A new airborne instrument to image ocean-atmosphere dynamics at the sub-mesoscale: OSCAR instrument capabilities and the SEASTARex airborne campaign

Adrien Martin, David McCann, Karlus Macedo, Wenming Lin, Giuseppe Grieco, Louis Marié, José Marquez, Ruben Carrasco, Rui Duarte, Marcos Portabella, Adriano Meta, Christine Gommenginger, Petronilo Martin-Iglesias, Tania Casal

SeaSTAR motivation

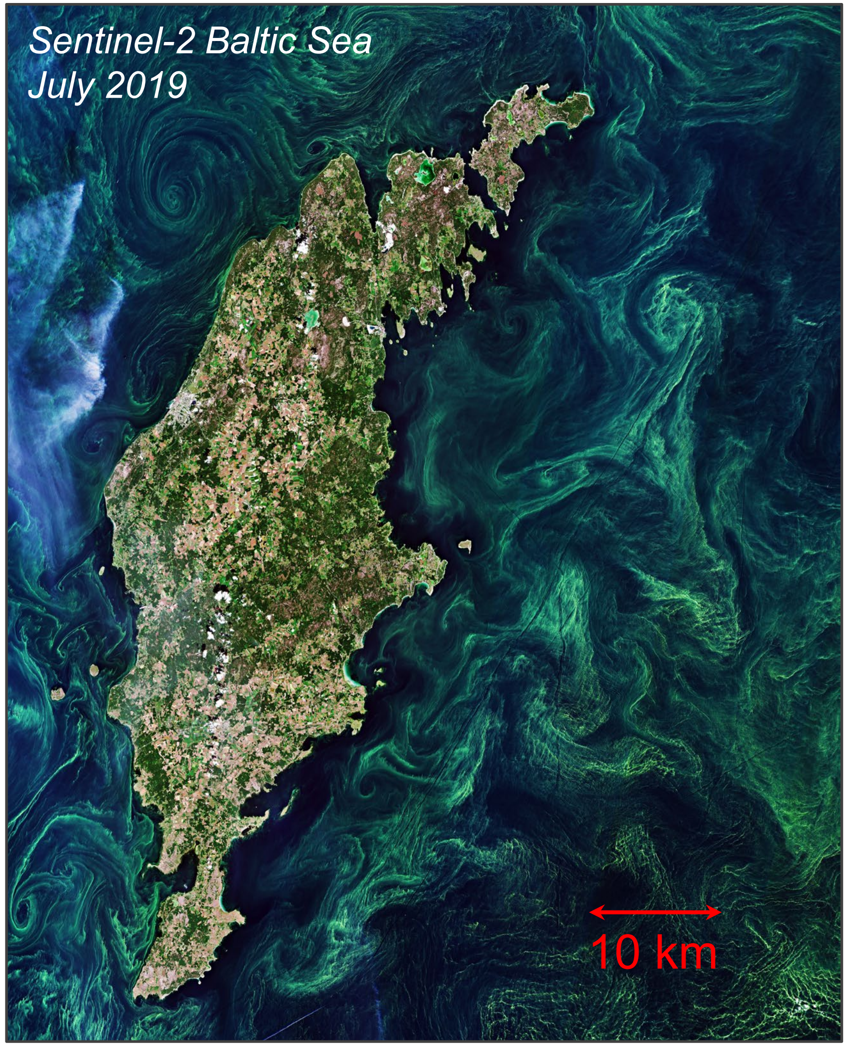
High-resolution satellite images often show small ocean eddies, swirls and filaments at scales below 10 km.

- Frequent near jets, large eddies, in coastal and polar seas
- Fingerprints of dynamic processes at the sea surface
- Few observations of surface dynamics at these scales
  - Challenging & expensive

Numerical models indicate small-scale ocean phenomena have major impact on global ocean circulation and climate.

- Key role of ageostrophic circulation and interactions with surface winds and waves
- Impact on vertical exchanges e.g. heat, CO_2, nutrients…
- Impact on horizontal dispersion & pathways e.g. debris, oil…

No existing or planned mission with the necessary performance and space-time sampling to observe these small and fast processes.



SeaSTAR Primary science objectives

to measure, for the first time, **2D images** of **Total Surface Current Vectors** and **Ocean Surface Vector Winds** at **1 km resolution** with high accuracy, over all **coastal seas, shelf seas and Marginal Ice Zones**.

to characterise their **magnitude**, **2D spatial variability** and **temporal variability** on **daily, seasonal to multi-annual** time scales.

to deliver, for the first time, **high-order derivative products like gradients, vorticity, strain and divergence** to explore the relations between small-scale phenomena and **vertical exchanges between the atmosphere and the ocean interior**.

to investigate the relations between small-scale surface dynamics and **marine productivity** using **synergy with in situ data and high-resolution optical, thermal and microwave satellite data**.

to **validate high-resolution and coupled models** and support the development of new parameterisations **to improve operational forecasts and reduce uncertainties in climate projections**.

SeaSTAR Secondary science objectives

to measure **instantaneous sea ice drift vectors** with high-accuracy to observe **the sea ice and ice floes response at small scales for different wind, waves & current forcing**.

to develop new experimental products for **full directional ocean wave spectra** (including wind waves) to study localised surface phenomena, including fronts, wave breaking, Langmuir cells…

to examine ocean current and wind fields **close to major estuaries** to investigate the **dispersion of major river plumes** in coastal zones **and the fate of terrestrial inputs to the ocean**.

SeaSTAR Primary Products & Requirements

SeaSTAR Primary Products (Level 2)		
Total Surface Current Vector (L2-TSCV)		
	One continuous swath:	≥ 100-150 km
	Horizontal posting (resolution):	≤ 1 km
	TSCV Uncertainty @ 1km resolution:	≤ 0.1 m/s or 10%
Ocean Surface Vector Wind (L2-OSVW)		
	Same swath as TSCV	
	Same horizontal posting as TSCV	
	OSVW Uncertainty @ 5km resolution: ≤ 1 m/s or 10%	

Essential requirements

SeaSTAR measurement principle

Squinted SAR Along-track Interferometry (ATI), Ku-band

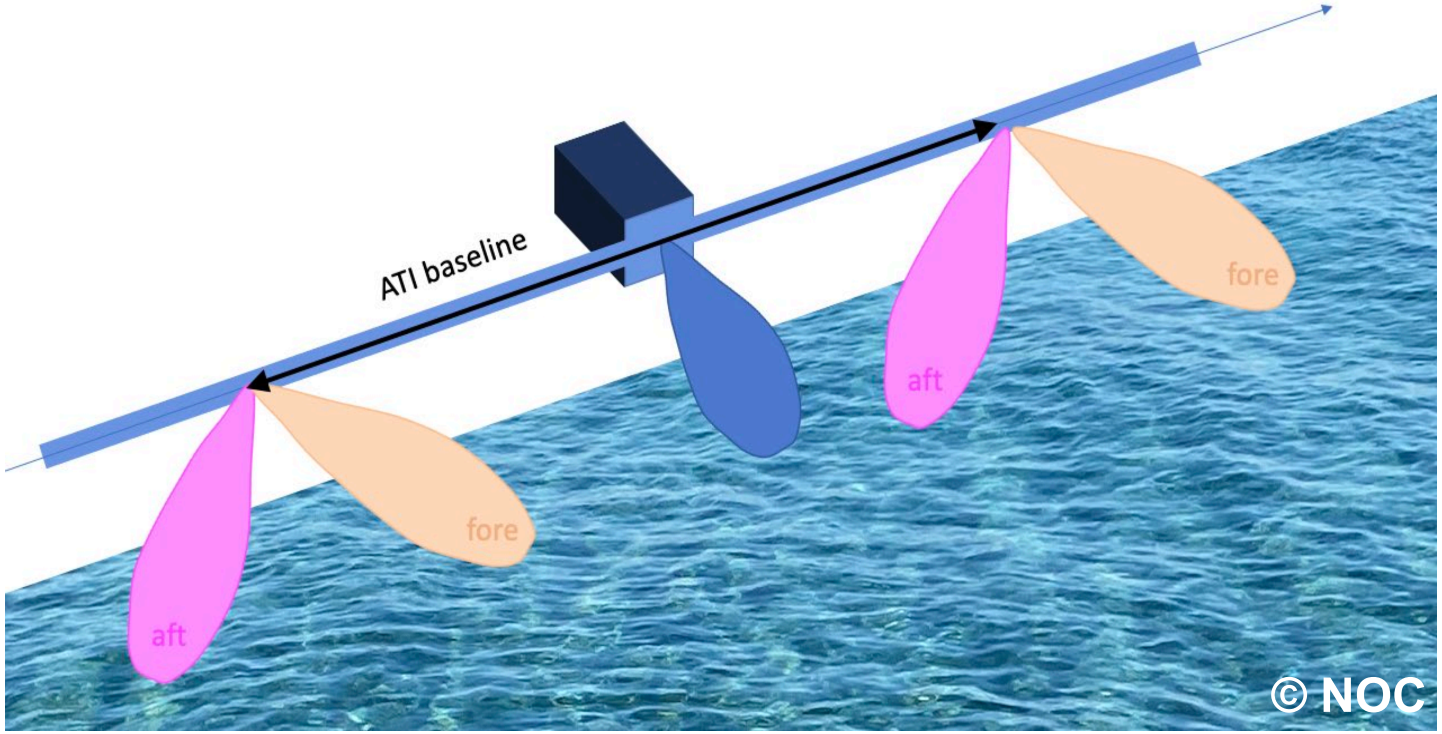
Backscatter & Doppler in 3 azimuth directions

Simultaneous measurements of total current vector, wind vectors and directional wave spectrum

- one pair looking forward (+45°)(VV)
- one pair looking backward (-45°)(VV)
- one broadside DCA or ATI (VV, HH)

Heritage

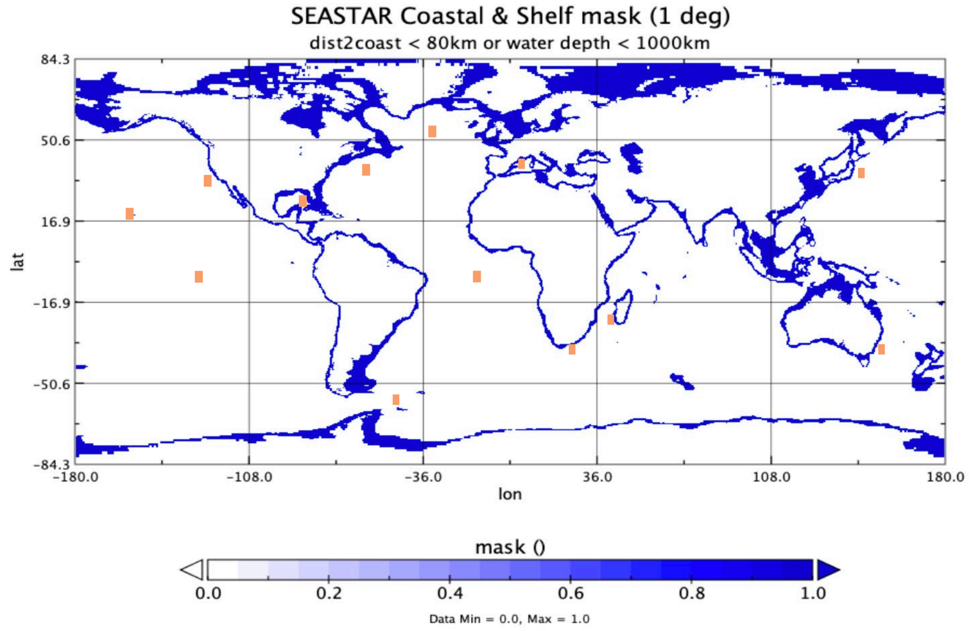
- Scatterometry
- SAR Doppler Anomaly
  - *Envisat ASAR, Tandem-X, Sentinel-1*
- Dual-Beam Interferometer
- Wavemill



SeaSTAR Space-time sampling

Focus on Coastal, Shelf-seas & Marginal Ice Zones + Open-ocean Regions of Special Interest

As an independent dedicated mission, SeaSTAR can tailor its space-sampling to its science needs



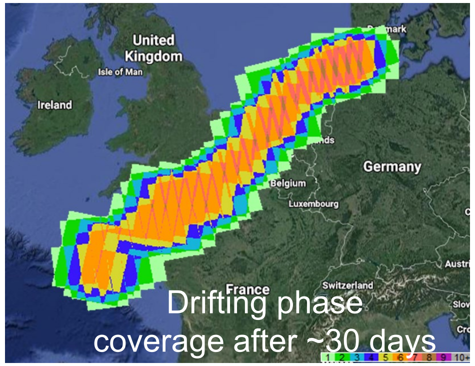
Two mission phases:

Fast-repeat phase (6 months)

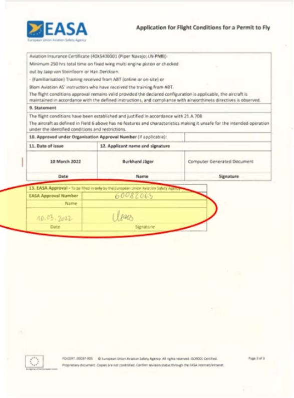
- 1 day repeat
- 150 scenes every day, each 250 km long

Drifting orbit (4 years)

- ~30-day repeat, 1-day sub-cycle
- 50% swath overlap at the Equator



OSCAR/SEASTARex Campaign - Long story short – start in 2016



EASA
European Union Aviation Safety Agency

Application for Flight Conditions for a Permit to Fly

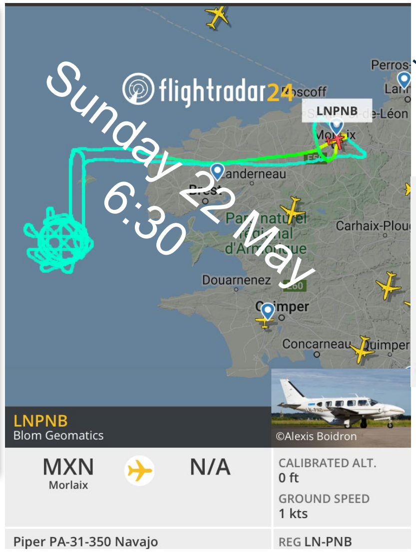
Aviation Insurance Certificate (40XS400001 (Piper Navajo; LN-PNB)): Minimum 250 hrs total time on fixed wing multi engine piston or checked out by Jaap van Steinfoorn or Han Dercksen. - (Familiarisation) Training received from ABT (online or on-site) or Blom Aviation AS' instructors who have received the training from ABT. The flight conditions approval remains valid provided the declared configuration is applicable, the aircraft is maintained in accordance with the defined instructions, and compliance with airworthiness directives is observed.
9. Statement
The flight conditions have been established and justified in accordance with 21.A.708 The aircraft as defined in Field 6 above has no features and characteristics making it unsafe for the intended operation under the identified conditions and restrictions.
10. Approved under Organisation Approval Number (if applicable):

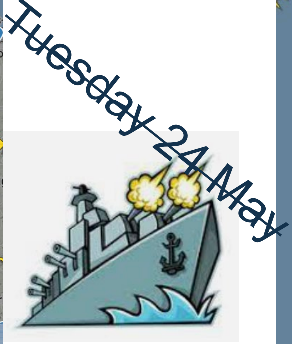
11. Date of issue	**12. Applicant name and signature**	
10 March 2022	Burkhard Jäger	Computer Generated Document
Date	Name	Signature

13. EASA Approval - To be filled in **only** by the European Union Aviation Safety Agency	
EASA Approval Number	60082063
Name	
10.03.2022	[signature]
Date	Signature

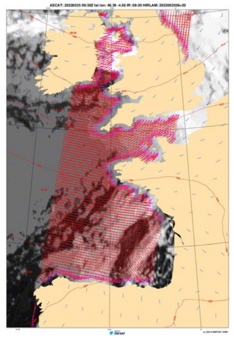
Aircraft certification
Feb 2022

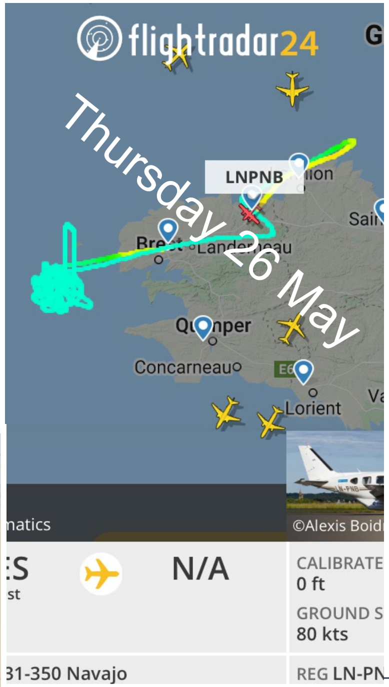

Tuesday 17 May
Ushant
Ile-Molène


Sunday 22 May
6:30
flightradar24
LNPNB
Blom Geomatics
©Alexis Boidron
MXN
Morlaix
N/A
CALIBRATED ALT.
0 ft
GROUND SPEED
1 kts
Piper PA-31-350 Navajo
REG LN-PNB
Perros
Douarnenez
Concarneau
Carhaix-Plou

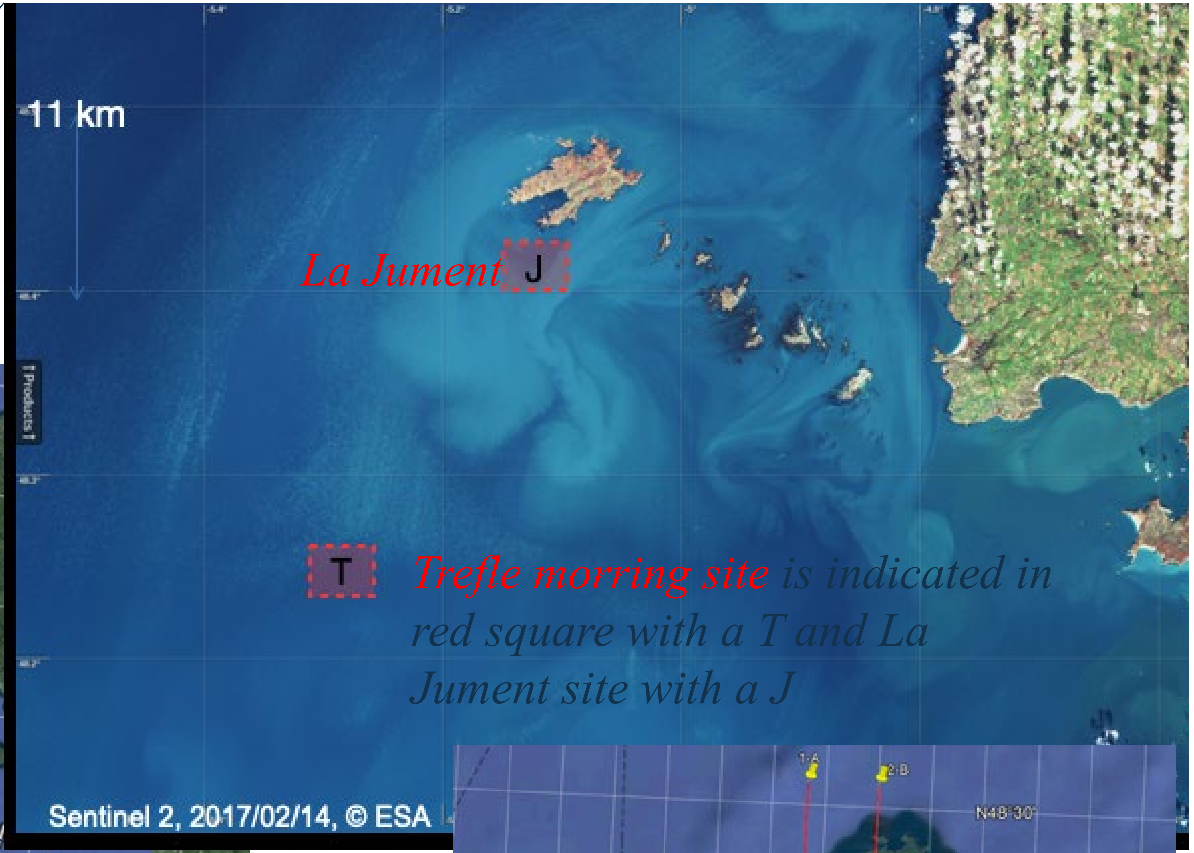

Tuesday 24 May

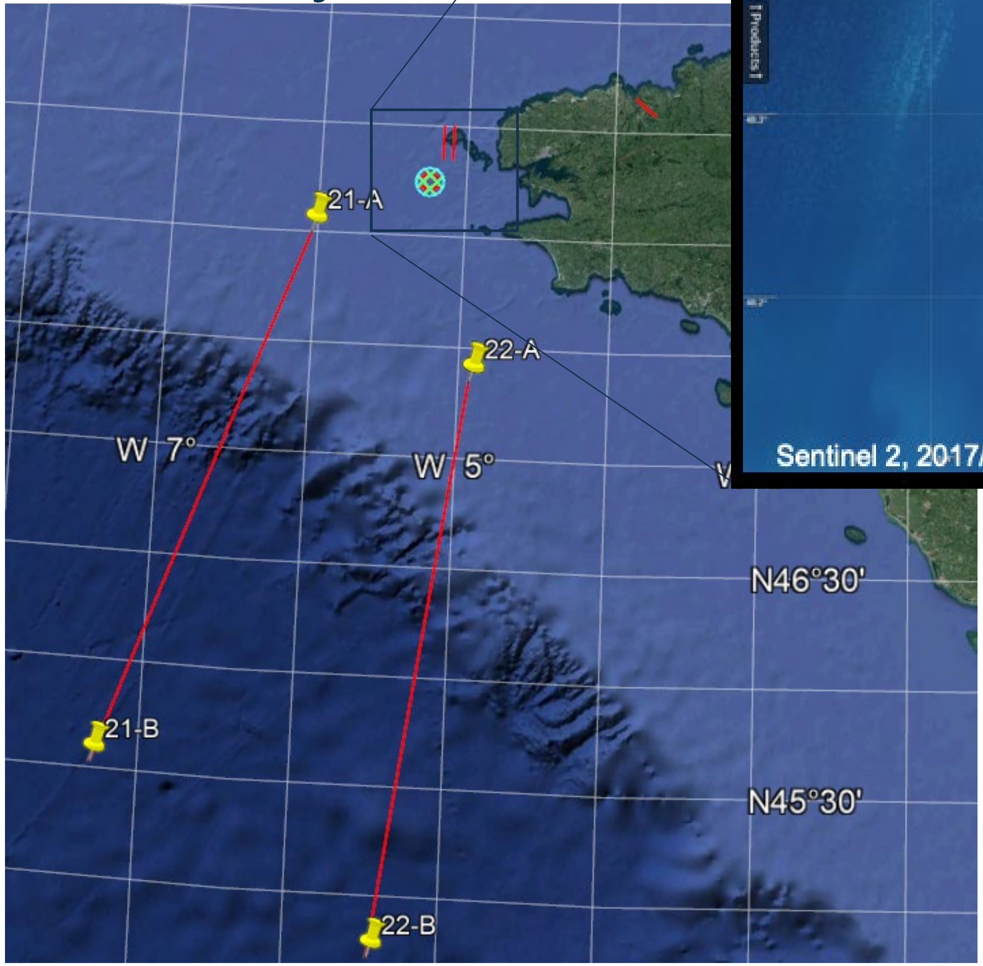

Search
Wed. 25 May
LNPNB
Saint-Brieuc
Concarneau

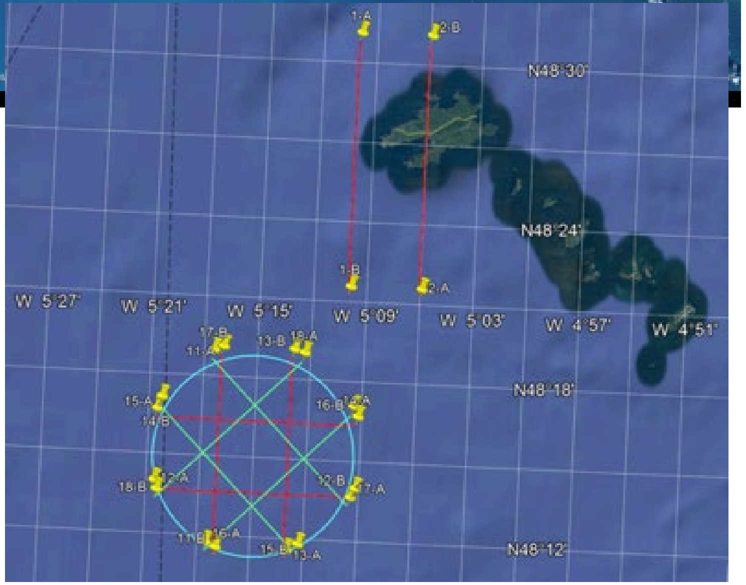



flightradar24
Thursday 26 May
LNPNB
Landerneau
Concarneau
Lorient
©Alexis Boid
N/A
CALIBRATE
0 ft
GROUND S
80 kts
31-350 Navajo
REG LN-PN

SEASTARex campaign Iroise Sea May 2022



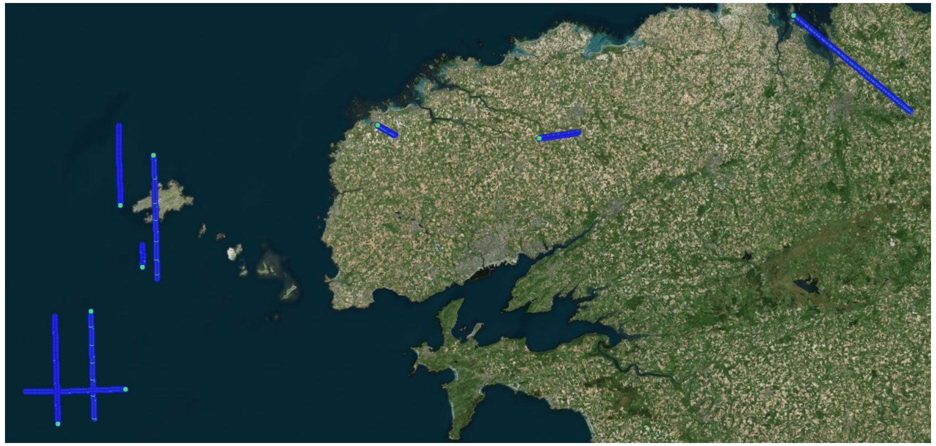




Data Production Updates

We have focused all 17, 22, 25, 26 days (besides the circular tracks)

17



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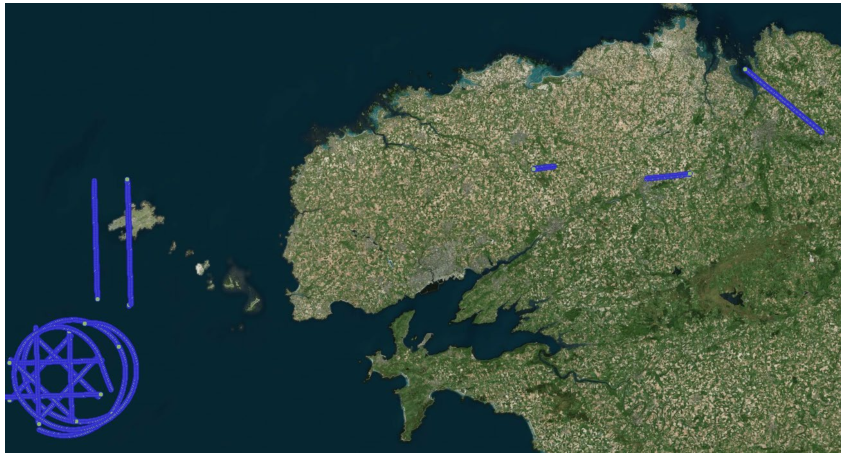


25

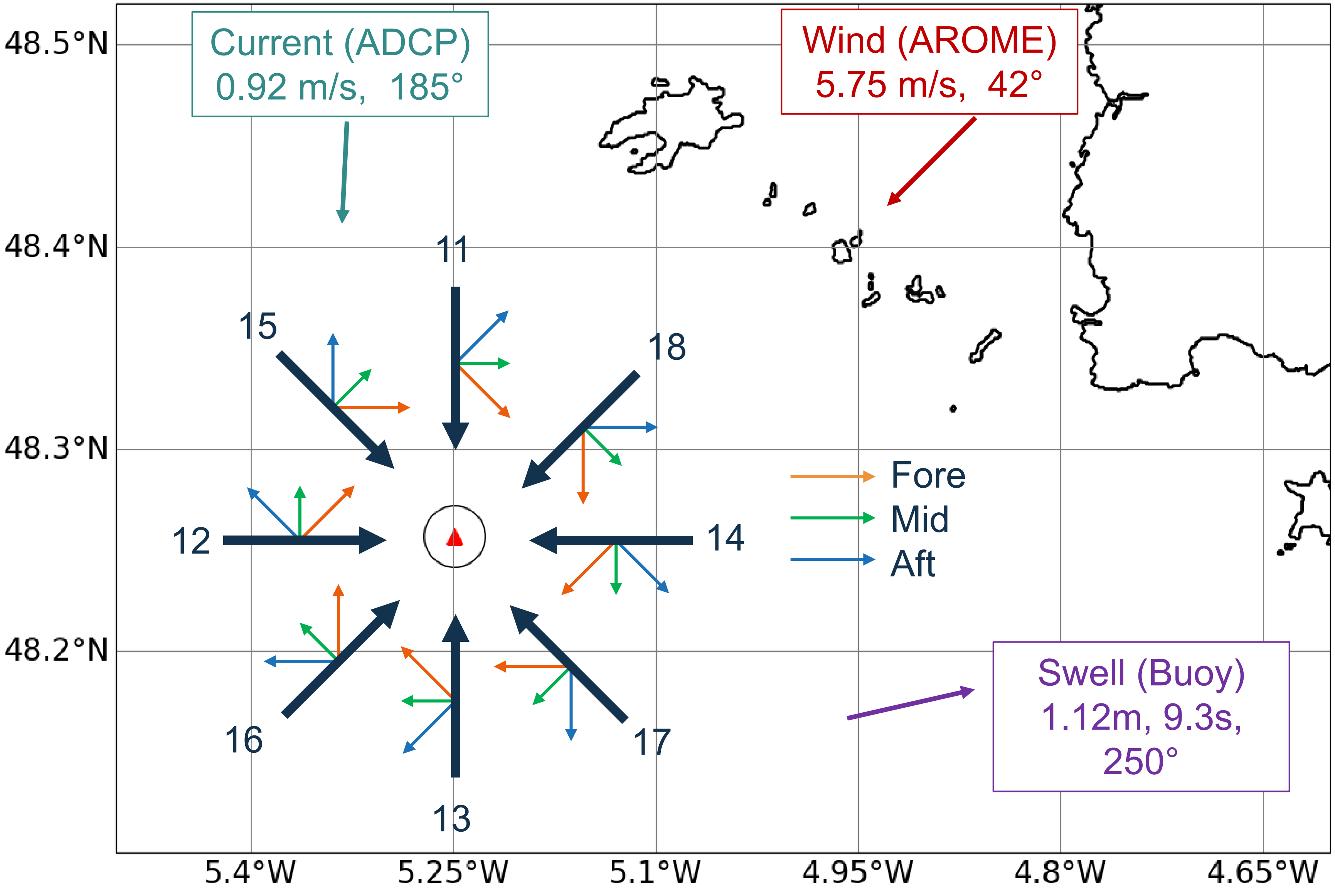
26

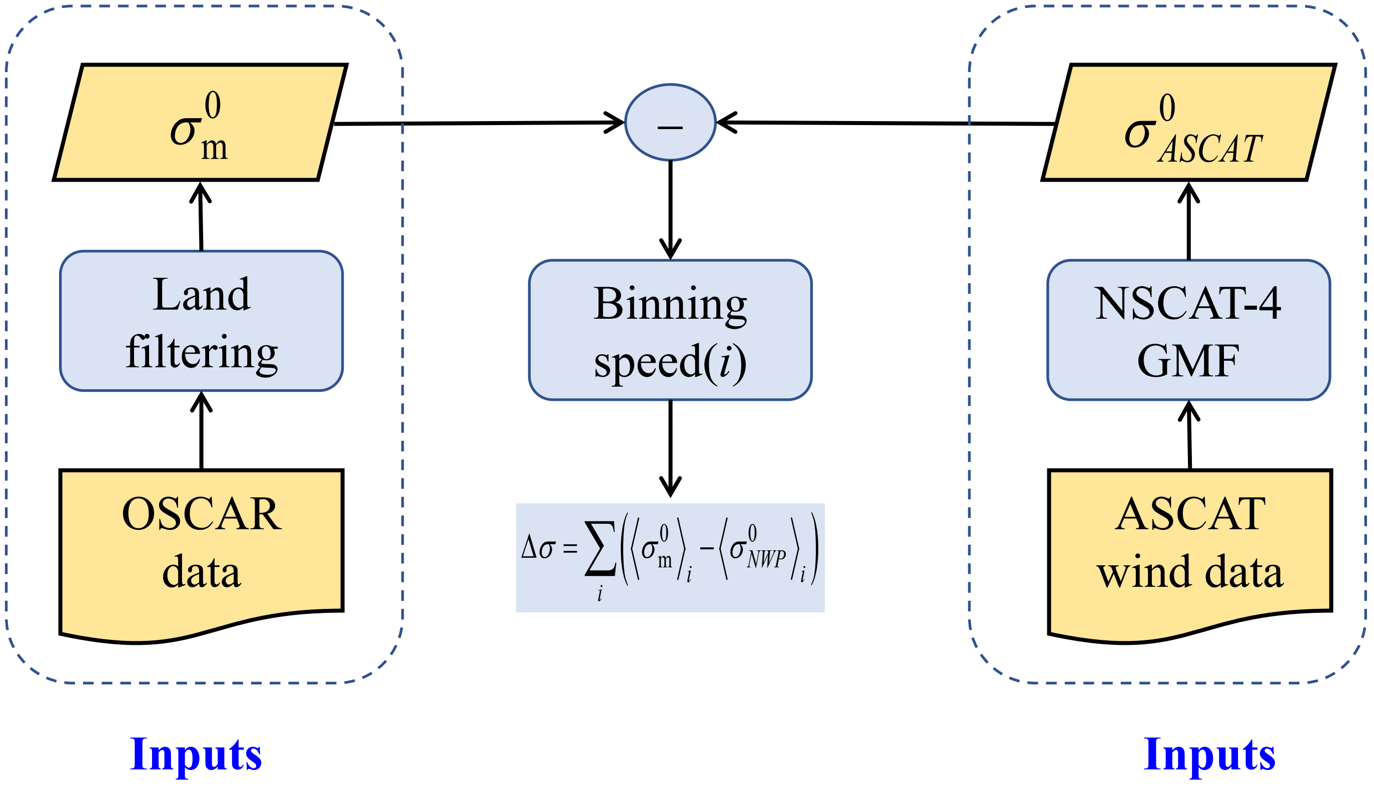
METASENSING Radar Solutions

Star-pattern tracks

The star-pattern was flown so each channel effectively gives look directions at 45° intervals around the compass

Assuming environmental homogeneity we can then group data by incidence angle and look azimuth



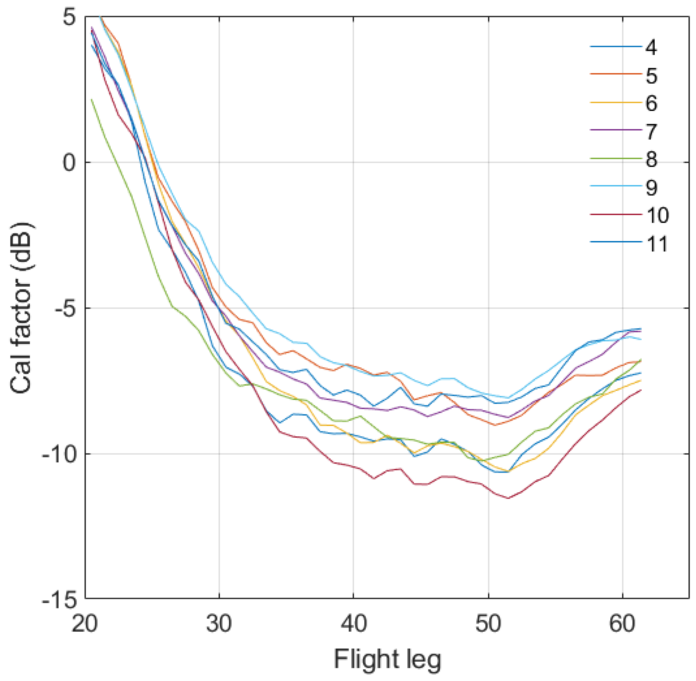


1. Filter the OSCAR land data using the GSHHG land-sea mask;
2. Collocate ASCAT winds with OSCAR observation (<1 h) ;
3. Interpolate ASCAT u/v wind components bi-linearly to OSCAR grids;
4. Simulate sigma0_ASCAT;
5. Calculate the difference between measured and simulated sigma0 (binning@0.2 m/s and 1°)
6. Average the sigma0 difference over all the wind speed bins.

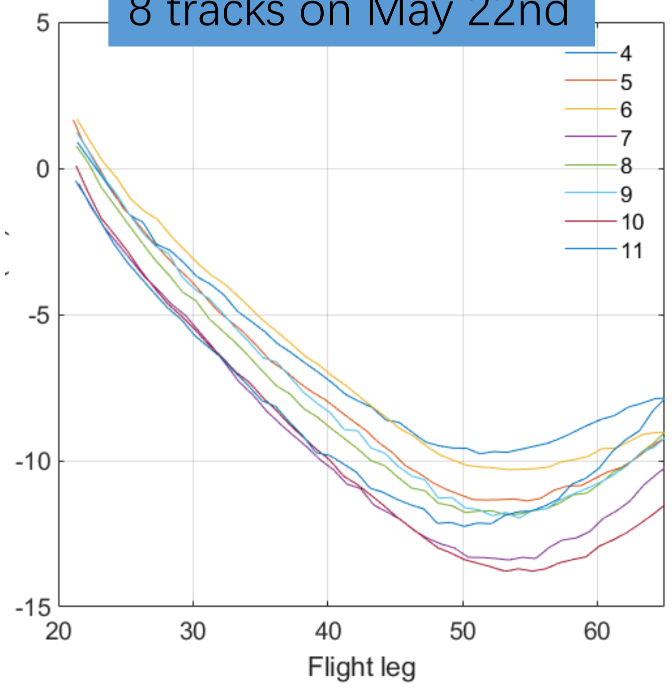
Ocean Calibration results

南京信息工程大学
Nanjing University of Information Science & Technology

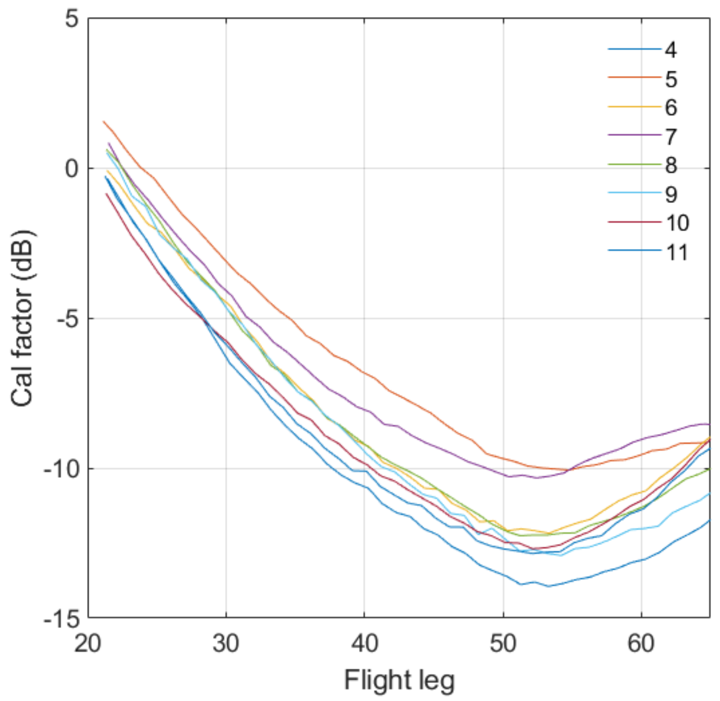
8 tracks on May 22nd



Beam 00(mid)



Beam 33(fore)



Beam 77(fixed)

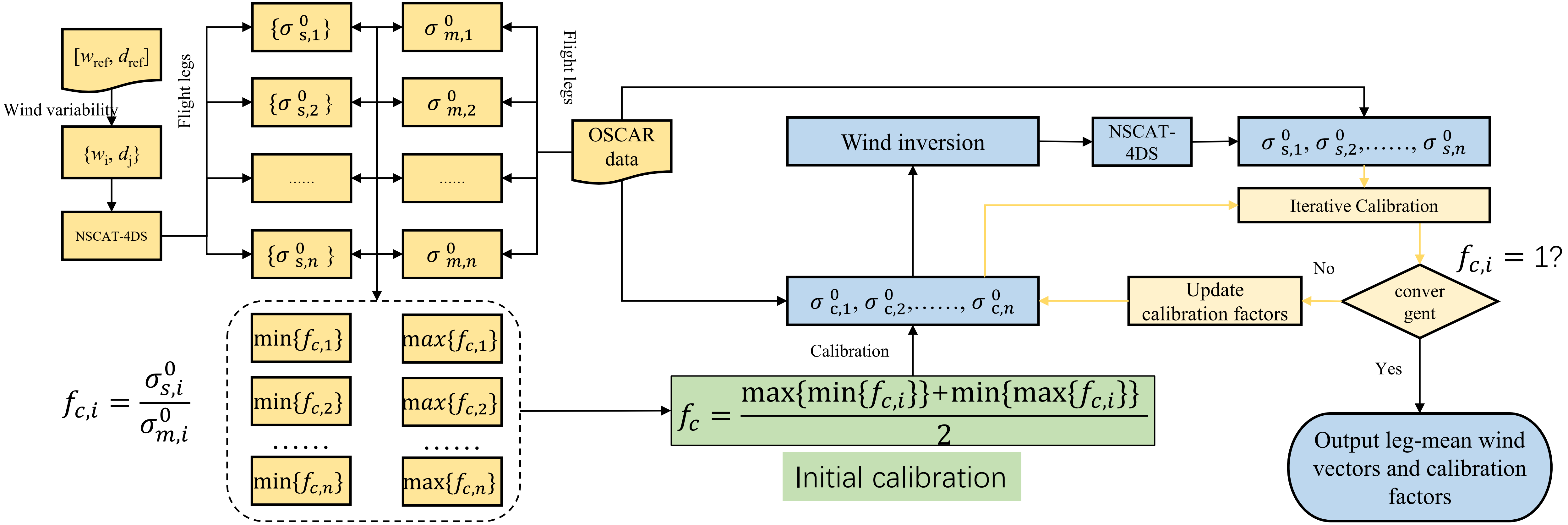
Using the collocated ECMWF winds as calibration reference. The discrepancy is assumed to be due to wind variability effect

New Ocean Calibration algorithm

Nanjing University of Information Science & Technology

Assumptions:

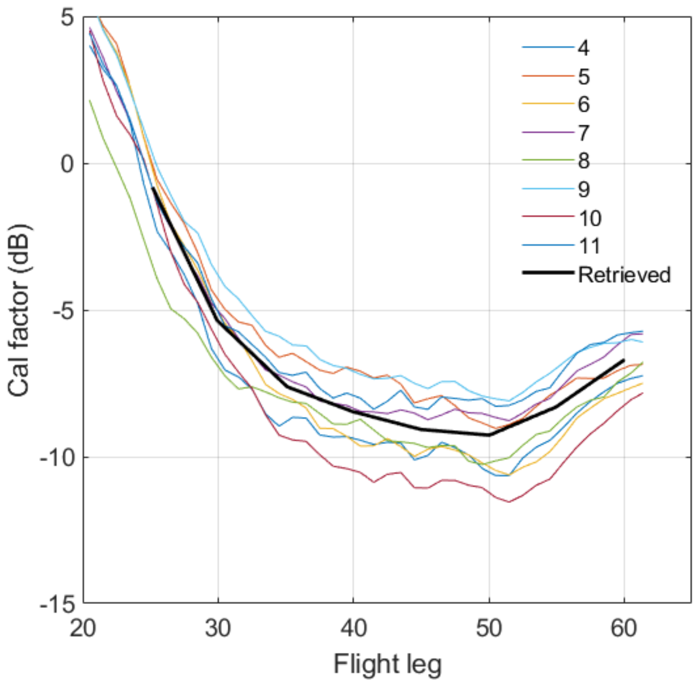
1. The radar instrument is stable over the whole particular day;
2. The wind vector is constant for one particular flight leg. However, the wind vector may vary with the flight leg.
3. The calibration factor only depends on the incidence angle.
4. The wind speed variability is smaller than 3 m/s, and the wind direction variability is smaller than 30°.



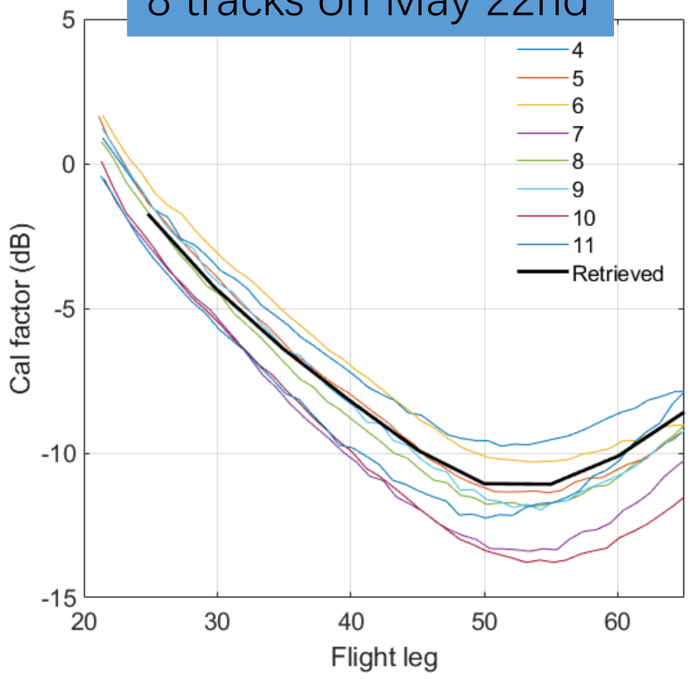
Ocean Calibration results

Nanjing University of Information Science & Technology

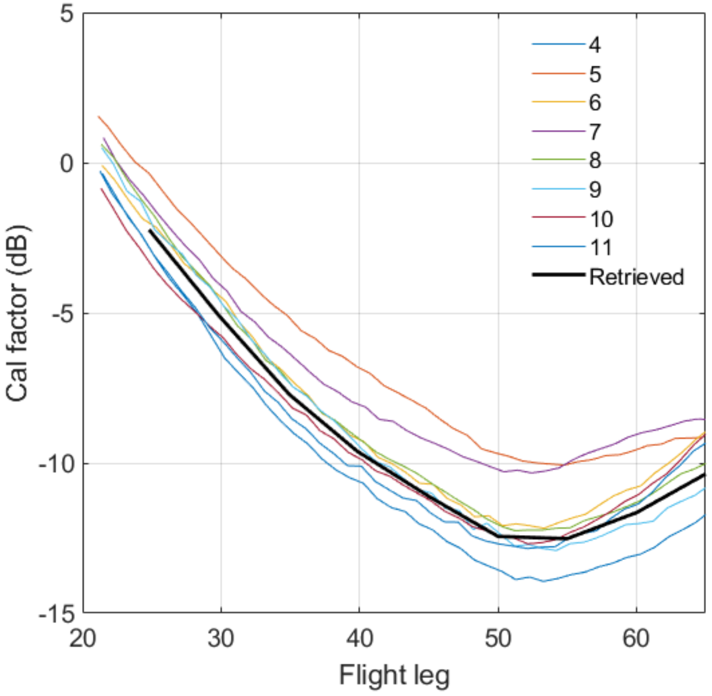
8 tracks on May 22nd



Beam 00(mid)



Beam 33(fore)

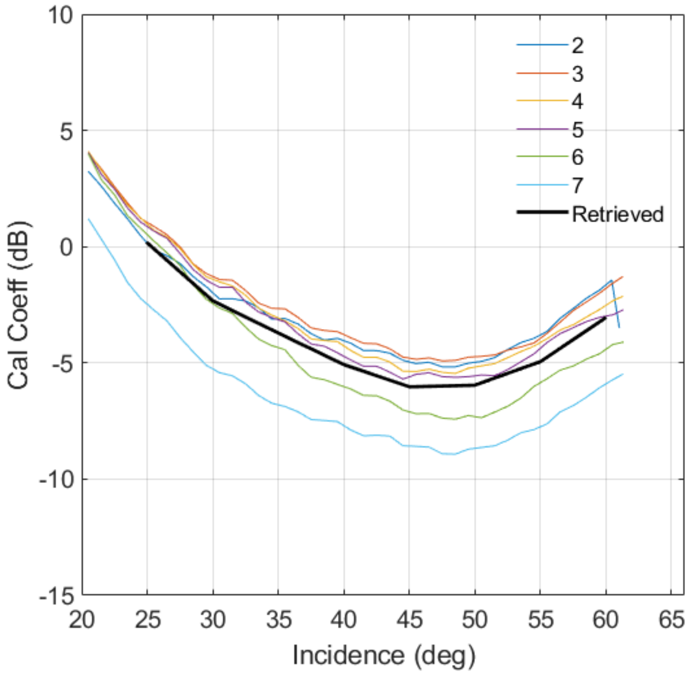


Beam 77(fixed)

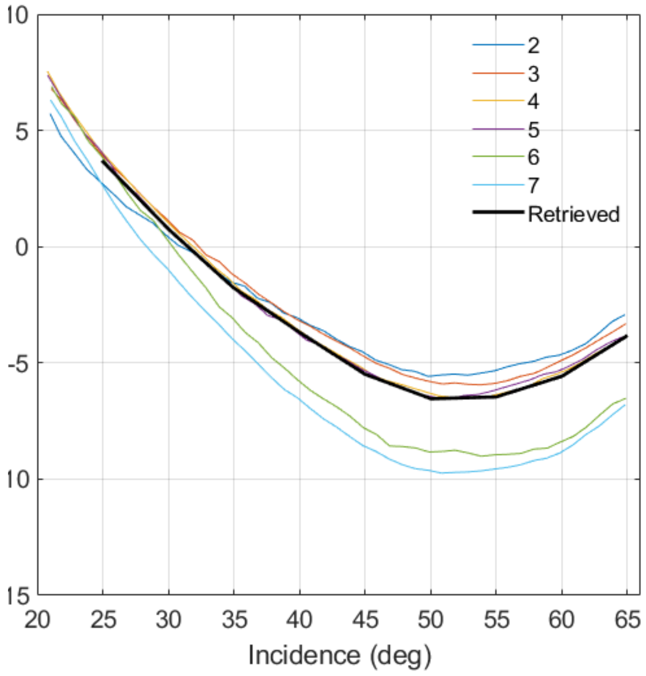
Using the collocated ECMWF winds
Compared with the above 'retrieved' calibration curve (black)

Ocean Calibration results (using May 25th data)

南京信息工程大学
Nanjing University of Information Science & Technology

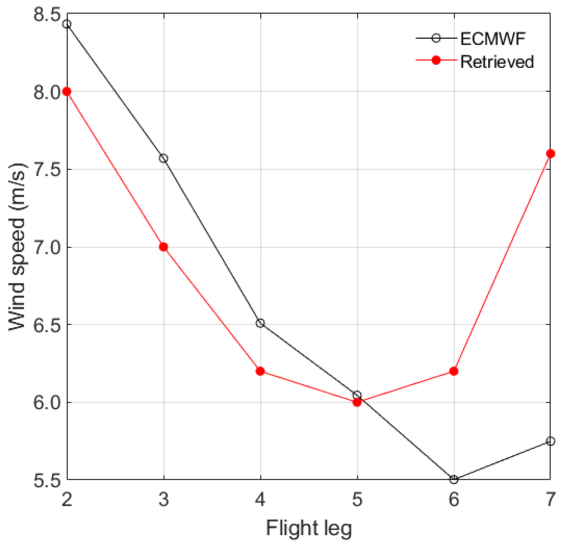


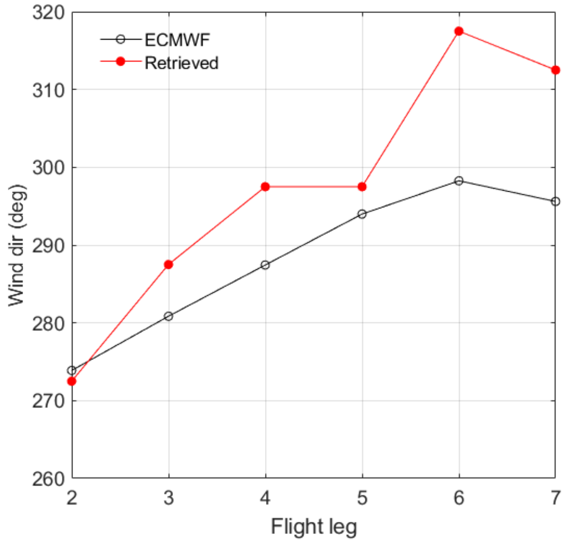
Beam 00 (mid)



Beam 33 (fore)

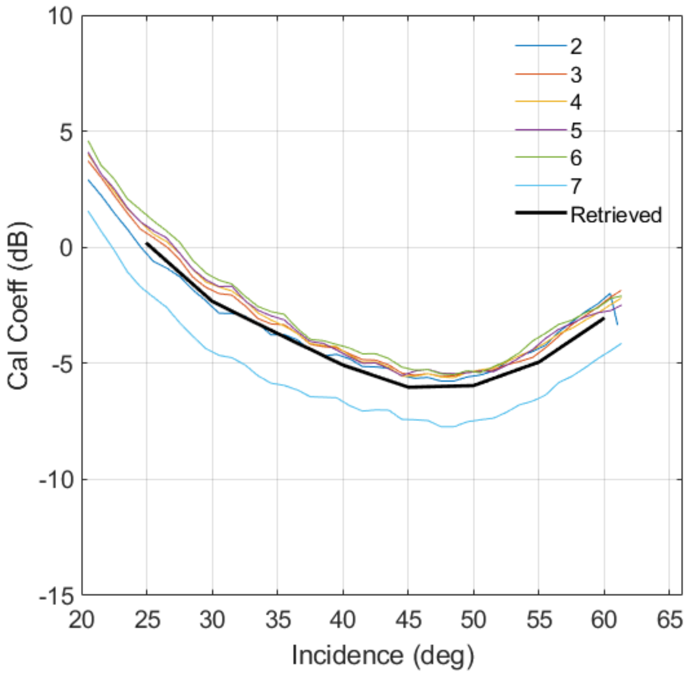
Color curves: calibration using ECMWF wind vectors
Black curves: calibration using the new method



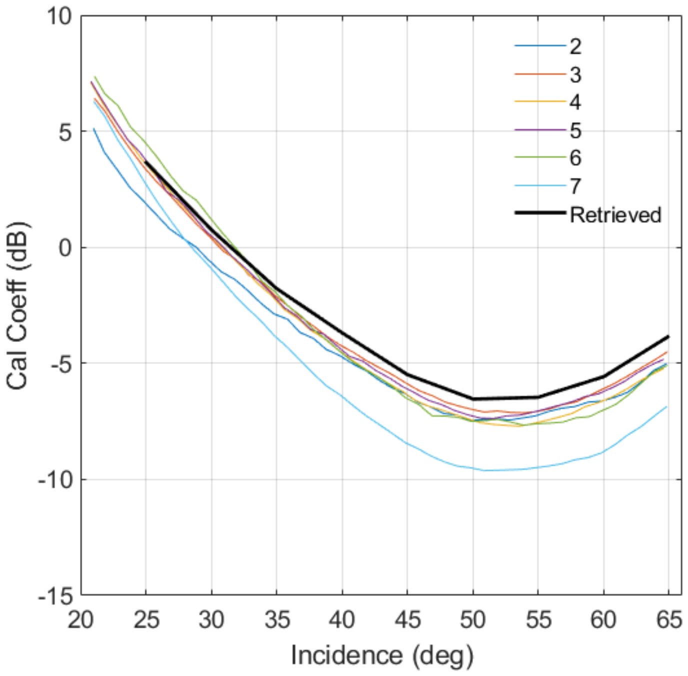


Black curves: ECMWF wind vectors
Red curves: Retrieved by the new method

Ocean Calibration results (using May 25th data)

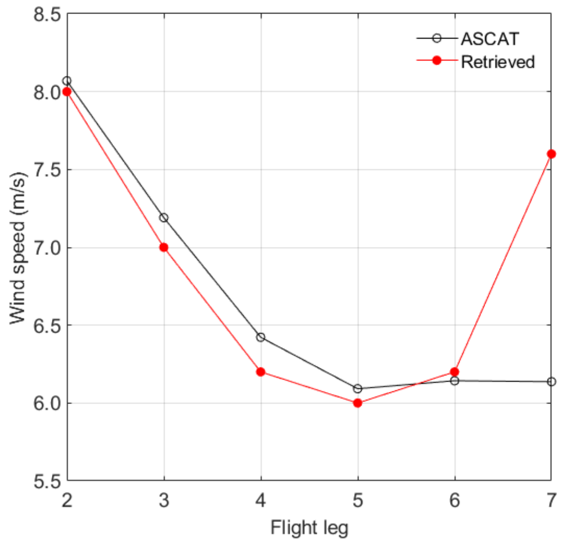


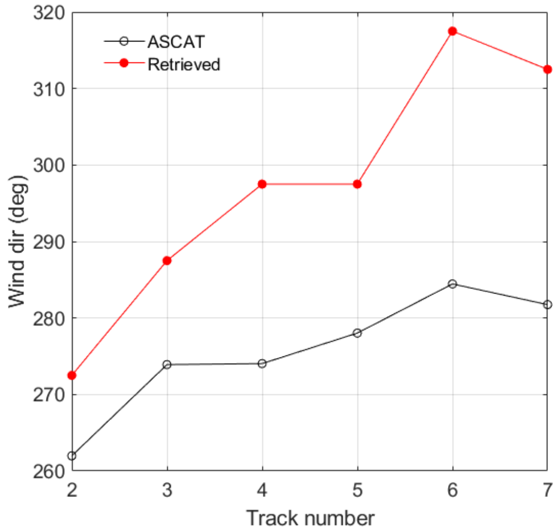
Beam 00 (mid)



Beam 33 (fore)

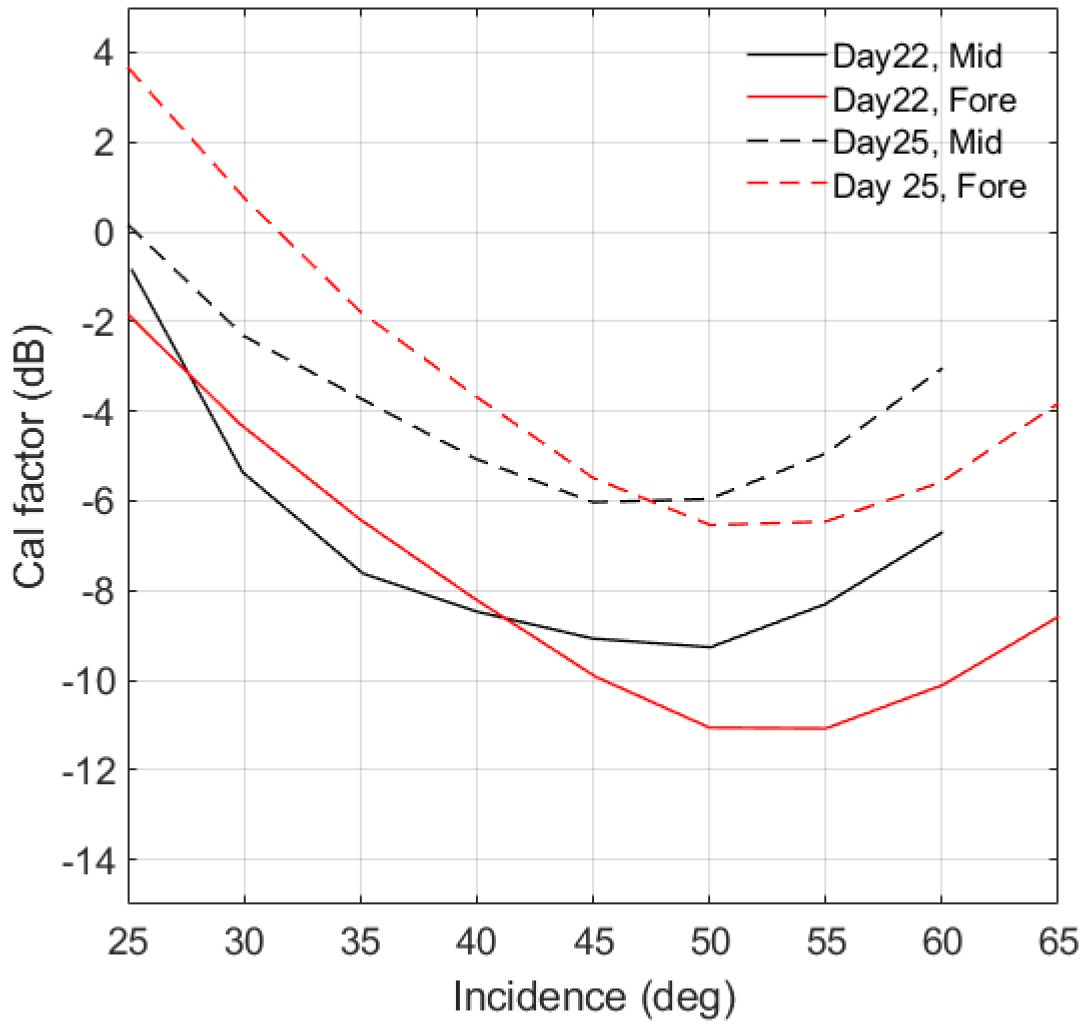
Color curves: calibration using ASCAT wind vectors
Black curves: calibration using the new method





Black curves: ASCAT wind vectors
Red curves: Retrieved by the new method

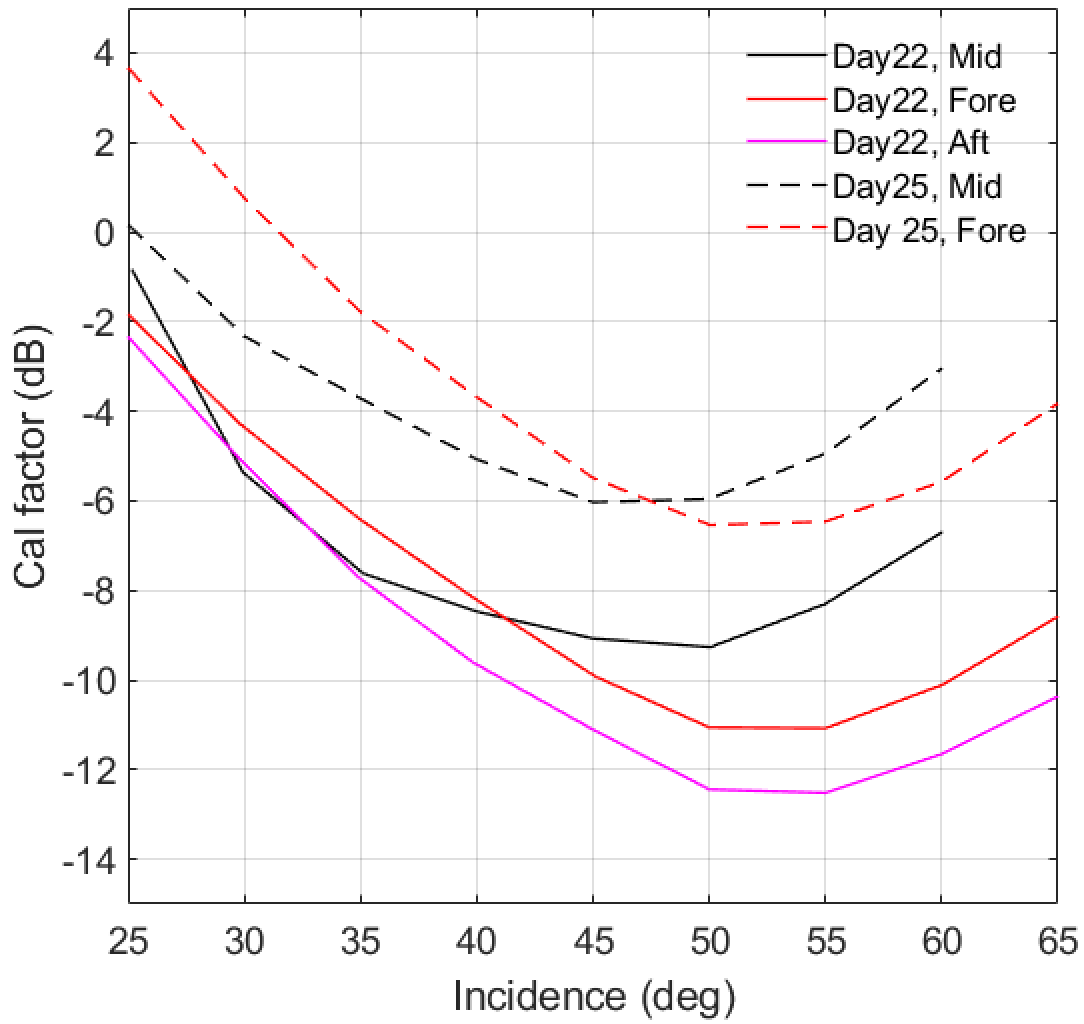
Calibration factors for May 22nd & May 25th



Calibration factors for different dates

For a given beam (Mid or Fore), the calibration factors are of similar shapes on different days, but with a bias of 3-4 dB.

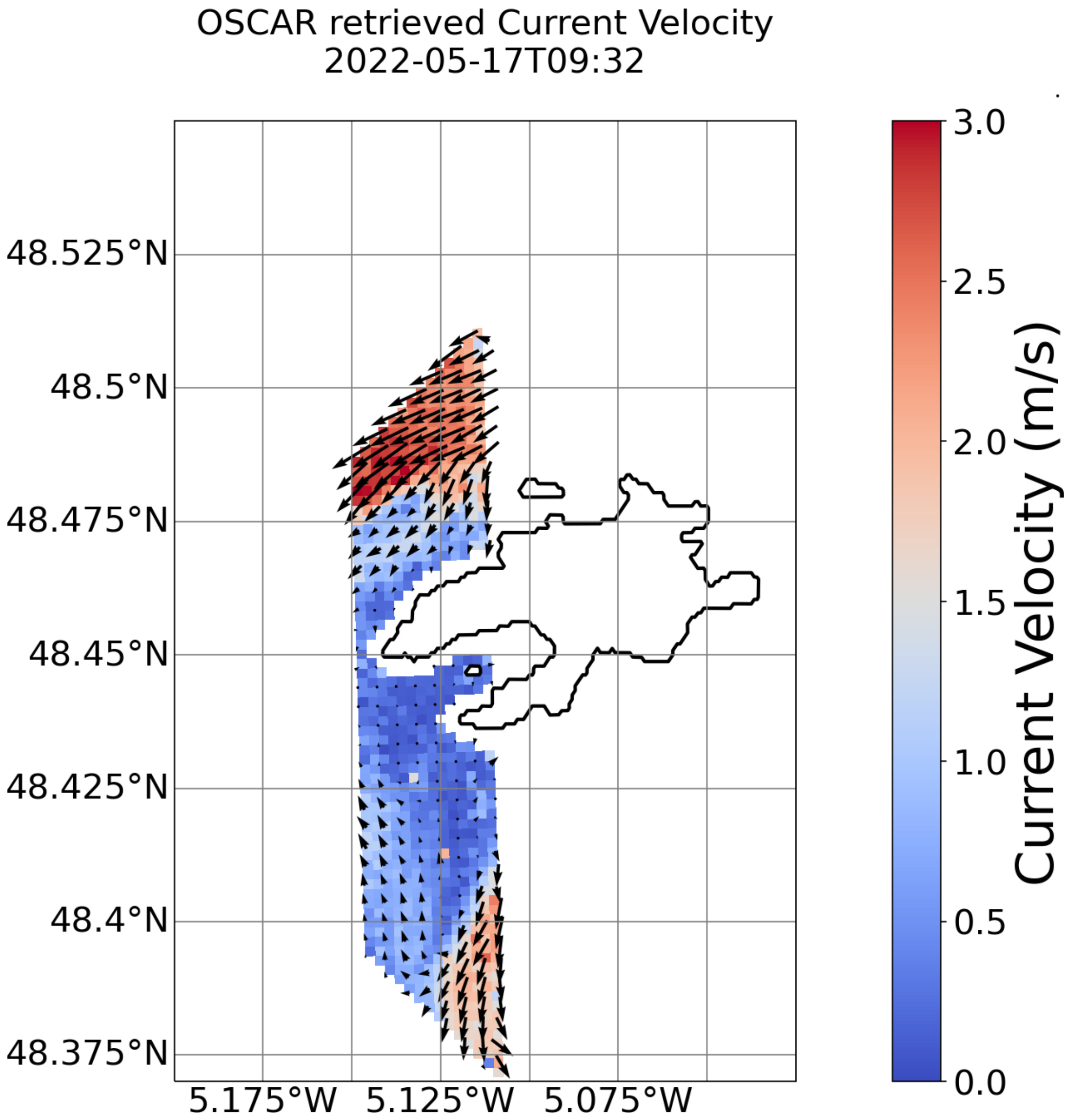
Calibration factors for May 22nd & May 25th

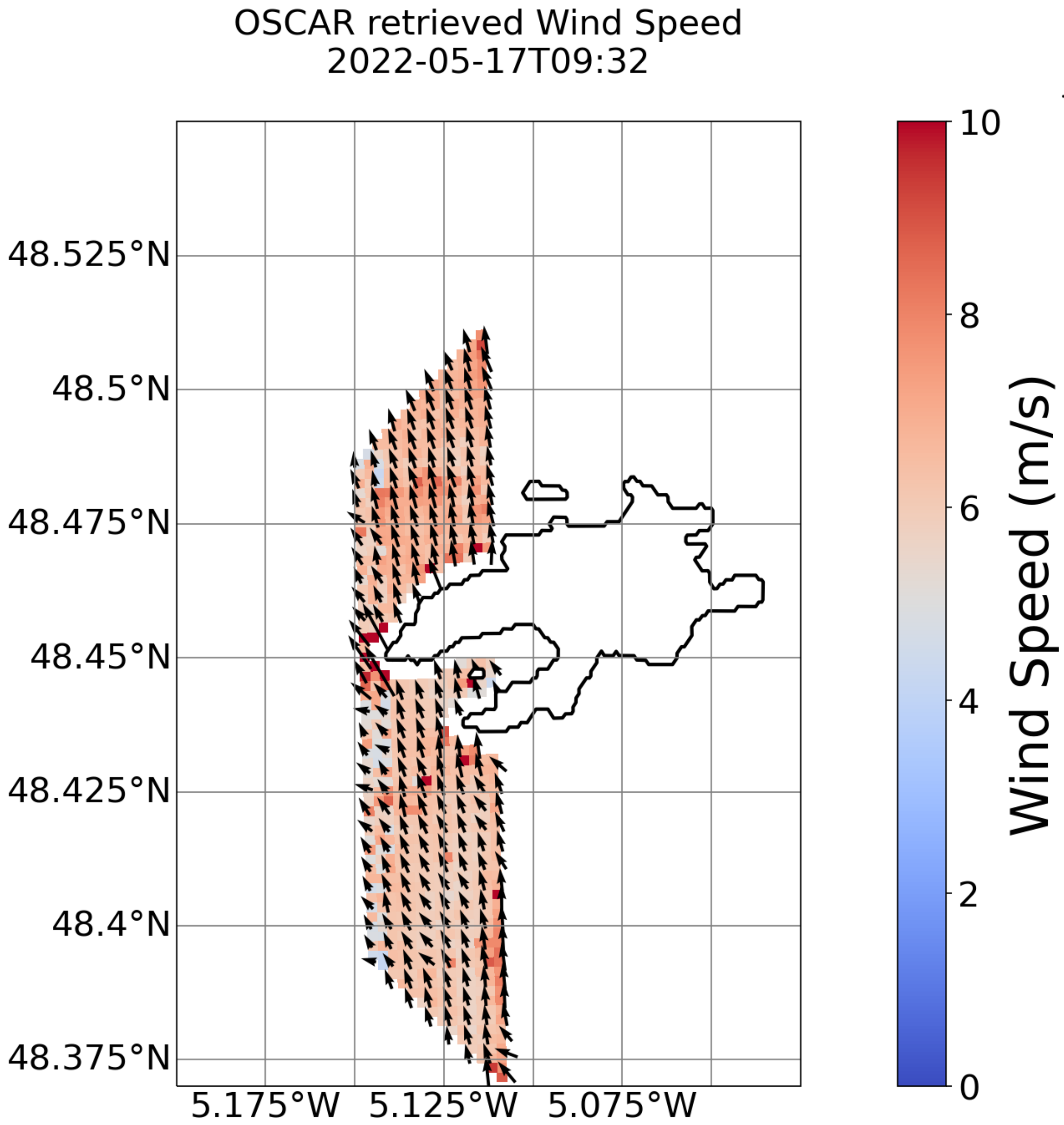


Calibration factors for different dates

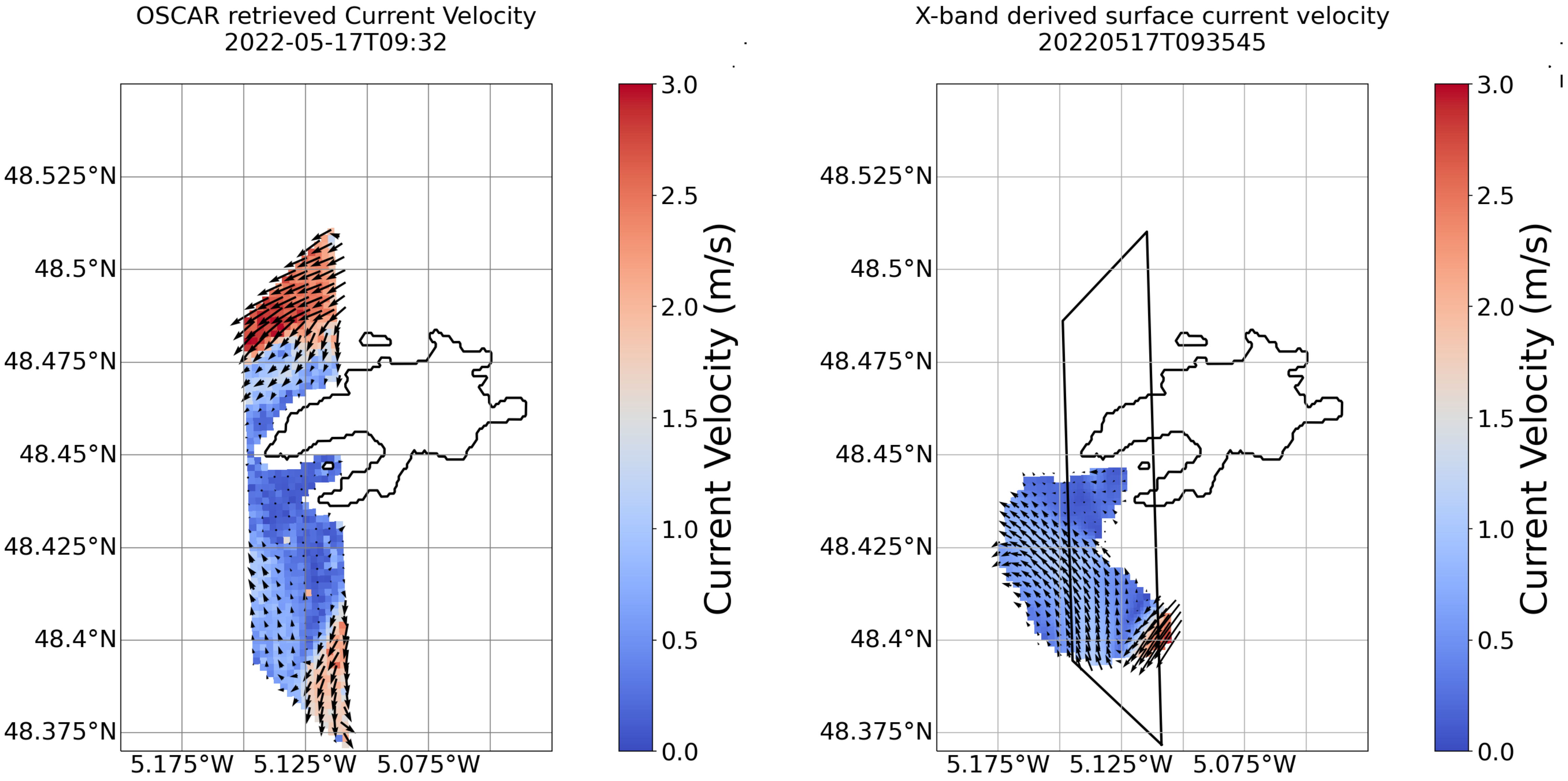
For a given beam (Mid or Fore), the calibration factors are of similar shapes on different days, but with a bias of 3-4 dB.

L2 simultaneous retrieval results

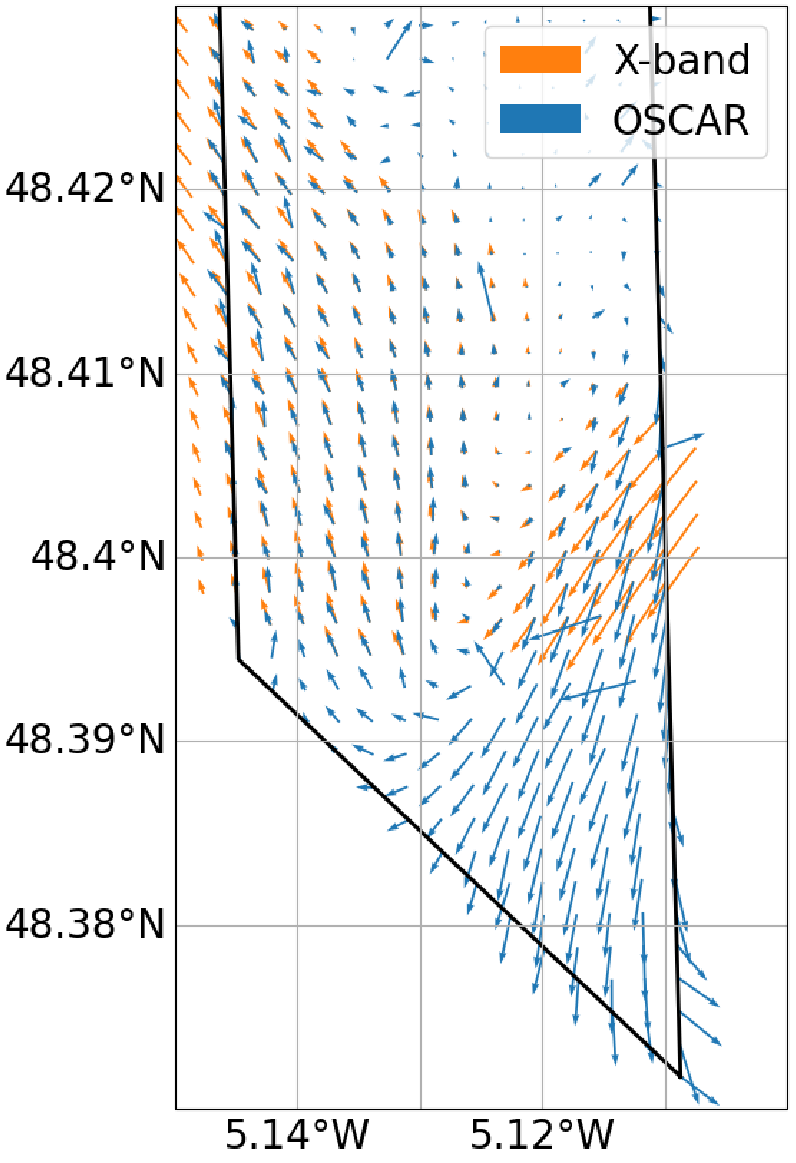


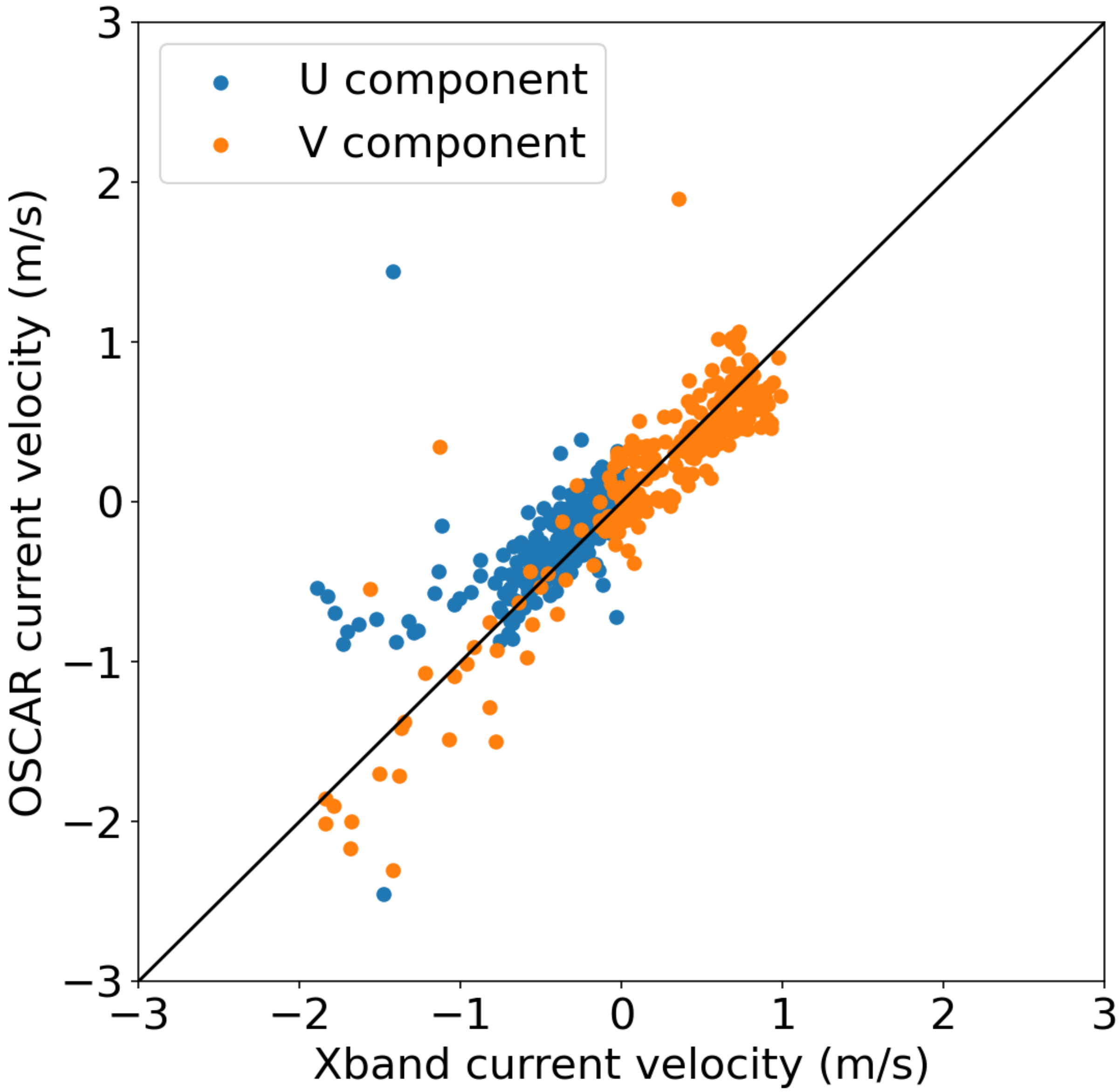


Comparison with X-band

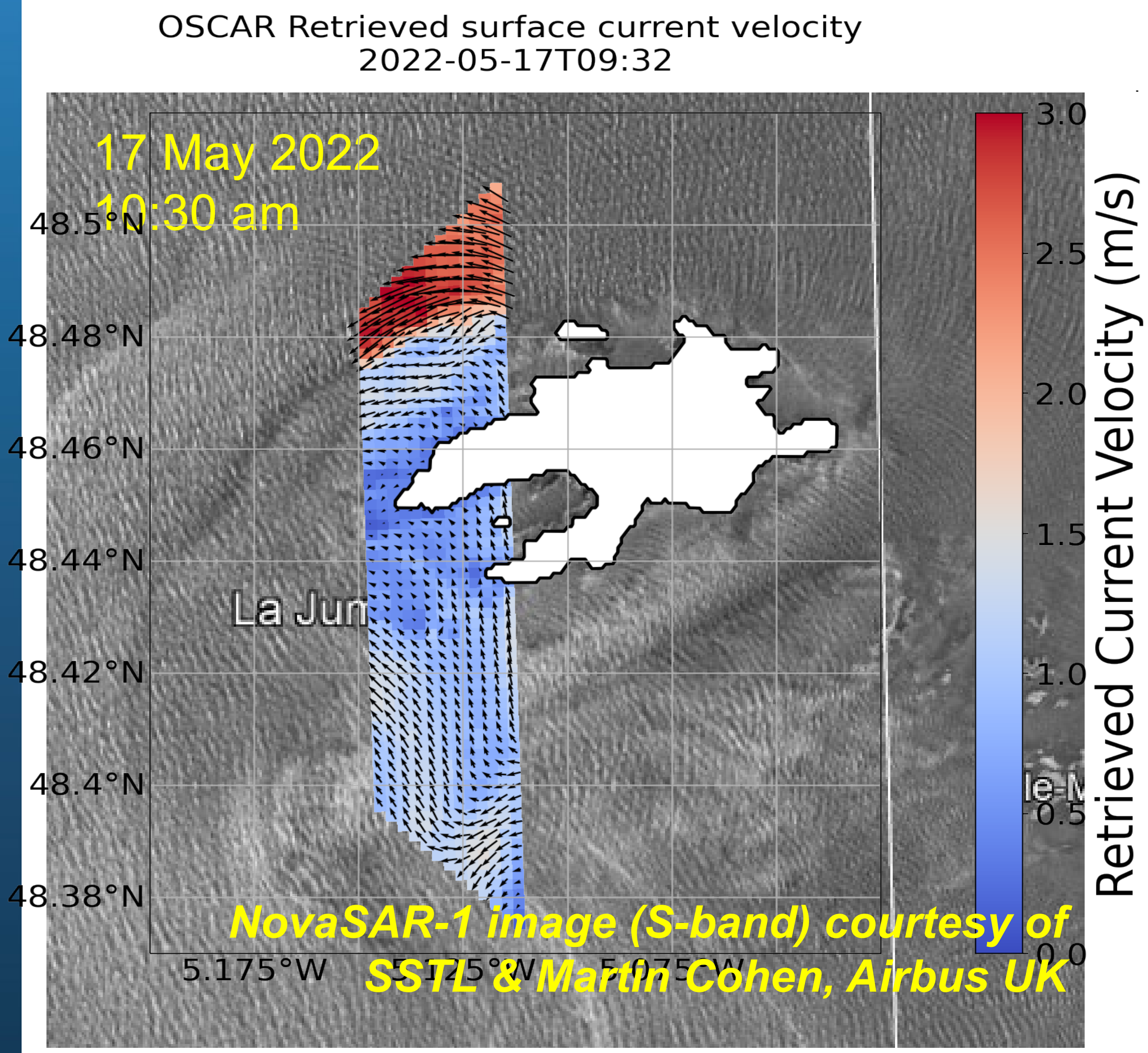


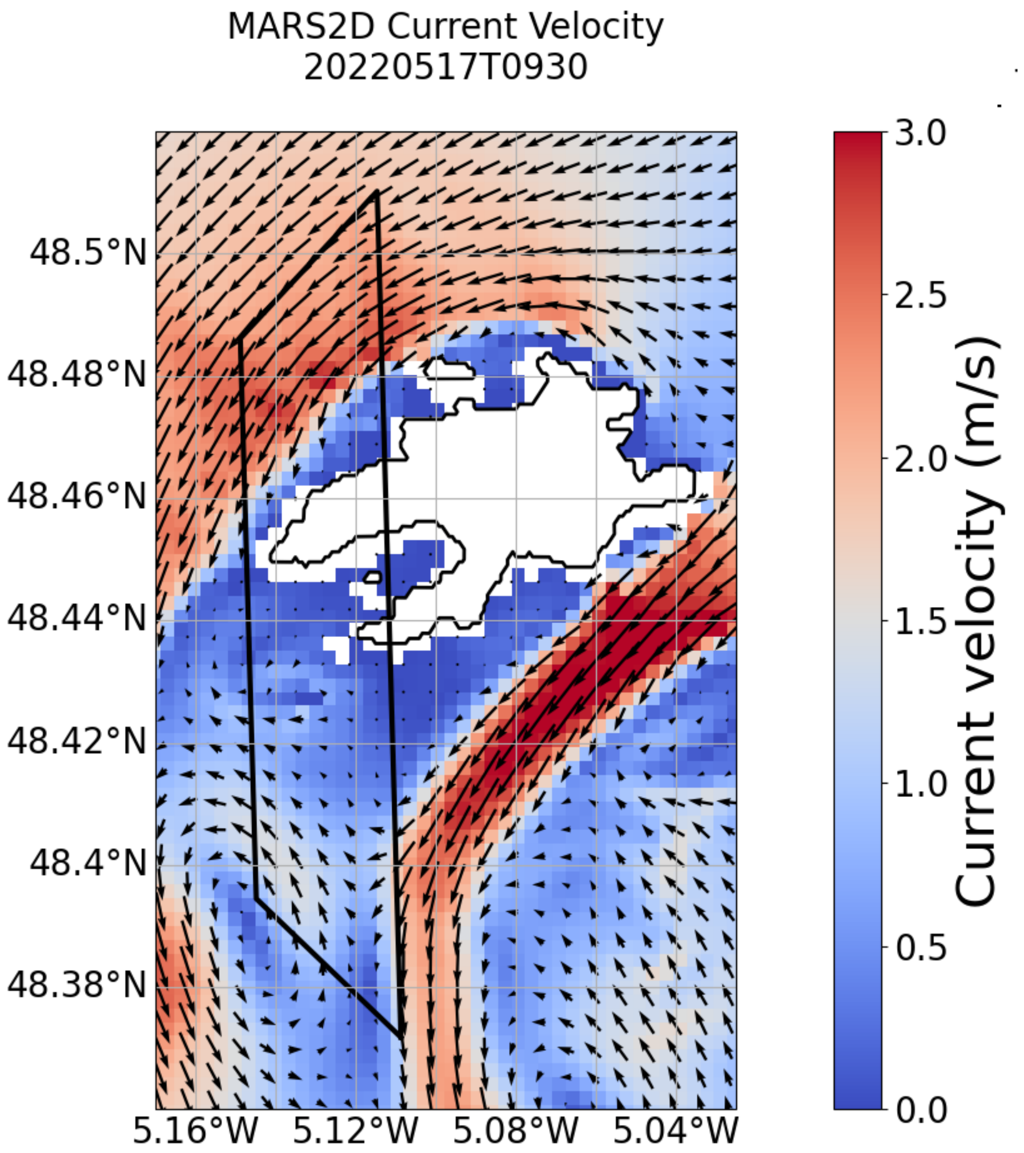
Comparison with X-band



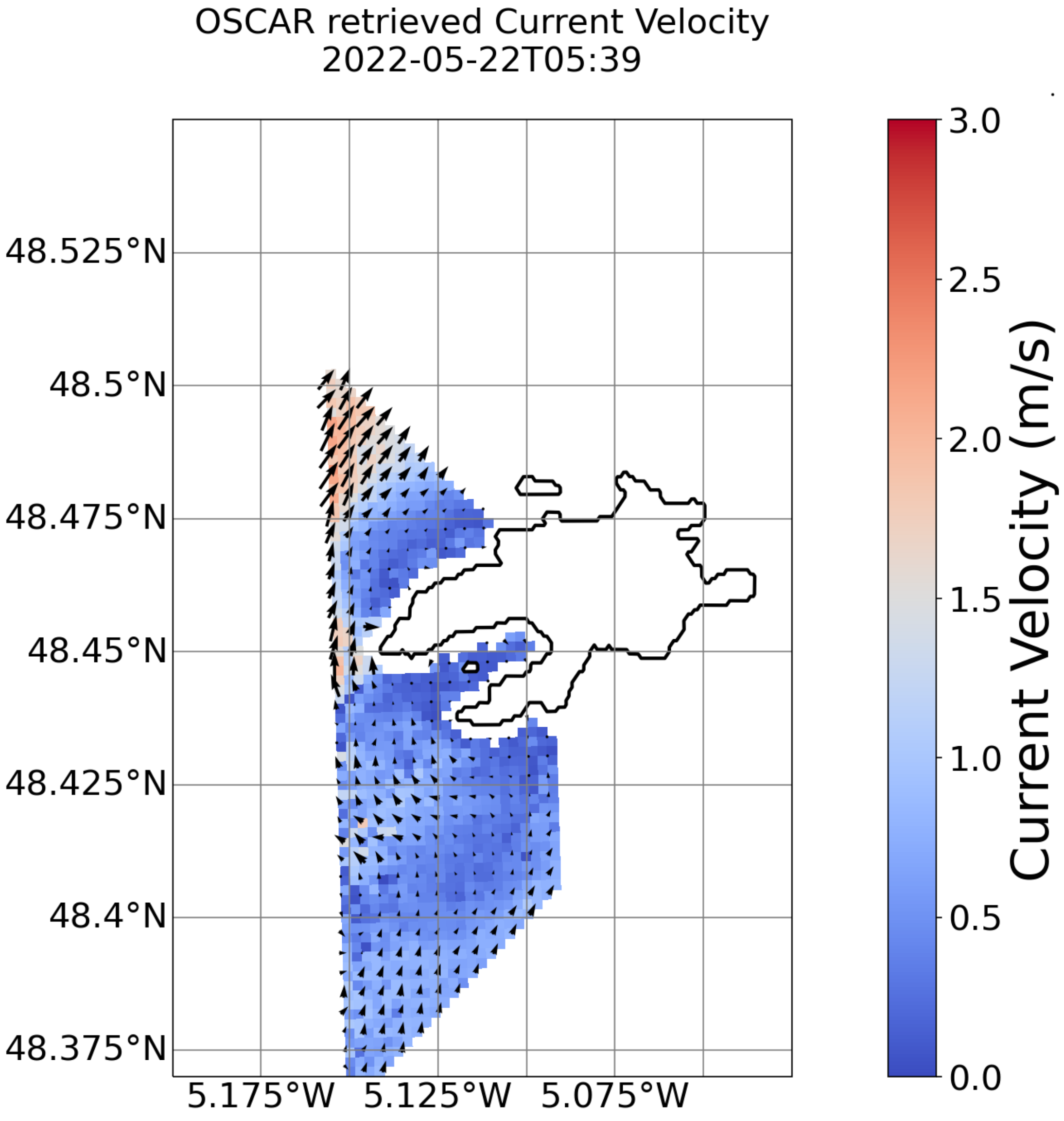


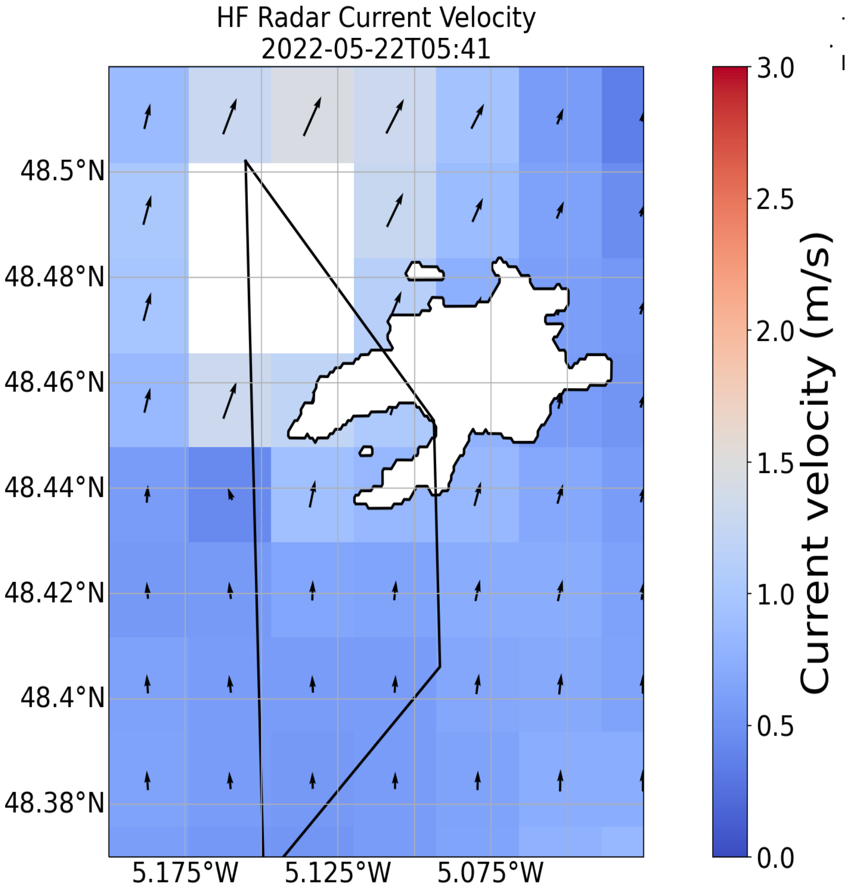
NovaSAR-1 & MARS2D comparison



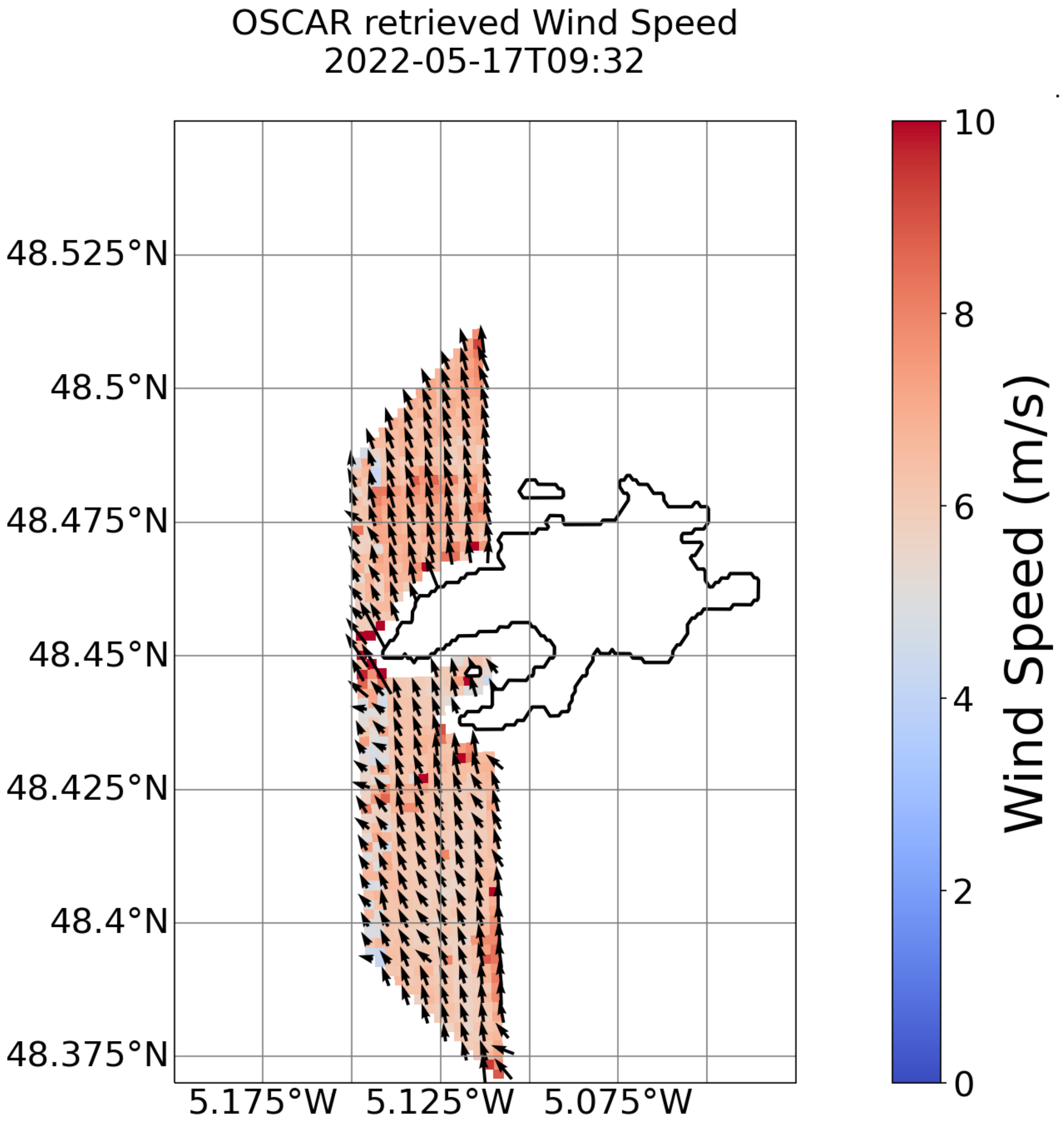


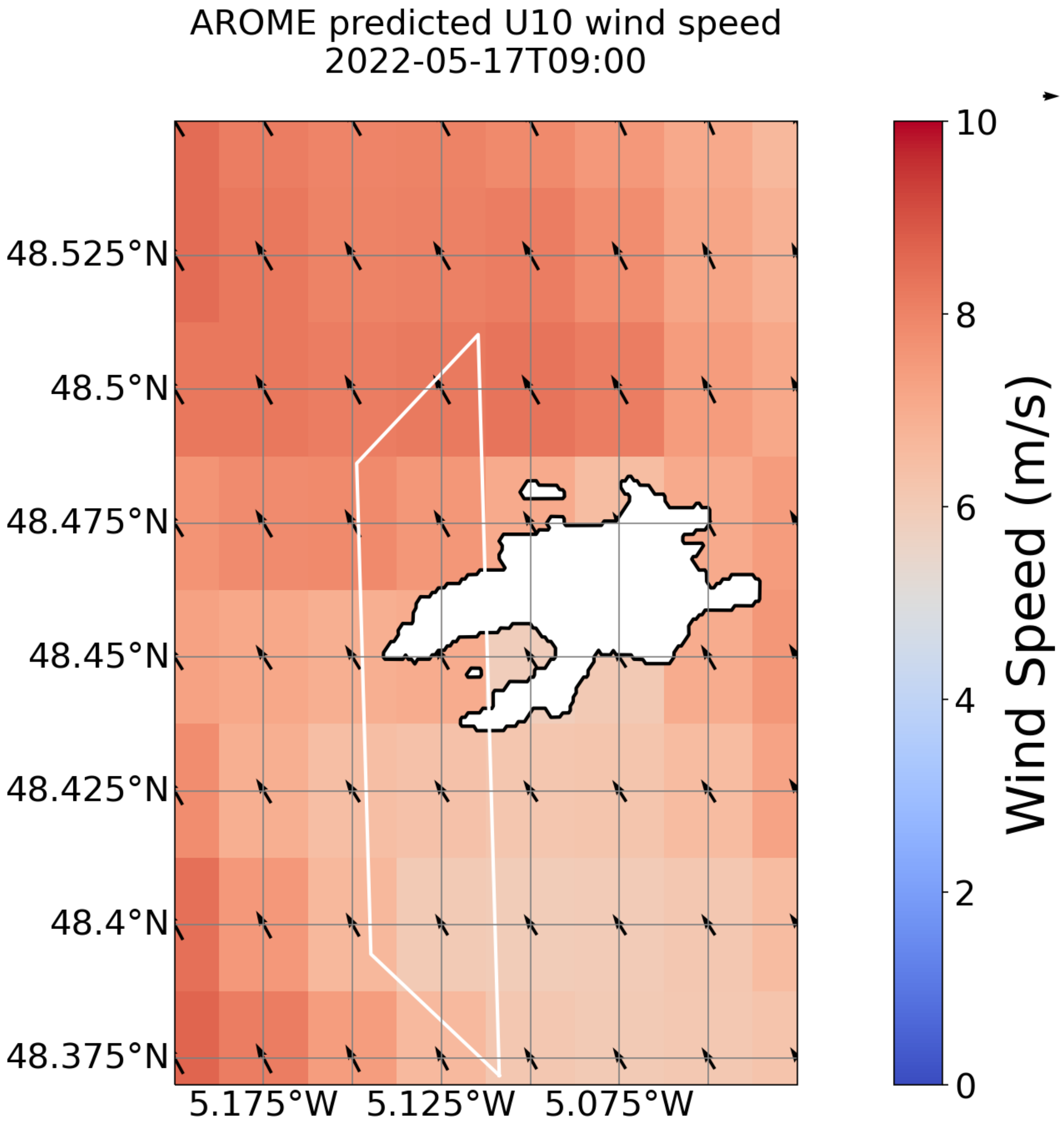
Comparison with HF Radar



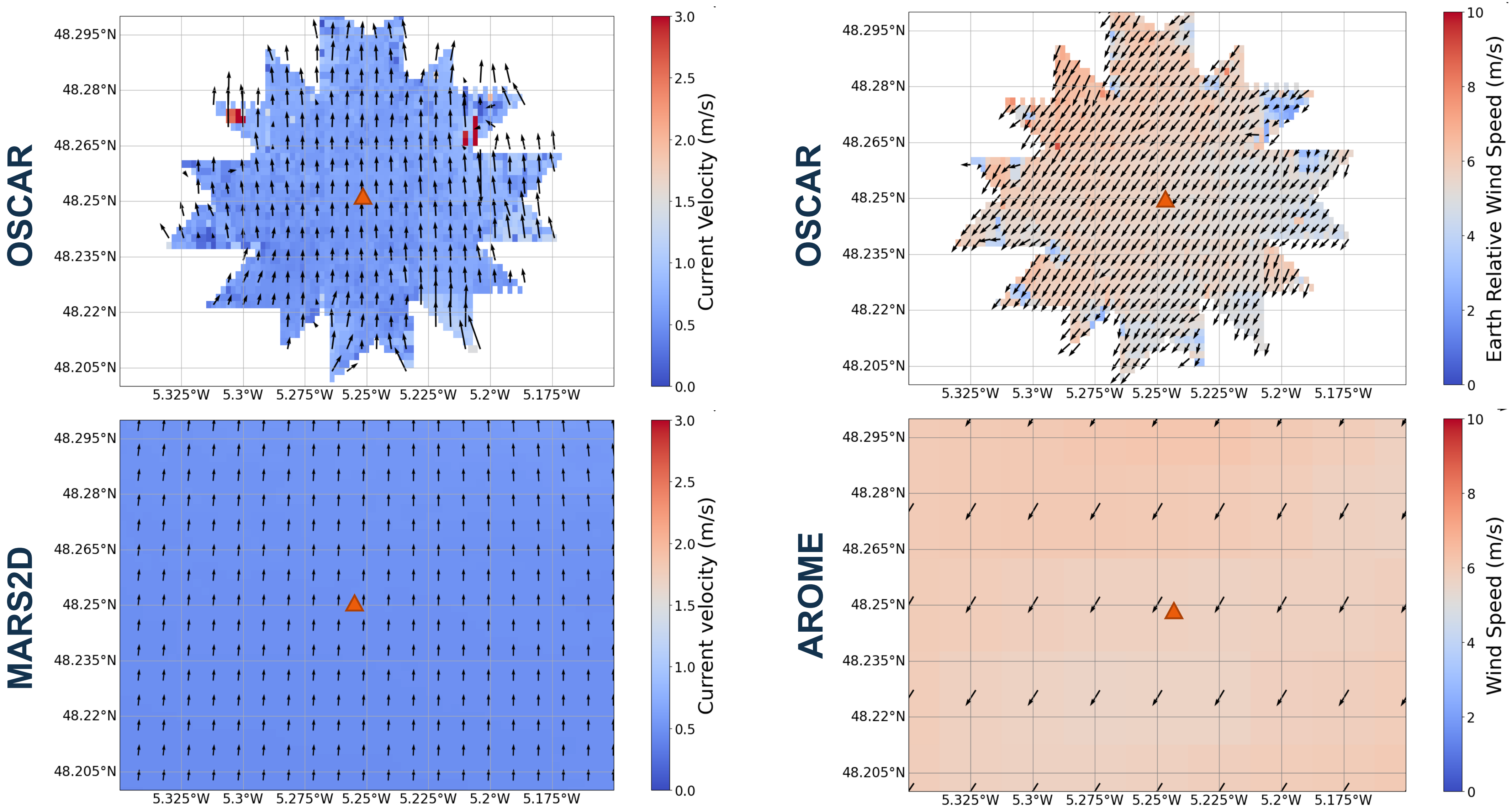


Comparison with AROME





Star pattern

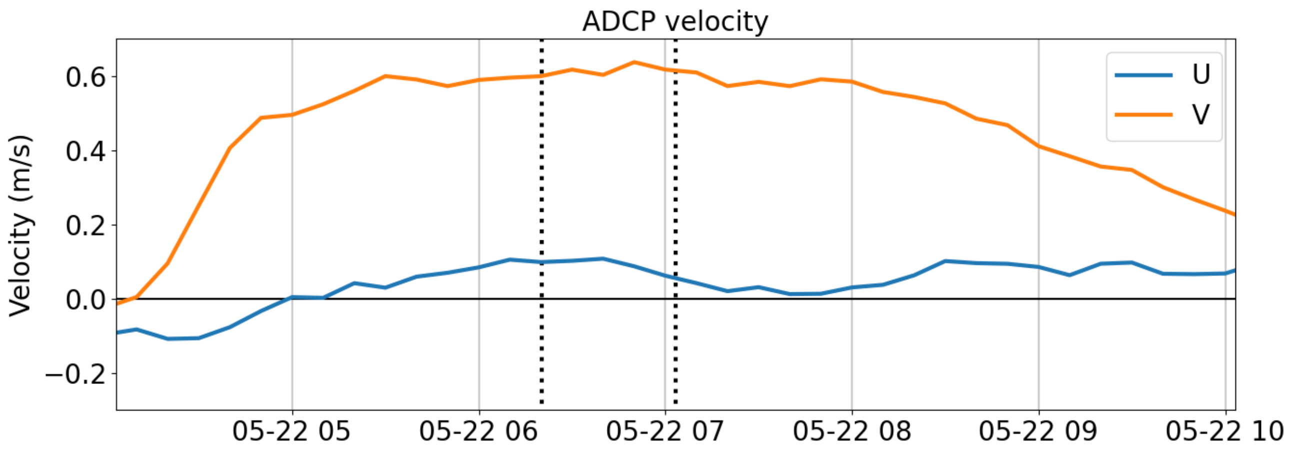


Validation

Assumption of temporal and spatial homogeneity allows us to take the mean retrieved parameter for each track of the pattern

No wind buoy (FLAME), so interpolated AROME to 200m grid, comparing at retrieved pixel level for RMSE

Currents			
	OSCAR	**ADCP**	**RMSE**
Velocity (m/s)	0.64	0.62	0.08
Direction (degrees N)	14.4	8.4	8.5
Winds			
	OSCAR	**AROME**	**RMSE**
Speed (m/s)	5.54	5.86	0.44
Direction (degrees N)	49.08	45.75	5.43



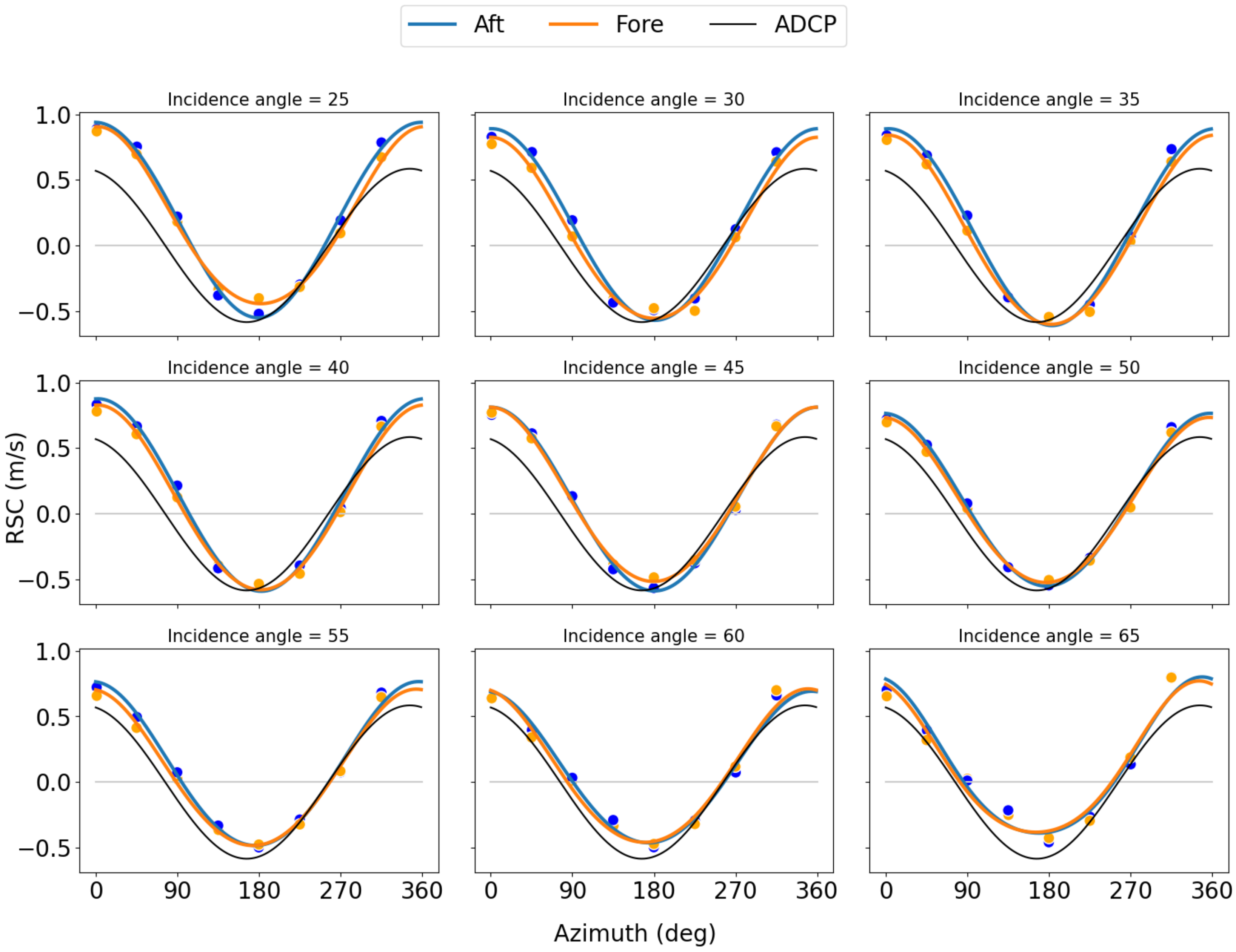
Radial Surface Current

'Star-pattern' analysis of grouping data by incidence angle and azimuth

GMF = Mouche (2012)

RSC data (points) with fitted curves (lines) for Fore and Aft channels

Black line is ADCP



From SEASTARex to OSCAR-Med

The SEASTARex campaign focused on demonstrating the OSCAR instrument capabilities regarding SEASTAR primary objective:

- To measure, for the first time, **2D images** of **Total Surface Current Vectors** and **Ocean Surface Vector Winds** at **1 km resolution** with high accuracy, over all **coastal seas, shelf seas and Marginal Ice Zones**.
- Target: a strong tidal current region, i.e., the Iroise Sea

The next objective is to prove the OSCAR capabilities on

- Delivering, for the first time, **high-order derivative products like gradients, vorticity, strain and divergence** to explore the relations between small-scale phenomena and **vertical exchanges between the atmosphere and the ocean interior**.
- Target: a region with mesoscale and submesoscale features associated with strong vorticity and divergence fields and vertical exchanges between the ocean interior and the atmosphere, i.e., the Western Mediterranean

The OSCAR-Med campaign aims at flying OSCAR over the Western Mediterranean Sea to complement in situ research activities taking place in the context of the SWOT mission

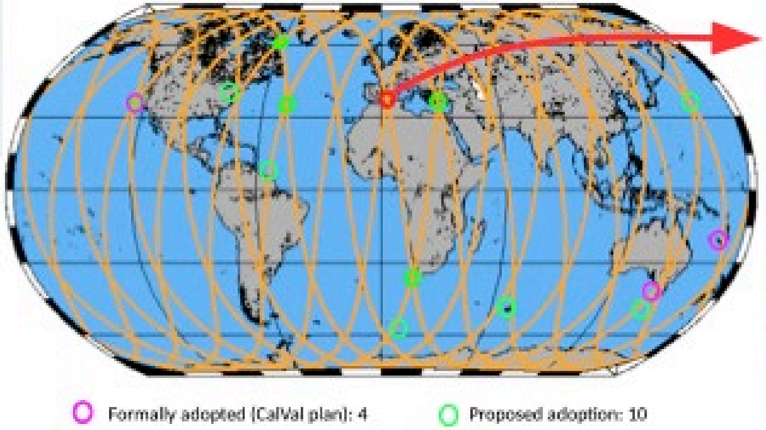
BIOSWOT-Med

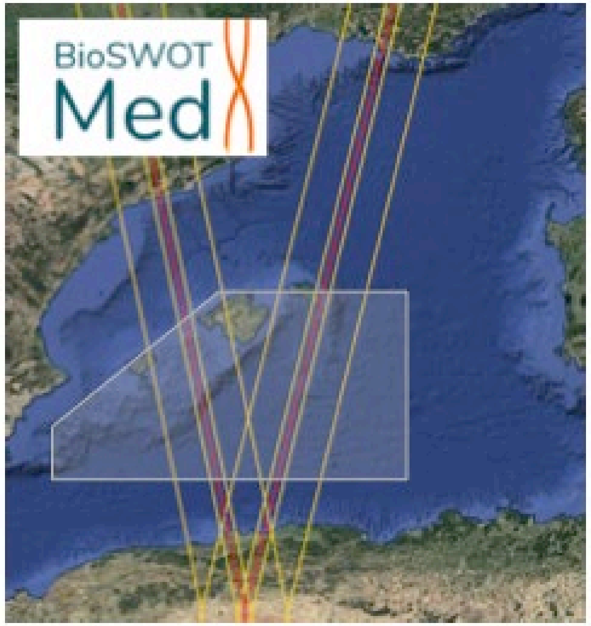
PIs A.M.Doglioli and G.Grégori

The BioSWOT-AdAC cruise
in the SW Mediterranean Sea

SWOT
SURFACE WATER & OCEAN TOPOGRAPHY
NASA • CNES • CSA • UKSA

SWOT AdAC





BioSWOT Med

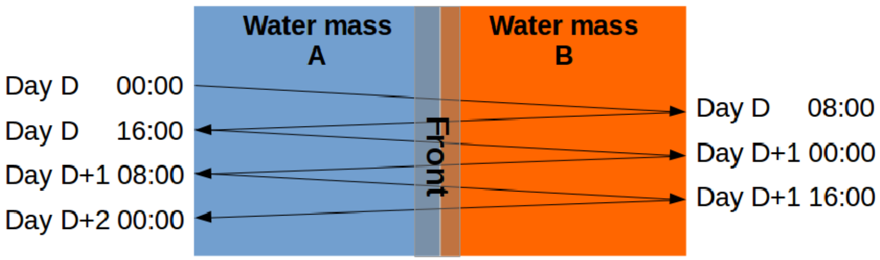
Track 6 (Marseille):	Track 19 (Baleares)
91,2023-04-21 20:36:00,	90,,2023-04-21 07:25:53
92,2023-04-22 20:26:37,	91,,2023-04-22 07:16:30
93,2023-04-23 20:17:14,	92,,2023-04-23 07:07:07
94,2023-04-24 20:07:51,	93,,2023-04-24 06:57:44
95,2023-04-25 19:58:28,	94,,2023-04-25 06:48:21
96,2023-04-26 19:49:05,	95,,2023-04-26 06:38:58
97,2023-04-27 19:39:42,	96,,2023-04-27 06:29:35
98,2023-04-28 19:30:19,	97,,2023-04-28 06:20:12
99,2023-04-29 19:20:56,	98,,2023-04-29 06:10:49
100,2023-04-30 19:11:33,	99,,2023-04-30 06:01:26
101,2023-05-01 19:02:10,	100,,2023-05-01 05:52:03
102,2023-05-02 18:52:47,	101,,2023-05-02 05:42:40
103,2023-05-03 18:43:24,	102,,2023-05-03 05:33:17
104,2023-05-04 18:34:01,	103,,2023-05-04 05:23:54
105,2023-05-05 18:24:38,	104,,2023-05-05 05:14:31
106,2023-05-06 18:15:15,	105,,2023-05-06 05:05:08
107,2023-05-07 18:05:52,	106,,2023-05-07 04:55:45
108,2023-05-08 17:56:29,	107,,2023-05-08 04:46:22
109,2023-05-09 17:47:06,	108,,2023-05-09 04:36:59
110,2023-05-10 17:37:43,	109,,2023-05-10 04:27:36
111,2023-05-11 17:28:20,	110,,2023-05-11 04:18:13
112,2023-05-12 17:18:57,	111,,2023-05-12 04:08:50
113,2023-05-13 17:09:34,	112,,2023-05-13 03:59:27
114,2023-05-14 17:00:11,	113,,2023-05-14 03:50:04

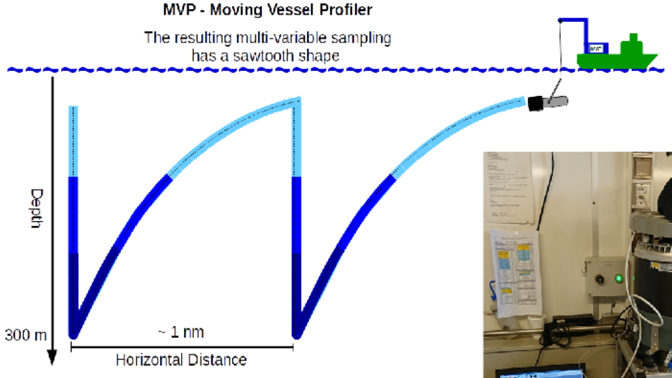
Strategy and methodology

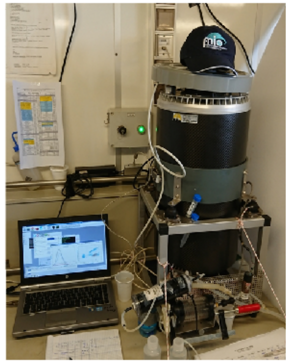
adaptive Lagrangian sampling strategies & Innovative instrumentation

SPASSO & MVP, gliders, AUV, drifters & floats, FFADCP, VVP, Cytometry, zooplankton and omics

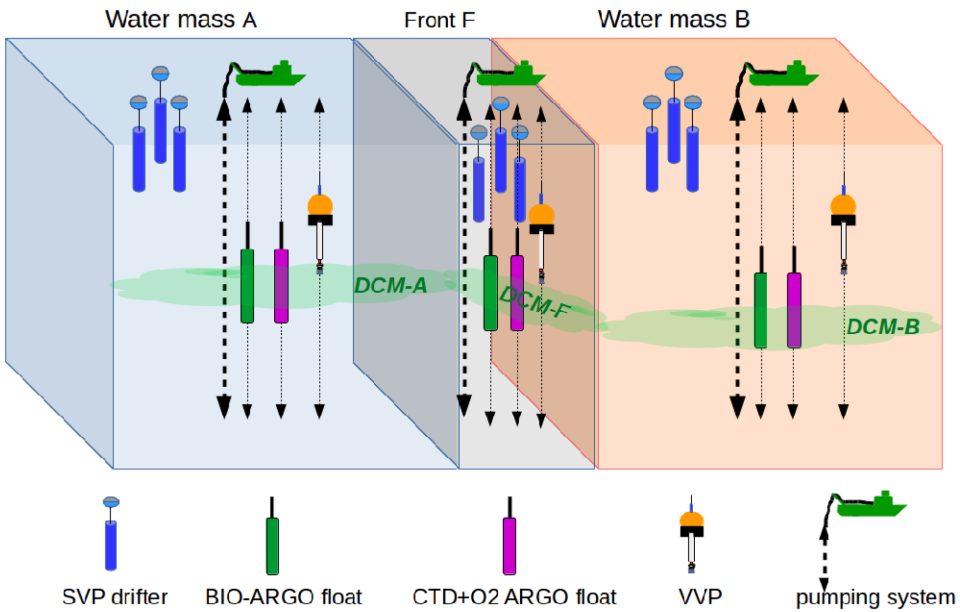
« back and forth » strategy for the horizontal continous sampling

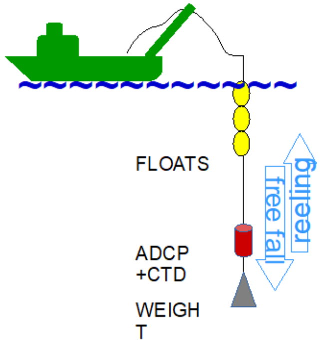


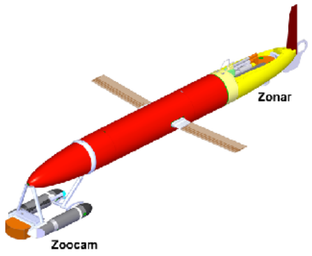


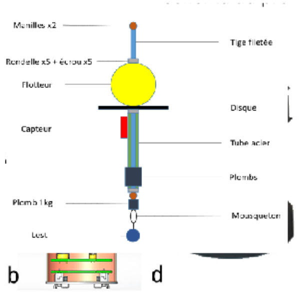


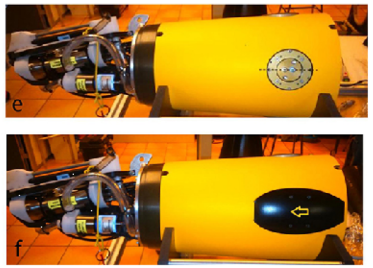
« Lagrangian stations» strategy for the vertical sampling











SeaSTAR community

ESA team

Alejandro Egido (Mission Scientist)
Tania Casal (Airborne Campaigns scientist)
Kevin Hall (System Study Manager)
Petronilo Martin-Iglesias (Payload & Performance)
Valeria Gracheva (Payload & Performance)
Dulce Lajas (E2E Simulators)
+ Lorenzo Iannini, M
Cipollini, Craig Donlo

Science Consolidation team

Christine Gommenginger, Adrien Martin (National Oceanography Centre, Uk)
Fabrice Collard, Clément Ubelmann (Ocean Data Lab, France)
Anis Elyouncha, Leif Eriksson (Chalmers University Of Technology, Sweden)
Joanna Staneva, Benjamin Jacob, Johannes Schulz-Stellenfleth (Helmholtz-Zentrum Hereon, Germany)
Louis Marié, Fabrice Ardhuin (Ifremer, France)

Unfortunately, SEASTAR was not selected!
EE13 candidate mission?

SeaSTARe

Adrien Martin, Chris
David McCann (NOC, UK)
Christian Trampuz, Adriano Meta (MetaSensing, NL)
Karlus Macedo (MetaSensing, NL)
Louis Marié (Ifremer, FR)
Jean-Francois Fillipot (France Energies Marines, FR)
Jose Marquez (RadarMetrics, SP)
Jochen Horstmann (Helmholtz-Zentrum Hereon, DL)
Wenming Lin (NUIST, CN)
Giuseppe Grieco (ISMAR, IT)
Marcos Portabella (ICM-CSIC, SP)

And more…

Aida Alvera-Azcarate (University of Liege, Belgium)
Ole Baltazar Andersen (DTU Space, Denmark)
Fabrice Ardhuin (CNRS / LOPS, France)
Antonio Bonaduce (NERSC, Norway)
Øyvind Breivik (Norwegian Meteo Institute, Norway)
Fabrice Collard (OceanDataLab, France)
Mohammed Dabboor (Environment and Climate Change, Canada)
Robert King (Met Office, United Kingdom)
Joanna Staneva (Helmholtz-Zentrum Hereon, Germany)
Ad Stoffelen (KNMI, The Netherlands)
David Woolf (Heriot Watt University, United Kingdom)

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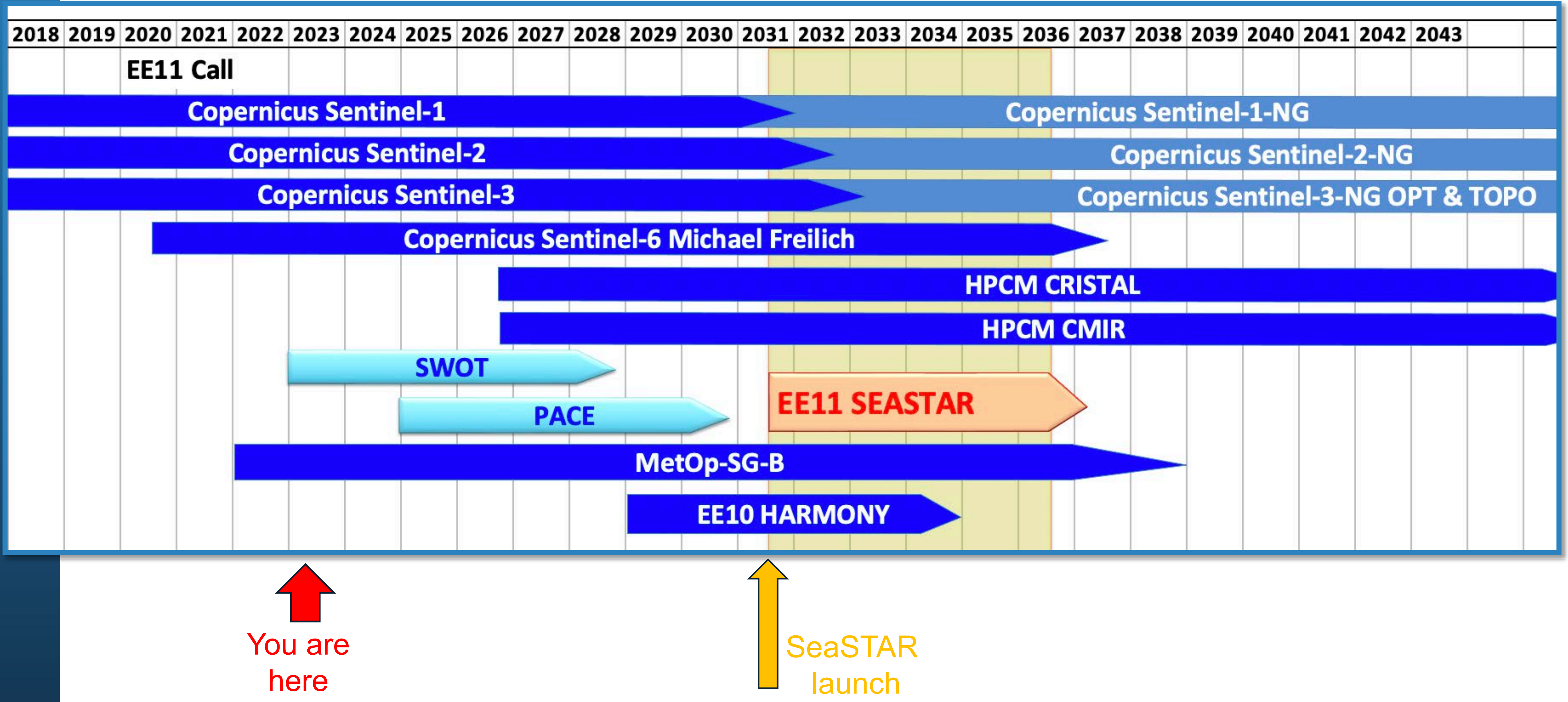
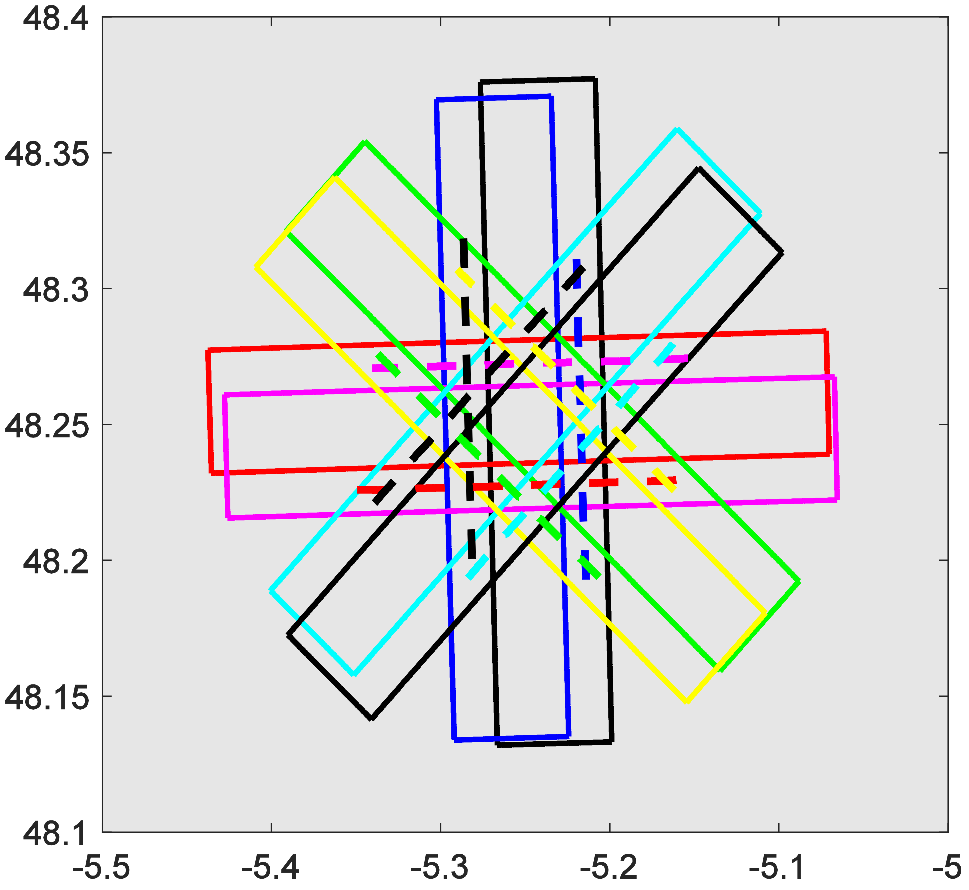
SEASTAR: A Mission to Study Ocean Submesoscale Dynamics and Small-Scale Atmosphere-Ocean Processes in Coastal, Shelf and Polar Seas

Christine Gommenginger[1], Bertrand Chapron[2], Andy Hogg[3], Christian Buckingham[4], Baylor Fox-Kemper[5], Leif Eriksson[6], Francois Soulat[7], Clément Ubelmann[7], Francisco Ocampo-Torres[8], Bruno Buongiorno Nardelli[9], David Griffin[10], Paco Lopez-Dekker[11], Per Knudsen[12], Ole Andersen[12], Lars Stenseng[13], Neil Stapleton[14], William Perrie[15], Nelson Violante-Carvalho[16], Johannes Schulz-Stellenfleth[17], David Woolf[18], Jordi Isern-Fontanet[19], Fabrice Ardhuin[2], Patrice Klein[2], Alexis Mouche[2], Ananda Pascual[20], Xavier Capet[21], Daniele Hauser[22], Ad Stoffelen[23], Rosemary Morrow[24], Lotfi Aouf[25], Øyvind Breivik[26,27], Lee-Lueng Fu[28], Johnny A. Johannessen[29], Yevgeny Aksenov[1], Lucy Bricheno[30], Joel Hirschi[1], Adrien C. H. Martin[1], Adrian P. Martin[1], George Nurser[1], Jeff Polton[30], Judith Wolf[30], Harald Johnsen[31], Alexander Soloviev[32], Gregg A. Jacobs[33], Fabrice Collard[34], Steve Groom[35], Vladimir Kudryavtsev[36], John Wilkin[37], Victor Navarro[38], Alex Babanin[39], Matthew Martin[40], John Siddorn[40], Andrew Saulter[40], Tom Rippeth[41], Bill Emery[42], Nikolai Maximenko[43], Roland Romeiser[44], Hans Graber[44], Aida Alvera Azcarate[45], Chris W. Hughes[30,46], Doug Vandemark[47], Jose da Silva[48], Peter Jan Van Leeuwen[49,50], Alberto Naveira-Garabato[51], Johannes Gemmrich[52], Amala Mahadevan[53], Jose Marquez[54], Yvonne Munro[54], Sam Doody[54] and Geoff Burbidge[54]*

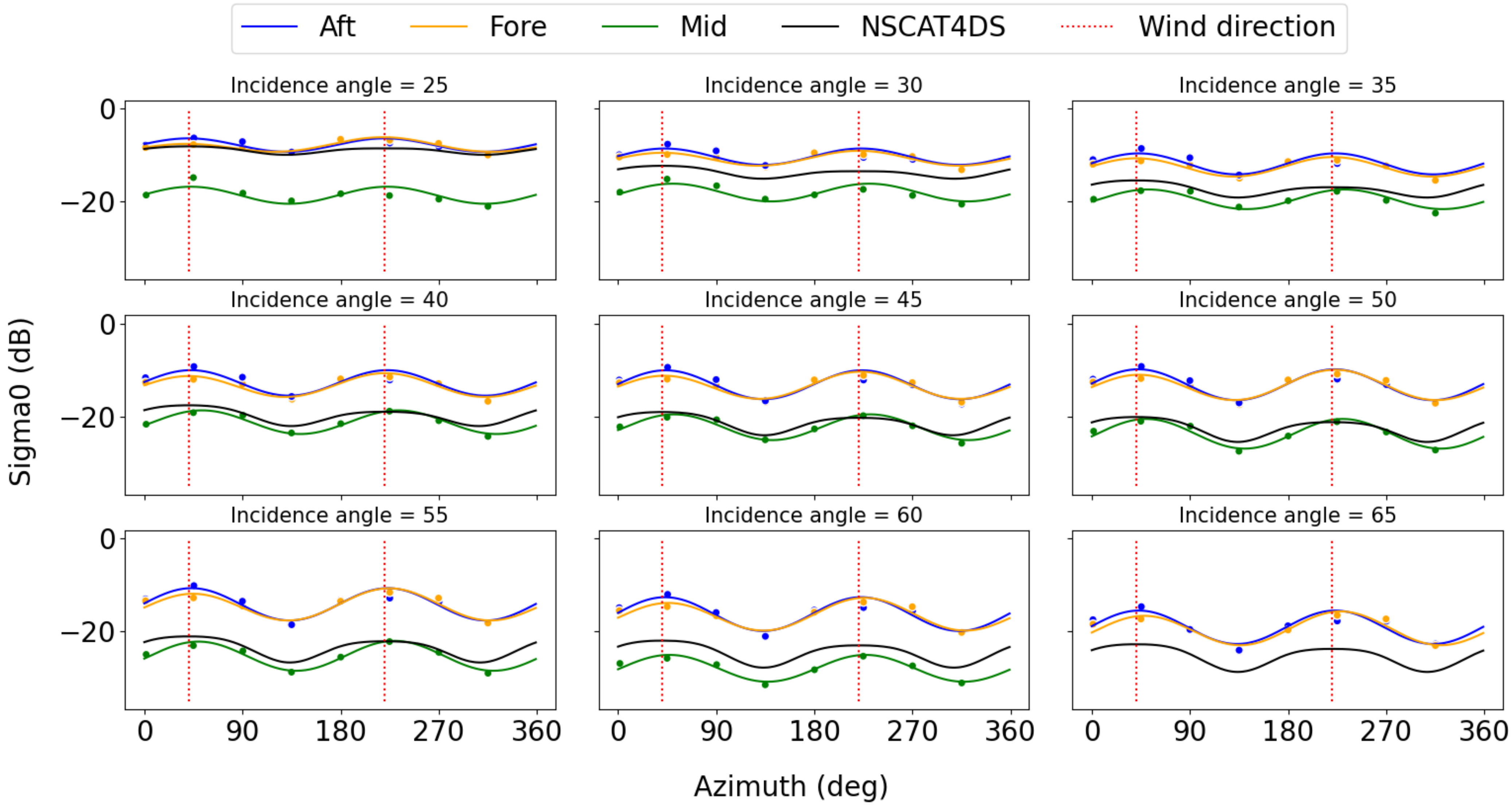
Synergy with other missions



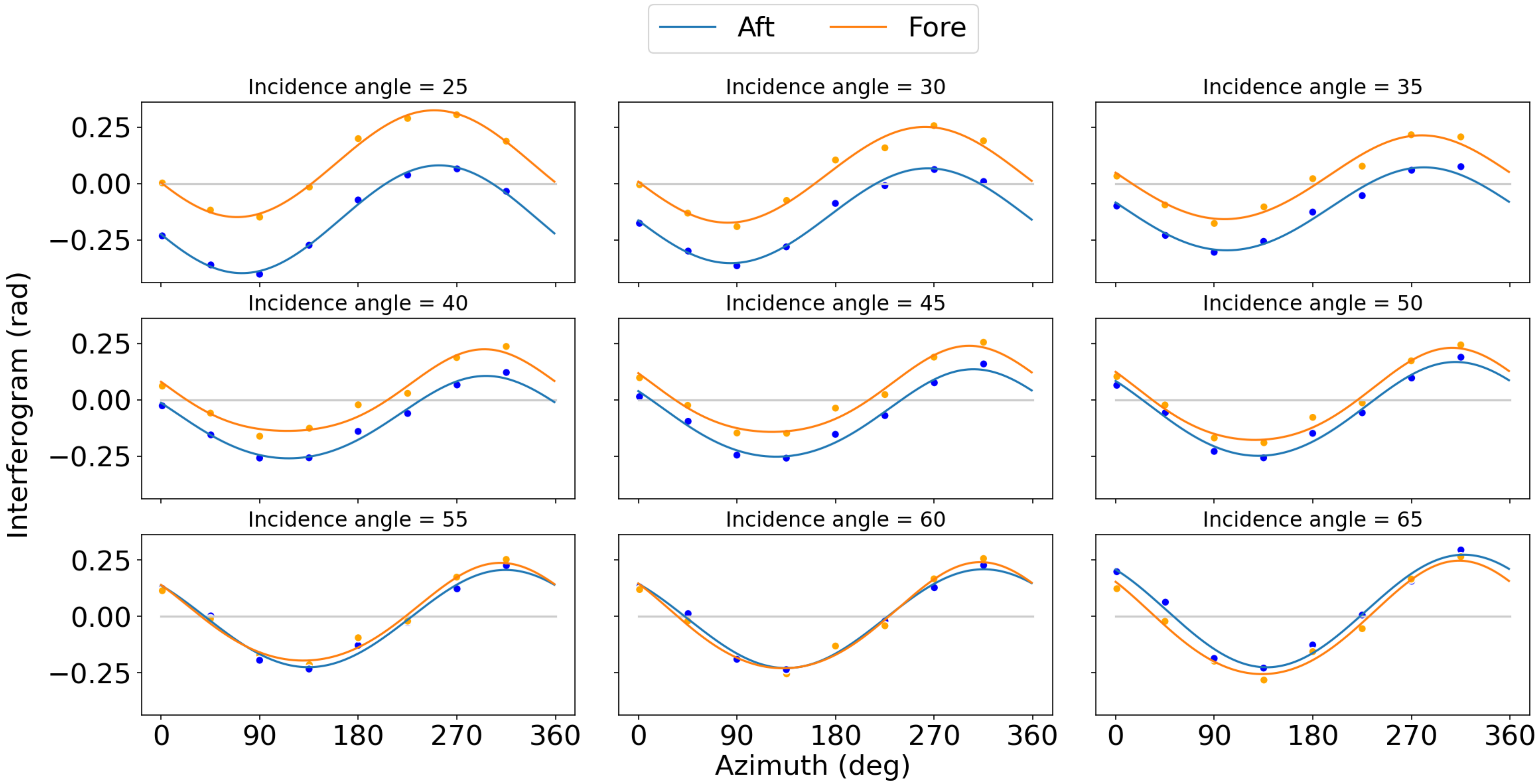


Star-pattern on May 22nd

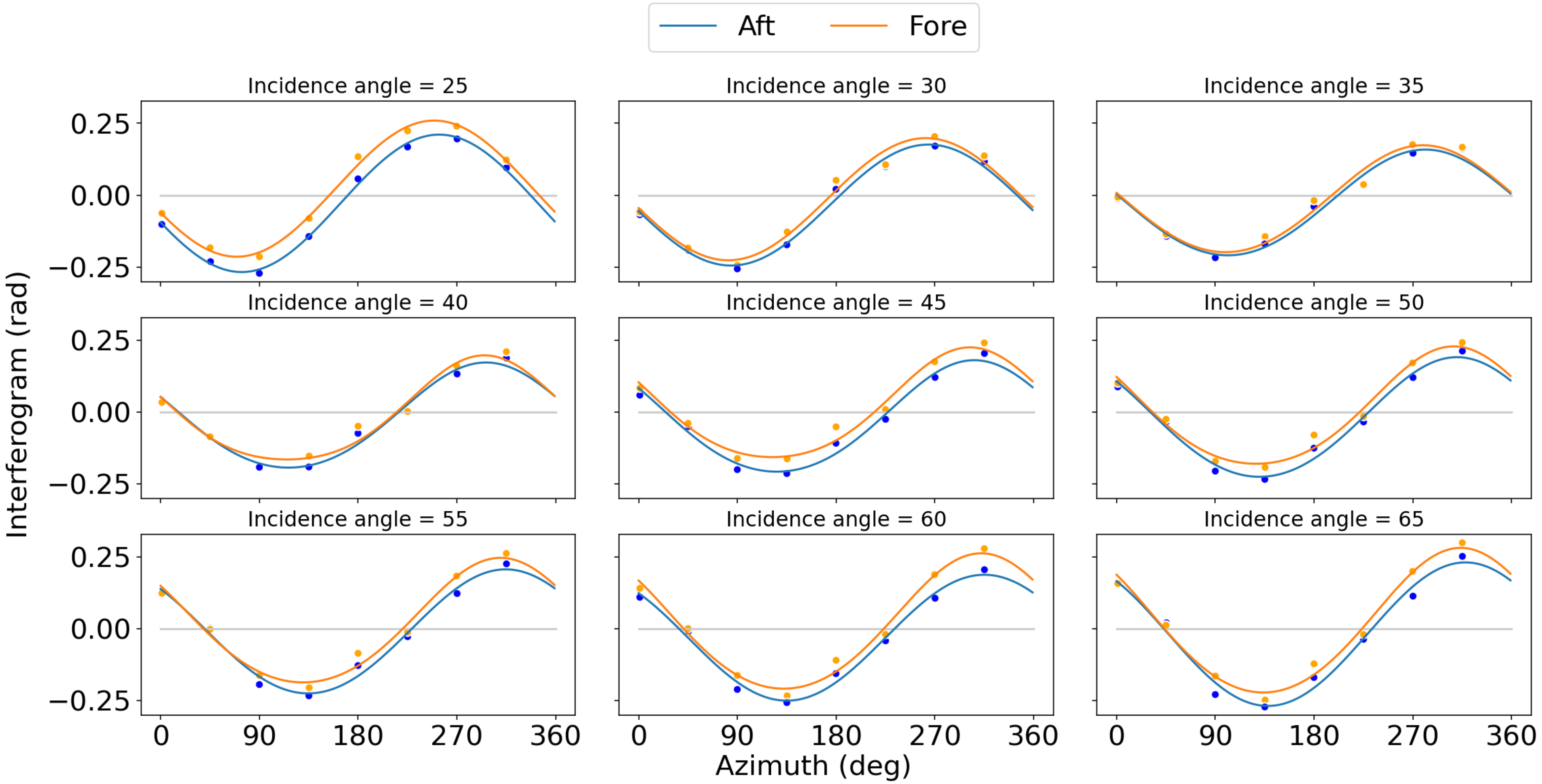
Calibration (Sigma-0)



Interferograms (uncalibrated)



Interferogram – land calibrated (L1c)

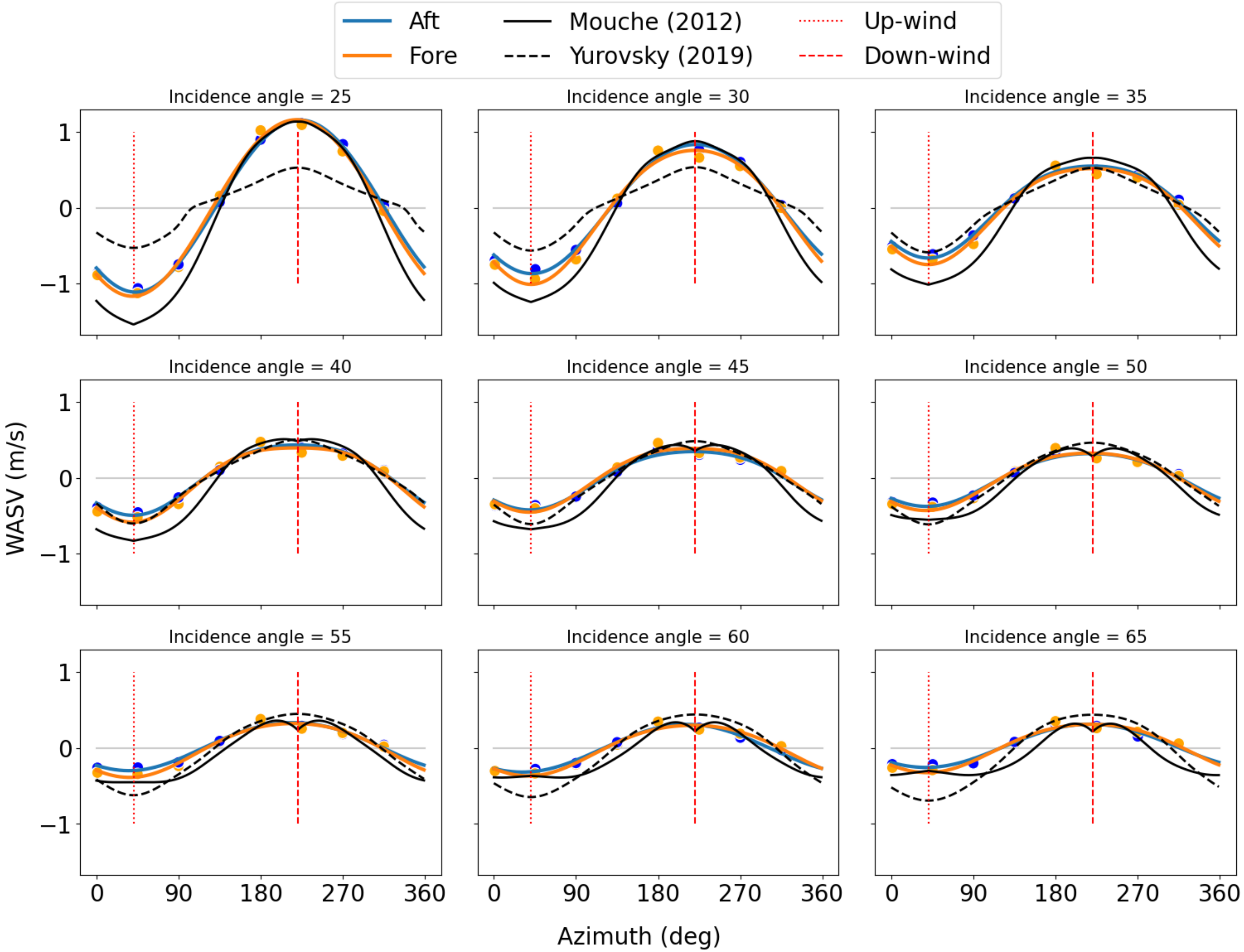


Wind-wave Artefact Surface Velocity (WASV)

'Star-pattern' analysis of grouping data by incidence angle and azimuth

RSV data (points) with fitted curves (lines) for Fore and Aft channels

$$WASV = RSV - ADCP$$



What about extremes?

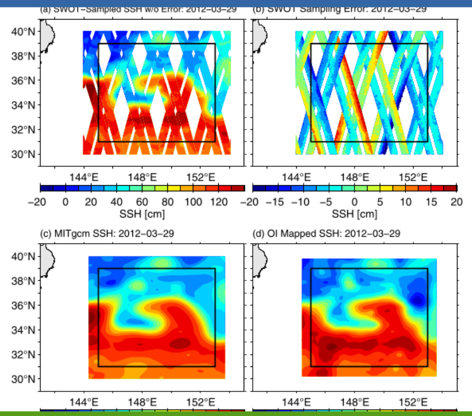
Over hurricanes (sampling permitting)

- SeaSTAR instrument operates in Ku-band, thus limited by rain contamination effects
- But at high spatial resolution!
- +heritage from Ku-band scatterometer QC

Before and after hurricanes, we could study

- The formation and temporal evolution of cold wakes
- The response of the ocean meso- and submesoscale to intense atmospheric events

1) vertical advection



From altimetry to *w*

Numerous works (e.g. Lapeyre, G., & Klein, Qiu et al, 2016,2020, Pietri et al 2021) show a need of :

in situ direct measurement of the balanced (Med Sea ideal conditions with no tide) in particular in the surface layer

associated with

- Mixing microstructure measurment
- High resolution ctd cast
- Horizontal vorticity

Our strategy :

*BIOSWOT-**Med***

Innovative methods :
5-beams acoustic (FFADCP)
& buoyancy profiler (VVP)

Turbulence profiler (VMP)

Towed fish (MVP/SeaSoar)
Argo drifting profilers
gliders

hull mounted ADCP and surface drifters

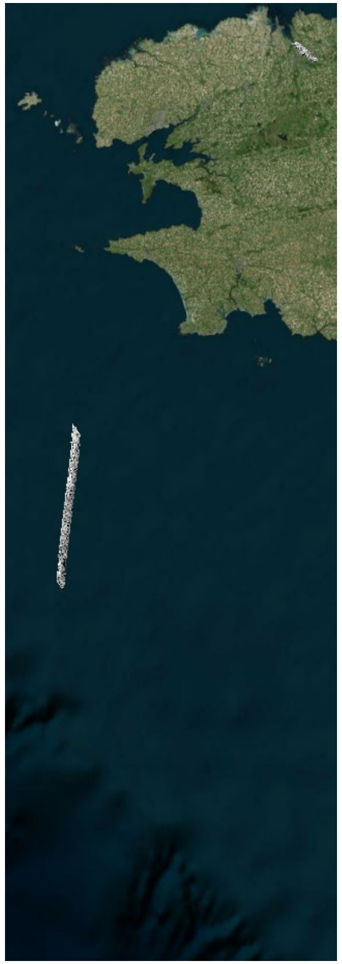
Data Production Updates

We have focused all 17, 22, 25, 26 days (besides the circular tracks)

17 (cal + 1 available)

22 (cal + all available)

25 (cal + 1)



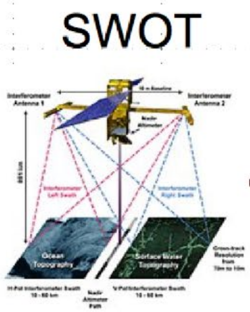
26 (cal)

Pierre Garreau (IFREMER), Frank Dumas (LOPS-SHOM)

C-SWOT 2023

A TWO SHIPS STRATEGY FOR MORE SYNOPTICITY

+



+

March - April 2023
N-W Mediterranean Sea

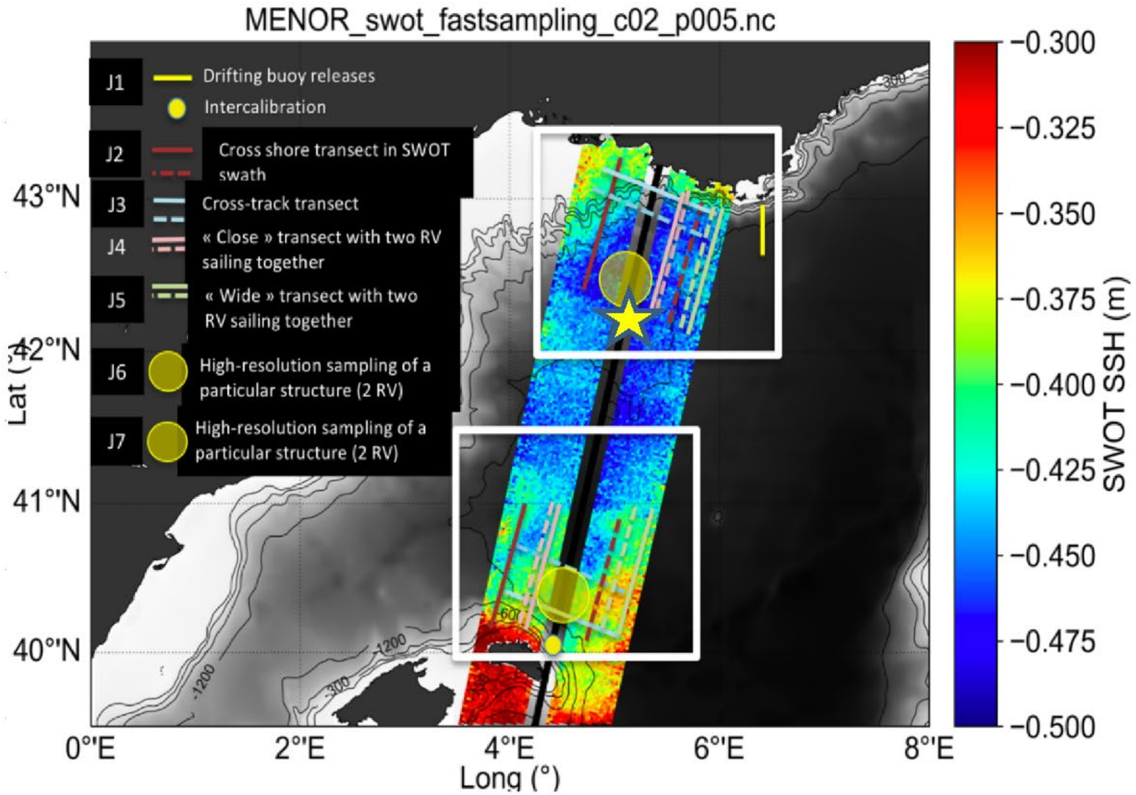
High resolution
Parallel transects and synoptic observations (MVP/ Seasoar / S-ADCP / Drifting buoys)

Exploring the variability of the North-Current

Revisit mesoscales and sub-mesoscales dynamics in the North Balearic Front

Participating to Calibration / validation

Evaluate the 2-ship strategy



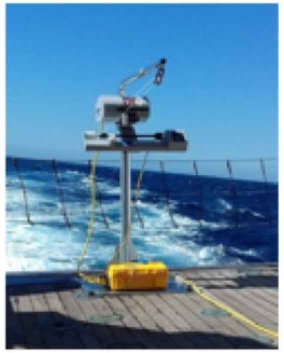
C-SWOT 2023

TOOLS TO BE DEPLOYED DURING THE CRUISES

High resolution transects


MVP (0-400m)


SEASOAR (0-400m)


U-CTD (0-400m)


VMADCP (0-400m)

Lagrangian approach


Carthe drifters


GDP drifters


Spotter buoys (sea state)

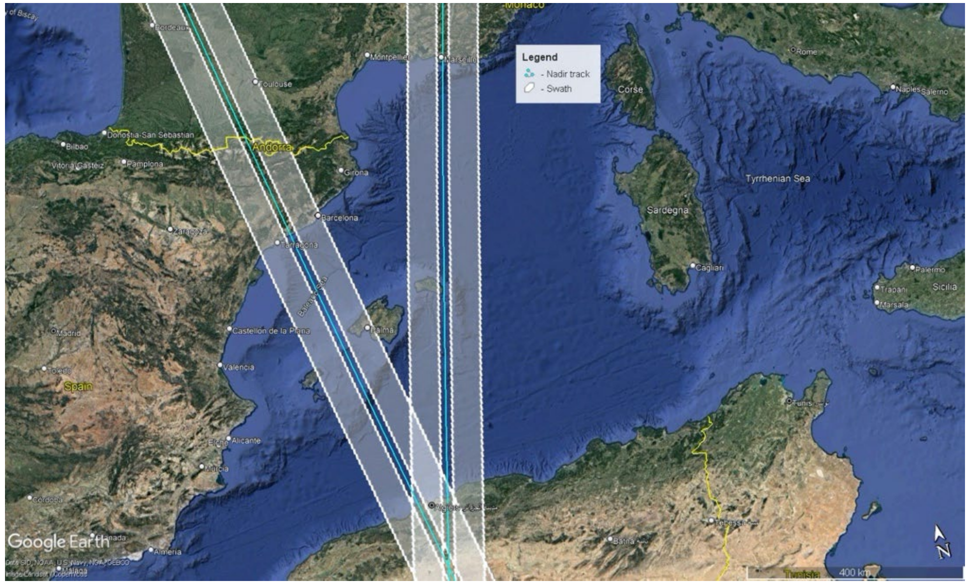

"Flame" buoys (Air-Sea exchanges)

Classical hydrology using CTD and LADCP

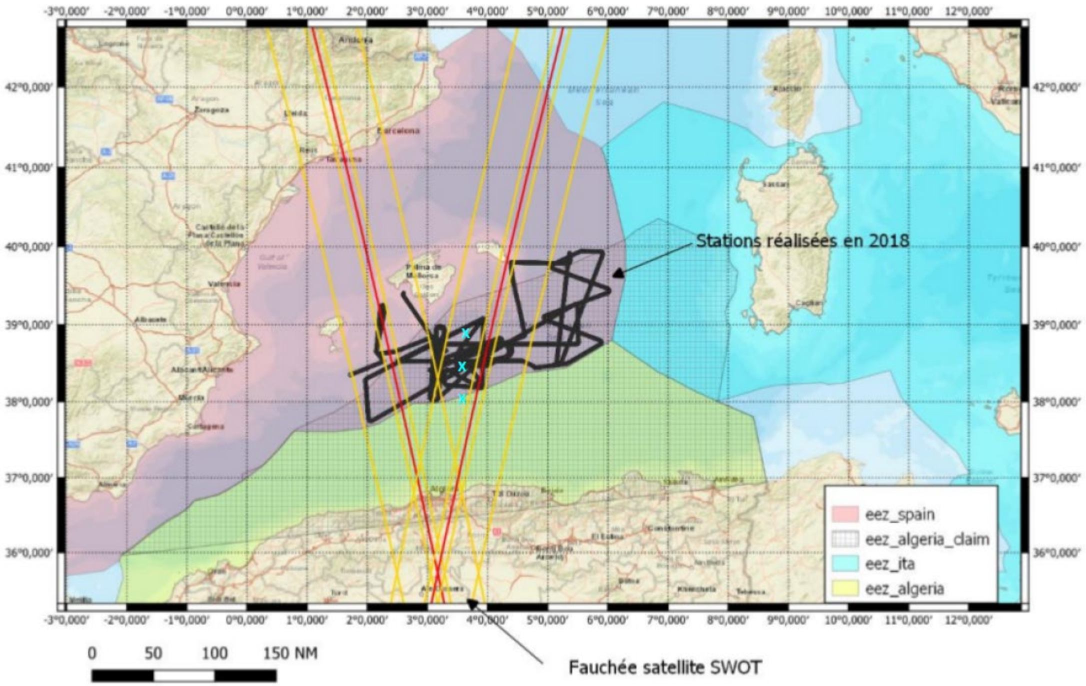
DRIX USV
Unmanned surface vehicle

ADCP Moorings

C-SWOT

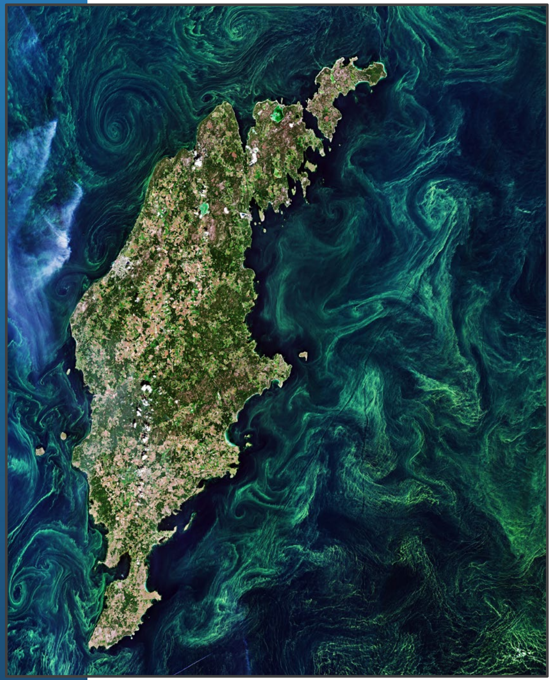


SWOT orbits during the Cal/Val phase over the Mediterranean Sea



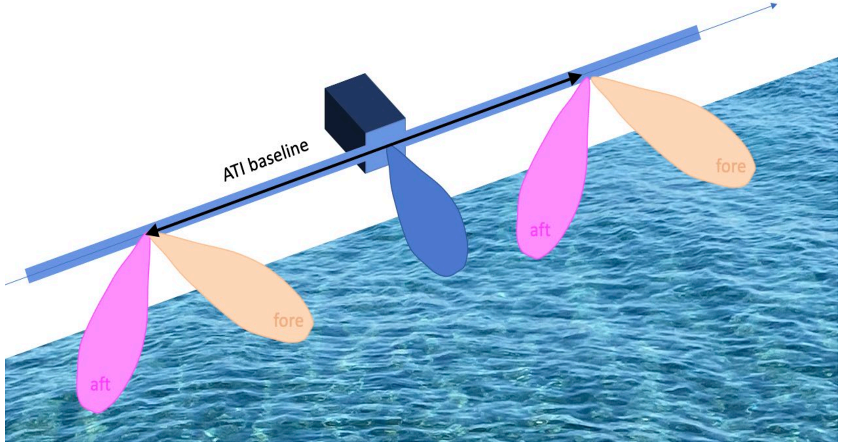
Location of the BioSWOT ship campaign in 2018. The BioSWOT-Med campaign in May 2023 would take place in the same area (currently waiting for authorisation by Spanish authorities).

SeaSTAR Summary



SeaSTAR is a dedicated ocean mission to address clear and urgent scientific needs for new synoptic imaging of ocean current and wind vectors at fine resolution ~ 1km.

SeaSTAR focuses on key interfaces of the Earth system and is relevant to a large and growing community of ocean, atmosphere, cryosphere, coastal and climate scientists and operators.



https://projects.noc.ac.uk/seastar/

A 'quantum leap in knowledge' for Earth Observation and Earth Science

The first mission of its kind, with some ambitious elements, that builds on high levels of scientific and technological readiness in Europe.