UNIVERSITÉ DE TOULON

mio
Institut Méditerranéen d'Océanologie

Analyse des vagues extrêmes en mer croisée

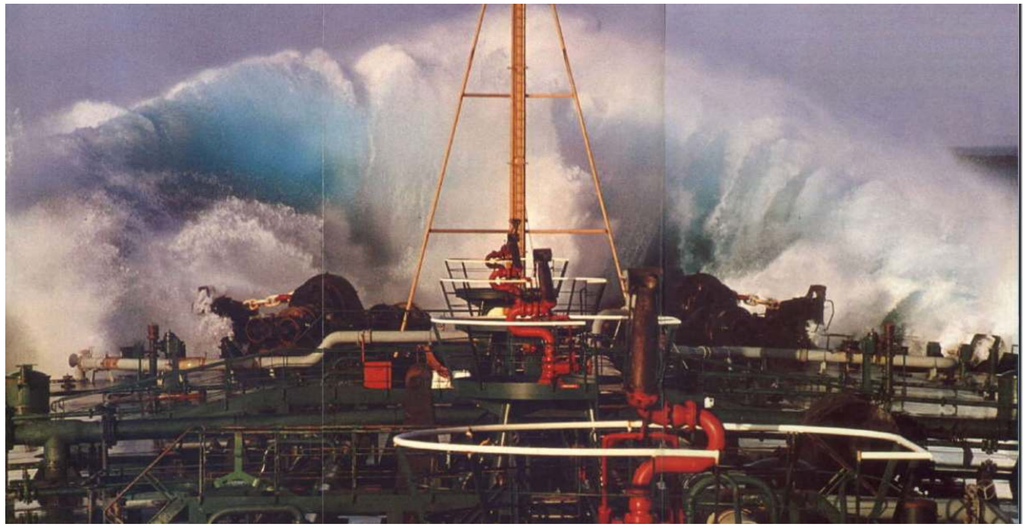
DE MURCIA LÉO L2 PC - 24 JUIN 2025

TUTEUR : MARC FRANCIUS

Sommaire

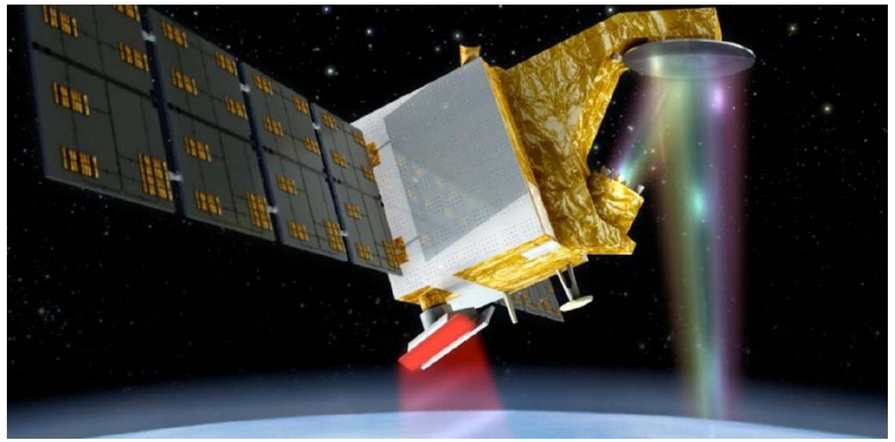
De quoi s’agit-il ?

- Vagues scélérates/extrêmes
- Rapport tel que $H > 2 \times Hs$
- Forte amplitude et forme particulière
- Risque important pour les navires et structures offshore

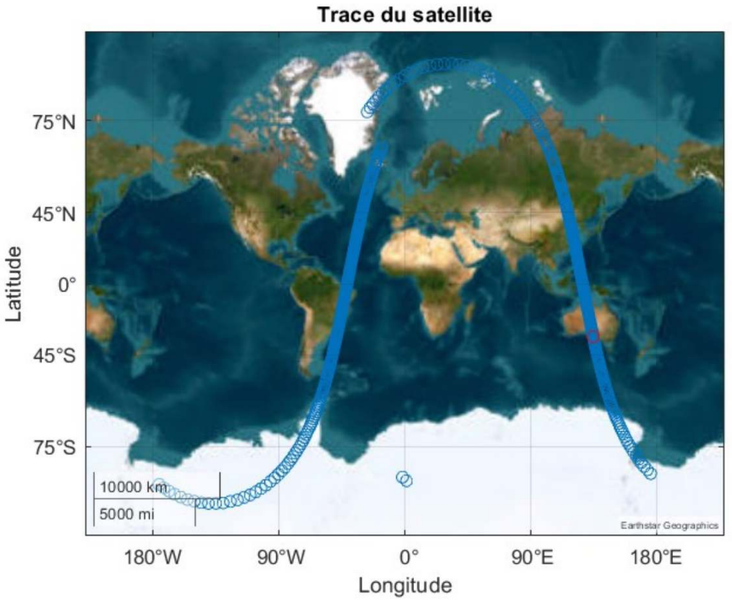


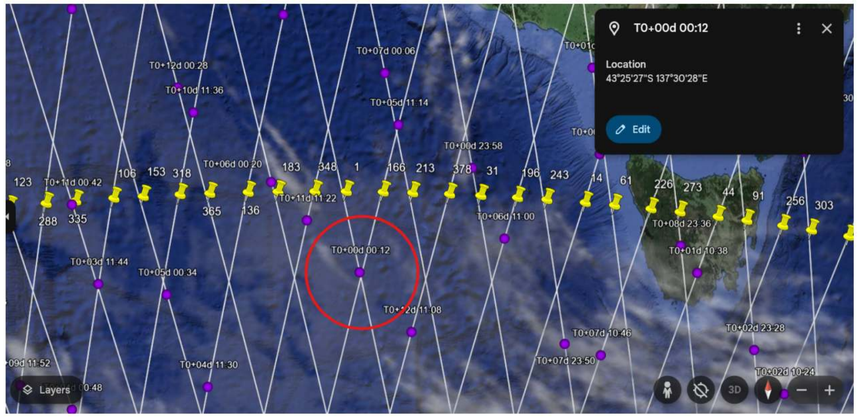
CFOSAT

Chines French Occeanography SATellite



Satellite de la mission CFOSAT

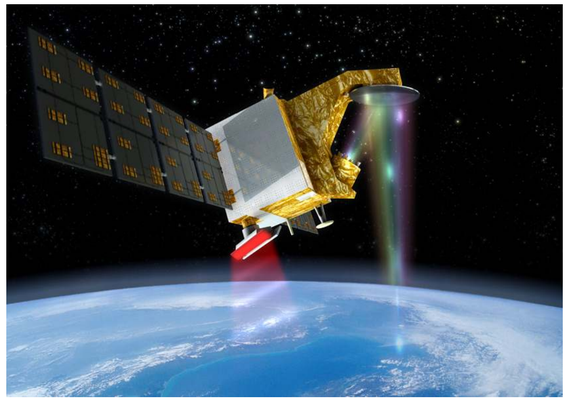


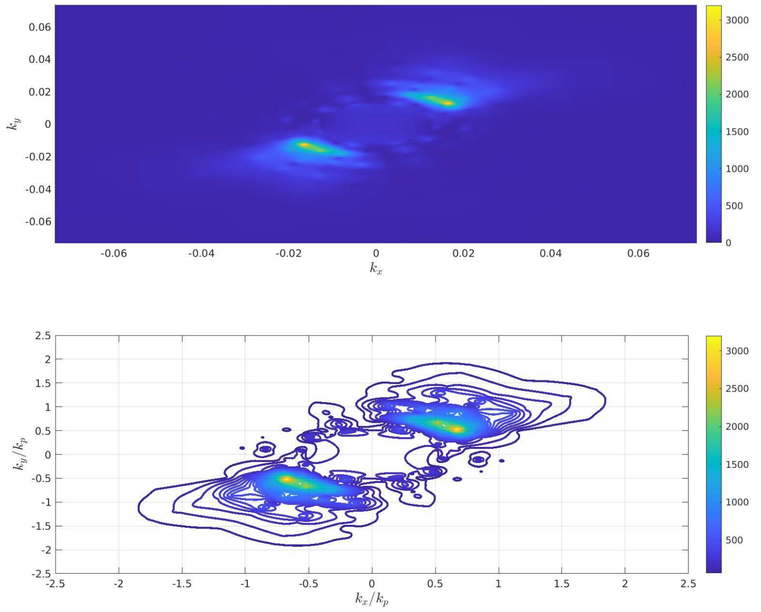


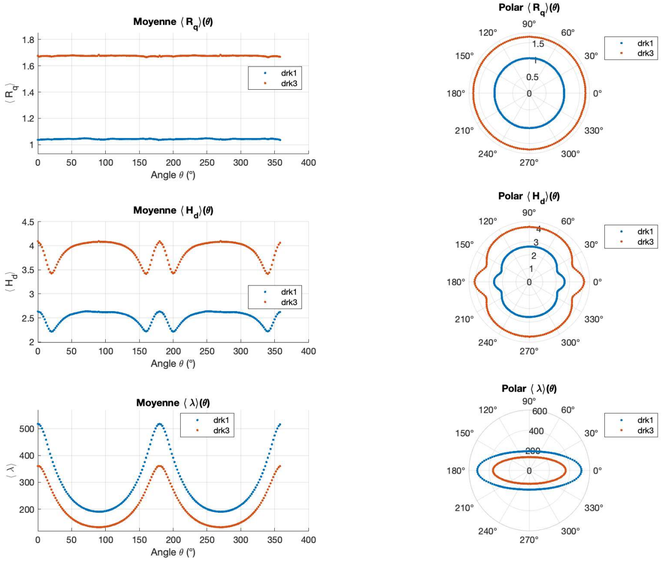
- 500 km d’altitude
- Radar SWIM / SCAT
- Tour de la Terre en 13 jours

Mon objectif

- Comprendre la génération des surfaces 2D à partir des données CFOSAT
- Mettre en place une méthode d'analyse numérique de ces surfaces

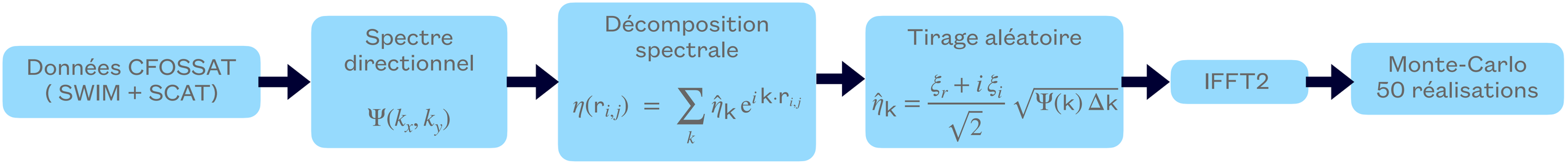






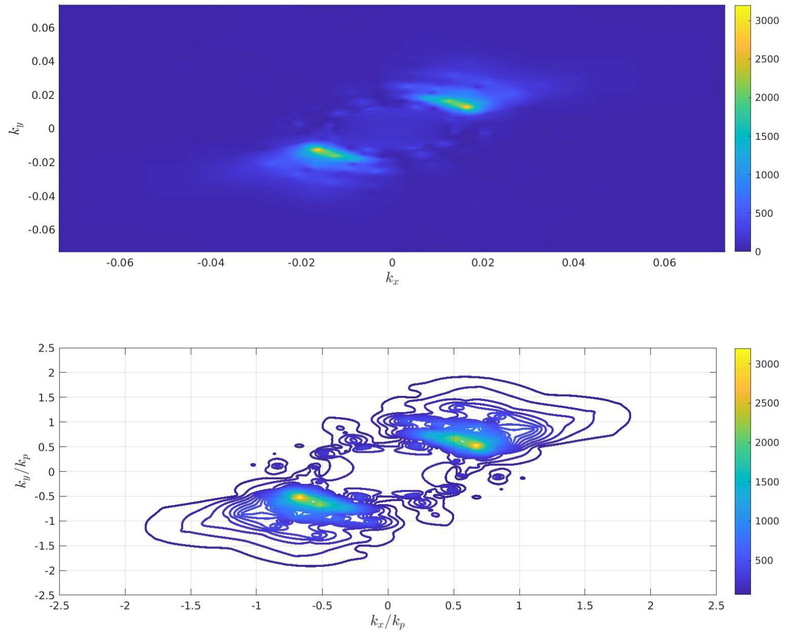
Génération des surfaces 2D

- Schéma de la génération d'une carte 2D

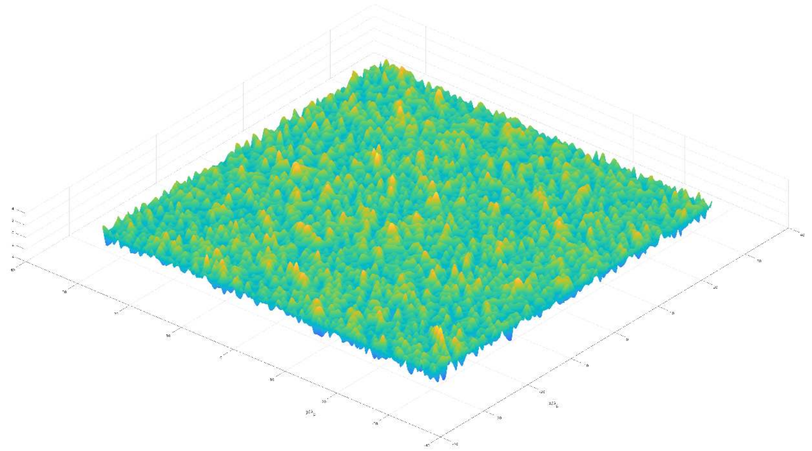


Surfaces 2D générées

Spectre directionnel



Vue 3D de la surface

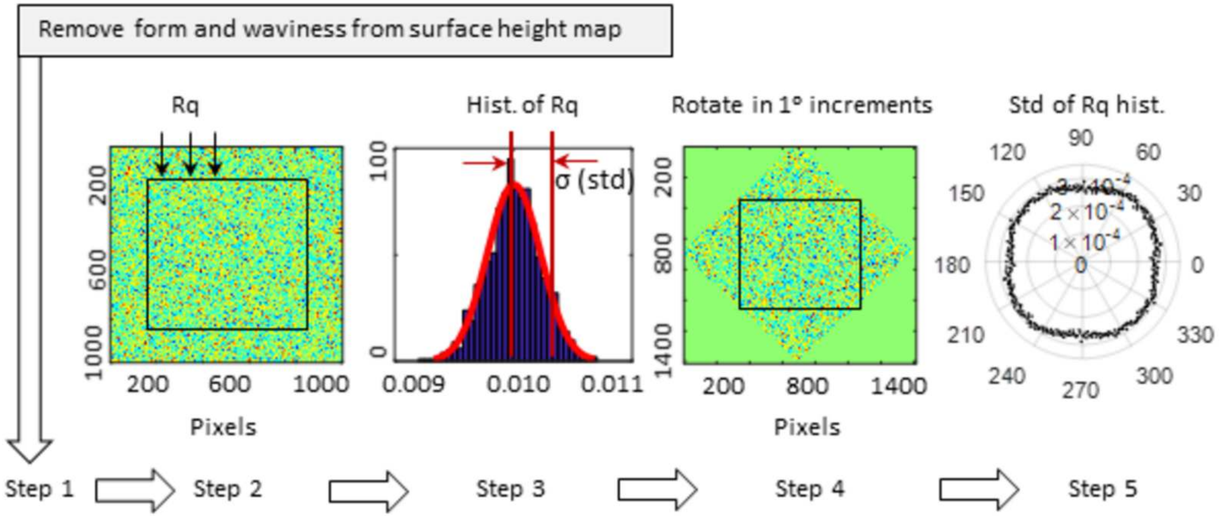


Méthode d'Azimi

- Etapes de la méthode

Rugosité quadratique :

$$R_q(j) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\eta_{\mathrm{rot}}(i,j)\right]^2}$$

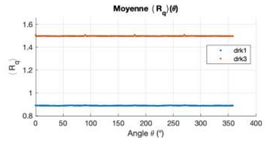


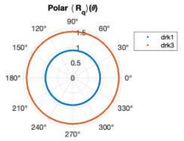
Application de la méthode

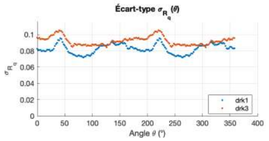
- On applique la méthode aux données CFOSAT et à des données synthétiques

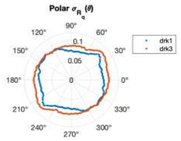
Cas	**Système 1 (Hs, Lp/Tp, θ_p)**	**Système 2 (Hs, Lp/Tp, θ_p)**
1. Unimodal	$\mathrm{Hs} = 6.59$ m, $\mathrm{Tp} = 12.43$ s, $\theta_p = -36°$	—
2. Bimodal	$\mathrm{Hs}_1 = 6.23$ m, $\mathrm{Tp}_1 = 13.18$ s, $\theta_{p1} = -30°$	$\mathrm{Hs}_2 = 2.90$ m, $\mathrm{Tp}_2 = 11.63$ s, $\theta_{p2} = 58°$
3. Bimodal CFO_20200225	$\mathrm{Hs}_1 = 3.745$ m, $\mathrm{Lp}_1 = 153.8$ m, $\theta_{p1} = 53.44°$	$\mathrm{Hs}_2 = 3.454$ m, $\mathrm{Lp}_2 = 283.7$ m, $\theta_{p2} = 47.02°$
4. Bimodal CFO_20190610	$\mathrm{Hs}_1 = 3.315$ m, $\mathrm{Lp}_1 = 189.5$ m, $\theta_{p1} = -26.45°$	$\mathrm{Hs}_2 = 2.648$ m, $\mathrm{Lp}_2 = 313.9$ m, $\theta_{p2} = 68.42°$
5. Synthétique 1	$\mathrm{Hs}_1 = 4.805$ m, $\mathrm{Tp}_1 = 10$ s, $\theta_{p1} = 20°$	$\mathrm{Hs}_2 = 4.805$ m, $\mathrm{Tp}_2 = 10$ s, $\theta_{p2} = -20°$
6. Synthétique 2	$\mathrm{Hs}_1 = 4.805$ m, $\mathrm{Tp}_1 = 10$ s, $\theta_{p1} = 60°$	$\mathrm{Hs}_2 = 4.805$ m, $\mathrm{Tp}_2 = 10$ s, $\theta_{p2} = -60°$

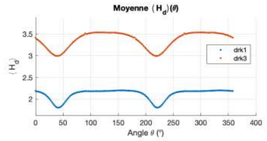
Cas 1 et 2

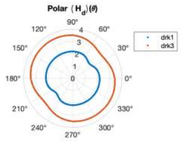

Moyenne ⟨ R_q ⟩(θ)
⟨ R_q ⟩
Angle θ (°)
drk1
drk3

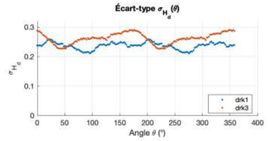

Polar ⟨ R_q ⟩(θ)
drk1
drk3

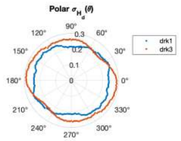

Écart-type σ_Rq (θ)
σ_Rq
Angle θ (°)
drk1
drk3

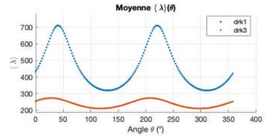

Polar σ_Rq (θ)
drk1
drk3

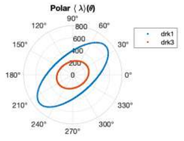

Moyenne ⟨ H_d ⟩(θ)
⟨ H_d ⟩
Angle θ (°)
drk1
drk3

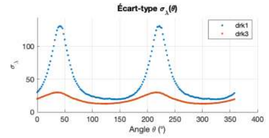

Polar ⟨ H_d ⟩(θ)
drk1
drk3

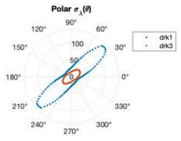

Écart-type σ_Hd (θ)
σ_Hd
Angle θ (°)
drk1
drk3

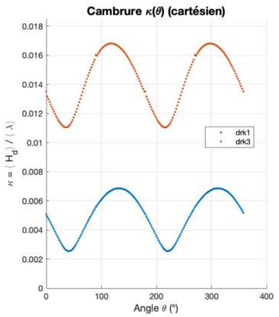

Polar σ_Hd (θ)
drk1
drk3

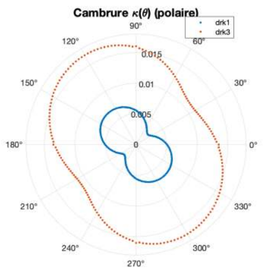

Moyenne ⟨ λ ⟩(θ)
⟨ λ ⟩
Angle θ (°)
drk1
drk3

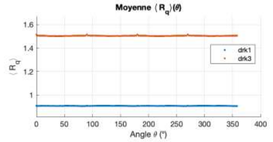

Polar ⟨ λ ⟩(θ)
drk1
drk3

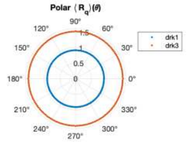

Écart-type σ_λ (θ)
σ_λ
Angle θ (°)
drk1
drk3

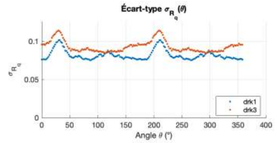

Polar σ_λ (θ)
drk1
drk3

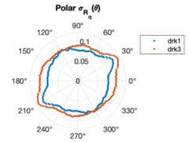

Cambrure κ(θ) (cartésien)
κ = | H_d | / ⟨ λ ⟩
Angle θ (°)
drk1
drk3

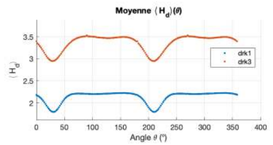

Cambrure κ(θ) (polaire)
drk1
drk3

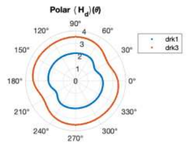

Moyenne ⟨ R_q ⟩(θ)
⟨ R_q ⟩
Angle θ (°)
drk1
drk3

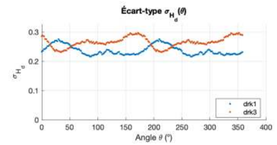

Polar ⟨ R_q ⟩(θ)
drk1
drk3

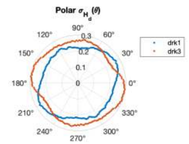

Écart-type σ_Rq (θ)
σ_Rq
Angle θ (°)
drk1
drk3

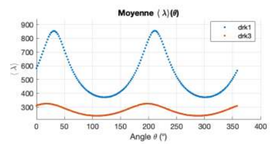

Polar σ_Rq (θ)
drk1
drk3

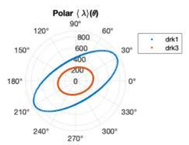

Moyenne ⟨ H_d ⟩(θ)
⟨ H_d ⟩
Angle θ (°)
drk1
drk3

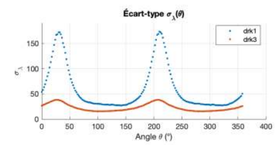

Polar ⟨ H_d ⟩(θ)
drk1
drk3

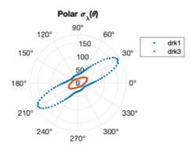

Écart-type σ_Hd (θ)
σ_Hd
Angle θ (°)
drk1
drk3

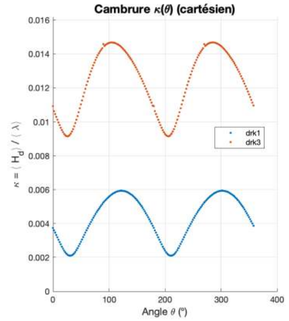

Polar σ_Hd (θ)
drk1
drk3

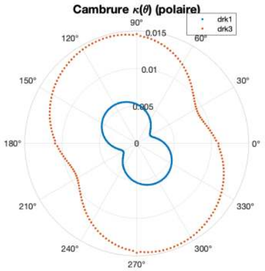

Moyenne ⟨ λ ⟩(θ)
⟨ λ ⟩
Angle θ (°)
drk1
drk3


Polar ⟨ λ ⟩(θ)
drk1
drk3

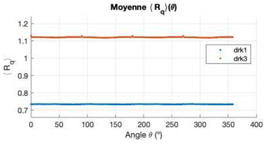

Écart-type σ_λ (θ)
σ_λ
Angle θ (°)
drk1
drk3

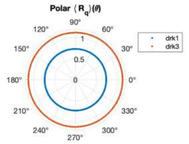

Polar σ_λ (θ)
drk1
drk3

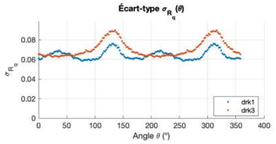

Cambrure κ(θ) (cartésien)
κ = | H_d | / ⟨ λ ⟩
Angle θ (°)
drk1
drk3

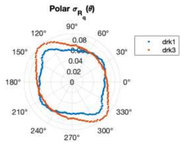

Cambrure κ(θ) (polaire)
drk1
drk3

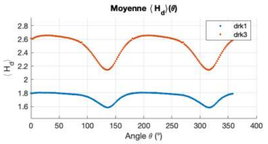
Cas 3 et 4

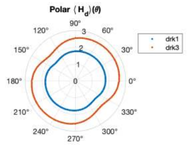

Moyenne ⟨ R_q ⟩(θ)
drk1
drk3
Angle θ (°)

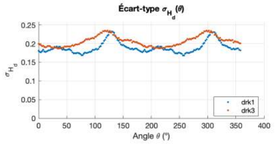

Polar ⟨ R_q ⟩(θ)
drk1
drk3

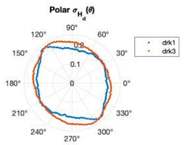

Écart-type σ_{R_q}(θ)
drk1
drk3
Angle θ (°)

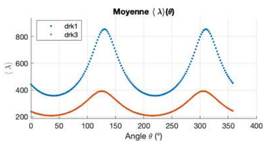

Polar σ_{R_q}(θ)
drk1
drk3

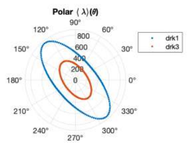

Moyenne ⟨ H_d ⟩(θ)
drk1
drk3
Angle θ (°)

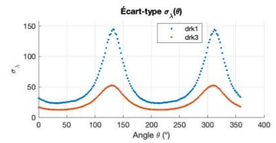

Polar ⟨ H_d ⟩(θ)
drk1
drk3

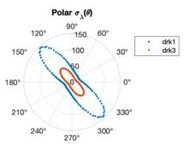

Écart-type σ_{H_d}(θ)
drk1
drk3
Angle θ (°)

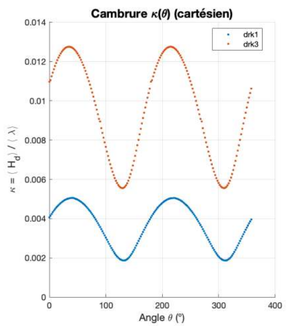

Polar σ_{H_d}(θ)
drk1
drk3

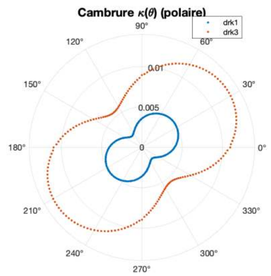

Moyenne ⟨ λ ⟩(θ)
drk1
drk3
Angle θ (°)

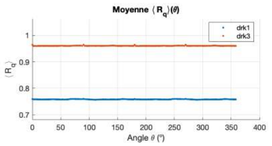

Polar ⟨ λ ⟩(θ)
drk1
drk3

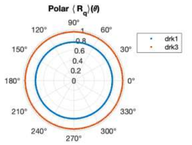

Écart-type σ_λ(θ)
drk1
drk3
Angle θ (°)

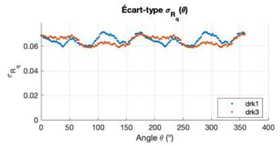

Polar σ_λ(θ)
drk1
drk3

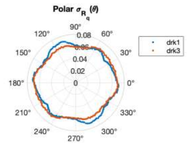

Cambrure κ(θ) (cartésien)
drk1
drk3
Angle θ (°)

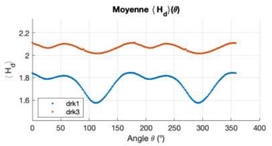

Cambrure κ(θ) (polaire)
drk1
drk3

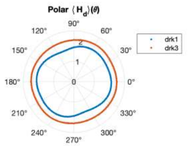

Moyenne ⟨ R_q ⟩(θ)
drk1
drk3
Angle θ (°)

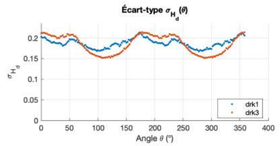

Polar ⟨ R_q ⟩(θ)
drk1
drk3

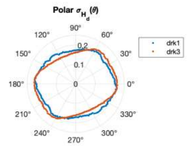

Écart-type σ_{R_q}(θ)
drk1
drk3
Angle θ (°)

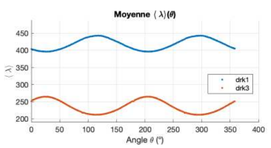

Polar σ_{R_q}(θ)
drk1
drk3

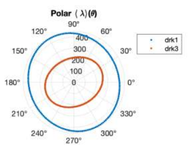

Moyenne ⟨ H_d ⟩(θ)
drk1
drk3
Angle θ (°)

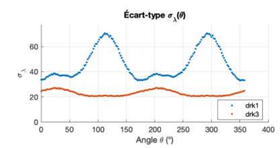

Polar ⟨ H_d ⟩(θ)
drk1
drk3

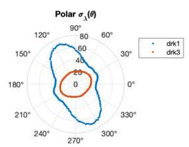

Écart-type σ_{H_d}(θ)
drk1
drk3
Angle θ (°)

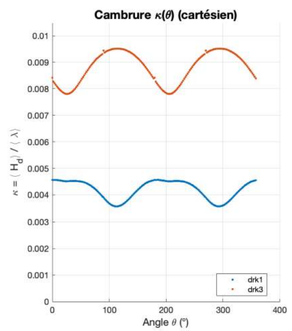

Polar σ_{H_d}(θ)
drk1
drk3

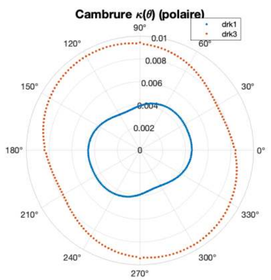

Moyenne ⟨ λ ⟩(θ)
drk1
drk3
Angle θ (°)


Polar ⟨ λ ⟩(θ)
drk1
drk3

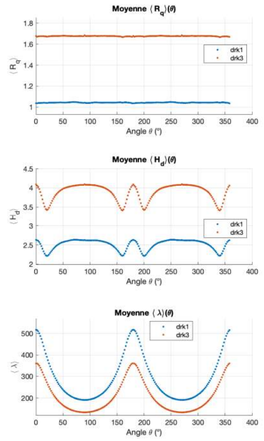

Écart-type σ_λ(θ)
drk1
drk3
Angle θ (°)

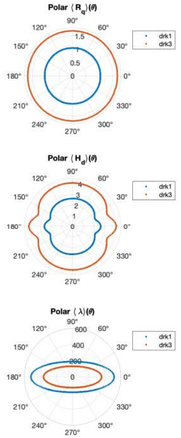

Polar σ_λ(θ)
drk1
drk3

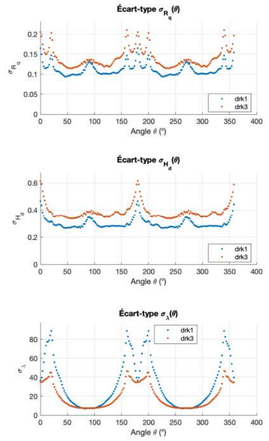

Cambrure κ(θ) (cartésien)
drk1
drk3
Angle θ (°)

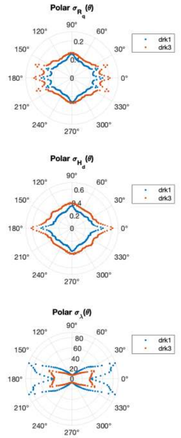

Cambrure κ(θ) (polaire)
drk1
drk3

Cas 5 et 6


Moyenne ⟨ R_q ⟩(θ)
drk1
drk3
⟨ R_q ⟩
Angle θ (°)


Polar ⟨ R_q ⟩(θ)
drk1
drk3


Écart-type σ_Rq (θ)
drk1
drk3
σ_Rq
Angle θ (°)


Polar σ_Rq (θ)
drk1
drk3

Moyenne ⟨ H_d ⟩(θ)
drk1
drk3
⟨ H_d ⟩
Angle θ (°)

Polar ⟨ H_d ⟩(θ)
drk1
drk3

Écart-type σ_Hd (θ)
drk1
drk3
σ_Hd
Angle θ (°)

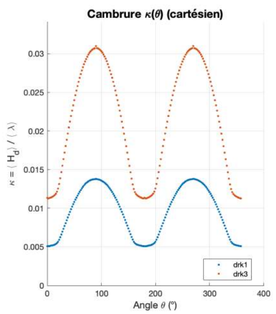
Polar σ_Hd (θ)
drk1
drk3

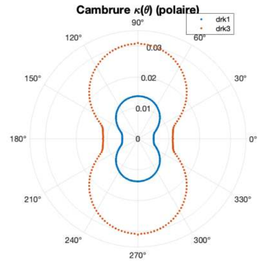
Moyenne ⟨ λ ⟩(θ)
drk1
drk3
⟨ λ ⟩
Angle θ (°)

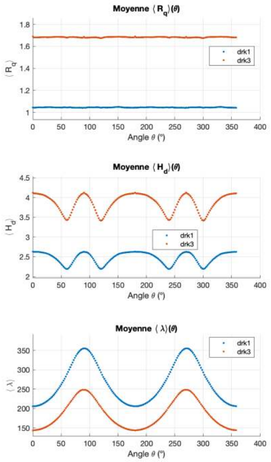
Polar ⟨ λ ⟩(θ)
drk1
drk3

Écart-type σ_λ (θ)
drk1
drk3
σ_λ
Angle θ (°)

Polar σ_λ (θ)
drk1
drk3

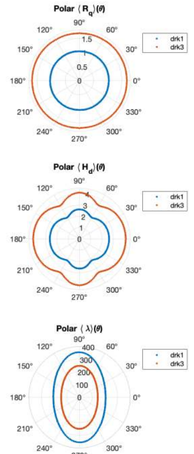

Cambrure κ(θ) (cartésien)
drk1
drk3
κ ≡ | H_d / ⟨ λ ⟩ |
Angle θ (°)


Cambrure κ(θ) (polaire)
drk1
drk3


Moyenne ⟨ R_q ⟩(θ)
drk1
drk3
⟨ R_q ⟩
Angle θ (°)

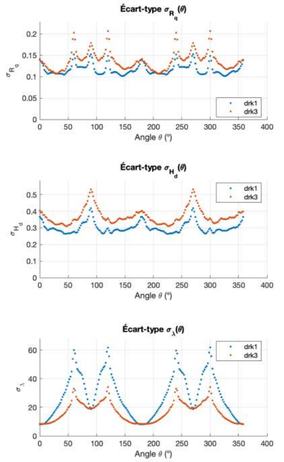
Moyenne ⟨ H_d ⟩(θ)
drk1
drk3
⟨ H_d ⟩
Angle θ (°)

Moyenne ⟨ λ ⟩(θ)
drk1
drk3
⟨ λ ⟩
Angle θ (°)


Polar ⟨ R_q ⟩(θ)
drk1
drk3

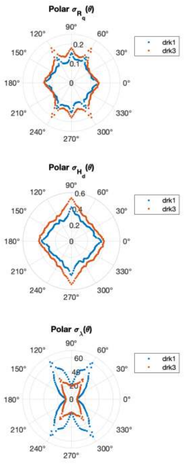
Polar ⟨ H_d ⟩(θ)
drk1
drk3

Polar ⟨ λ ⟩(θ)
drk1
drk3


Écart-type σ_Rq (θ)
drk1
drk3
σ_Rq
Angle θ (°)

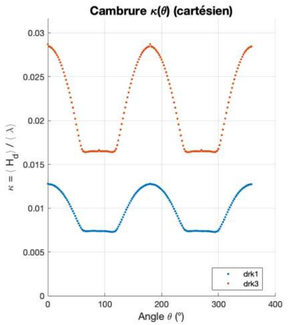
Écart-type σ_Hd (θ)
drk1
drk3
σ_Hd
Angle θ (°)

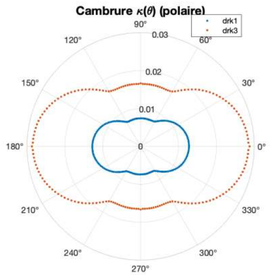
Écart-type σ_λ (θ)
drk1
drk3
σ_λ
Angle θ (°)


Polar σ_Rq (θ)
drk1
drk3

Polar σ_Hd (θ)
drk1
drk3

Polar σ_λ (θ)
drk1
drk3


Cambrure κ(θ) (cartésien)
drk1
drk3
κ ≡ | H_d / ⟨ λ ⟩ |
Angle θ (°)


Cambrure κ(θ) (polaire)
drk1
drk3

Conclusion

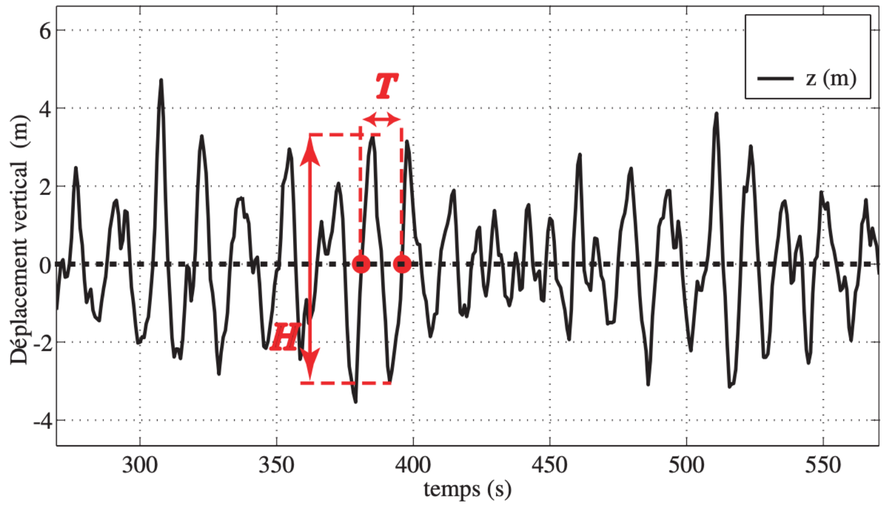
- Recherches cruciales pour améliorer la sécurité maritime
- Voies de recherches prometteuses car peu d’études faites sur ce sujet

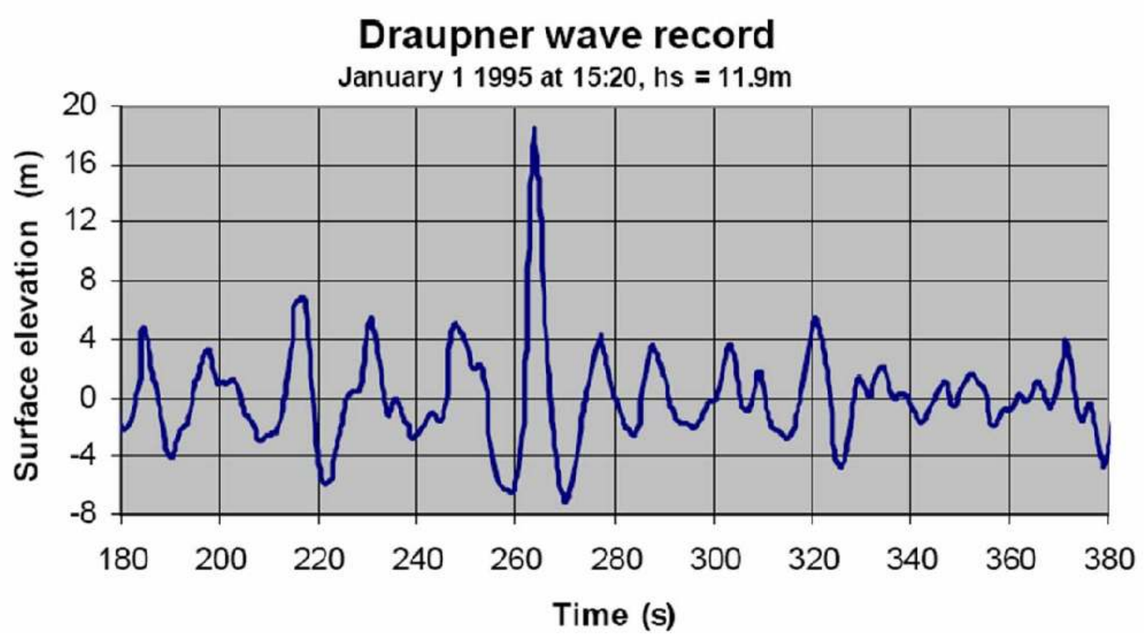
Prochaines étapes

- Analyse statistique des vagues scélérates
- Modélisation non linéaire
- Prédiction et détection

Merci pour votre attention !

Caractérisation des vagues scélérates

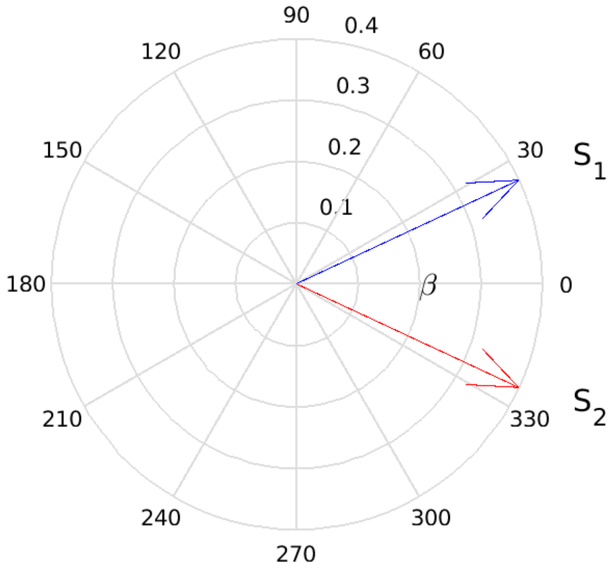


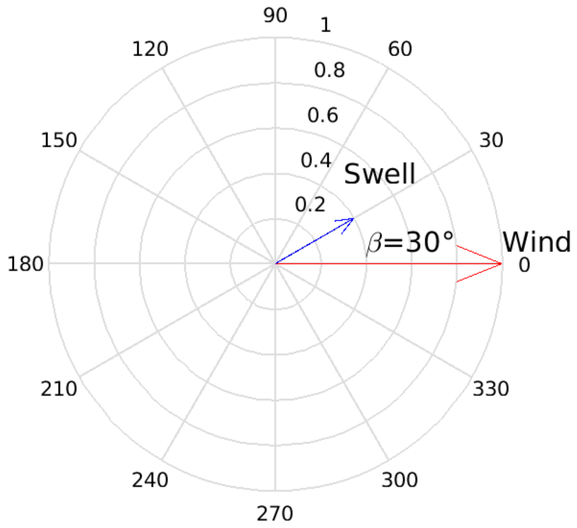


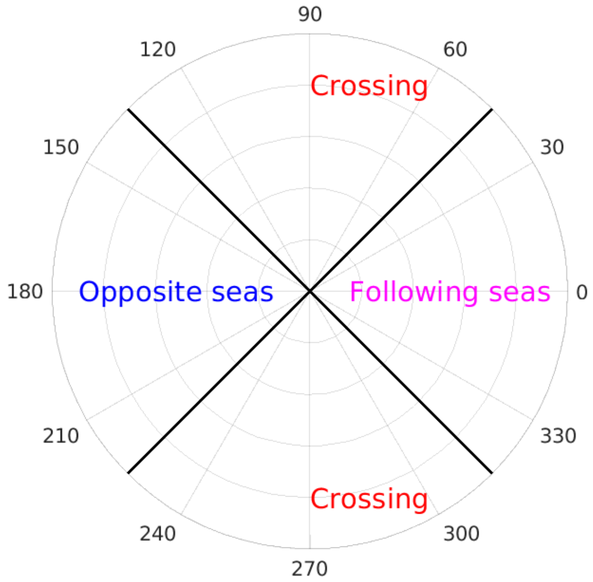
Critère de définition d'une vague scélérate : H/Hs ≥ α

Formation de vagues scélérates

- Collisions de systèmes non colinéaires
- Mer directionnelle multimodale



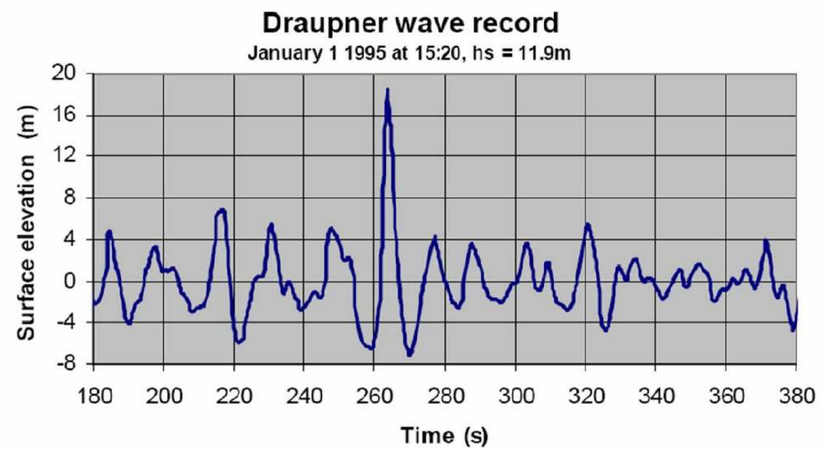




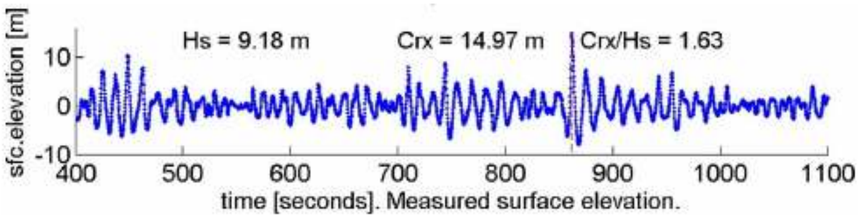
Formation de vagues scélérates quand $0 < \beta < 70°$

Exemples de vagues scélérates

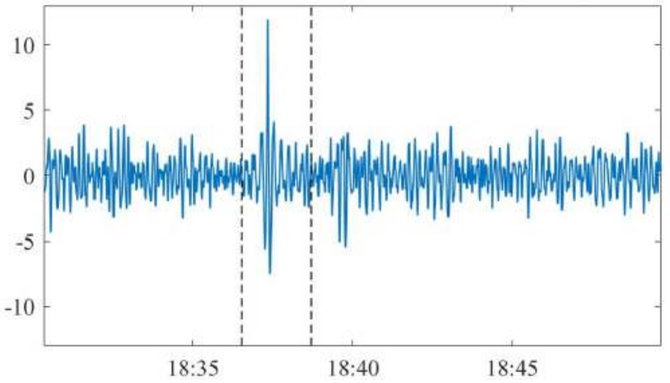
- Différents enregistrement



Andrea



Killard



Wave parameters	Draupner(1995)	Andrea(2007)	Killard(2014)
H_s(m)	11.2	10.0	11.4
T_p(s)	15.0	14.3	17.2
$H_{max}(m)$	23.5	23.0	26.1
H_{max}/H_s	2.10	2.3	2.29