

$\mu = 0.037 \text{ m/s}$

$\sigma = 0.332 \text{ m/s}$

w corrected (CTD)



w from 5th beam [m/s]



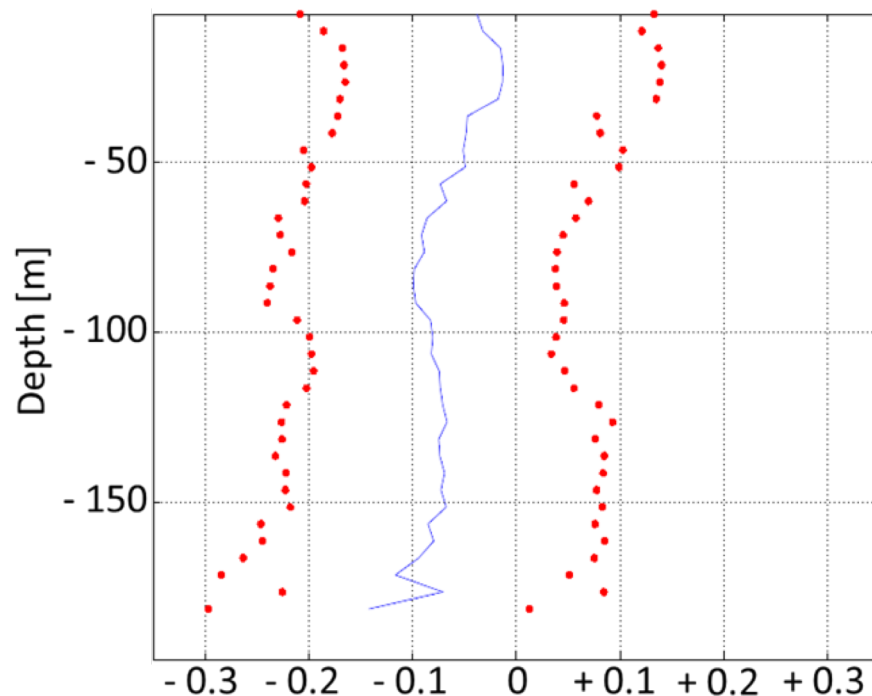
Sur la colonne d'eau

$\mu = 0.034 \text{ m/s}$

$\sigma = 0.332 \text{ m/s}$

STATION 4

w corrected (Sentinel)



w from 5th beam [m/s]

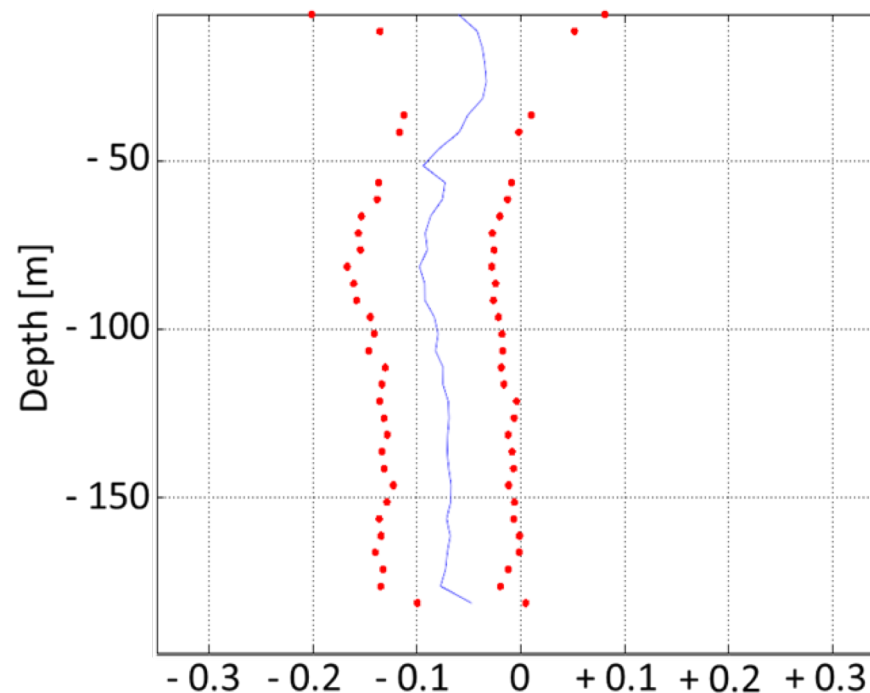


Sur la colonne d'eau

$$\mu = -0.070 \text{ m/s}$$

$$\sigma = 0.146 \text{ m/s}$$

w corrected (CTD)



w from 5th beam [m/s]



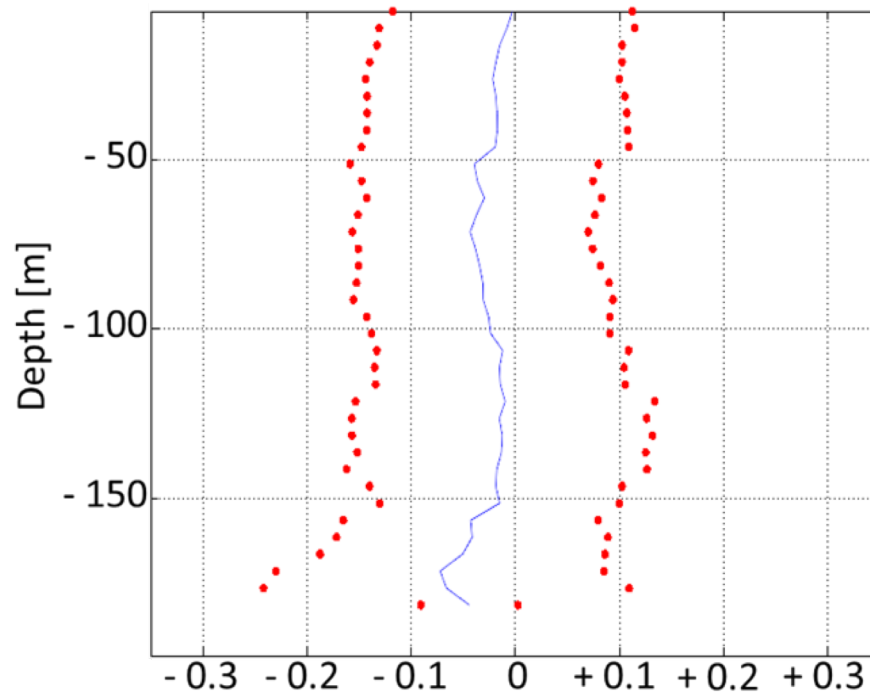
Sur la colonne d'eau

$$\mu = -0.070 \text{ m/s}$$

$$\sigma = 0.145 \text{ m/s}$$

STATION 5

w corrected (Sentinel)



w from 5th beam [m/s]

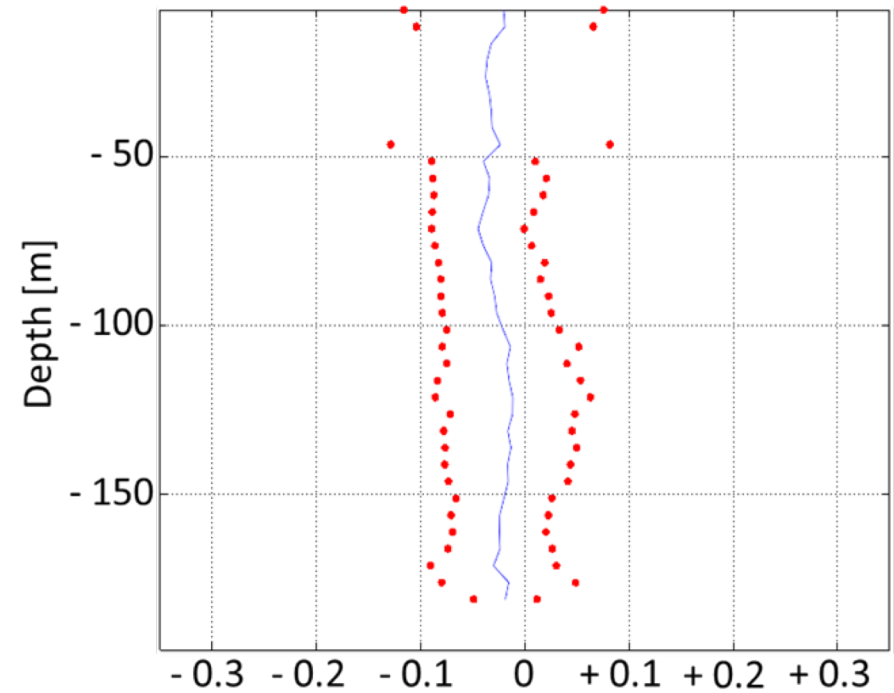


Sur la colonne d'eau

$$\mu = -0.027 \text{ m/s}$$

$$\sigma = 0.124 \text{ m/s}$$

w corrected (CTD)



w from 5th beam [m/s]



Sur la colonne d'eau

$$\mu = -0.026 \text{ m/s}$$

$$\sigma = 0.116 \text{ m/s}$$

STATION 6

Variables physiques

Température – Anomalie de masse volumique – Vitesse du son

