

Journée de la Science

journeescience2025-cnes.fr



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Observer et modéliser la dynamique océanique de fine échelle

Julien Le Sommer

Journée de la Science

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Take Home

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Take Home

1.

Observation et modélisation de l'océan
évoluent de manière complémentaire

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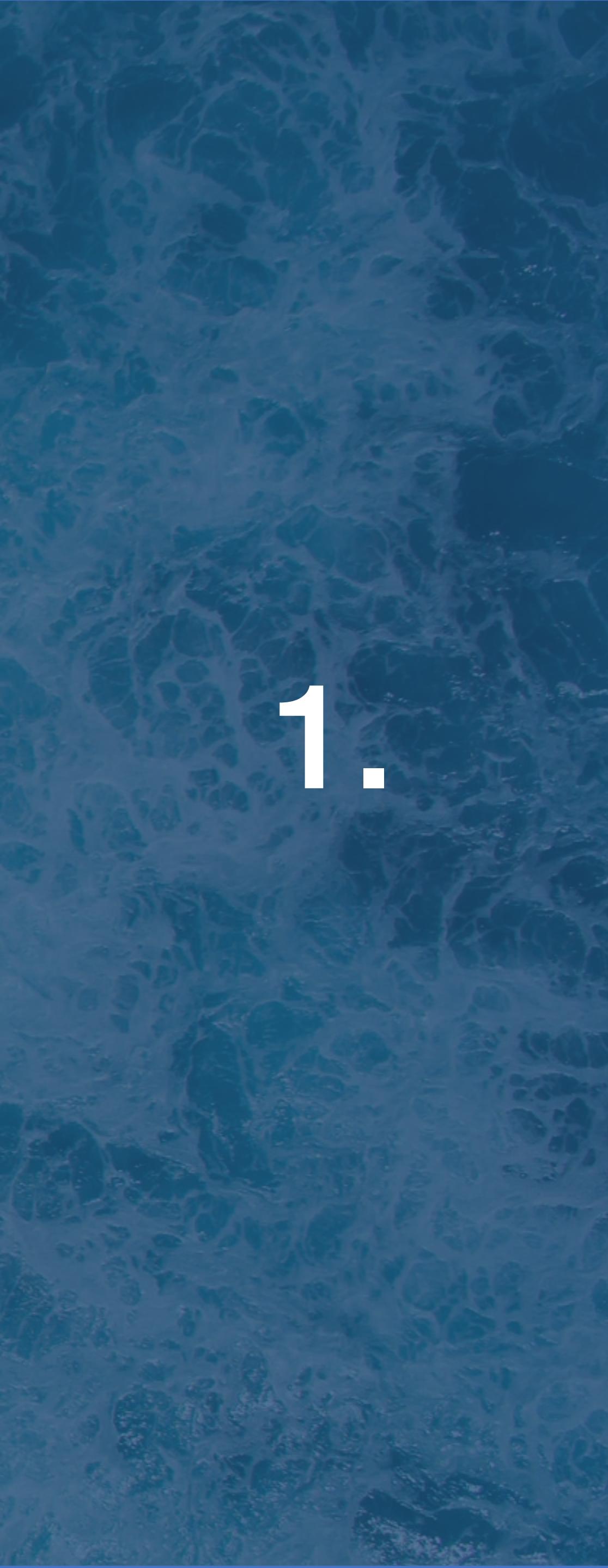
Take Home

1.

Observation et modélisation de l'océan évoluent de manière complémentaire

2.

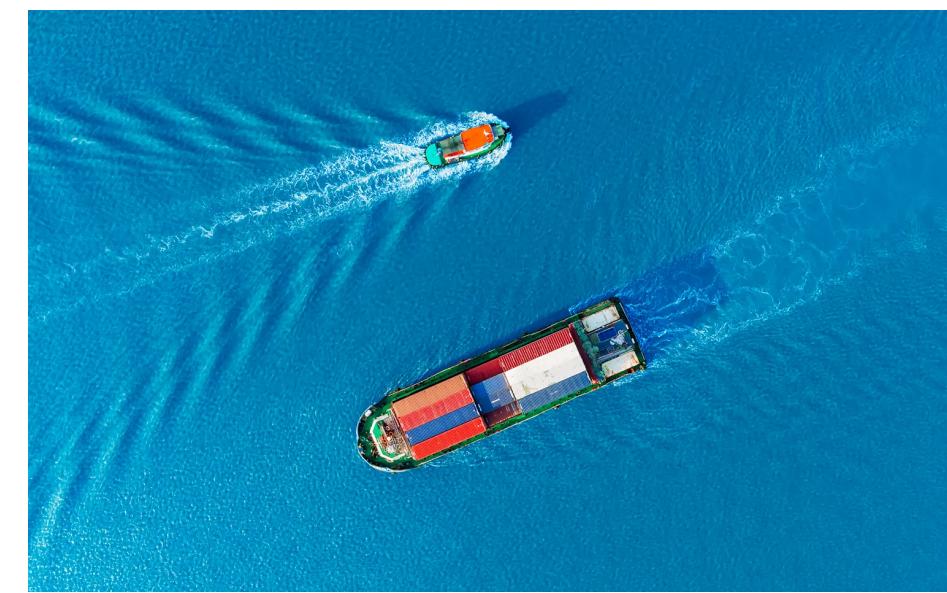
Les fines échelles (1-100km) concentrent des enjeux scientifiques et sociaux



1.

Observer un océan turbulent

Pourquoi observer l'océan ?



Transport / sécurité



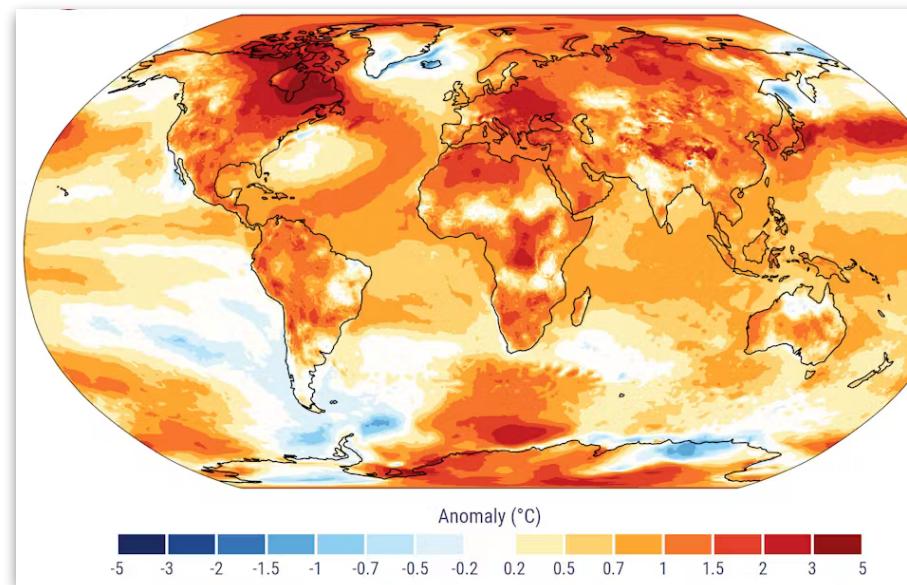
Energie



Alimentation

De multiples enjeux pour les sociétés humaines

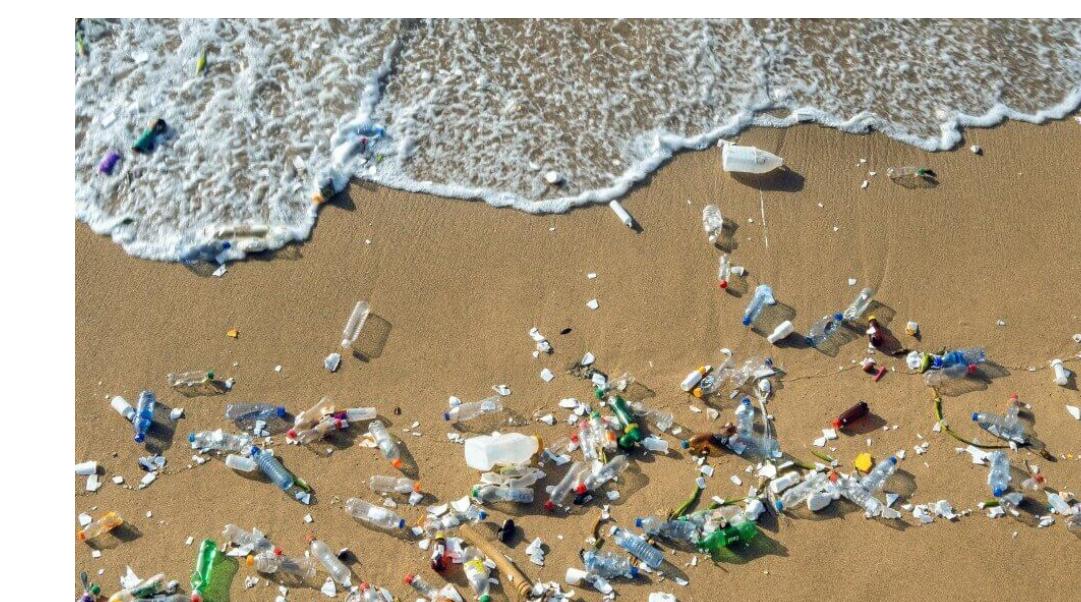
Pourquoi observer l'océan ?



Climat

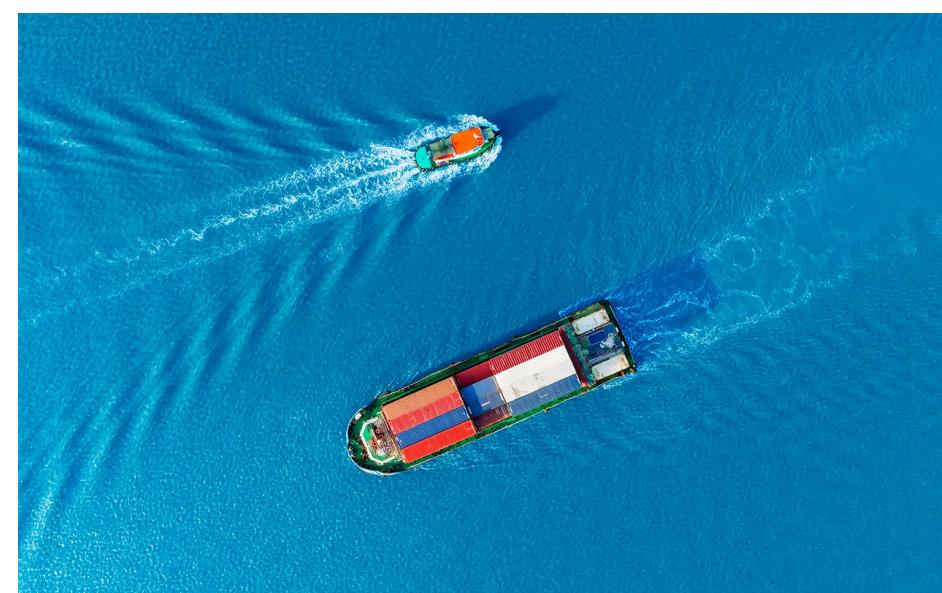


Biodiversité



Pollution

Un milieu subissant une triple crise sans précédent



Transport / sécurité



Energie

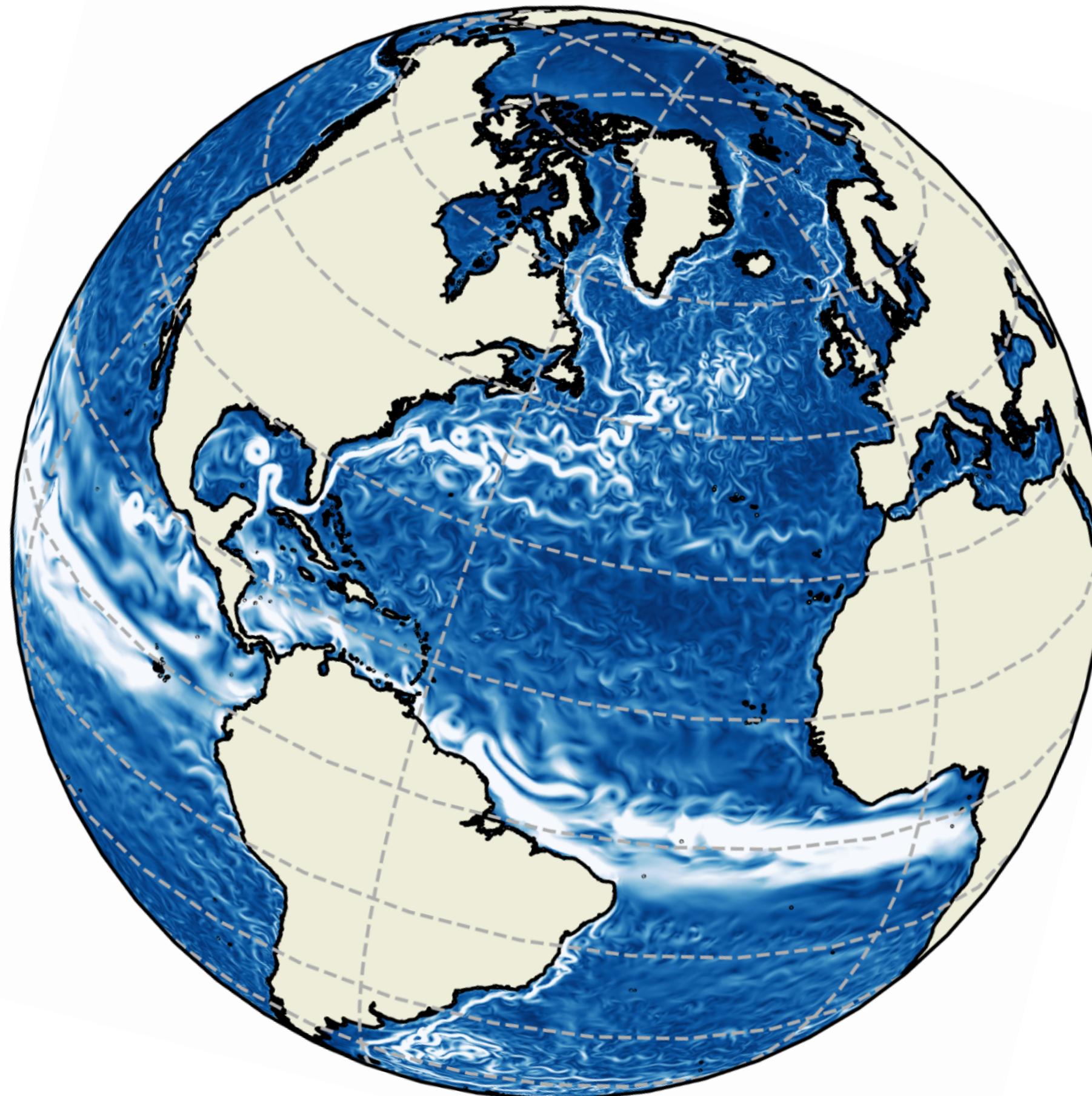


Alimentation

De multiples enjeux pour les sociétés humaines

Le champ de l'océanographie physique

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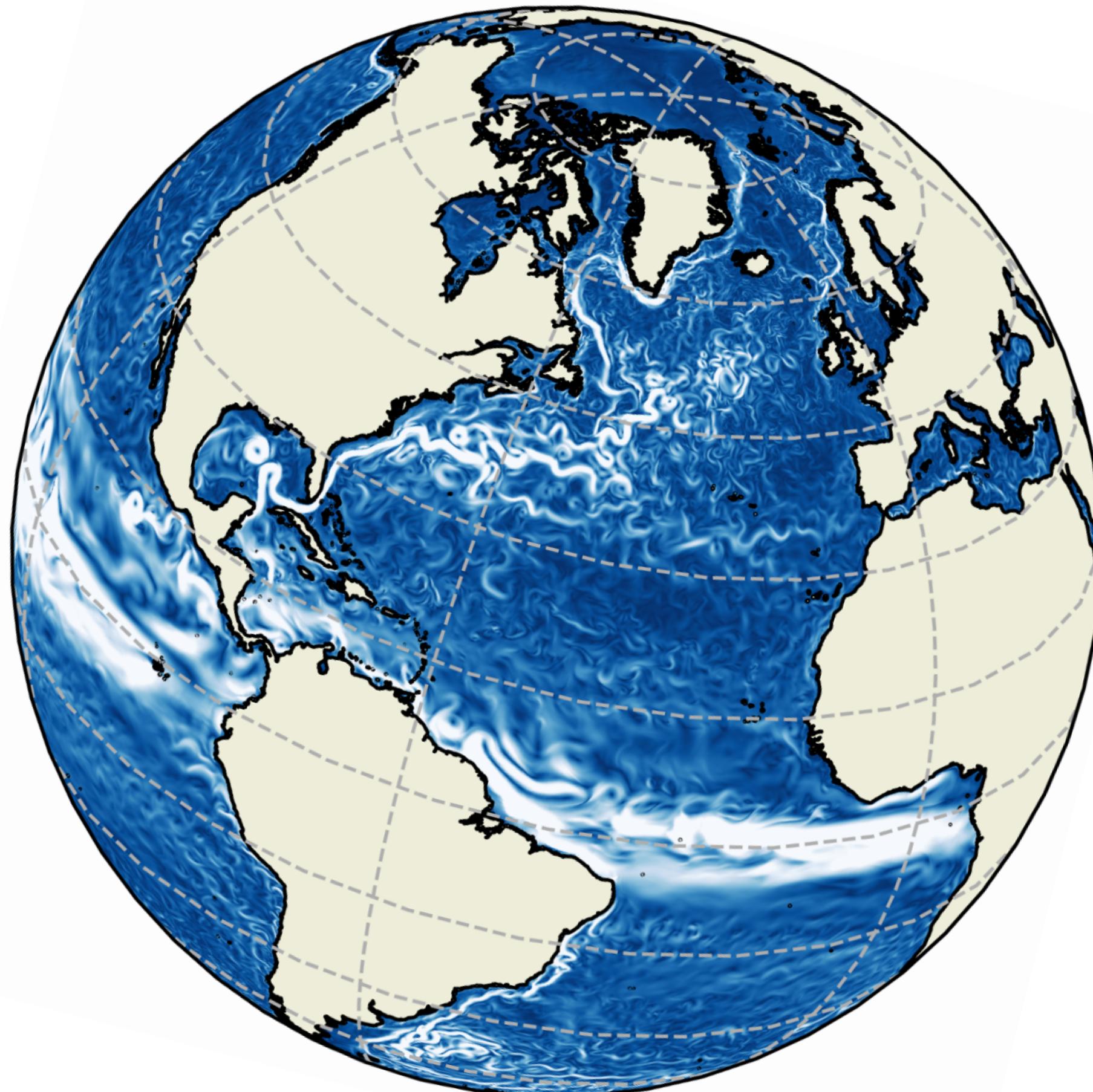


Paramètres physiques
courants, température...

- Comprendre le fonctionnement
- Prédire les évolutions (échelles)

climat - changements environnementaux
activities humaines - ressources

Le champ de l'océanographie physique



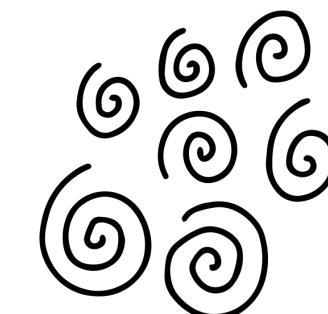
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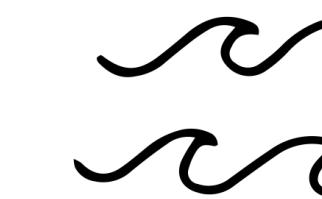
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Interaction entre ≠ échelles

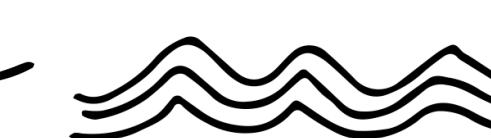
Macro-turbulence



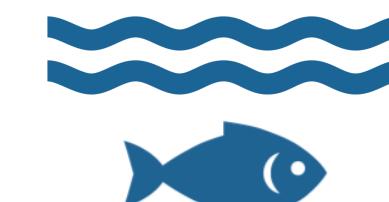
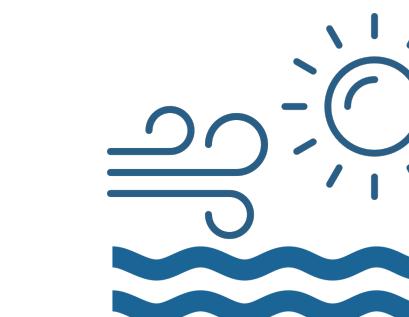
Surface waves



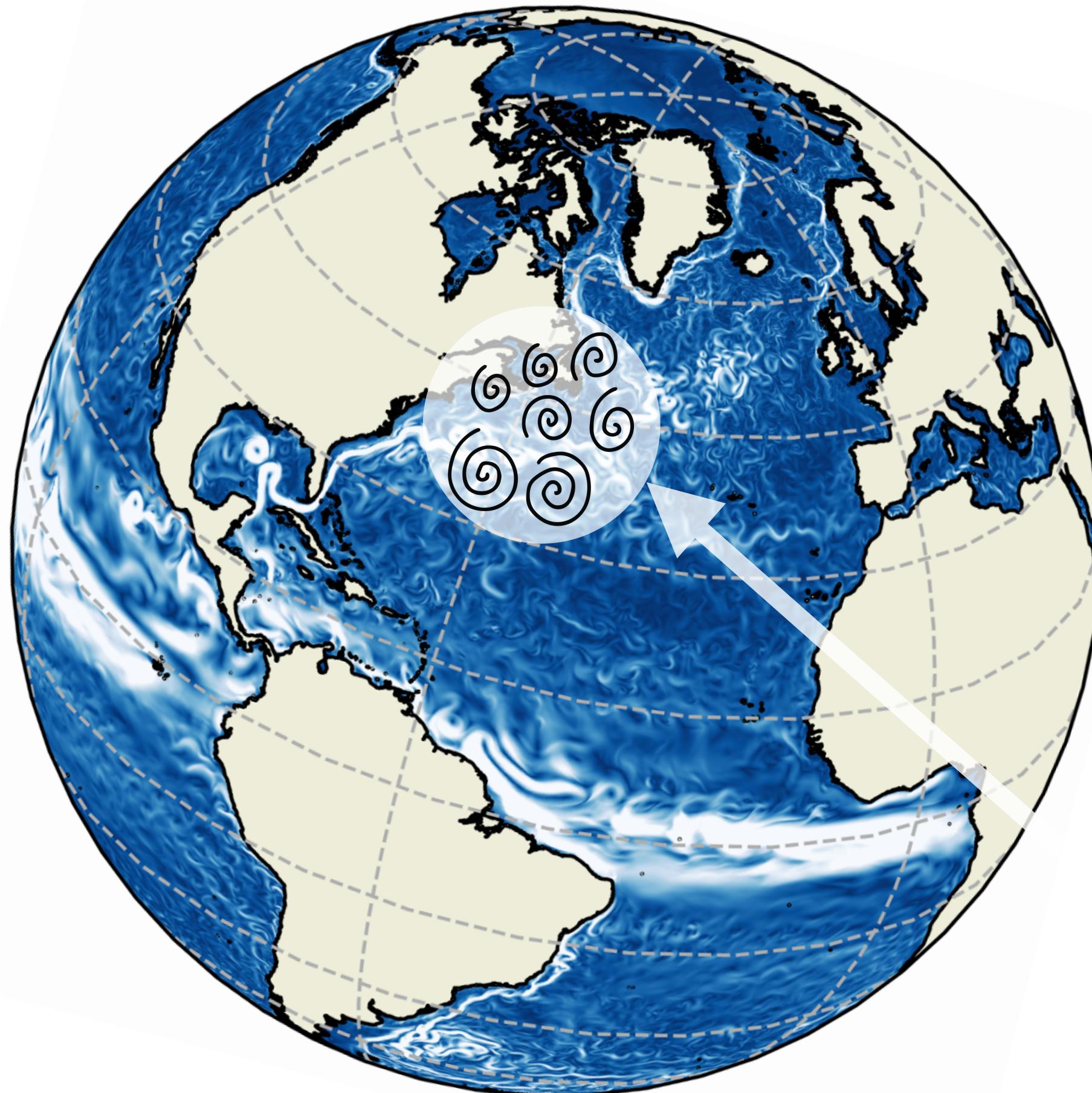
internal waves (tides)



Intéractions entre ≠ milieux



Le champ de l'océanographie physique



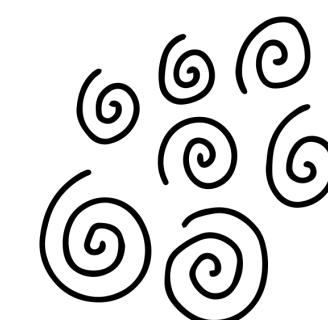
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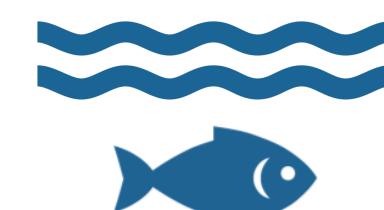
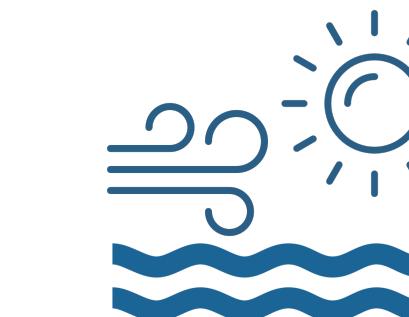
Surface waves



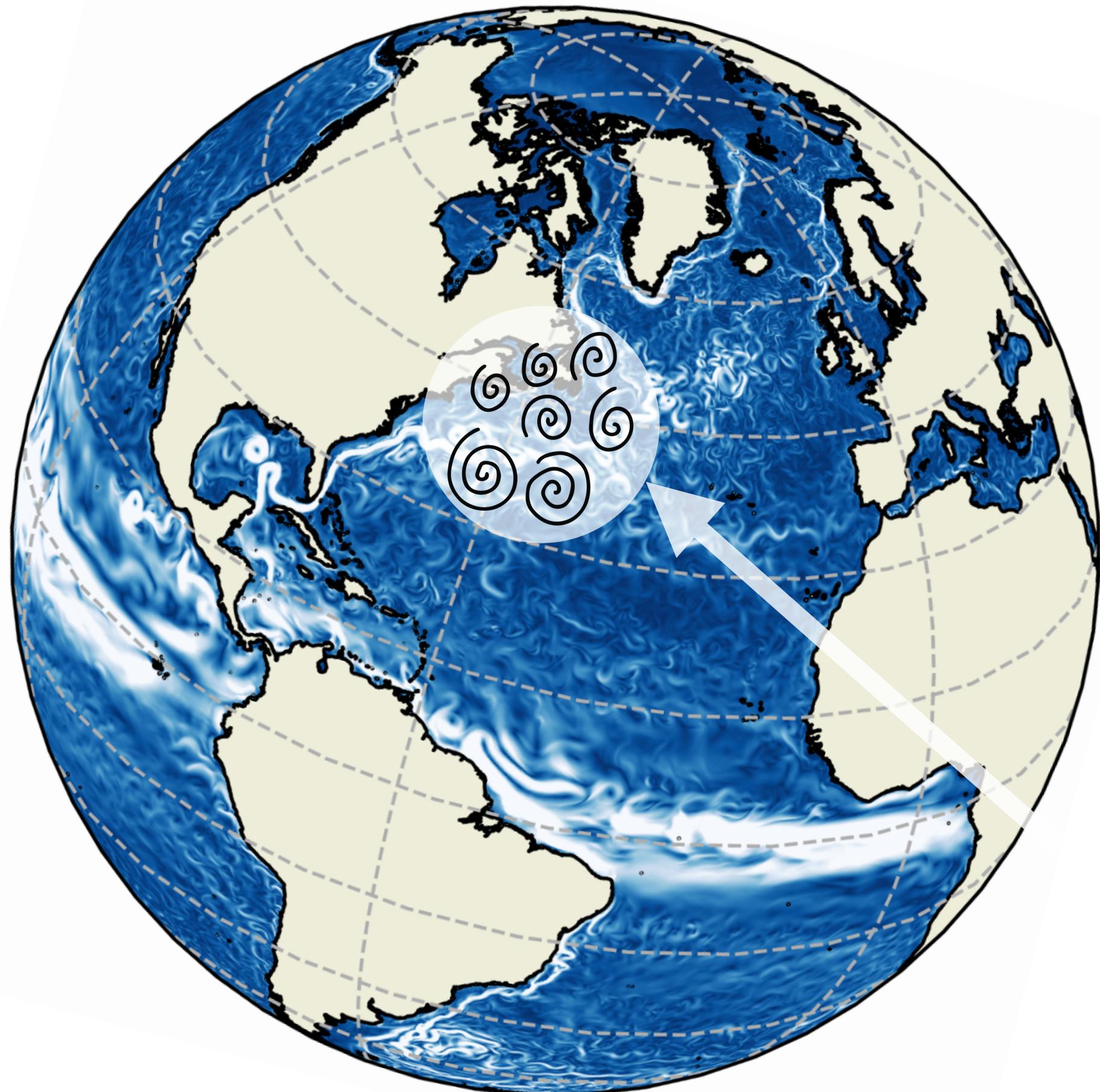
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Intéractions entre ≠ milieux



Le champ de l'océanographie physique



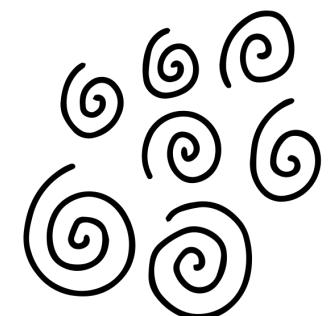
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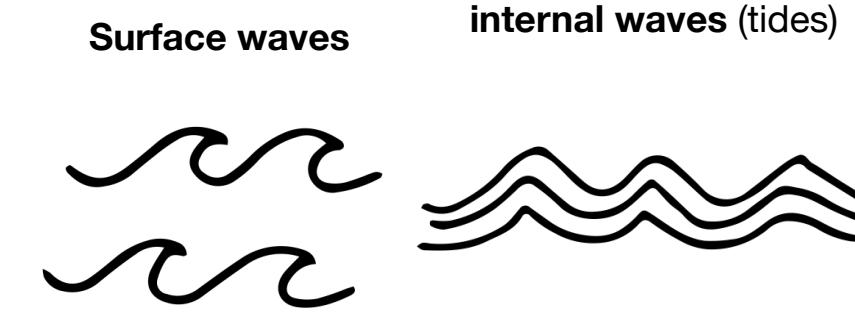
climat - changements environnementaux
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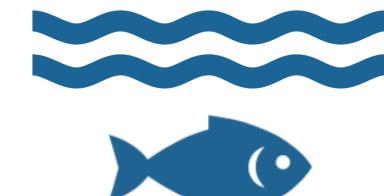
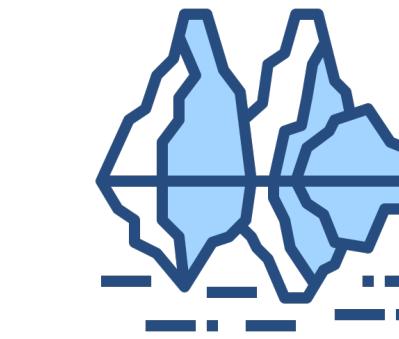
Surface waves



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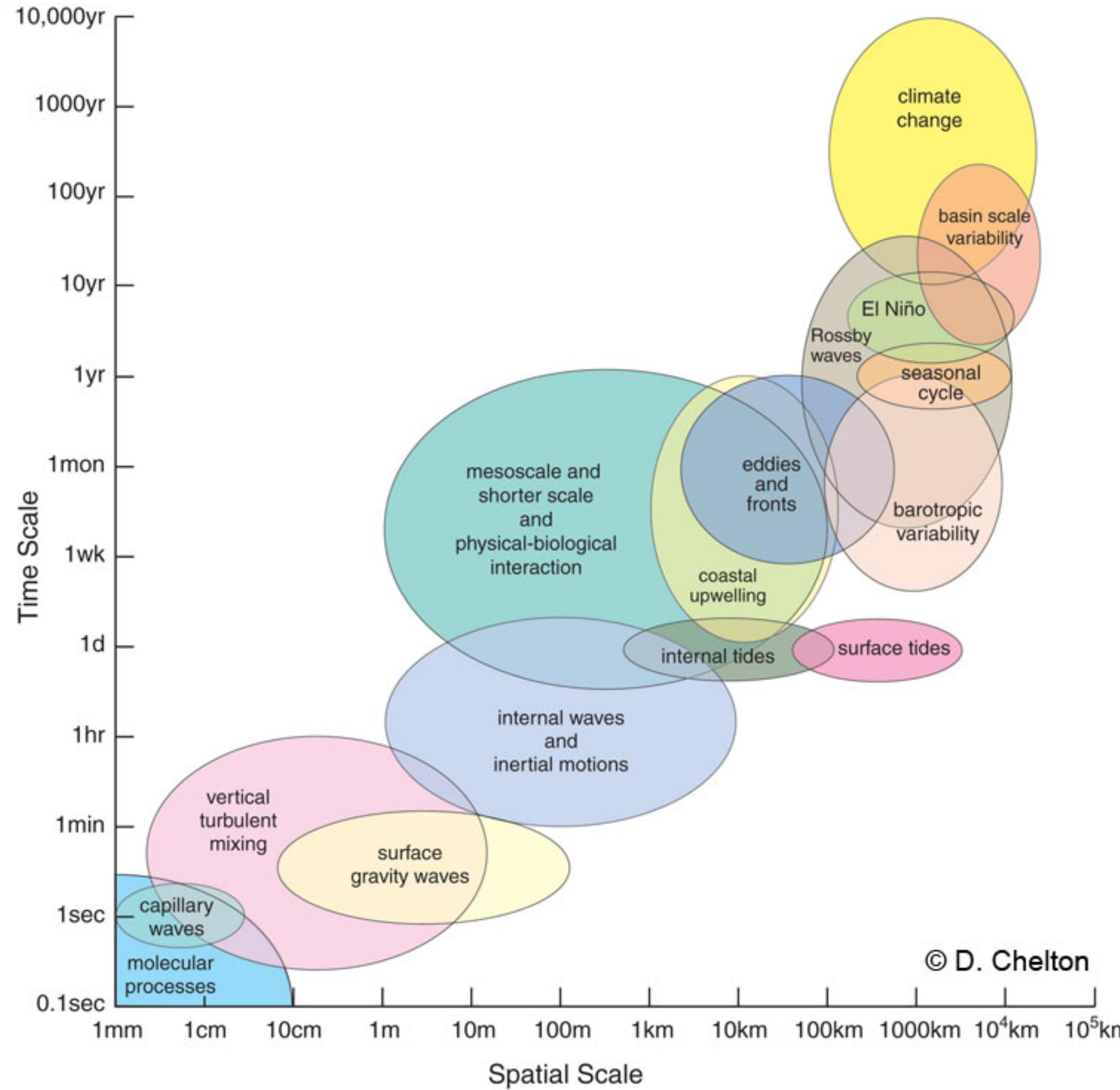


Intéractions entre ≠ milieux

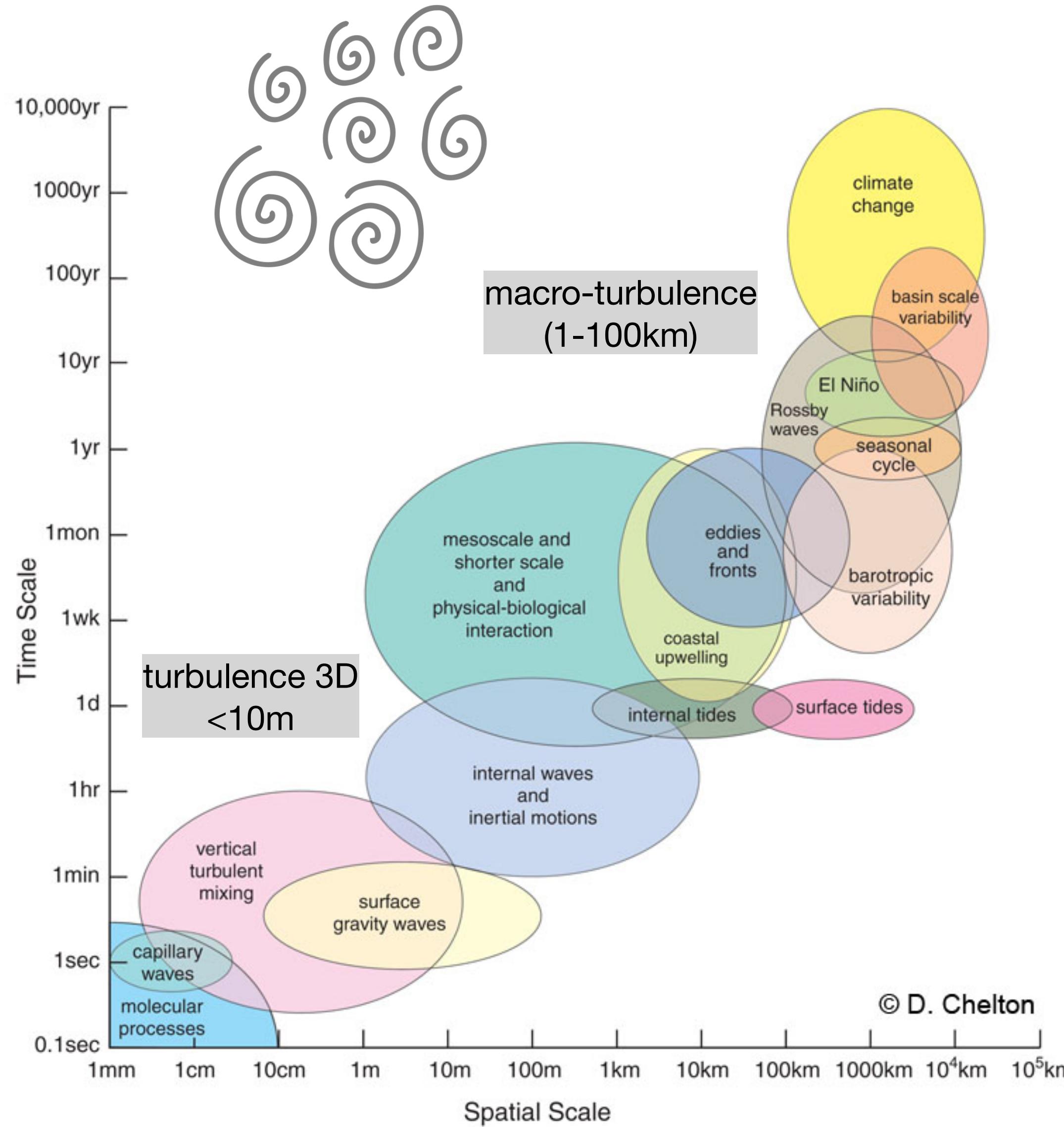


Role clé de la turbulence sur l'évolution de l'océan et les activités humaines

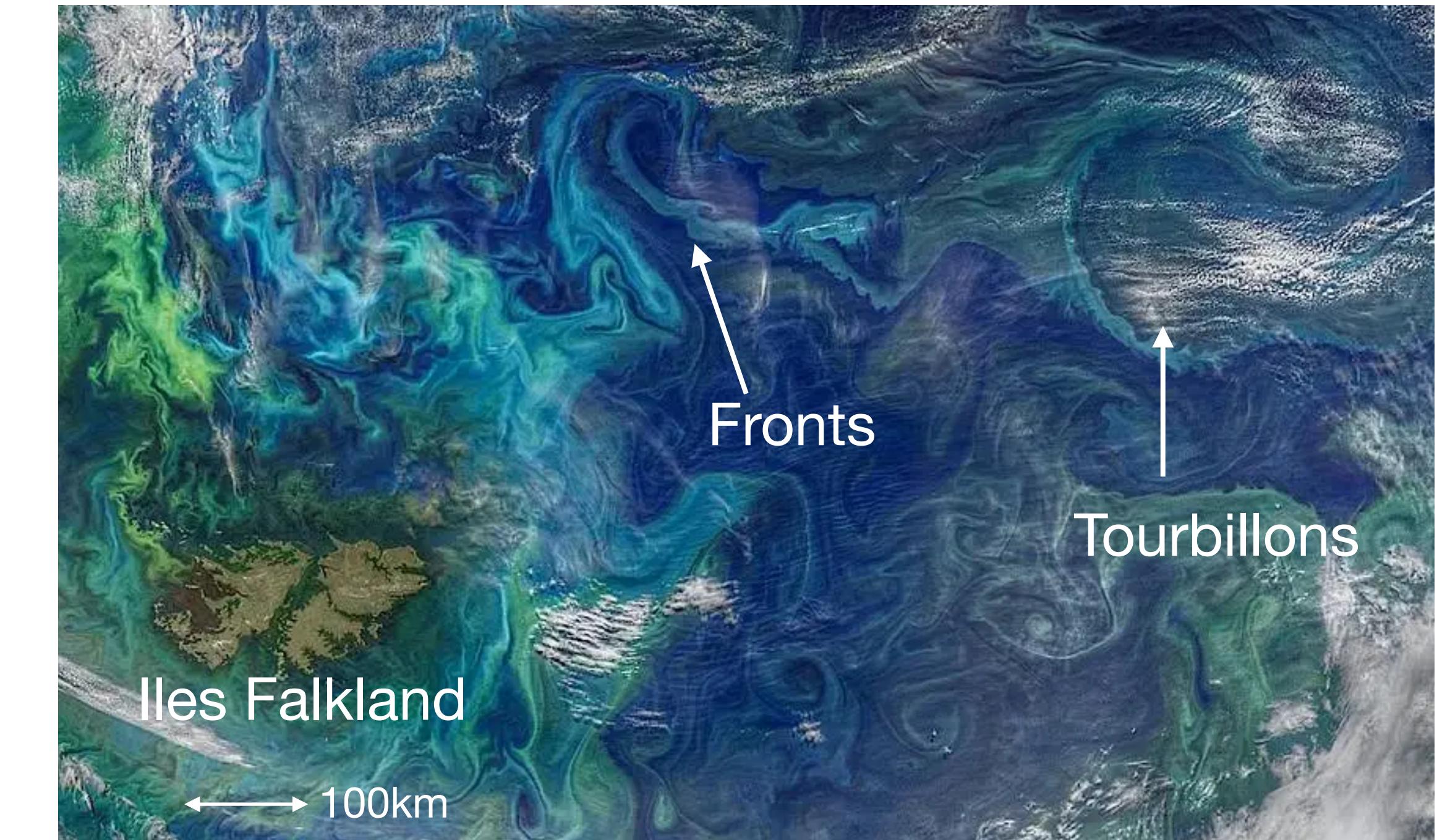
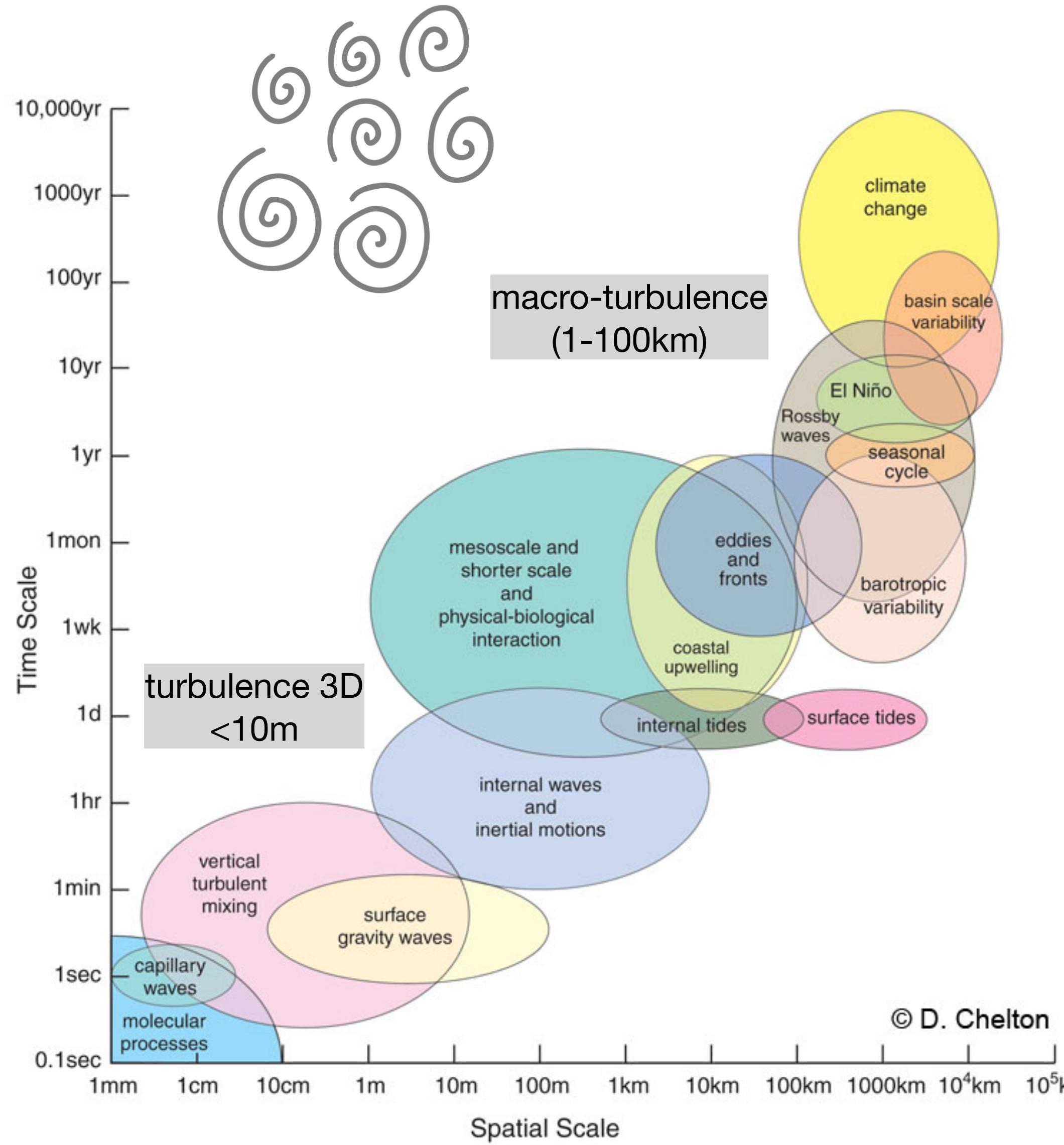
Turbulence océanique de macro-échelle



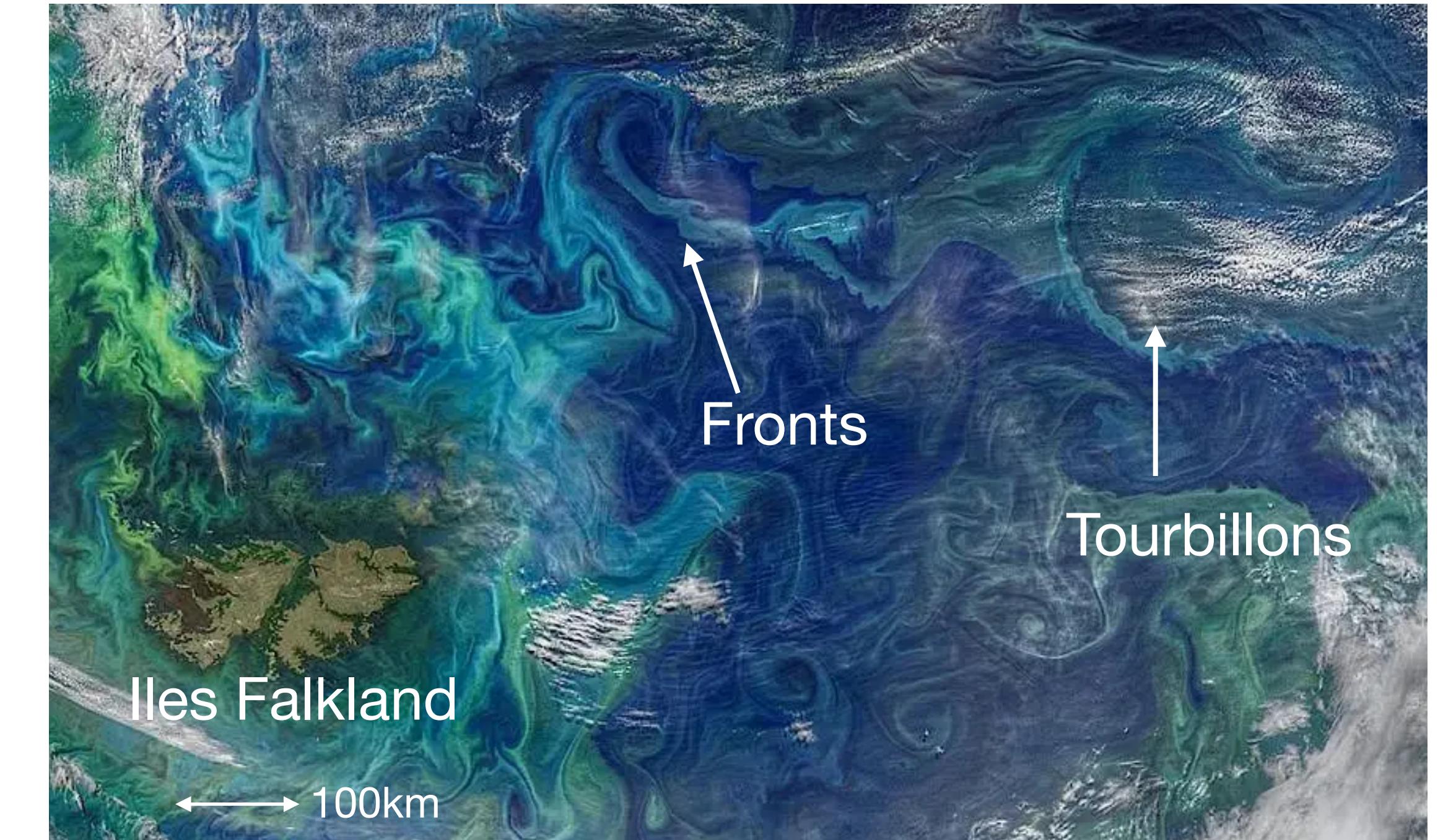
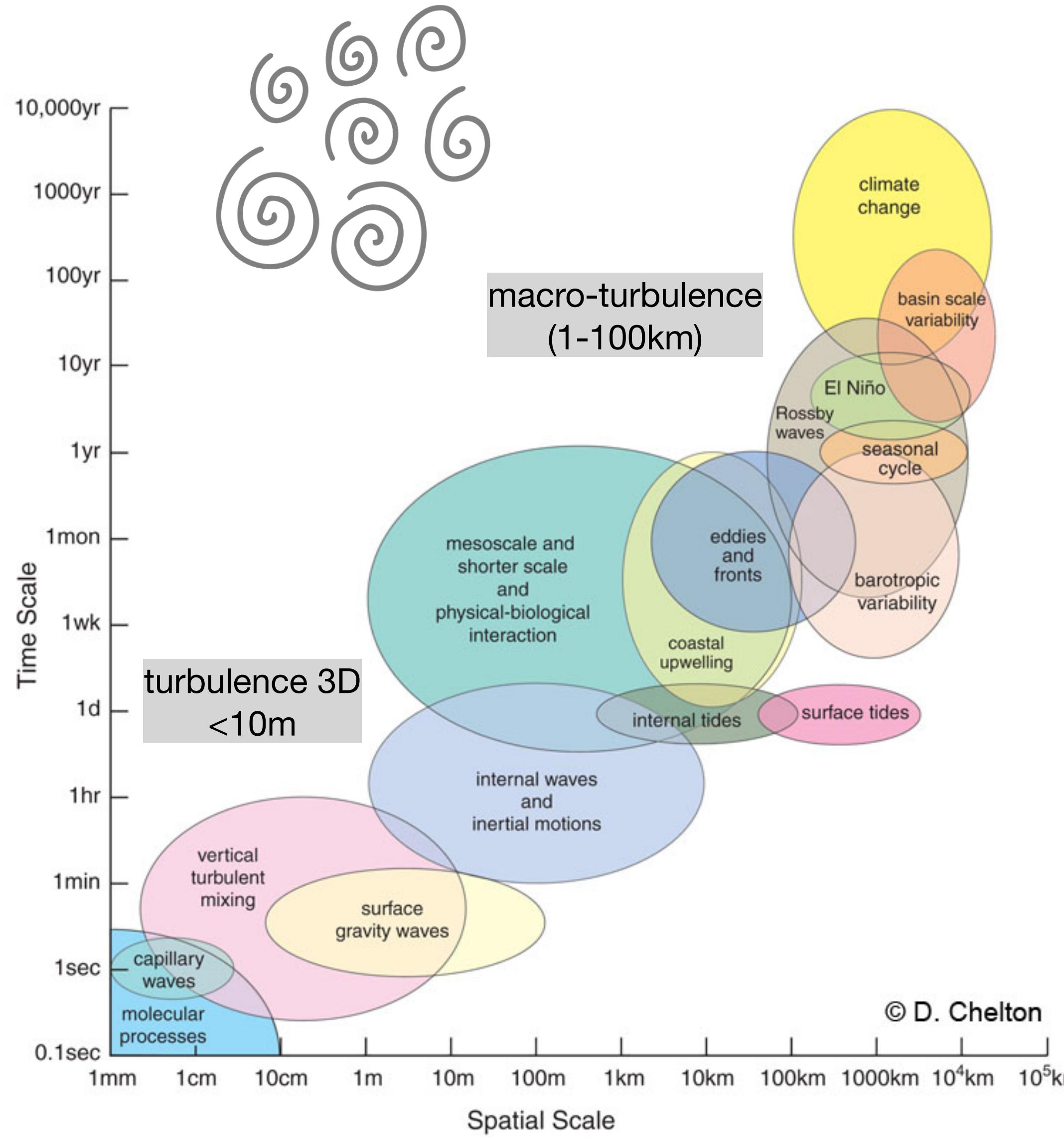
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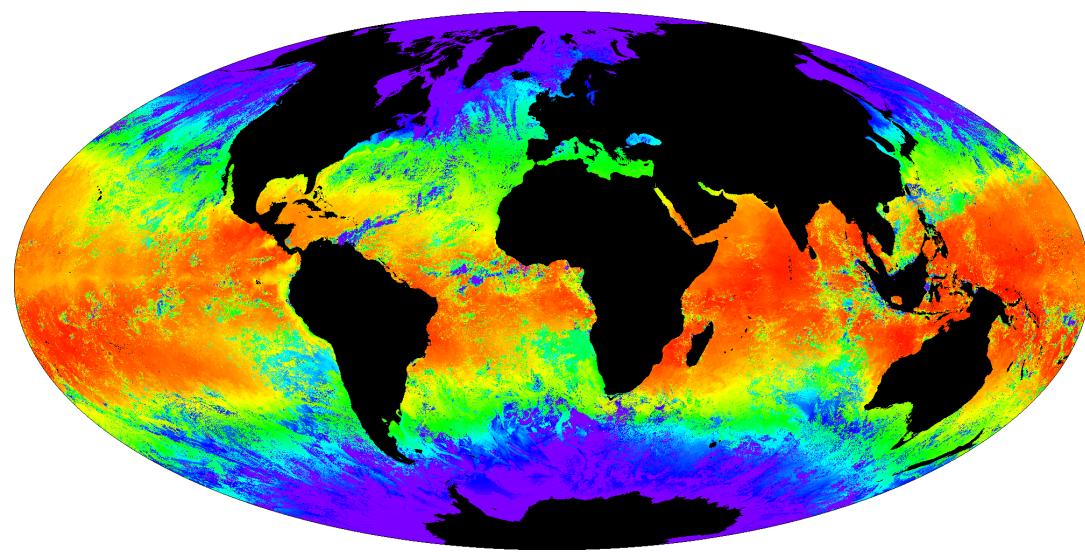
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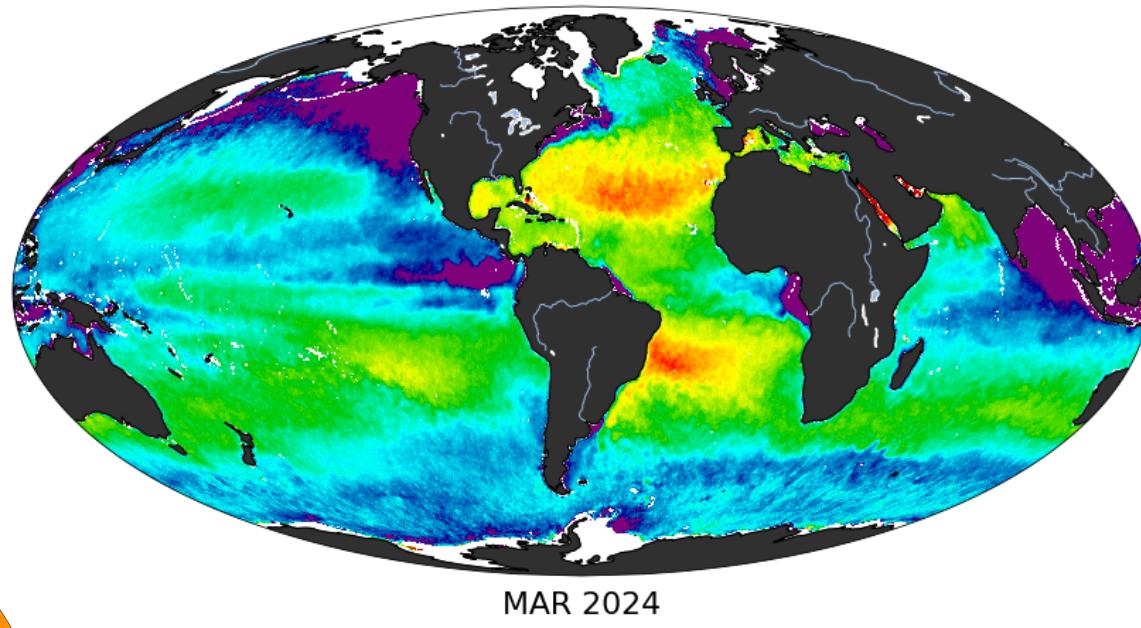
enjeux scientifiques :

- sources, variabilité, dissipation, ...
- impact sur biologie, flux-air-mer, ...
- prévision pour activités humaines, ...

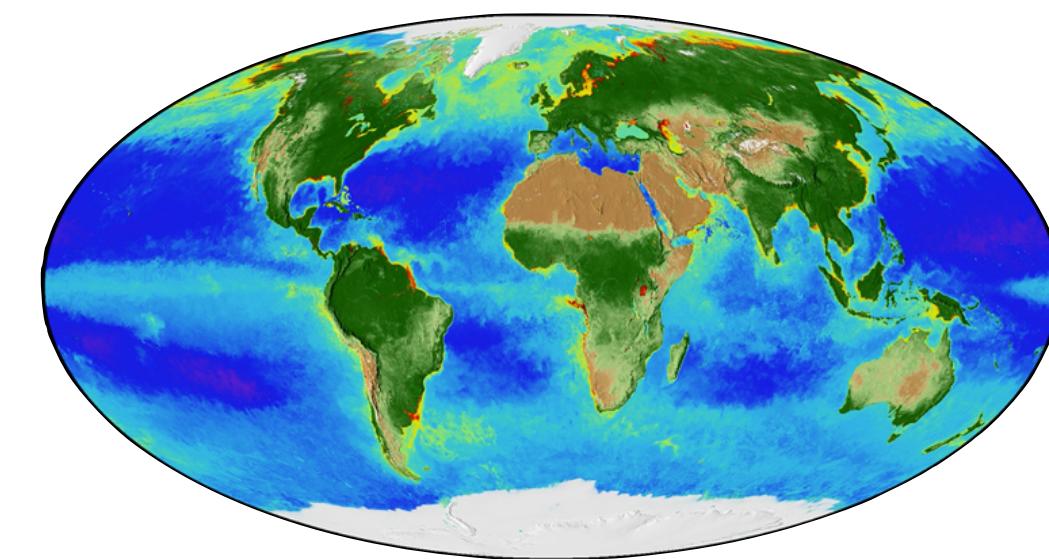
Macro-turbulence et observations spatiales



Temperature de surface



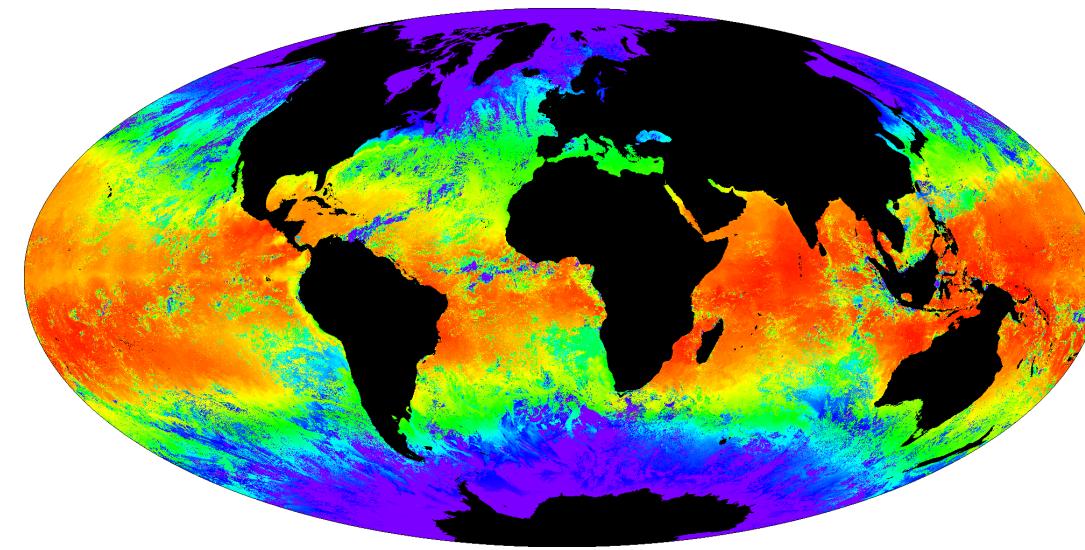
Salinité de surface



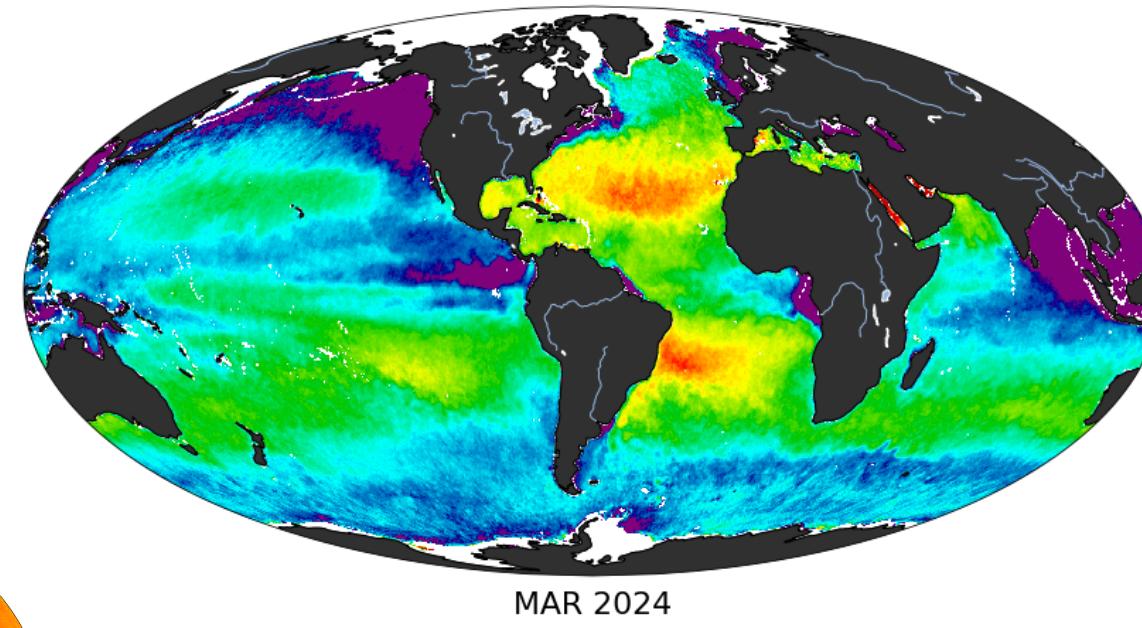
Couleur de l'eau

Signature des fronts et tourbillons
sur toutes les observables

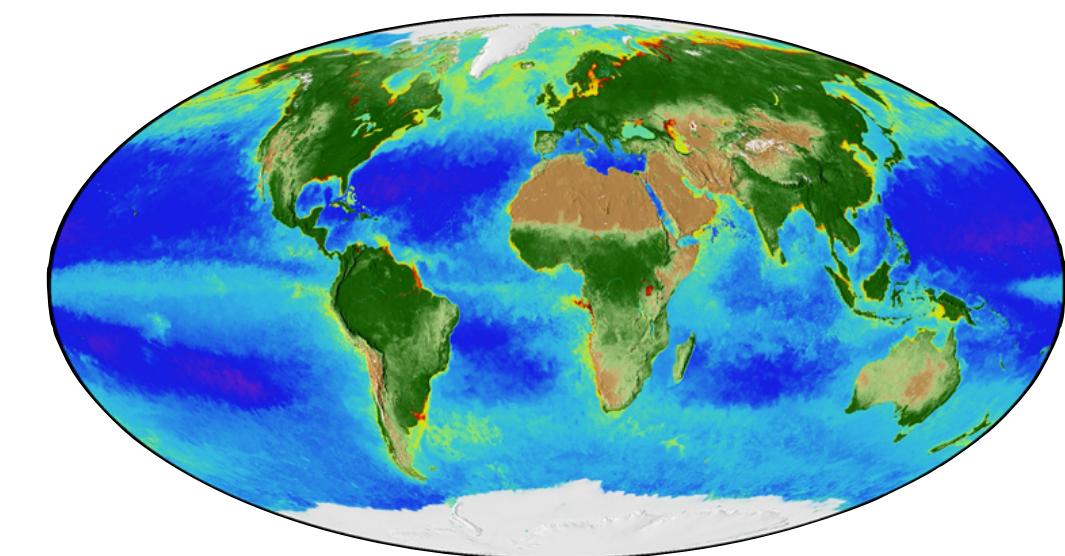
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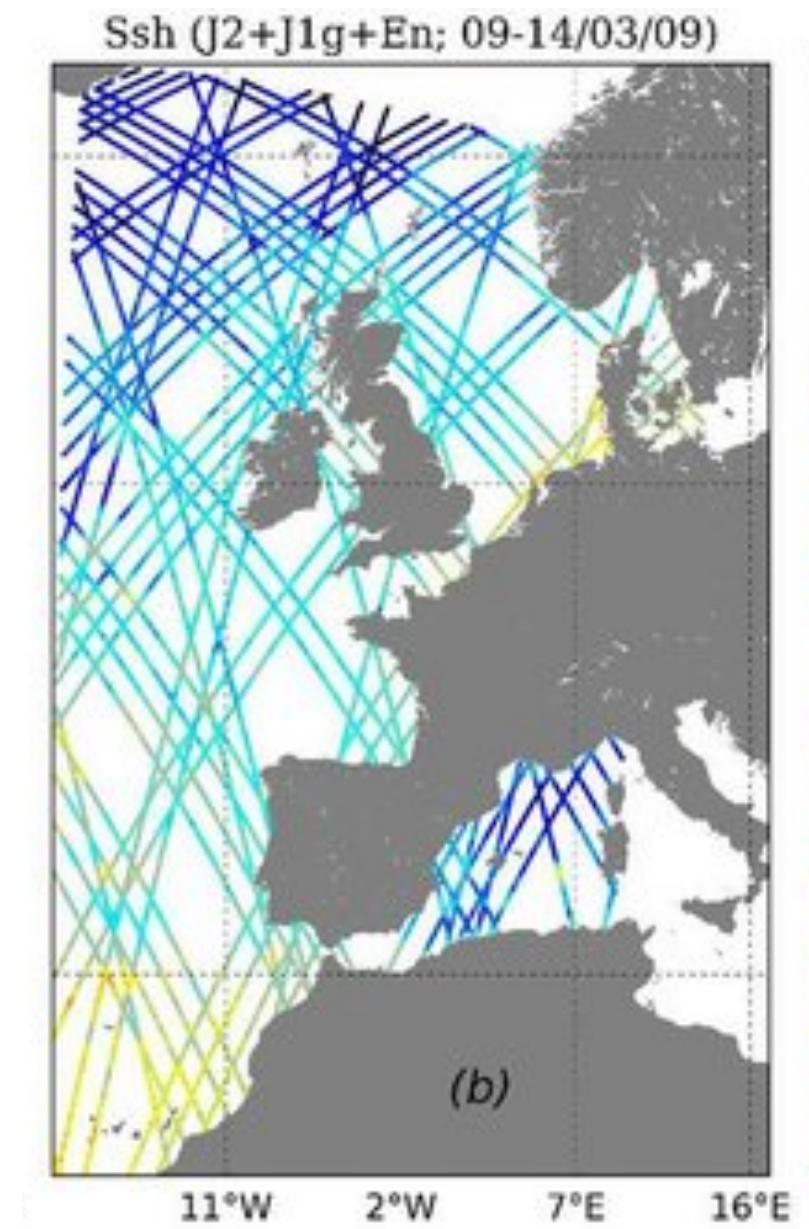
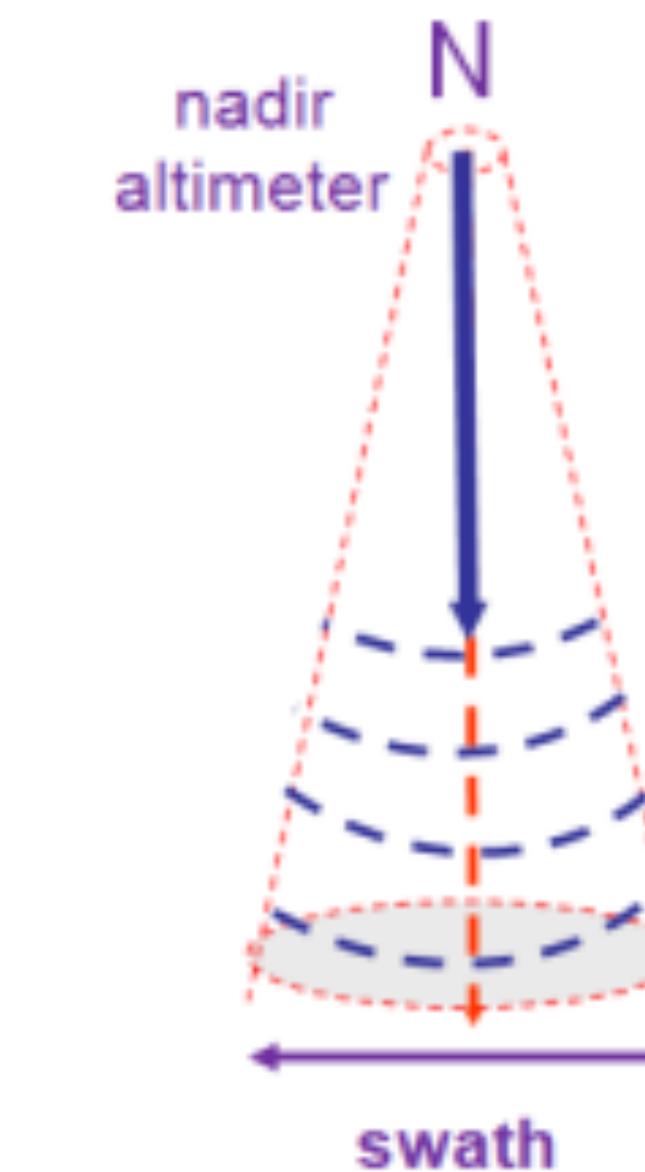
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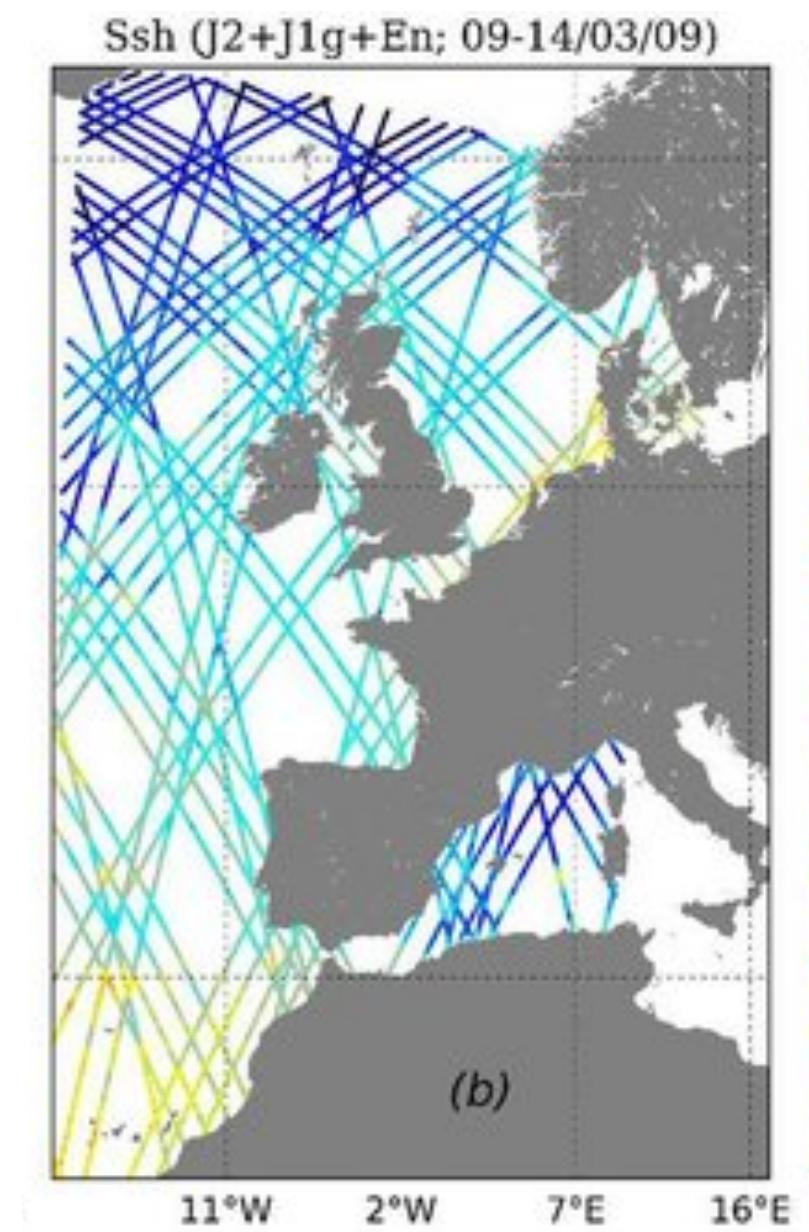
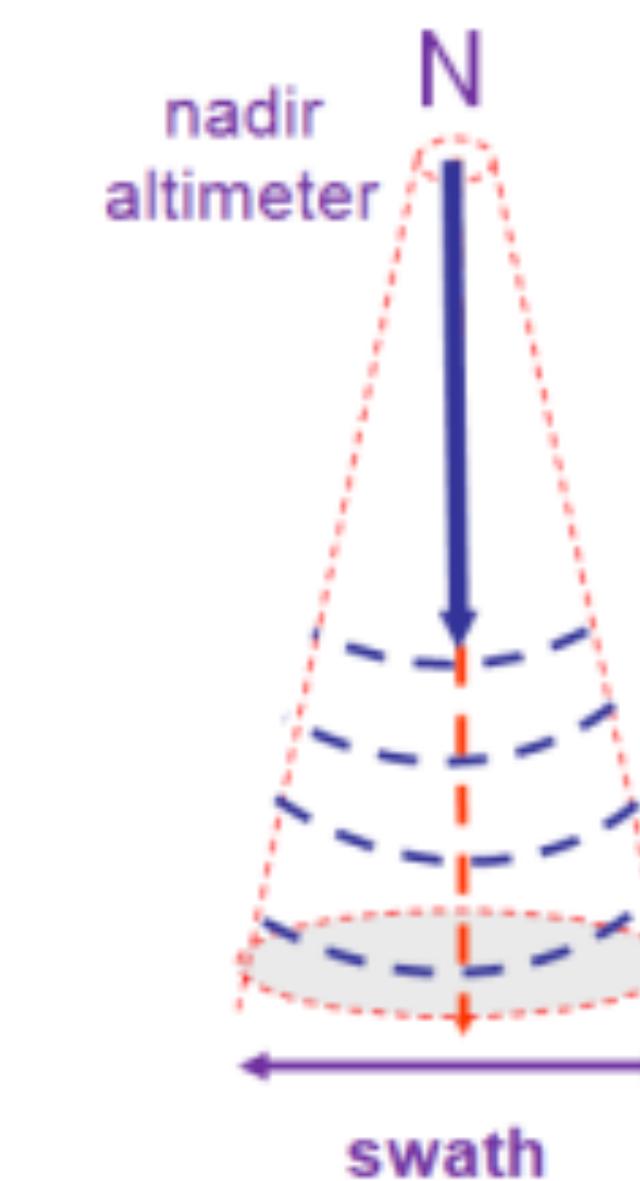
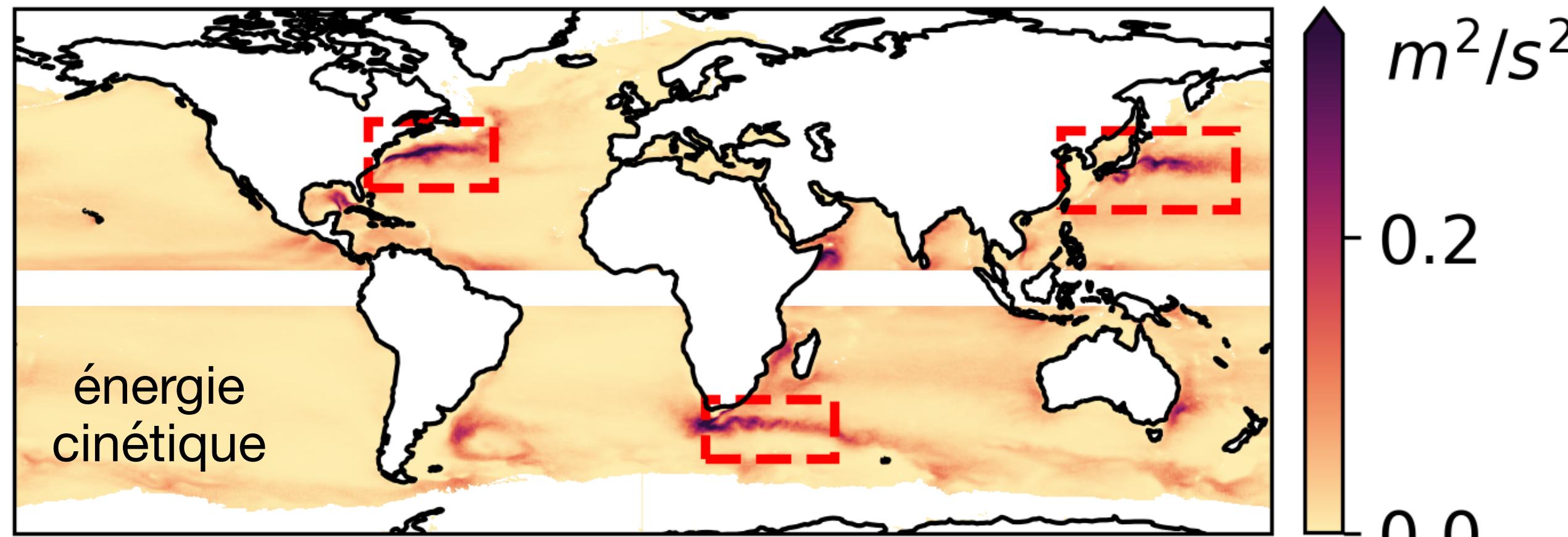


$\nabla SSH \rightarrow$ courants

Signature des fronts et tourbillons
sur toutes les observables

Rôle pivot de l'altimétrie radar
(Nadir, SWOT)

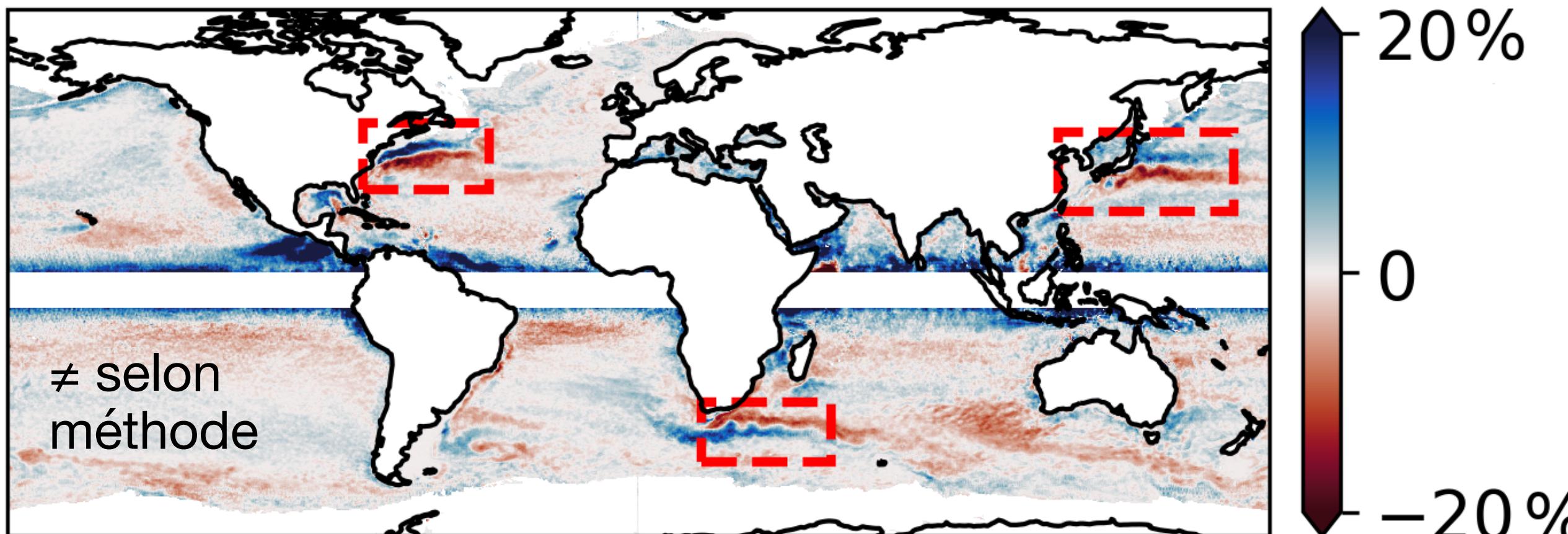
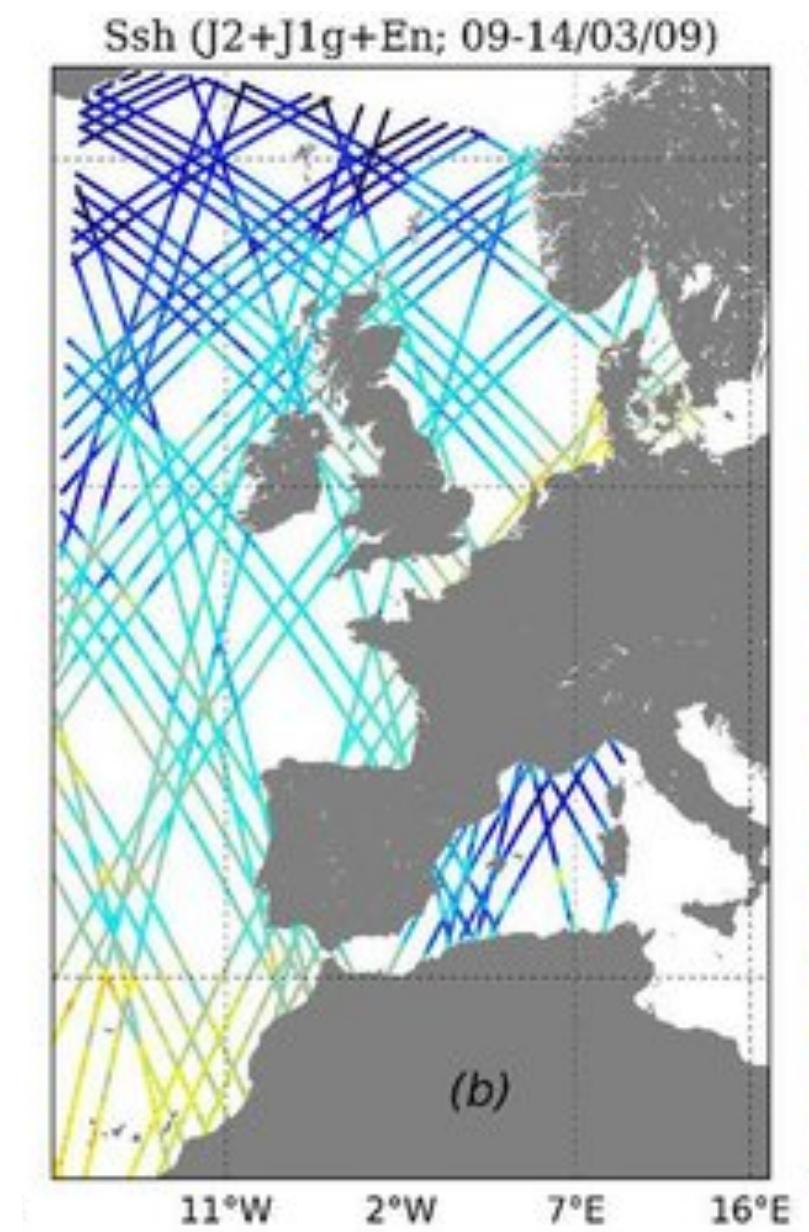
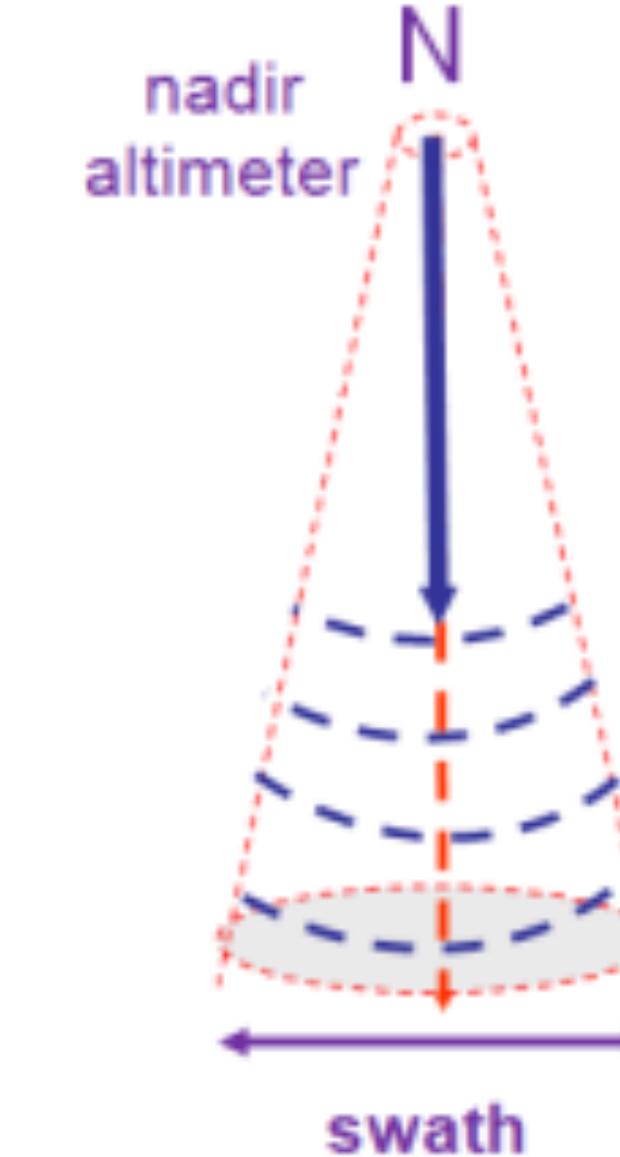
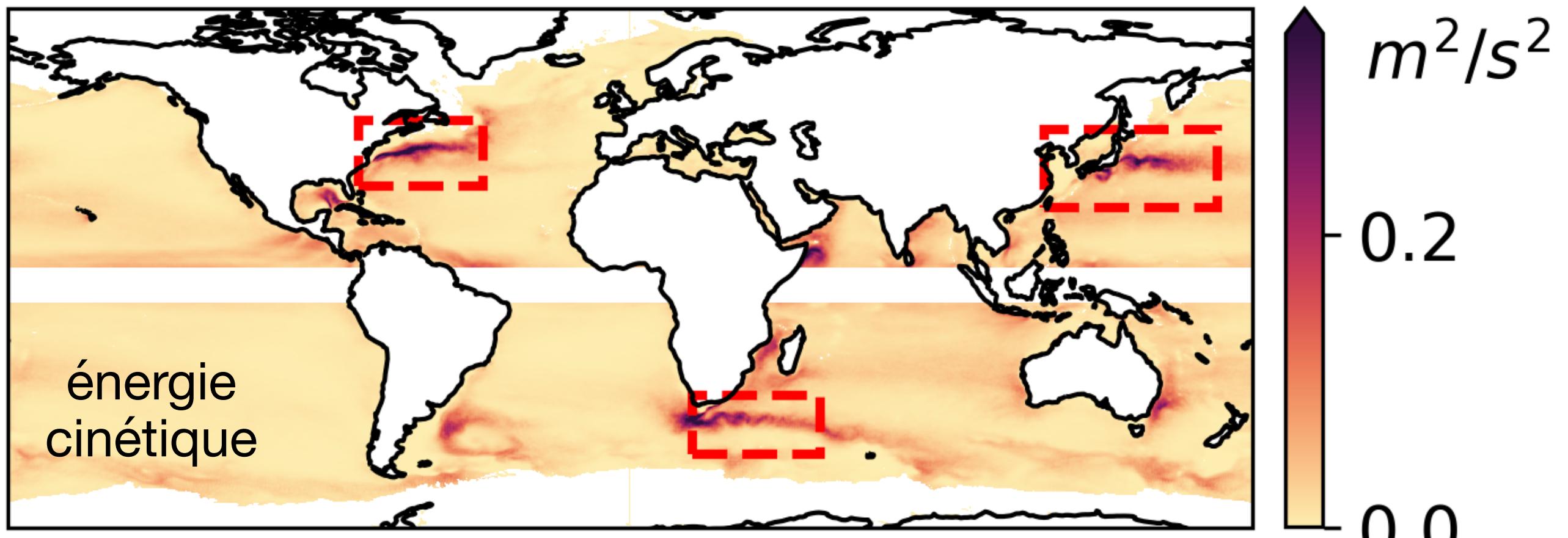
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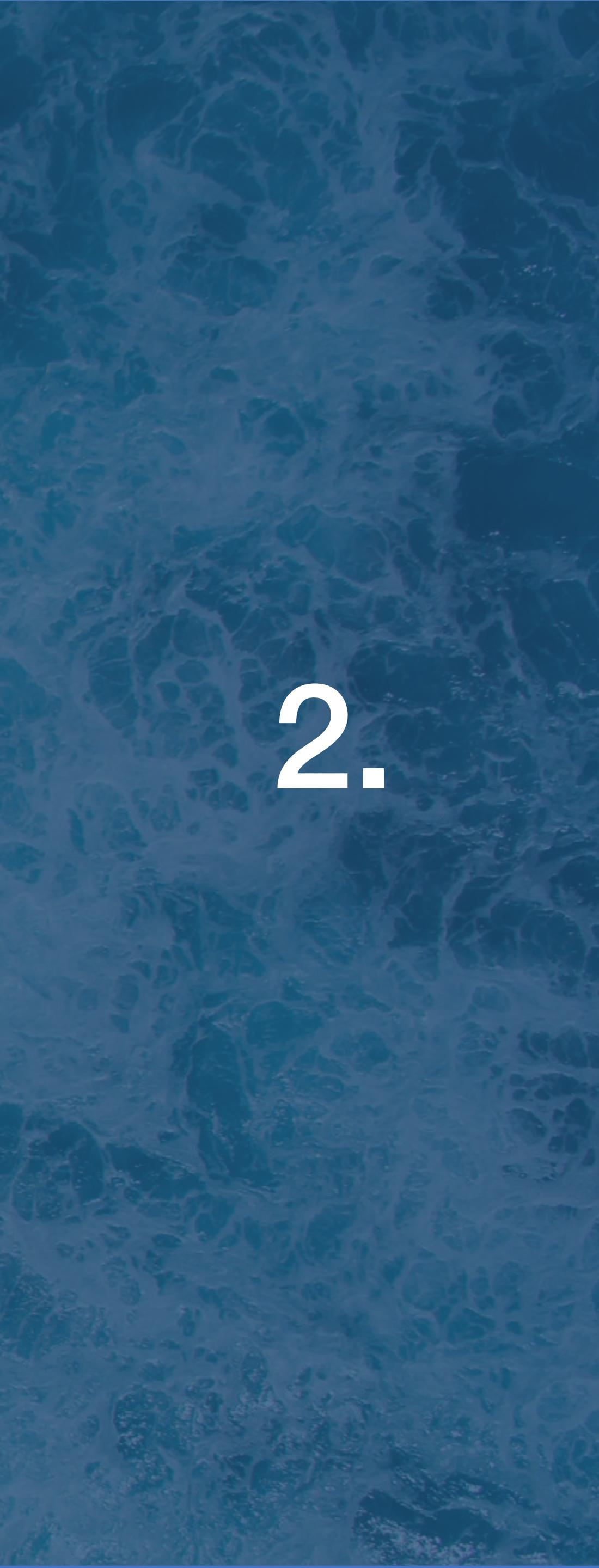


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Rôle pivot de l'altimétrie radar
(Nadir, SWOT)

Bertrand et al. 2025

<https://doi.org/10.5194/egusphere-2025-4172>

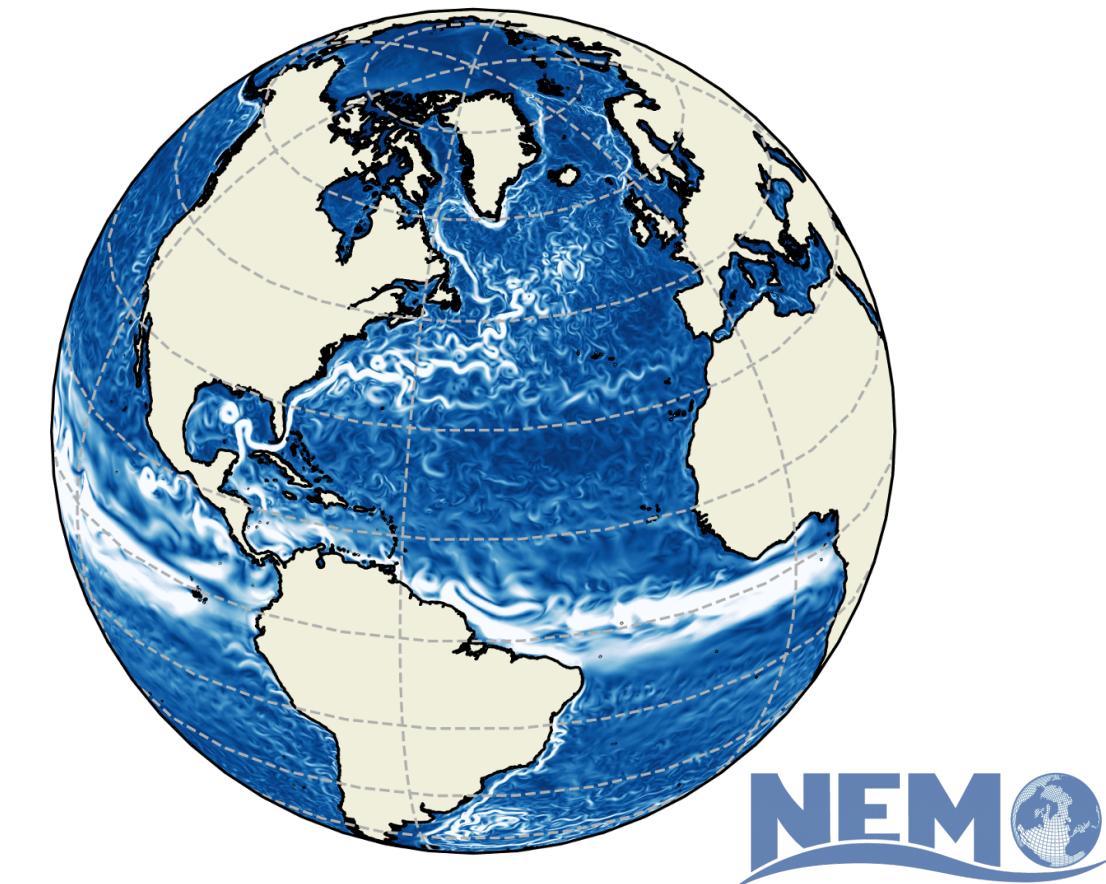
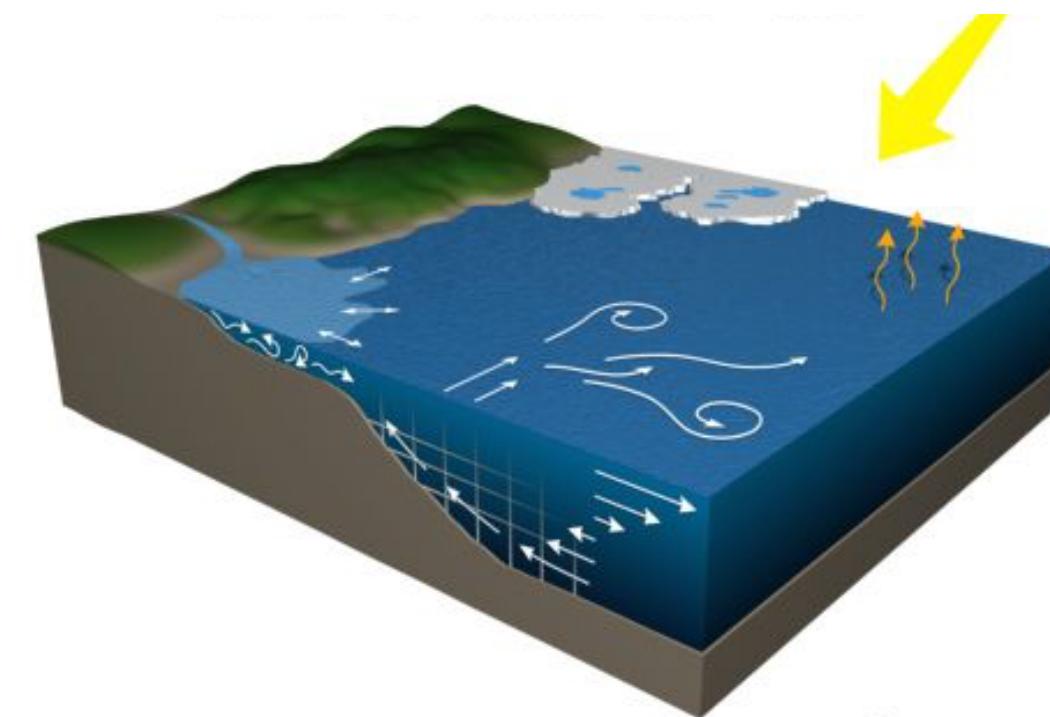


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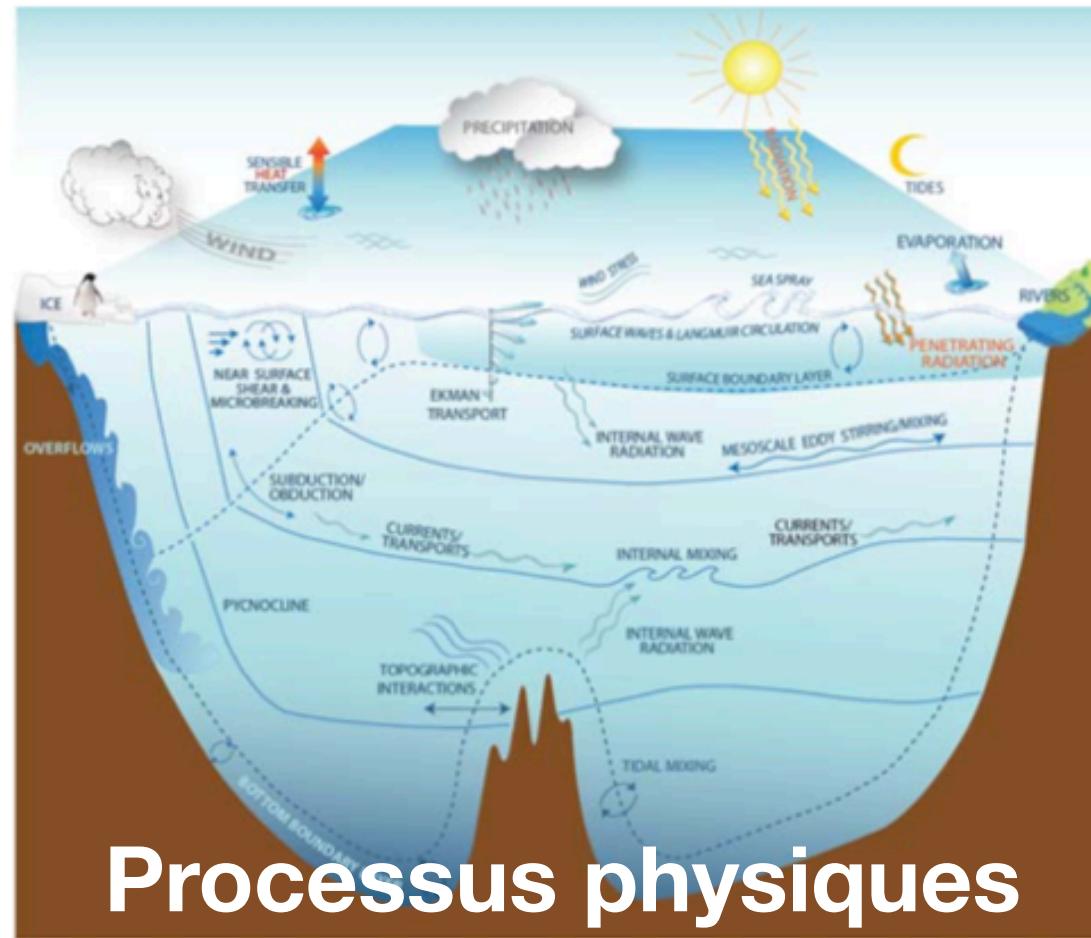
Modéliser la circulation océanique

Modèles de circulation océanique

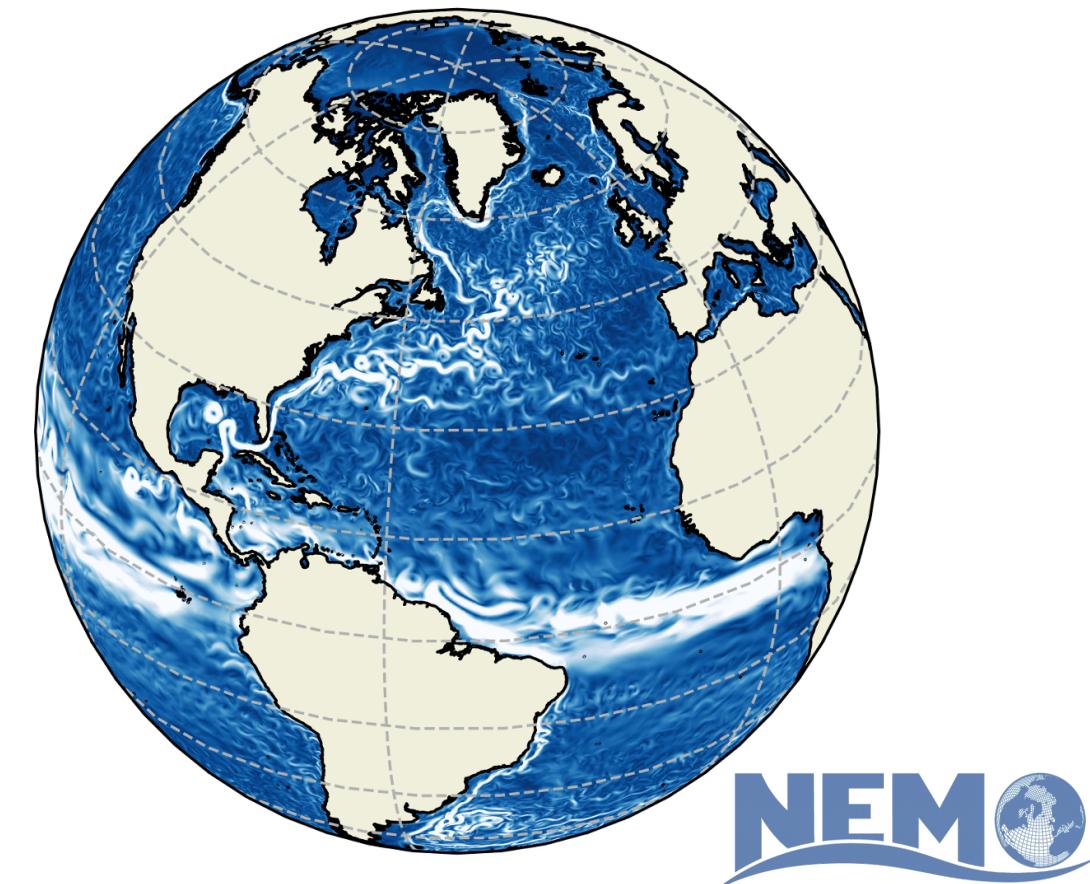
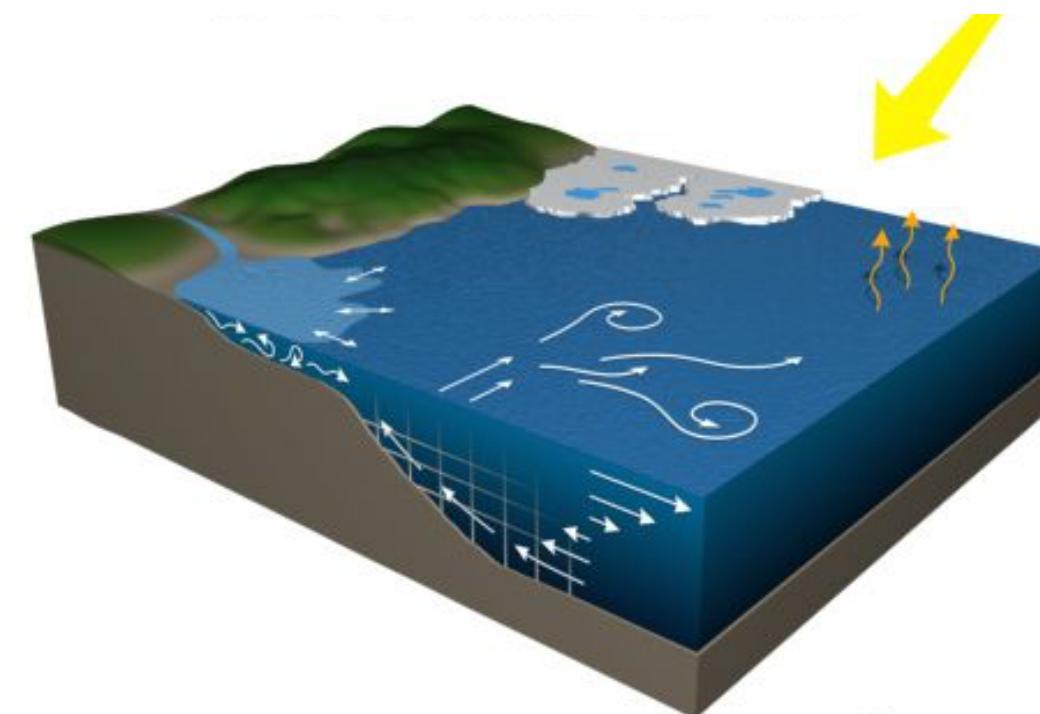
Modèles physiques



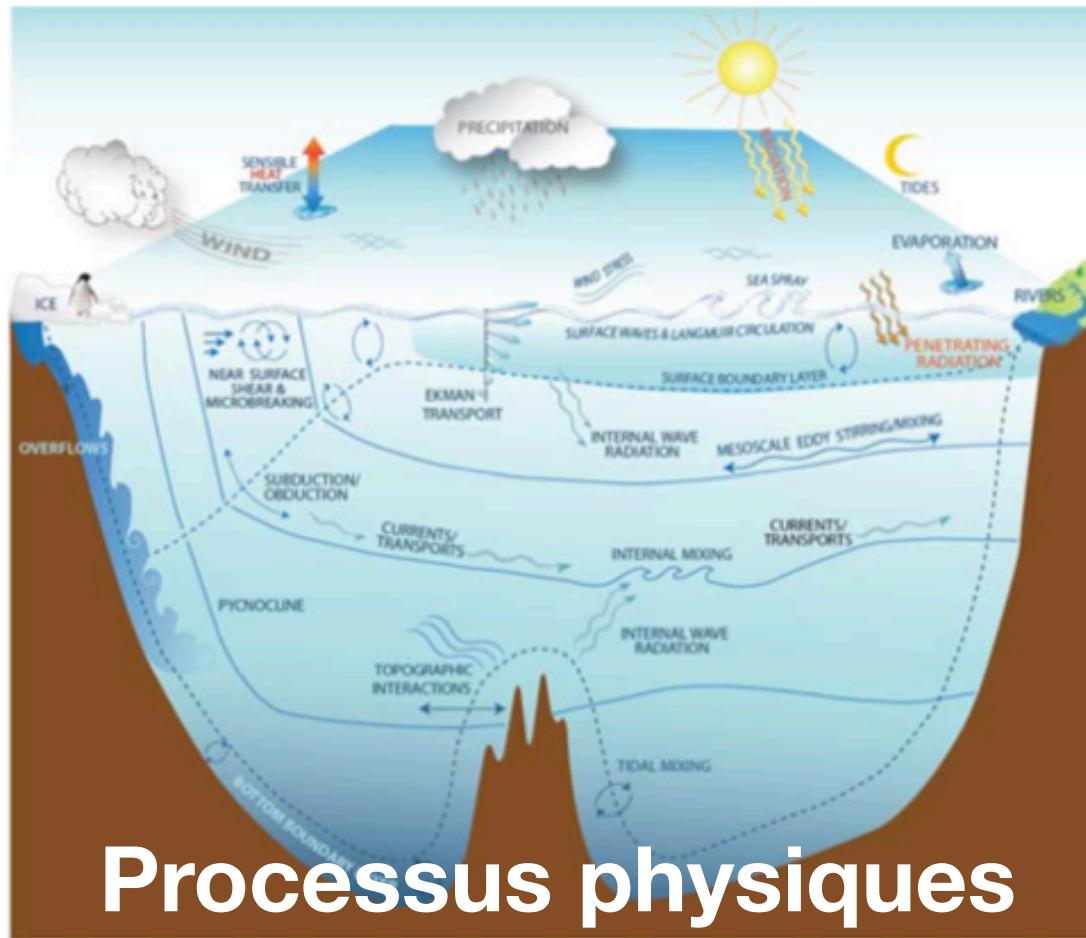
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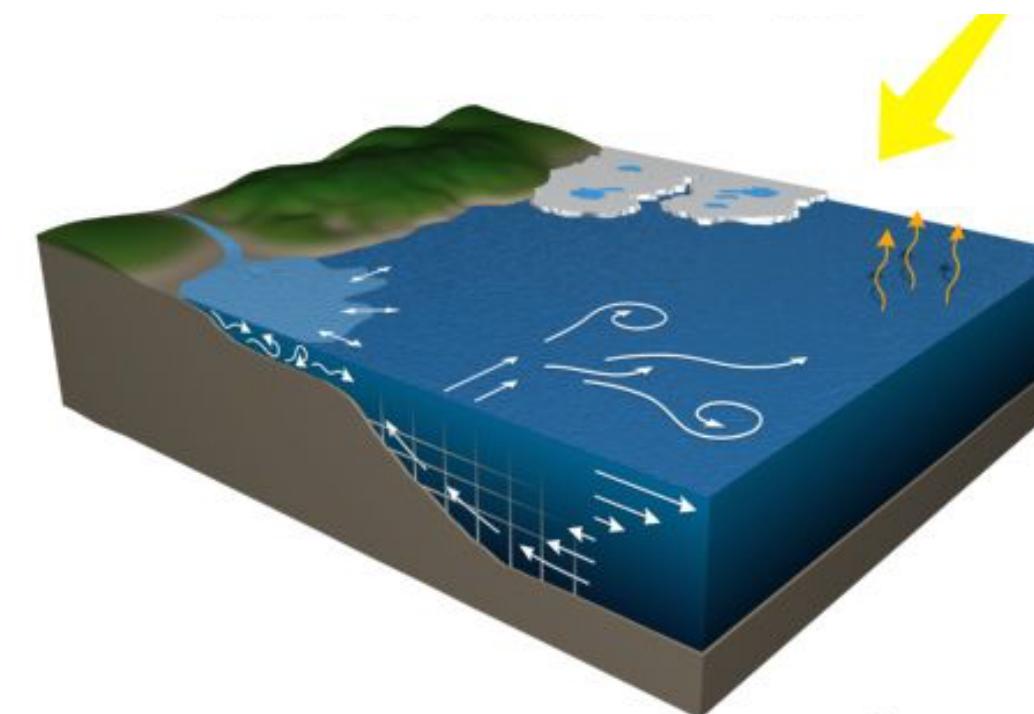
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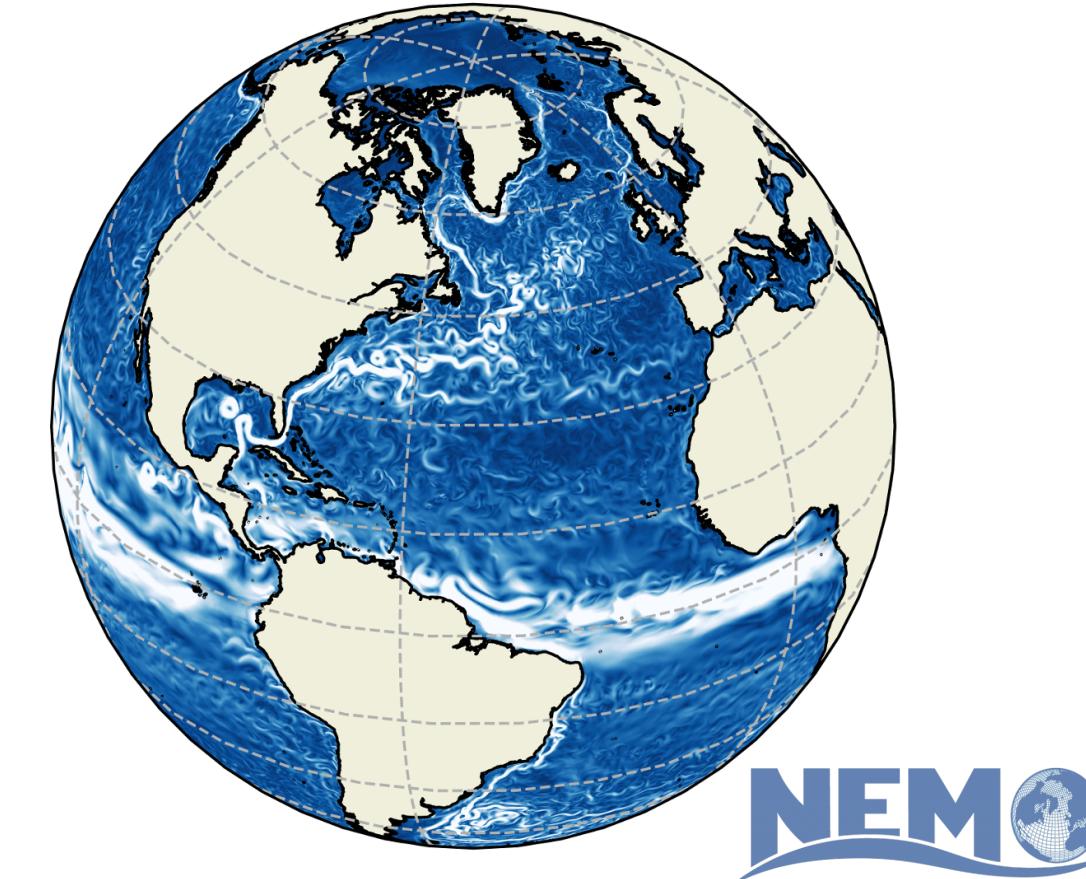
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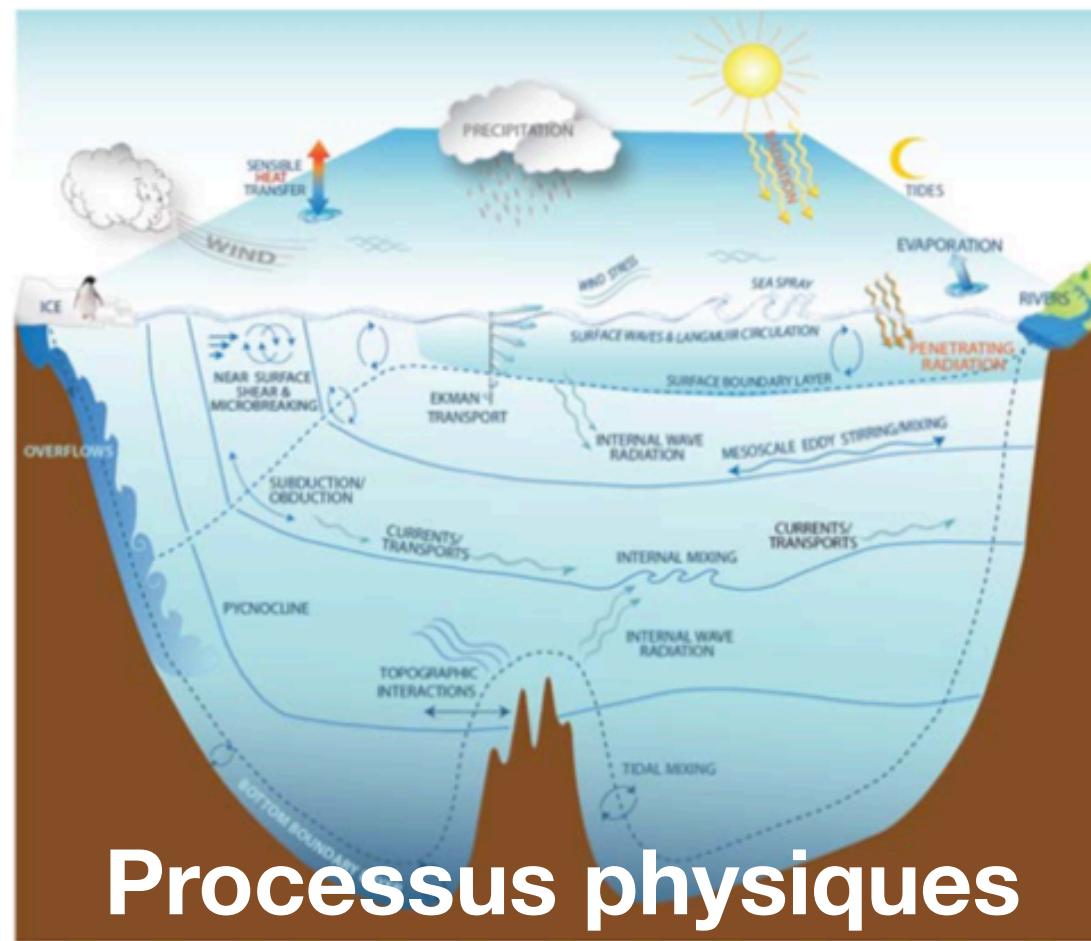
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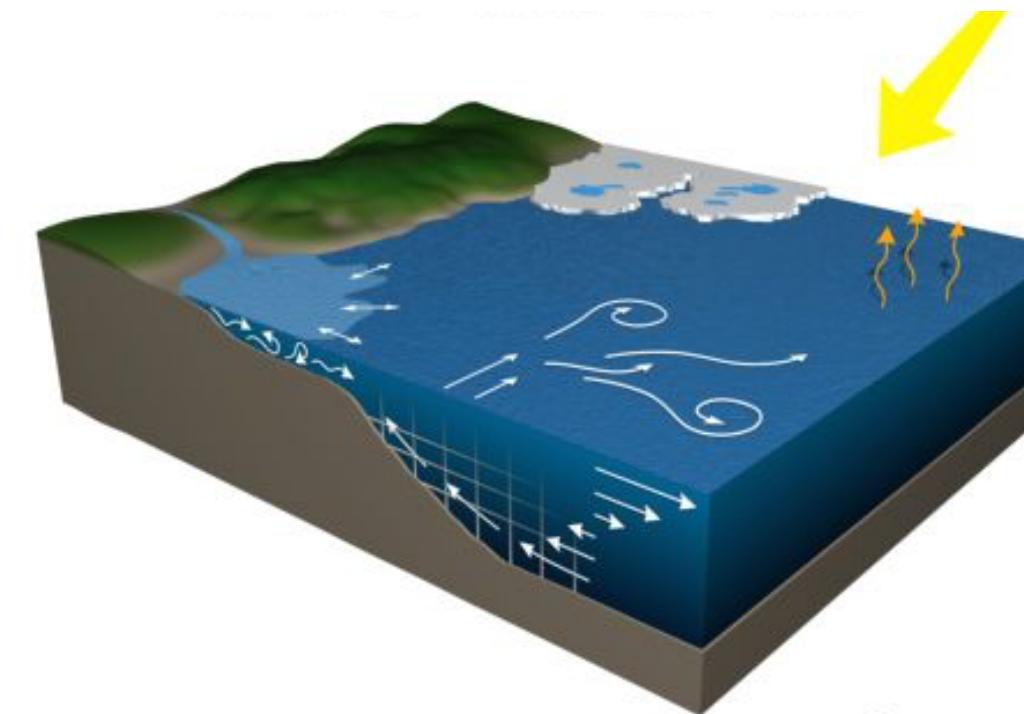
Théorie



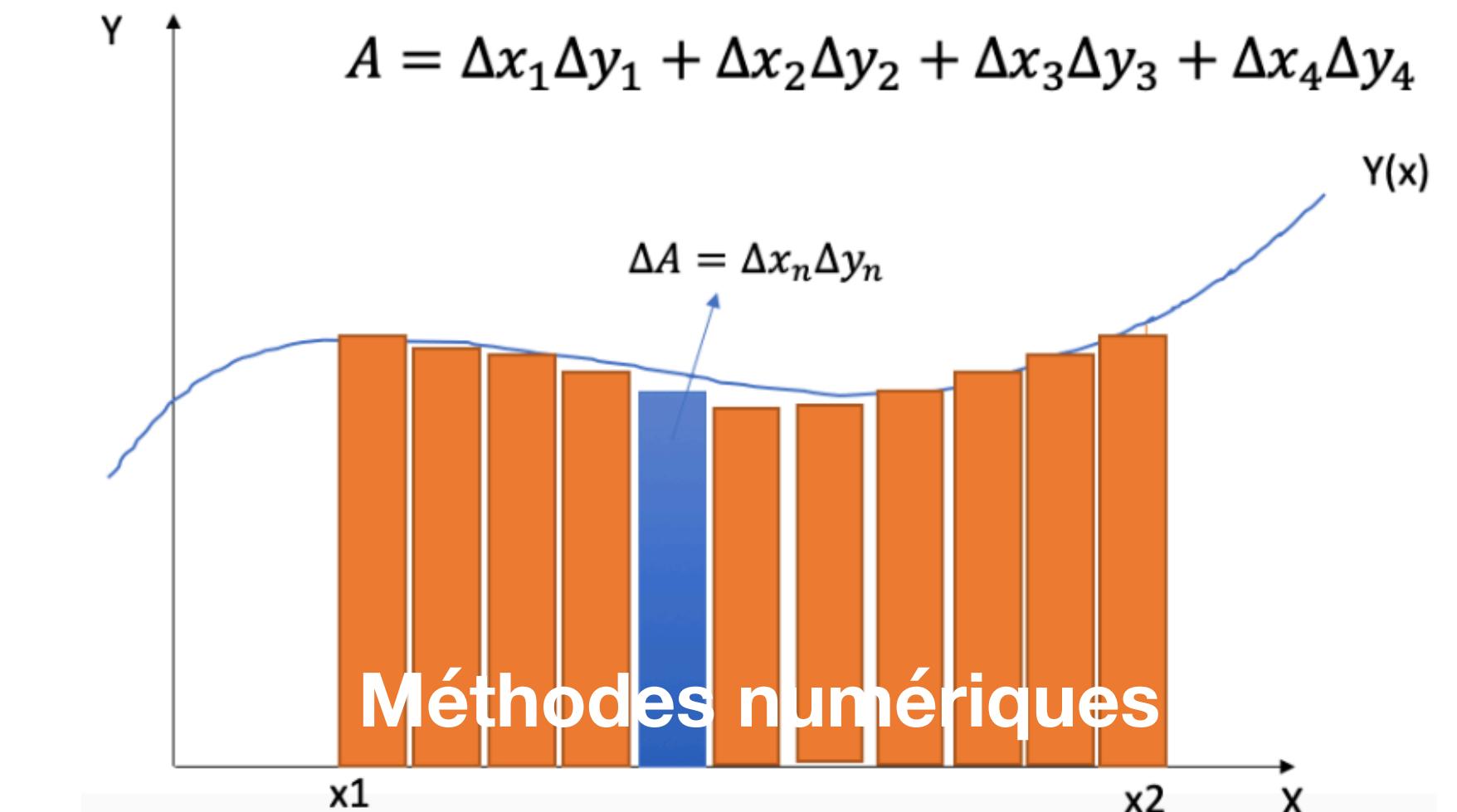
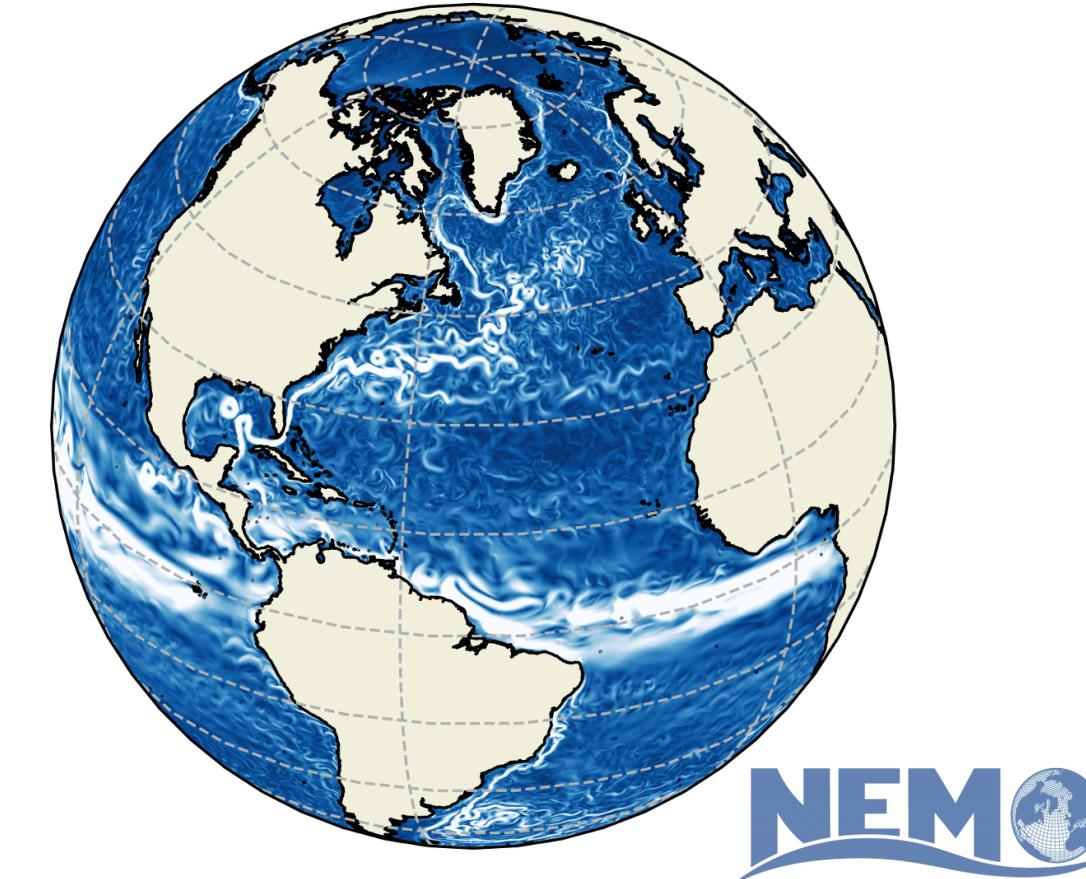
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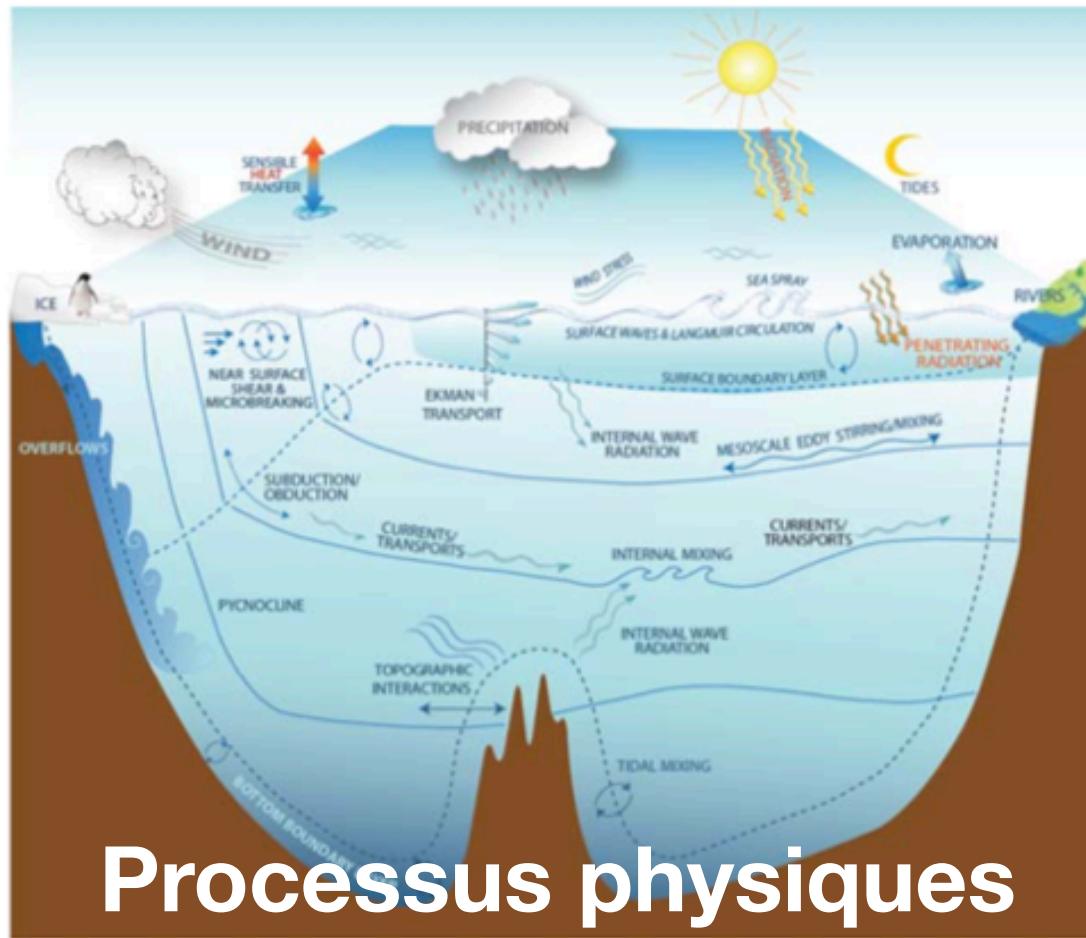
Modèles physiques



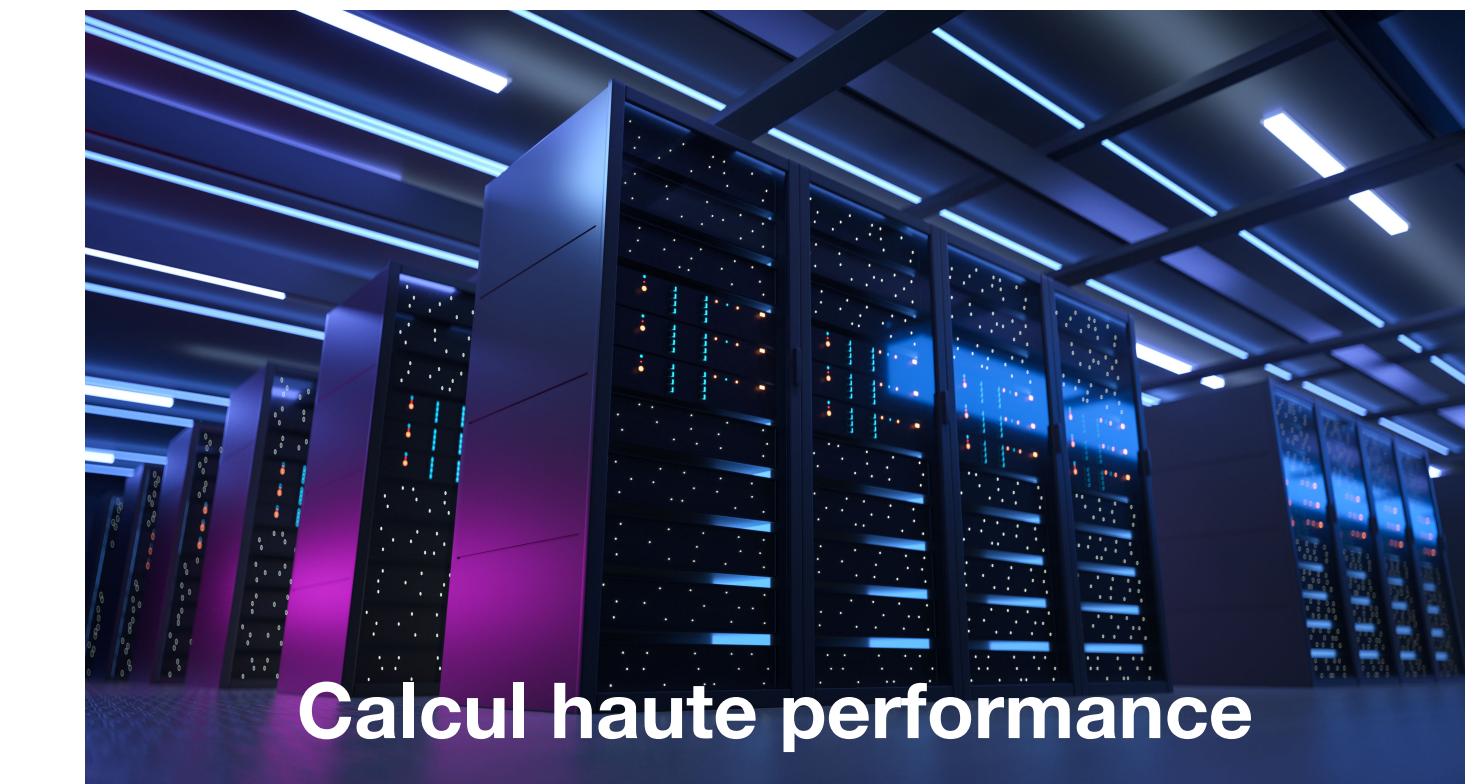
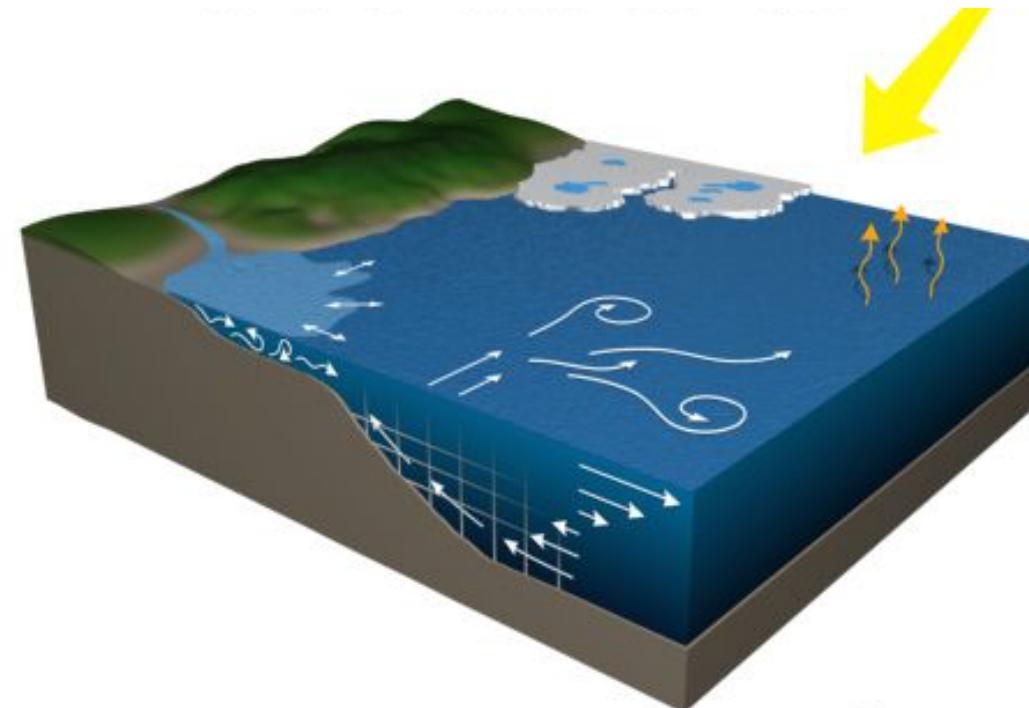
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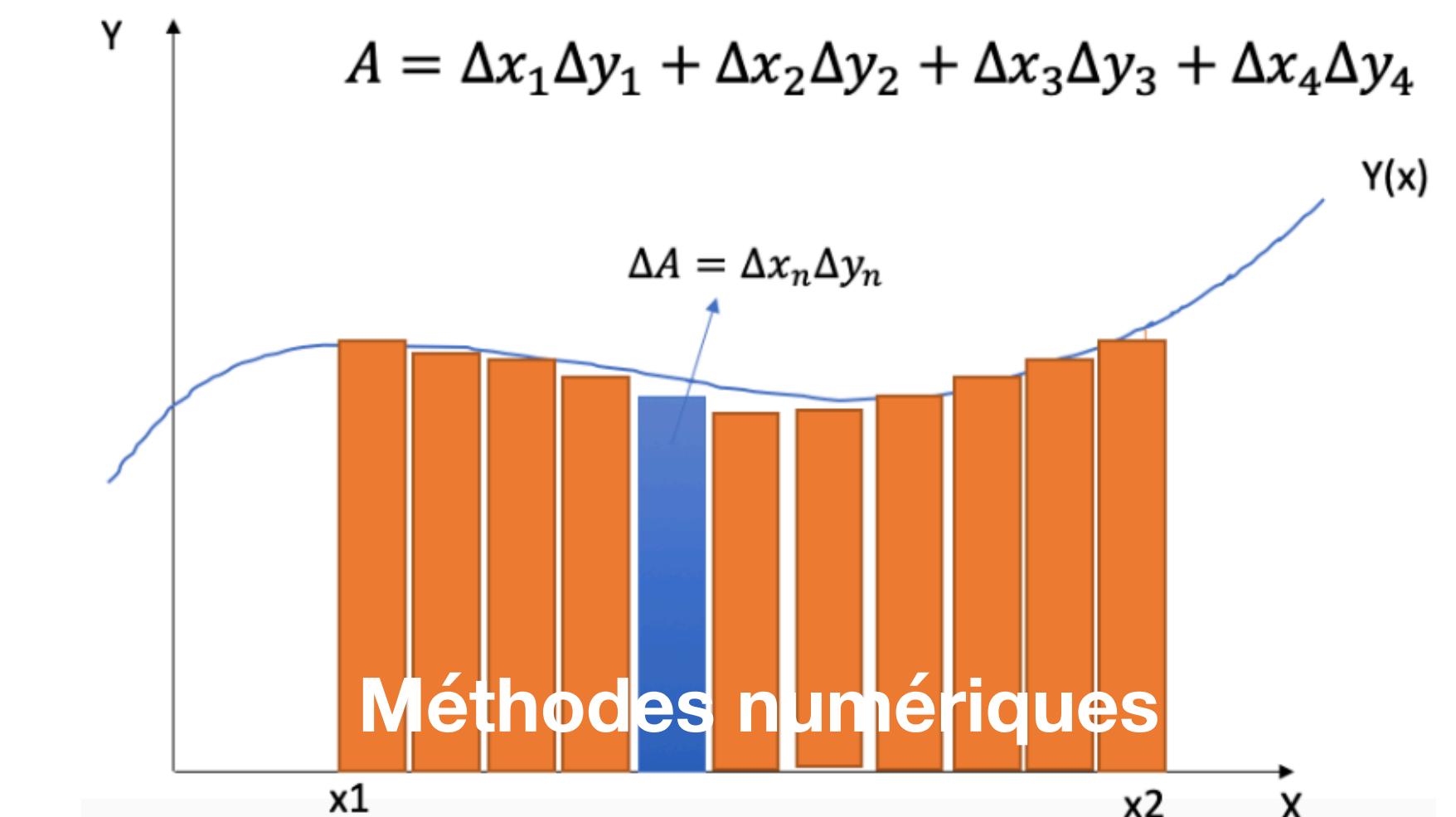
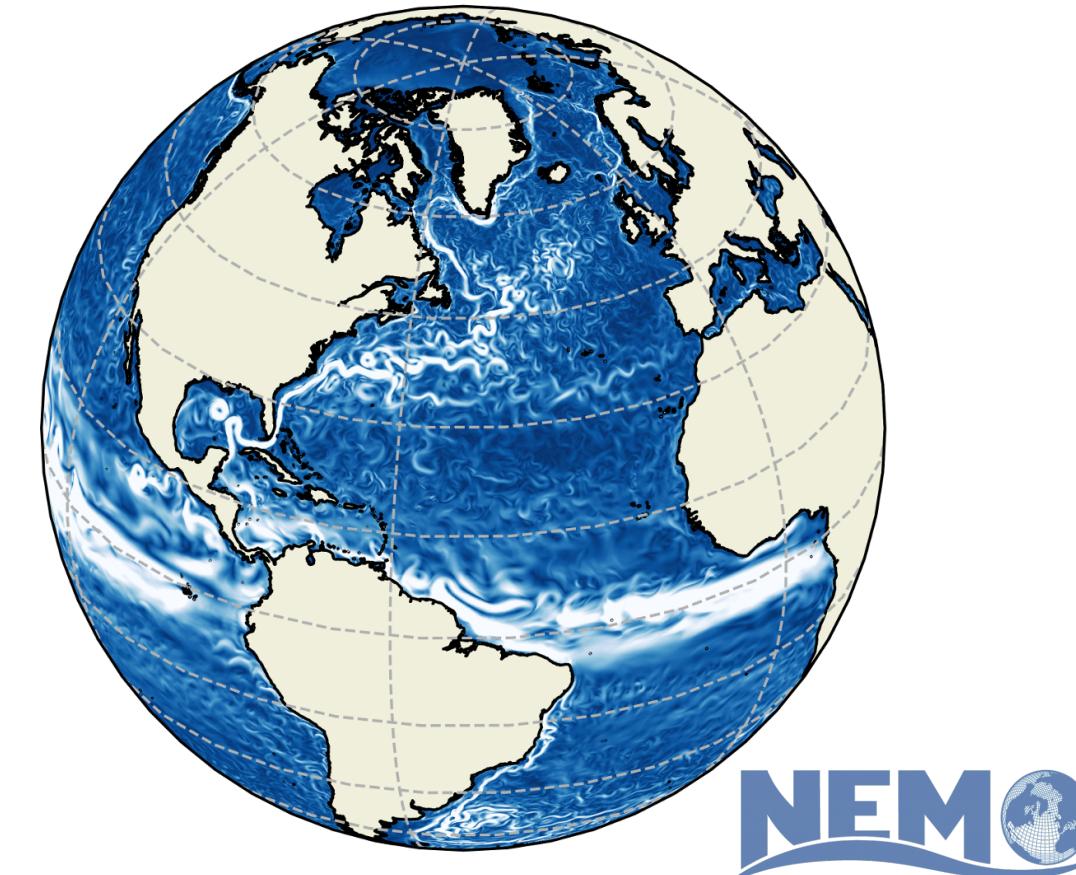
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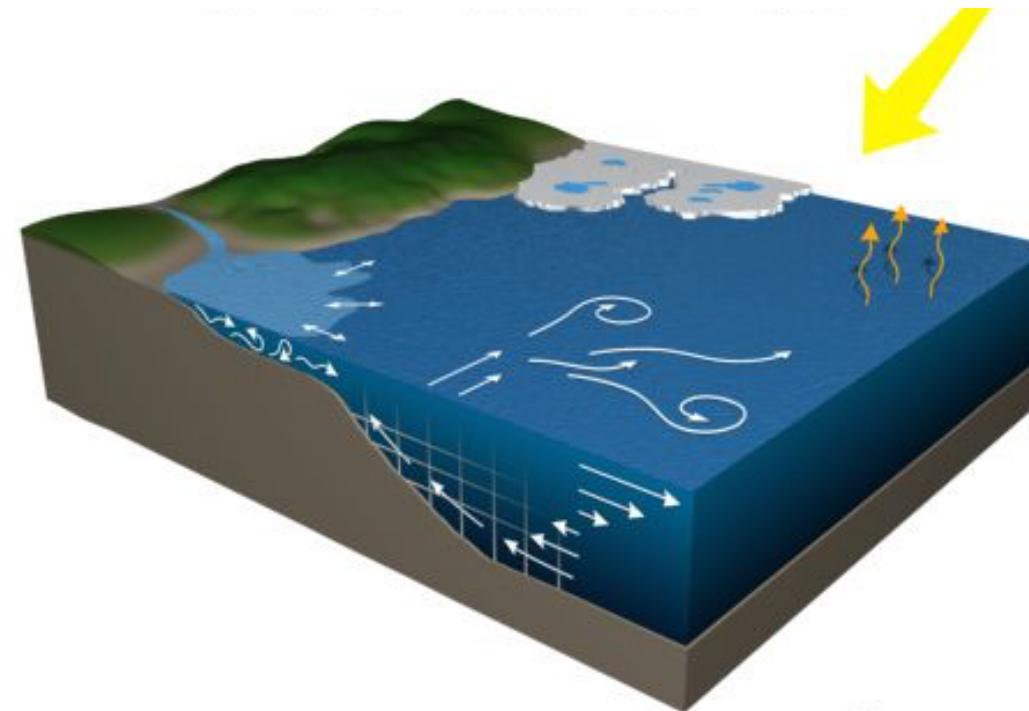
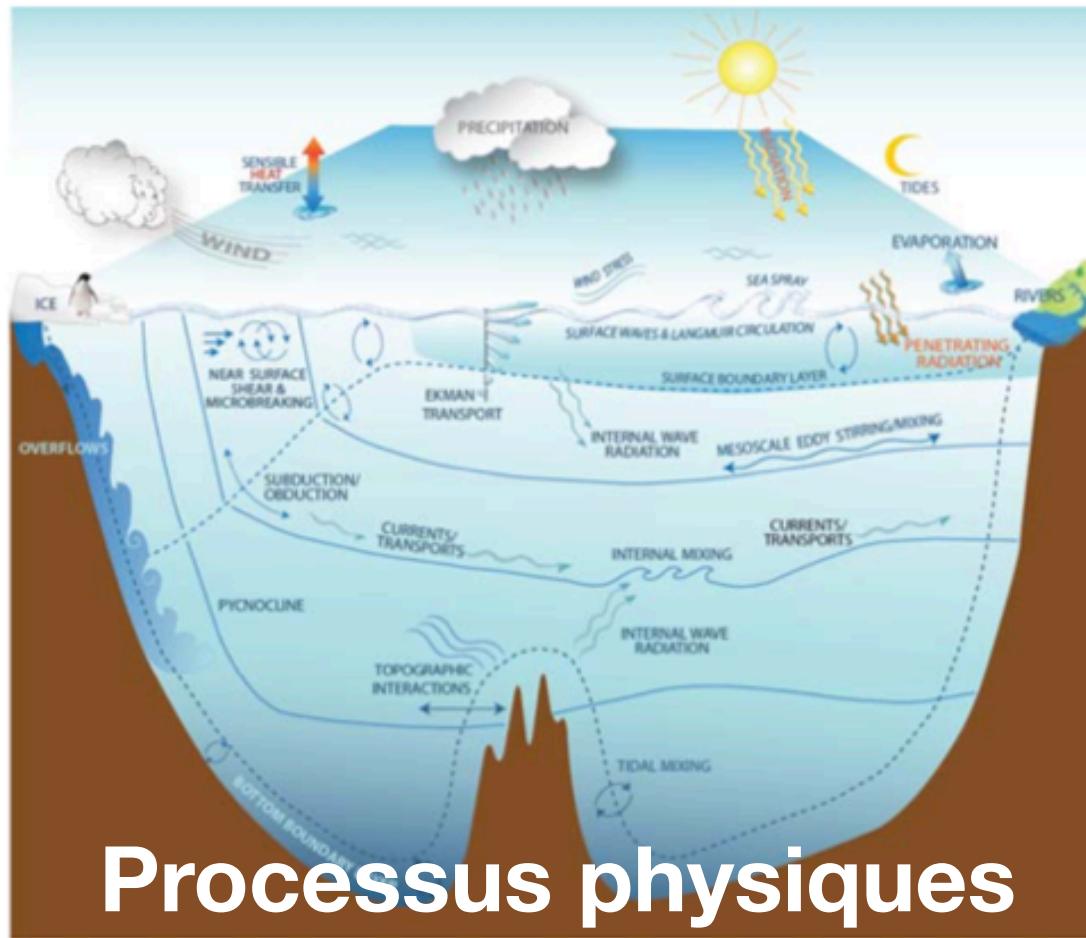
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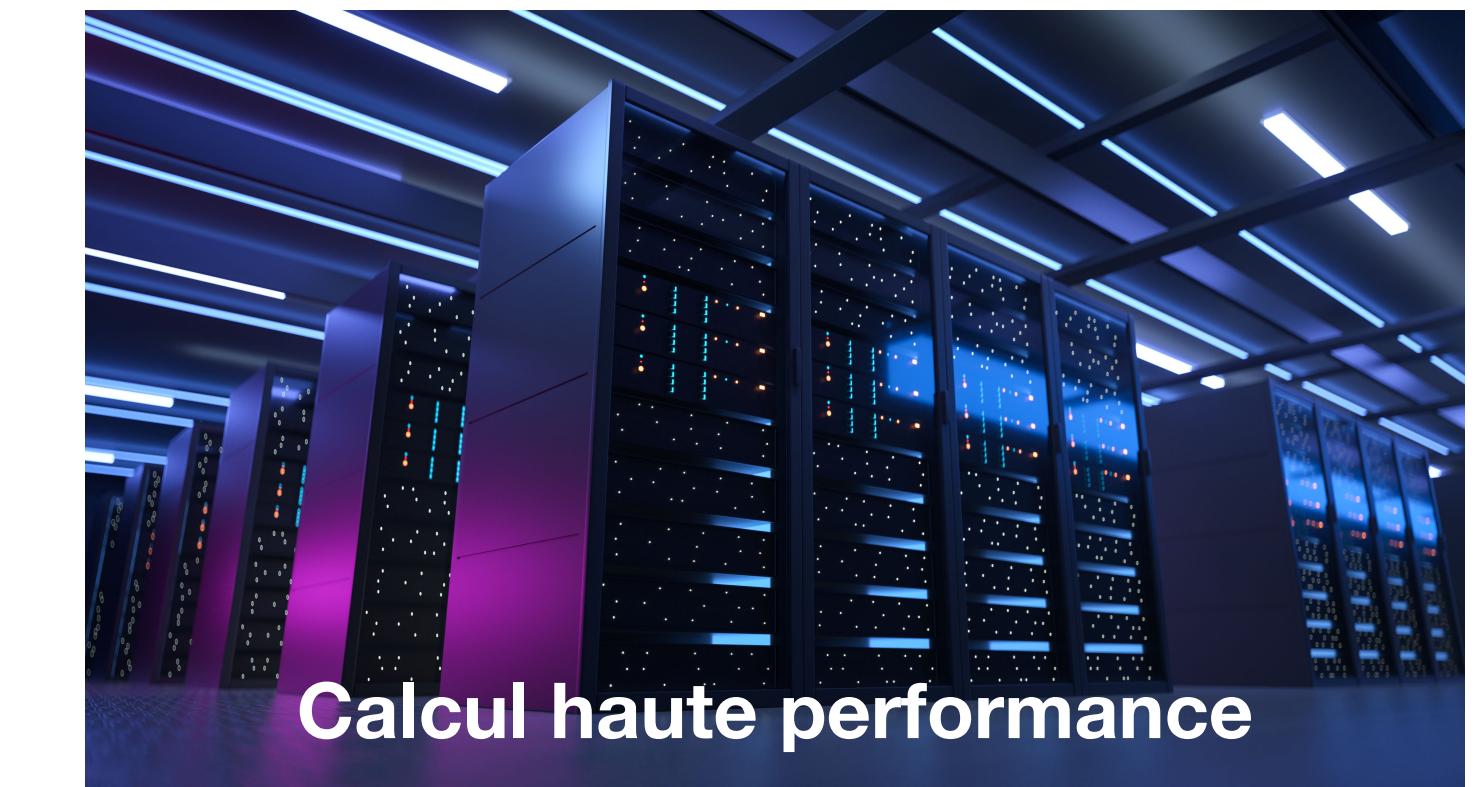
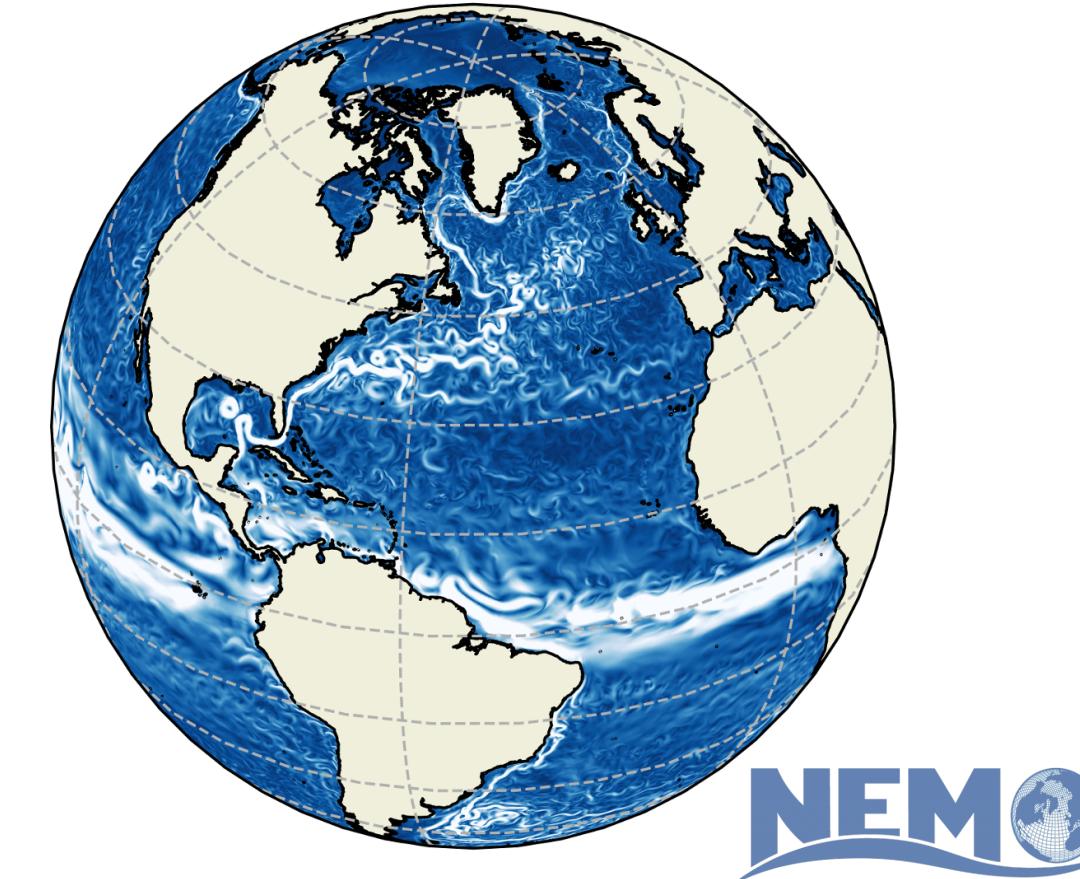


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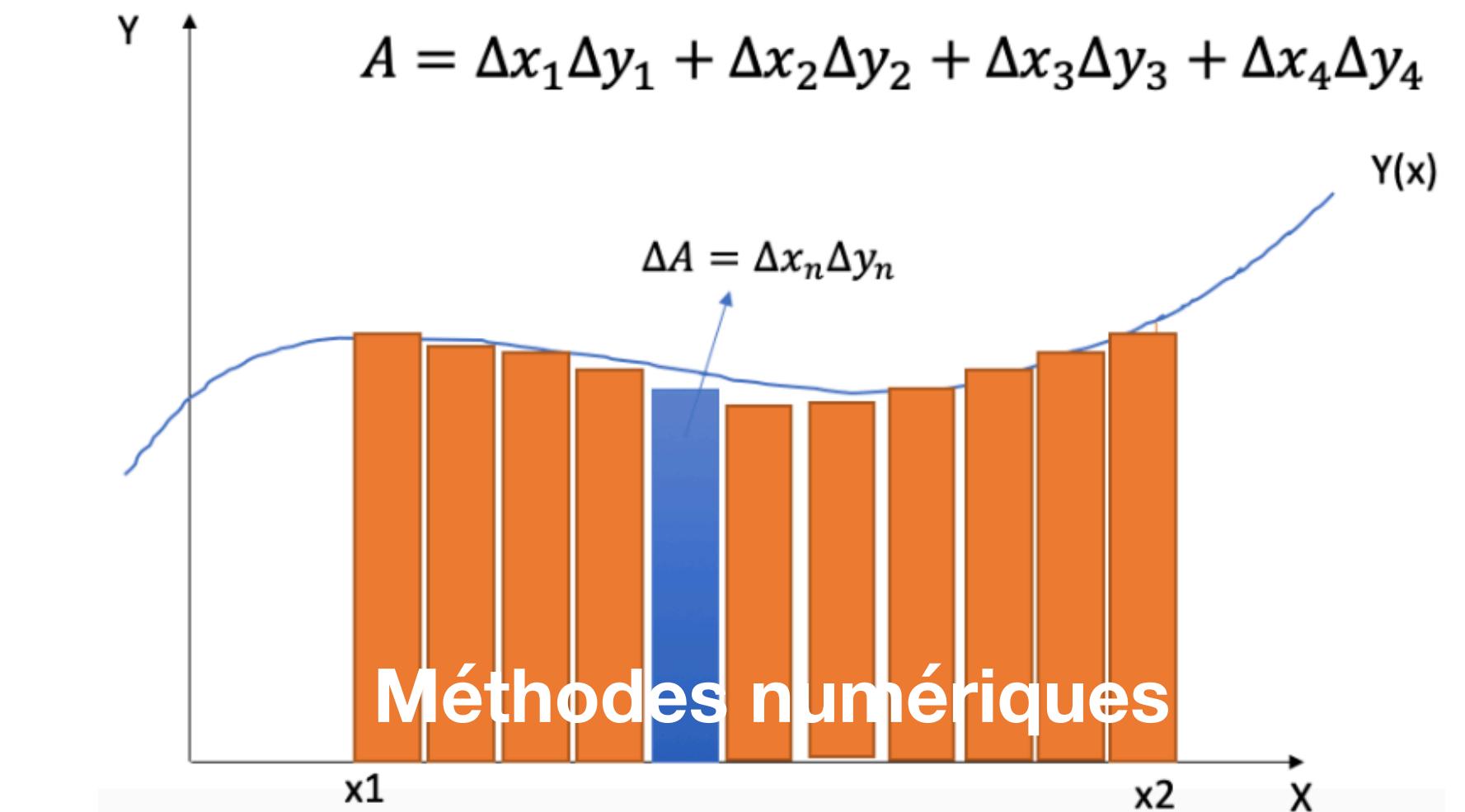


Modèles physiques

Théorie

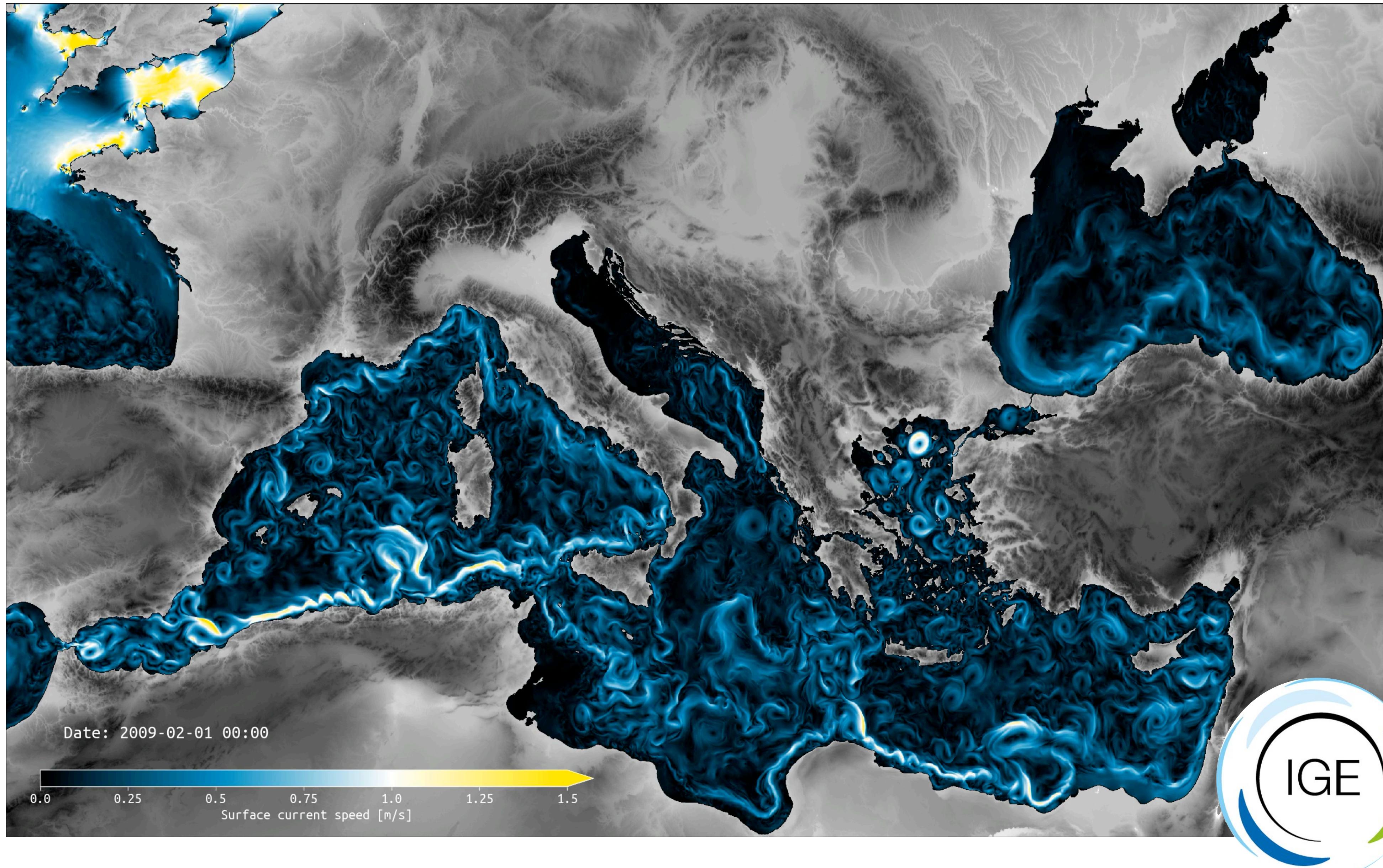


Calcul haute performance

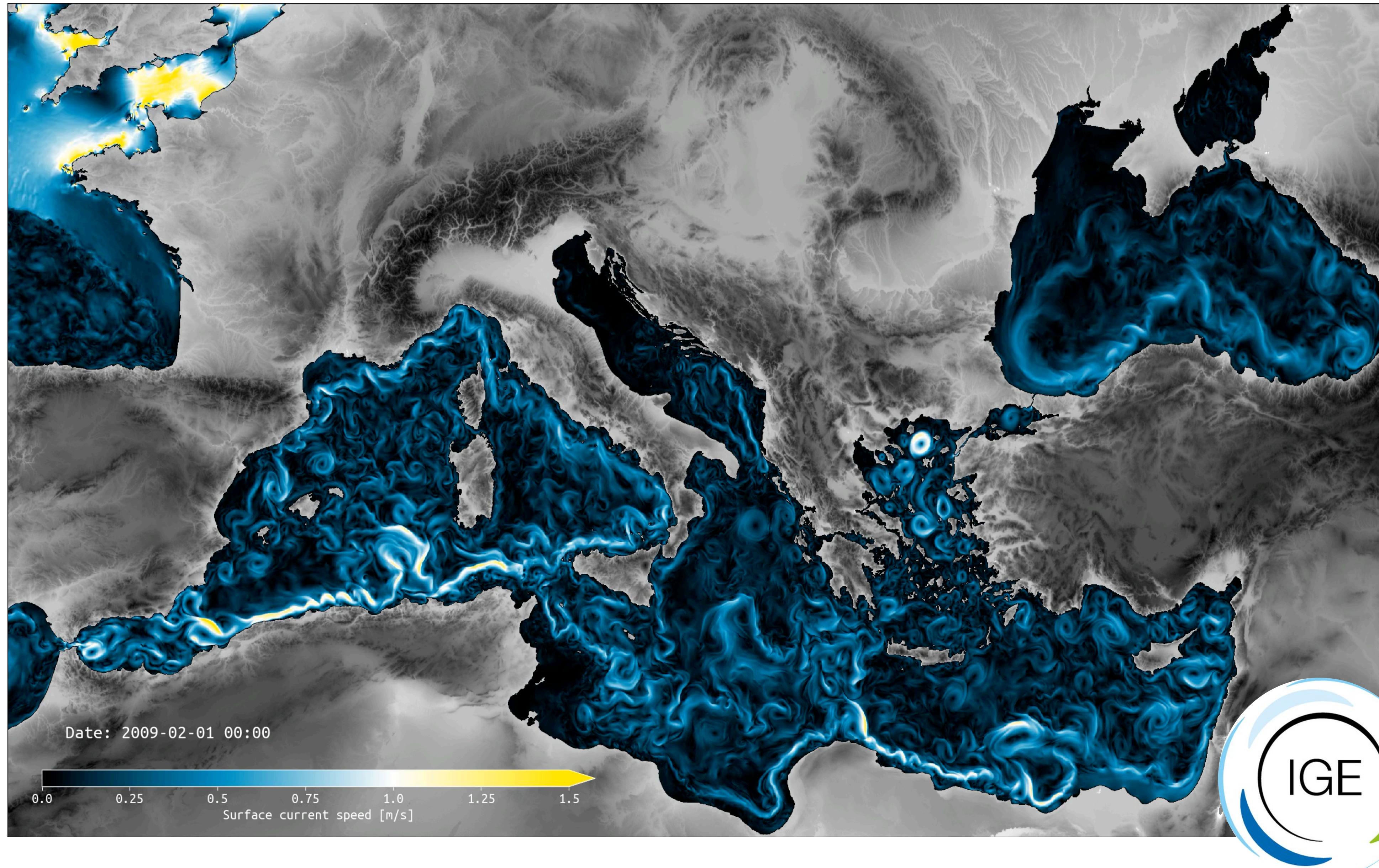


Des outils pour comprendre et prévoir la circulation océanique

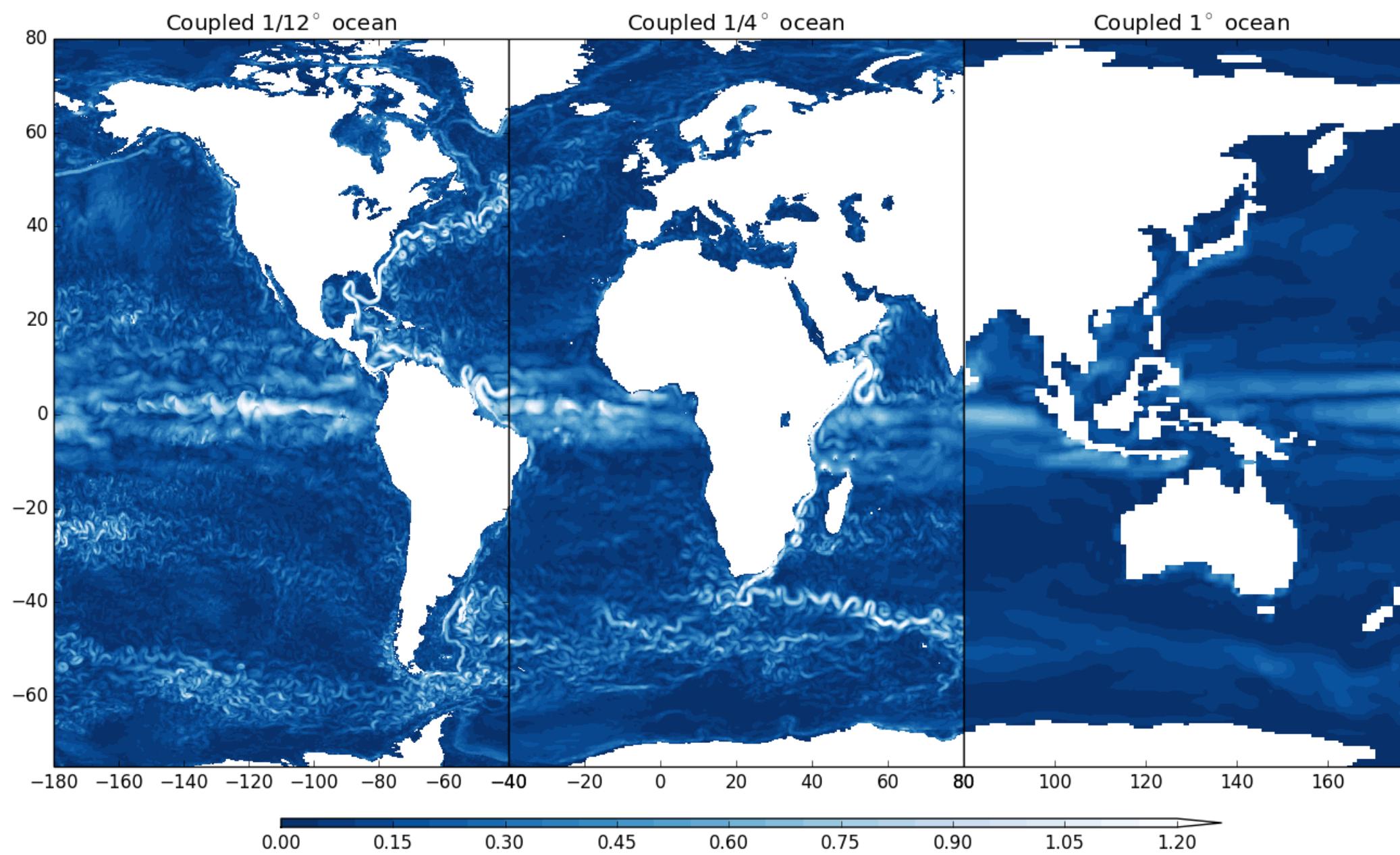
Modèles de circulation océanique



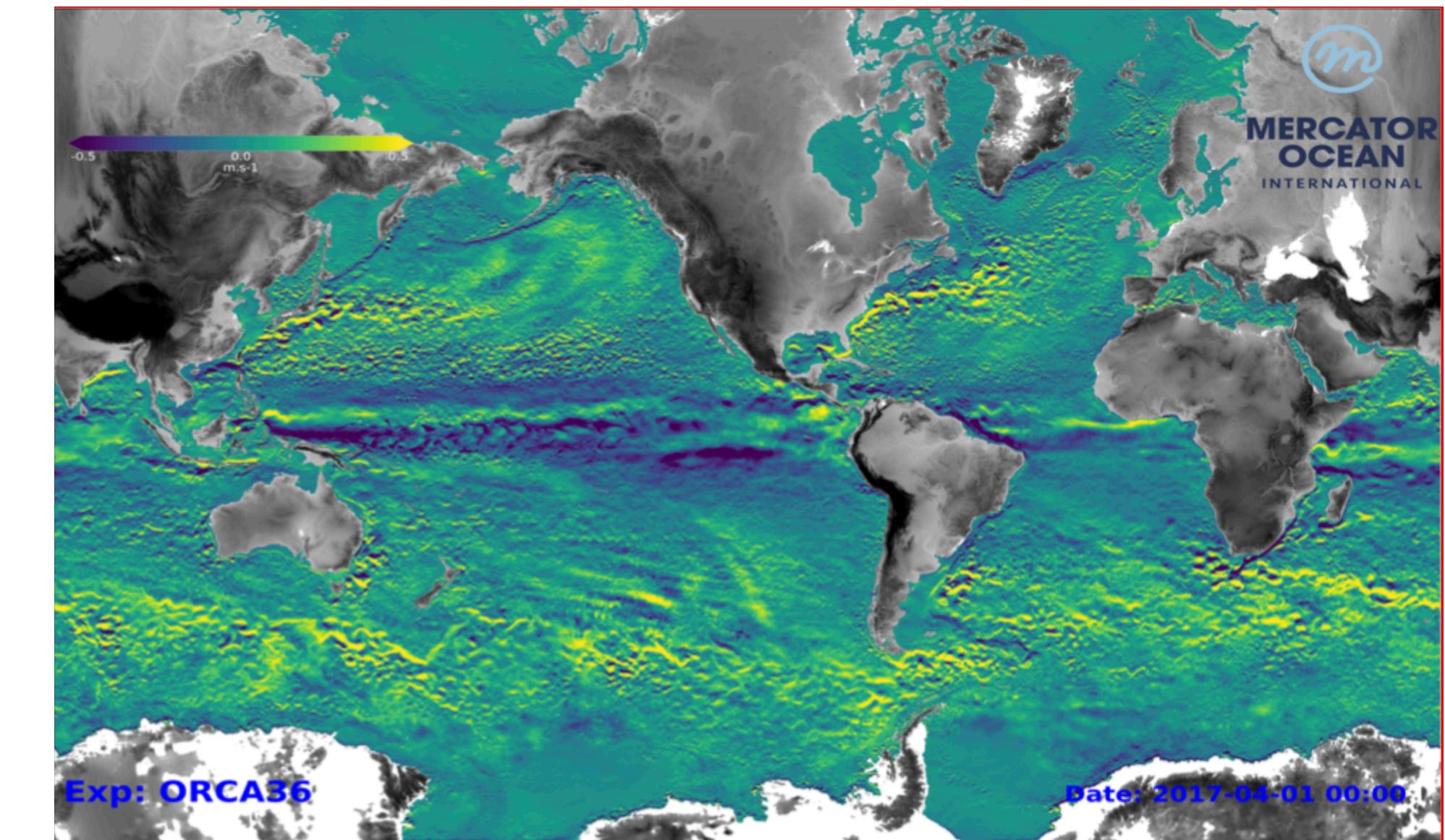
Modèles de circulation océanique



Différents modèles pour différents usages



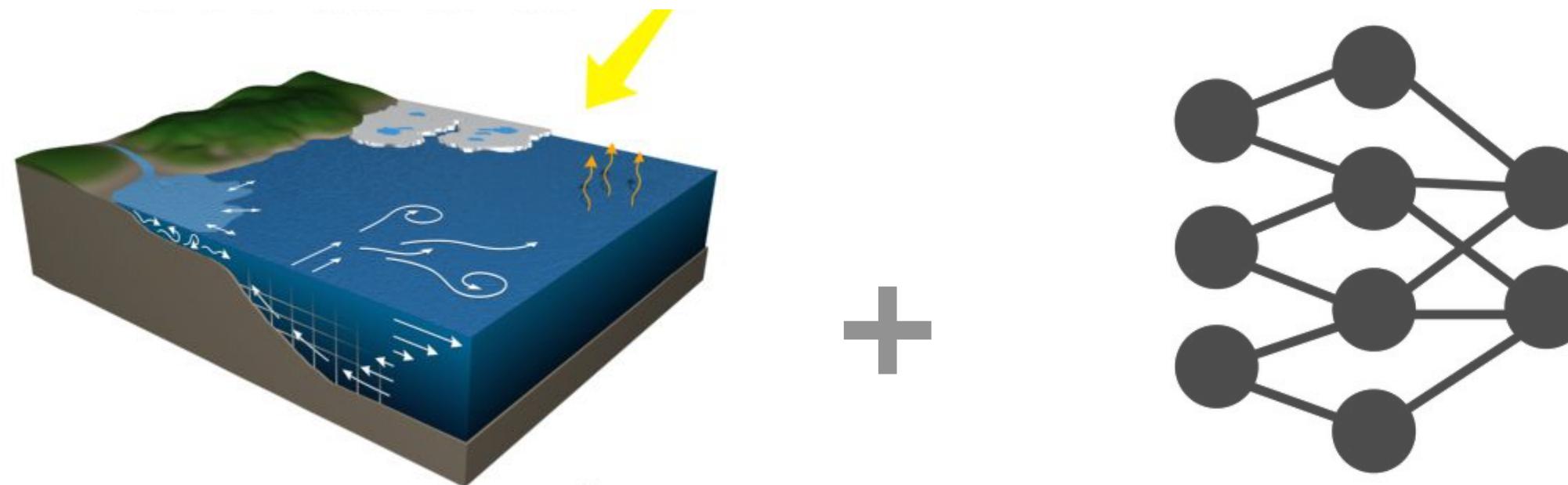
Projections climatiques
(+ couplage atmosphère)
résolution spatiale : $1^\circ \rightarrow 1/4^\circ$



Prévisions opérationnelles
(+assimilation de données)
résolution : $1/12^\circ \rightarrow 1/36^\circ$ (~2-4km)

Différents modèles basés sur les même codes, intégrés à des systèmes

Modèles hybrides et émulateurs IA

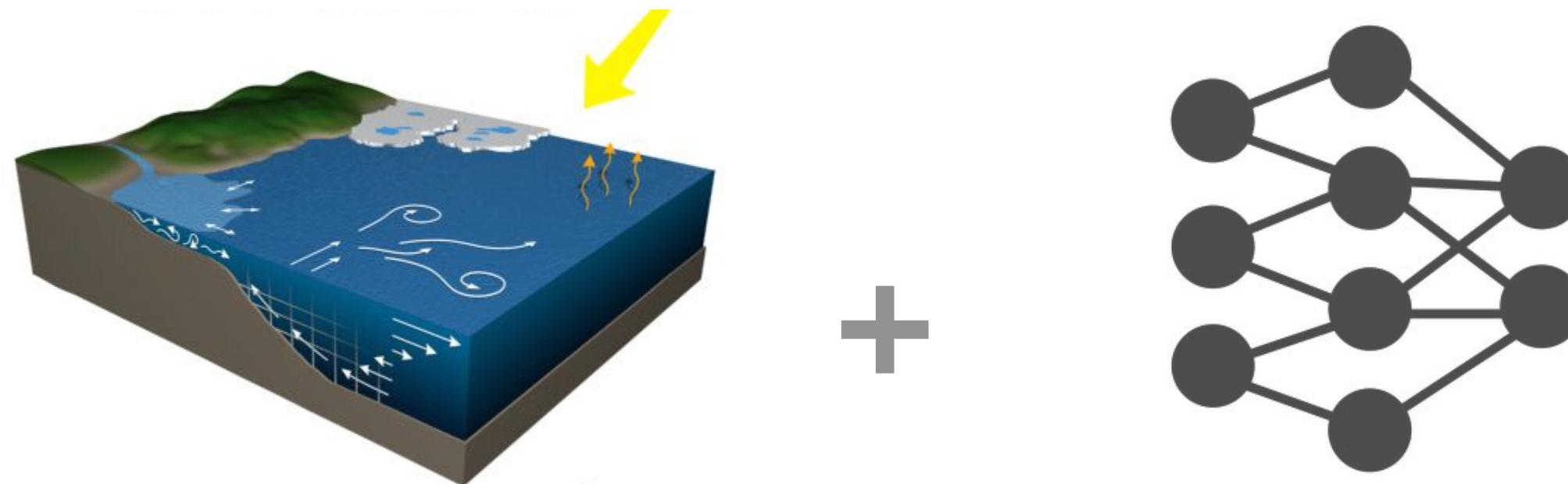


Voir par ex. Zanna et al. 2025

Modèles hybrides
combinant IA et physique

entraîné à partir de simulations LES
ou d'observations

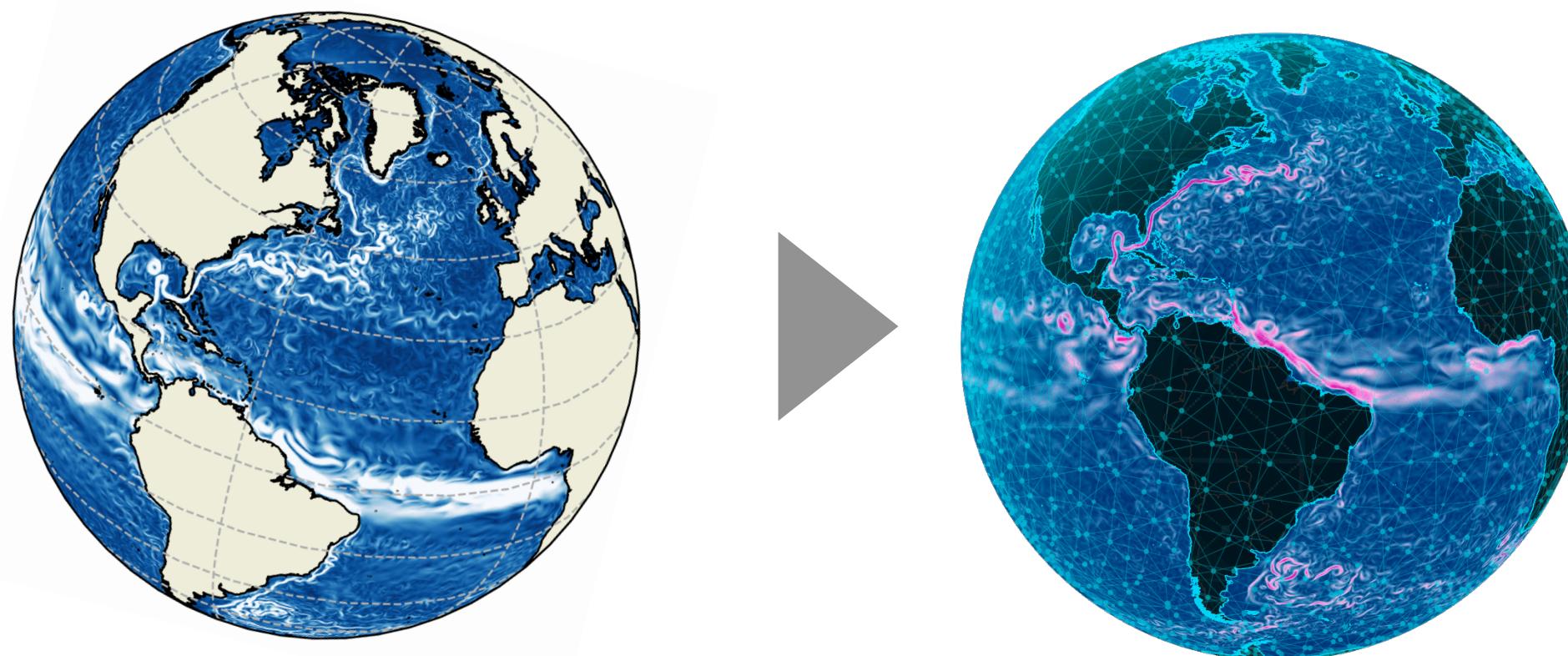
Modèles hybrides et émulateurs IA



Voir par ex. Zanna et al. 2025

Modèles hybrides
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entraîné à partir de simulations LES
ou d'observations



Voir par ex. El Aouni et al. 2025

<https://glonet.lab.dive.edito.eu/>

Émulateurs neuronaux
remplacent le modèle entier

entraîné à partir de modèles, de réanalyses
ou d'observations

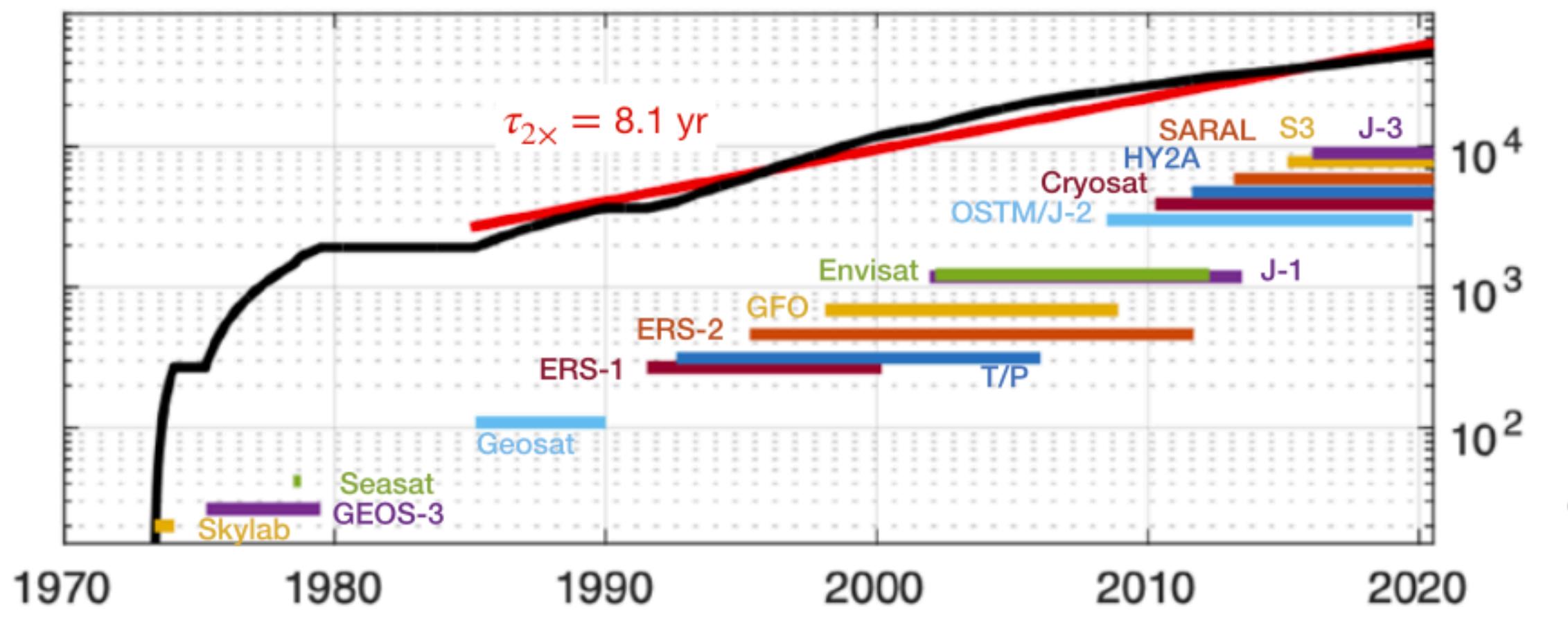
3.

Synergies modèles / observations

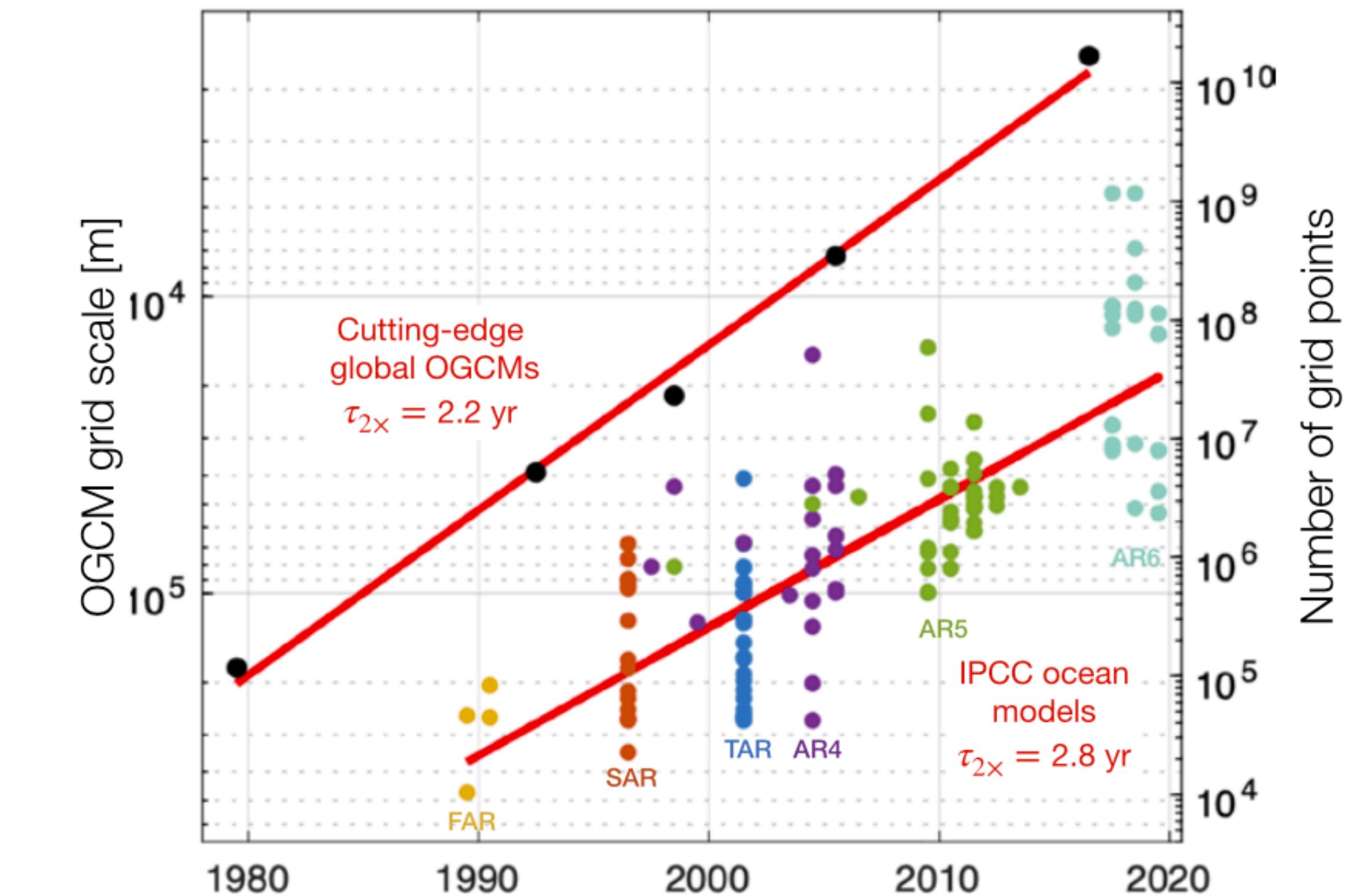
Co-évolution entre altimétrie et modèles depuis 1980

Haines et al. 2021

<https://doi.org/10.1175/BAMS-D-20-0258.1>



Cum. observing days

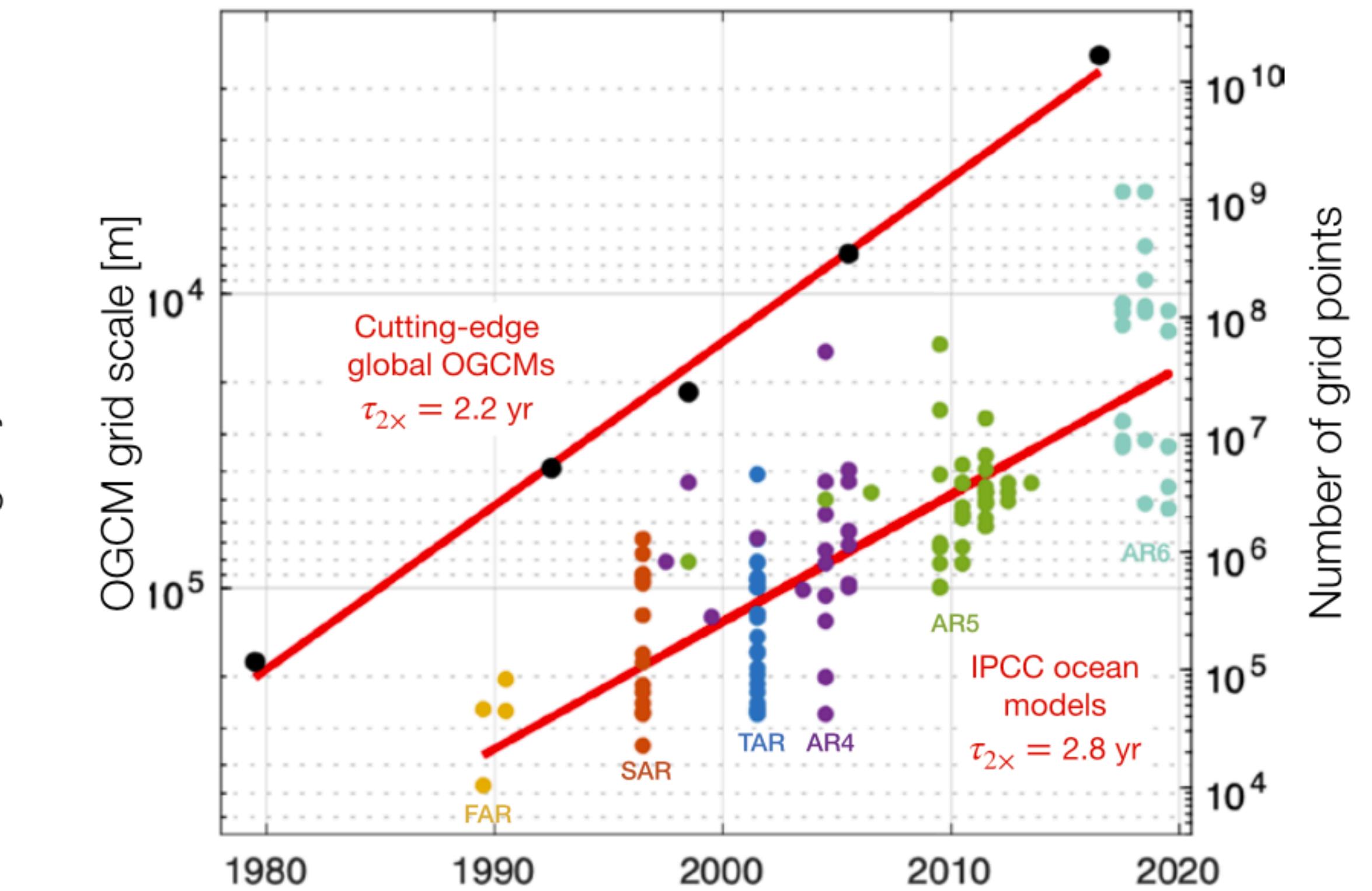
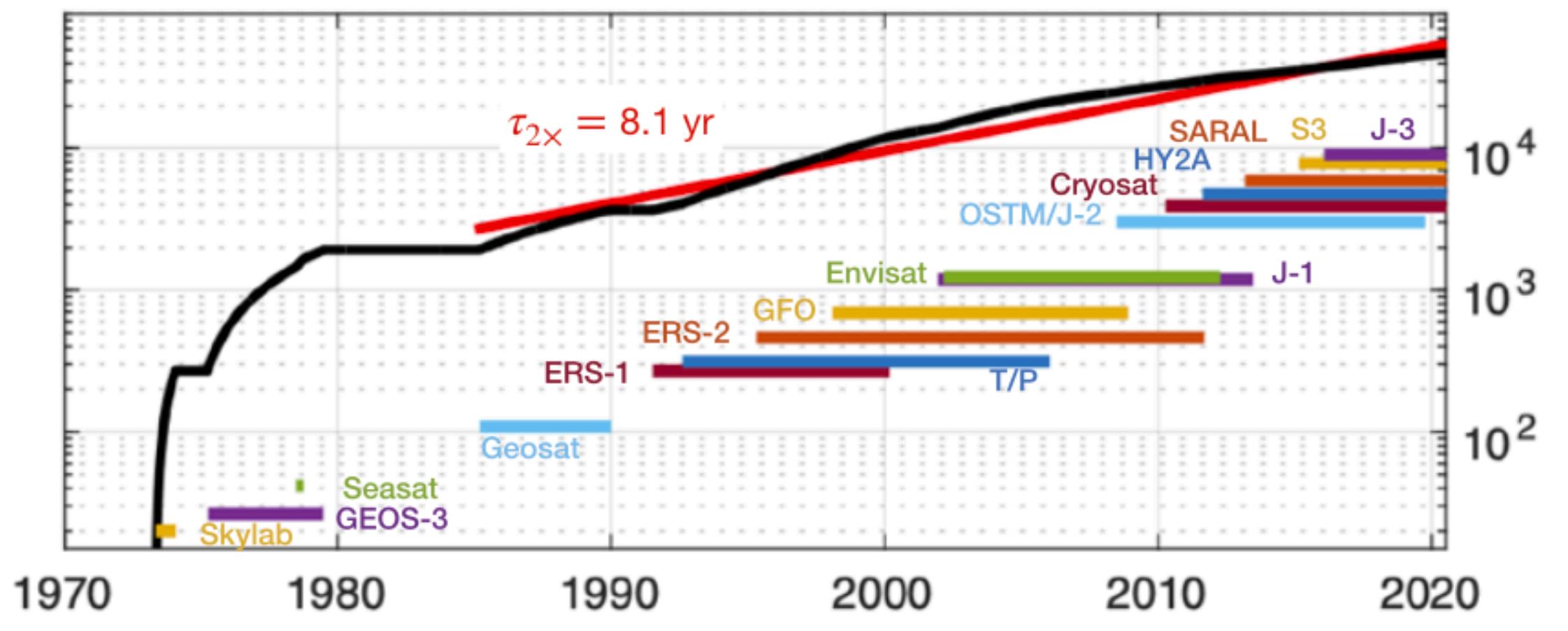


Number of grid points

Co-évolution entre altimétrie et modèles depuis 1980

Haines et al. 2021

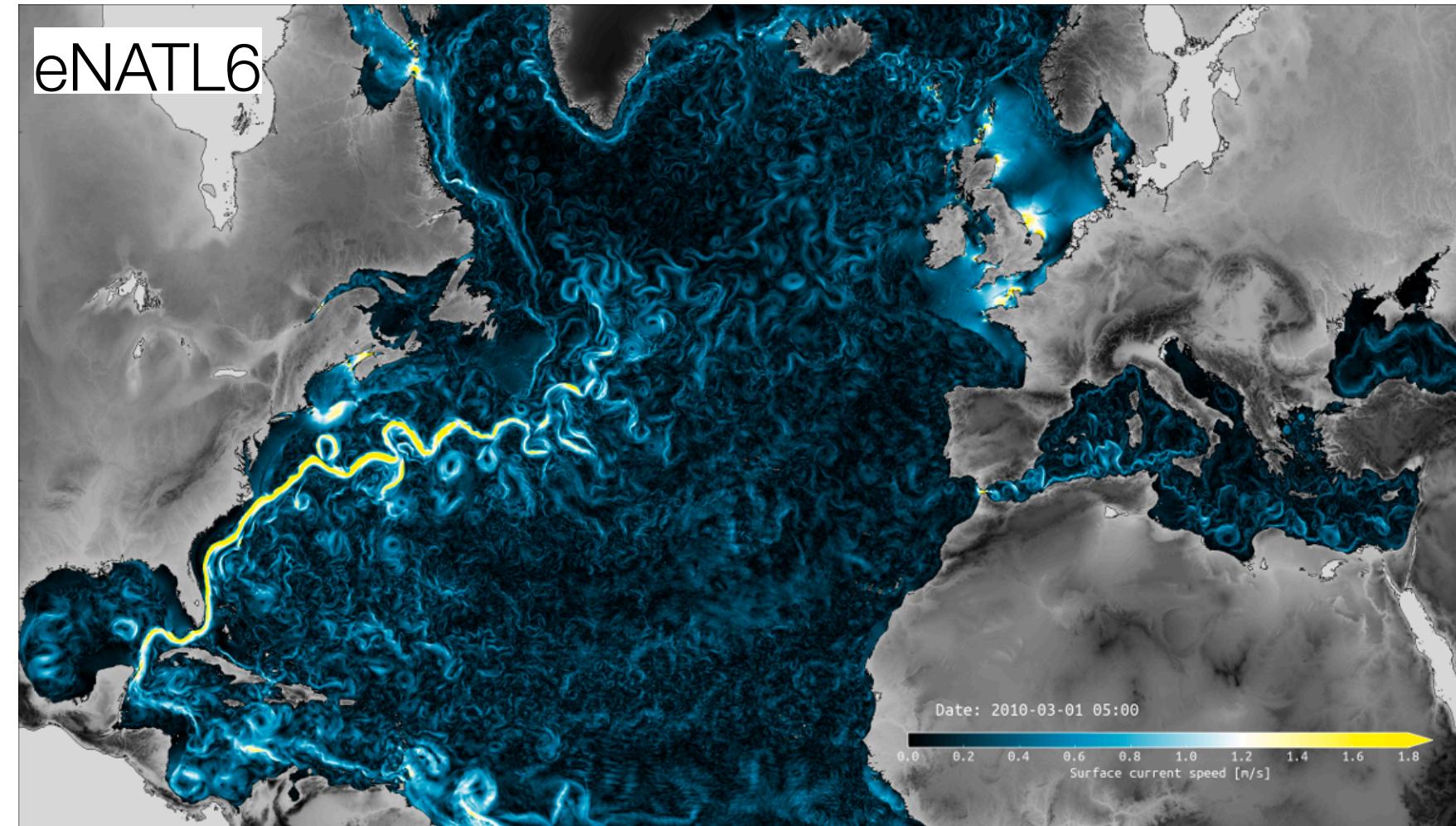
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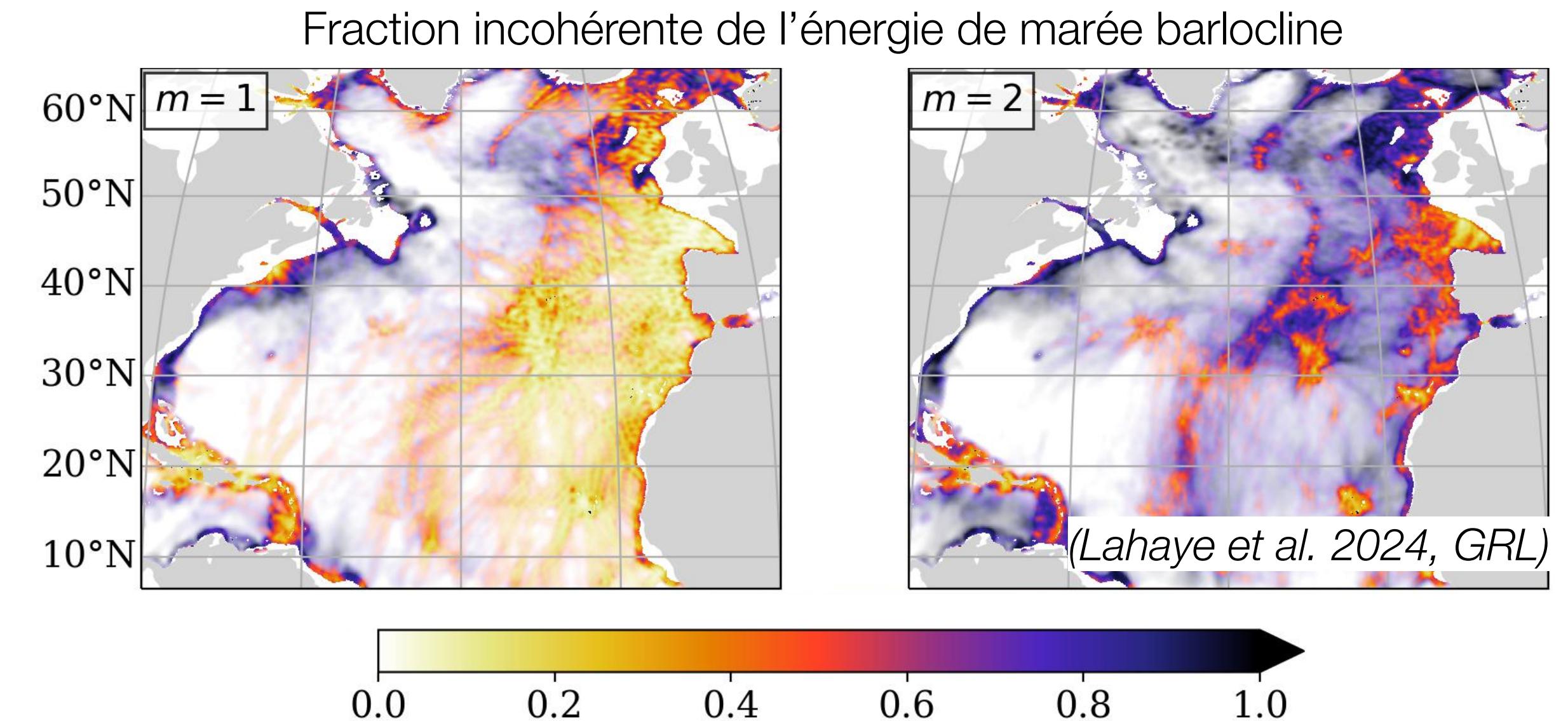
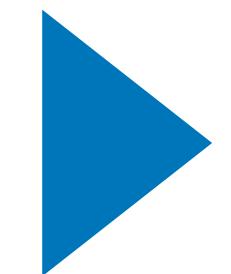
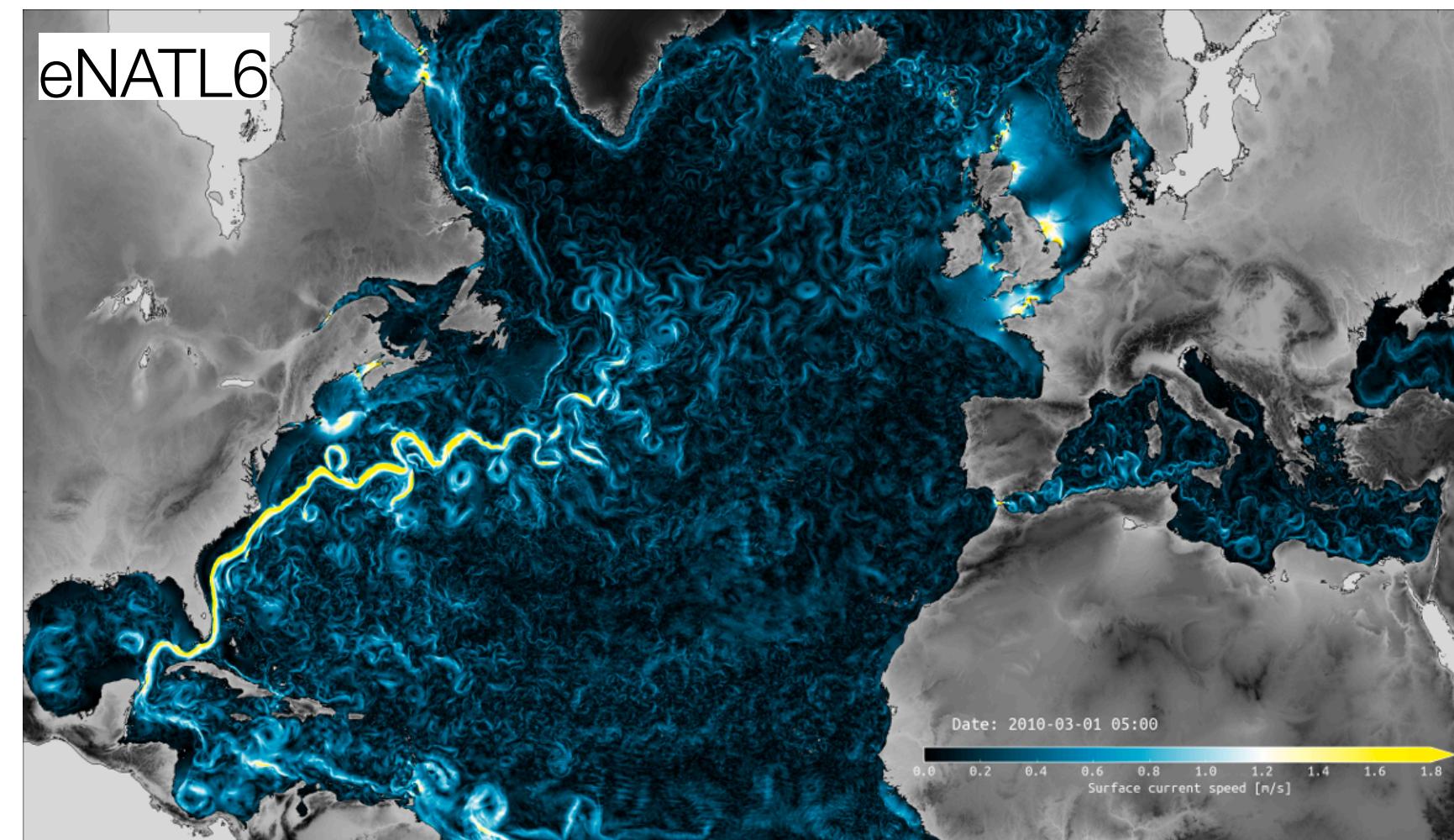
capacité à observer \leftrightarrow capacité à modéliser

mesoéchelle entre 1990-2010, vers la submesoéchelle depuis

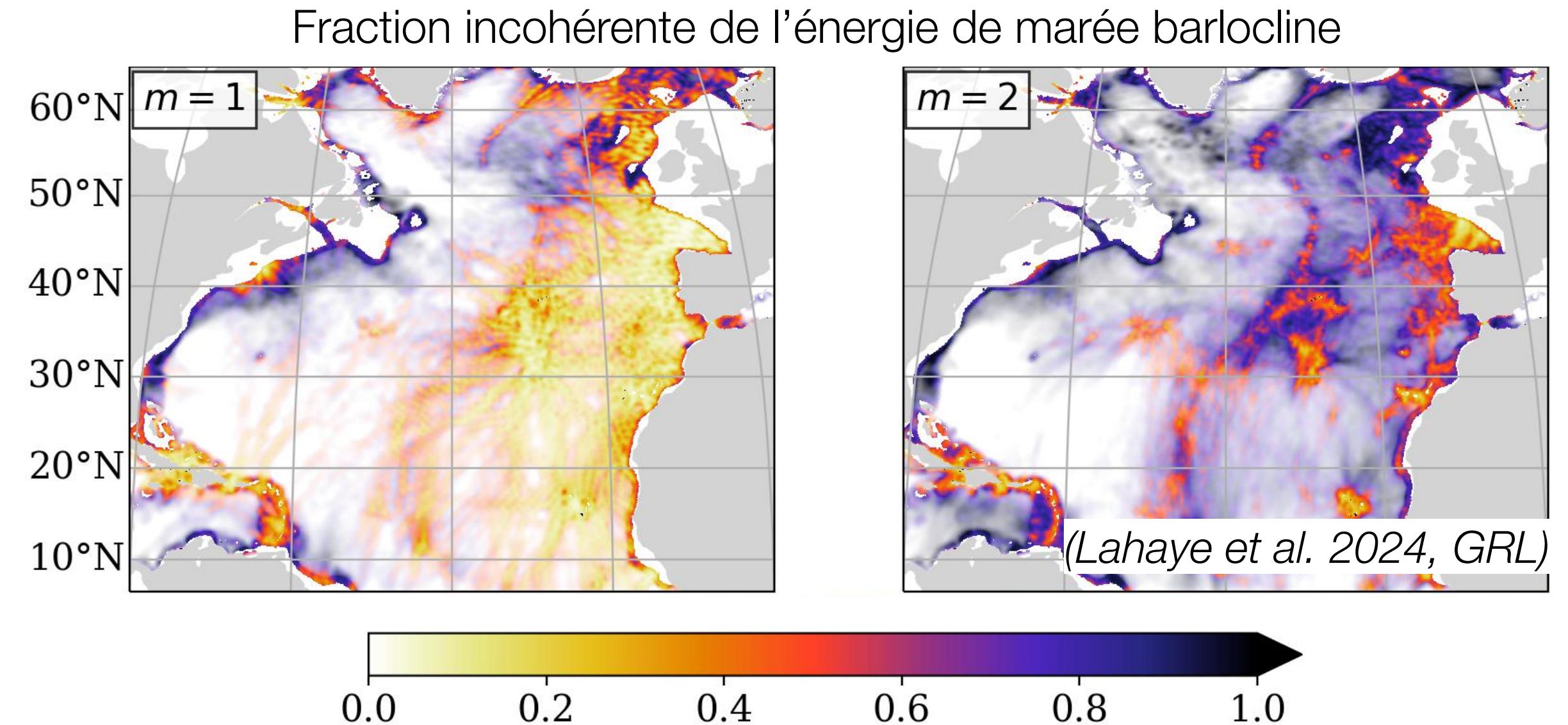
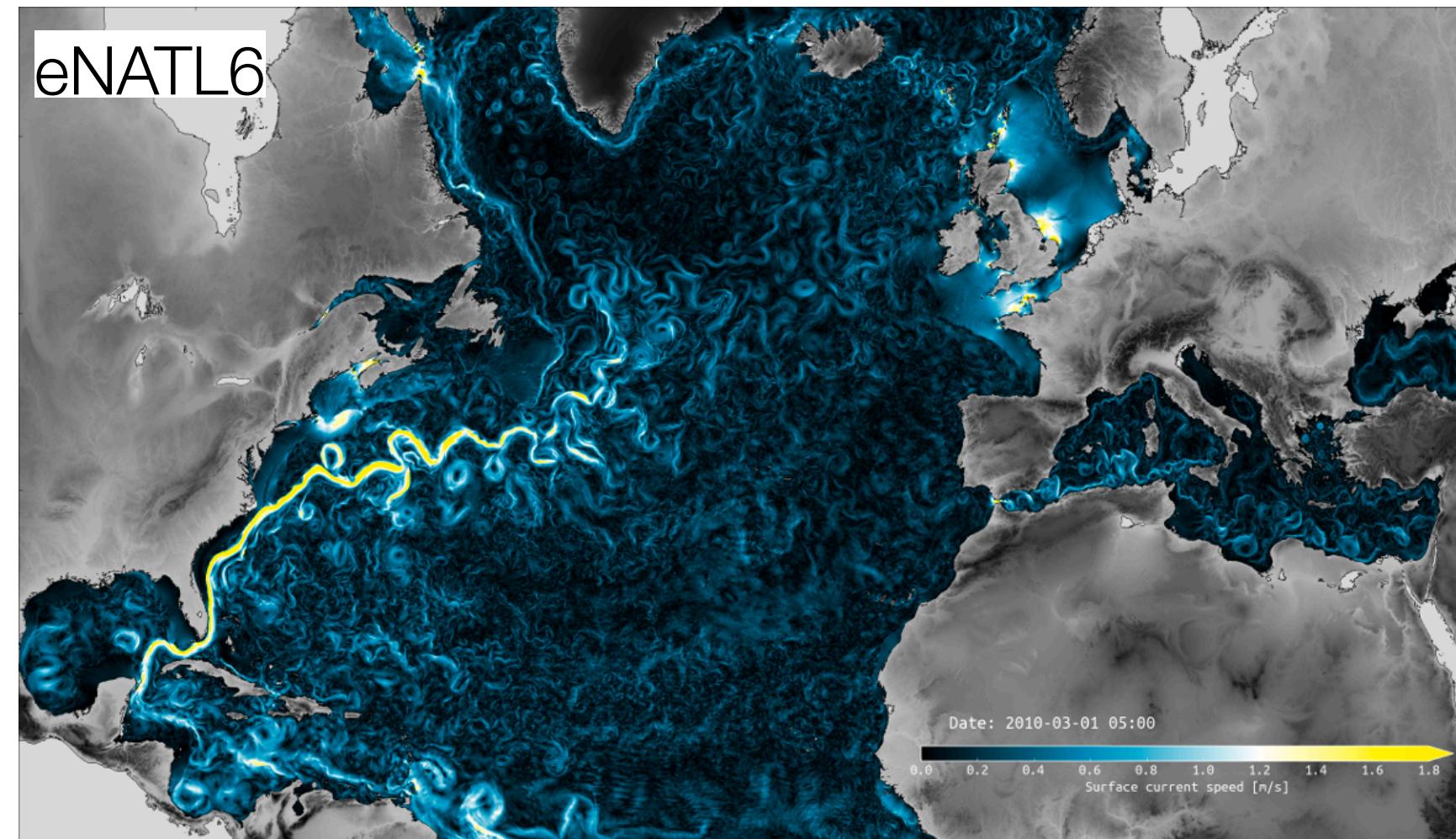
Ce que les modèles ont apporté à la mission SWOT



Ce que les modèles ont apporté à la mission SWOT

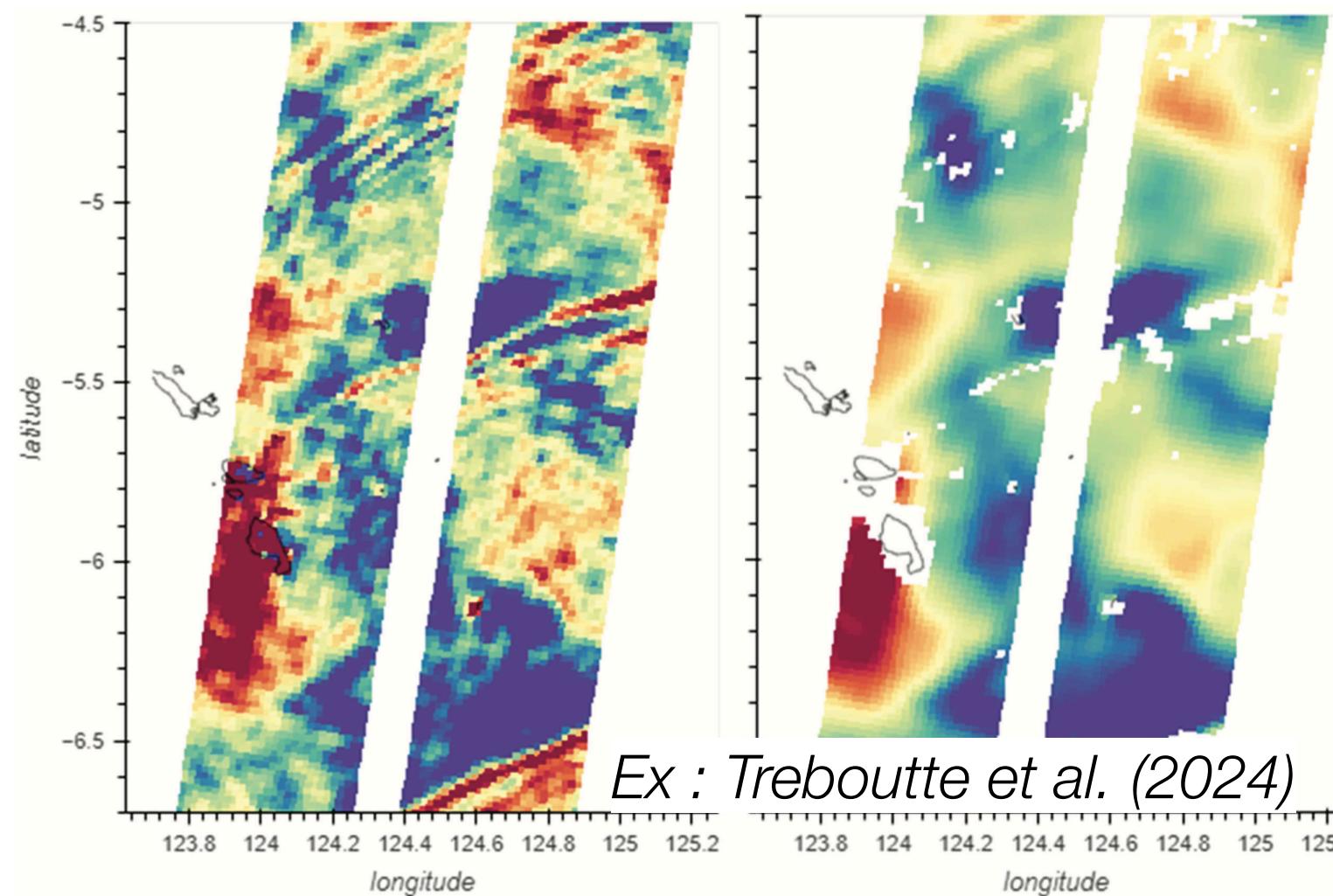
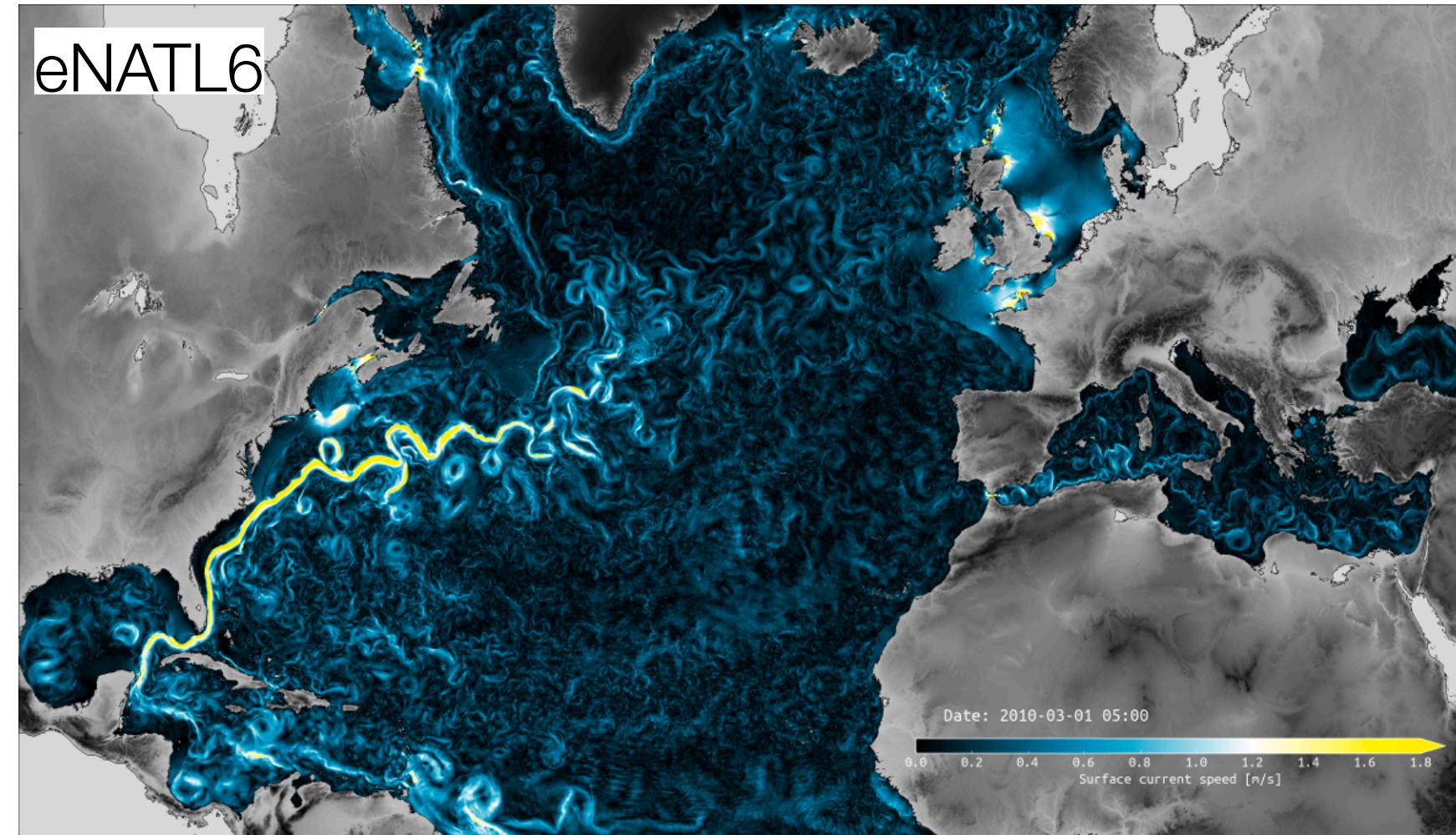


Ce que les modèles ont apporté à la mission SWOT



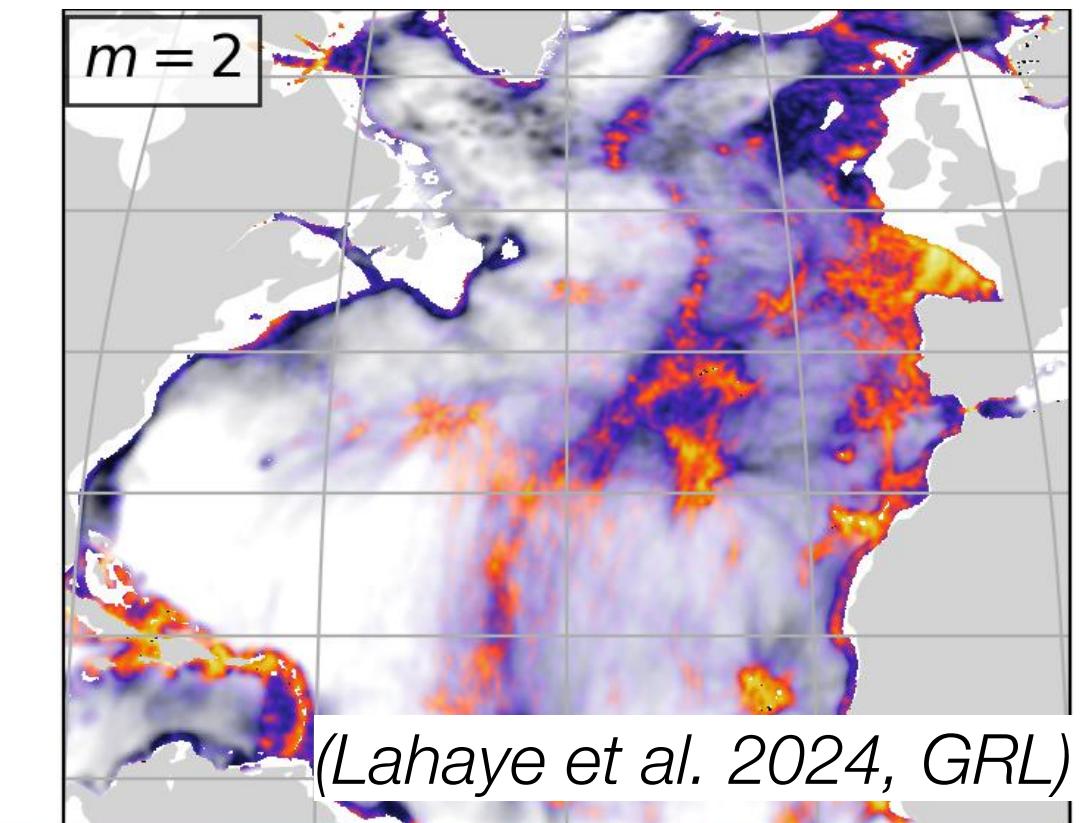
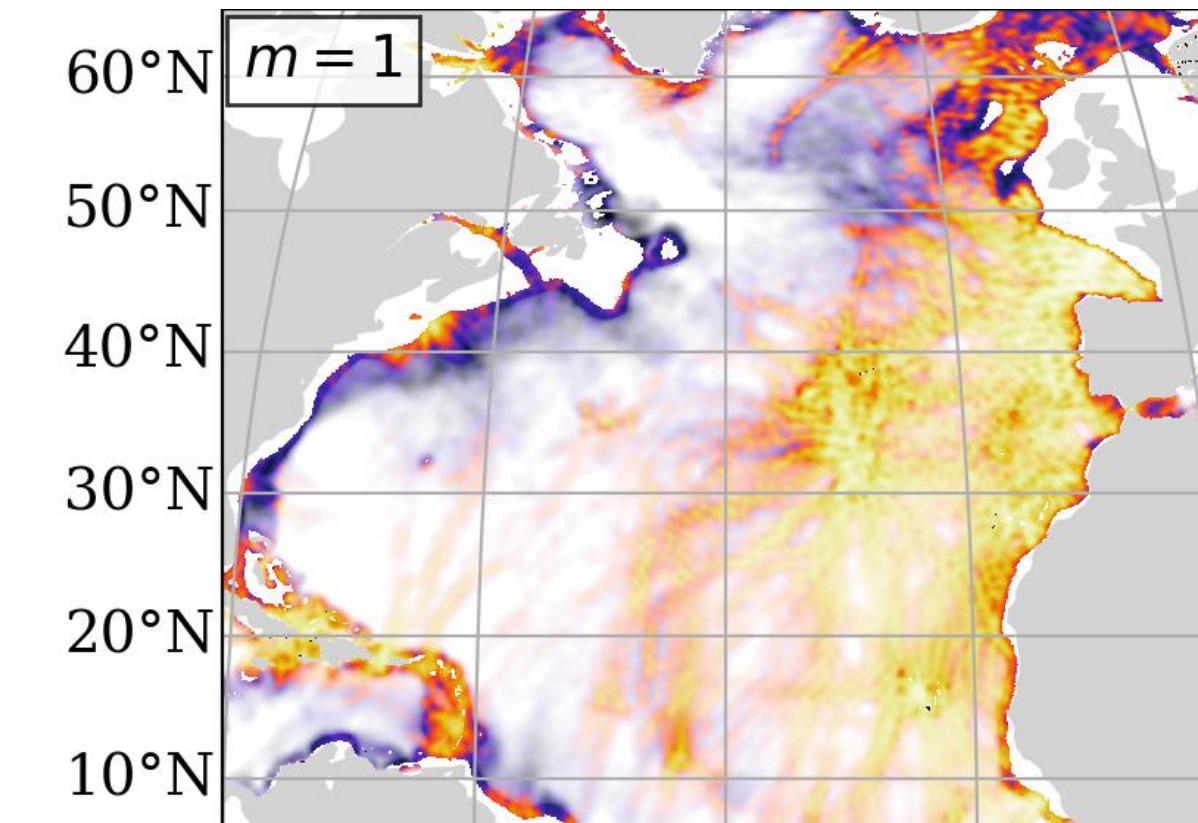
Préparer les
algorithmes et
les produits
de données

Ce que les modèles ont apporté à la mission SWOT



débruitage L3

Fraction incohérente de l'énergie de marée barlocline

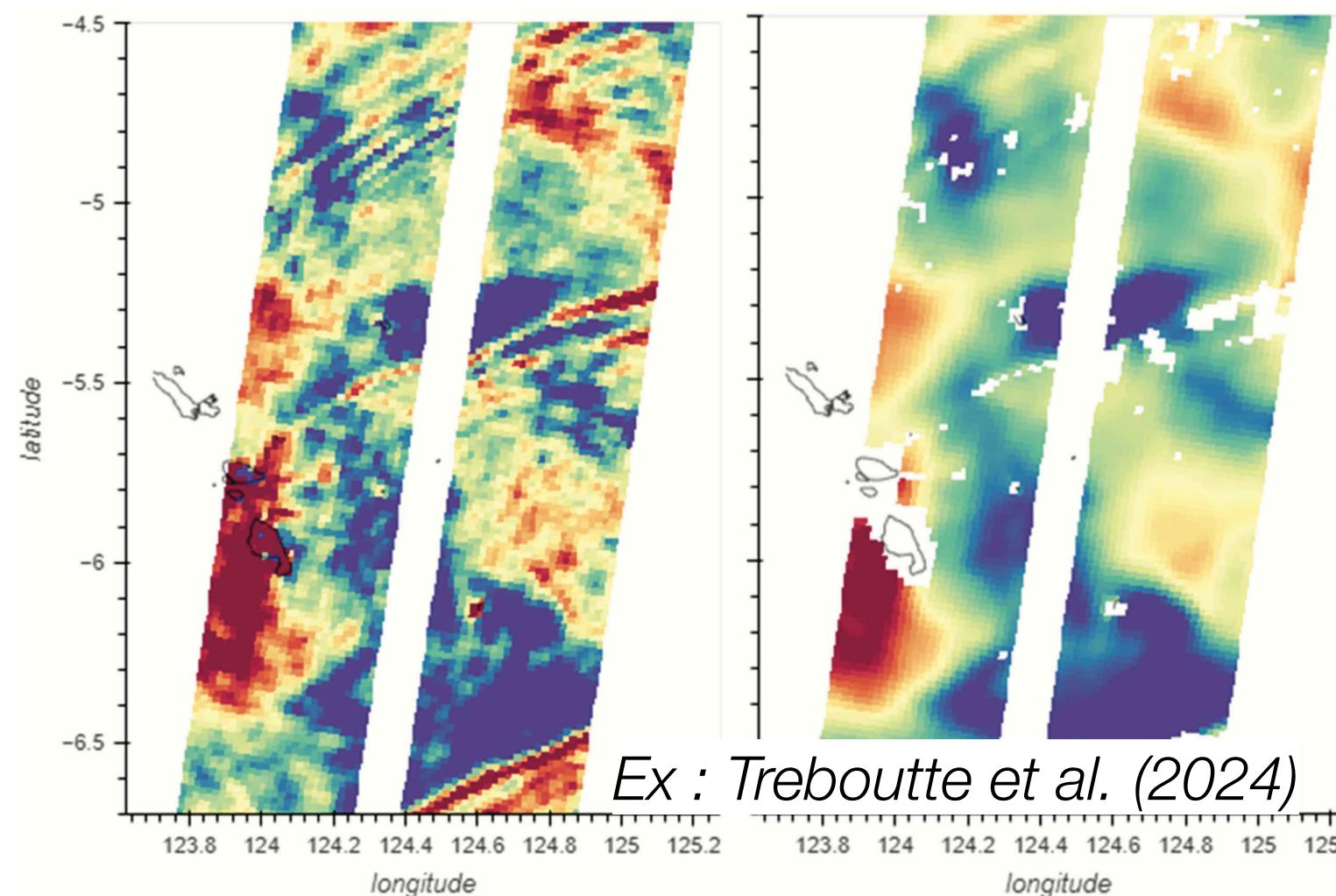
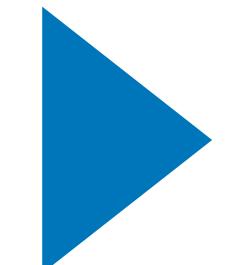
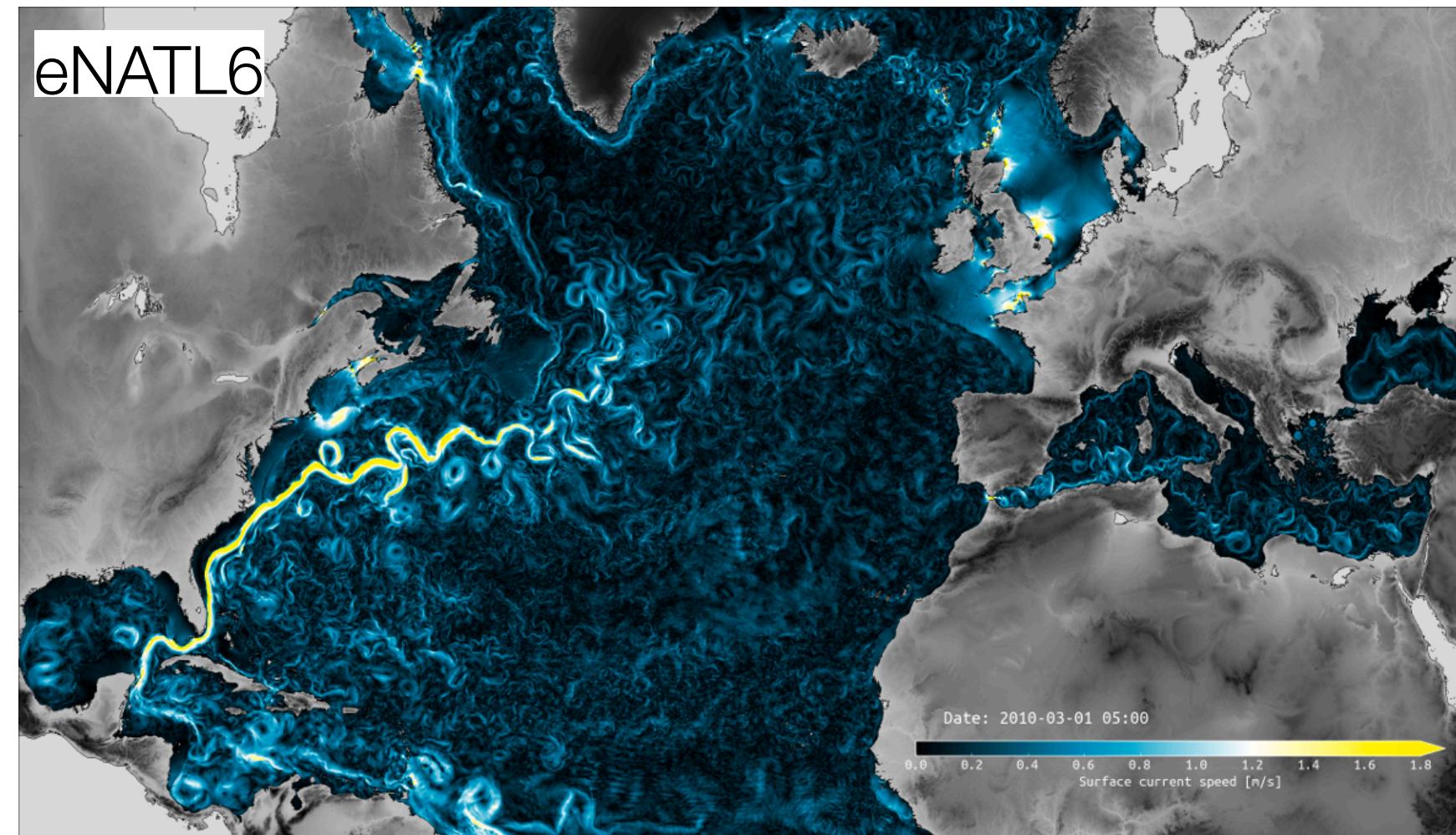


(Lahaye et al. 2024, GRL)



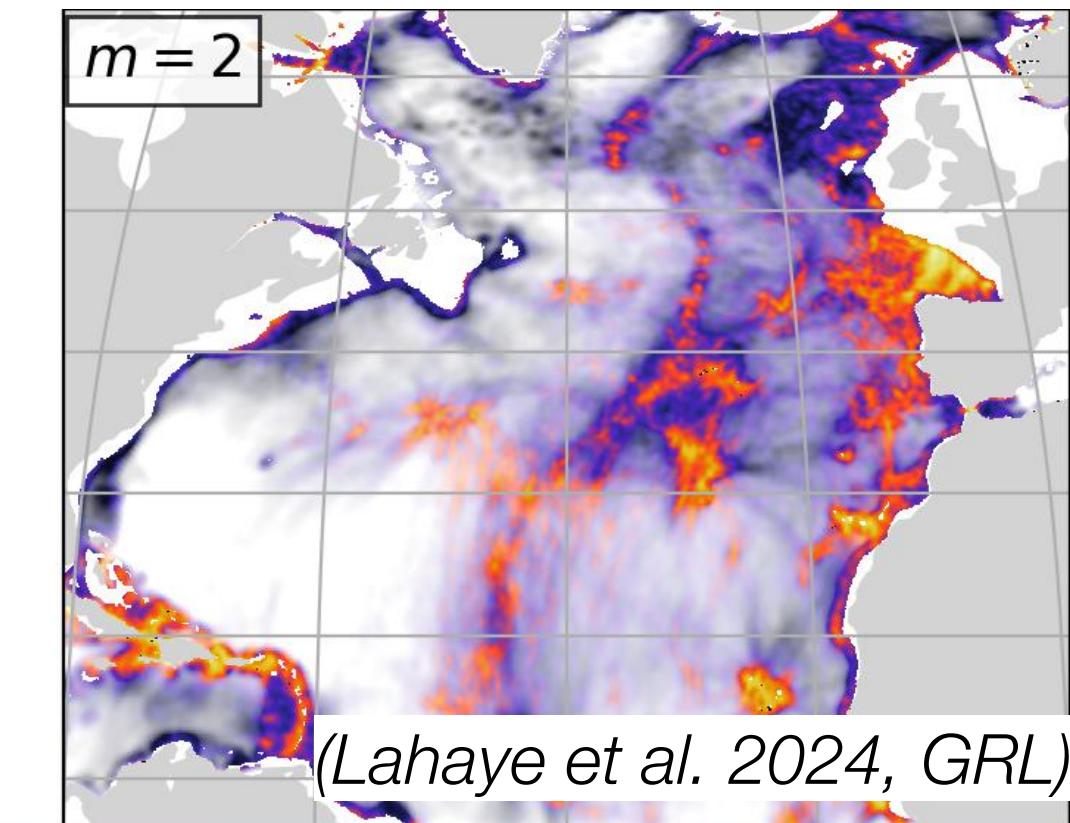
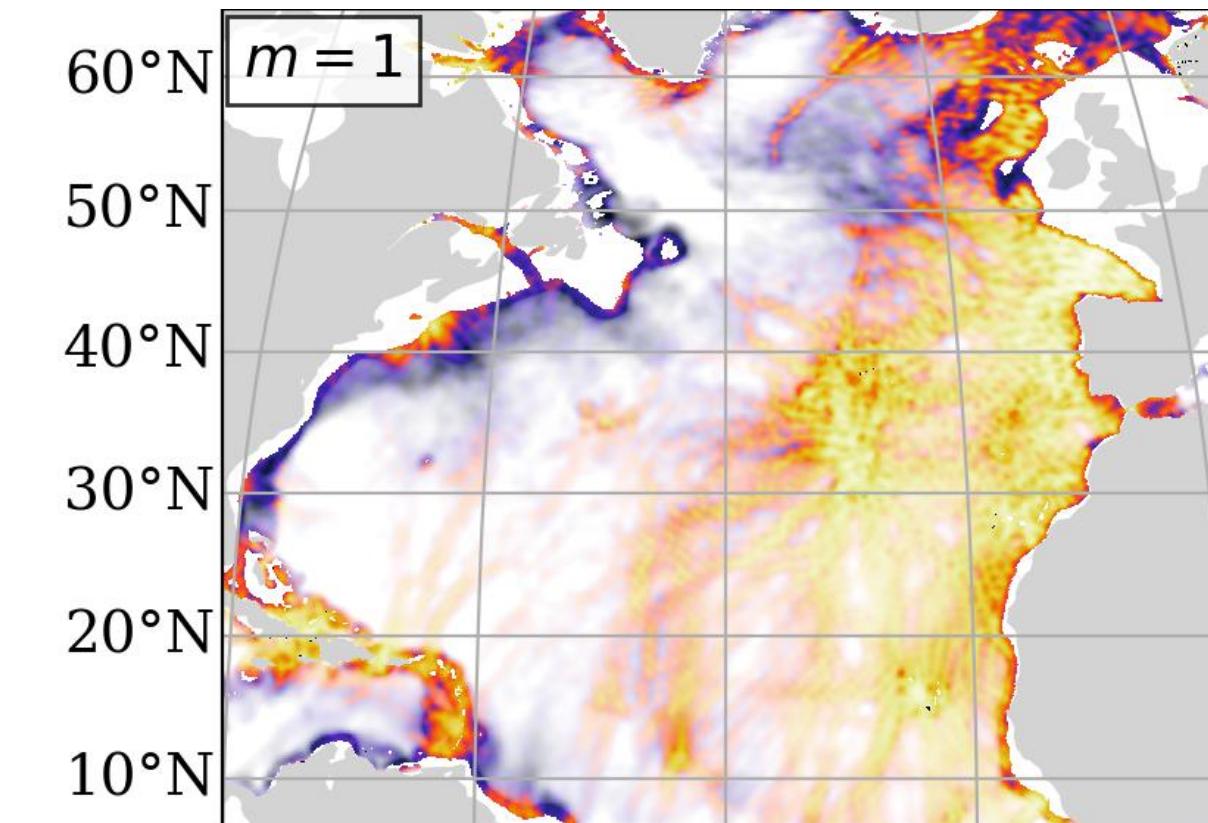
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Ce que les modèles ont apporté à la mission SWOT

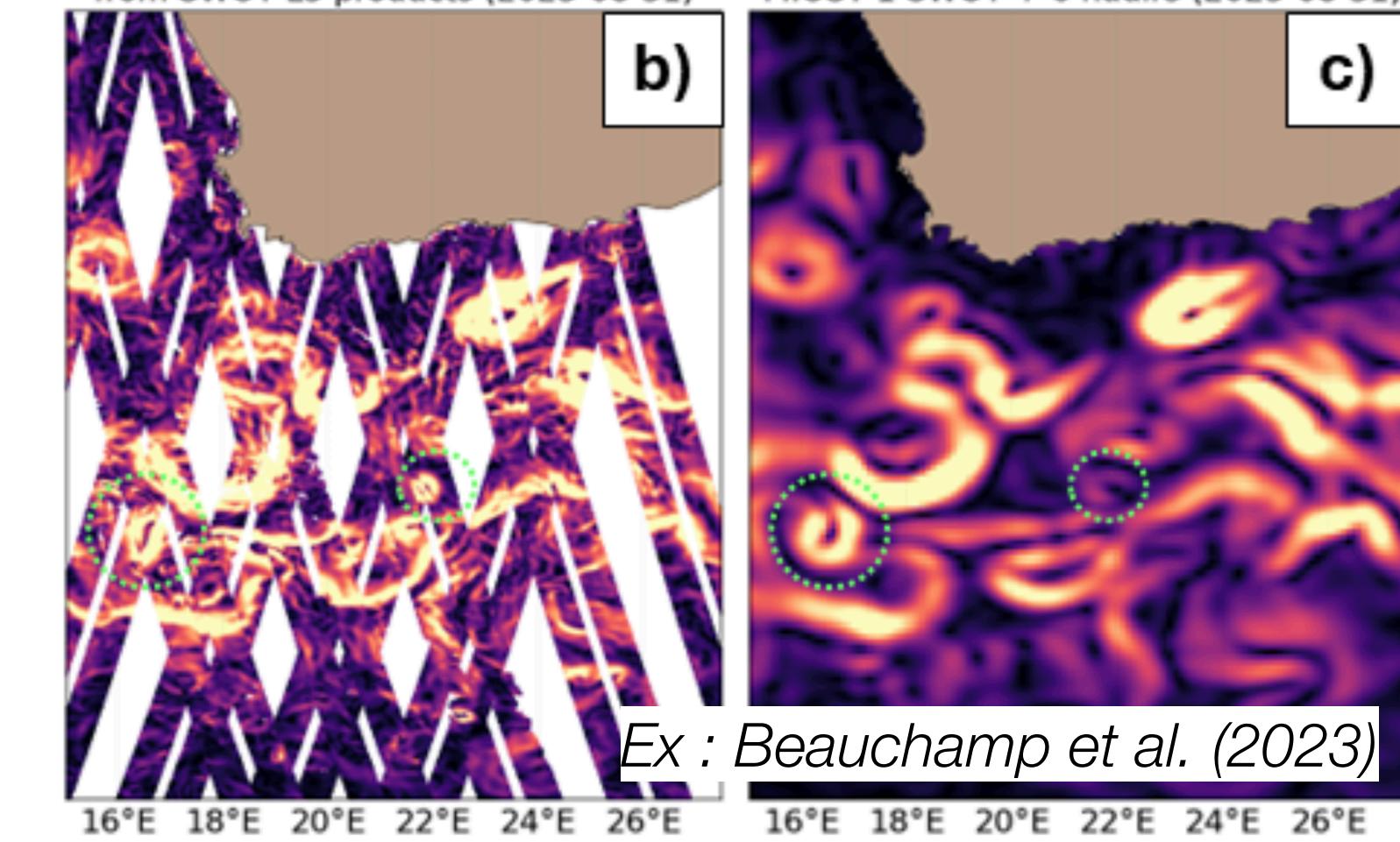


débruitage L3

Fraction incohérente de l'énergie de marée barlocline

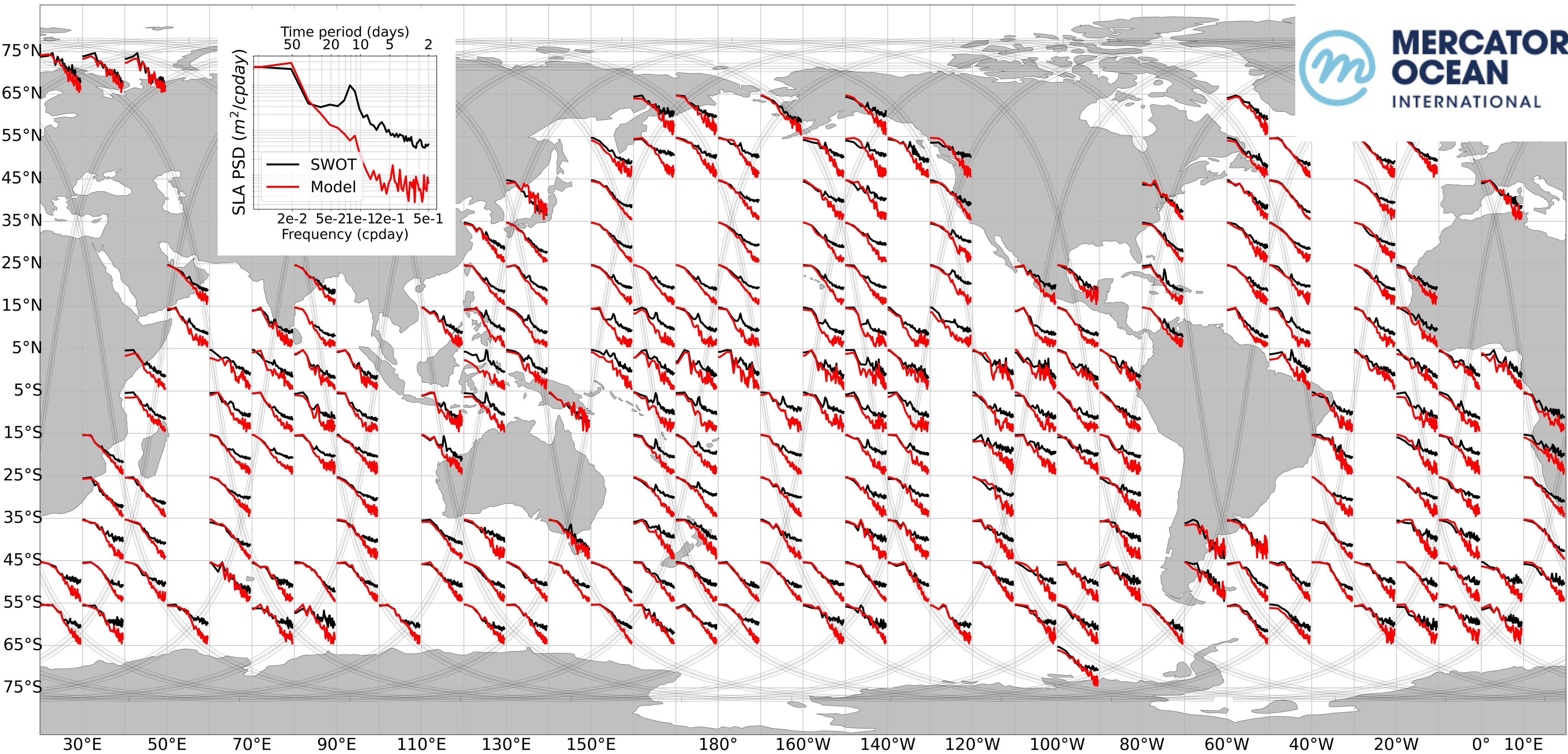


Préparer les
algorithmes et
les produits
de données



cartographie L4

Ce que SWOT apporte aujourd’hui aux modèles



MERCATOR
OCEAN
INTERNATIONAL

Ce que SWOT apporte aujourd’hui aux modèles

SWOT-OMIP : evaluating ocean models with SWOT data

M. Contreras¹, A. Ouhechou¹, M. Aguedjou², J. Le Sommer¹, F. Gouillon², A. Albert¹, T. Uchida³, C. Germeineaud², E. Chassignet⁴, C. Bricaud⁵, O. Tooth⁶

(1) IGE, UGA/CNRS/Grenoble-INP/INRAE/IRD (2) CNES (3) MIPT (4) COAPS/FSU (5) Mercator Ocean International (6) National Oceanography Center

Objectives :

- Describe the variability of macroturbulence in the global ocean from SWOT altimeter
- Evaluate how numerical ocean models capture this space and time variability
- Better understand the mechanisms driving the variability of ocean macroturbulence.

Model datasets

Simulation	Codebase	Grid size
GLO12v4	NEMO	~ 7.5 km
GLO36v1	NEMO	~ 2.5 km
HYCOM50	HYCOM	~ 1 km
eORCA025	NEMO	~ 22.5 km
eORCA12	NEMO	~ 7.5 km

Preliminary analysis

- data product : L3 v1.0.2
- variable : ssh + mdt (2km)
- regions : Uchida et al. 2024

Region A (JAS 2024) and Region B (JFM 2024) plots showing Power Spectral Density (PSD) vs Wavelength (km) for various models. The plots show a general decrease in PSD as wavelength decreases, with different models showing varying degrees of spread and spectral slopes.

Preliminary conclusions :

- Evidence of shallow SSH spectral slope (k^{-2}) in region B (low latitude/low energy), possibly related to the internal gravity wave (IGW) field
- Steeper spectral slopes (k^{-5}) in the mesoscale range in region A (mid latitude/high energy), as expected from QG theory
- Larger spread amongst models in region B, suggesting differences in models' ability to represent IGW
- Seasonal changes in SSH wavenumber spectra are (surprisingly) weaker than expected

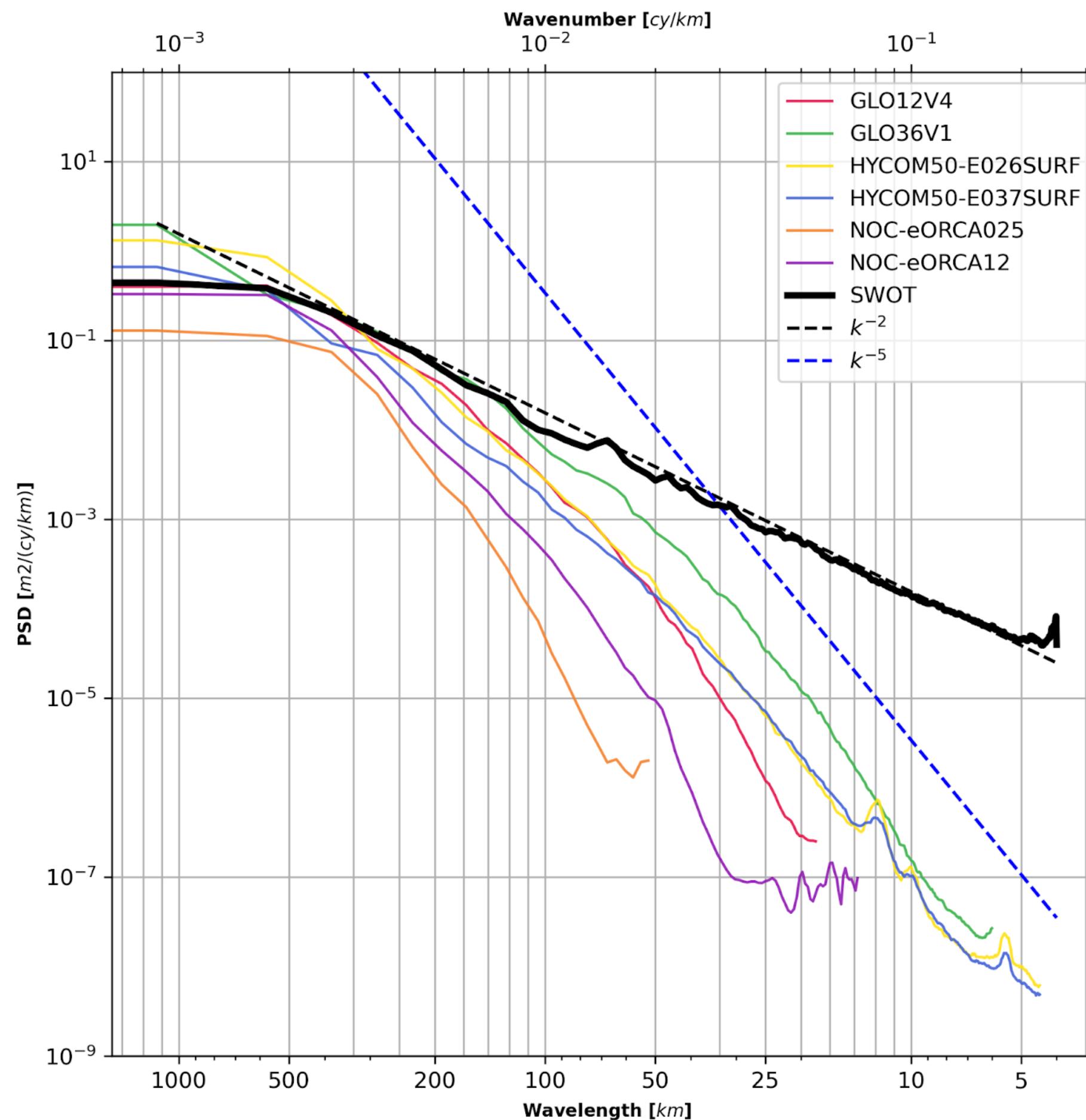
What's next :

- include more models in the analysis, please contact us on GH if interested !
- compute wavenumber spectra in $10^\circ \times 10^\circ$ boxes covering the global ocean
- investigate how SSH spectra vary across models, regions and seasons

Open workflow on GitHub

QR code linking to the GitHub repository.

Logos: IGE, cnrs, cnes, COAPS, National Oceanography Centre, MERCATOR OCEAN INTERNATIONAL



- Evaluation systématique et ouverte
- Distribution d'énergie par échelles

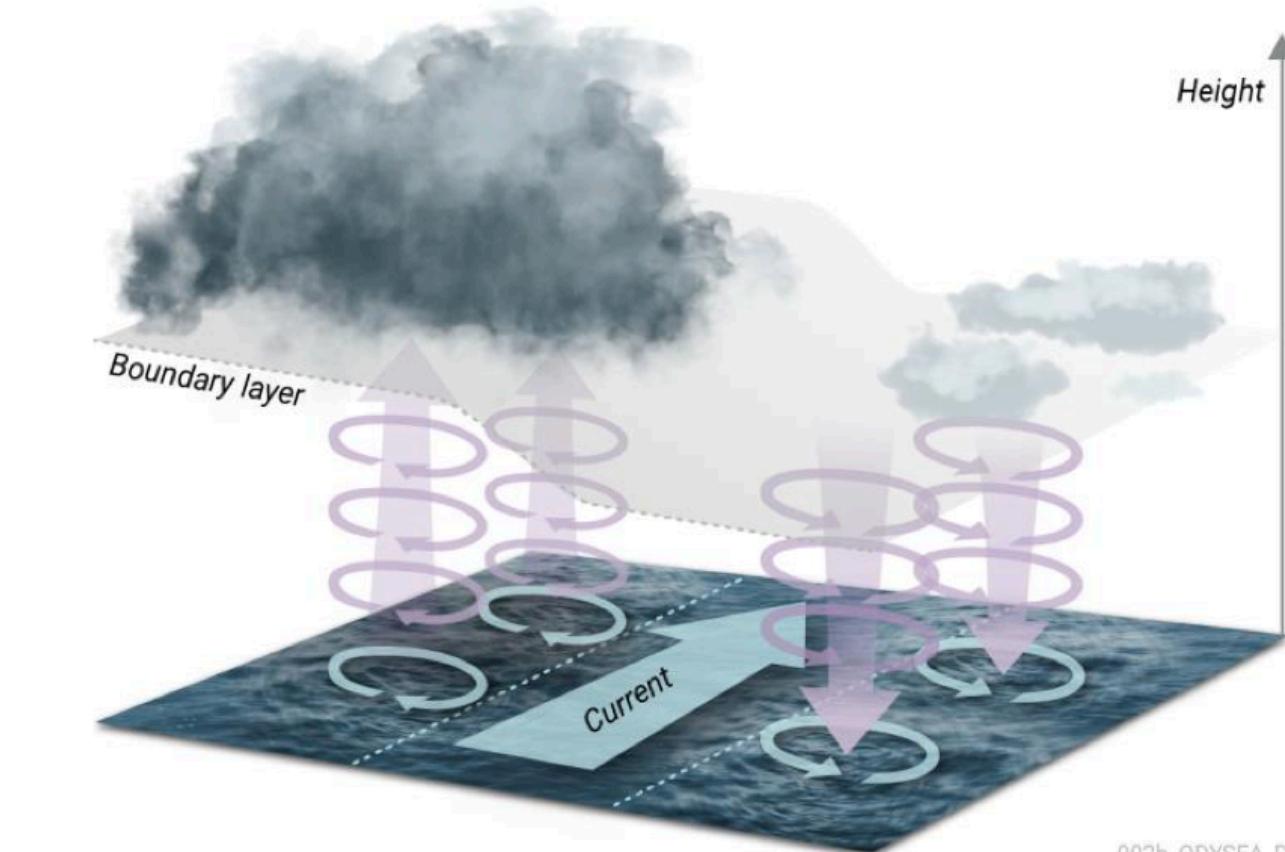
4.

Nouvelles frontières pour les modèles

Sources d'incertitude dans les modèles & prévisions

Sources d'incertitude dans les modèles & prévisions

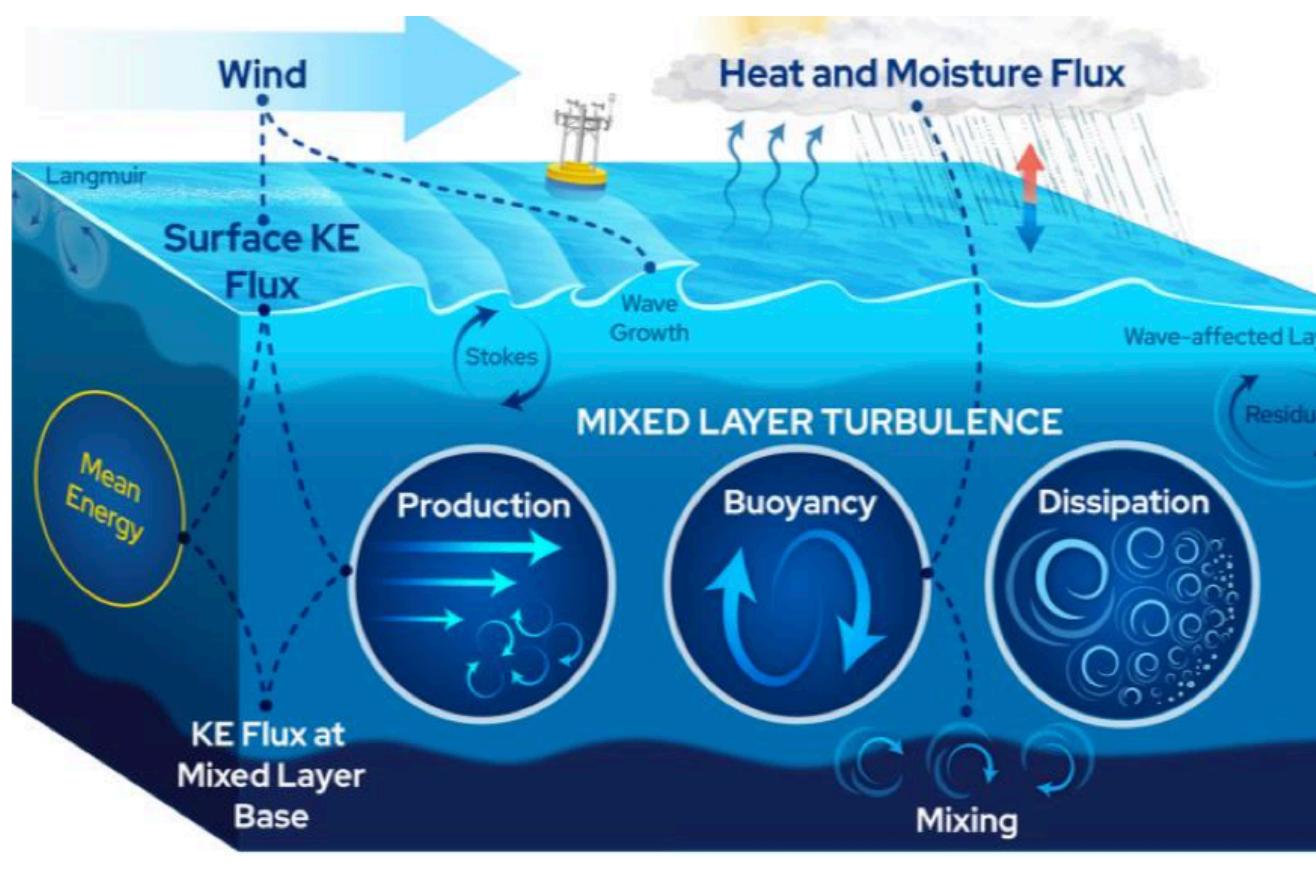
1. Forçage et interaction à l'interface ocean-atmosphère



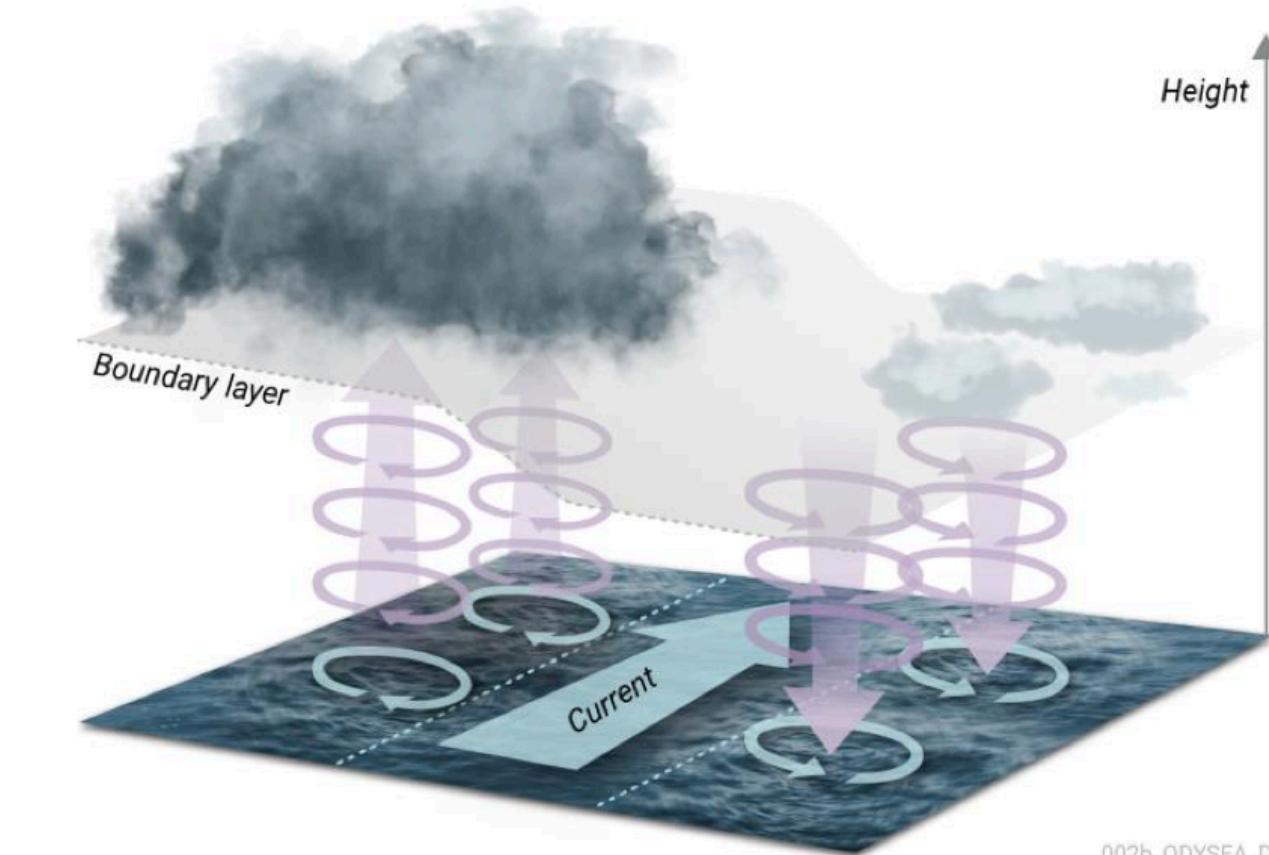
Interaction vents-courant-vagues
et impact sur couche limite atmosph.

Sources d'incertitude dans les modèles & prévisions

1. Forçage et interaction à l'interface ocean-atmosphère



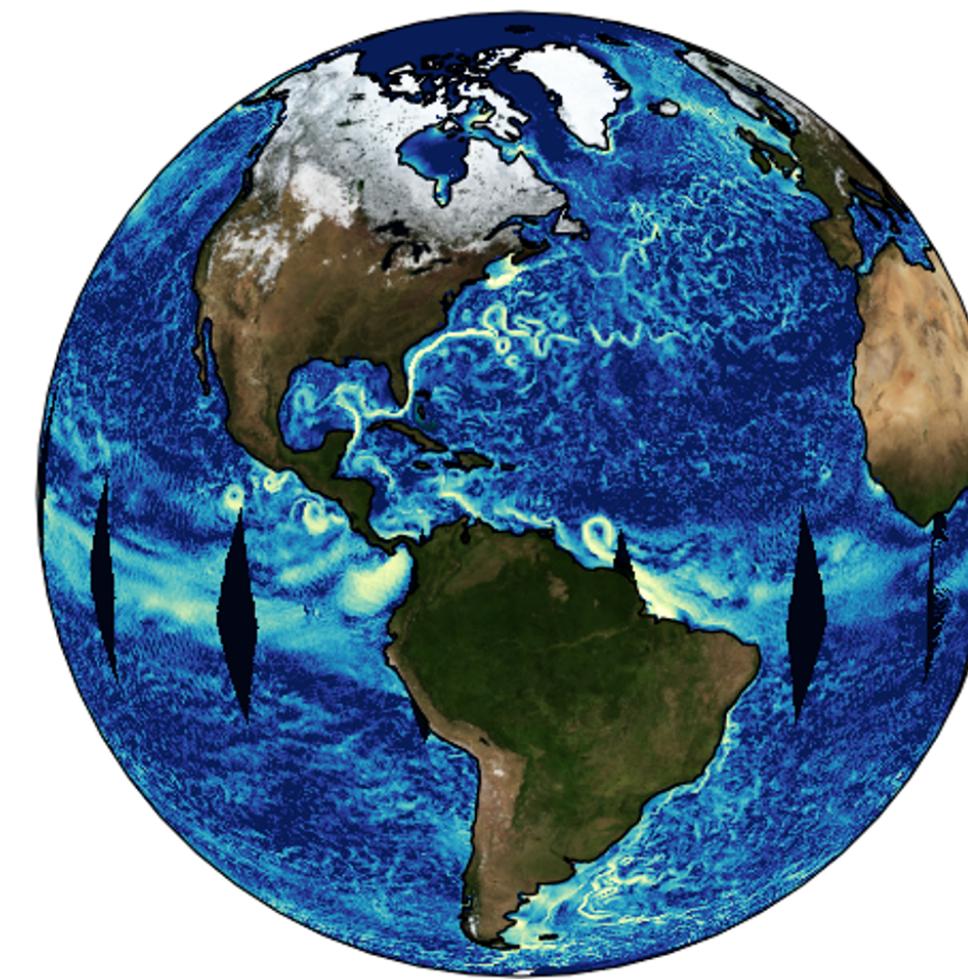
Mélange et dissipation d'énergie
dans les couches de surface



Interaction vents-courant-vagues
et impact sur couche limite atmosph.

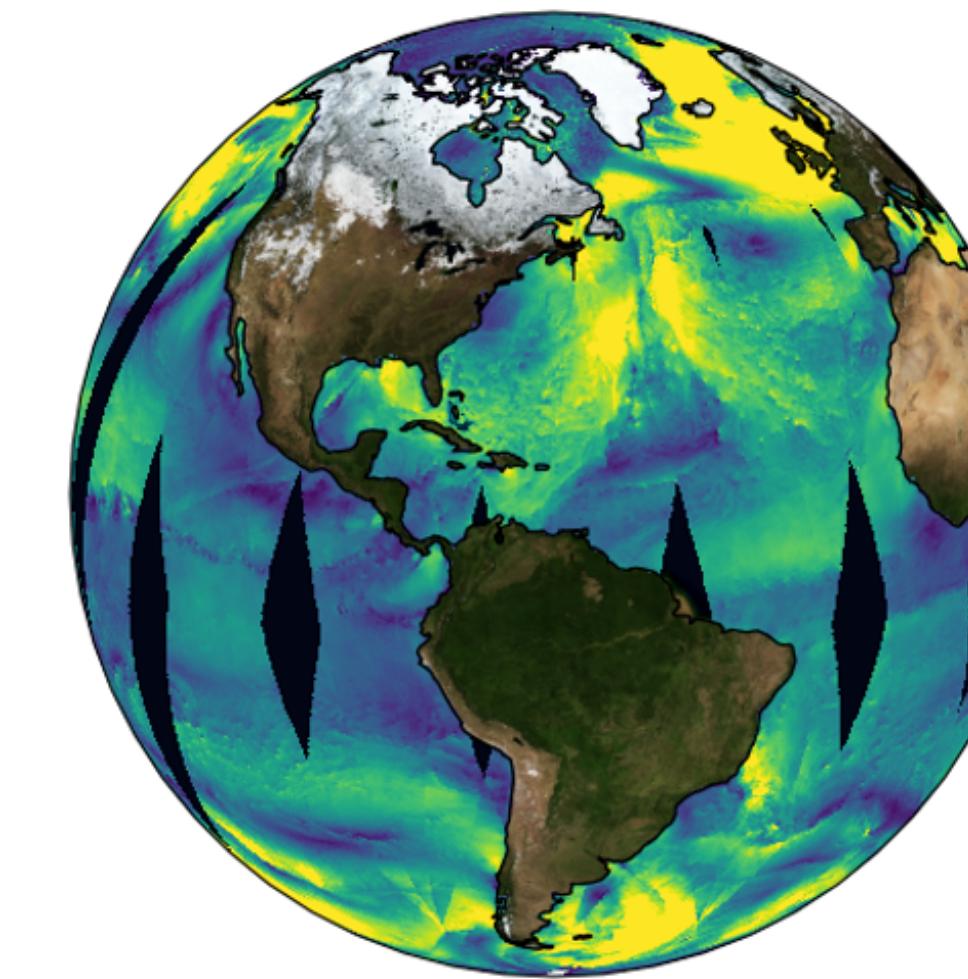
2. Mélange turbulent et dissipation d'énergie mécanique

Observations conjointes courants, vents, vagues



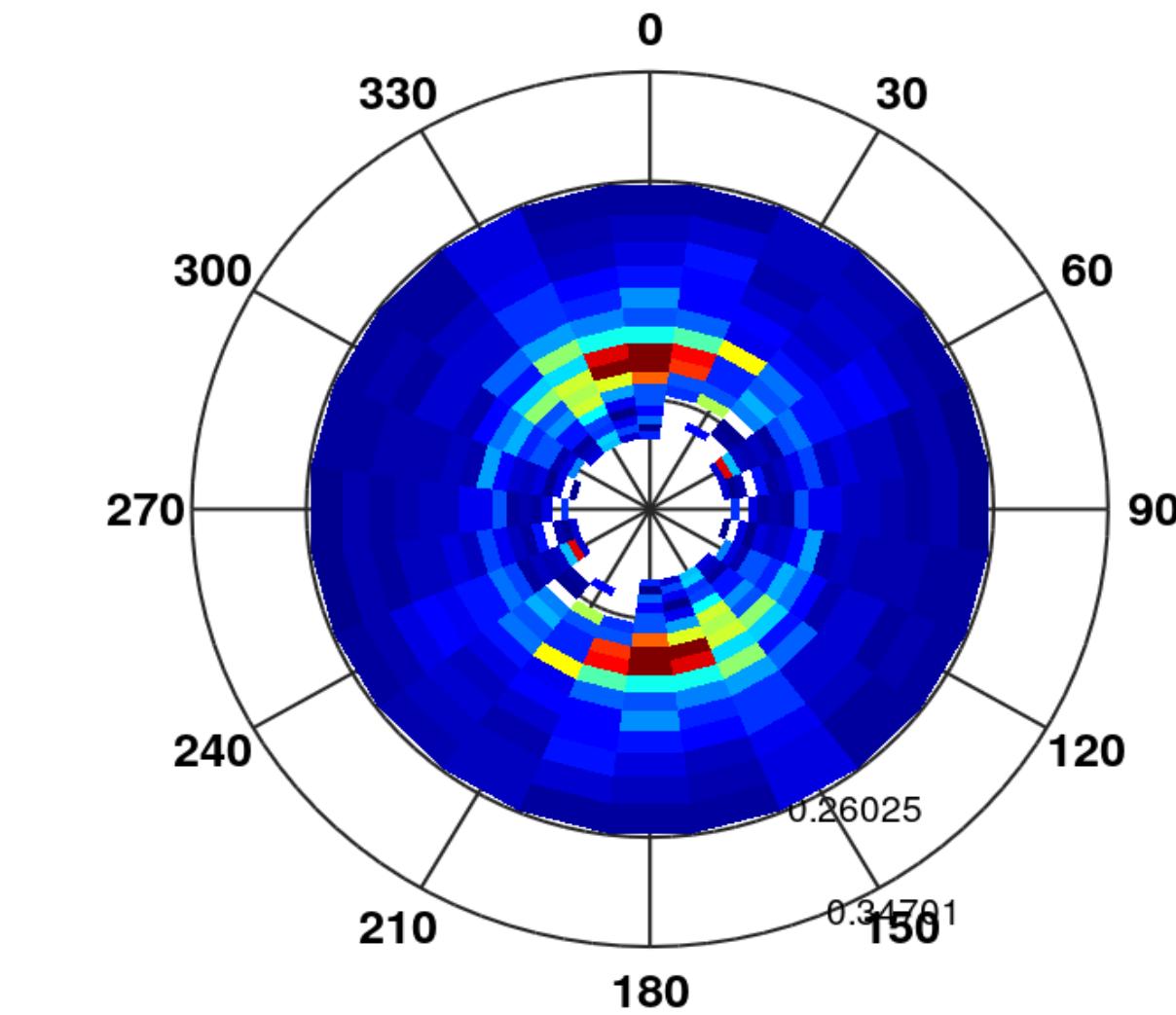
Courants de surface

+



Vents de surface

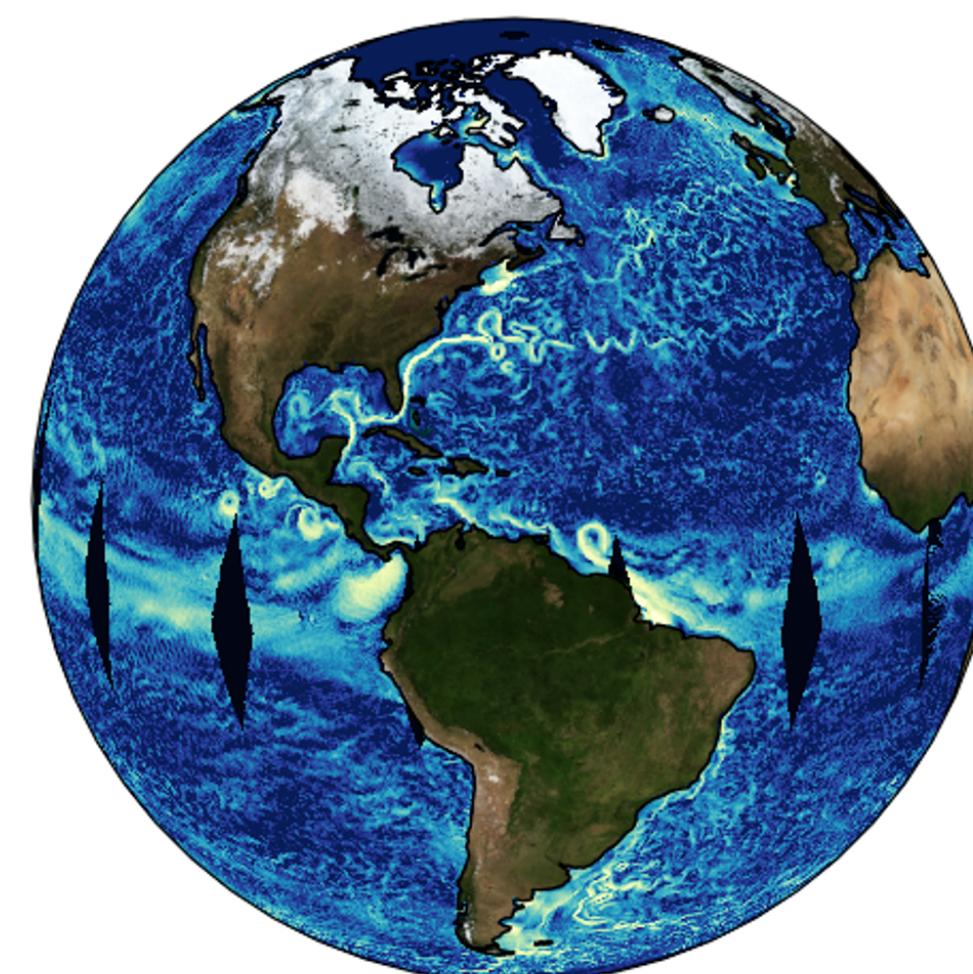
+



Spectre des vagues

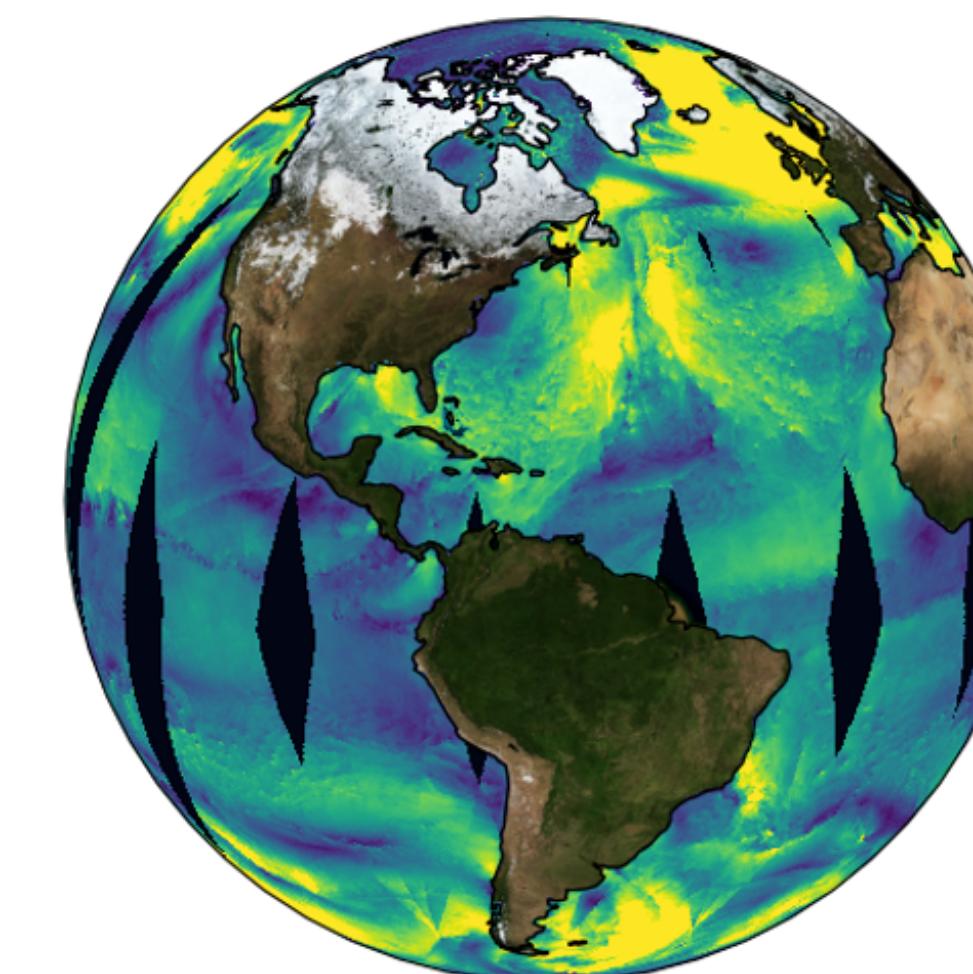
Cohérence et complémentarité des propositions de missions (+geostationnaire)

Observations conjointes courants, vents, vagues



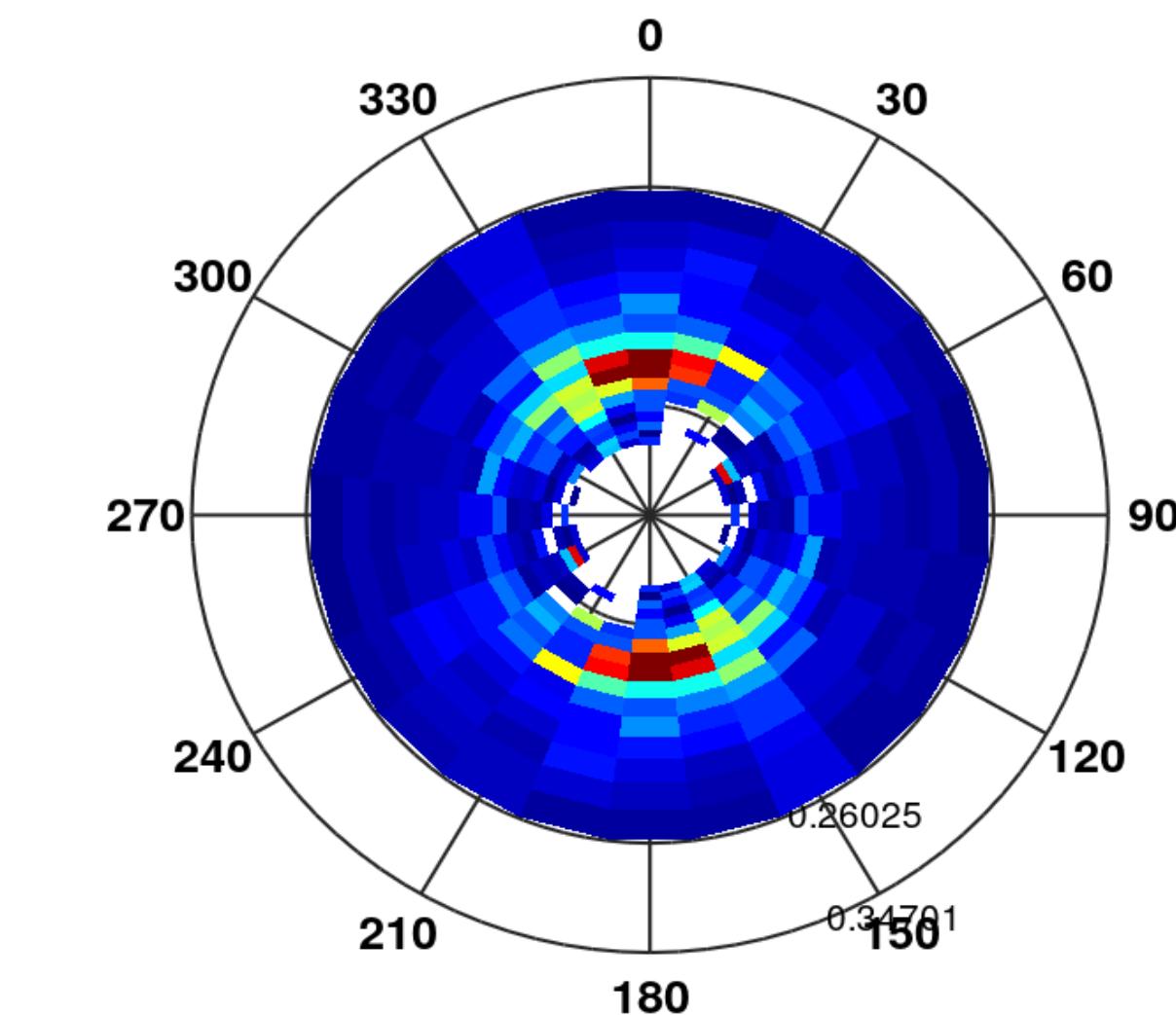
Courants de surface

+



Vents de surface

+



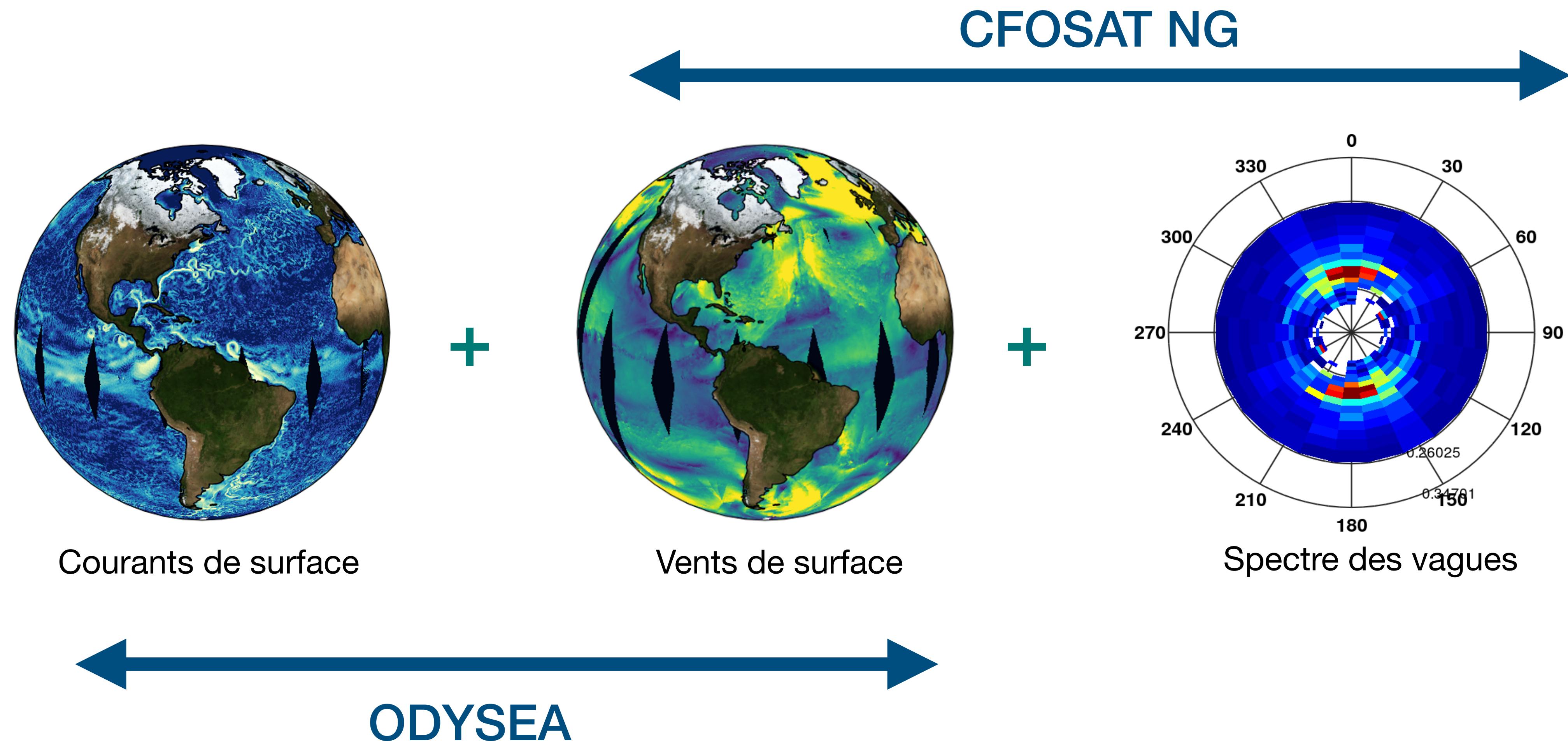
Spectre des vagues



ODYSEA

Cohérence et complémentarité des propositions de missions (+geostationnaire)

Observations conjointes courants, vents, vagues



Cohérence et complémentarité des propositions de missions (+geostationnaire)

Journée de la Science

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Take Home

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Take Home

1.

Observation et modélisation de l'océan évoluent
de manière complémentaire

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Take Home

1.

Observation et modélisation de l'océan évoluent
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2.

Les fines échelles (1-100km) concentrent des
enjeux scientifiques et sociaux

Journée de la Science

journeescience2025-cnes.fr



Take Home

1.

Observation et modélisation de l'océan évoluent de manière complémentaire

2.

Les fines échelles (1-100km) concentrent des enjeux scientifiques et sociaux

3.

Plusieurs missions cohérentes avec les besoins des modèles et système de prévision