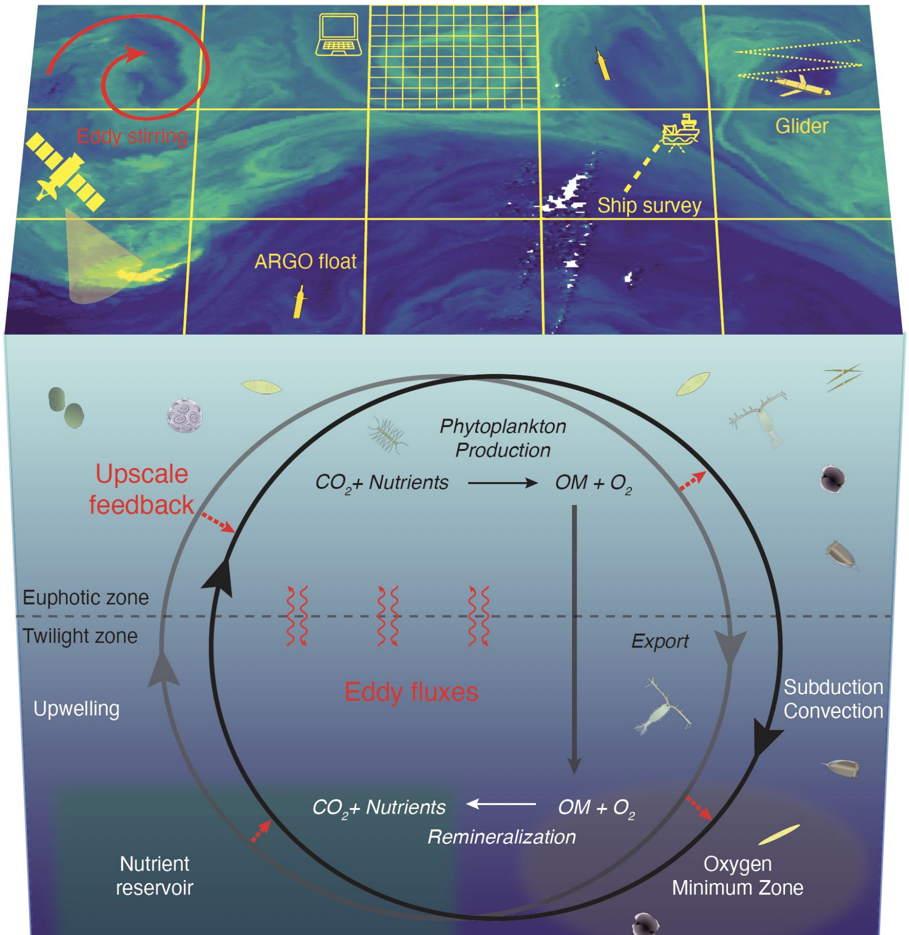
Impact of **finescale currents** on **biogeochemical cycles** in a **changing ocean**

Marina Lévy | LOCEAN-IPSL

Défis théoriques pour les sciences du climat
GDR

7 juin 2023

Introduction : Biogeochemical cycles

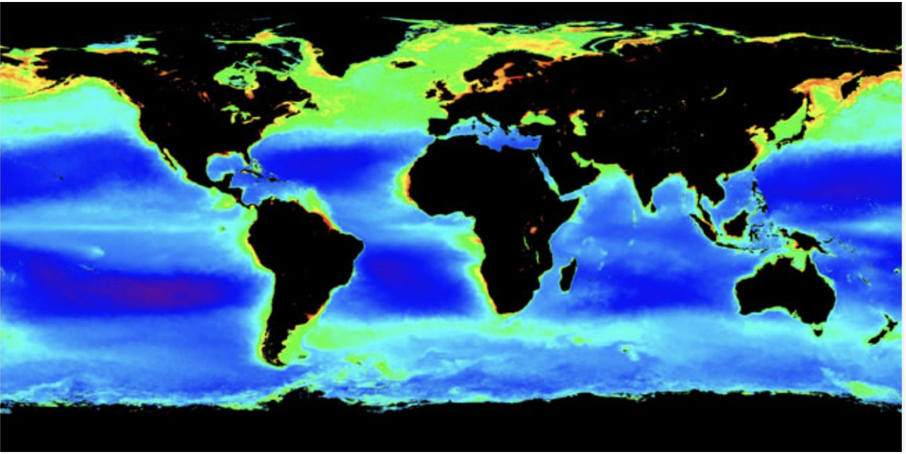


Transformation of C, N, O

Light absorption
Gravity

Biogeochemical provinces

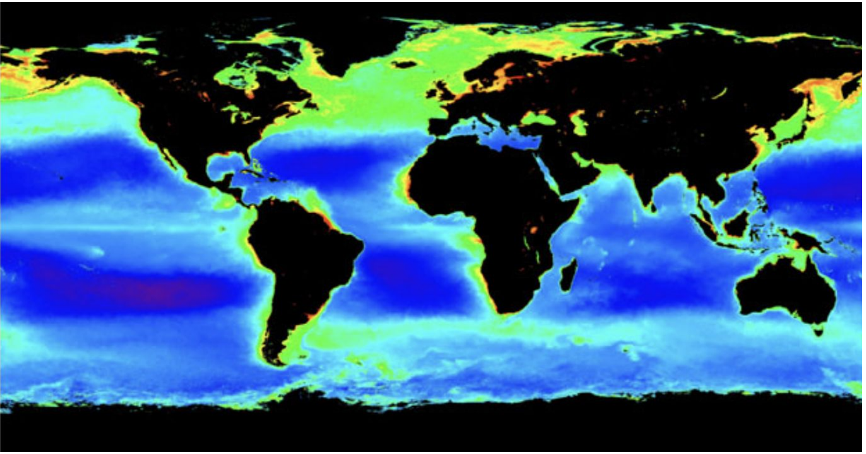
Surface Phytoplankton



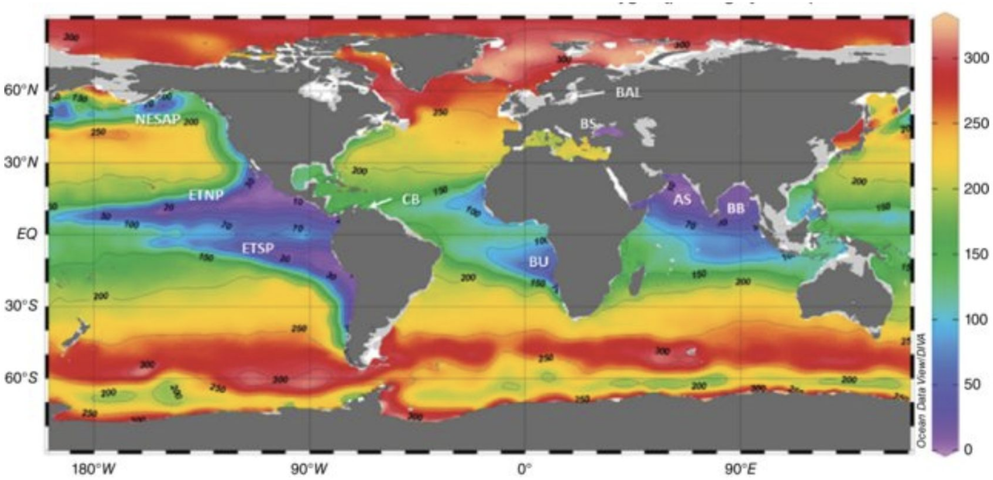
Annual Climatology

Biogeochemical provinces

Surface Phytoplankton



Oxygen 200m



Annual Climatology

Importance for climate

Biological Carbon pump
Anthropogenic CO_2 sequestration
Deoxygenation - N_2O emissions

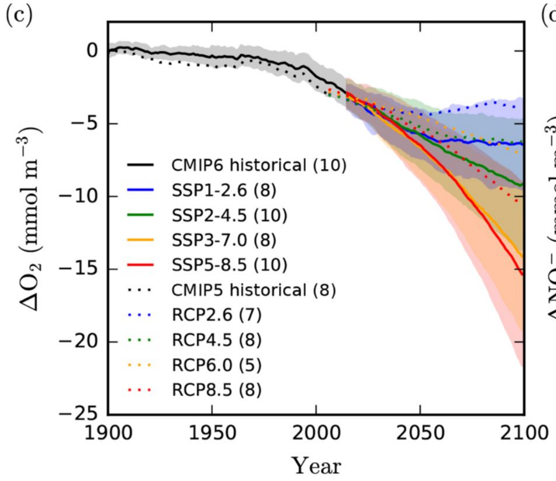
Importance for climate

Biological Carbon pump
Anthropogenic CO_2 sequestration
Deoxygenation - N_2O emissions

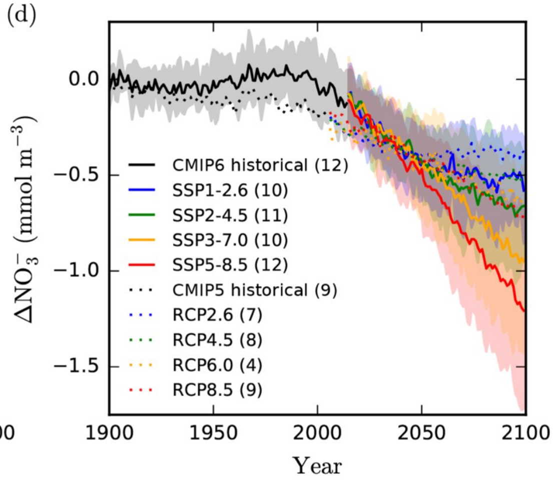
Importance for biodiversity

Major threats

Deoxygenation



Surface nitrate deficit (PP decline)

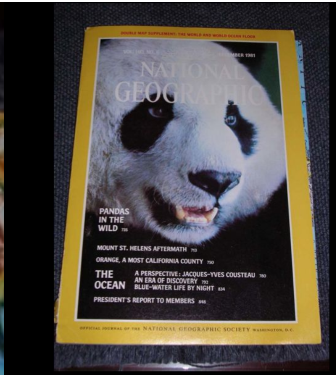


Twenty-first century ocean warming, acidification, deoxygenation, and upper-ocean nutrient and primary production decline from CMIP6 model projections

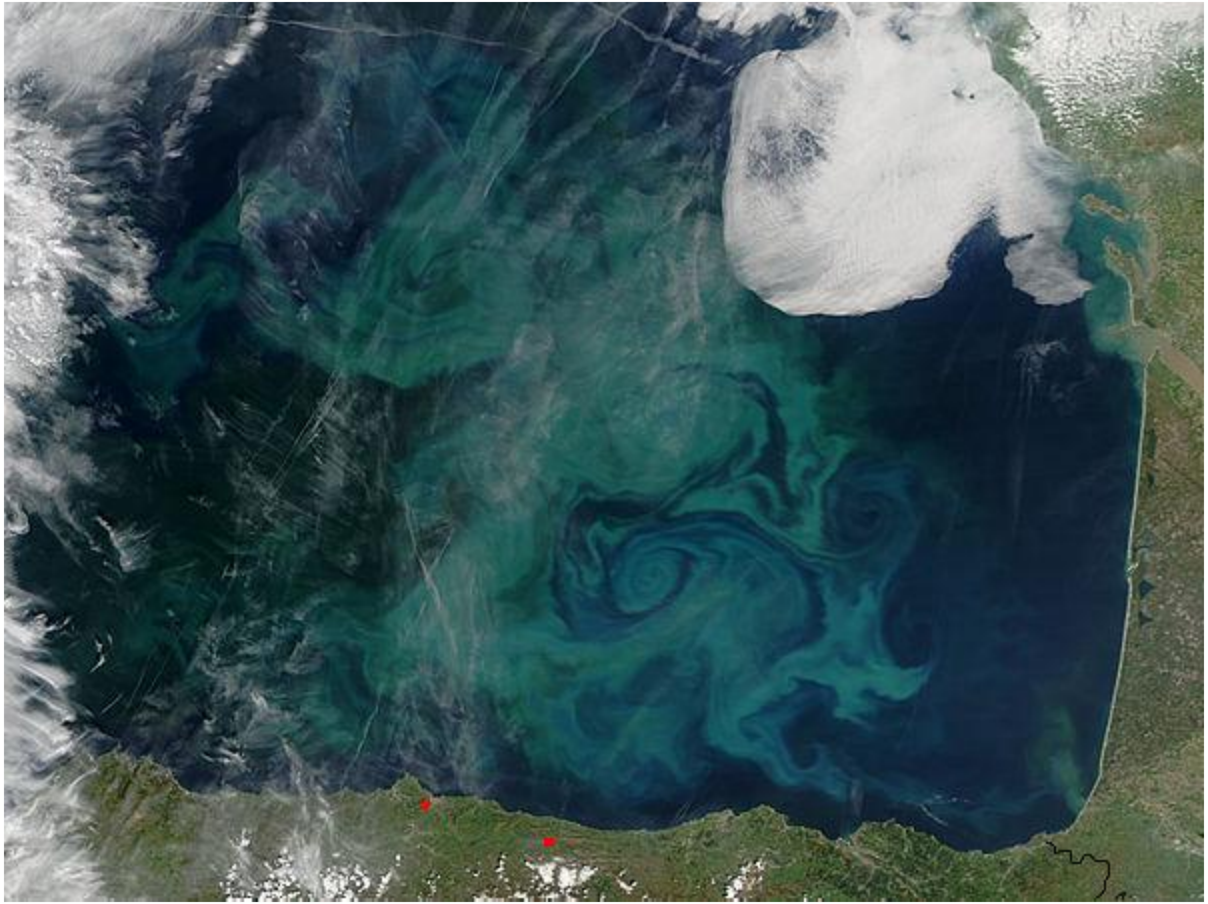
Lester Kwiatkowski[1], Olivier Torres[2], Laurent Bopp[2], Olivier Aumont[1], Matthew Chamberlain[3], James R. Christian[5], John P. Dunne[6], Marion Gehlen[7], Tatiana Ilyina[8], Jasmin G. John[6], Andrew Lenton[3,4], Hongmei Li[8], Nicole S. Lovenduski[9], James C. Orr[7], Julien Palmieri[10], Yeray Santana-Falcón[11], Jörg Schwinger[12], Roland Séférian[11], Charles A. Stock[6], Alessandro Tagliabue[13], Yohei Takano[8,14], Jerry Tjiputra[12], Katsuya Toyama[15], Hiroyuki Tsujino[15], Michio Watanabe[16], Akitomo Yamamoto[16], Andrew Yool[10], and Tilo Ziehn[3]

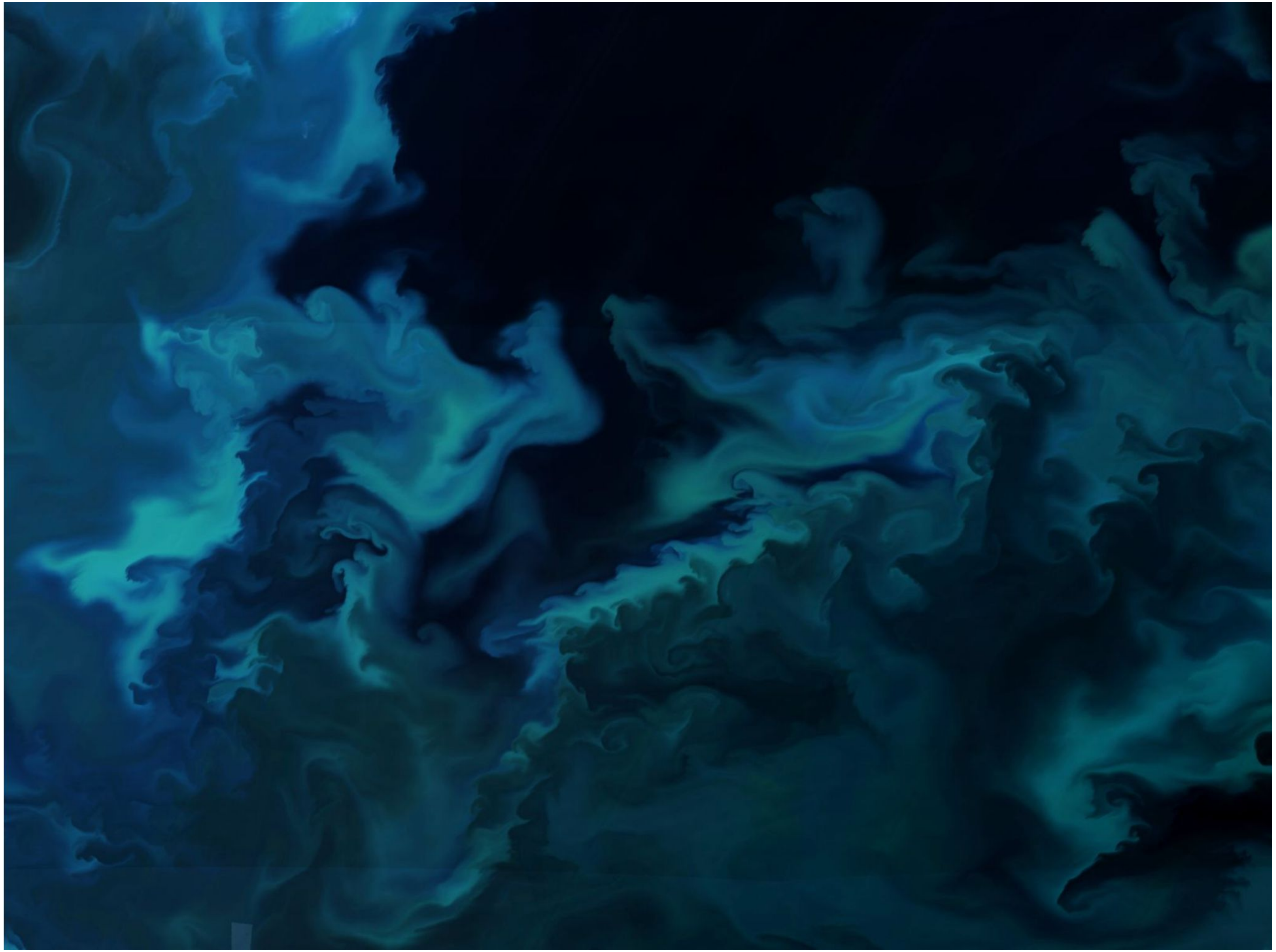
2020


Sensing the ocean's crop by satellite
"WHERE ARE THEY BITING?"
The CZCS is still experimental, and, in a time of budget cutting, its fate is uncertain. Yet it might prove as useful for the study of the sea as Landsat has been for continents and Tiros for weather forecasting.
MORE CHLOROPHYLL LESS
New York
Washington

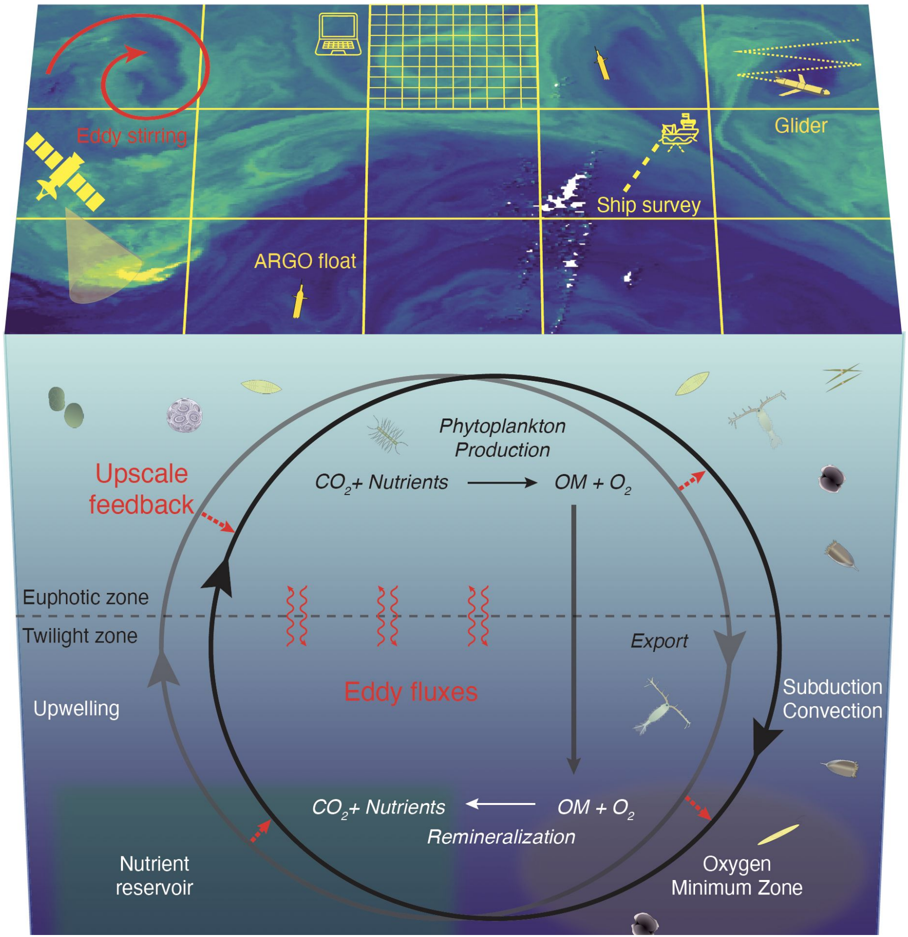

NATIONAL GEOGRAPHIC
PANDAS IN THE WILD
MOUNT ST. HELENS AFTERMATH
ORANGE, A MOST CALIFORNIA COUNTY
THE OCEAN
A PERSPECTIVE: JACQUES-YVES COUSTEAU
AN ERA OF DISCOVERY
BLUE-WATER LIFE BY NIGHT
PRESIDENT'S REPORT TO MEMBERS
OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY WASHINGTON, D.C.

1980





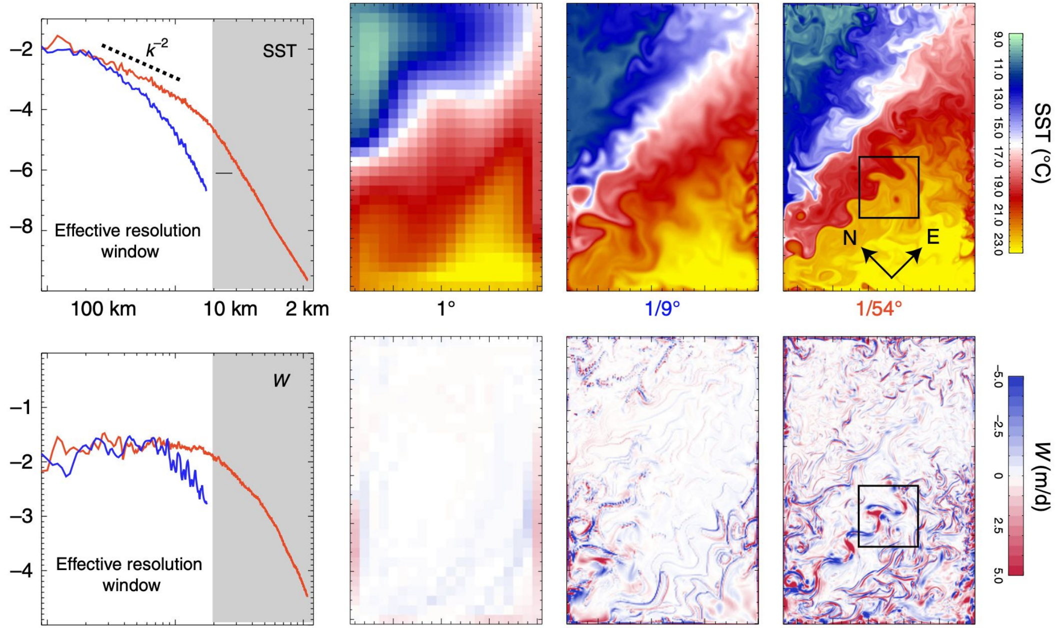
Challenge 1 : Conventional tools pushed to their limits



Challenge 1 : Conventional tools pushed to their limits

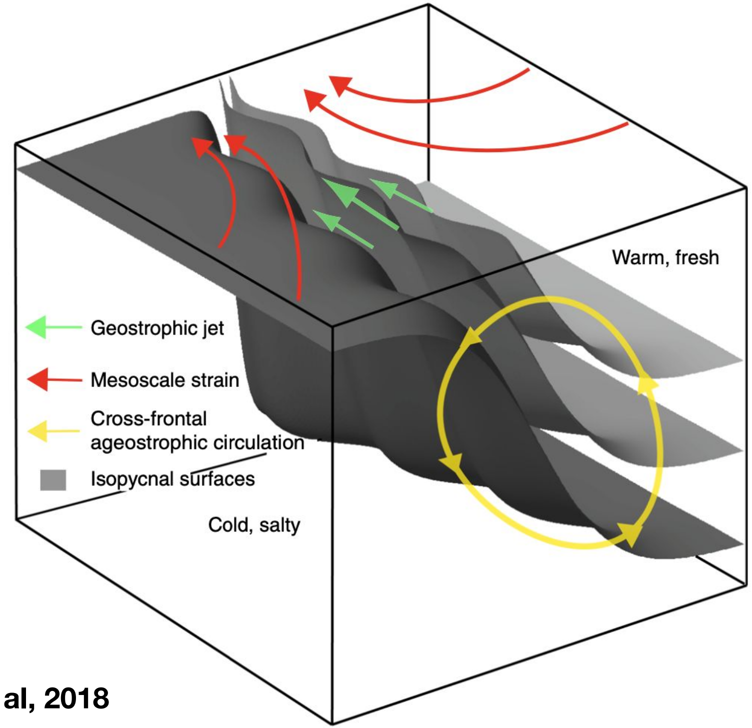
- lack of computing power
- lack of spatio-temporal coverage
- limited to surface phytoplankton

Have allowed targeted studies
Understanding of processes



More energetic meso + submeso at increasing model resolution

Fine scales = mesoscale (10-100 km / months) + submesoscale (1-10 km / days)



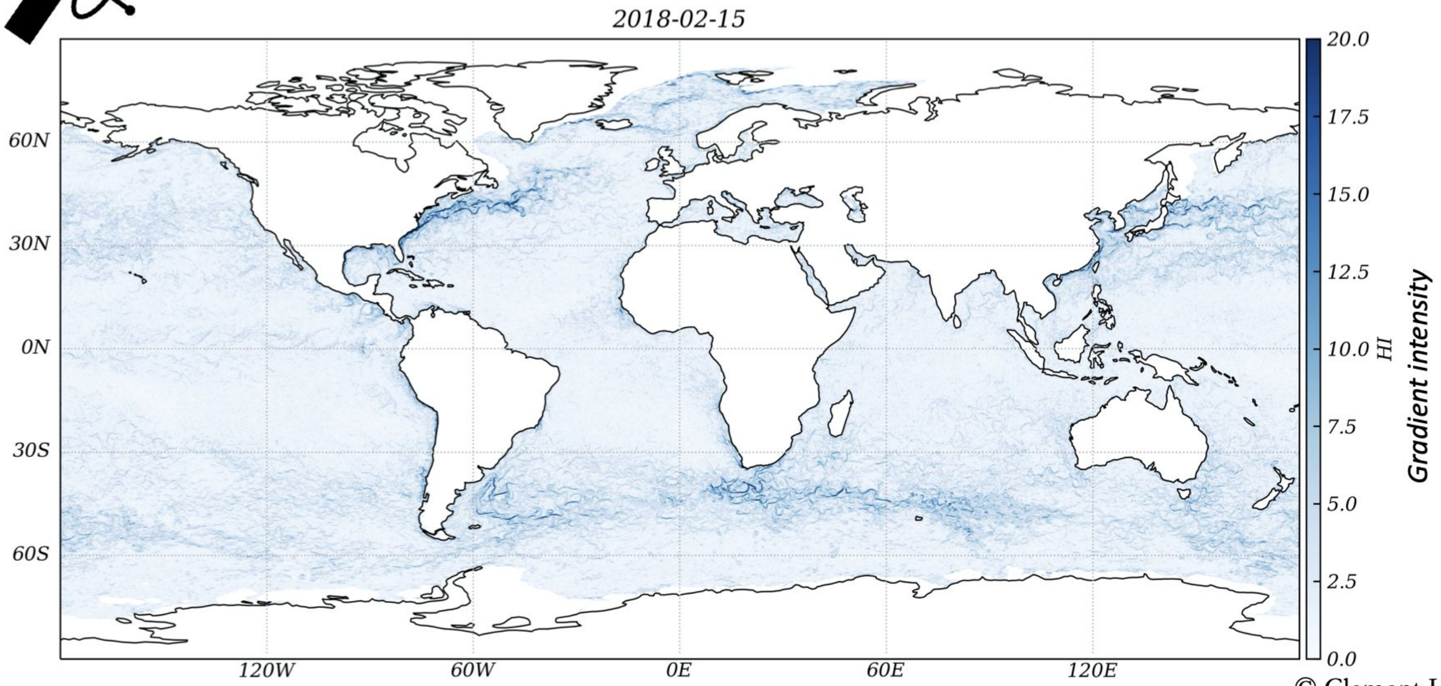
Levy et al, 2018

REVIEW ARTICLE
DOI: 10.1038/s41467-018-07059-3 OPEN

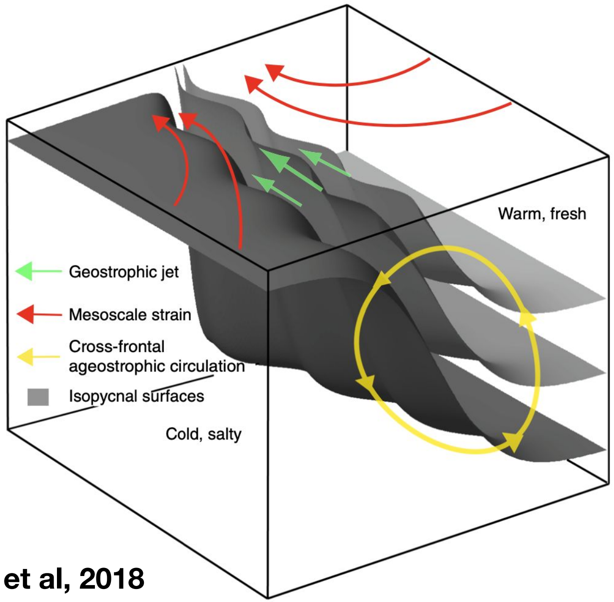
The role of submesoscale currents in structuring marine ecosystems

Marina Lévy[1], Peter J.S. Franks[2] & K. Shafer Smith[3,4]

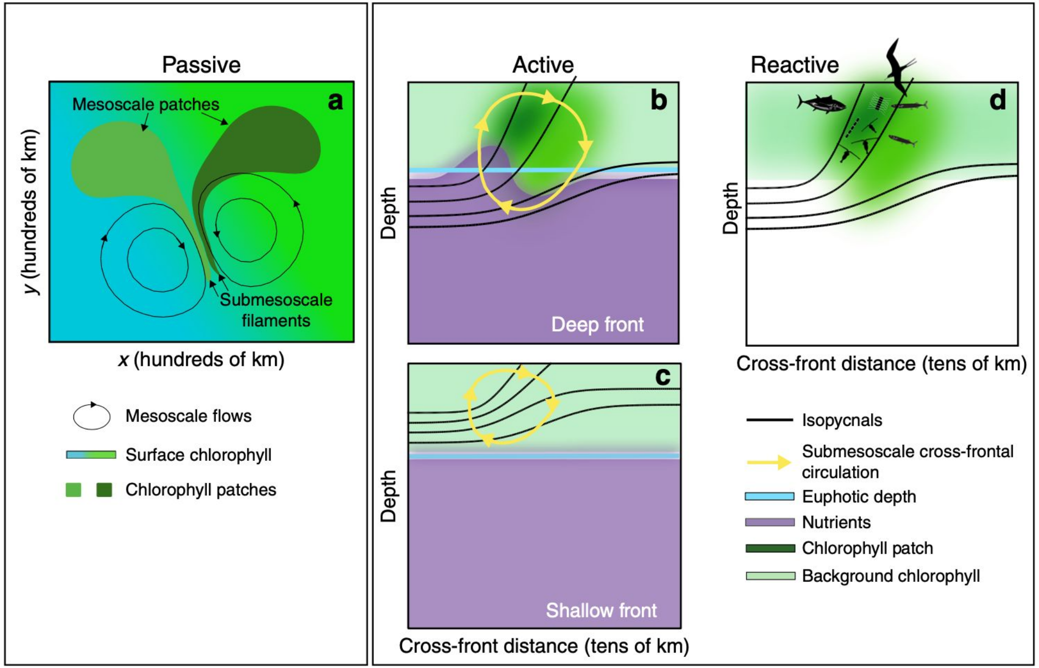
Sea-surface temperature fronts

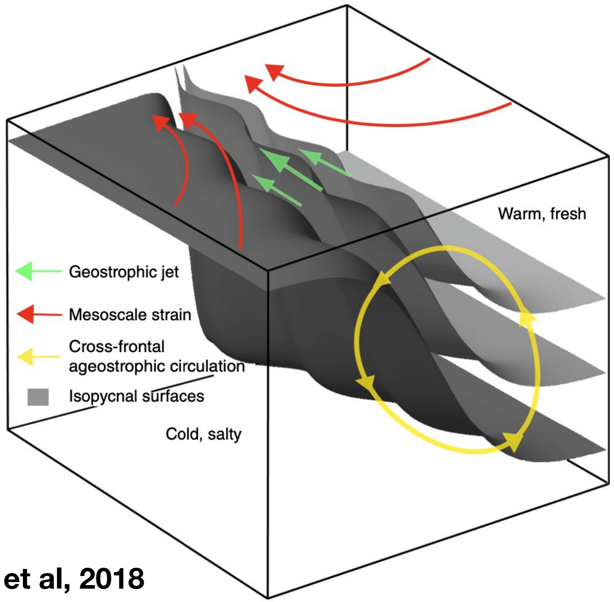


Introduction : individual processes

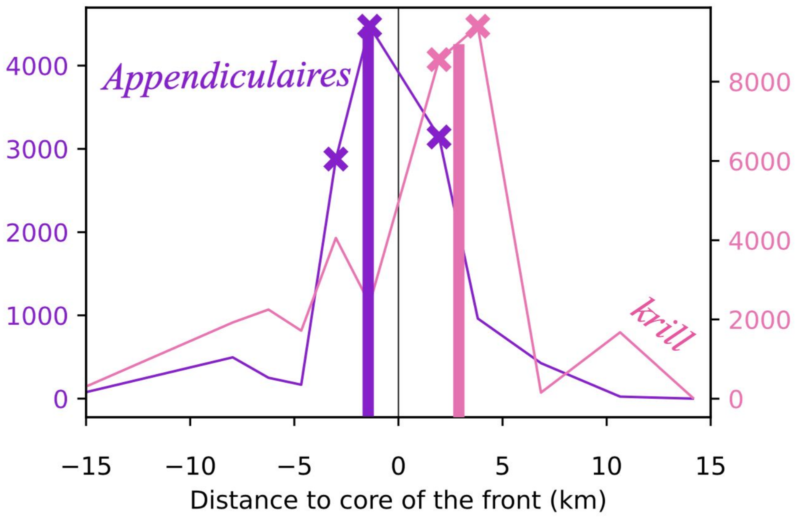


Levy et al, 2018





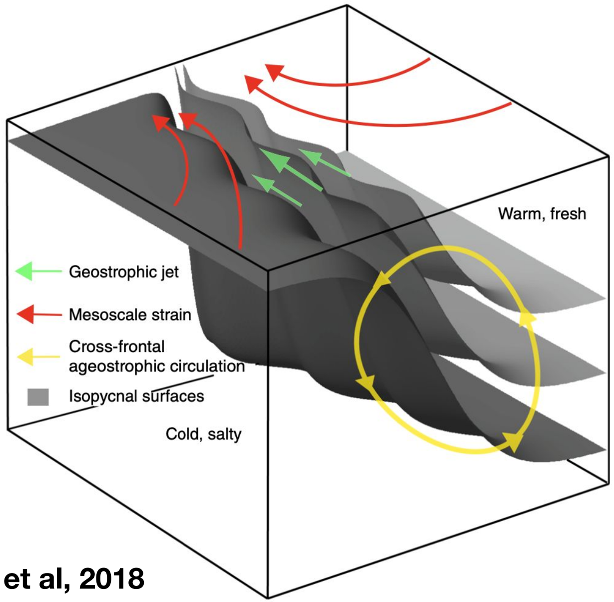
Levy et al, 2018



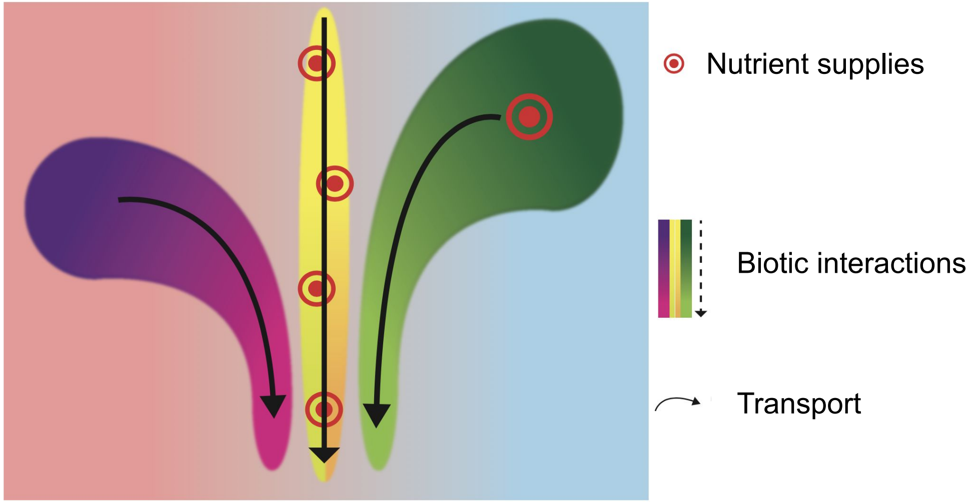
Mangolte et al, 2023

Fine scales = mesoscale (10-100 km / months) + submesoscale (1-10 km / days)

Introduction : processes acting together



Levy et al, 2018



Mangolte et al, 2023

What is the contribution of finescales to:

1. **mean** cycling of biogeochemical elements ?
2. their **natural variability** ?
3. their response to **climate change** ?

What is the contribution of finescales to:

1. **mean** cycling of biogeochemical elements ?
2. their **natural variability** ?
3. their response to **climate change** ?

Multi-scale problem

impact of finescale currents on province-scale budgets

Introduction : Impact of fine scales

$$\partial_t C = -\nabla \cdot (C\mathbf{v}) + \partial_z(k_z \partial_z C) + B_C$$

Advection

Vertical
Mixing

Biogeochemical
Reactions

$$\partial_t C = -\nabla \cdot (C\mathbf{v}) + \partial_z(k_z \partial_z C) + B_C$$

Advection

Vertical Mixing

Biogeochemical Reactions

$$\overline{C\mathbf{v}} = \overline{C}\,\overline{\mathbf{v}} + \overline{C'\mathbf{v}'}$$

Eddy/mean decomposition (1° - 1 month)

Introduction : Impact of fine scales

$$\langle\overline{\partial_t C}\rangle = -\langle\nabla\cdot(\overline{C}\overline{\mathbf{v}})\rangle - \langle\nabla\cdot(\overline{C'\mathbf{v}'})\rangle + \langle\partial_z(\overline{k_z}\partial_z\overline{C})\rangle + \langle\partial_z\overline{(k'_z\partial_z C')}\rangle + \langle\overline{B_C}\rangle + \langle\overline{B'_C}\rangle$$

< . > : Average over bio-provinces and over periods > 1 year

$$\langle\overline{\partial_t C}\rangle = -\langle\nabla\cdot(\overline{C}\,\overline{\mathbf{v}})\rangle - \langle\nabla\cdot(\overline{C'\mathbf{v}'})\rangle + \langle\partial_z(\overline{k_z}\partial_z\overline{C})\rangle + \langle\partial_z\overline{(k'_z\partial_z C')}\rangle + \langle\overline{B_C}\rangle + \langle\overline{B'_C}\rangle$$

- Mean advection
- Eddy advection
- Mean Vertical mixing
- Eddy Vertical mixing
- Mean biogeochemical reactions
- Eddy biogeochemical reactions

< . > : Average over bio-provinces and over periods > 1 year

Introduction : Impact of fine scales

$$\langle\overline{\partial_t C}\rangle = -\langle\nabla\cdot(\overline{C}\overline{\mathbf{v}})\rangle - \langle\nabla\cdot(\overline{C'\mathbf{v}'})\rangle + \langle\partial_z(\overline{k_z}\partial_z\overline{C})\rangle + \langle\partial_z\overline{(k_z'\partial_z C')}\rangle + \langle\overline{B_C}\rangle + \langle\overline{B_C'}\rangle$$

Mean advection

Eddy advection

Mean Vertical mixing

Eddy Vertical mixing

Mean biogeochemical reactions

Eddy biogeochemical reactions

< . > : Average over bio-provinces and over periods > 1 year

$$\langle\overline{\partial_t C}\rangle = \begin{cases} 0 & \text{: Mean state} \\ > \text{ and } < & \text{: Natural variability} \\ \text{long term trend} & \text{: Climate change} \end{cases}$$

Impact of fine scales on the mean state

$$0 = -\langle \nabla \cdot (\overline{C}\overline{\mathbf{v}}) \rangle - \langle \nabla \cdot (\overline{C'\mathbf{v}'}) \rangle + \langle \partial_z (\overline{k_z} \partial_z \overline{C}) \rangle + \langle \partial_z \overline{(k'_z \partial_z C')} \rangle + \langle \overline{B_C} \rangle + \langle \overline{B'_C} \rangle$$

Mean advection

Eddy advection

Mean Vertical mixing

Eddy Vertical mixing

Mean biogeochemical reactions

Eddy biogeochemical reactions

Eddy advection

$$\langle\overline{\partial_t C}\rangle = -\langle\nabla\cdot(\overline{C}\overline{\mathbf{v}})\rangle - \langle\nabla\cdot(\overline{C'\mathbf{v}'})\rangle + \langle\partial_z(\overline{k_z}\partial_z\overline{C})\rangle + \langle\partial_z\overline{(k_z'\partial_z C')}\rangle + \langle\overline{B_C}\rangle + \langle\overline{B_C'}\rangle$$

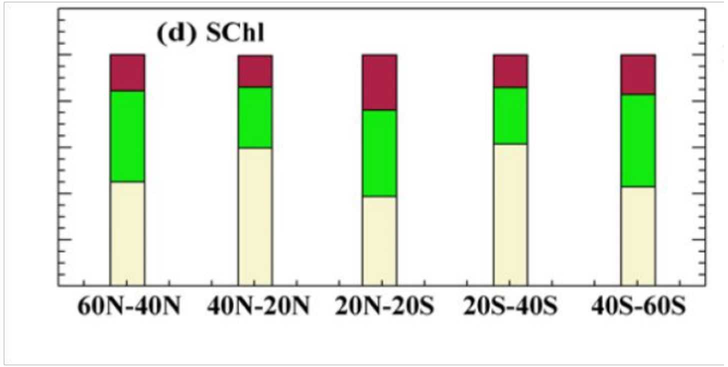
> 200 papers

Primary production
Carbon export
Oxygen ventilation

10 to 100 %

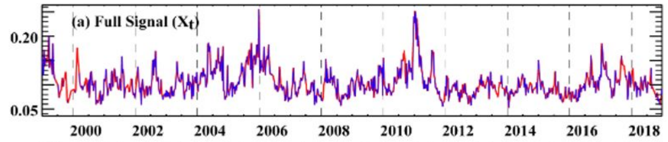
1) Horizontal eddy advection: stirring
2) Vertical eddy advection: nutrient supply
3) Vertical eddy advection: oxygen ventilation

Global Estimate of Horizontal Eddy Advection



⅓ of Chl-a variance due to fine-scales

Chl-a



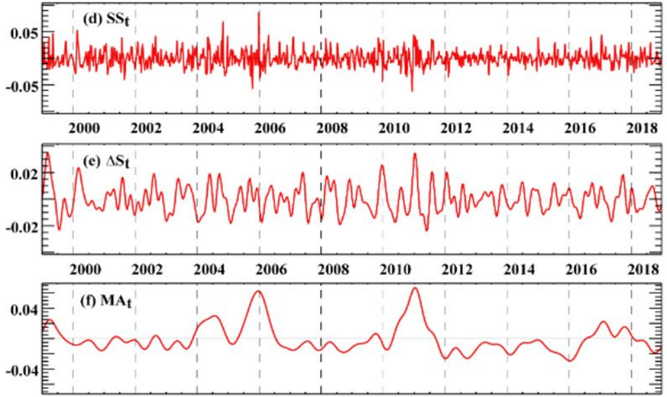
Decomposition into:

Subseasonal	20-100 km
Seasonal	>> 100 km
Multi-annual	>> 100 km

Subseasonal

Seasonal

Multi-annual



nature geoscience

Article https://doi.org/10.1038/s41561-022-01057-3

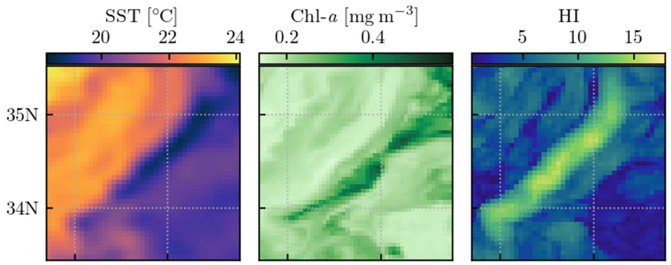
Annual variations in phytoplankton biomass driven by small-scale physical processes

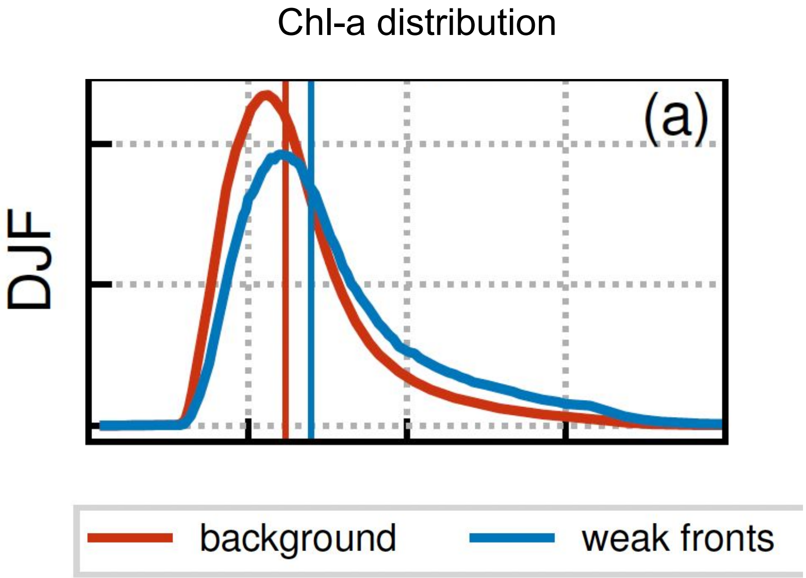
Received: 14 September 2021

Accepted: 22 September 2022

M. G. Keerthi[1], C. J. Prend[2], O. Aumont[1] & M. Lévy[1]

Regional Estimate of Vertical Eddy Advection





up to + 30% more Chl-a over fronts

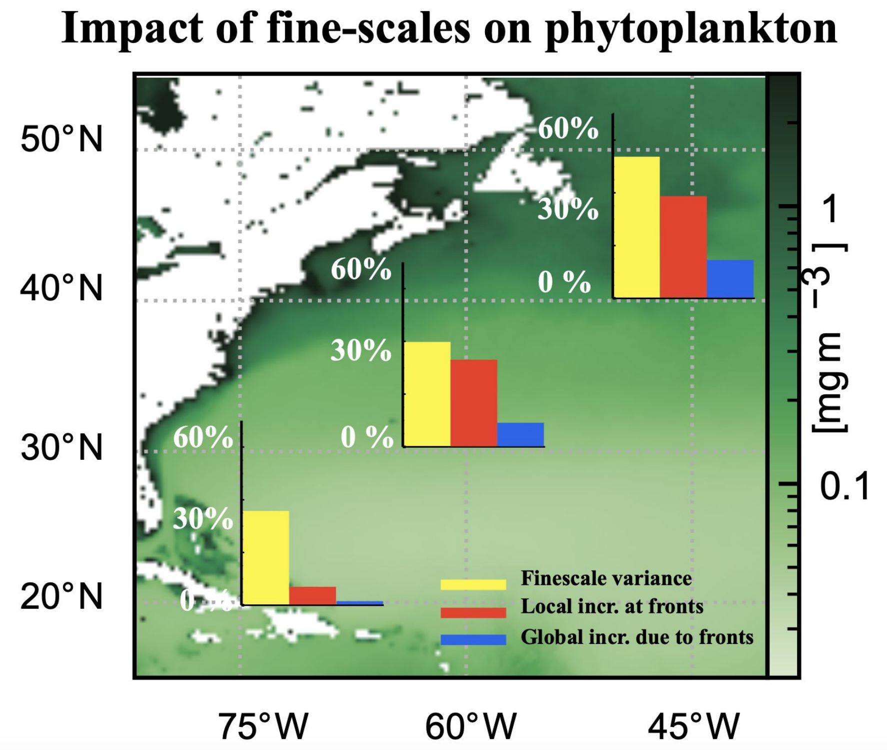
https://doi.org/10.5194/egusphere-2022-1489
Preprint. Discussion started: 6 January 2023

EGUsphere
Preprint repository

marina.levy@locean.ipsl.fr

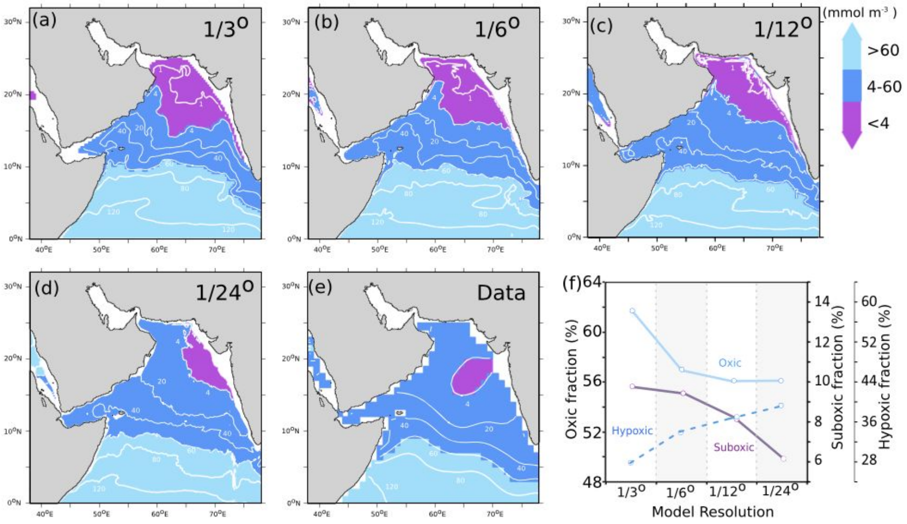
Satellite data reveal earlier and stronger phytoplankton blooms over fronts in the Gulf Stream region

Clément Haëck[1], Marina Lévy[1], Inès Mangolte[1], and Laurent Bopp[2]
[1]LOCEAN-IPSL, Sorbonne Université, CNRS, IRD, MNHN, Paris, France
[2]LMD-IPSL, École Normale Supérieure / Université PSL, CNRS, École Polytechnique, Paris, France



Less than + 10% more Chl-a attributed to finescales

Eddy advection of Oxygen



More than + 70% of O_2 ventilation attributed to finescales

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL069876

Eddies reduce denitrification and compress habitats in the Arabian Sea

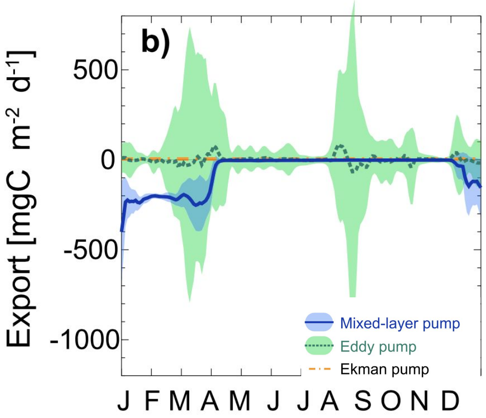
Zouhair Lachkar[1], Shafer Smith[1,2], Marina Lévy[3], and Olivier Pauluis[1,2]

Key Points:
- Lateral eddy transport of dissolved oxygen plays a lead role in ventilating

Eddy vertical mixing

$$\langle \overline{\partial_t C} \rangle = -\langle \nabla \cdot (\overline{C}\overline{\mathbf{v}}) \rangle - \langle \nabla \cdot (\overline{C'\mathbf{v}'}) \rangle + \langle \partial_z (\overline{k_z}\partial_z \overline{C}) \rangle + \langle \partial_z \overline{(k_z' \partial_z C')} \rangle + \langle \overline{B_C} \rangle + \langle \overline{B_C'} \rangle$$

1 paper
Resplandy et al (2019)

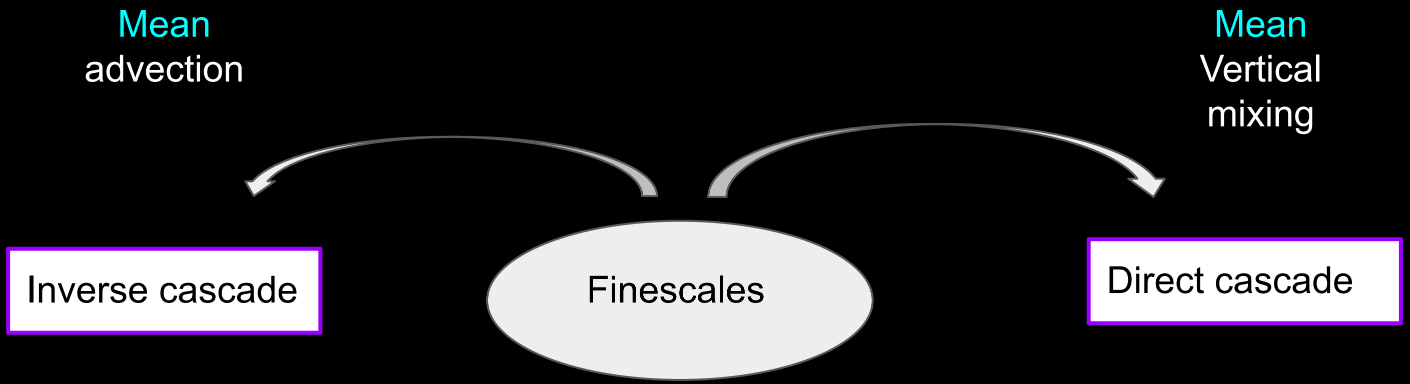


Eddy Biogeochemical Reactions

$$\langle\overline{\partial_t C}\rangle = -\langle\nabla\cdot(\overline{C}\,\overline{\mathbf{v}})\rangle - \langle\nabla\cdot(\overline{C'\mathbf{v}'})\rangle + \langle\partial_z(\overline{k_z}\partial_z\overline{C})\rangle + \langle\partial_z\overline{(k'_z\partial_z C')}\rangle + \langle\overline{B_C}\rangle + \langle\overline{B'_C}\rangle$$

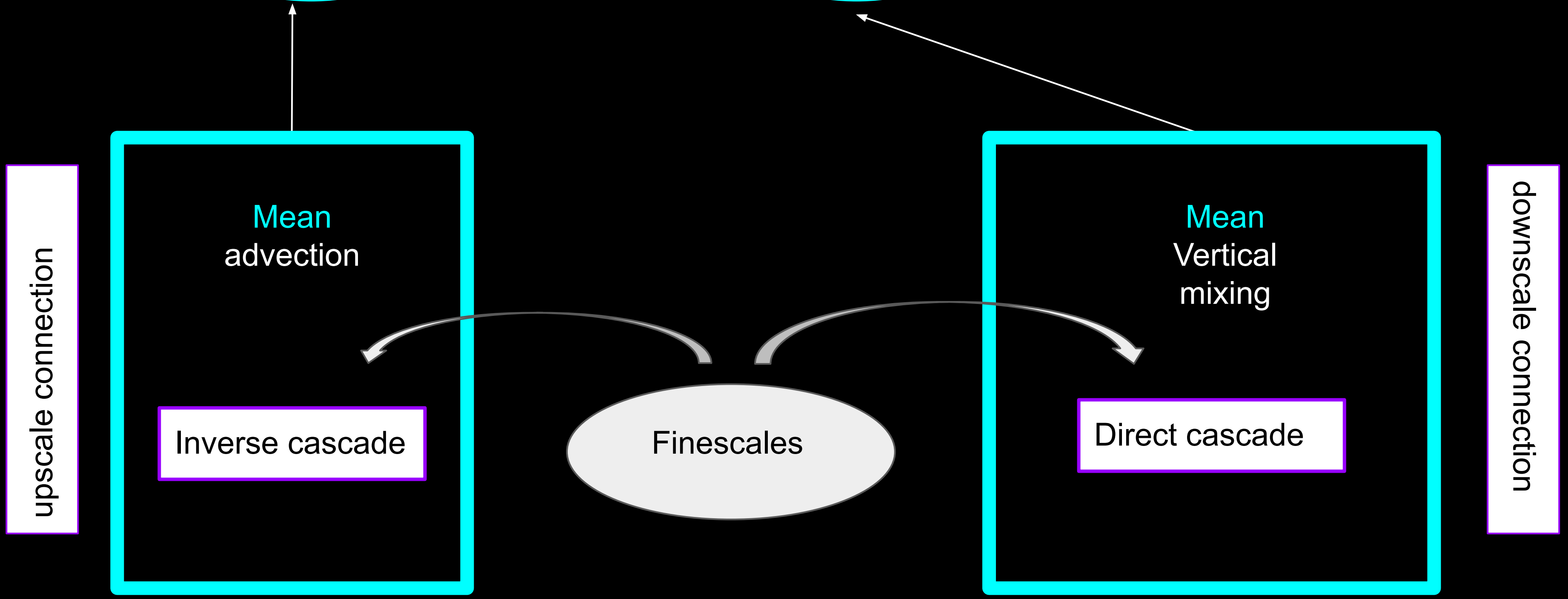
2 papers
Levy et al (2014)
Martin et al (2015)
1-5 %

Impact of fine scales on the mean state

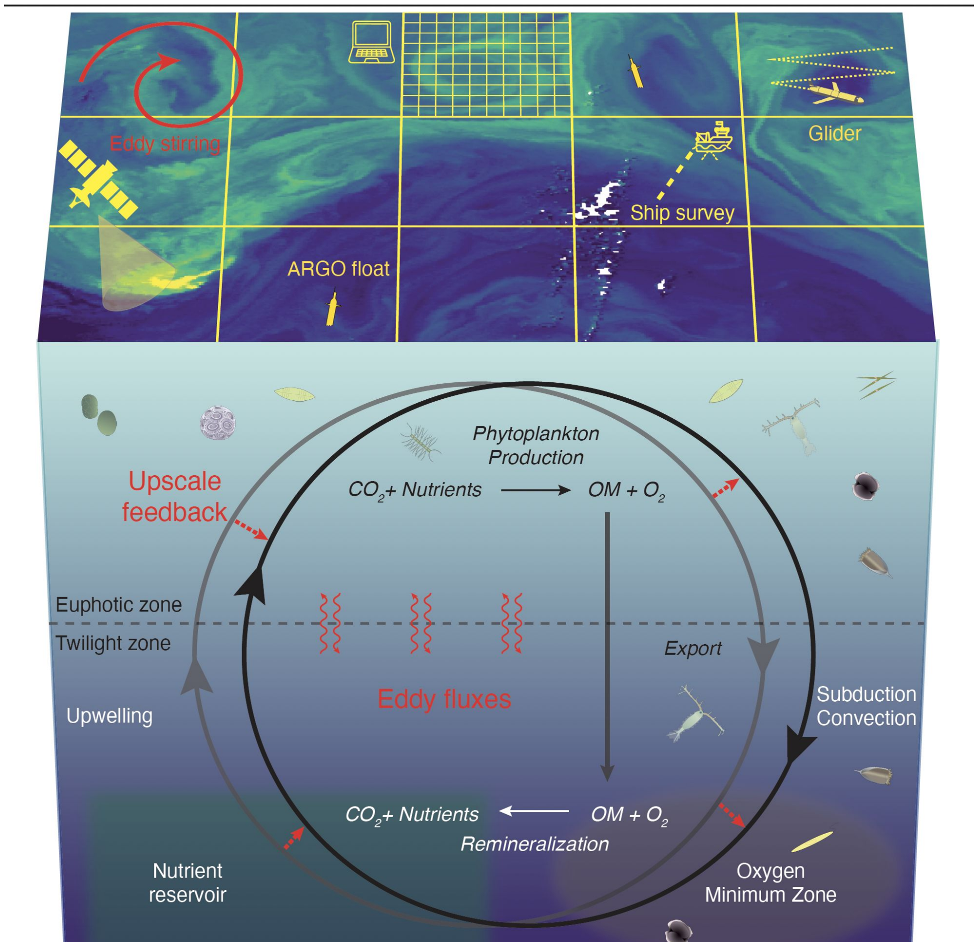


Impact of fine scales on the mean state

$$0 = -\langle \nabla \cdot (\overline{C}\,\overline{\mathbf{v}}) \rangle - \langle \nabla \cdot (\overline{C'\mathbf{v}'}) \rangle + \langle \partial_z (\overline{k_z} \partial_z \overline{C}) \rangle + \langle \partial_z (\overline{k'_z \partial_z C'}) \rangle + \langle \overline{B_C} \rangle + \langle \overline{B'_C} \rangle$$

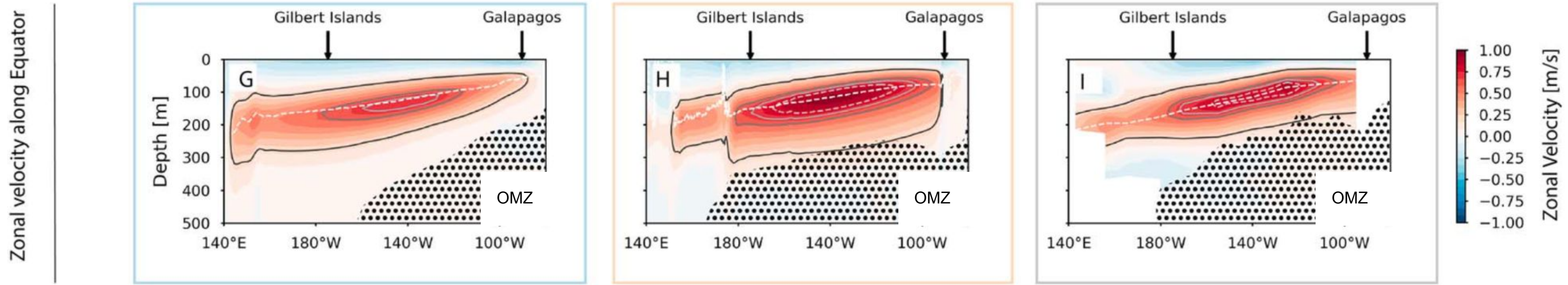


Challenge 2 : Scale interactions



Equatorial Pacific Oxygen Minimum Zone (OMZ)

1° resolution model | 1/10° resolution model | Observations



Change in position and strength of equatorial undercurrent affects the OMZ

Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL082692

The Equatorial Undercurrent and the Oxygen Minimum Zone in the Pacific

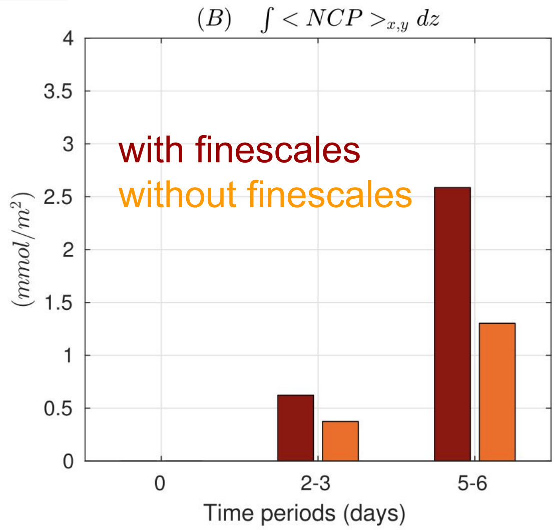
Julius J. M. Busecke[1], Laure Resplandy[1], and John P. Dunne[2]

Department of Geosciences,[1]Princeton University, Princeton, NJ, USA, [2]NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA

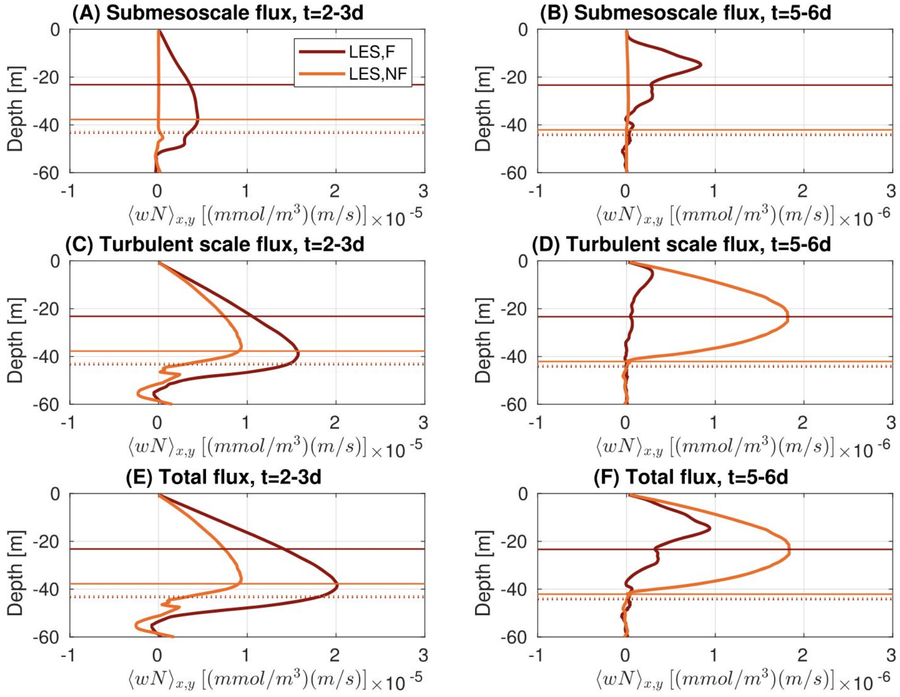
Key Points:
- The Equatorial Undercurrent dynamics control the structure of the oxygen minimum zone (OMZ) in the equatorial Pacific
- The mean shape of the OMZ

Downscale connection

Phytoplankton production



Nutrient vertical fluxes in LES model



JGR Oceans

RESEARCH ARTICLE
10.1029/2019JC015370

Submesoscales Enhance Storm-Driven Vertical Mixing of Nutrients: Insights From a Biogeochemical Large Eddy Simulation

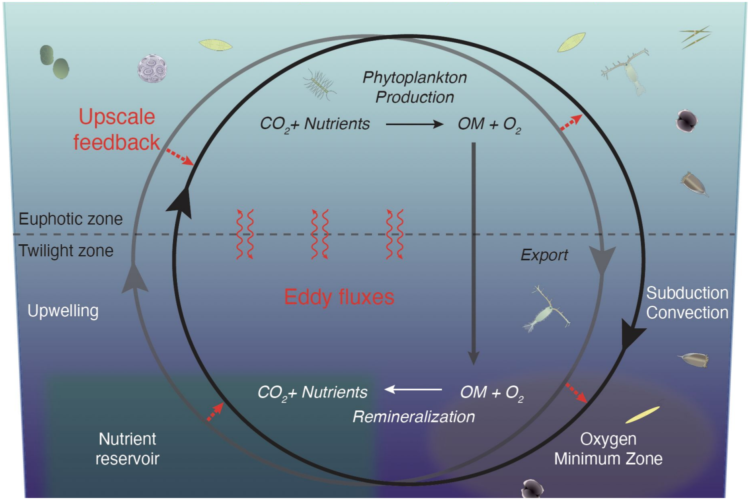
D. B. Whitt[1], M. Lévy[2], and J. R. Taylor[3]

[1]National Center for Atmospheric Research, Boulder, CO, USA, [2]Sorbonne Université CNRS/IRD/MNHN, LOCEAN-IPSL, Paris, France, [3]Department of Applied Mathematics and Theoretical Physics, Centre for Mathematical Sciences, University of Cambridge, Cambridge, UK

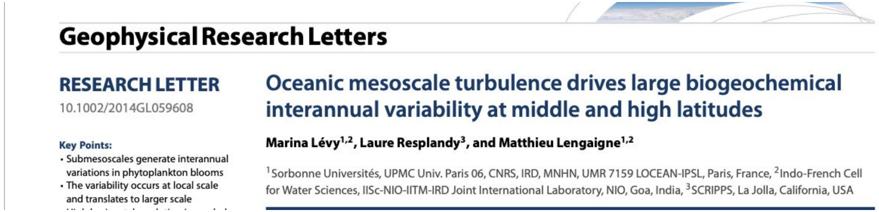
Key Points:
- Physical/biogeochemical large eddy simulations show that submesoscales enhance turbulent mixing and net community production during a storm
- Submesoscales suppress mixed-layer turbulence after the storm and facilitate the formation of vertical

Impact of finescales on Biogeochemical cycles Natural variability

$$\langle \partial_t \overline{C} \rangle = -\langle \nabla \cdot (\overline{C}\,\overline{\mathbf{v}}) \rangle - \langle \nabla \cdot (\overline{C'\mathbf{v}'}) \rangle + \langle \partial_z (\overline{k_z} \partial_z \overline{C}) \rangle + \langle \partial_z \overline{(k'_z \partial_z C')} \rangle + \langle \overline{B_C} \rangle + \langle \overline{B'_C} \rangle$$



Upscale feedback


Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL059608

Key Points:
- Submesoscales generate interannual variations in phytoplankton blooms
- The variability occurs at local scale and translates to larger scale

Oceanic mesoscale turbulence drives large biogeochemical interannual variability at middle and high latitudes

Marina Lévy[1,2], Laure Resplandy[3], and Matthieu Lengaigne[1,2]

[1]Sorbonne Universités, UPMC Univ. Paris 06, CNRS, IRD, MNHN, UMR 7159 LOCEAN-IPSL, Paris, France, [2]Indo-French Cell for Water Sciences, IISc-NIO-IITM-IRD Joint International Laboratory, NIO, Goa, India, [3]SCRIPPS, La Jolla, California, USA


SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL088304

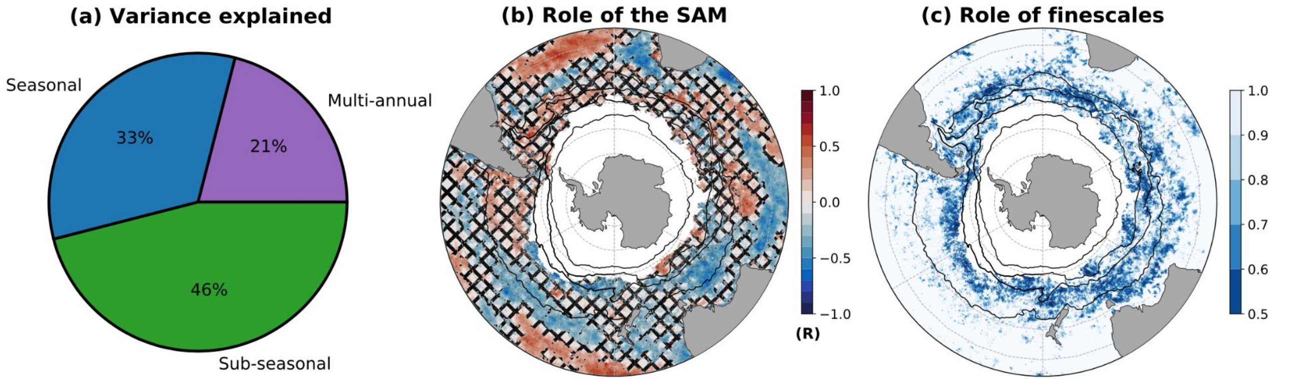
Key Points:
- Interannual chaotic intrinsic (CIV)

Quantification of Chaotic Intrinsic Variability of Sea-Air CO_2 Fluxes at Interannual Timescales

M. Gehlen[1], S. Berthet[2], R. Séférian[2], Ch. Ethé[3], and T. Penduff[4]

Eddy fluxes

Drivers of phytoplankton interannual variability



Finescales explain most of phytoplankton interannual variations in the SO

Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1029/2022GB007329

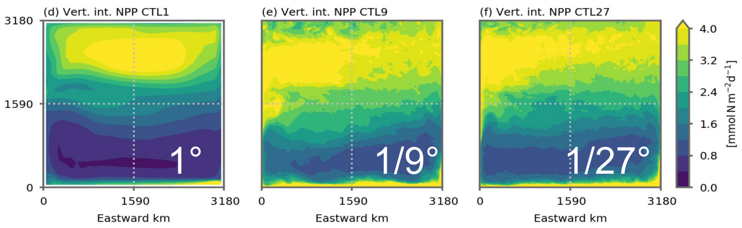
Special Section:
Southern Ocean and Climate:
Biogeochemical and Physical

Sub-Seasonal Forcing Drives Year-To-Year Variations of Southern Ocean Primary Productivity

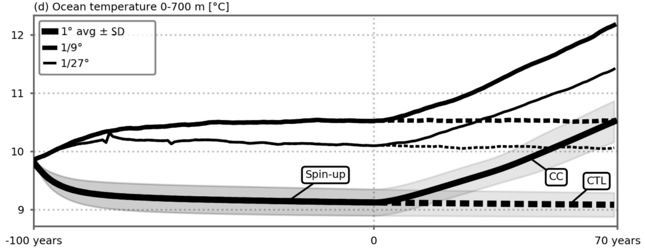
Channing J. Prend[1], M. G. Keerthi[2], Marina Lévy[2], Olivier Aumont[2], Sarah T. Gille[1], and Lynne D. Talley[1]

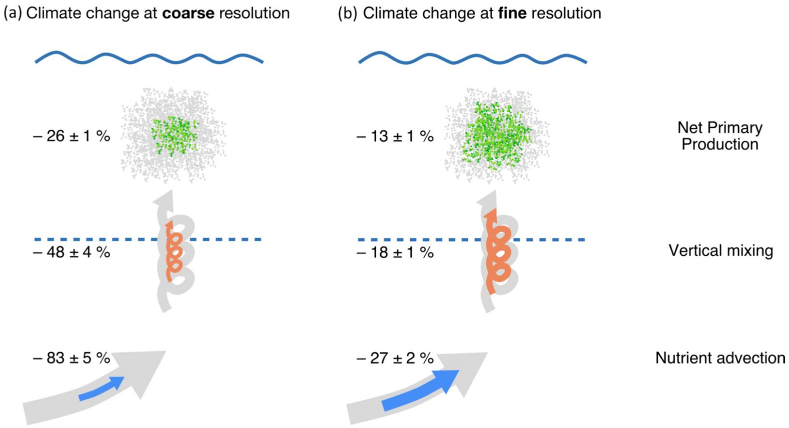
Impact of finescales on Biogeochemical cycles projections

CTL Primary production



Climate change (warming)

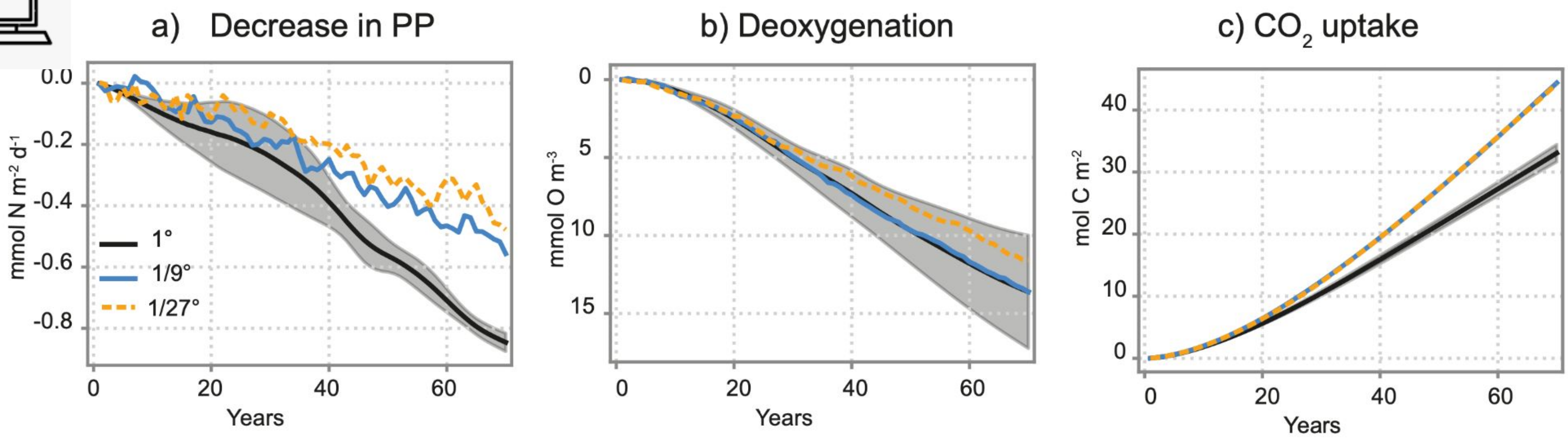




Oceanic primary production decline halved in eddy-resolving simulations of global warming

Damien Couespel[1], Marina Lévy[1], and Laurent Bopp[2]

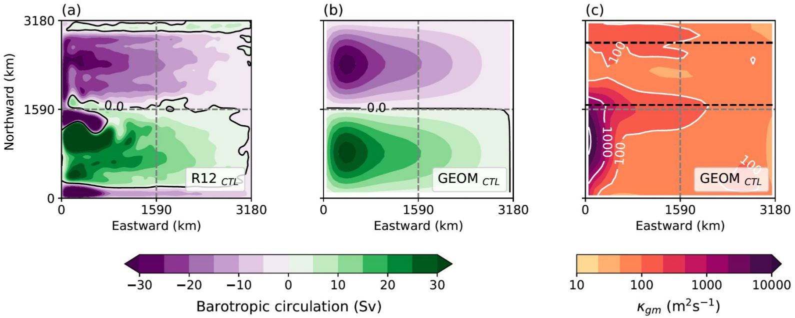
Impact of finescales on Biogeochemical cycles projections



Damping of climate change impacts and of climate change with finescales

due to upscale feedback

no change in eddy fluxes



Diagnostic	R12 values	CONST values	GEOM values	improve over CONST
northward heat transport (10^{15} W) (Fig. 3*d*, *e*, *f* and 9*d*, *e*, *f*)				
area average (CTL)	0.146	0.078	0.094	✓
area average (CC)	0.148 (+2.0%)	0.097 (+23.5%)	0.099 (+5.7%)	✓ (✓)
sensitivity (L^2)	0.004	0.020	0.006	✓
NPP (mmol N m^{-2} day^{-1}) (Fig. 5 and 11)				
area average (CTL)	3.67	2.76	2.91	✓
area average (CC)	3.16 (−13.8%)	2.13 (−22.9%)	2.22 (−23.6%)	✓ (×)

Physique

Bio

Combined physical and biogeochemical assessment of mesoscale eddy parameterisations in ocean models: eddy induced advection at non-eddying resolutions

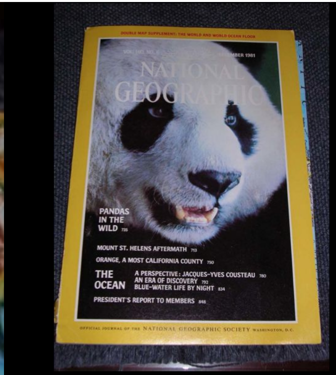
2023

X. Ruan[a,b,1], D. Couespel[c,d], M. Lévy[d], J. Li[a,b], J. Mak[a,b,1], Y. Wang[a,b]

Summary points

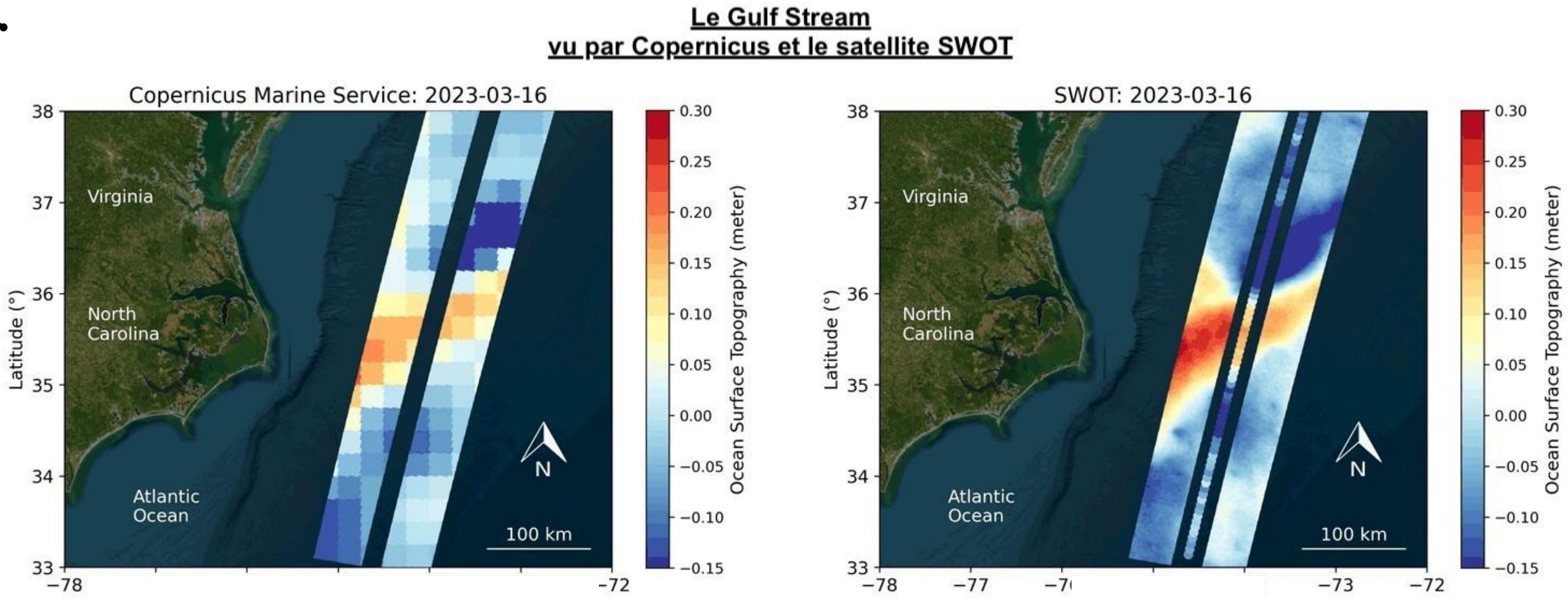
1. Multiple processes at play
2. Progress on understanding the processes
3. Challenge in quantifying them due to the multi-scale nature of the problem
4. Parametrisation for the physics are unsufficient
5. Upscale feedback seems to prevail for CC


Sensing the ocean's crop by satellite
"WHERE ARE THEY BITING?"
That familiar fisherman's question cannot yet be answered directly from space. However, the Coastal Zone Color Scanner (CZCS) aboard the Nimbus 7 satellite can answer this question: Where are the regions of greatest phytoplankton concentration? Where they are abundant, a fully developed food chain follows, including commercially valuable fish.
A CZCS image of the Atlantic (foldout, right), printed by a computer, shows concentrations of phytoplankton. The scanner detects absorption of certain wavelengths of light by the chlorophyll that plankton use for photosynthesis.
The CZCS is still experimental, and, in a time of budget cutting, its fate is uncertain. Yet it might prove as useful for the study of the sea as Landsat has been for continents and Tiros for weather forecasting.
MORE
CHLOROPHYLL
LESS
New York


NATIONAL GEOGRAPHIC
PANDAS IN THE WILD
MOUNT ST. HELENS AFTERMATH
ORANGE, A MOST CALIFORNIA COUNTY
THE OCEAN
A PERSPECTIVE: JACQUES-YVES COUSTEAU
AN ERA OF DISCOVERY
BLUE-WATER LIFE BY NIGHT
PRESIDENT'S REPORT TO MEMBERS

1980

Opportunities : New tools



Conventional altimetry

SWOT

43 years later

March 2023

The Impact of Fine-Scale Currents on Biogeochemical Cycles in a Changing Ocean

Marina Lévy,[1] Damian Couespel,[2] Clément Haëck,[1] Madhavan Girijakuma Keerthi,[1] Inès Mangolte,[1] and Channing J. Prend[3,4]

[1]Laboratoire d'Océanologie et de Climatologie: Expérimentations et Analyses Numériques–Institut Pierre Simon Laplace (LOCEAN-IPSL), Sorbonne University, Paris, France; email: marina.levy@locean.ipsl.fr
[2]Norwegian Research Centre (NORCE), Bjerknes Centre for Climate Research, Bergen, Norway
[3]School of Oceanography, University of Washington, Seattle, Washington, USA
[4]Department of Environmental Science and Engineering, California Institute of Technology, Pasadena, California, USA

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