

The Fine Resolution Explorer for Salinity Carbon and Hydrology **FReSCH** *L-band mission*

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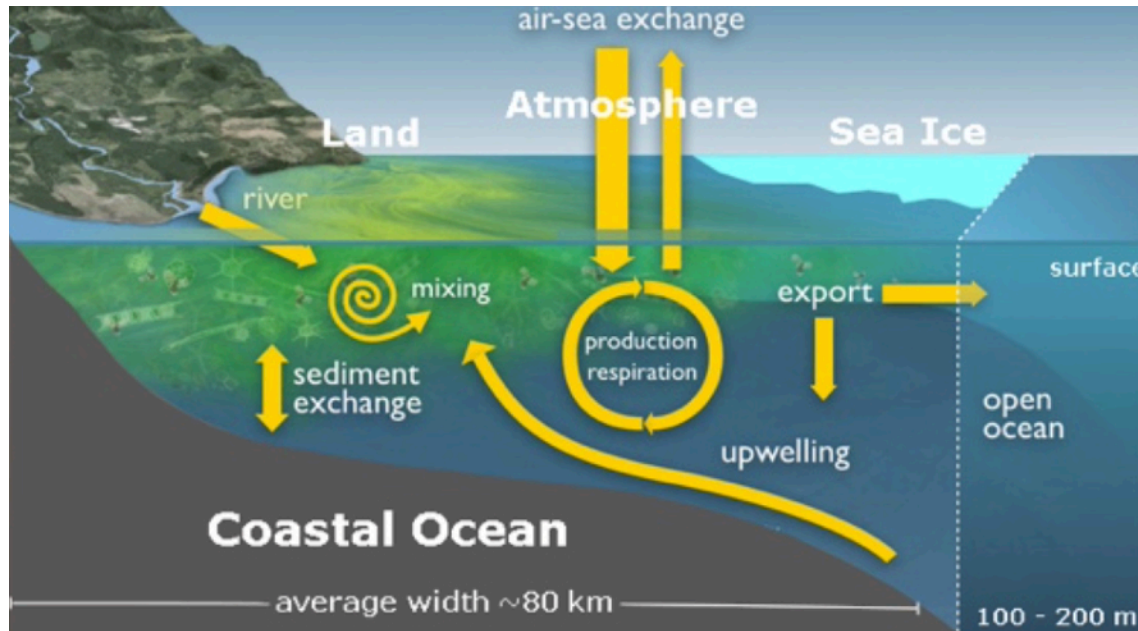


Figure from NOAA Panel Marine Environmental Laboratory

Goal Understanding the spatial and temporal variability of the processes taking place at the ocean’s interface with land and ice in coastal regions (home to 38% of the world's population, 2007)

Rivers and ice melting bring **freshwater** to the ocean.

- Transport of **nutrients**, pollutants, phosphates, nitrates → **eutrophication**
- Transport of **carbon**:
 - **Acidification**
 - Global carbon budget (Bauer *et al.*, 2013): disproportionately important with respect to the size of continental shelves

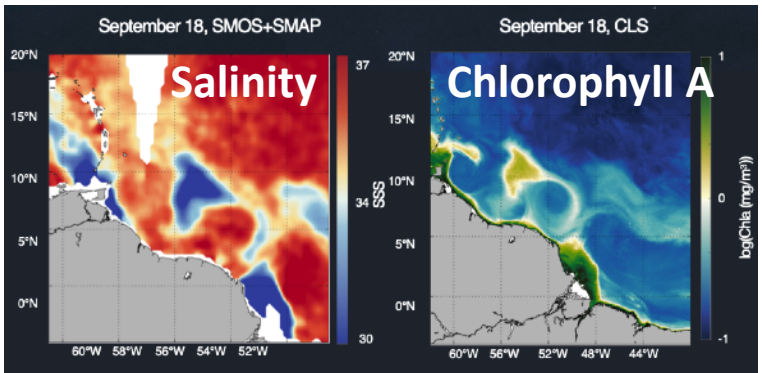
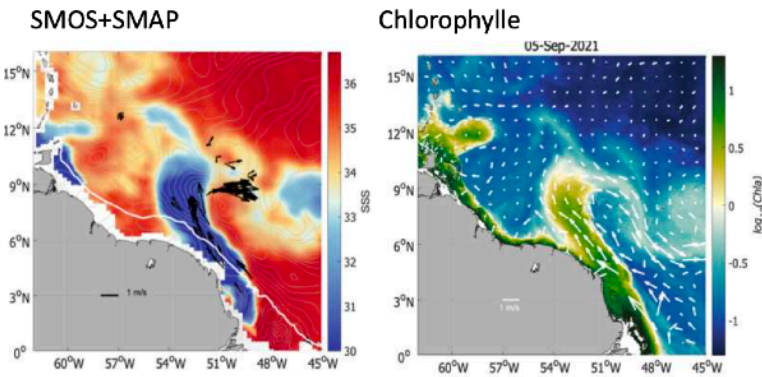
Continental shelves: 7 % of global ocean but ...

- 10–30% of global marine primary production
- 30–50% of inorganic carbon
- 80% of organic carbon burial in sediments
- Up to about 50% of the organic carbon supplied to the deep open ocean

Estuaries : ~14 % of the coastal ocean (Kang *et al.*, 2013). < 1% of the ocean area but ...

- CO₂ emissions of 0.2–0.4 Pg C yr⁻¹
- 5-10 % of anthropogenic CO₂ emissions for Western Europe (Frankignoulle *et al.* 1998)

- Sea surface salinity can be used to trace transport processes



Amazon plume, Olivier et al. 2024

SMOS, Aquarius, and SMAP (resolutions of 50-100 km) data have only been used to study the discharge of the world's largest rivers (Fournier and Lee, 2021)

FRESCH : 10 km resolution

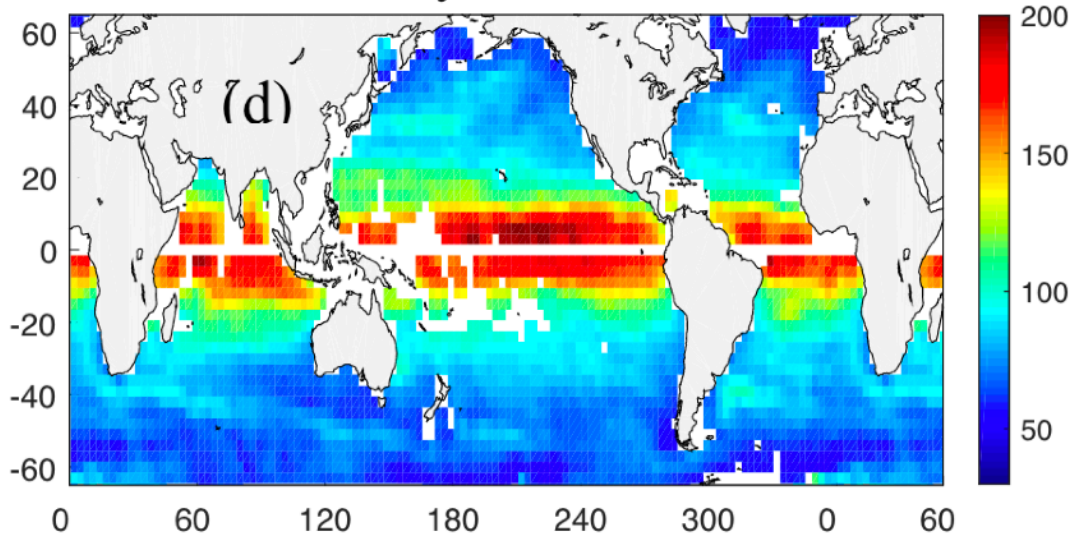
- Study a large number of river plumes
- Resolve mesoscale in the large river plumes
- Upwelling processes
- Transport to the open ocean via eddies

(sub)meso-scale processes

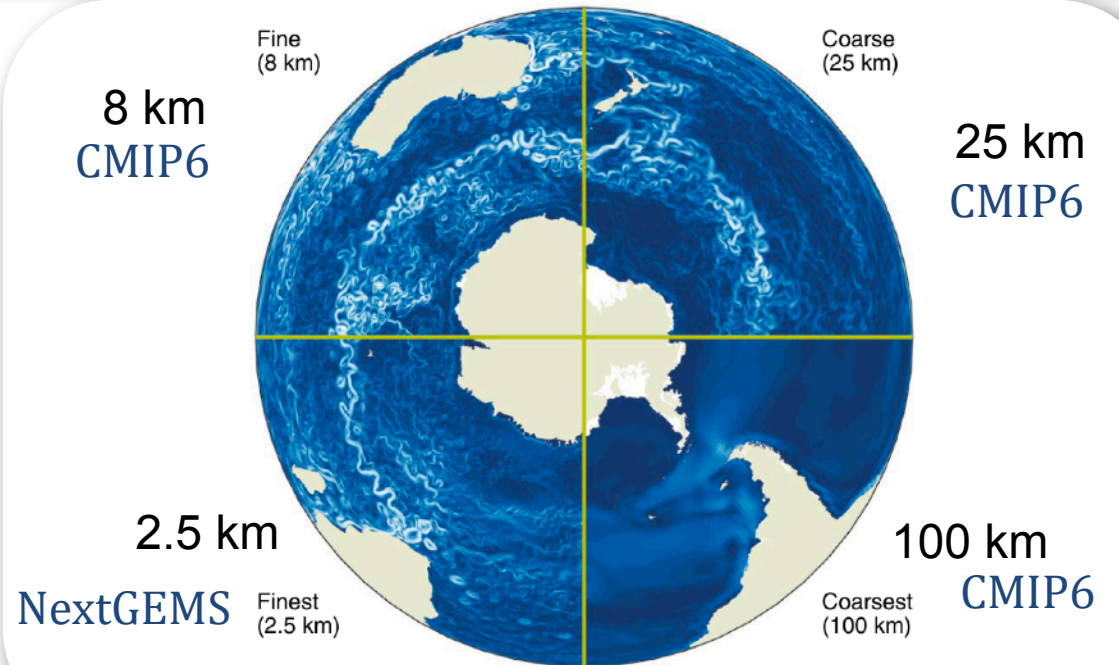
- Formation and dissipation of filaments and ocean fronts
- Transport of heat, salt, nutrients, oxygen, and pollutants over long distances
- They influence the air-sea exchange of heat and matter, the sea ice growth and melting
- Promising studies using SMAP and SMOS but limited due to their sensitivity and spatial resolution
- Poor representation (sub)mesoscales processes is considered one of the main reasons for the pronounced long-standing model biases (Fox-Kemper *et al.*, 2019; Chassignet *et al.*, 2020; Iovino *et al.* 2023)

Melnichenko et al. 2017, 2021.

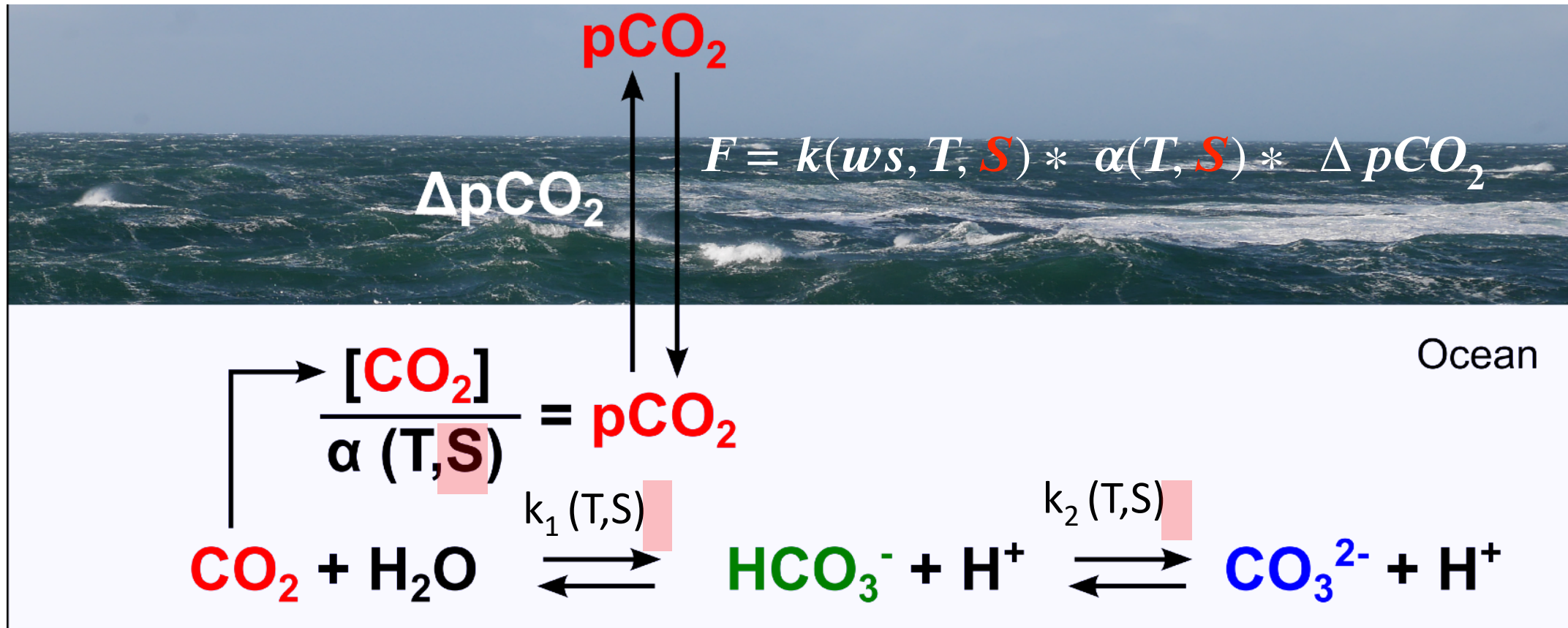
Eddy radius scale



Melnichenko et al. 2021.



Hewitt et al. 2021



$$\text{DIC} = \text{CO}_2 + \text{HCO}_3^- + \text{CO}_3^{2-}$$

$$\text{TA} = \text{HCO}_3^- + \text{CO}_3^{2-} \text{ and some other the components}$$

$$p\text{CO}_2 = f(\text{DIC}, \text{TA}, T, S)$$

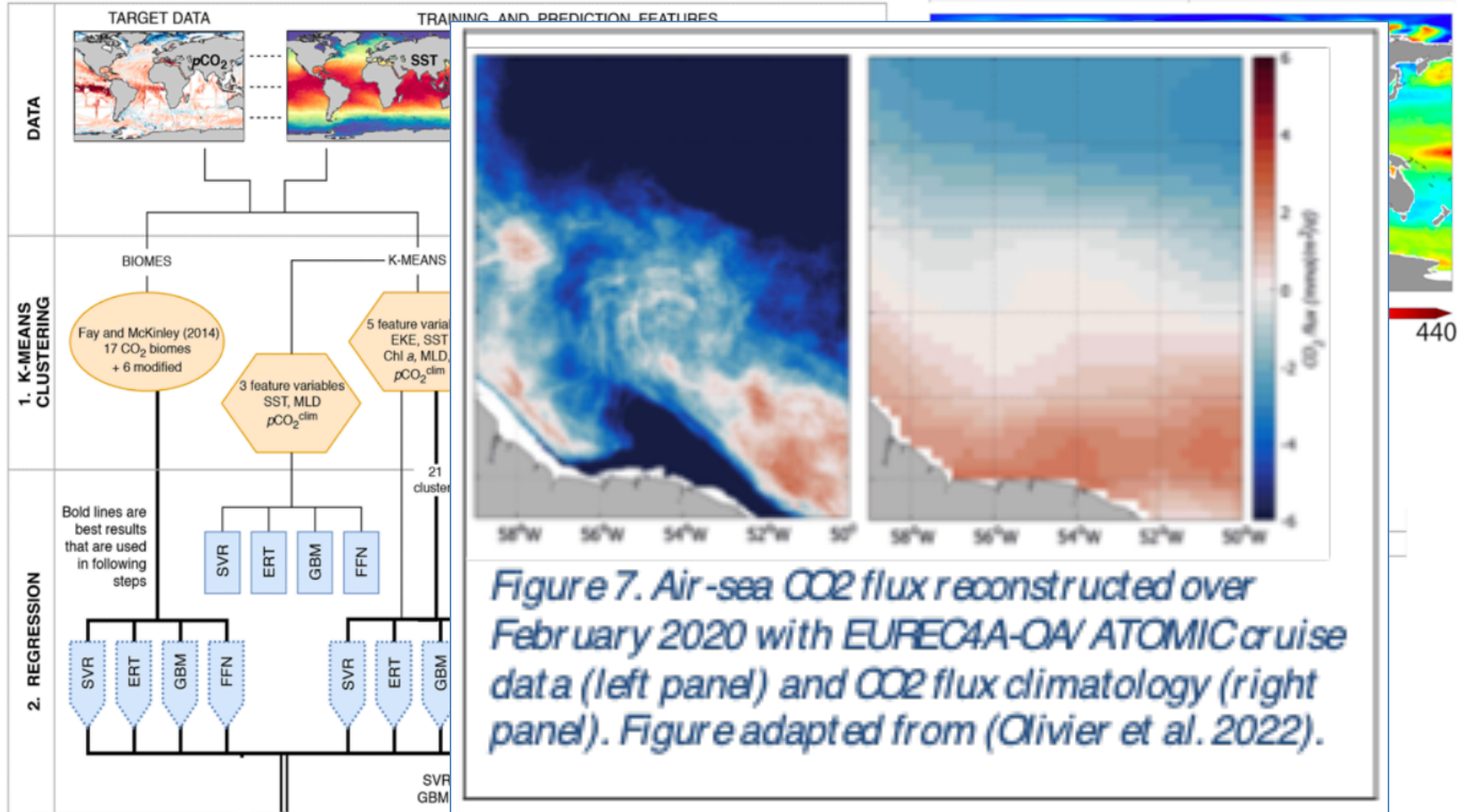


Figure 5. Schematic representation of the development of an pCO₂ retrieval algorithm as obtained from Gregor et al. 2019 and Landschützer et al. 2020.

Mission objectives

- Understanding the spatial and temporal variability of the processes taking place at the ocean's interface with land and ice in coastal regions
- Resolving (sub)mesoscale circulation patterns in the ocean
- Detecting pCO₂ in the surface ocean

Variables

Sea surface **salinity**

Accuracy **0.4 pss** (1 day, 15 km)

Surface partial pressure of CO₂ (**pCO₂**)

Accuracy < **12 µatm** (1 day, 15 km)

Requirements

Coverage : global

Temporal revisit: 1-3 days

Spatial Resolution : 10 km

Secondary objectives

- Terrestrial carbon and water cycle : fluxes in the land-ocean interface regions
- Improving estimates of the shrinking cryosphere. Ice-ocean interfaces
- Monitoring of extreme events, hazards and operational applications

Other variables

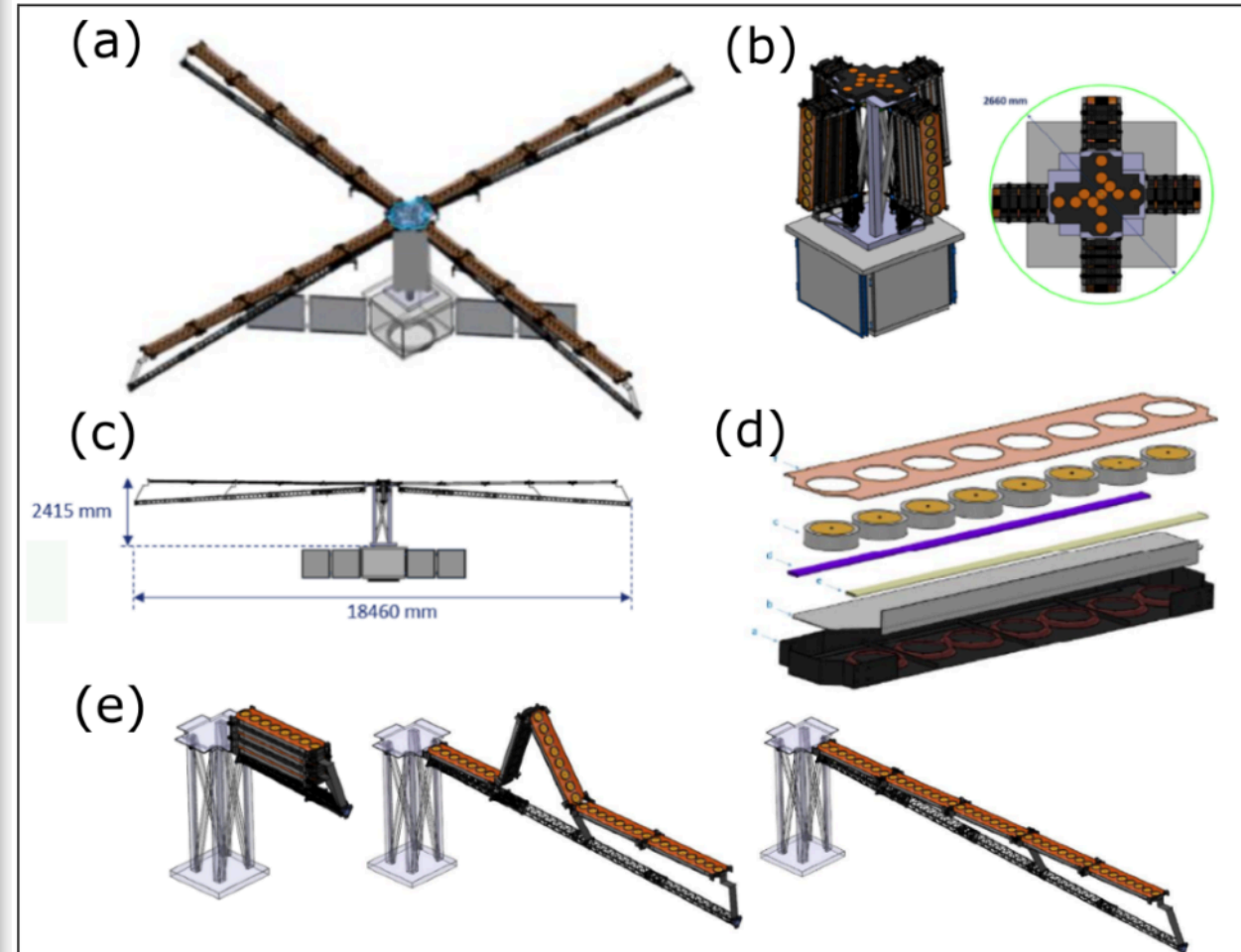
- **Soil moisture**, **soil freeze/thaw**, **high winds** over the ocean, **thin ice** sheets, **vegetation** water content, biomass, ...

Four Essential climate variables (ECVs) : SSS, SM, Biomass, sea ice

Relevant information for other four ECVs: evapotranspiration, fires, permafrost surface temperature, dissolved inorganic carbon

Technical specifications

- **Concept:** Full polarization and multi-incidence angle imager instrument operating at L-band
- **Antenna:** Array with four orthogonal arms of 8.6 m with 171 elementary antennas of 14 cm and a spacing of 0.95λ
- **Acquisition mode:**
 - Phased array (**Digital Beam Forming**)
 - Simultaneous two polarization acquisitions
- **Frequency:** 1413.5 MHz **Bandwidth:** 21 MHz
- **Orbit height:** 685 km
- **Spatial resolution** (nadir, before apodisation): 10.1 km
- **Incidence angles:** 0° - 60°
- **Radiometric accuracy:** 1.1 K @ 90 K in a single snapshot, **0.17 K** using all incidence angles
 - *With respect to SMOS, compared at the same spatial resolution it is a factor of ~4 better !*



Observation geometry

Patented antenna array layout to decrease aliasing (Kerr et al. 2019, Patent FR3071068)

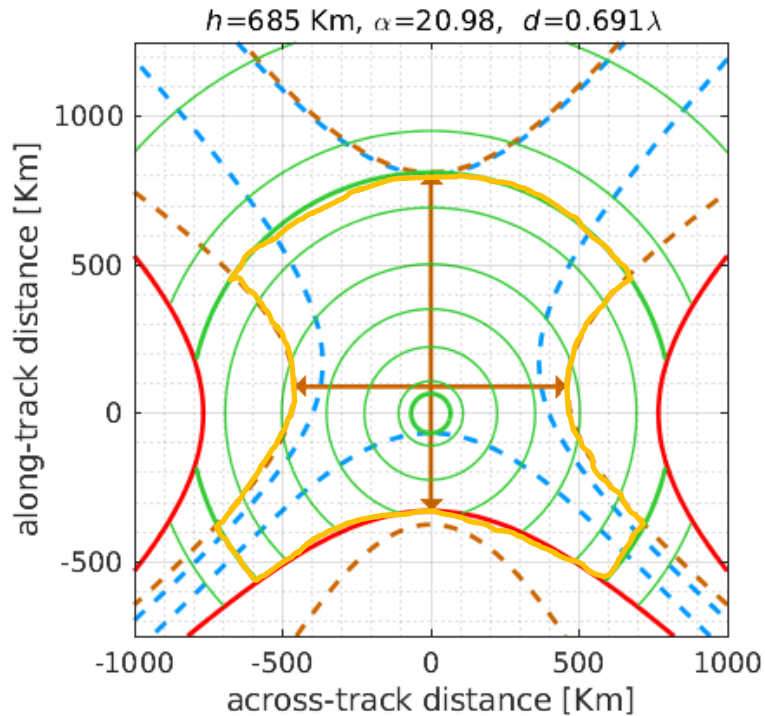
Spacing of the antennas: 0.97λ

Spatial frequencies sampling: 0.69λ

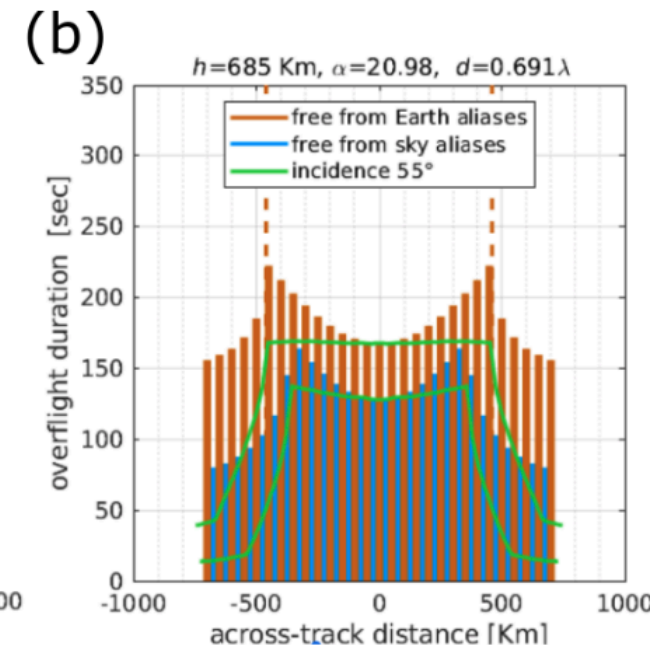
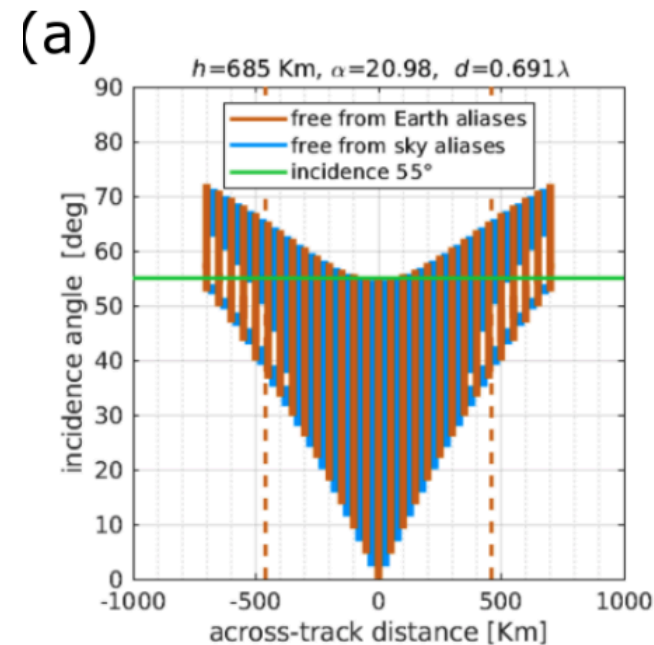
Spatial resolution: 10.1 km at Nadir before apodisation.

Integration time: 3.6 sec (ground incidence angle variation $< 2^\circ$)

Up to 44 snapshots of a point in the surface along the dwell line



Earth alias-free field of view for angles $< 55^\circ$

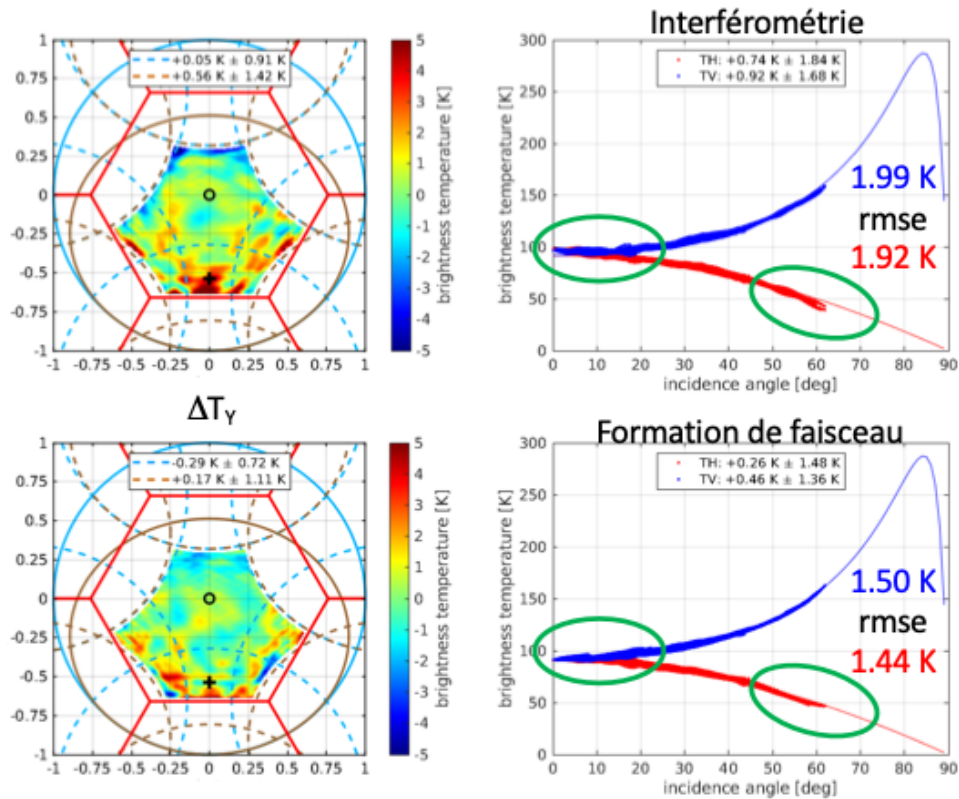


Acquisition mode: digital beam forming



- Used in telecommunications and recently in radioastronomy
- Robust image reconstruction

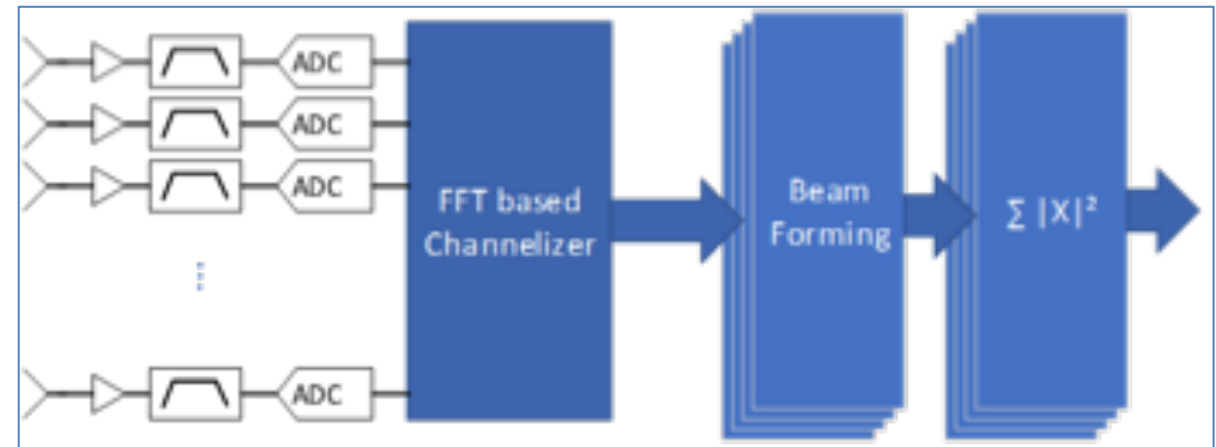
Anterrieu et al. 2022, Rem. Sens.



Number of beams : 176^2

Using symmetries to reduce the number of computations from 638 TMAC/s to 16 TMAC/s
Anterrieu & Mege (2024)

→ 2-3 times more than using aperture synthesis



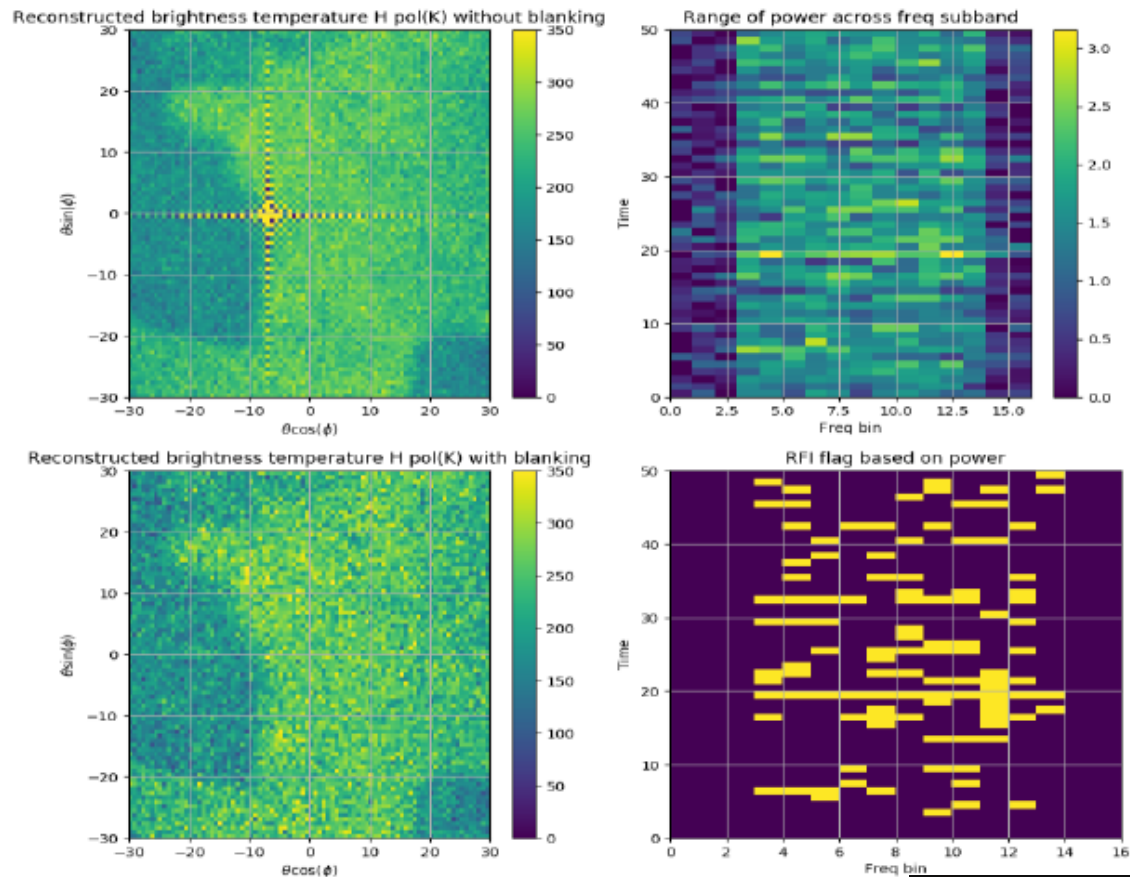
RFI mitigation

RFI filtering in 1-1.5 MHz sub bands

Patent WO/2021/001408

Image reconstruction in 5 MHz sub-bands

Anterrieu (2021, CESBIO report)



Budgets

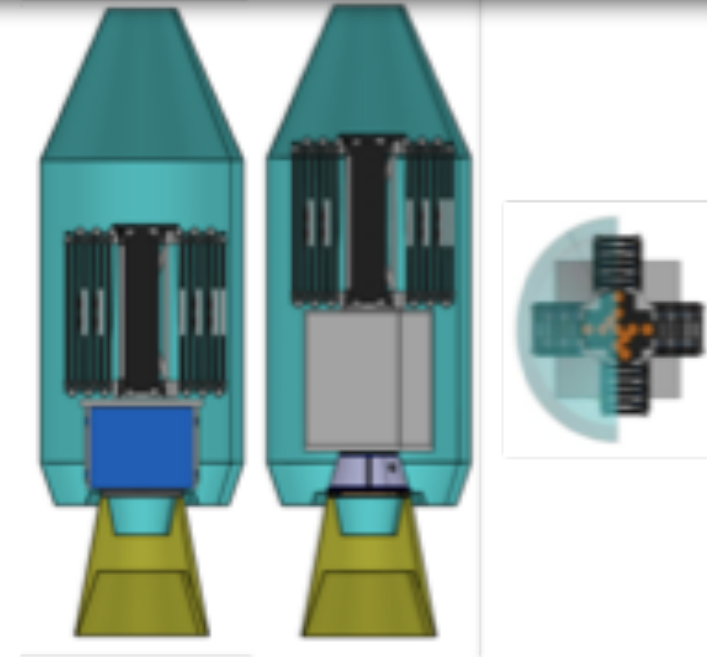
FReSCH

Dimensions (Payload included) :

Height = 4,2 m, Diameter = 2,7 m

Mass: 1767 kg (dry); 1967 kg (wet, with margins)

Power: 3000 W (with margins)



FReSCH accommodation under Vega C fairings in lower and upper configuration

Science evaluation

- Timely mission filling science gaps
- Innovative and feasible
- Addressing up 14 ESA challenges
- pCO₂ estimation is innovative but challenging
- And a number of fair comments of salinity and pCO₂ estimation (next slides)

Technical evaluation

- Unique and technically innovative concept
- Good technical maturity
- And a number of comments:
 - Difficult to get the antenna position requirement
 - Beam forming unit power consumption

EE12 outcome (April 2024) :
« Commended mission »:



FANTASIOR

Funded by CNES, CESBIO and INGEspace

A 32 antennas array

Goal: performing measurements in the lab and in the field and compare different acquisition techniques and image reconstruction algorithms:

- Beam forming vs aperture synthesis
- Different array layouts
- Different antenna numbers



Presentation by Anterrieu et al.



ESA Pre-phase 0 Science Consolidation study

Funded by ESA

Salinity retrievals

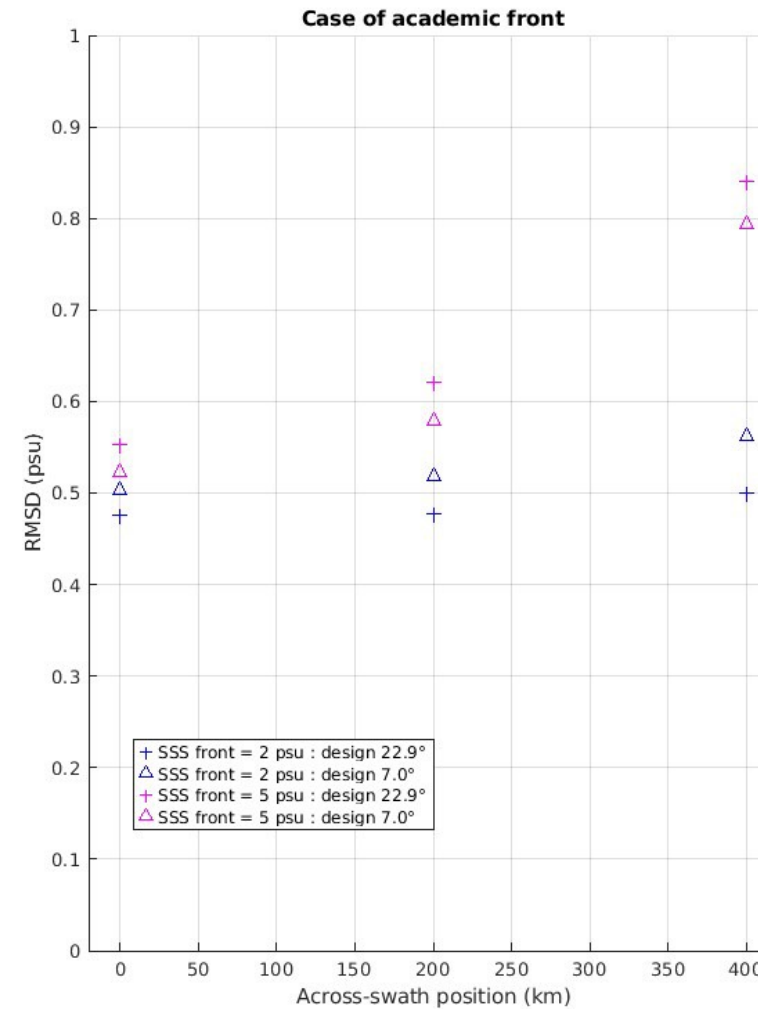
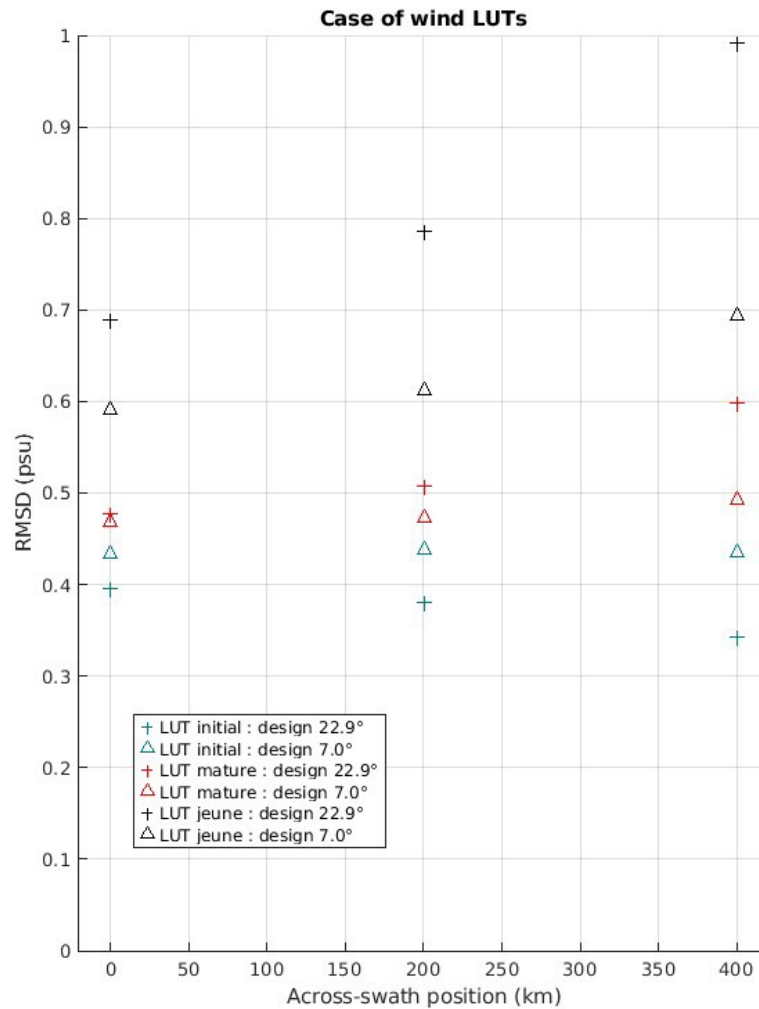
- Land-sea contamination
- Uncertainties in auxiliary data close to the coast : wind speed, sea surface temperature (

pCO₂ estimation

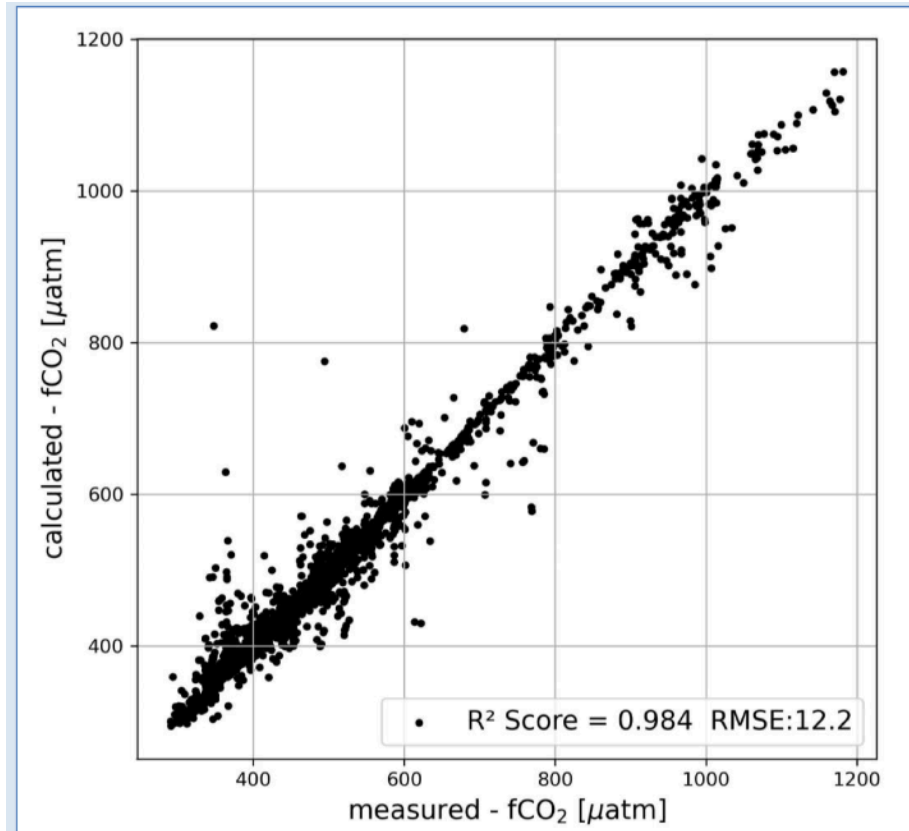
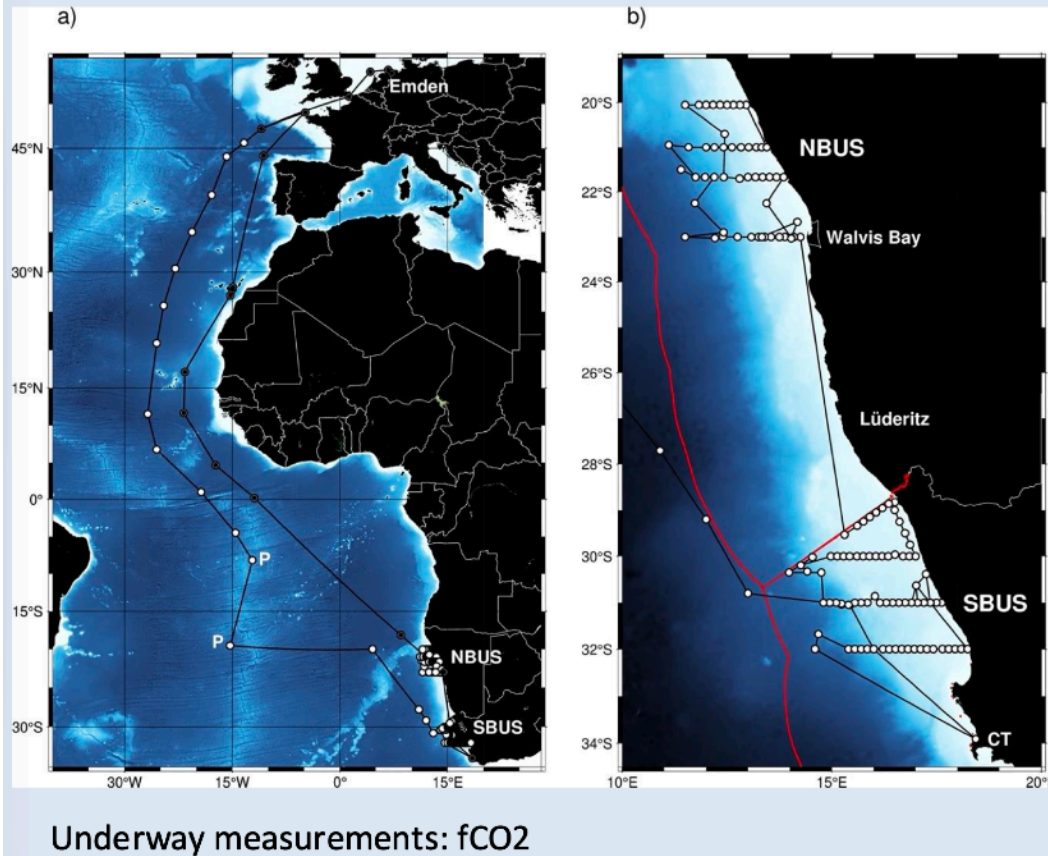
- Physical vs statistical methods
- Uncertainties
- Roadmap for campaign data

SSS, wind speed and instrument co-design

SSS RMSD with across-swath positions for different satellite designs (WS = 7 m/s)



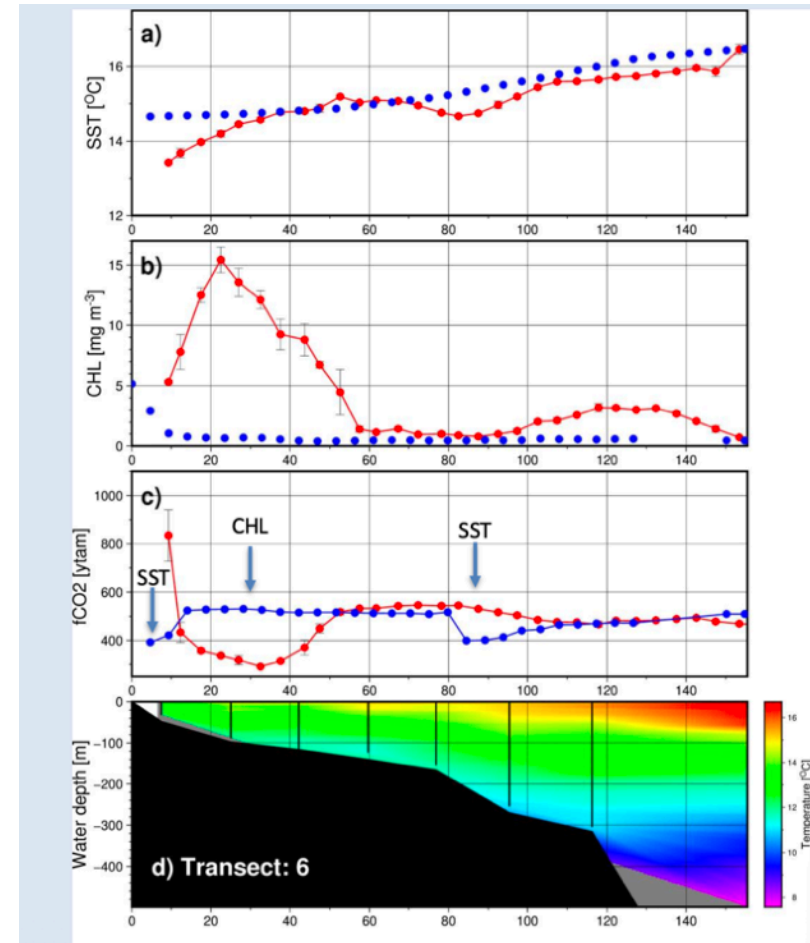
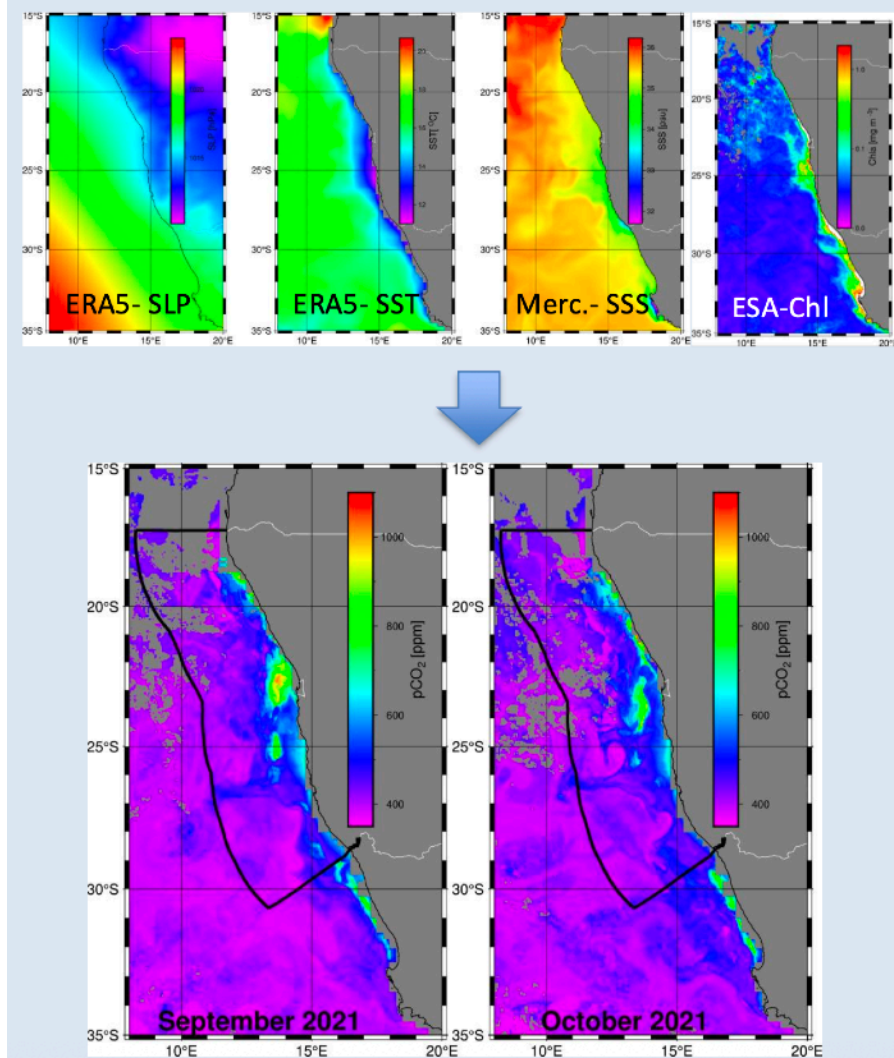
Research cruise SO285: August - October 2021



Underway measurements:
 fCO_2 , SST, SST, Chl-a, air pressure

Rixen, Landshutzer et al.

Ongoing studies $p\text{CO}_2$ estimation and uncertainty



Rixen, Landshutzer et al.

Science gap filler (processes, observables, regions, time, ...) thanks to technical innovation

Low risk (builds on a concept studied up to Phase A at CNES: SMOS-HR)

Adaptable to different programmatic contexts (EE-envelope compatible)

We keep improving the science case and the technical concept

