30 Years of Progress in Radar Altimetry Symposium

2-7 September 2024 | Montpellier, France

Icebergs Detection in the Southern Oceans Based on a Multi-Sensor Approach

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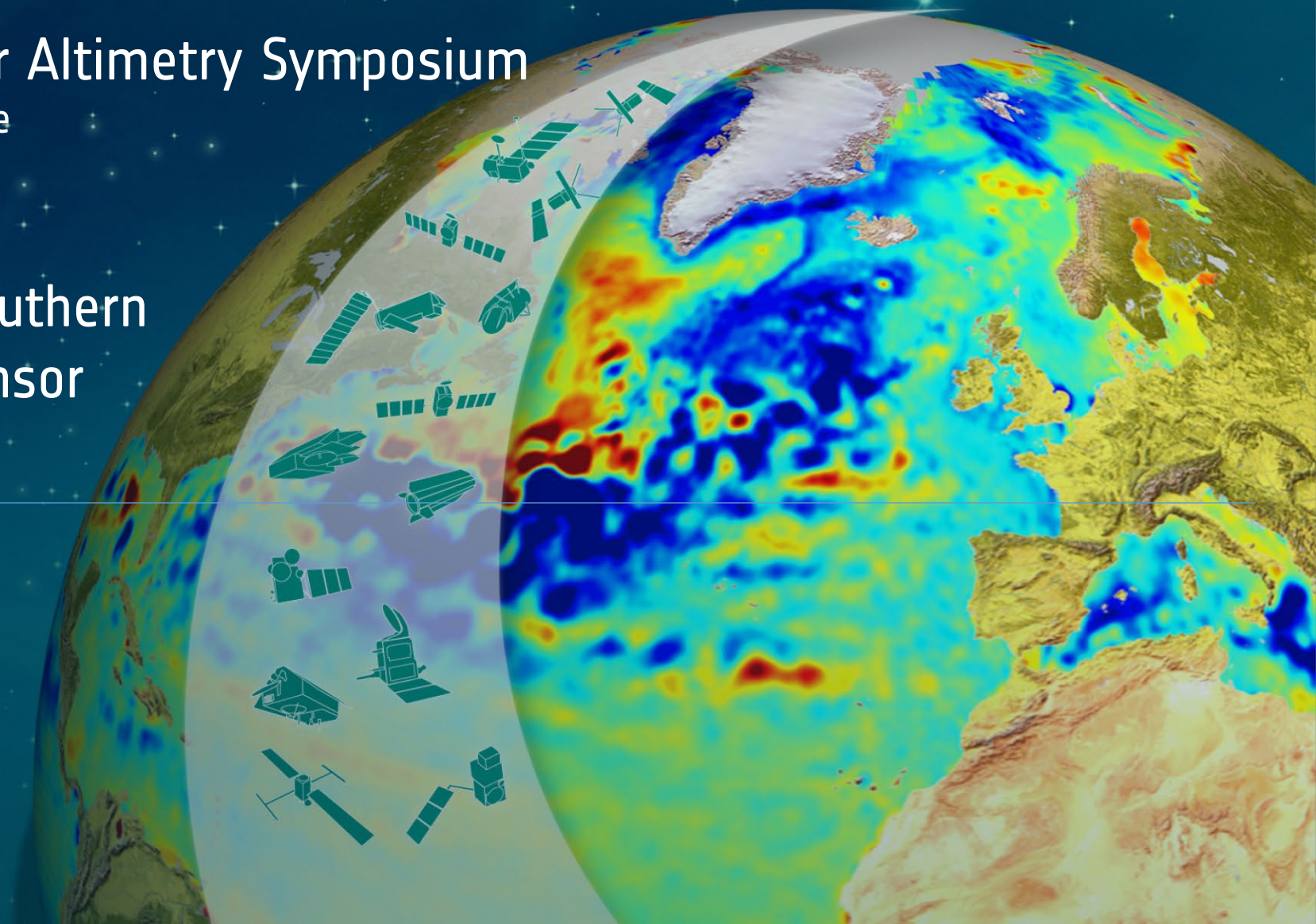
CLS

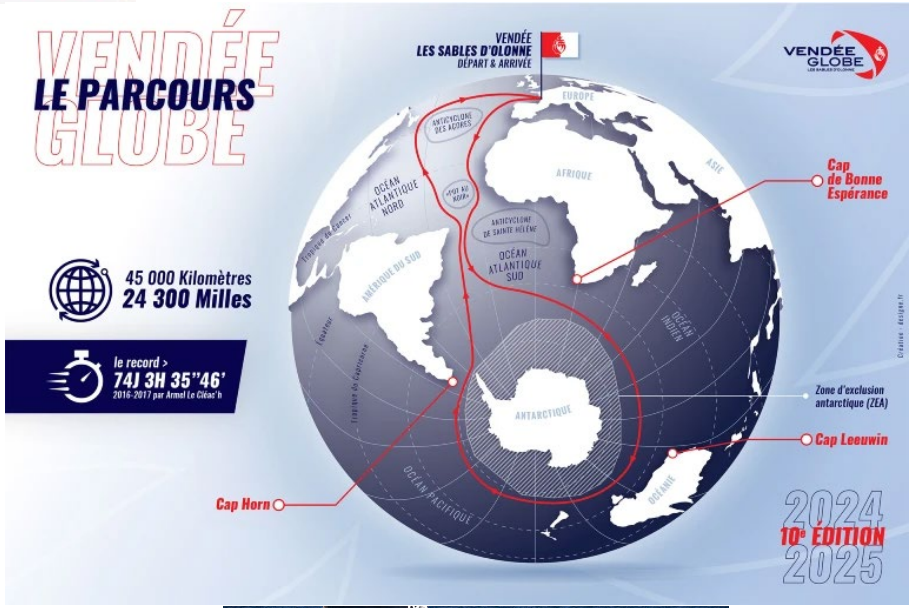


2014 2015
barcelona world race

vendéeglobe
Les Sables d'Olonne

MACIF (2017, solo): 42d16h

VOLVO OCEAN RACE
ROUND THE WORLD



TROPHÉE JULES VERNE

THE OCEAN RACE
ROUND THE WORLD
SINCE 1973

ARKEA ULTIM CHALLENGE BREST

IDEC Sport (2017, crew): 40d23h

Introduction

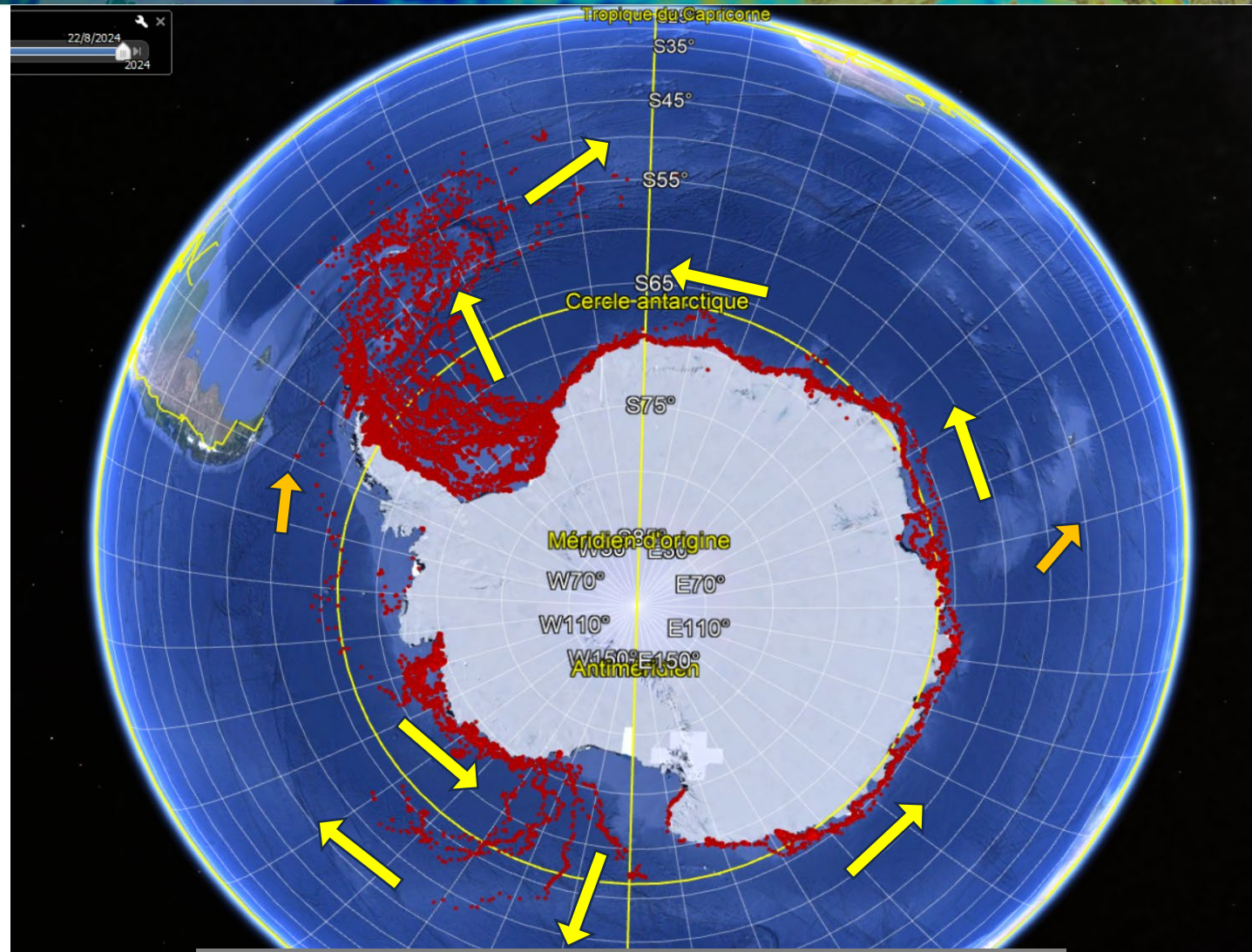
Icebergs detected in the southern oceans calved from the Antarctic continent and ice shelves.

Icebergs can spend several (tens of) years slowly moving (mainly westward) along Antarctica's coasts.

Once they reach the open ocean, their drift may last several months and reach areas near 40°S with SST > 15°C.

Each of the smallest icebergs (65 km^2) on the figure on the right can produce 20 000 theoretical cubic icebergs (100mx100mx100m).

Our service aims at detecting **icebergs with max length >= 100m.**



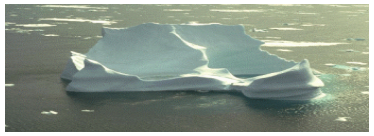
Weekly positions of giant icebergs: area > 65 km^2 or length > 18 km
Source: US National Ice Center
Data from Nov 2014 to Aug 2024

Various shapes, size, surface structure and rugosity…

→ Significant variability of the radiometric signature

ICEBERG SIZE CLASSIFICATION

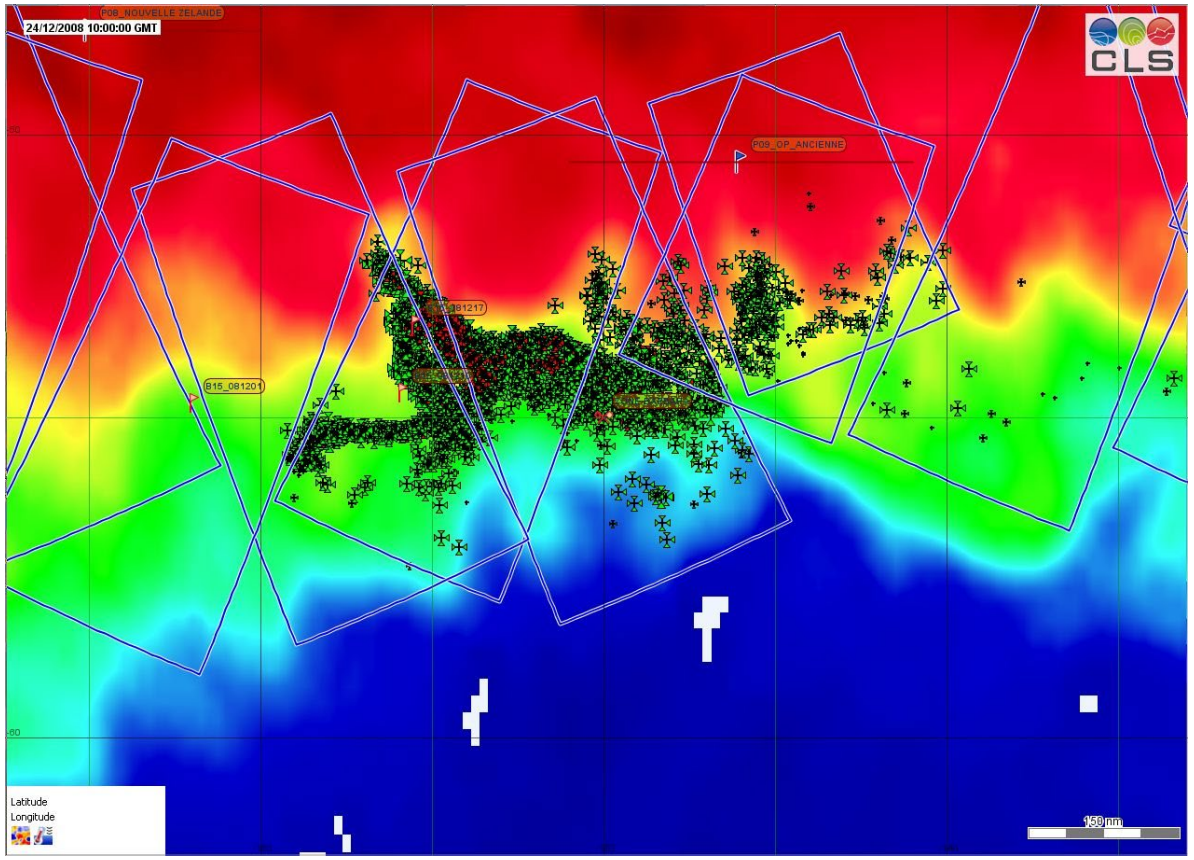
SIZE CATEGORY	HEIGHT(FT)	HEIGHT(M)	LENGTH(FT)	LENGTH(M)	Satellite Detection
Growler	less than 3	less than 1	less than 16	less than 5	
Bergy Bit	3-16	1-5	16-49	5-15	
Small	16-49	5-15	49-197	15-60	
Medium	50-148	16-45	198-394	61-120	
Large	149-246	46-75	395-656	121-200	
Very Large	Over 246	Over 75	Over 656	Over 200	



- Only **Medium** to **Very Large** icebergs can be identified by satellites
- **Small** icebergs (<80 m in length) **ARE NOT** detectable !

However, smaller icebergs are residues of larger icebergs.
(no spontaneous generation of icebergs !)

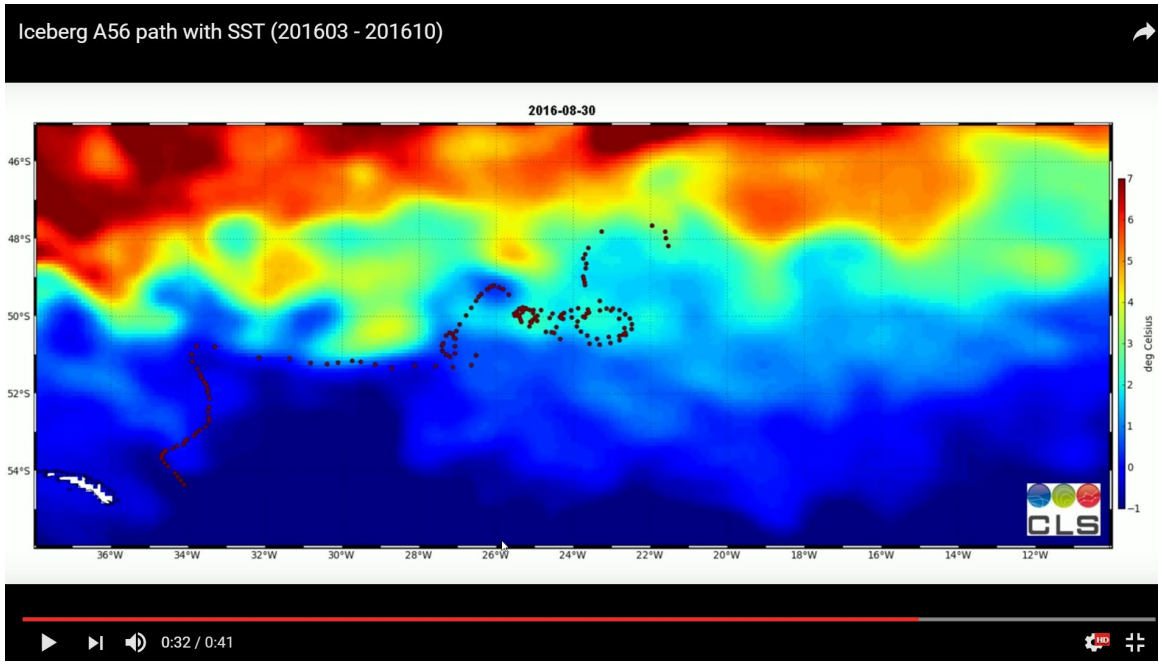
The positions, distribution and trajectories of icebergs are closely dependent on ocean structures.



Animation of A56 tabular iceberg between march and october 2016: https://youtu.be/6yeZmeULesA

In the South Atlantic Ocean, icebergs « frequently » die in 10°C water near 45°S !!

In December 2018, we spotted a 300m iceberg by 40.5°S in a 17°C sea water, North-East off Falklands



Combination of several observation/detection capabilities

SAR Imagery

- **Night / day / cloud**
- Up to 500x500kmSAR images with 80m pixel resolution
- Open access data: Copernicus **Sentinel-1**: Conventional imagery and **WaveMode**
- Commercial imagery: **RadarSat2**, (CSK, TSX, PAZ)
- CLS: programming, acquisition and analysis capabilites
- CLS: Ground Station VIGISAT (Brest)
- > 15 years of experience
- 24/7 analyst team

The most efficient sensors !

Altimetry

- **Night / day / cloud**
- Open access data: Sentinel-3A/3B/6A, Jason3, AltiKa, SWOT Nadir, (SWOT KaRin)
- CLS: very long and broad expertise in altimetry
- > 30 years of experience

Good (and low-cost) spatio-temporal monitoring.

Optical/multispectral Imagery

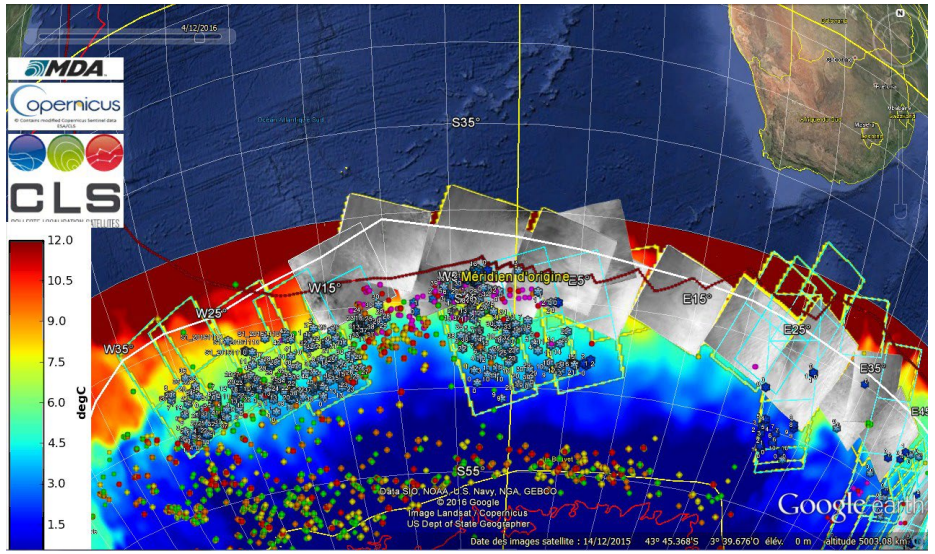
- ~~Night~~ / **day** / ~~cloud~~
- Open access data: Sentinel-3A/3B (OLCI), MODIS, VIIRS and even Sentinel-2

very complementary dataset !

(Operational) Oceanography

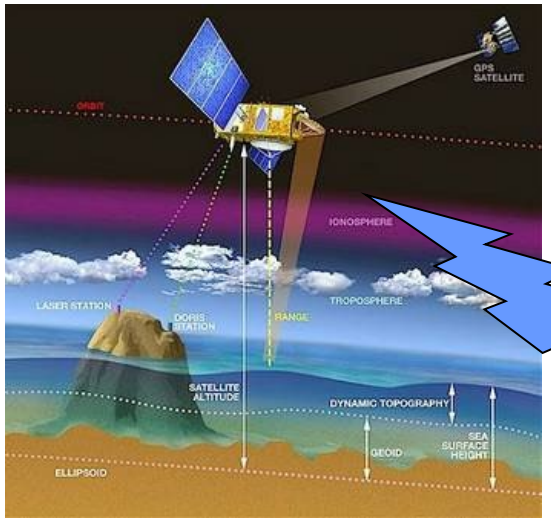
Contextualization of detections and added value

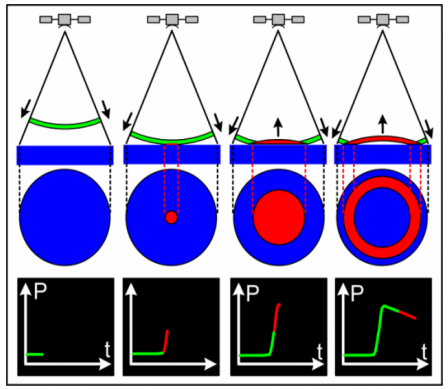
- **Ancillary data sources**
  - Sea Surface Temperature
  - Ocean Currents
  - Sea-ice edge
  - SAT-AIS (ships position database)
- **Drift Model**

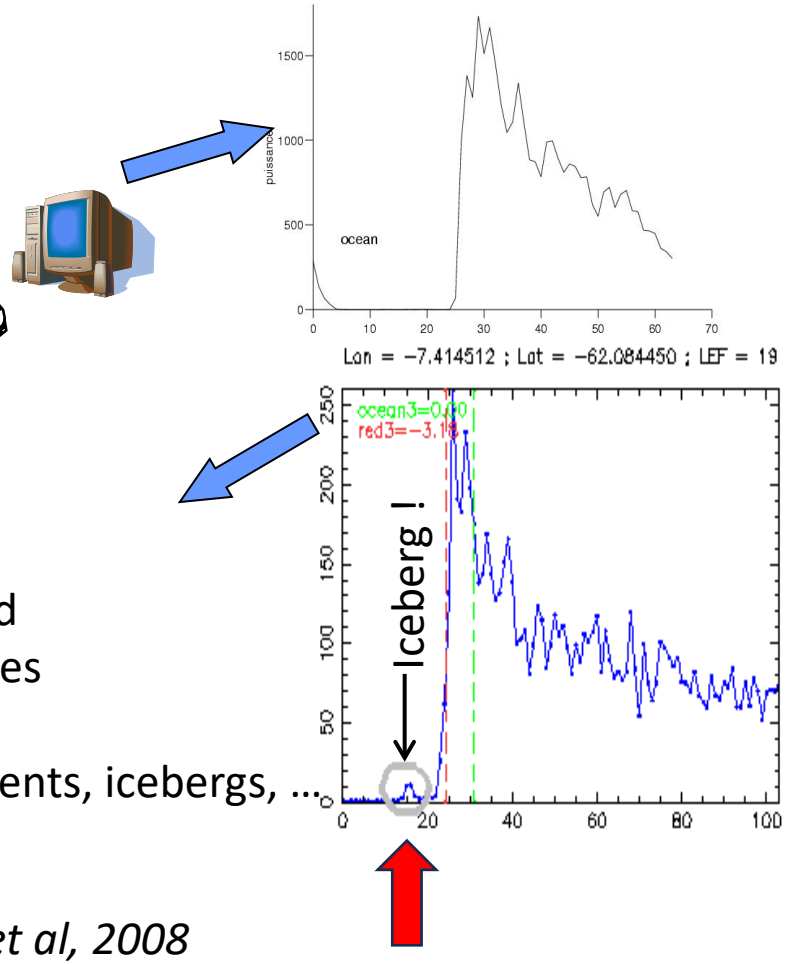


Detection of Icebergs with Satellite Altimetry

(Jason3, AltiKa, S3A, S3B, S61, SWOT Nadir)





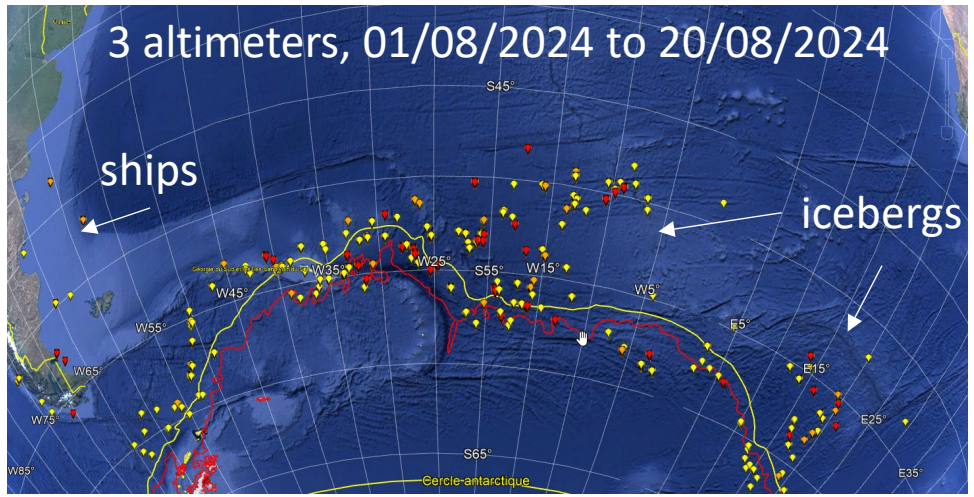


- SSH
- Wind
- Waves
- …
- Currents, icebergs, …

Pionneer work by Tournadre et al, 2008

- Opportunity measurement for the detection of (moving) floating reflectors (ships, icebergs)
- **Identification of small anomalies in the thermal noise part of the waveforms**
- **No need of correction, calibration, validation → only the waveform !**

Iceberg minimum size for detection: ~ 200m



Detection of Icebergs with Satellite Altimetry

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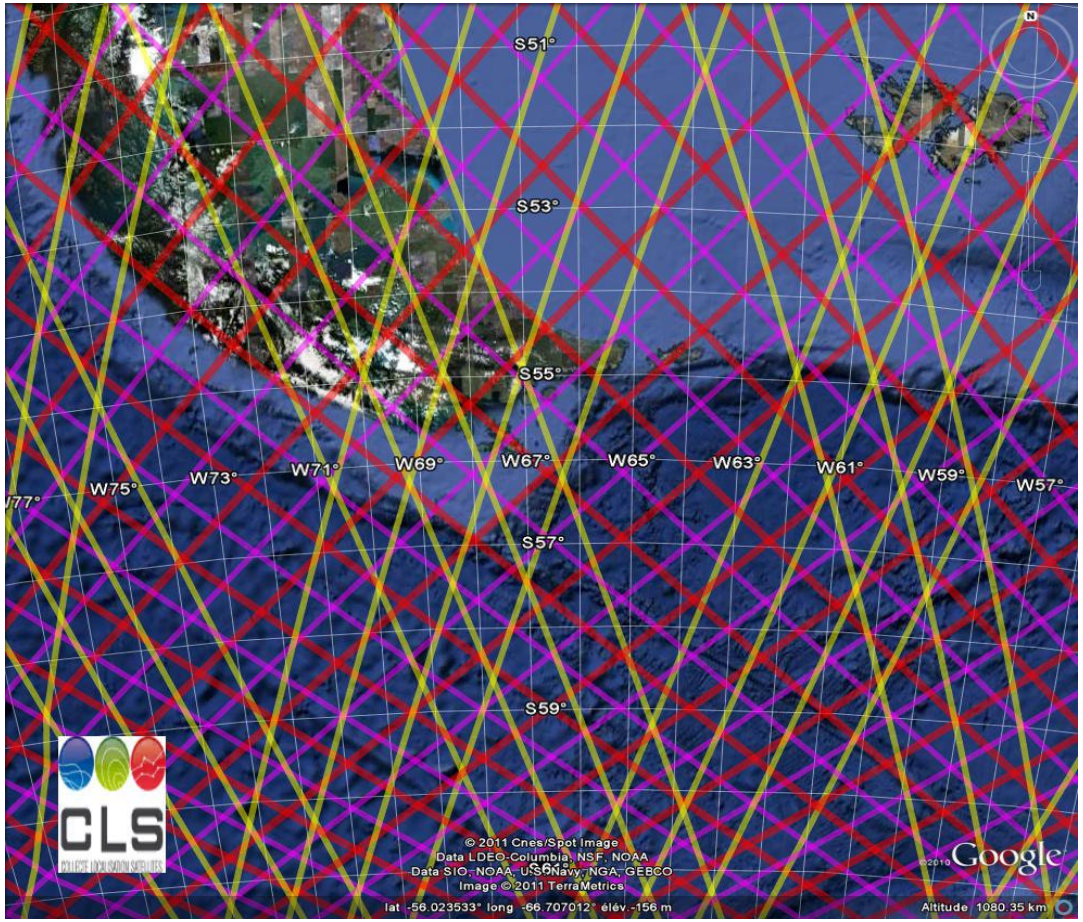


- Example of (real) coverage over 10 days with 3 satellites (mesh with holes…)
- Detection is possible only right beneath the satellites tracks
- **Radar** → detection also possible by night and through clouds

→ Requires a « rendez-vous » (same location, same time) between the iceberg and the satellite

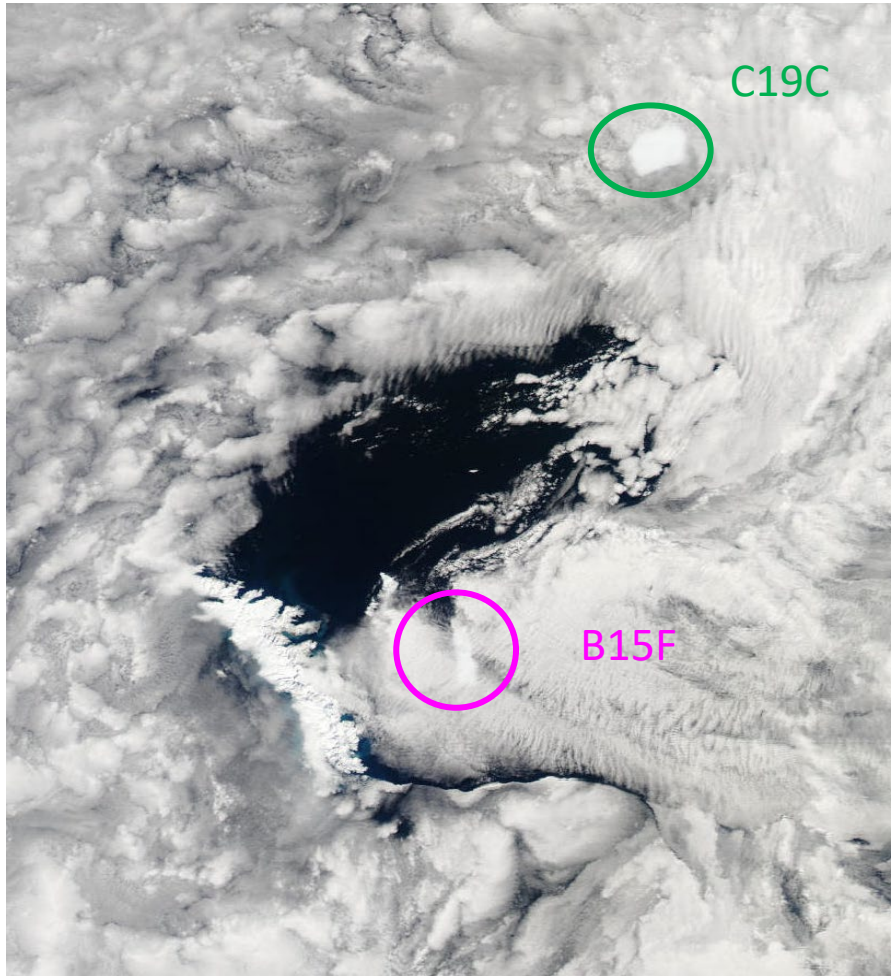
→ Crude spatial coverage, but global + repetitivity and **growing number of sensors**

→ Still low performance on small and/or isolated icebergs

→ **Affordable synoptic view/monitoring of the main iceberg populations/distributions**

Detection of Icebergs with Multispectral Imagery

(Terra/MODIS, Aqua/MODIS, S3A/OLCI, S3B/OLCI, NPP/VIIRS, NOAA20/VVIRS, NOA21/VIIRS, S2)



- **Optical technique** → requires clear weather and daylight. Very large tabulars may be observed trough thin cloud coverage.
- Global coverage imagery, **several images per day (useful for validation !)**, **resolution ~300m (= minimum size of detectable icebergs)**
- **S2 can be used in the vicinity of Cape Horn or some isolated islands**
- 2-D description of iceberg populations
- Possible « identification » of very large icebergs (recognition of the silhouette)

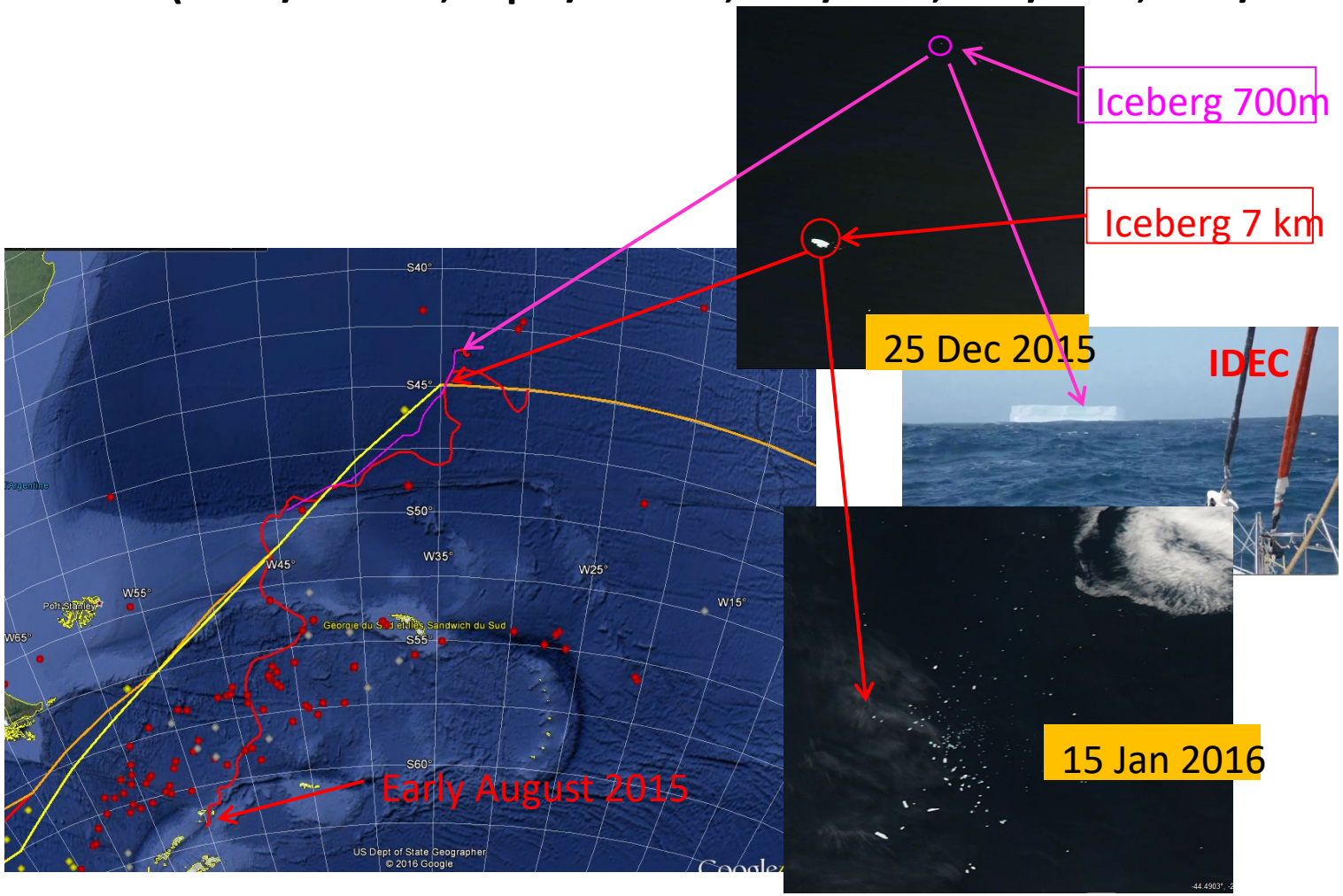
→ **Refining of the general situation obtained with altimetry**

→ **Possible detection of isolated icebergs**

→ Reconstruction of the trajectories of the largest icebergs.

Detection of Icebergs with Multispectral Imagery

(Terra/MODIS, Aqua/MODIS, S3A/OLCI, S3B/OLCI, NPP/VIIRS, NOAA20/VVIRS, NOA21/VIIRS , S2)



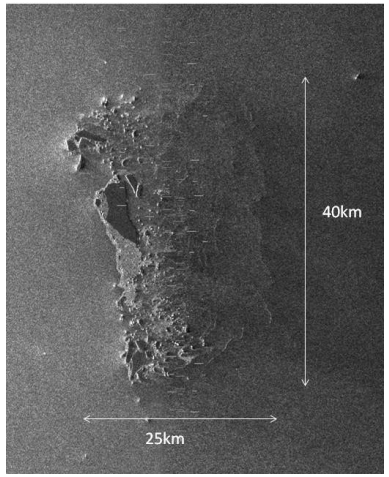
Example of reconstructed trajectory of a large iceberg with multispectral imagery from august to december 2015.

A 700-metre-long iceberg broke off from the main iceberg in November and shot by IDEC yacht on 25 dec 2015 (On that day, the visibility conditions were ideal, both on site and for MODIS) !!

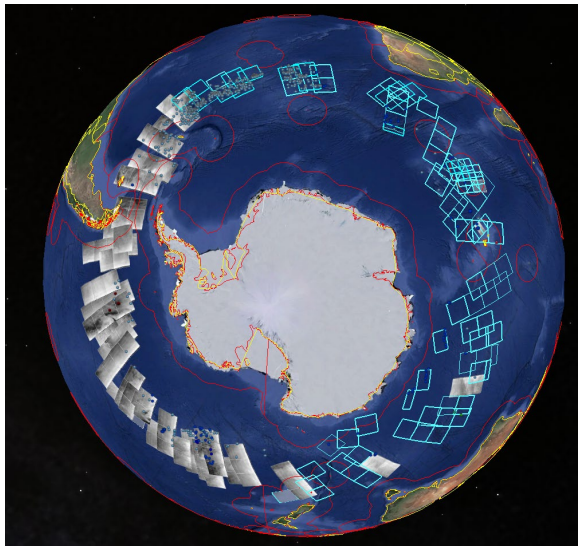
The main iceberg (7km) suddenly disintegrated 3 weeks later.

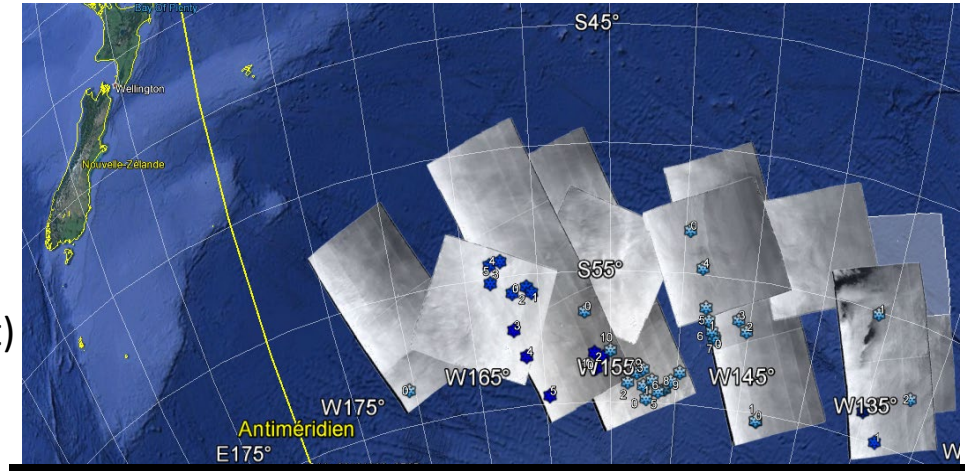
These images are scanned daily, looking for bright spots in clearing areas in the surrounding of areas identified previously with altimetry.

Detection of Icebergs with SAR Imagery



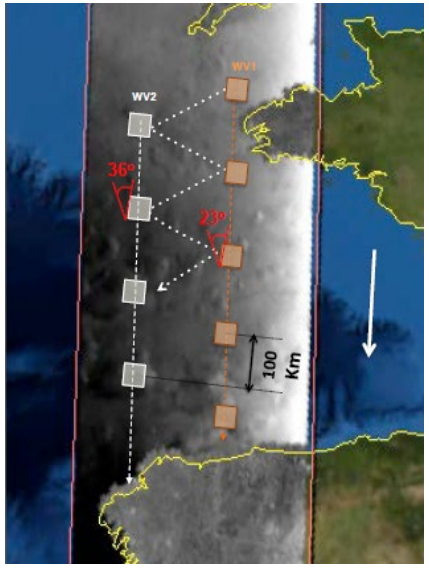
- The **most efficient technology** for the monitoring of sea ice, and the detection of icebergs and ships.
- However, in the Southern hemisphere, **the coverage of Sentinel-1 open access SAR imagery is usually limited to sea-ice areas, islands and continents, but few images in the open ocean…** (but WaveMode !!)
- Commercial SAR imagery is used on-demand, according to the clients' needs. (The most expensive part of the service…)
- The acquisition modes and formats best suited to the needs are on **Radarsat-2** (cov. 500kmx500km, res. 80m, urgent programming). TSX, CSK and PAZ are backup solutions
- Radar images analysed by CLS radar experts (within 2 hours if needed, 24/7, VIGISAT CLS antenna in Brest)

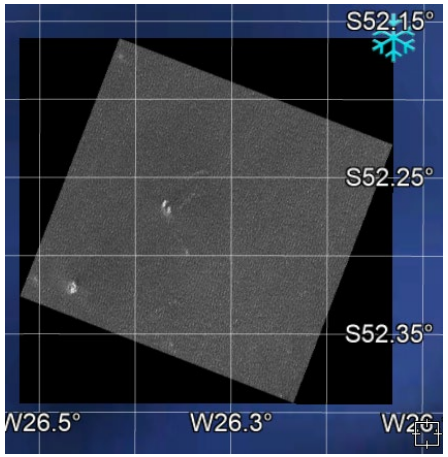




Iceberg detection on SAR imagery during VG 16

Detection of Icebergs with SAR S1 WaveMode Imagery



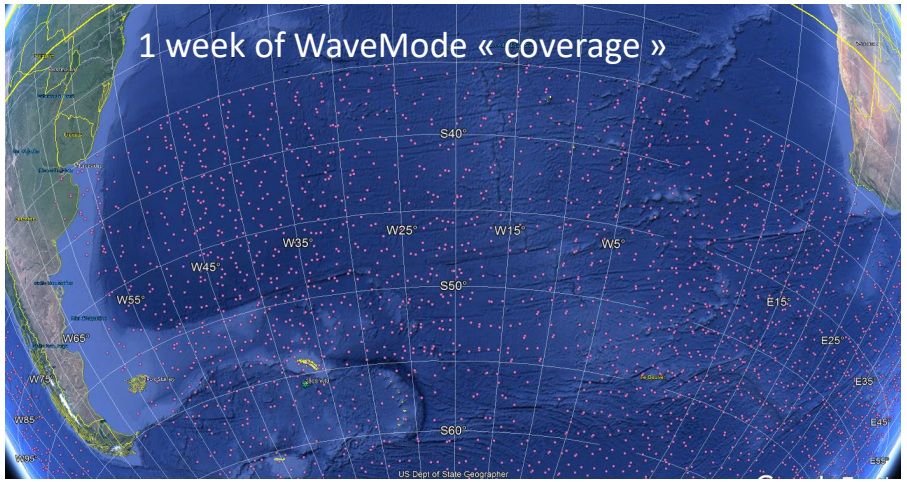


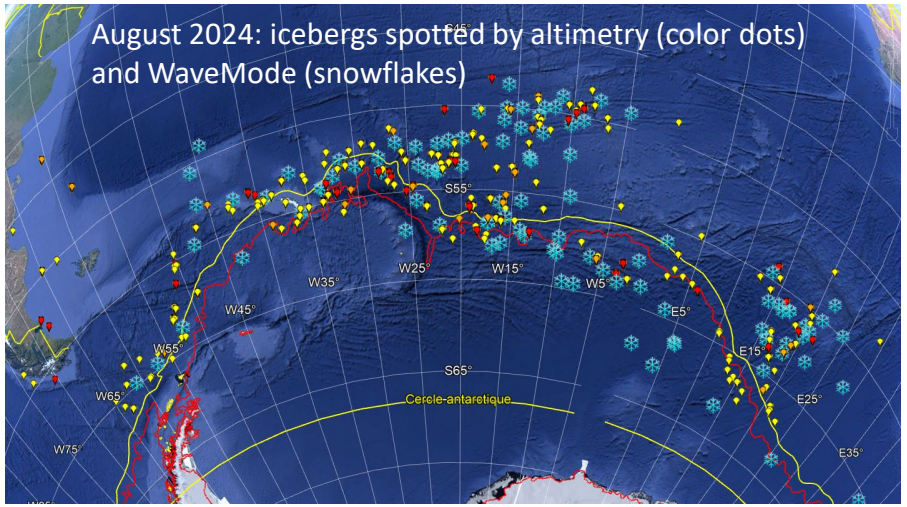
In the open ocean, Sentinel-1 satellites operate in "WaveMode":

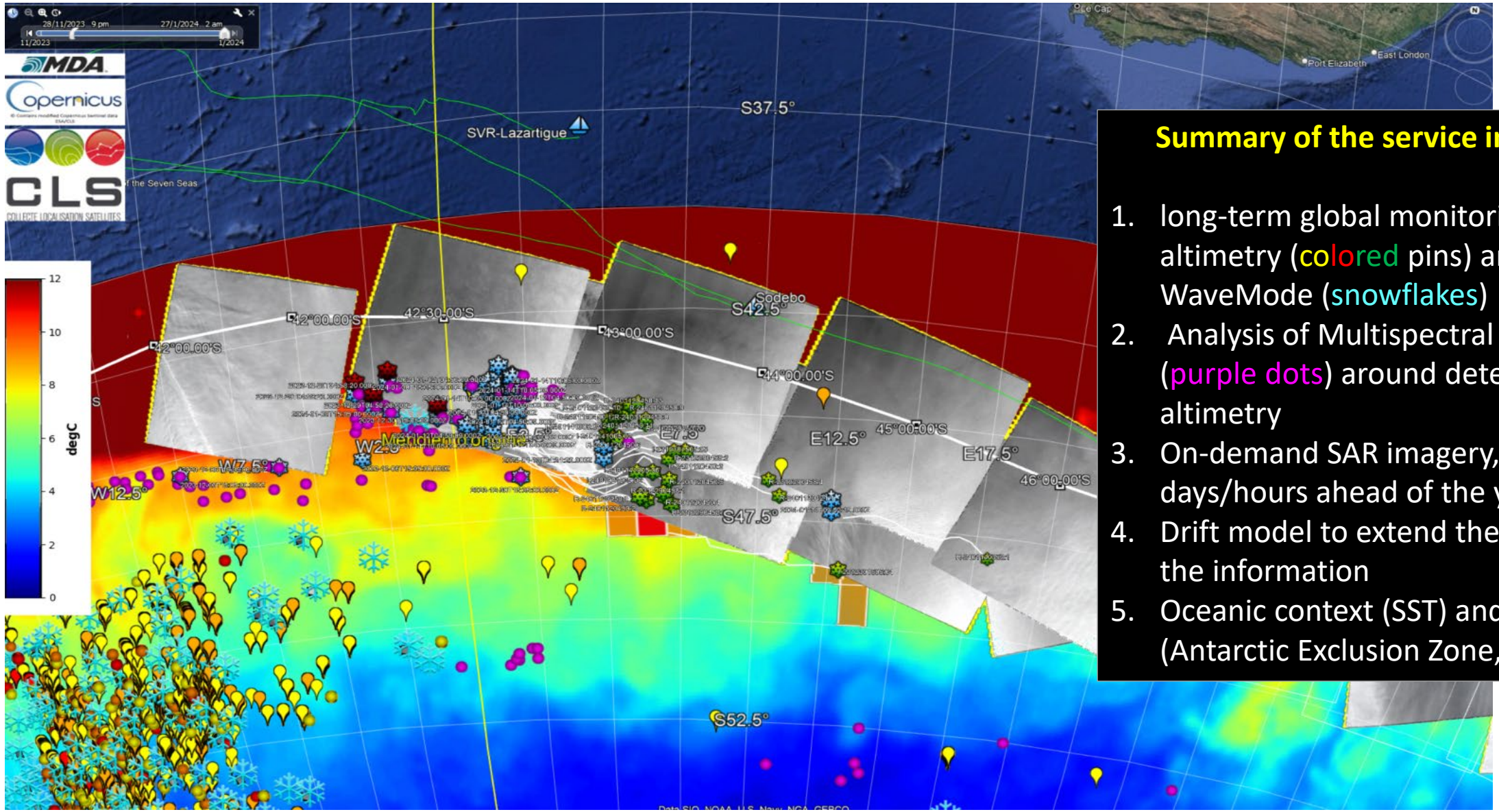
- 20kmx20km thumbnails acquired staggered under satellite orbit (to study the swell) instead of the usual swath
- **Resolution 5m**
- Thumbnails spaced and staggered about 100km

→ **a kind of sparsed global statistical sampling, but with high resolution small images**

→ **Complementary to altimetry !!**







Summary of the service in one slide !

1. long-term global monitoring with altimetry (colored pins) and S1 WaveMode (snowflakes)
2. Analysis of Multispectral imagery (purple dots) around detections from altimetry
3. On-demand SAR imagery, a few days/hours ahead of the yachts
4. Drift model to extend the relevance of the information
5. Oceanic context (SST) and race context (Antarctic Exclusion Zone, yachts tracks)

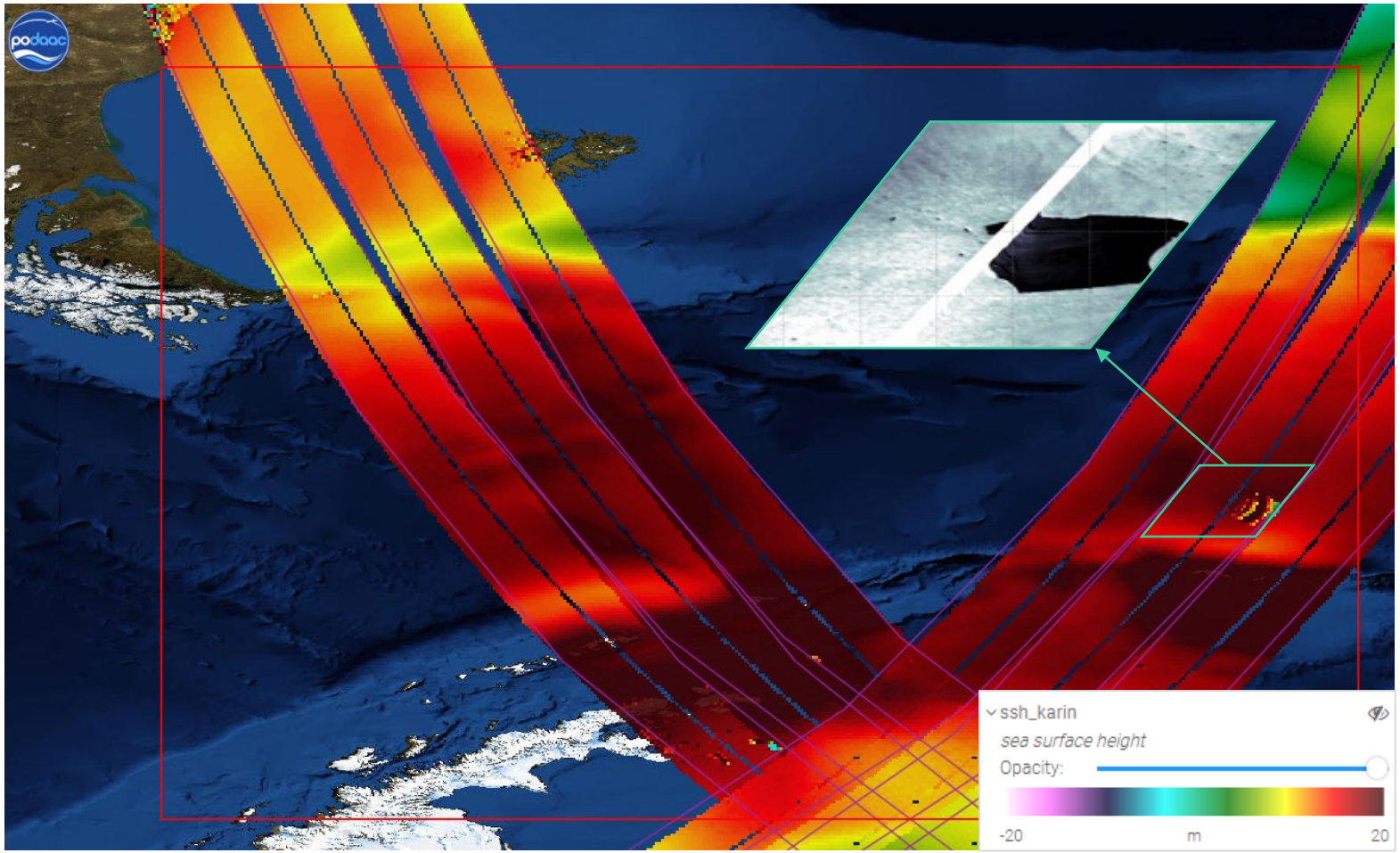
Ongoing development: SWOT's relevance for the service

Interest of SWOT :

- Global coverage over Southern oceans
- Independent of cloud cover, by night
- Open access data at minimal costs
- Use of two-dimensional altimetric data

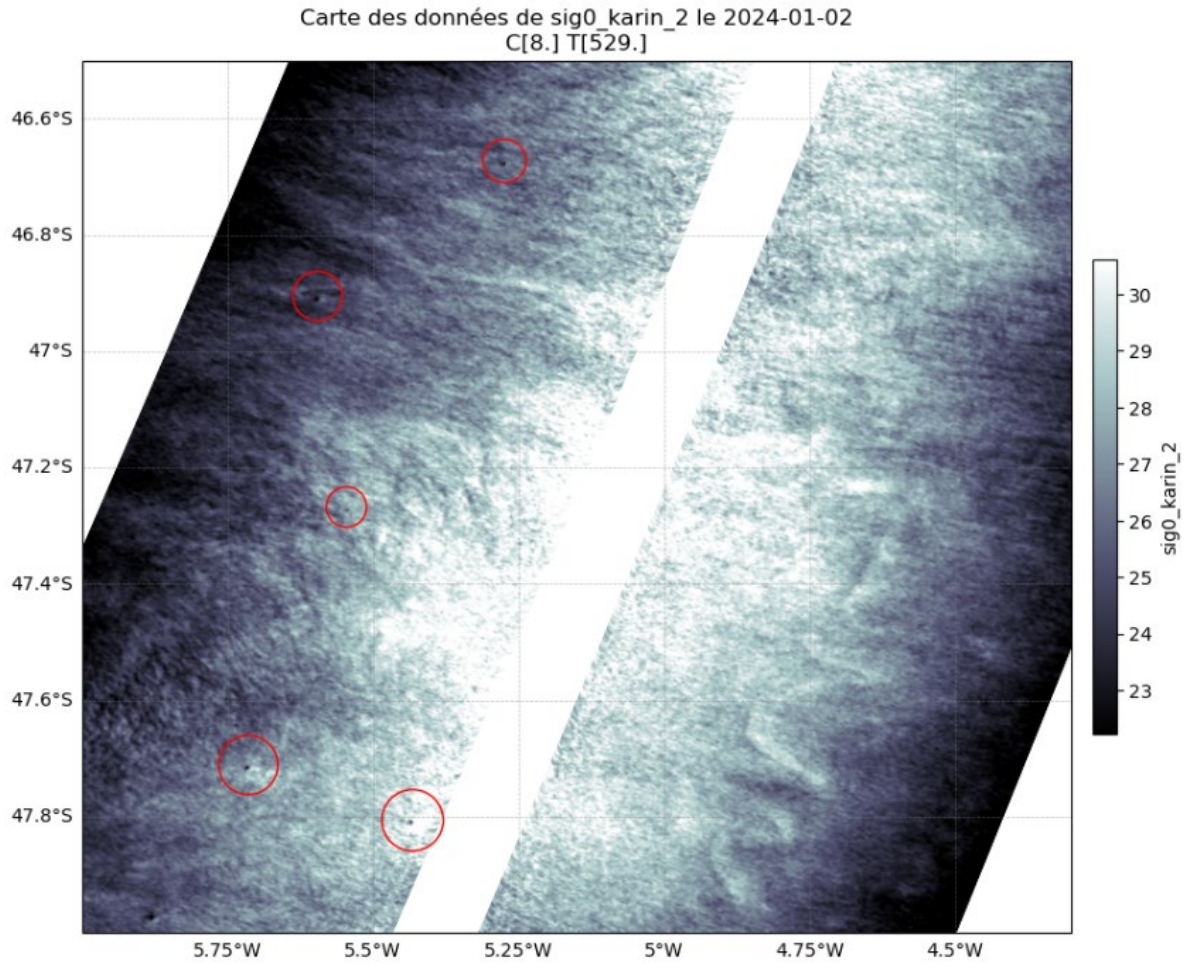
Preparation of future missions :

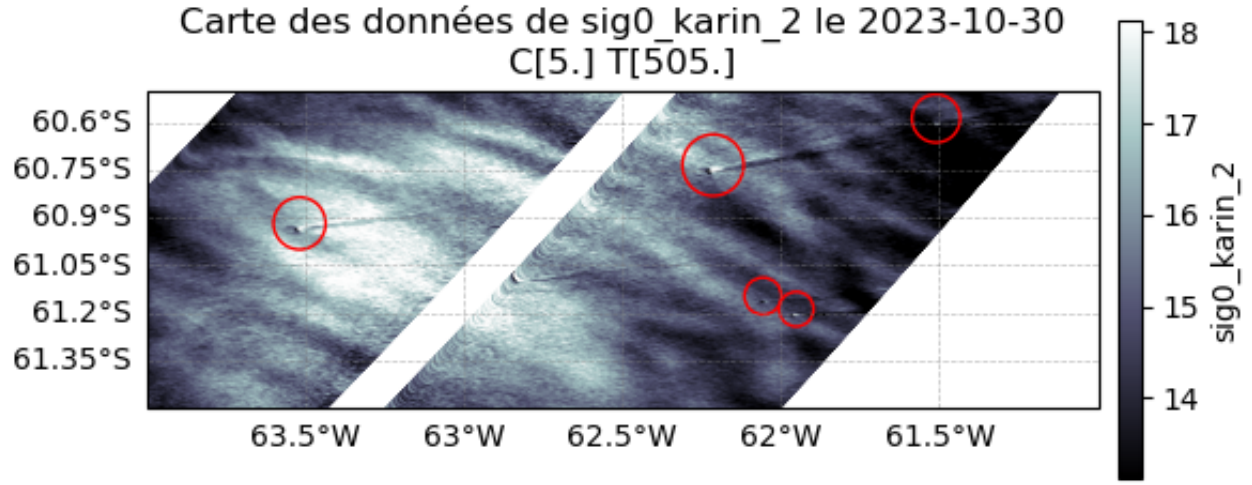
- Understanding specific signature of icebergs
- Use of deep learning for icebergs detection
- Preparation for the integration and utilization of data from Sentinel-3NG

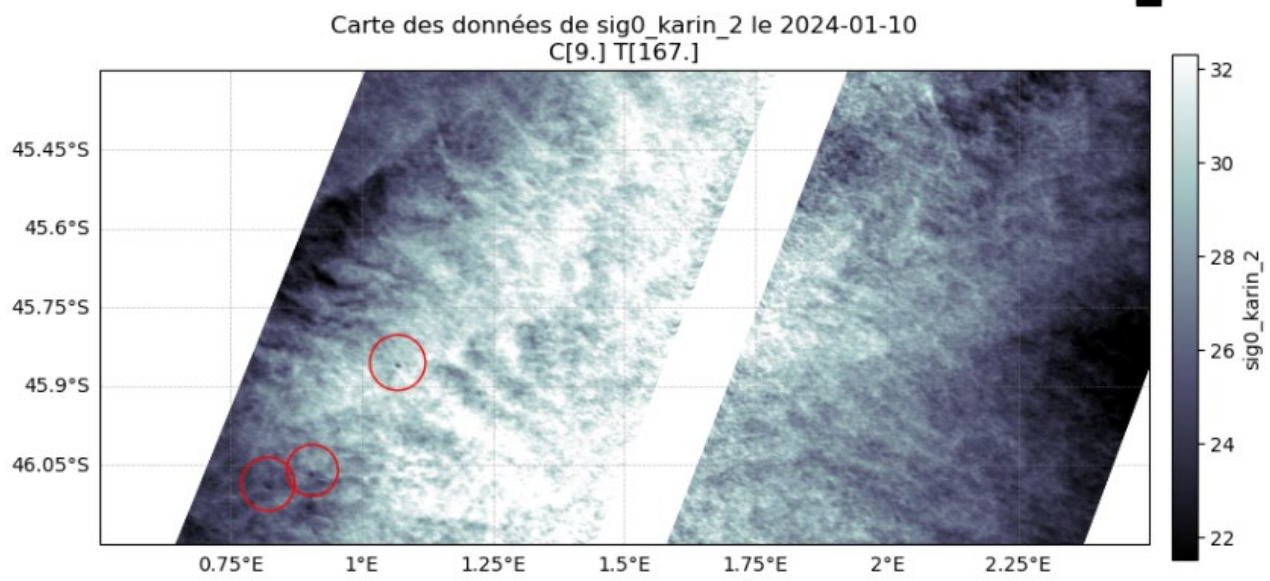


Source : HiTIDE

SWOT's icebergs detection performance (ongoing)







Conclusions:

- Satellite altimetry provides **measurements of opportunity** to detect moving floating targets such as icebergs
- Altimetry provides a **synoptic view** of the iceberg population
- Only the **waveform** is required: not need of correction/calibration

⇒ The combined use of different techniques/sensors (**altimetry** with **SAR** and **optical imagery)** provides **added-value results** and allows the detection and monitoring of icebergs (~100m).

- The **2D SWOT altimeter measurements** are relevant for iceberg detection and will improve the service.

Recommendations

- To maintain a relatively high number of altimeter sensors
- To keep the relatively high repetitivity of the altimeter measurements
- To facilitate the combined use of different sensors