Next Generation Climate Science in Europe for Oceans
End-term Meeting

EUREC^{4}A-OA

Improving the representation of small-scale nonlinear ocean-atmosphere interactions in Climate Models by innovative joint observing and modelling approaches

29 April 2024

Project Partners

- LMD-IPSL, France (Coordinator)
- LOCEAN-IPSL, France
- LEGOS, France
- CNRM, France
- LOPS, France
- UIB, Norway
- NORCE, Norway
- GEOMAR, Germany
- MPI-Hamburg, Germany
- HEREON, Germany
- UNIMIB, Italy
- CIMA Foundation, Italy

4 Countries | 12 Partners

6 WPs | 13 tasks

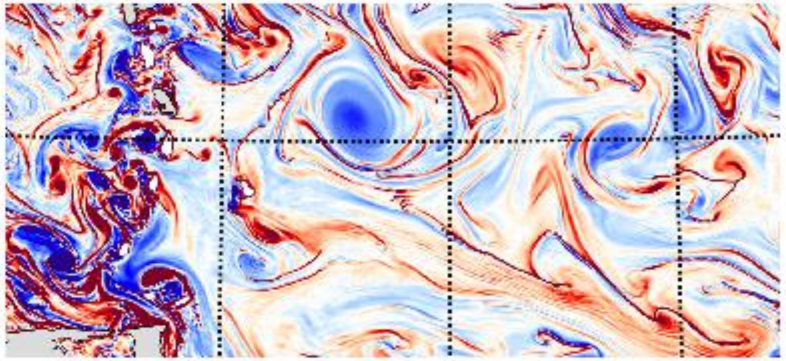
4 Milestones -- 4 Deliverables

Budget 1.9 M€

EUREC^{4}A-OA main objectives were:

1. Assess **the impact of the diurnal cycle on energy, water and CO2 ocean-atmosphere exchanges** & modification of the diurnal cycle and the related exchanges by ocean small scales and other extreme conditions;
2. **Identify and quantify the processes ruling the ocean-atmosphere exchanges** and uptake of heat, momentum and CO2 at the ocean small scales;
3. **Determine the role of the diurnal cycle, ocean nonlinear small scales, boundary layer aerosols on the atmospheric shallow convection and cloud formation**;
4. **Provide improved model-metrics and parameterizations** for the above processes to be integrated into operational prediction systems and ESMs.

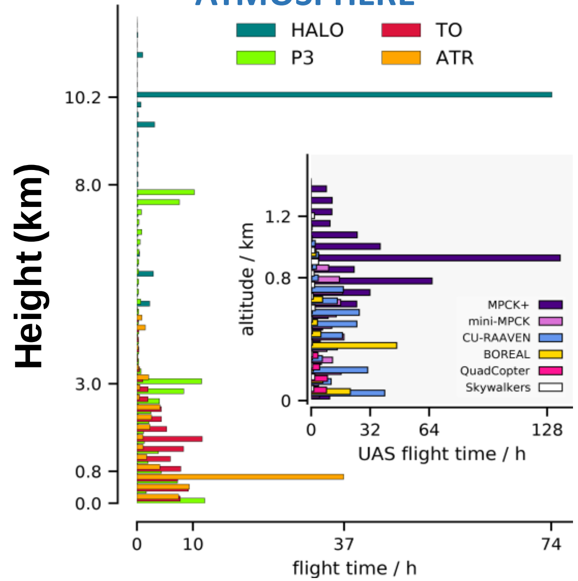
1-month multiplatform field experiment



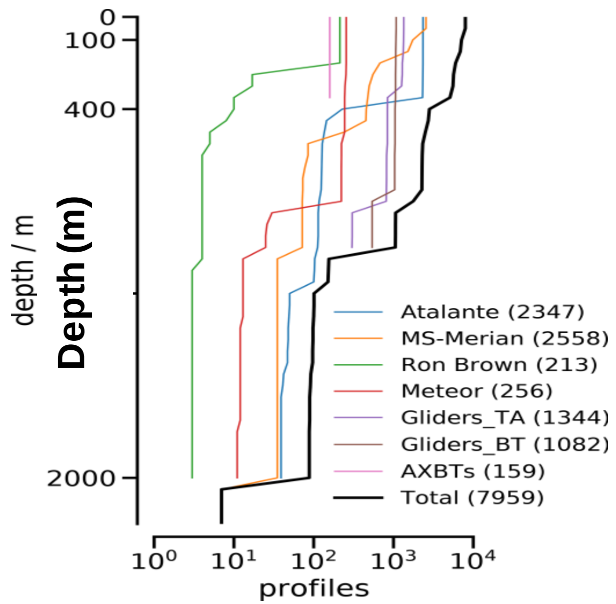
A large variety of ocean, atmosphere & coupled OA models

EUREC^{4}A-OA – ATOMIC: Collected Observations

ATMOSPHERE

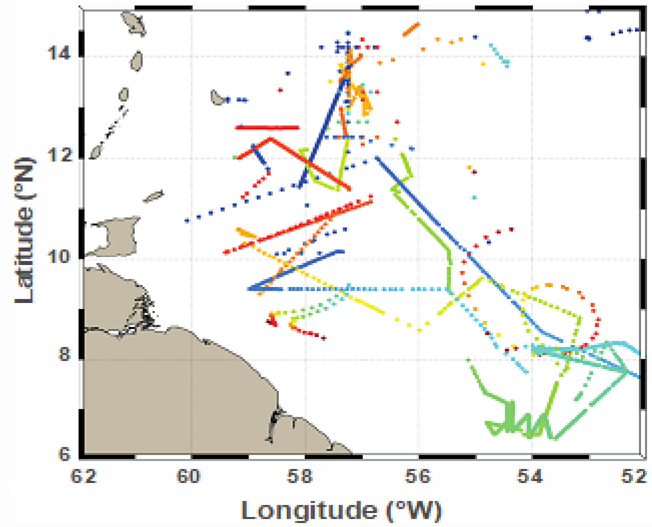


OCEAN

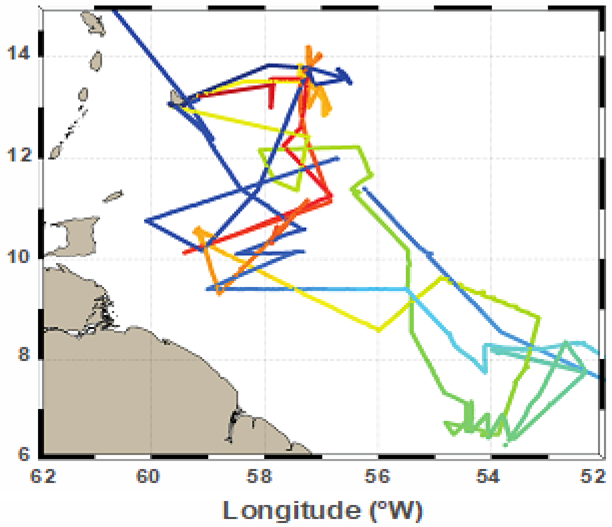


Ocean Database of Cross-Validated Observations (*L'Hégaret et al., 2023*)

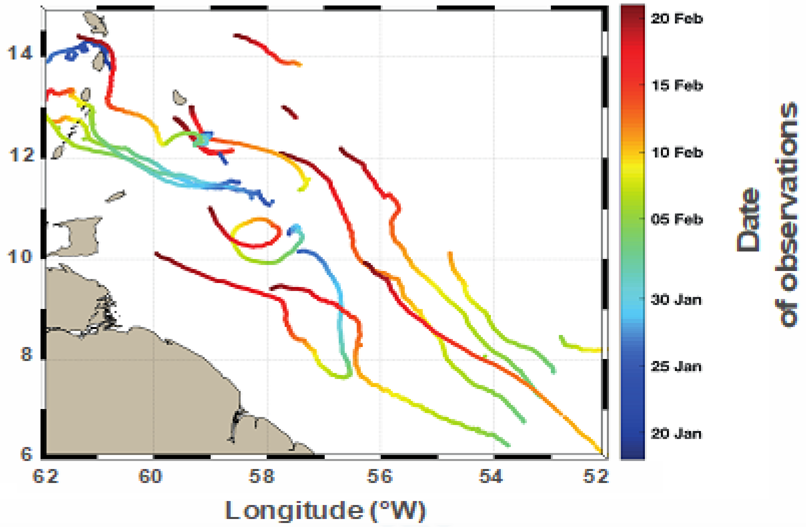
8 000+ Hydrographic Profiles (10% > 400 dbar)



110 000+ S-ADCP Profiles (65% > 400 dbar)



Surface Buoys Trajectories 16 active at least 1 week



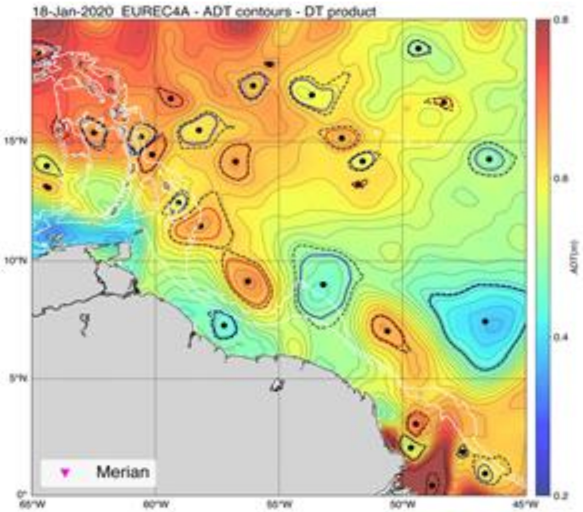
EURECA-OA

JPI OCEANS

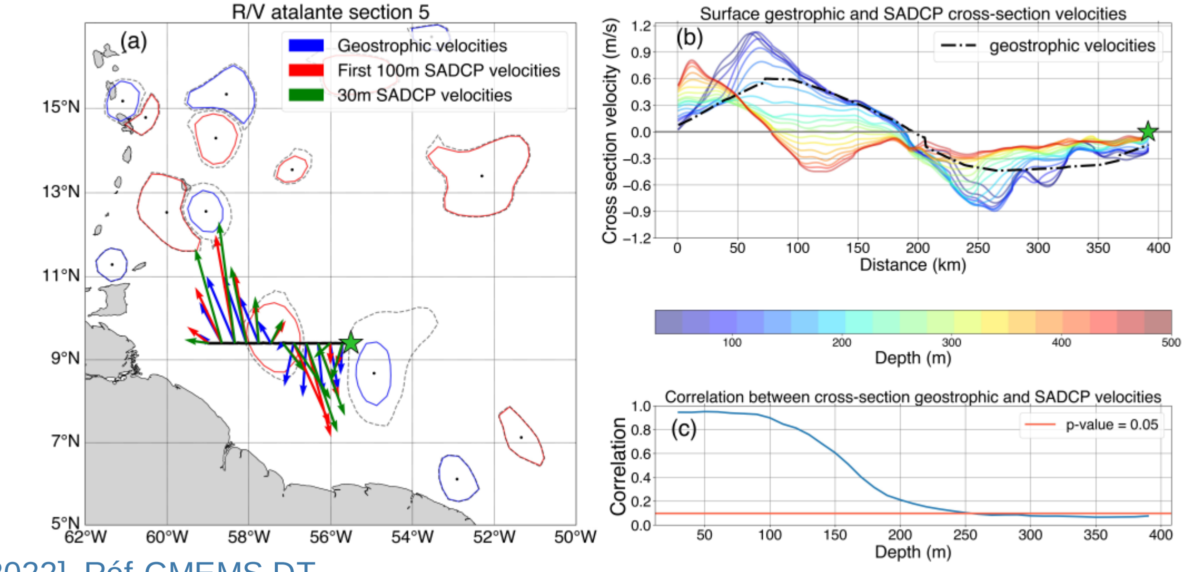
JPI Climate

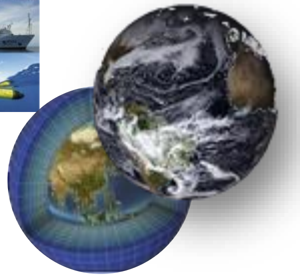
Very high-resolution sampling for understanding processes and validating models

Synoptical situation



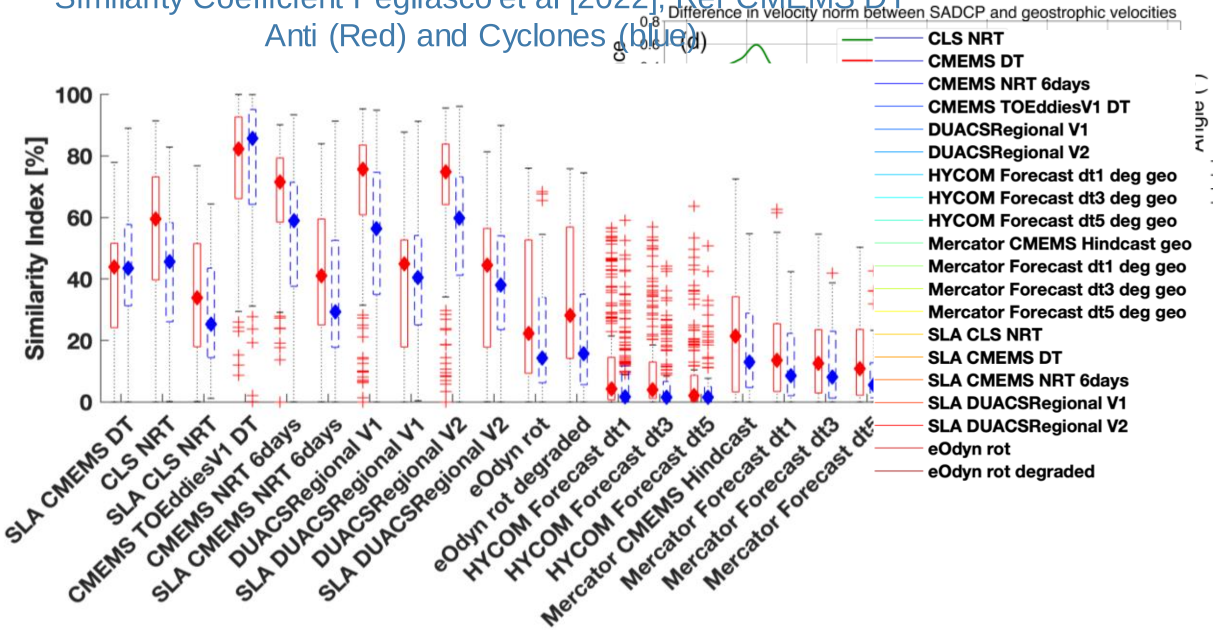
Comparison of eddies with altimetry (TOEddies, ADT)

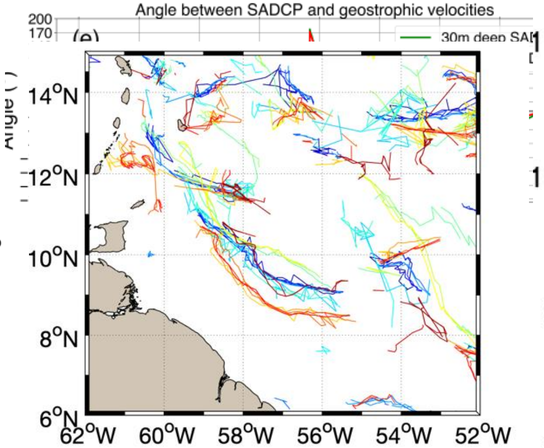


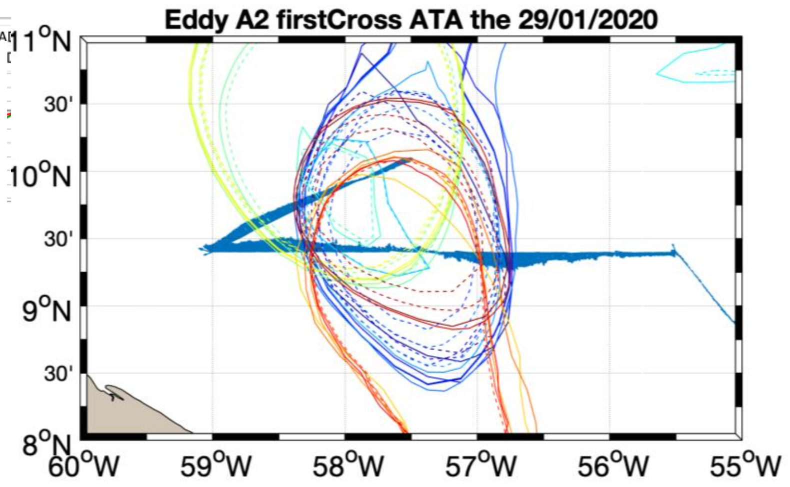


L'Hégaret et al., 2023;
Subirade et al., 2023;
Laxenaire et al., in prep.

Similarity Coefficient Pegliasco et al [2022], Réf CMEMS DT
Anti (Red) and Cyclones (blue)



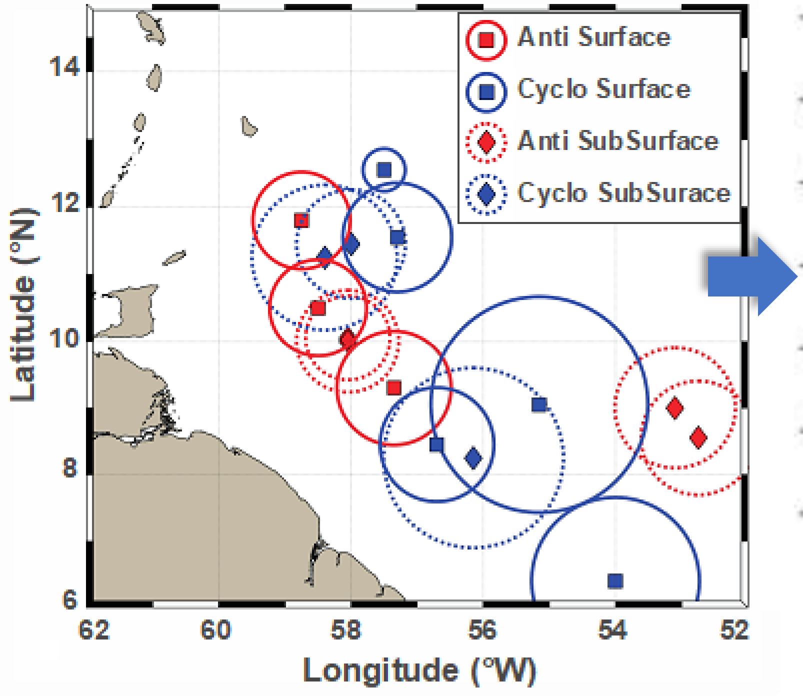




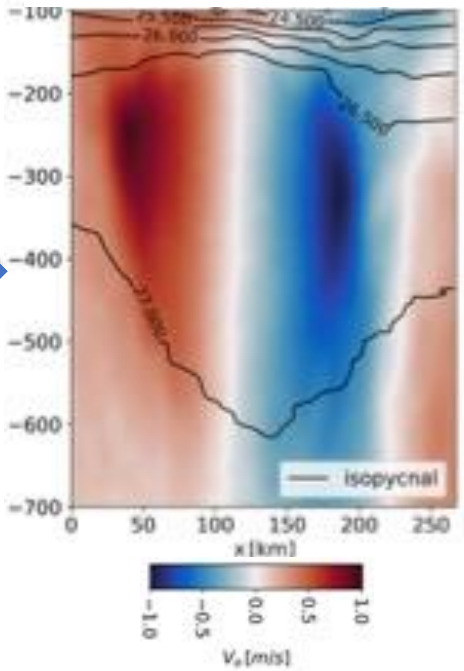
Exemple de différences entre les bases de données ;
Trajectoires des anticyclones (à gauche) et position d'un tourbillon traversé par le N/O Atalante (ADCP moyenné dans les 150 premiers mètres).

Very high-resolution sampling led to new insights on the mesoscale

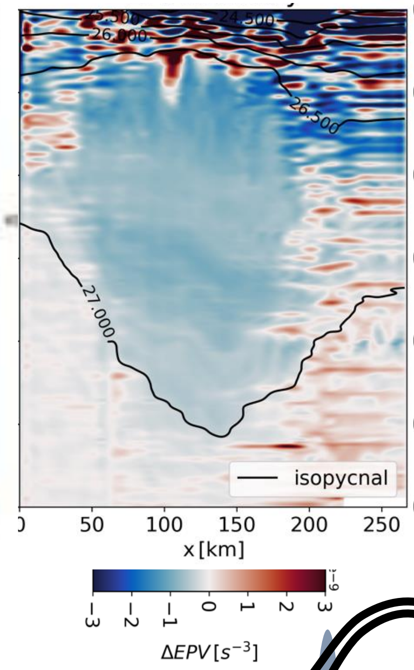
Eddies from S-ADCP using the Nencioli et al. (2018)'s method



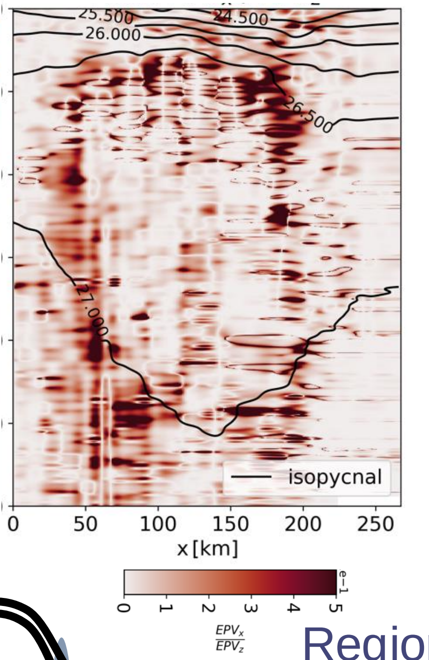
S-ADCP orthogonal velocity



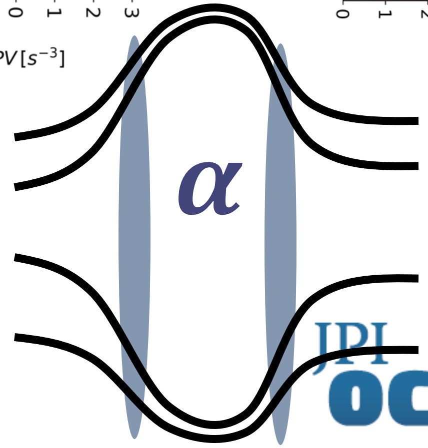
EPV anomaly



Ratio EPV_x/EPV_z



- Ertel PV **anomaly** on isopycnal surfaces → Core characterization
  - $\Delta EPV = EPV - \overline{EPV}$
- Ertel PV **ratio** → Frontal boundary characterization
  - $|\boldsymbol{EPV_x}| - \boldsymbol{\alpha}|\boldsymbol{EPV_z}| > \boldsymbol{0}$



Regions where $|EPV_x| - \alpha|EPV_z| > 0$ coincides vertically with the inflection points of isopycnals.

Barabinot et al., 2024

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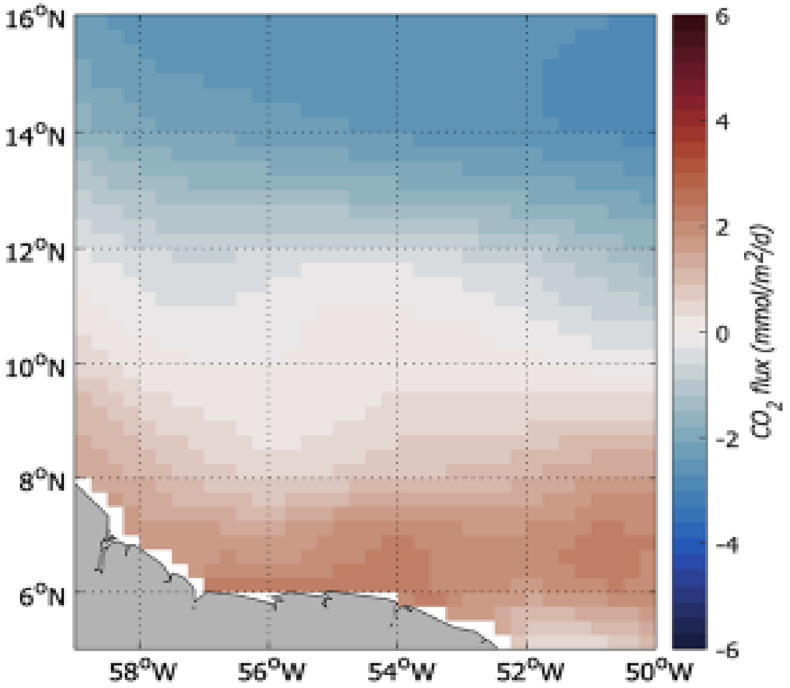
JPI Climate

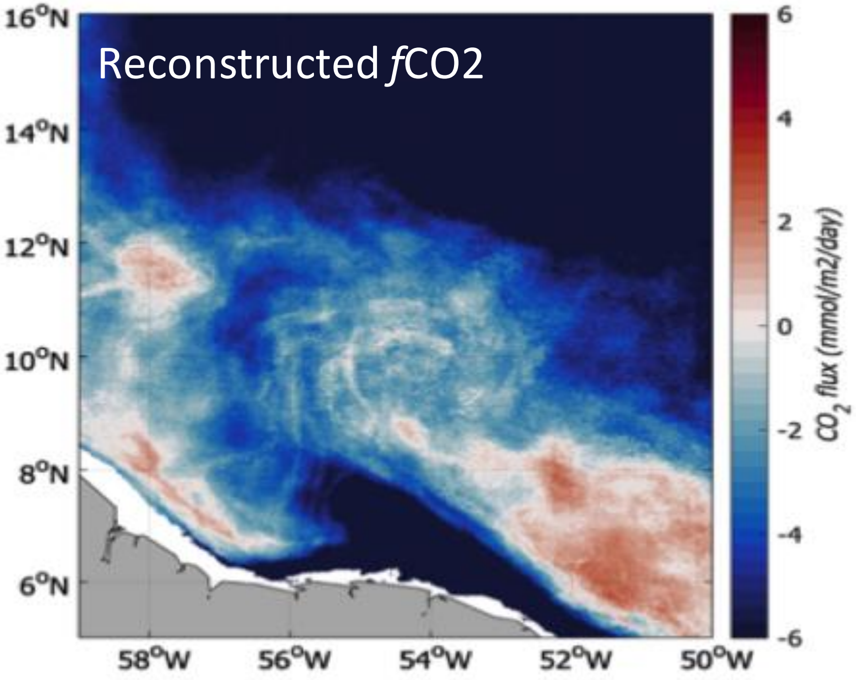
The ocean small-scale & CO2 Air-Sea exchanges

Ocean small-scale matters & fluxes are intenser than climatology

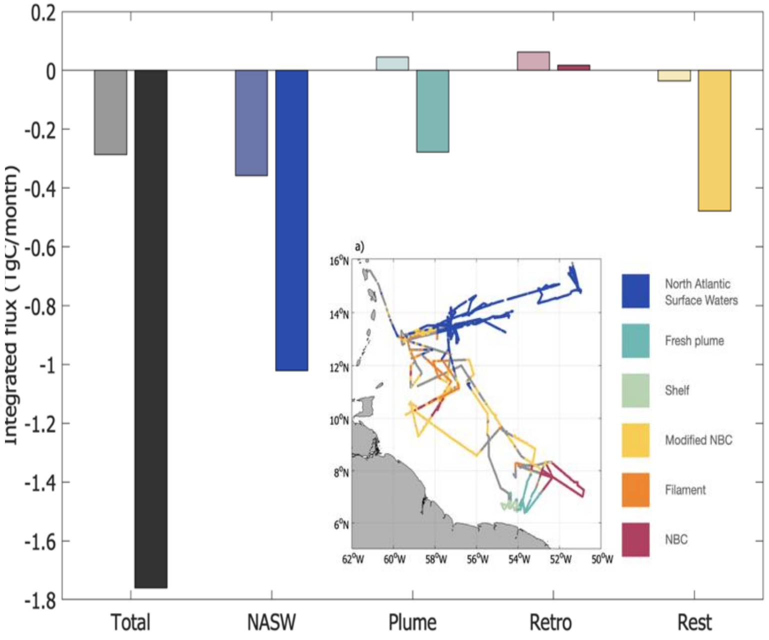
February air-sea CO_2 flux climatology
(Landschützer et al., 2020)



Reconstruction from R/V Atalante, Merian and Ron Brown & Satellite data
(EUREC[4]A-OA/ATOMIC, Jan-Feb 2020)

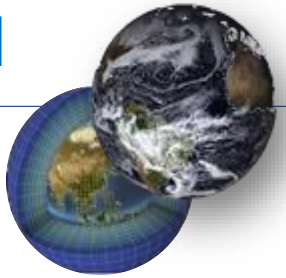


CO2 AIR-SEA FLUX BUDGET
EUREC4A-OA/ATOMIC vs CLIMATOLOGY

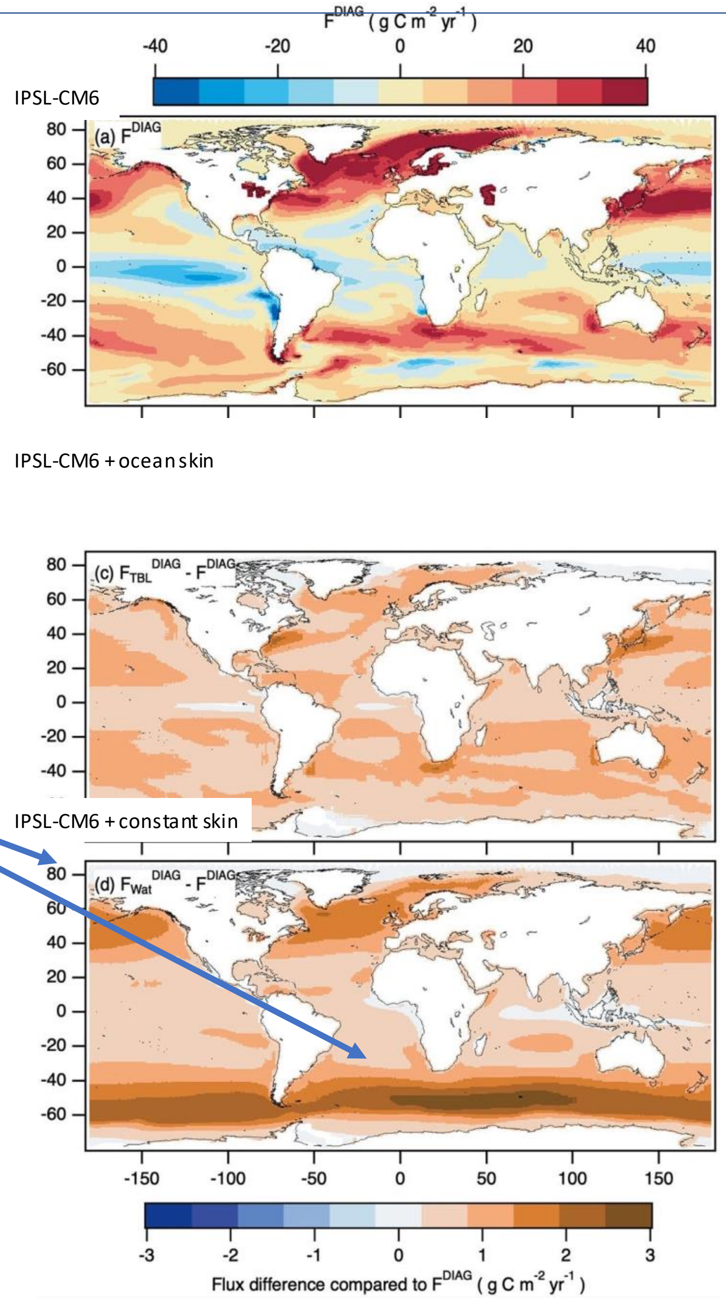


Olivier et al., 2022

Air-sea CO2 exchanges in global model



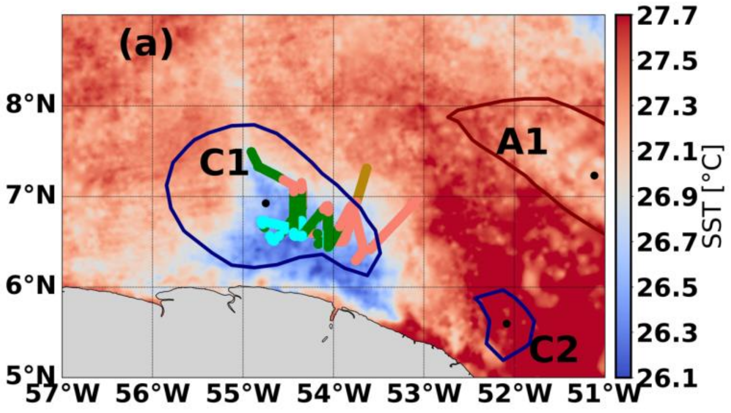
- Watson et al. (2020, Nat. Comm.) re-initiated a debate on the impact of the 1 mm depth oceanic diffusive layer (ocean's cool skin) on the global air-sea flux of CO_2. **Using a constant skin they diagnosed an increase of 15% of the global air-sea sink.**
- **Using IPSL-CM6 with a physical model for the ocean skin**, we found that this effect goes **down to 5% in a coupled configuration**.
- Considering a **constant cool skin leads to overestimation of the skin effect** in mid-to-high latitudes.
- Considering that the cool skin is implicitly taken into account in bulk parameterization lead to the same regional errors.

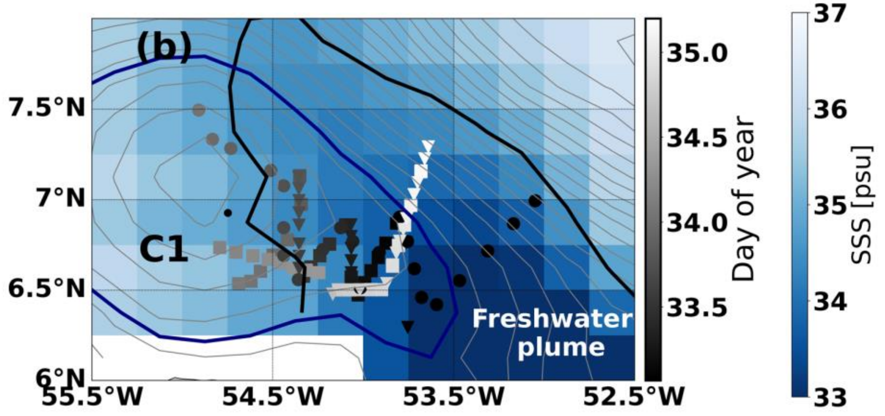


Bellenger et al. 2023, JGR-O

The ocean small-scale & Air-Sea Heat Turbulent Fluxes

Ocean small-scale matters: air-sea fluxes of heat depend on them too

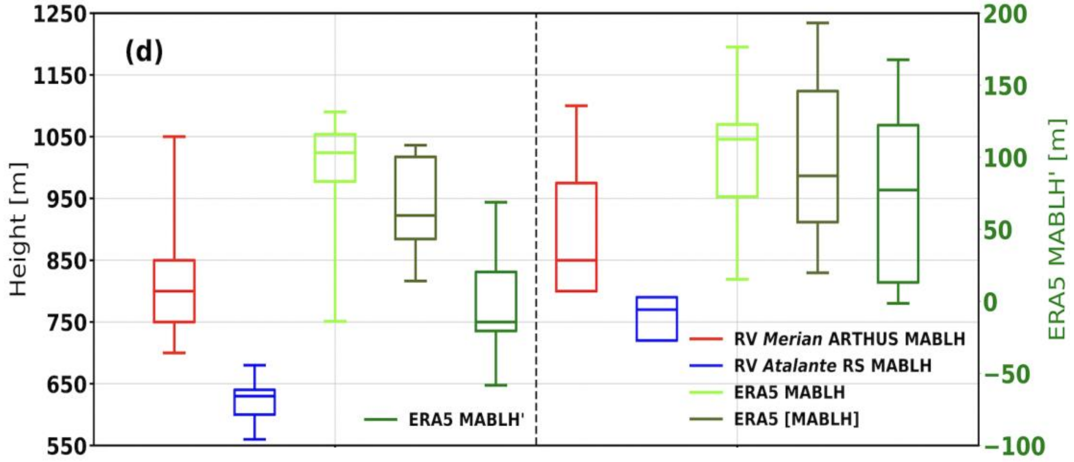




Sampling of 4 different water masses

Cooler SST patch (coastal upwelling) + Amazon plume + NBC rings:

ΔSST 2ºC, ΔSSS 6 psu



Cold side of the front   Warm side of the front

- **First – order effects**: wind speed and SST
- **Second – order effects**: subsurface warm layers, covariance between wind and Δq, TFB, and CFB.

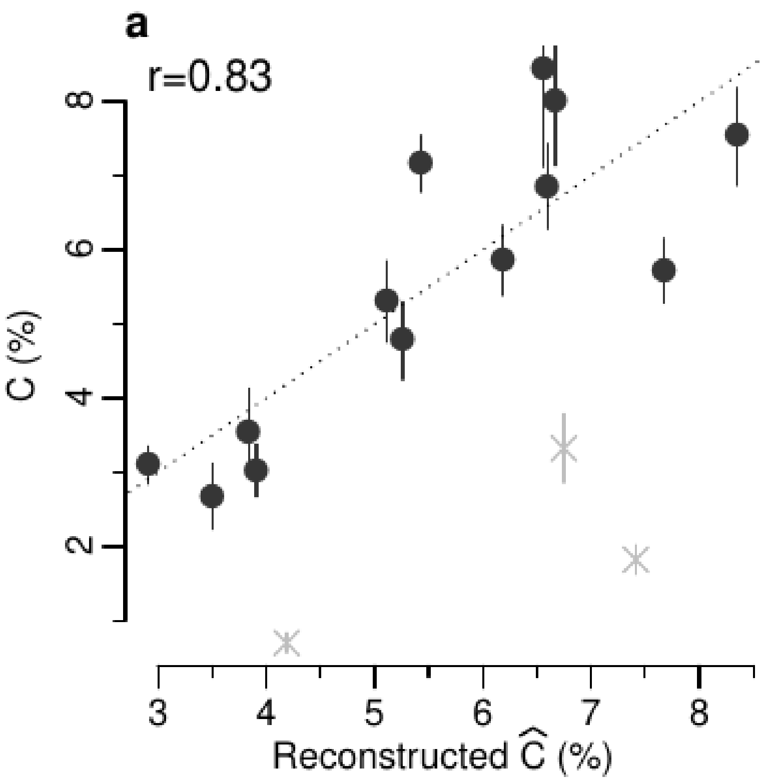
The changes in near-surface winds induced by mesoscale (and smaller scale) SST structures (TFB) and near-surface currents (CFB) are on average 10-30% depending on the water mass

Fernandez et al., 2024

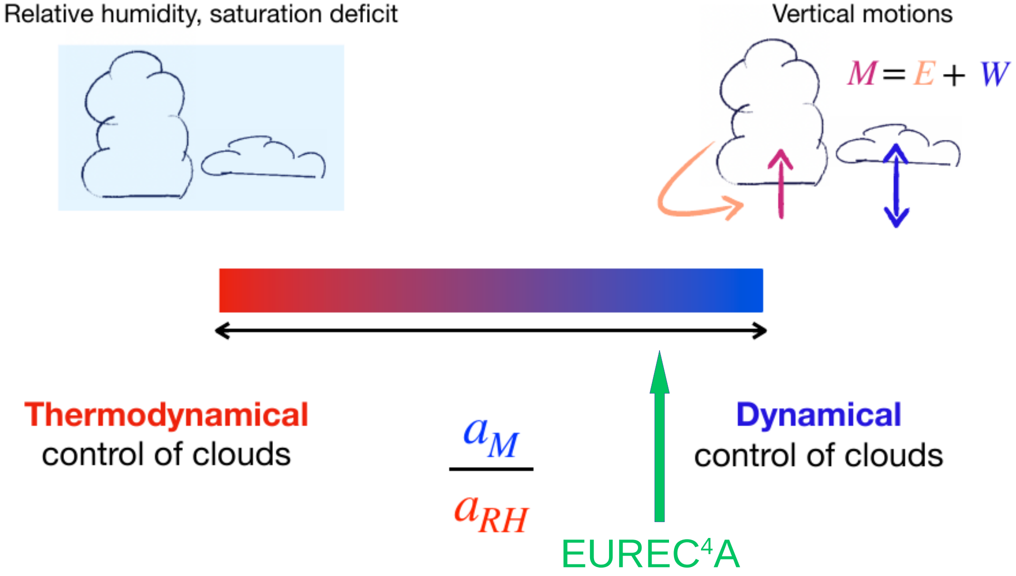
The cloud cycle in the atmosphere depends on the dynamical process

The dynamical processes (versus the thermodynamic control) depend on the ocean small-scale

$$\hat{C} = a_{RH}\widetilde{RH} + a_M\widetilde{M} + a_0$$



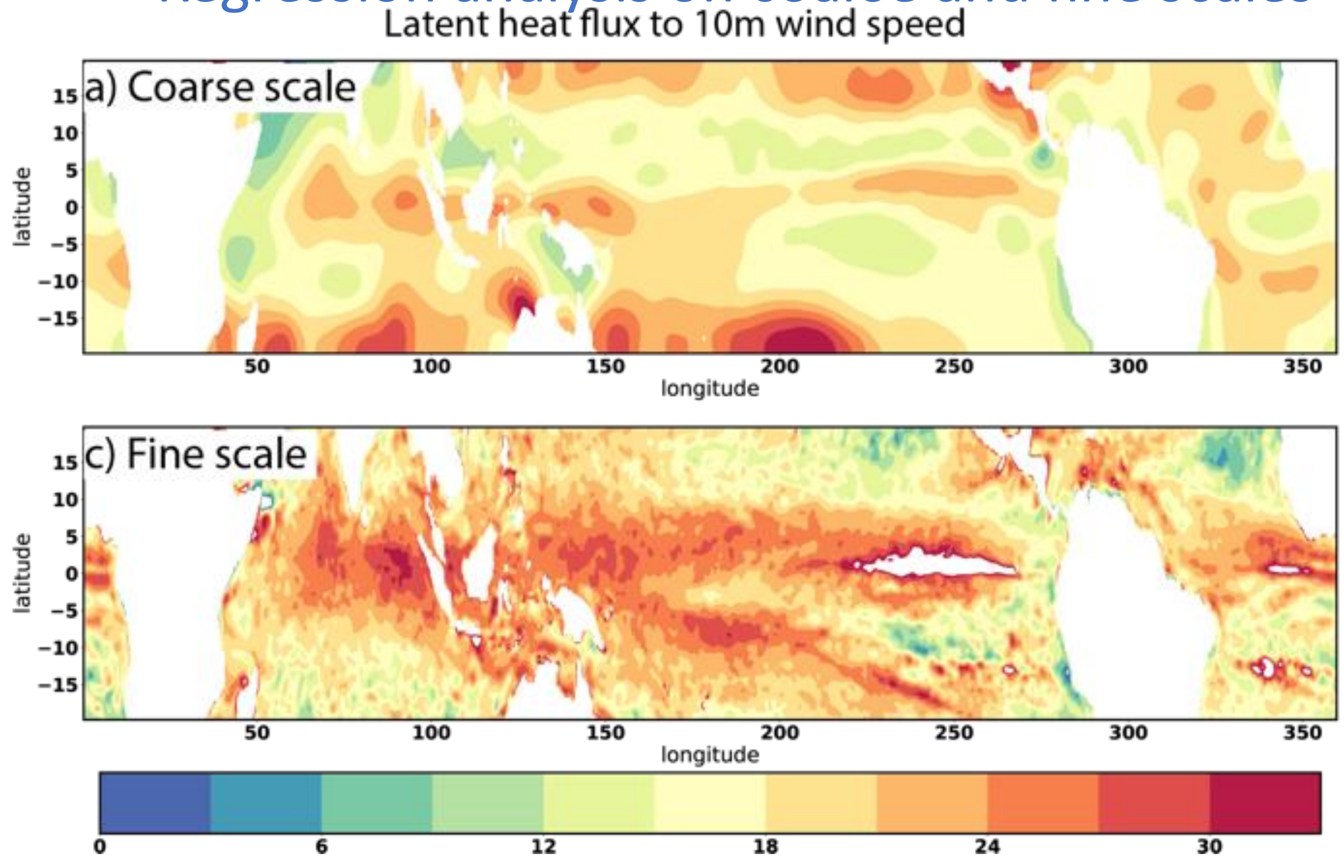
The dynamical control of clouds overwhelms the thermodynamic control through humidity



Tropical rainfall model biases and the role of fine-scale air-sea interaction

Analysis of high-resolution (25km) NorESM simulation shows that latent heat flux is overestimated on finer-scales. This points to important directions for modelling

Regression analysis on coarse and fine scales



Additional experiments have shown the importance of finescales for low-level clouds over the EURECA region

EURECA-OA

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Tian, F., et al. Resolution-Dependent Sensitivity of Tropical Precipitation and Latent Heat Flux in the NorESM Model, submitted to JAMES

Reducing climate model bias in Low Level Cloud

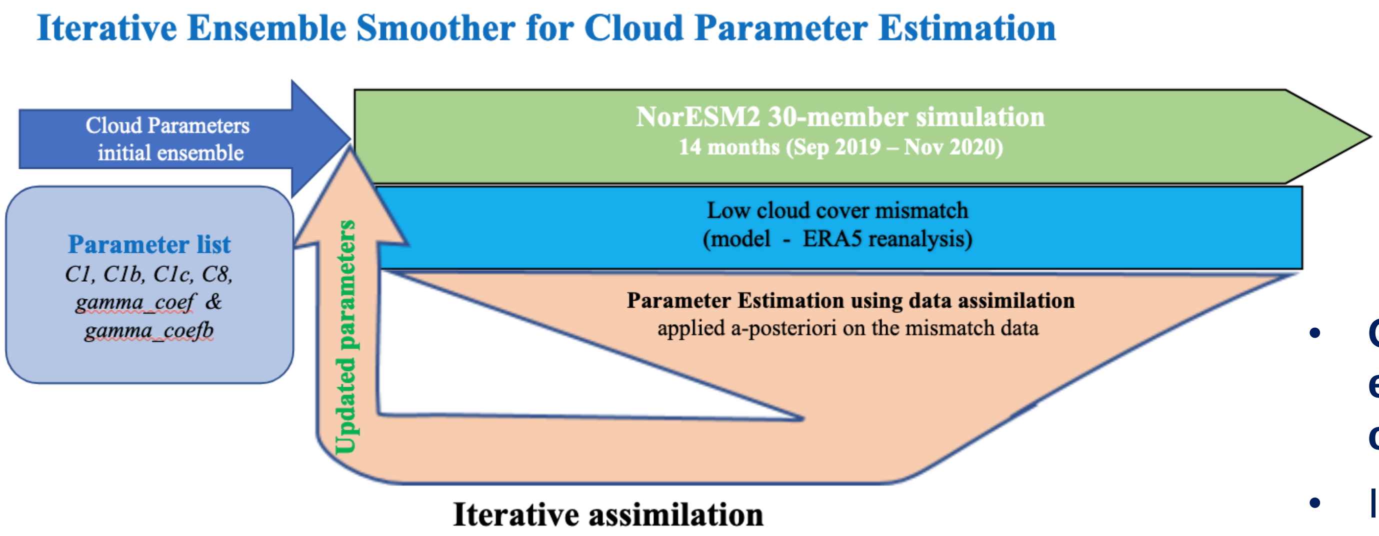


Figure 1. Flowchart for the offline data assimilation method

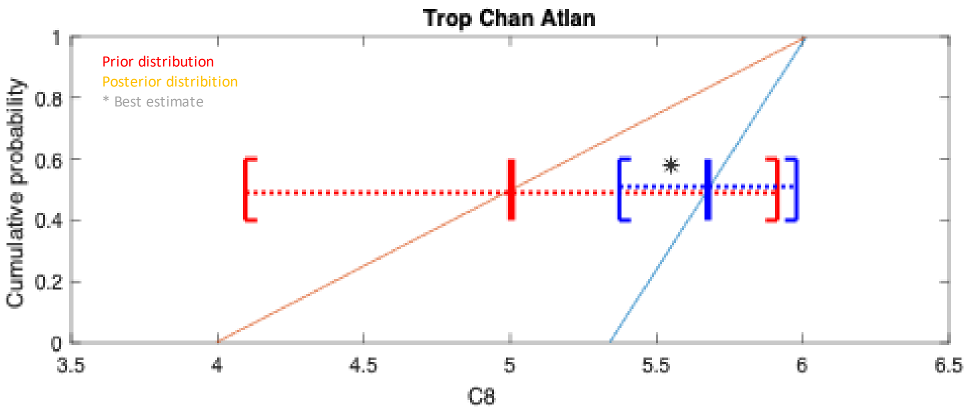


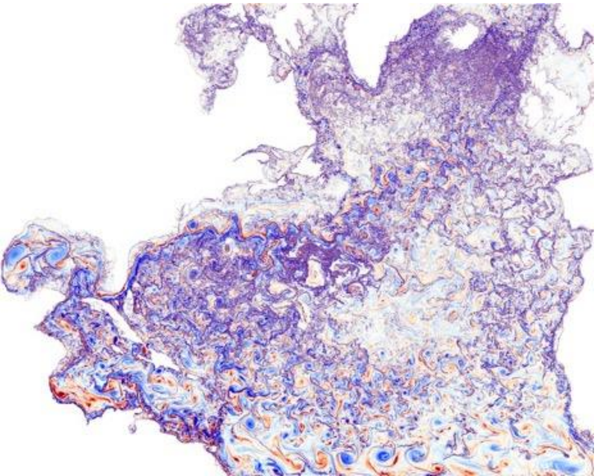
*Figure 2. Prior (red) and posterior (blue) distributions for the parameter C8 with the best estimate from the DA method indicated by a *.*

Key findings:

- **Offline data assimilation for parameter estimation efficiently converged on parameter values for the cloud scheme, CLUBB**.
- Iterative modelling approach confirmed optimum parameters.
- Cost function can be readily adapted to optimise model bias across multiple variables. E.g. minimize Low Level Cloud bias within a tolerable range of SST bias.
- Just two parameters (C8 and γ) strongly controlled Low Level Cloud in the fully coupled NorESM.
- Reduced NorESM bias in low level cloud *without* introducing large bias in other components.

Conclusions

- **Ocean small (meso-submeso) scales** contributes to first and second order air-sea fluxes in the Northwest Tropical Atlantic
- **Measured CO2 fluxes are higher** than those accounted for in the climatology (Jan-Feb 2020 was a large sink of CO2)
- The **complex interaction between Amazon freshwater and NBC rings affects also heat turbulent fluxes (LHF)**
- **LHF is strongly shaped by submesoscale dynamics (**SST fronts).
- **The Dynamic effect (MABL changes) is more important than the Thermodynamic one.**
- **The ocean is an active 3D system**, at submeso & mesoscale. 2D assessments need to be confronted with 3D varying in time ocean structure
- **The parallel approaches of observations with hierarchy of models was strategic**.

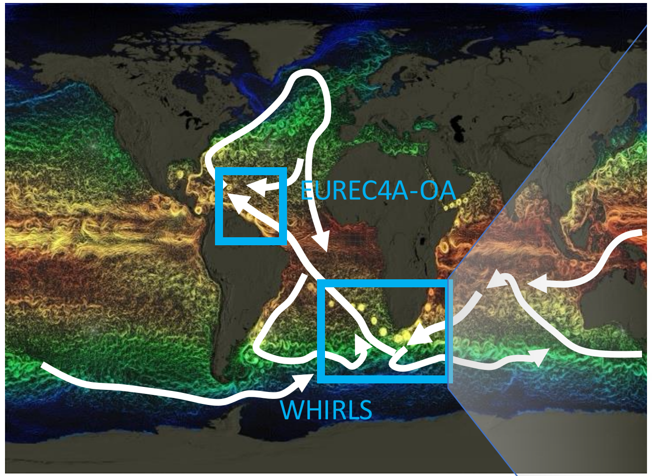


European Research Council
Established by the European Commission

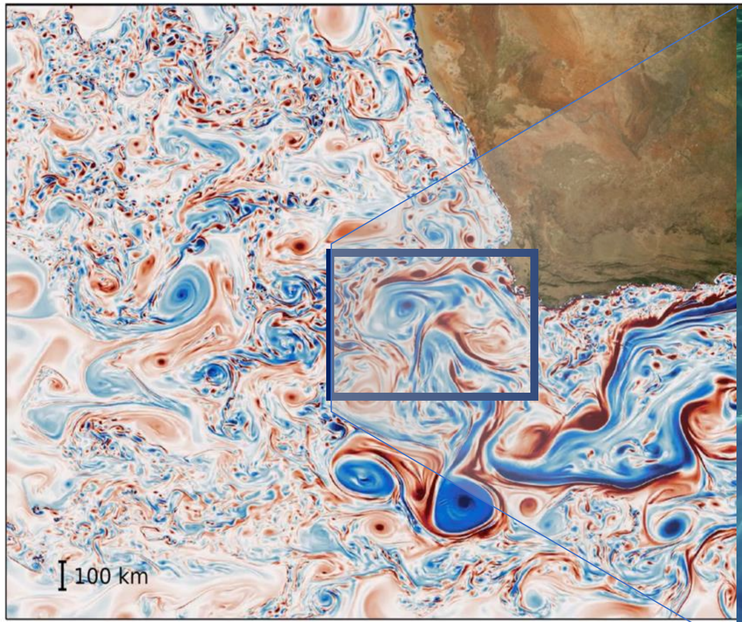
WHIRLS

A project to continue to improve our knowledge on the physics of the small scales of the ocean and their impact on climate and ecosystems

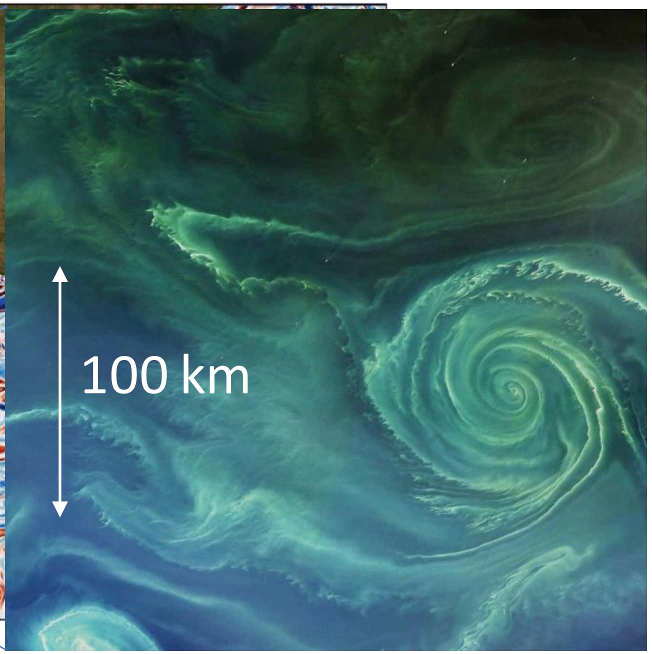
Arne Biastoch (GEOMAR), Sabrina Speich (LMD-ENS), Sebastiaan Swart (UGOT), Sarah Fawcett (UCT)



Ocean surface currents and temperature



Turbulence



Surface chlorophyll

LMD ENS | PSL GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel GÖTEBORGS UNIVERSITET

Fine scales:
Mesoscale [10–100 km]
Submesoscale [1–10 km]