Étalonnage de marégraphes par combinaison d'instruments

Kevin Gobron [a] ***- Olivier de Viron*** [a] ***- Guy Wöppelmann*** [a] ***– Étienne Poirier*** [a] ***- Michel van Camp*** [b]

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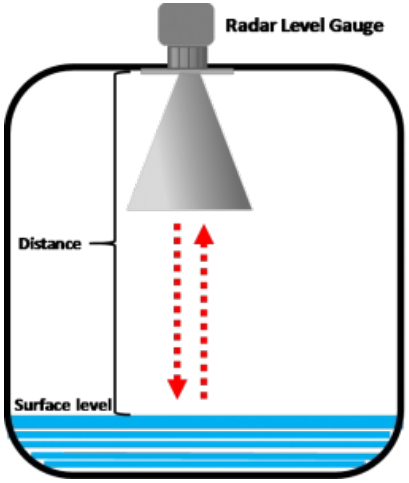
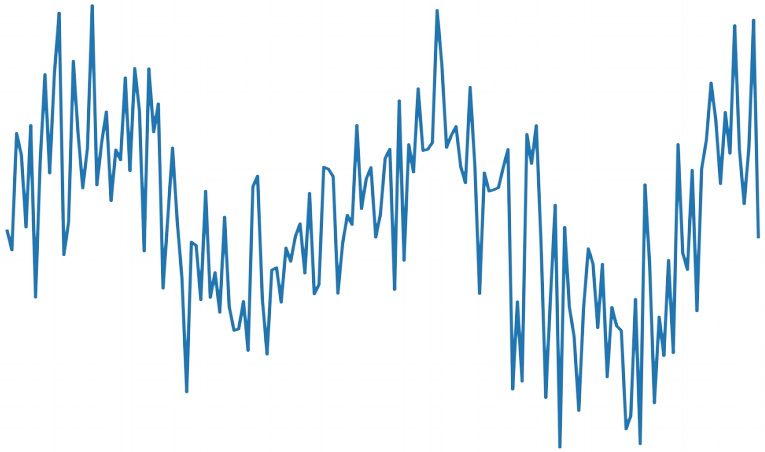
[b] **Observatoire Royal de Belgique (ORB)**

– Motivations –





Signal ou **bruit + biais instrumentaux** ?

Motivations – **Objectifs de précision**

- Beaucoup de technologies disponibles : **RADAR, Pression, LASER, GNSS-R, Bouée GNSS, …**

Motivations – **Objectifs de précision**

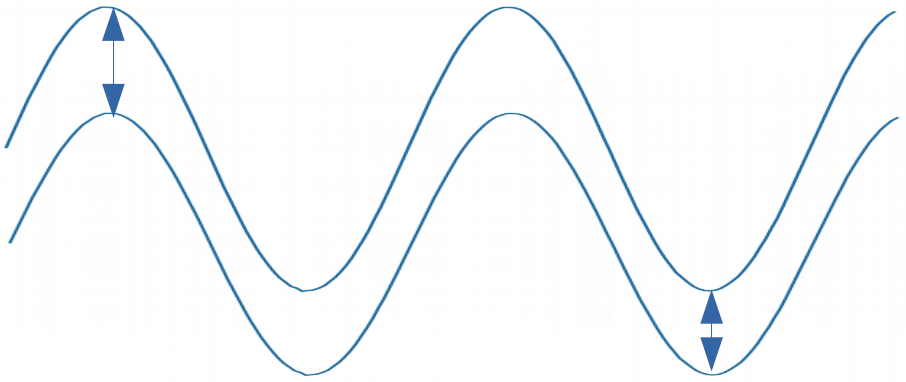
- Beaucoup de technologies disponibles : **RADAR, Pression, LASER, GNSS-R, Bouée GNSS, …**

*– Commission Océanographique Intergouvernementale (**IOC**) 2016 –*

*« A requirement for a tide gauge in GLOSS is for it to be capable of **measuring instantaneous sea level to better than 1 cm at all times** (i.e. in all conditions of tide, waves, currents, weather, etc …) »*

Quels biais/précisions en *<u>conditions réelles</u>* ?

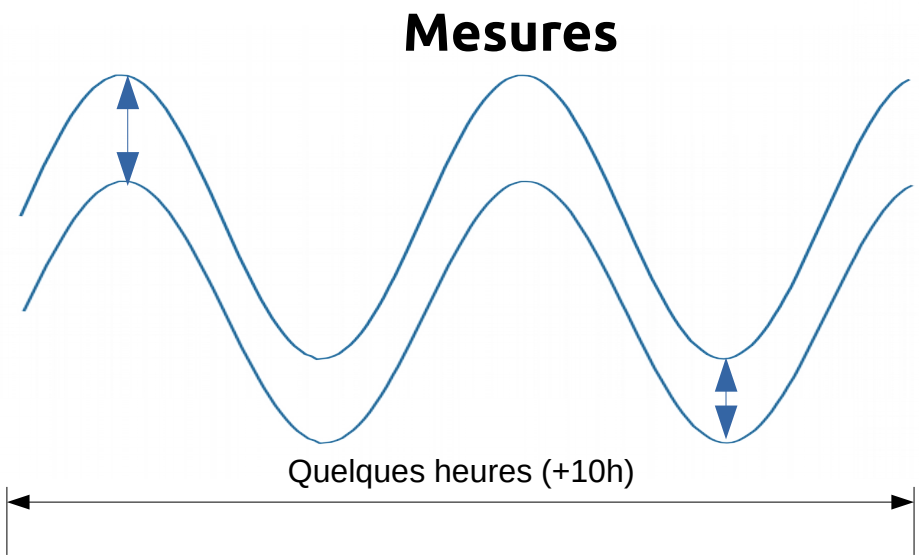
– Méthode actuelle : comparaison in-situ –

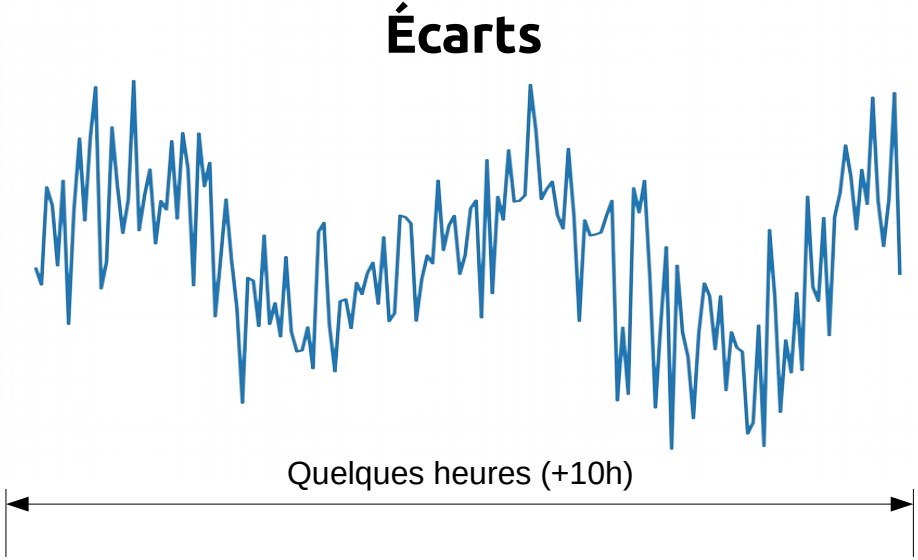


Méthodologie d’estimation des **biais instrumentaux**

Méthodes – Campagne de comparaison

Étalonnage → Étalon → Comparaison d'observations

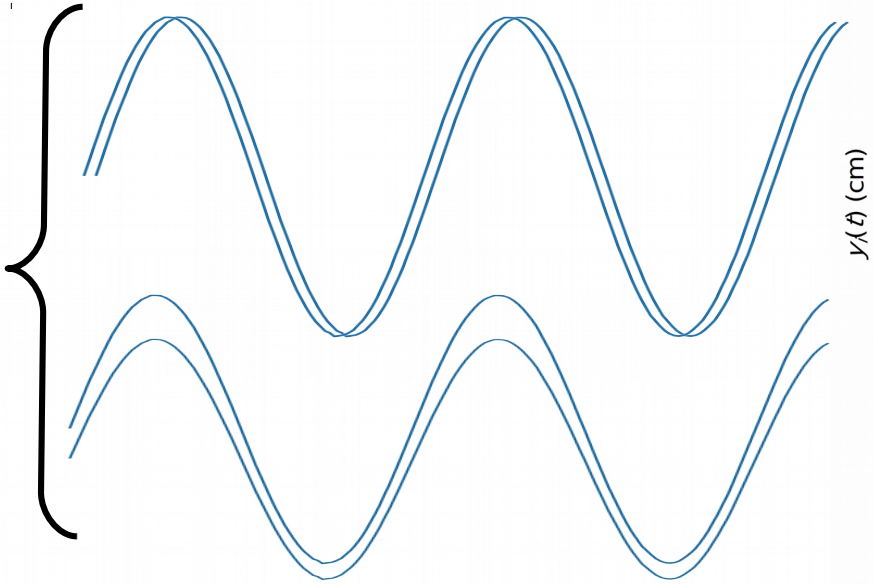




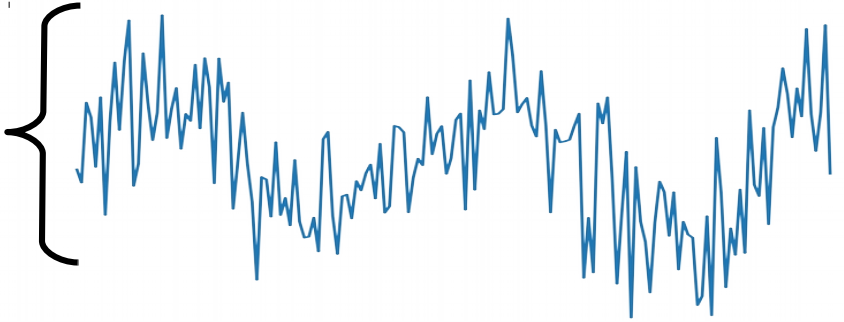
Étalon ~~parfait~~ ~ **Écarts = biais**
+ incertitude instrument
+ incertitude étalon

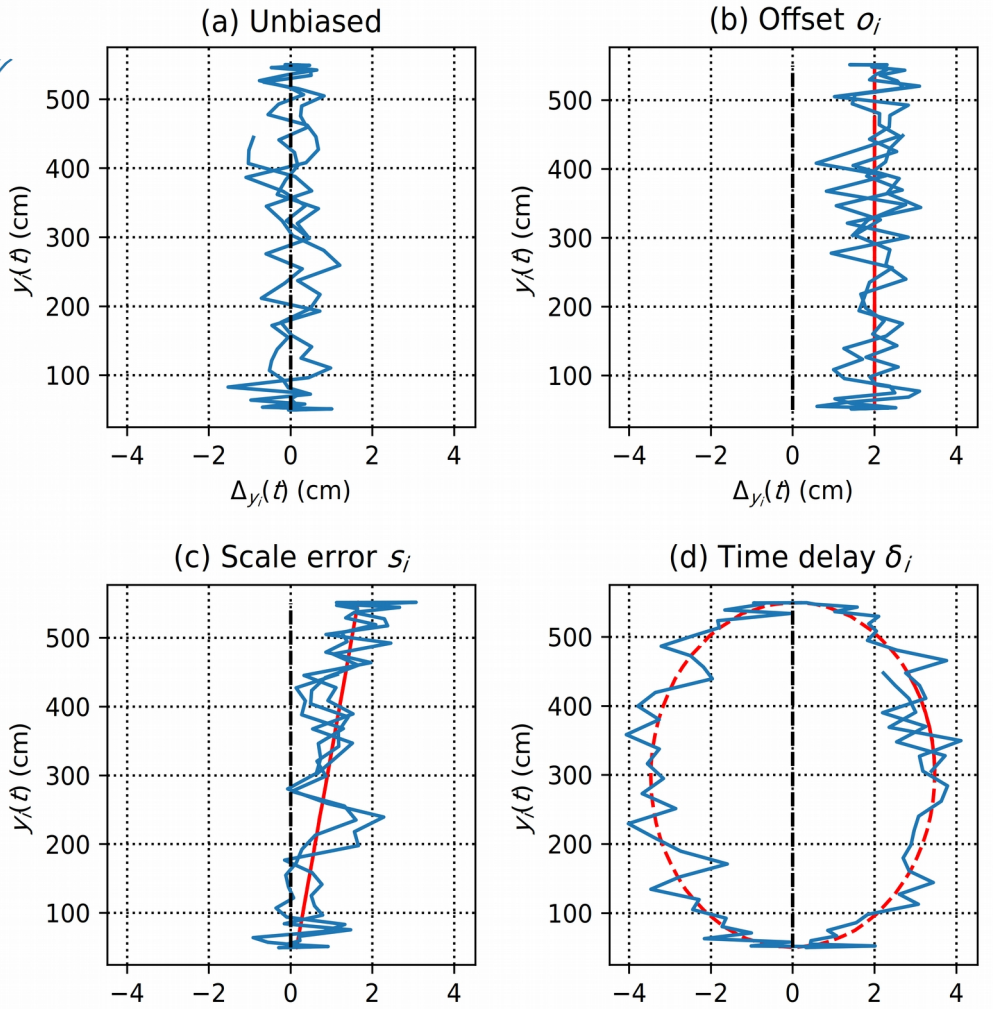
Méthodes – **Test de Van de Casteele**

Mesures

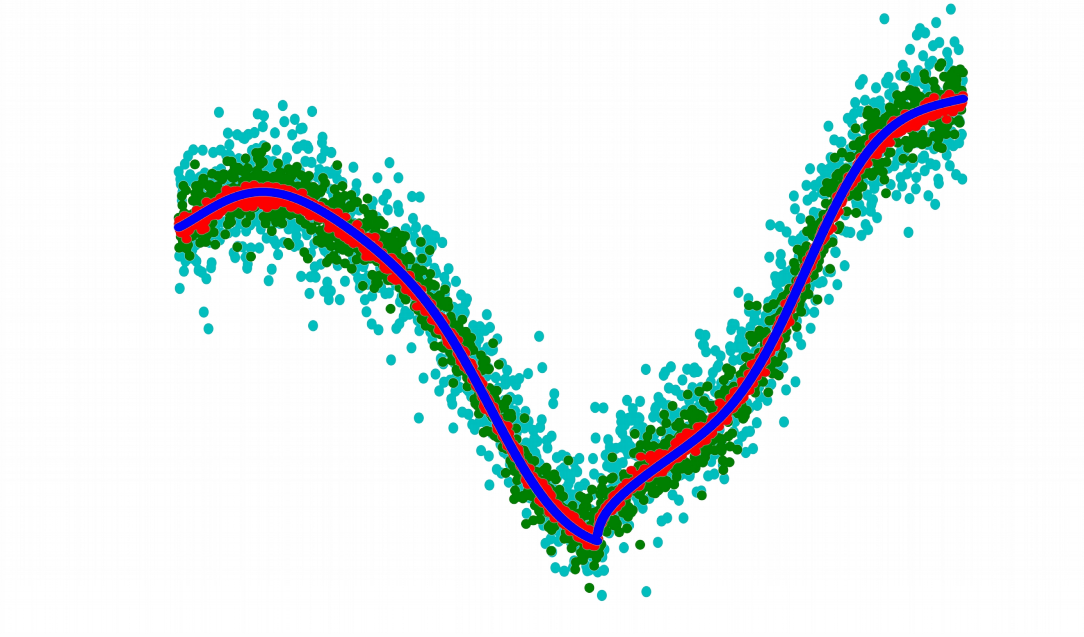


Écarts





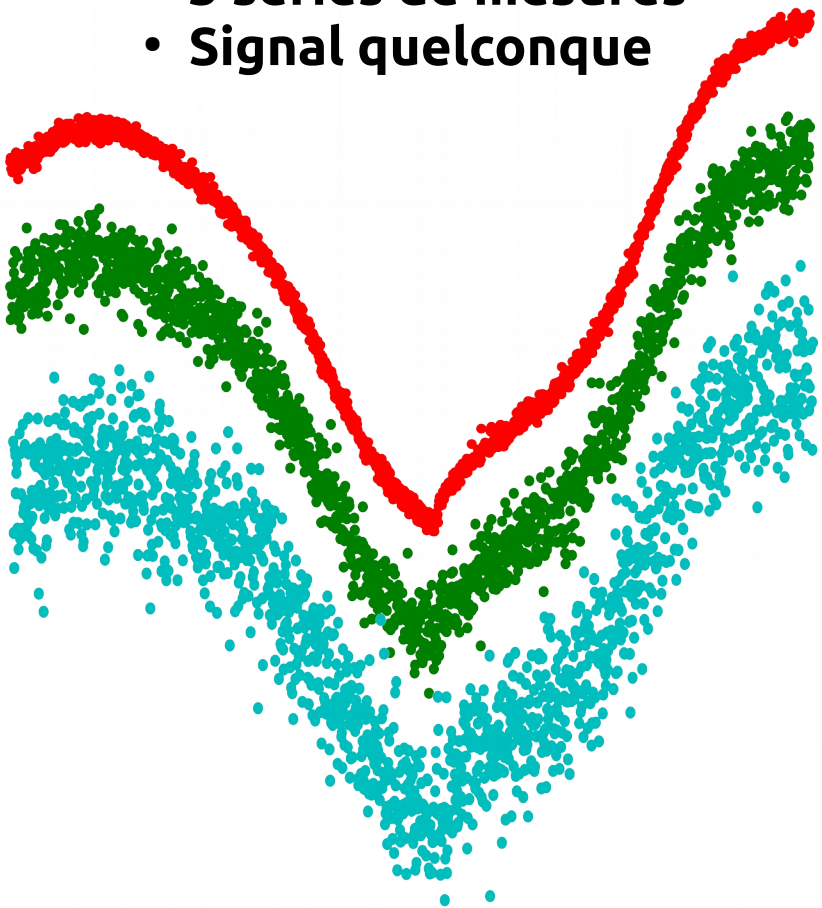
Alternative proposée : combinaison d'instruments

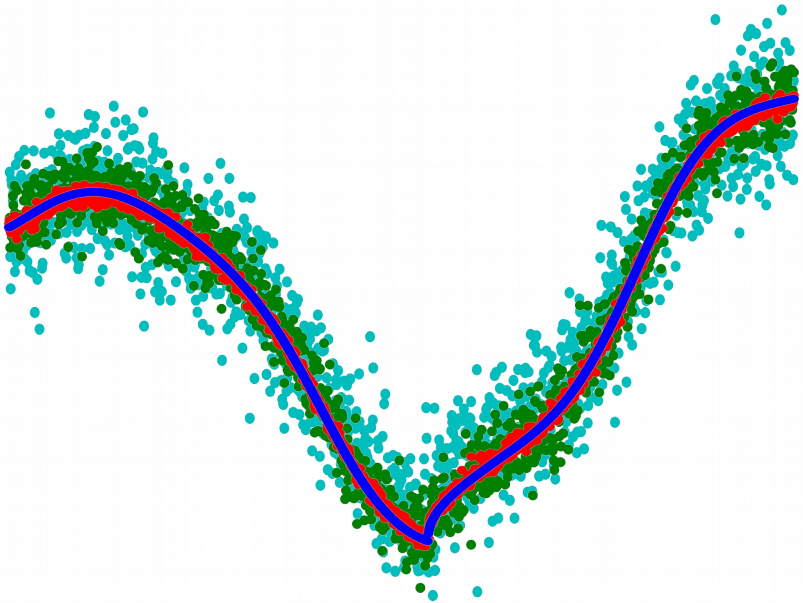


Méthodologie d'estimation des **biais & incertitudes**

Combinaison – **Principe général (sans biais)**

- **3 séries de mesures**
- **Signal quelconque**





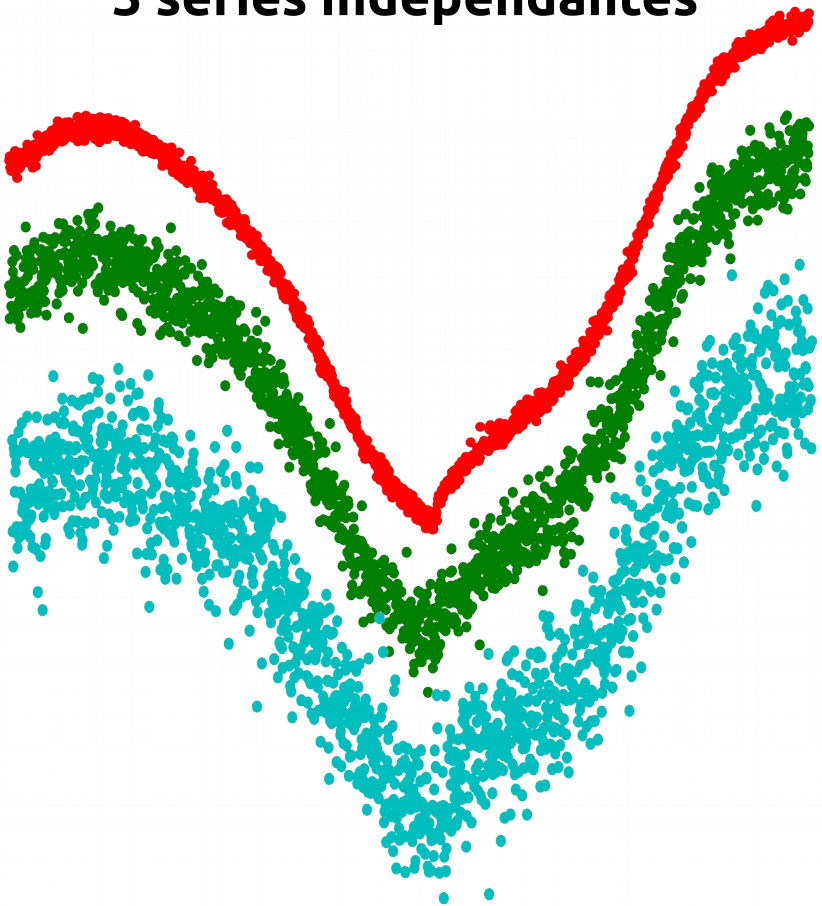
Estimation d'une série combinée

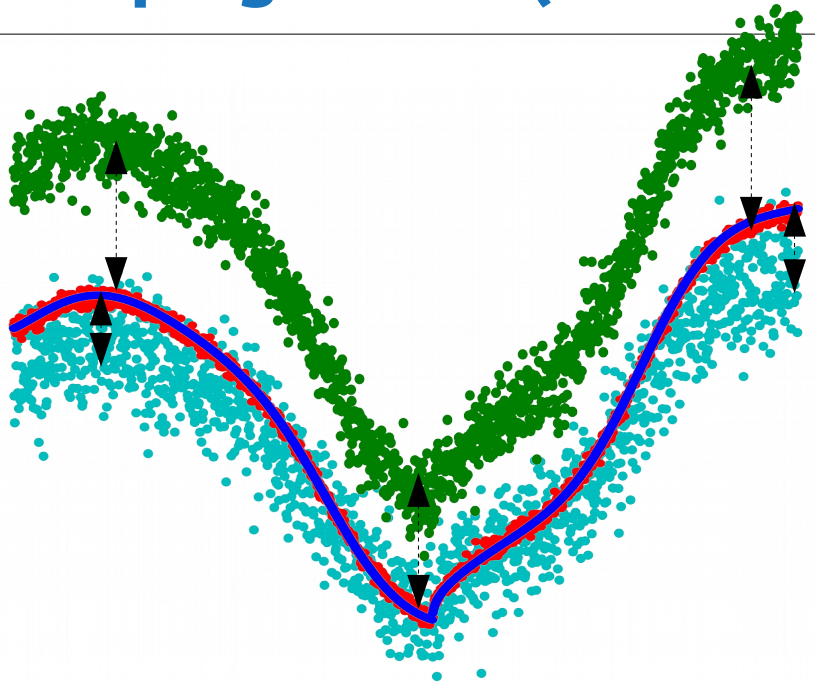
Quelles observations ?
Quels modèles ?

$$\begin{cases} y = ? \\ E(y) = ? \\ var(y) = ? \end{cases}$$

Combinaison – **Principe général (avec biais)**

3 séries indépendantes





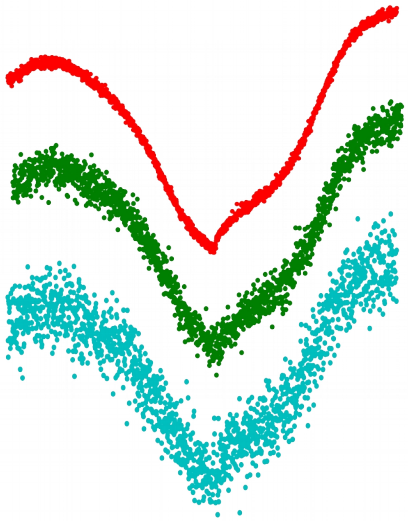
Estimation d'une série combinée

Quelles observations ?
Quels modèles ?

$$\begin{cases} y = ? \\ E(y) = ? \\ var(y) = ? \end{cases}$$

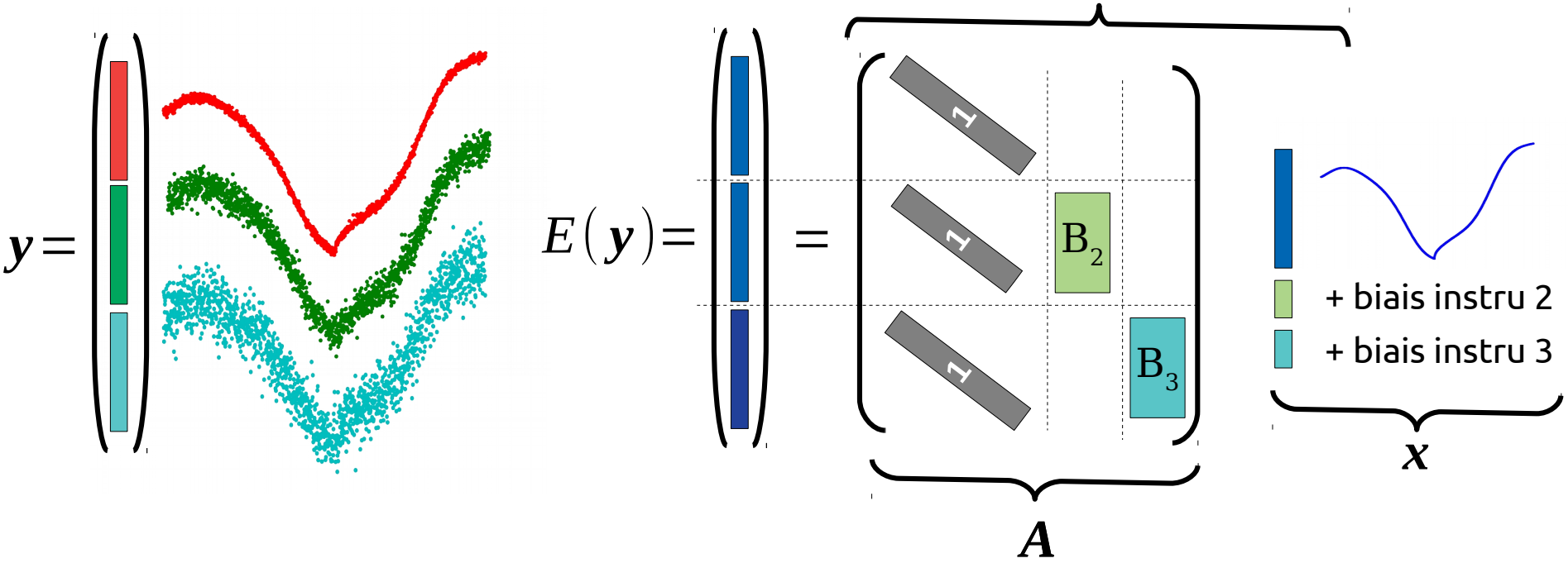
Combinaison – **Vecteur des observations**

$$\boldsymbol{y} = \begin{pmatrix} \\ \\ \\ \end{pmatrix}$$



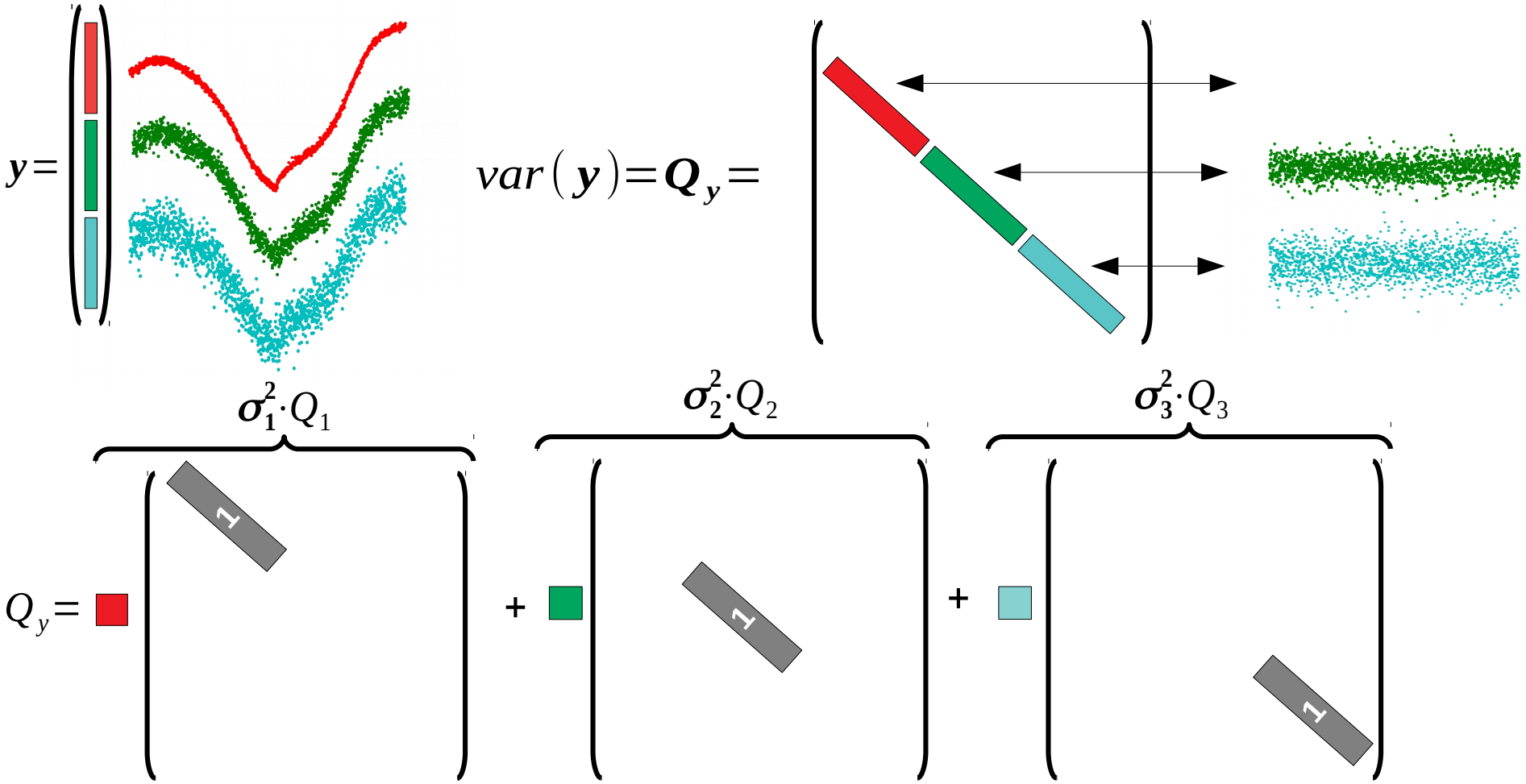
Combinaison – **Modèle linéaire de signal**

$$E(\boldsymbol{y}) = \boldsymbol{A}\boldsymbol{x}$$



$$Biais = \boldsymbol{B}_i(t) = \boldsymbol{\alpha}_i + \boldsymbol{\beta}_i \cdot H_i(t)$$

Combinaison – **Modèle linéaire d'incertitude**



Combinaison – **Estimation des paramètres**

Estimation du **signal combiné** & des **biais** :

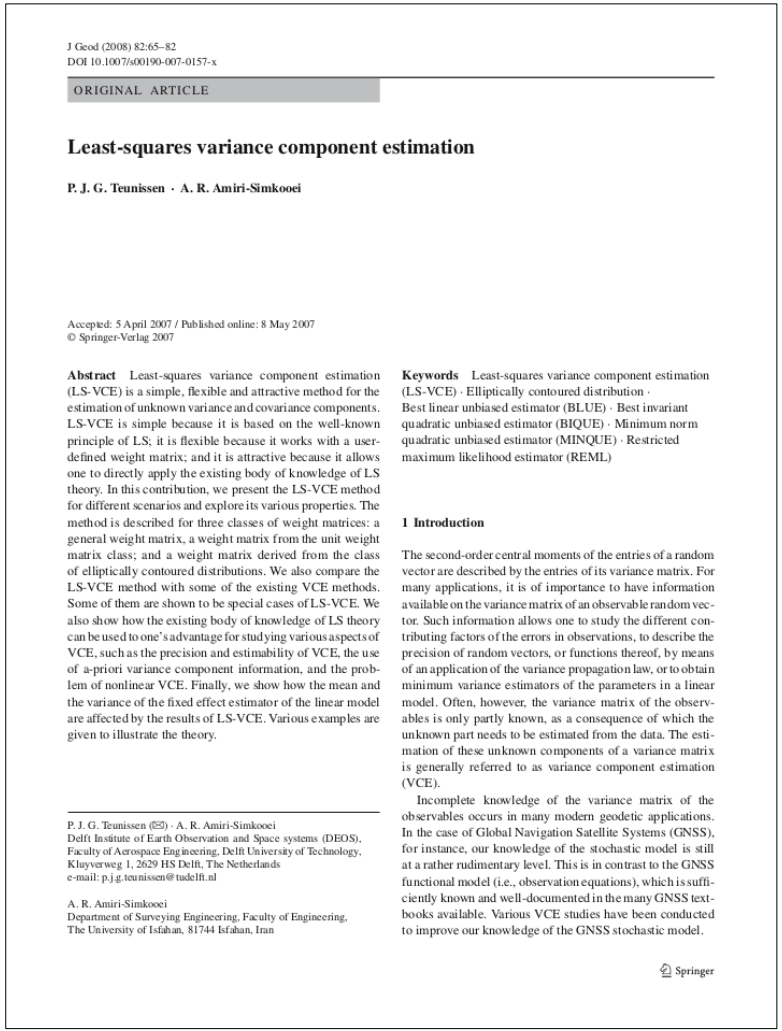
- ✓ **Méthode des moindres carrés (LS)**

Estimation des **incertitudes** :

- ✓ **Estimation des composantes de la variance par moindres carrés (LS-VCE)**

Pourquoi la LS-VCE ?

- ✓ **Non biaisée & variance minimale**
- ✓ **Incertitudes sur les variances estimées**



J Geod (2008) 82:65–82
DOI 10.1007/s00190-007-0157-x

ORIGINAL ARTICLE

Least-squares variance component estimation

P. J. G. Teunissen · A. R. Amiri-Simkooei

Accepted: 5 April 2007 / Published online: 8 May 2007
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Abstract Least-squares variance component estimation (LS-VCE) is a simple, flexible and attractive method for the estimation of unknown variance and covariance components. LS-VCE is simple because it is based on the well-known principle of LS; it is flexible because it works with a user-defined weight matrix; and it is attractive because it allows one to directly apply the existing body of knowledge of LS theory. In this contribution, we present the LS-VCE method for different scenarios and explore its various properties. The method is described for three classes of weight matrices: a general weight matrix, a weight matrix from the unit weight matrix class; and a weight matrix derived from the class of elliptically contoured distributions. We also compare the LS-VCE method with some of the existing VCE methods. Some of them are shown to be special cases of LS-VCE. We also show how the existing body of knowledge of LS theory can be used to one's advantage for studying various aspects of VCE, such as the precision and estimability of VCE, the use of a-priori variance component information, and the problem of nonlinear VCE. Finally, we show how the mean and the variance of the fixed effect estimator of the linear model are affected by the results of LS-VCE. Various examples are given to illustrate the theory.

Keywords Least-squares variance component estimation (LS-VCE) · Elliptically contoured distribution · Best linear unbiased estimator (BLUE) · Best invariant quadratic unbiased estimator (BIQUE) · Minimum norm quadratic unbiased estimator (MINQUE) · Restricted maximum likelihood estimator (REML)

1 Introduction

The second-order central moments of the entries of a random vector are described by the entries of its variance matrix. For many applications, it is of importance to have information available on the variance matrix of an observable random vector. Such information allows one to study the different contributing factors of the errors in observations, to describe the precision of random vectors, or functions thereof, by means of an application of the variance propagation law, or to obtain minimum variance estimators of the parameters in a linear model. Often, however, the variance matrix of the observables is only partly known, as a consequence of which the unknown part needs to be estimated from the data. The estimation of these unknown components of a variance matrix is generally referred to as variance component estimation (VCE).

Incomplete knowledge of the variance matrix of the observables occurs in many modern geodetic applications. In the case of Global Navigation Satellite Systems (GNSS), for instance, our knowledge of the stochastic model is still at a rather rudimentary level. This is in contrast to the GNSS functional model (i.e., observation equations), which is sufficiently known and well-documented in the many GNSS textbooks available. Various VCE studies have been conducted to improve our knowledge of the GNSS stochastic model.

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– Application à une expérience sur l'île d'Aix –

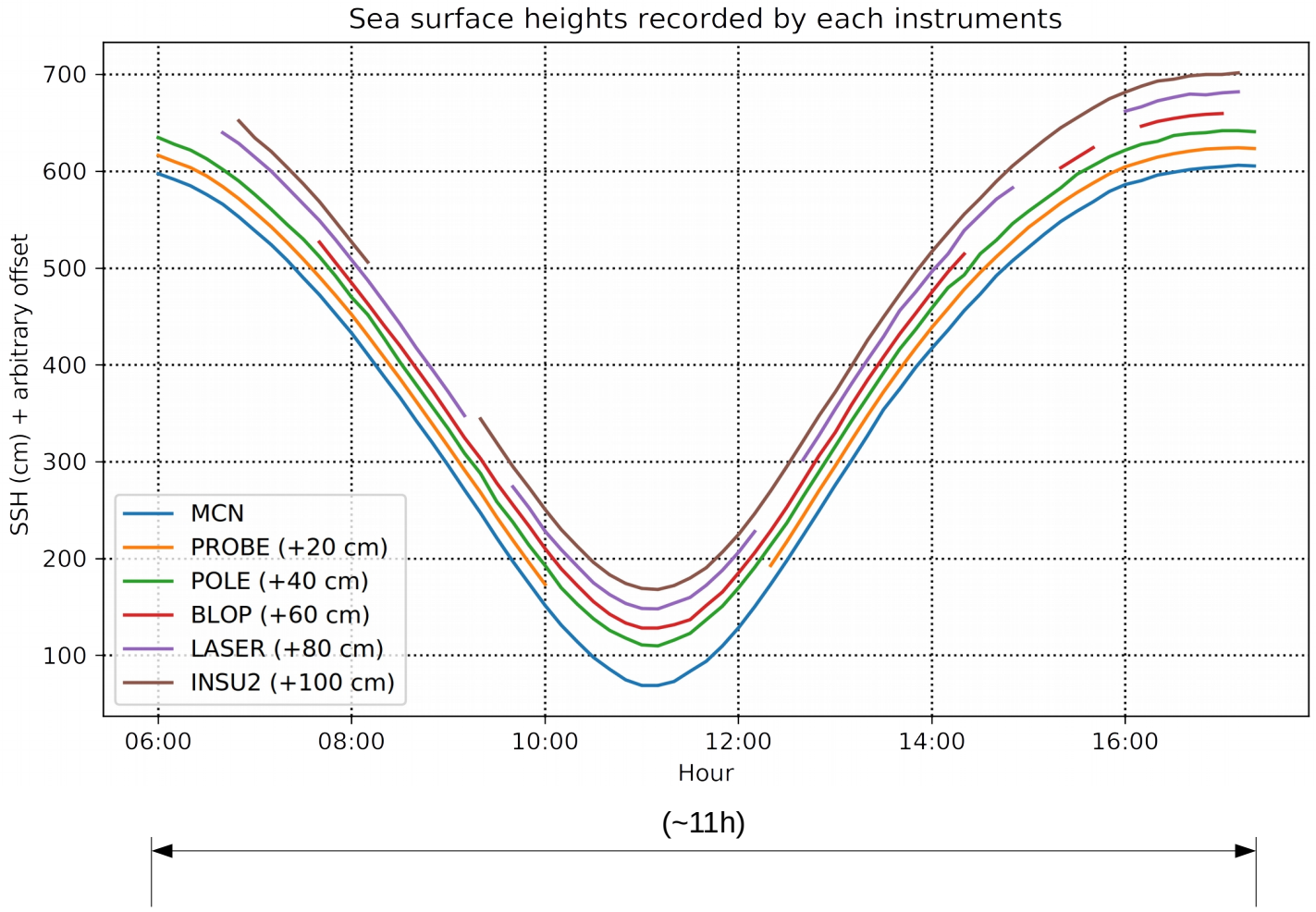
Expérience d'inter-comparaison réalisée par le SHOM & SONEL (et al.) en 2016

Application à une expérience sur l'île d'Aix

6 instruments :

- ✓ 11 h d'observation
- ✓ Mesures toutes les 10 min

Résultats – **Observations**



Sonde (PROBE)
Considérée non biaisée

Observations manquantes …

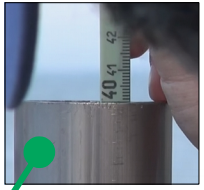
… mais la solution combinée existe à tous les instants !

Résultats – **Résultats de calibration**

$$Biais = \boldsymbol{B_i}(t) = \boldsymbol{\alpha_i} + \boldsymbol{\beta_i} \cdot H_i(t)$$

Information nouvelle

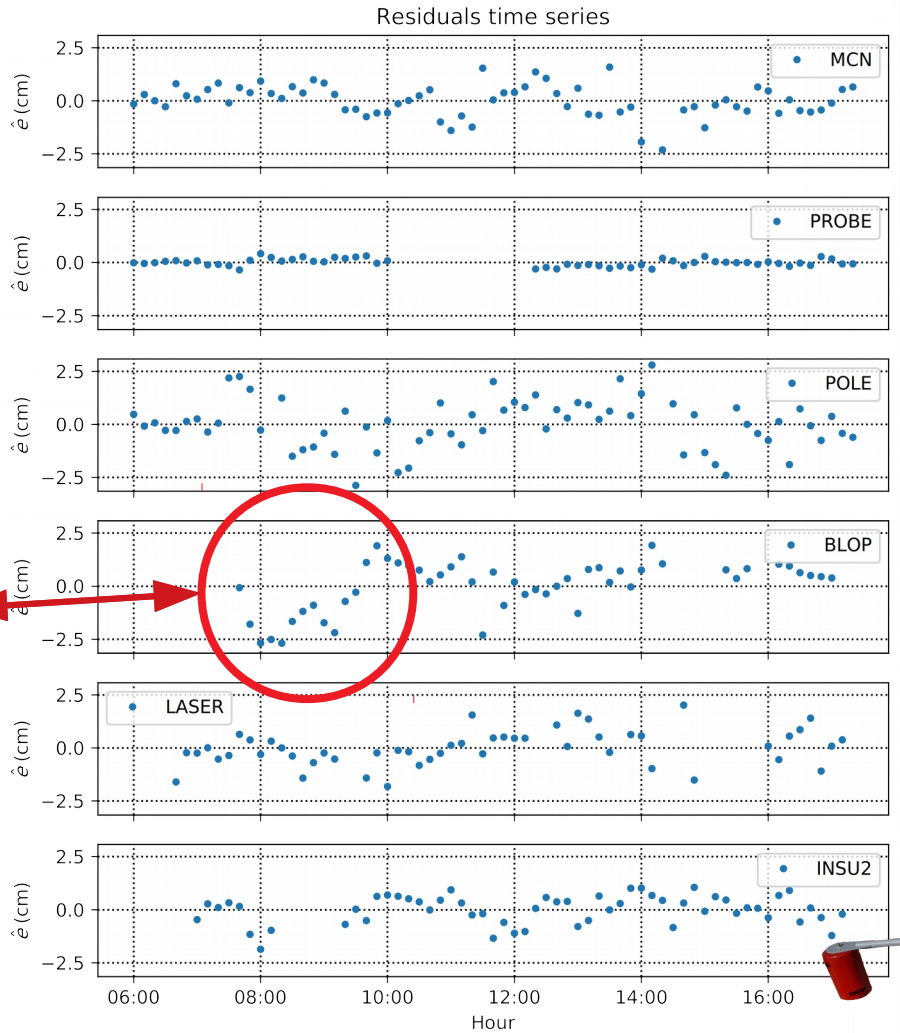
TG	α_i (cm*)	β_i (cm*/m*)	σ (cm)
PROBE	.	.	0.31 +/- 0.10
RADAR	-1.87 +/- 0.30	0.52 +/- 0.07	0.81 +/- 0.08
ECHELLE	0.13 +/- 0.39	-0.32 +/- 0.09	1.23 +/- 0.12
BLOP	-4.30 +/- 0.41	0.00 +/- 0.11	1.25 +/- 0.14
LASER	-3.42 +/- 0.35	0.13 +/- 0.08	0.90 +/- 0.10
INSU2	-3.52 +/- 0.30	0.17 +/- 0.07	0.74 +/- 0.09

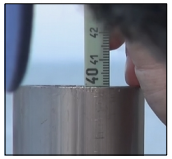


Résultats – **Analyse des résidus et interprétations**

σ (cm)
0.81 +/- 0.08
0.31 +/- 0.10
1.23 +/- 0.12
1.25 +/- 0.14
0.90 +/- 0.10
0.74 +/- 0.09

Artefact détecté

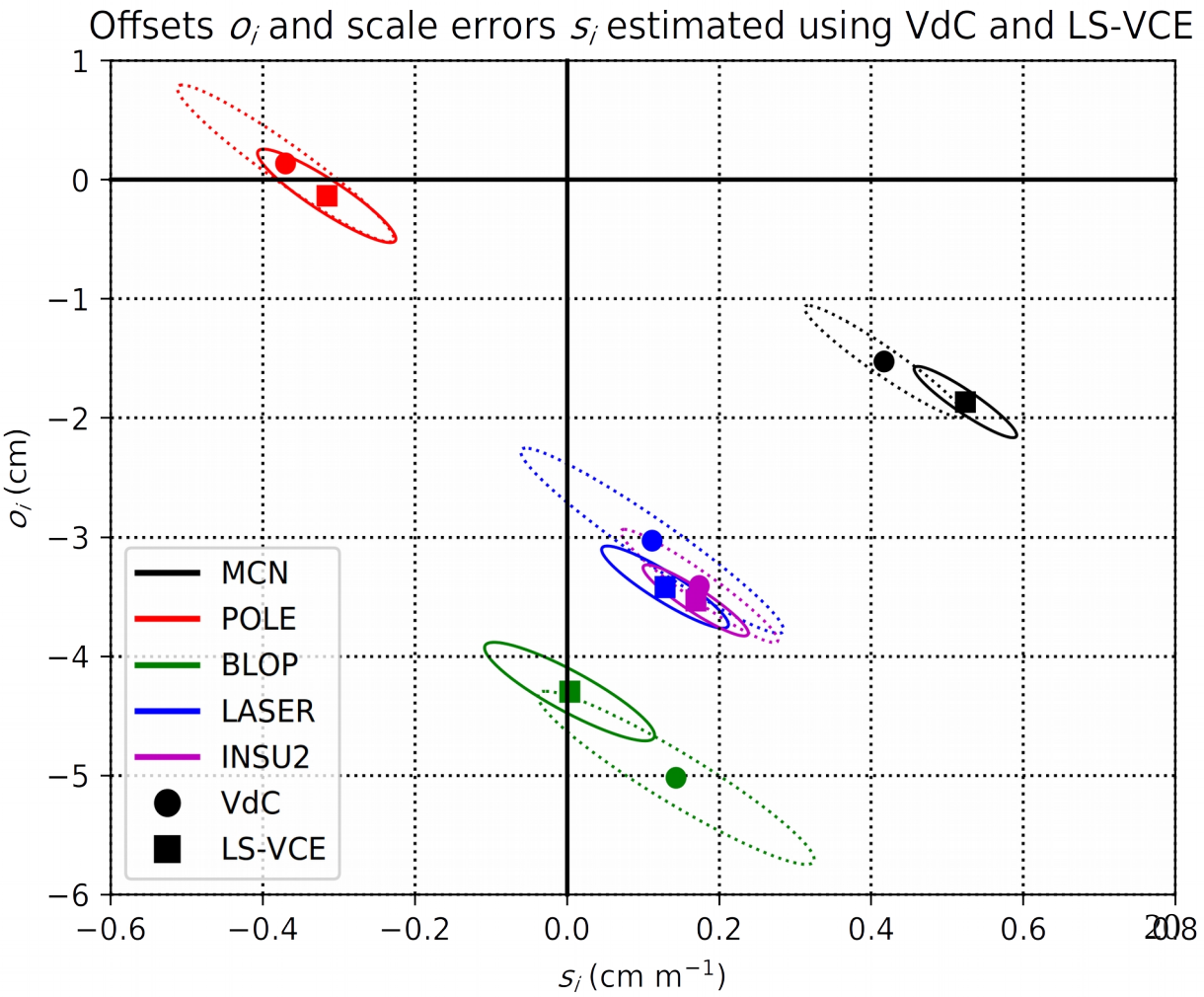




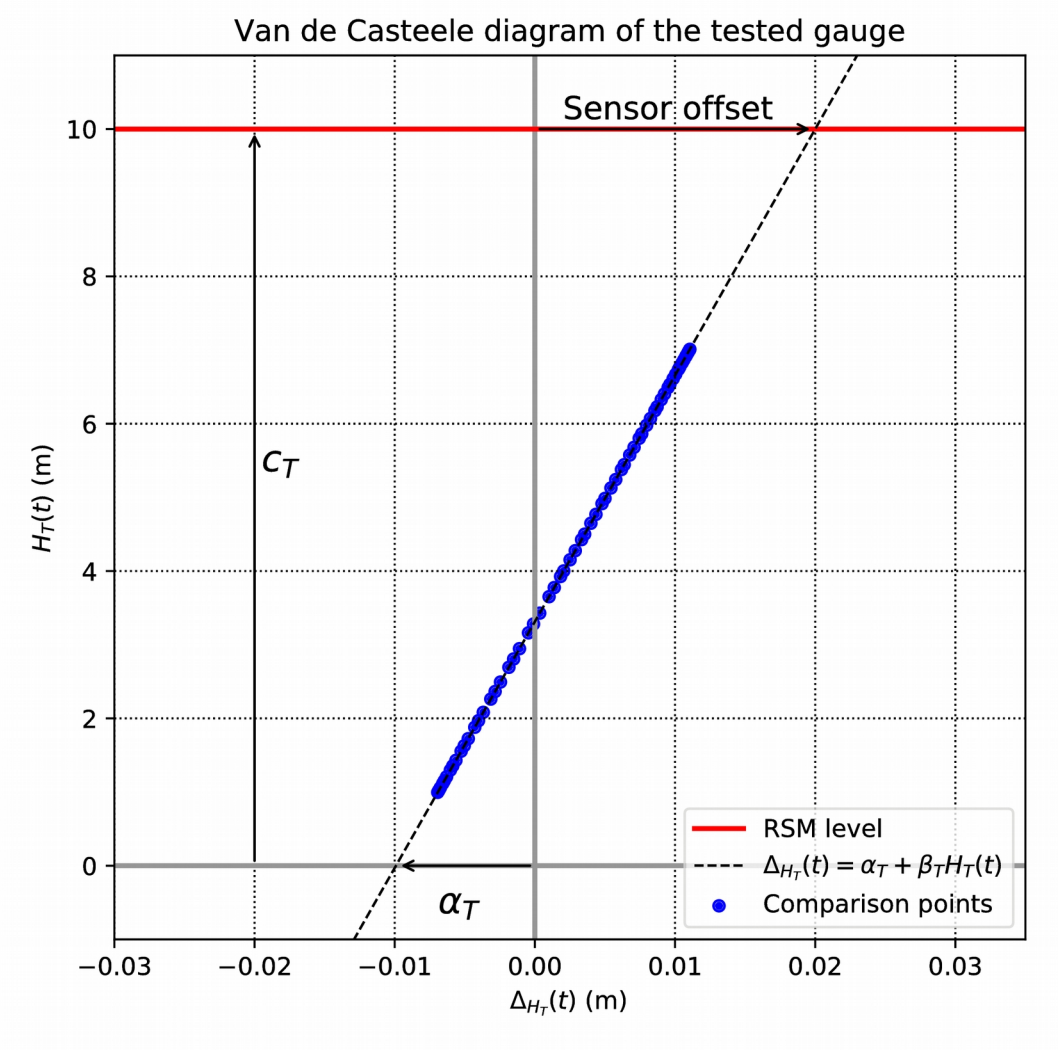
Résultats – **Meilleure estimation des biais**

- ≠ avec méthode usuelle :
  - ✓ **Biais différents**
  - ✓ **Incertitudes réduites (~30 % à 50%)**

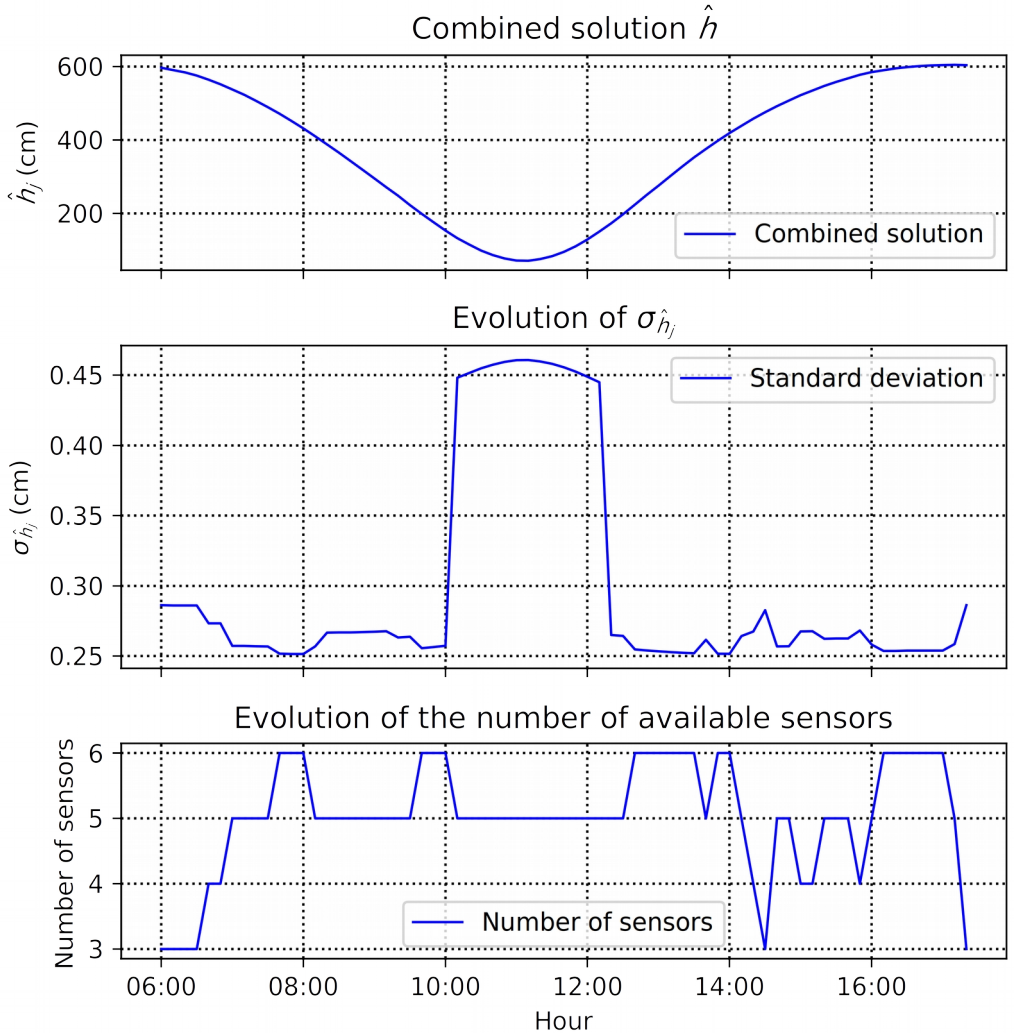
- Raison :
  - ✓ **Meilleure pondération**
  - ✓ **Plus d'observations**



Résultats – **Utilisation des paramètres de biais**



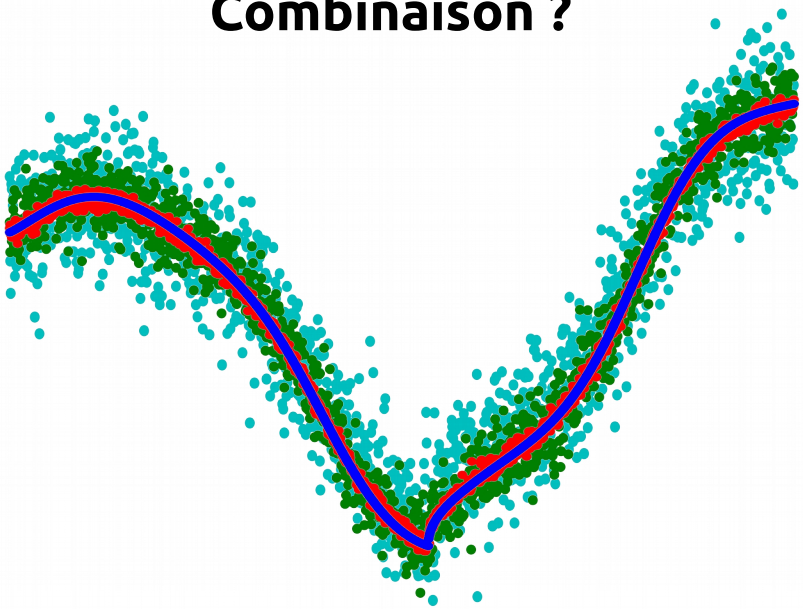
Méthodes – **Diagramme de Van de Casteele**



Série combinée (et corrigée) plus précise.

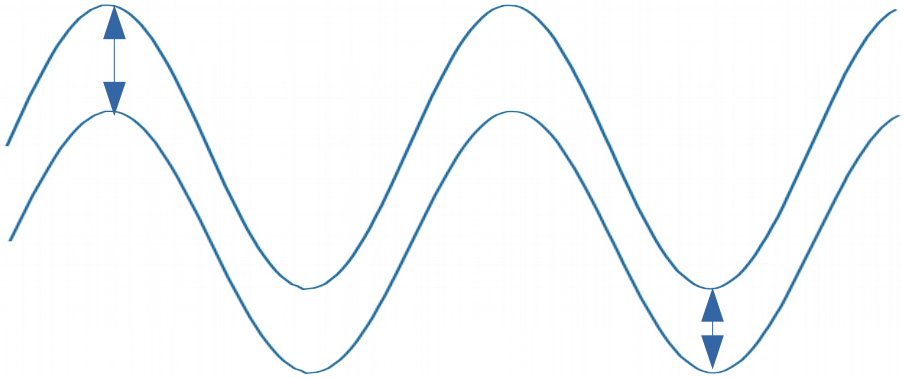
Conclusions

Combinaison ?



VS

Comparaison ?



Améliorations & perspectives

Conclusions – **Améliorations**

- **Plus de résultats en une seule étape :**
  - Biais des instruments & incertitudes associées
  - **Précision des instruments & incertitudes associées**
  - **Solution combinée & incertitudes associées**

- **Amélioration de l'estimation des biais :**
  - Pondération plus rigoureuse des observations
  - Estimation plus précise des biais

- **Flexibilité :**
  - Analyse de séries longues possible
  - Intégration de plusieurs étalons possible (ou étalons partiels)
  - D'autre modèles de variance sont possibles (corrélation temporelles et inter-techniques)

Conclusions – **Perspectives**

- **Analyses de séries marégraphiques plus longues :**
  - Détection d'autres types de biais (sauts, dérives en temps/température) ?
  - Utilisation de modèles stochastiques plus sophistiqués ?

- **Déploiement de la méthode :**
  - Validation sur d'autres expériences ?
  - Développement d'un petit logiciel (pour les opérateurs) ?

- **Extension à d'autres instruments/mesures en géodésie/géophysique ?**

- **Applicabilité à la calibration/validation des satellites altimètres ?**

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Merci pour votre attention !