PolarMonitoring CCN: CRISTAL orbit

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Introduction

M.Kern - ESA - introduction

Plan

Brief reminder about cycle & sub-cycle definition

Presentation of current & new orbit candidates

Diagnoses to evaluate the orbit candidates (Sea-Ice / Ice-sheet / Ocean)

Orbit assessment & evaluation (Sea-Ice / Ice-sheet / Ocean)

Conclusions & trade-off considerations

Orbit cycle & sampling properties

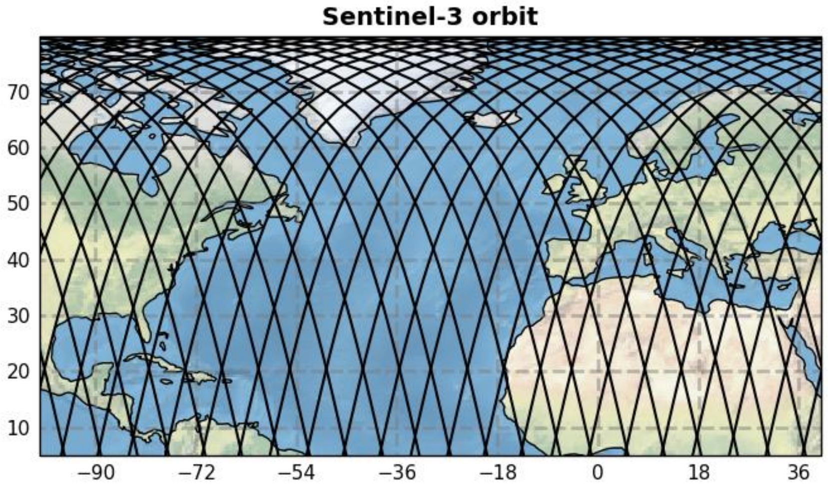
The sampling properties of an orbiting altimeter mission are controlled by three main parameters:

- **Repeat cycle or revisit time:** The number of days needed to revisit the **exact** same location on ground. This parameter defines the **temporal scales** that can be observed by the mission.
- **Spatial cross-track resolution:** The across-track distance between adjacent tracks, in general after a given cycle / sub-cycle. This parameter defines the **spatial scales** that can be observed by the mission.
- **Inclination:** Defines the band of latitudes covered by the mission.

Sub-cycle notion

- Near-repeat period for Earth remote-sensing satellites [Rees et al., 1992]
- Extremely important, as they provide a homogeneous sampling after N days
- Geodetic orbits can have 4 sub-cycles and more.

  => example: CryoSat-2 sub-cycles: 2 ; 29 ; 85 + 369 days cycle

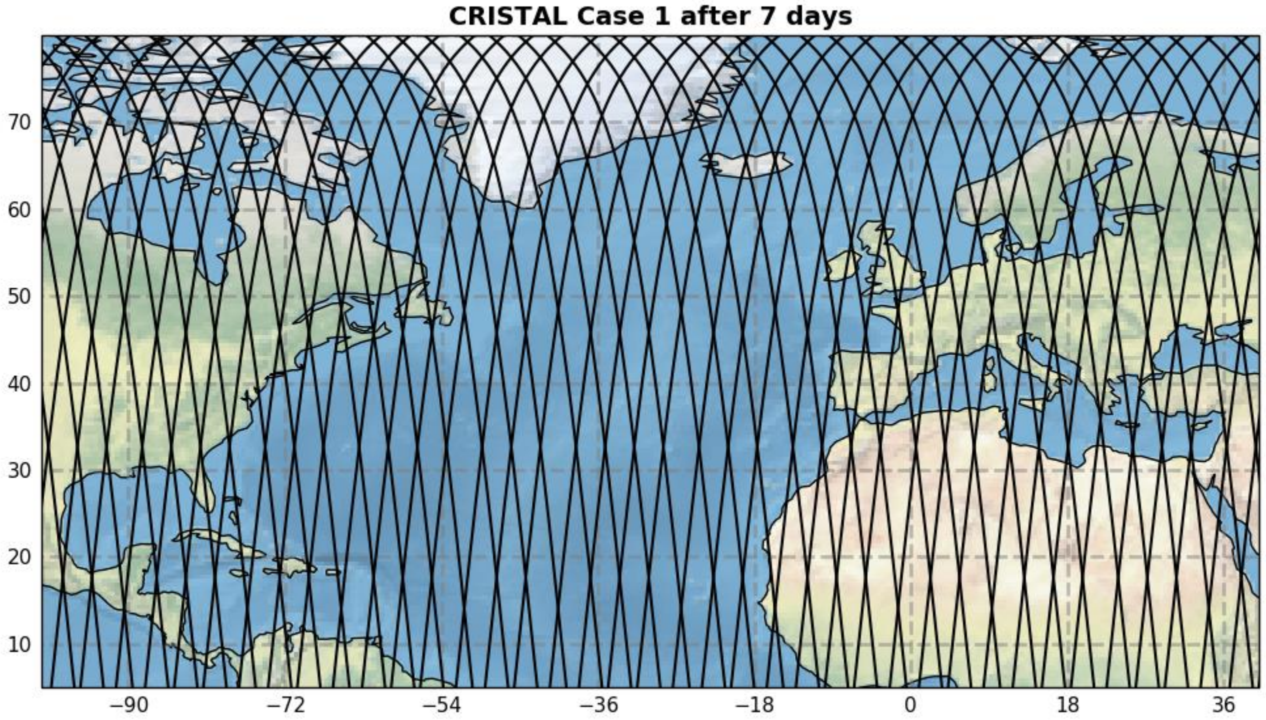


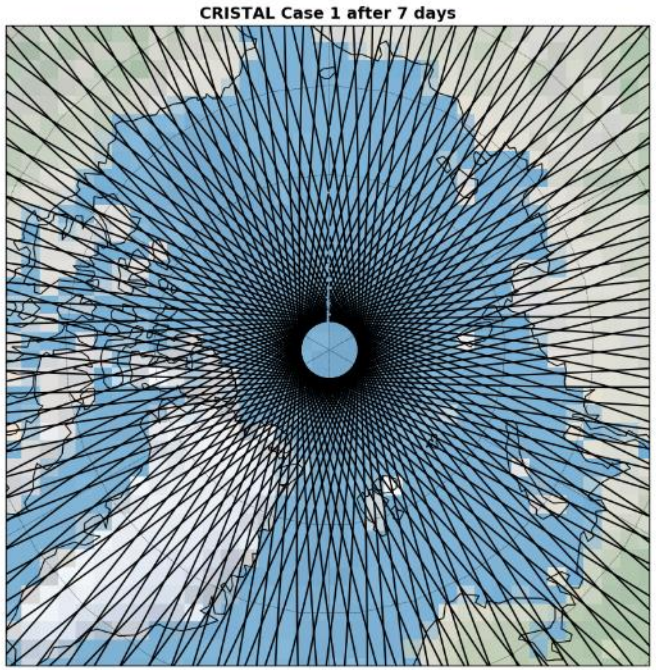
4 days sub-cycle of Sentinel-3

~700km equatorial distance between tracks

- Sub-cycle definition might be relatively arbitrary. We consider a sub-cycle when the across-track distance between adjacent tracks does not change with more than a factor 2. **So it ensures on-ground sampling homogeneity.**

Illustration for CRISTAL case-1

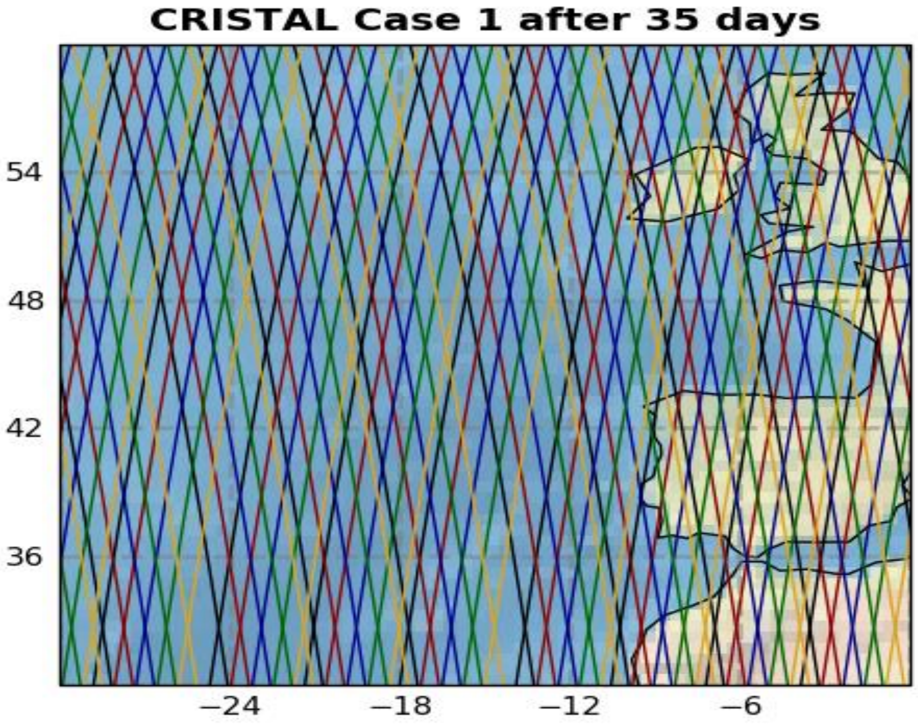


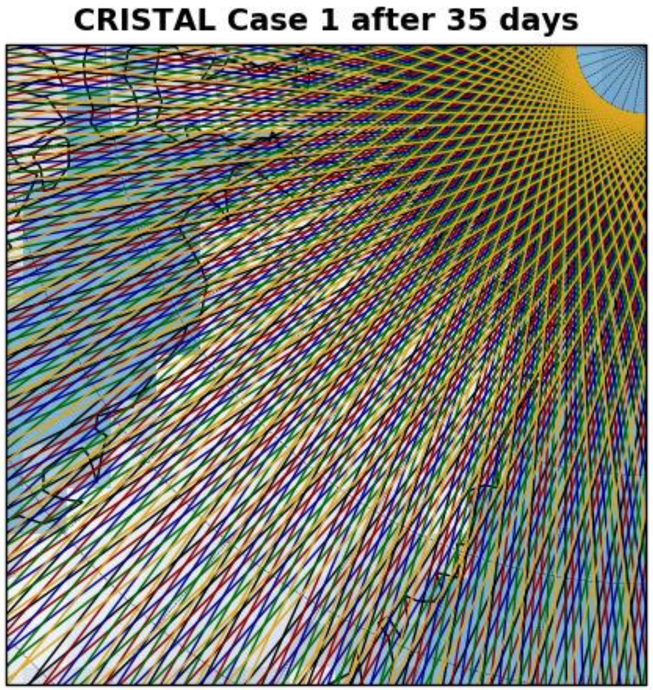


After 7 days a sub-cycle is reached

*Very good homogeneity with this orbit candidate, **minimum** across-track distance between adjacent tracks is 372km, **maximum** 456 km (equatorial distance)*

Pattern replication until a new sub-cycle is reached





After 31 days a sub-cycle is reached (before 35 days)

The orbit continues its deployment, and the different sub-cycles patterns intertwin

The current CRISTAL orbit candidates at first glance

All with an inclination of 92° - same as CryoSat-2

	< week	weekly	bi-weekly	monthly	quarterly	annual	others
Case 1 747km	**2**	**7**	/	**30**	/	**365**	**67**
Case G2 820km	**5**	/	**14**	**33**	/	**372**	**113**
Case 3 805km	**4**	/	/	**35**	/	**365**	**66**
Case 5 609km	/	**7**	/	**29**	/	**363**	**167**
ICESat-2 493km	**4**	/	/	**29**	**91**	/	/

Table indicating & sorting orbit sub-cycles. Duration indicated in number of days.

*<u>Definition of an orbit sub-cycle in this study:</u> Near repeat period providing an **homogenous** on-ground sampling. Two criteria:*

1- across-track distance between adjacent tracks does not change more than a factor of 2.

2 - across-track resolution of a given sub-cycle always smaller than the previous one by a factor of 2

Search for new orbit candidates based on MAG requests

MAG specified:

- ***Weekly sampling*** *is first priority for sea ice thickness objective.*
- ***Monthly sampling*** *is first priority for land ice objective.*
- *For Antarctica,* ***monthly sub-cycle*** *will be sufficient; for Greenland,* ***<30 days sub-sampling*** *would be desirable.*
- *Regular, homogeneous sampling is generally favorable.*
- *Additional sub-cycles such as* ***4 days sub-cycle****, and* ***quarterly sub-cycles*** *are nice to have.*
- ***The orbit must complement Sentinel-3 orbit pattern.***
- ***A 15 days sub-cycle for mid-latitude mesoscale is desirable*** *for oceanographic purposes and objectives but the lack of such a sub-cycle should not be a criterion to reject an orbit.*

3 new orbit candidates

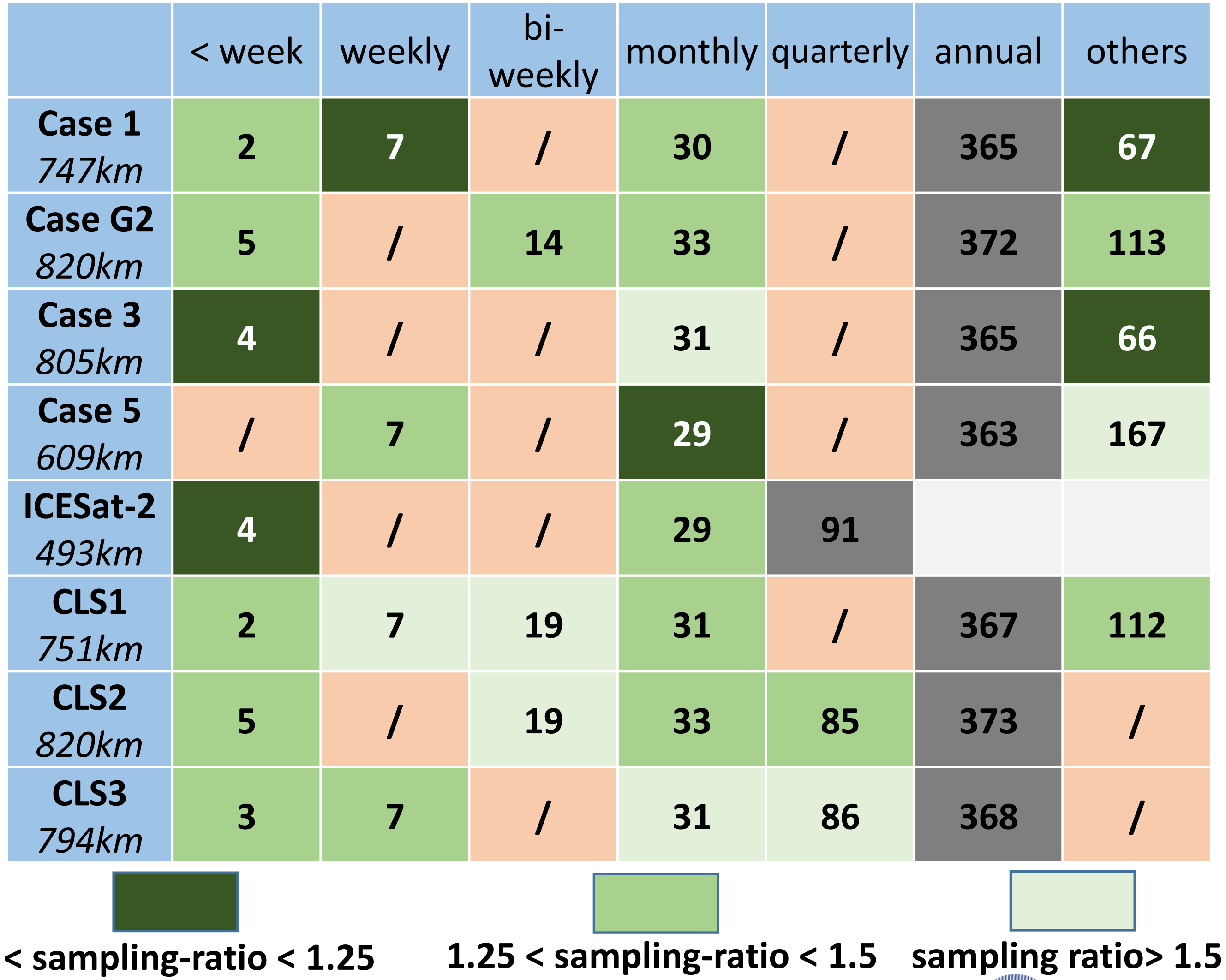
All with an inclination of 92° and a yearly cycle (following MRD)

	< week	weekly	bi-weekly	monthly	quarterly	annual	others
CLS1 *751km*	**2**	**7**	**19**	**31**	/	**367**	**112**
CLS2 820km	**5**	/	**19**	**33**	**85**	**373**	/
CLS3 *794km*	**3**	**7**	/	**31**	**86**	**368**	/

- As expected, **impossible to find a perfect candidate**. A trade-off will have to be made.
- **Impossible to have both 4 & 7 days sub-cycle**. *Is 4 days sub-cycle valuable wrt 7 days sub-cycle ? => To be discussed later in the presentation*
- A 19 days sub-cycle will be very advantageous for ocean purposes. Will it be valuable for Greenland ? as the MAG stated that “<30days would be desirable ”
- **CLS1 close to Case-1** ; **CLS2 close to G2**, both in term of altitude & sub-cycle properties.
- **CLS3** not close to any other orbit candidates

Sub-cycles - summary table

- All candidates have a **monthly sub-cycle**
- Some candidates don’t have an exact **7 days sub-cycle** (Case G2 ; Case 3 ; ICESat-2 ; CLS2). **Is 4-5 days sufficient for sea-ice thickness purposes?**
- Only 3 candidates with a quarterly sub-cycle: CLS2, CLS3 & ICESat-2. Two others with a ~4 months sub-cycle (G2 & CLS1). Is a ~4 months sub-cycle useful?
- **Overall sampling homogeneity of sub-cycles is ensured**, with a ratio between maximum / minimum intertrack distance < 1.5
- Only 3 orbit candidates are theoretically favourable for ocean, with bi-weekly sub-cycles (G2, CLS1, CLS2)



	< week	weekly	bi-weekly	monthly	quarterly	annual	others
Case 1 *747km*	2	7	/	30	/	365	67
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Case 5 *609km*	/	7	/	29	/	363	167
ICESat-2 *493km*	4	/	/	29	91		
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CLS3 *794km*	3	7	/	31	86	368	/

1 < sampling-ratio < 1.25 **1.25 < sampling-ratio < 1.5** **sampling ratio> 1.5**

Sea-ice

- **Ice charting:** Number of sea ice operational ice chart measured during 1 week period
- **Weekly products:** Sampling homogeneity after a 1 week period

Ice-sheets

- **Monthly products**: Average area sampled per 30-day epoch & consistency of sampling
- **Quarterly products**

Ocean

- **Oceanic mesoscale**: Decorrelation of mesoscale signals in space/time
- **Polar mesoscale:** Strategy based on sub-cycles

Complementarity with Sentinel-3A is taken into account for all diagnoses

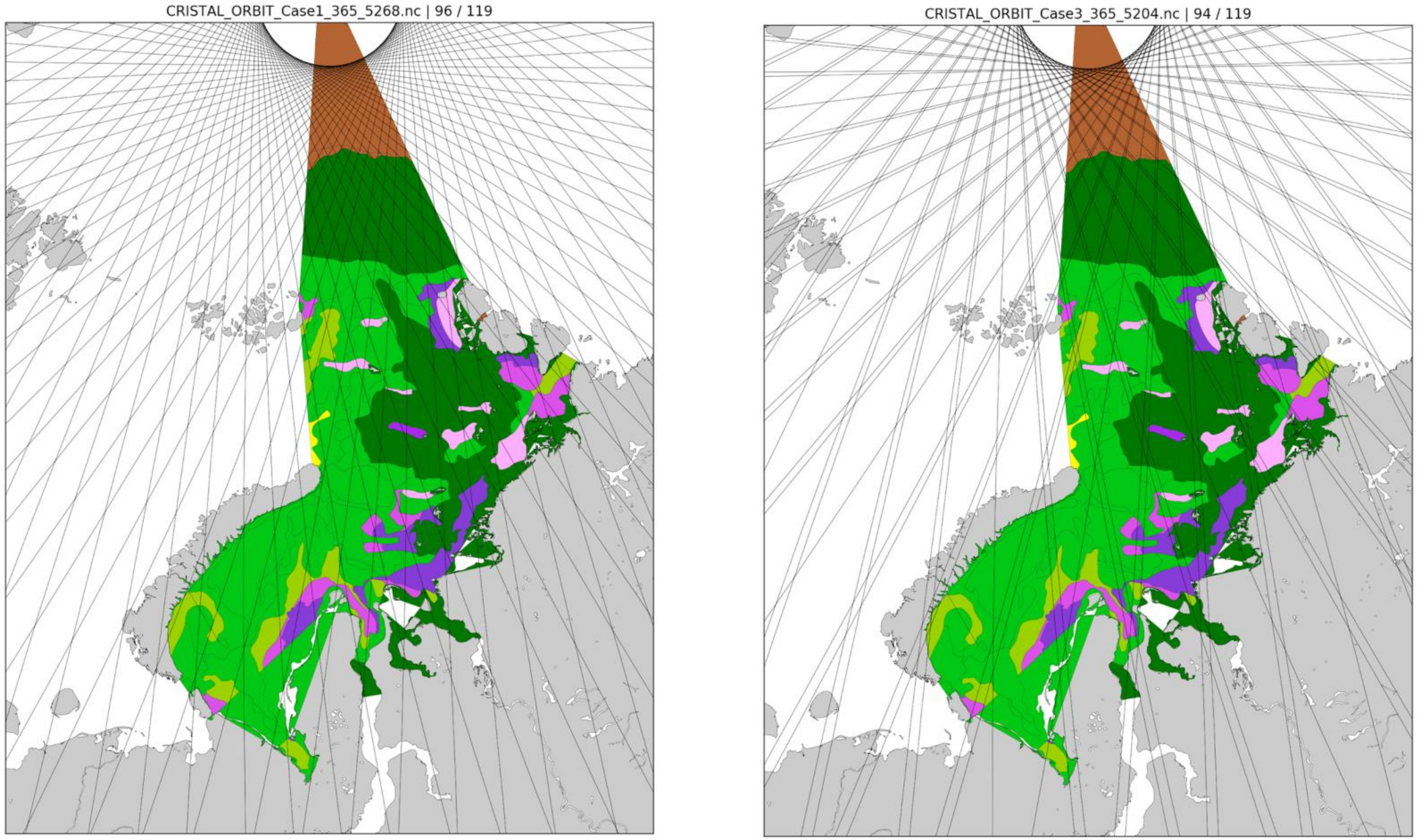
Sea-Ice Rationale

- Sea ice moves, and we will never hit same ice twice in the same place. Thus repeat cycles and crossovers have less meaning than for land ice. For climate purposes, as long as we fly close to the pole, any orbit is good.

- However, how well different orbit candidates are suited for operational sea ice charting?

- Study on Kara sea ice charts:
  - Hotspot for winter navigation
  - Weekly ice charts from AARI available
  - Gives a handle on the size of features relevant for navigation

Best vs. worst candidate

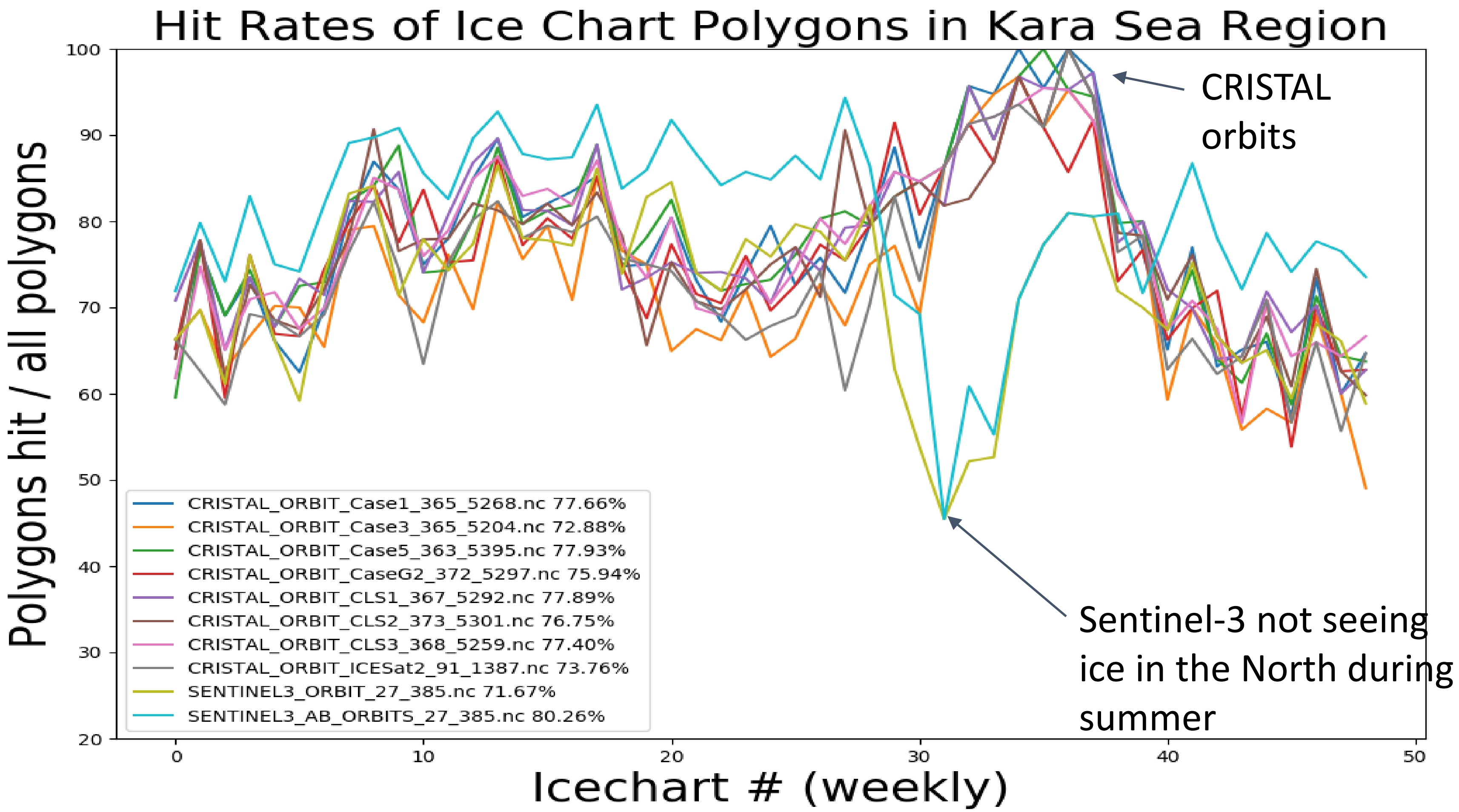


How many of the ice chart polygons are we able to measure between to ice charts (that is, in 7 days).

Weekly orbit pattern is significantly more sparse and uneven if the shortest repeat cycle is lot less than a week.

However, the difference in polygons caught is small. During the example week here, only 2 polygons less (94 vs. 96 out of 119) are measured with the worst candidate than with the best.

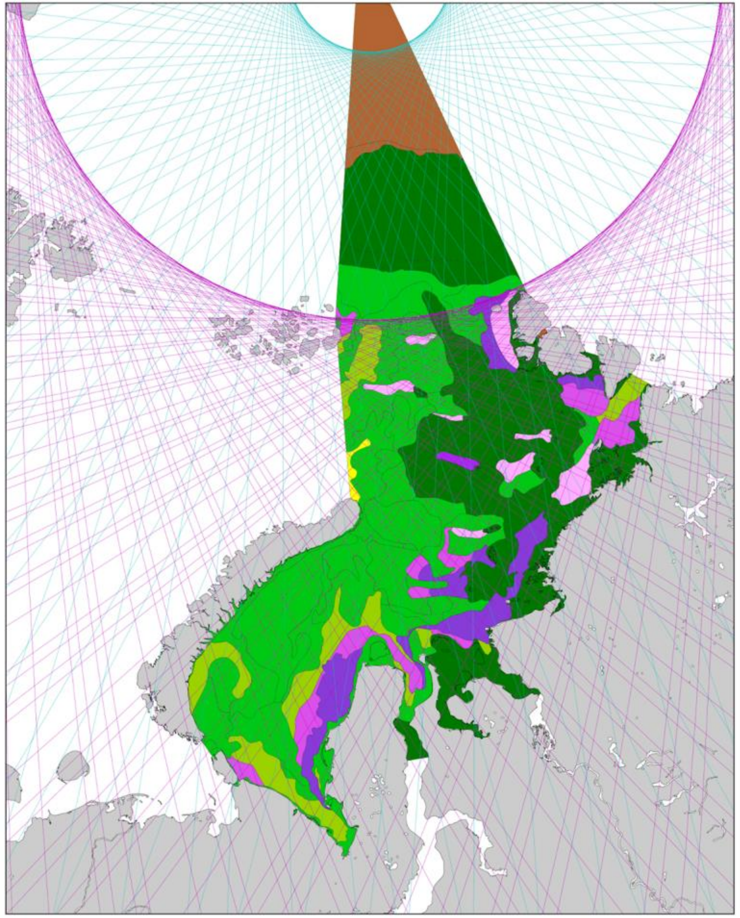
Time series of hit rates



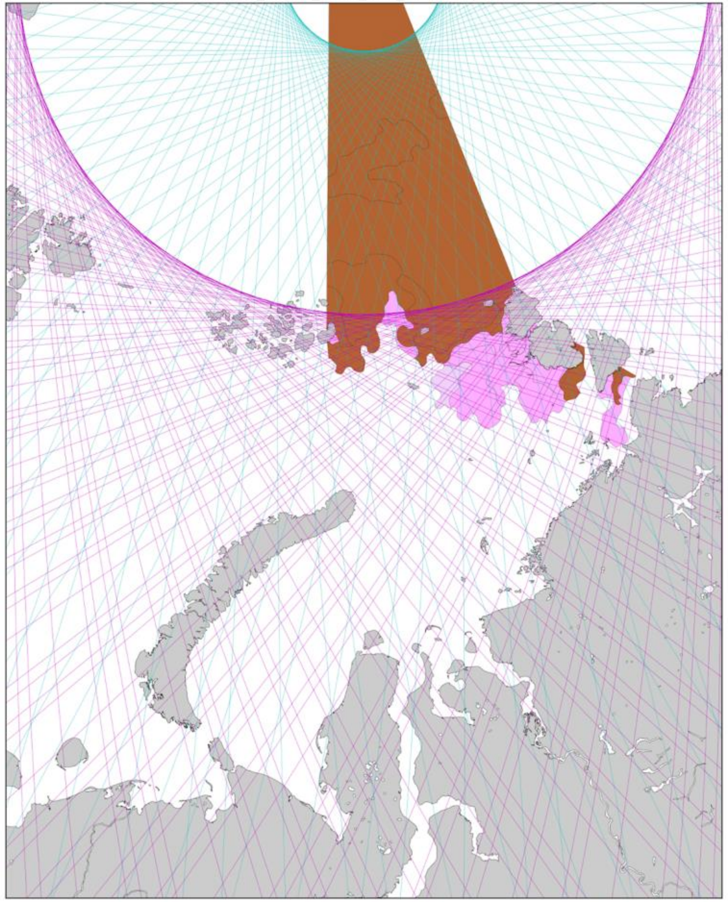
CRISTAL orbits

Sentinel-3 not seeing ice in the North during summer

But there is always Sentinel-3!



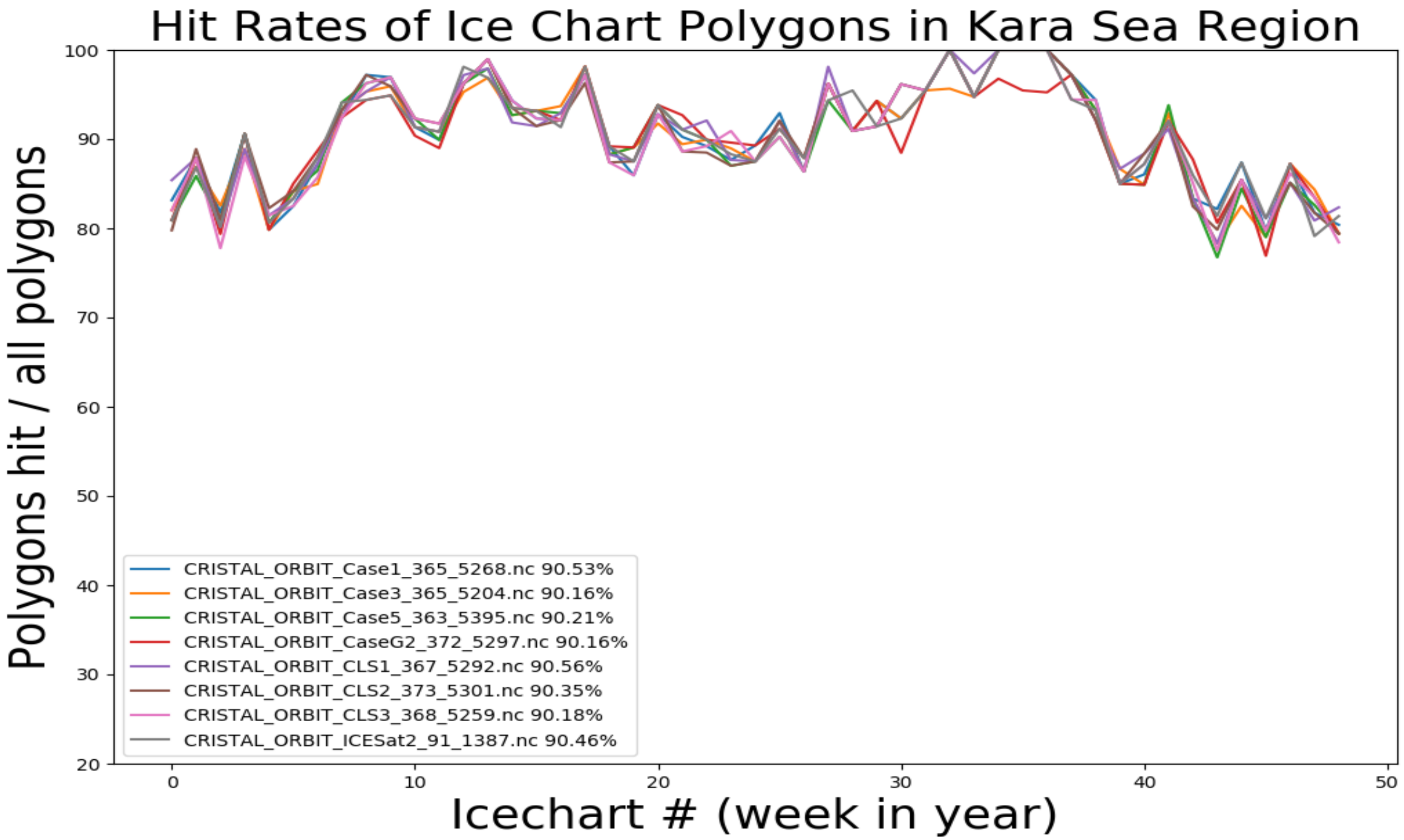
CRISTAL_ORBIT_CLS1_367_5292.nc | 111 / 119



CRISTAL_ORBIT_CLS1_367_5292.nc | 21 / 21

Sentinel-3 (cyan) will provide dense measurements below 82 N, complementing CRISTAL (light blue) during winter. In the summer, Sentinel-3 sees little ice, since most of it has retreated North of 82 N.

Polygons hit with CRISTAL or S3



4-5 day repeat vs. 7 day repeat for sea-ice weekly products

When looking at CRISTAL alone, 7 day repeat is better for weekly ice charting than a 4 or 5 day one. However, the difference is small: On average 78% vs 72% of polygons caught.

However, if we assume that Sentinel-3 satellites will provide dense measurements for areas south of 82 N, difference between CRISTAL orbit candidates becomes negligible: ~ 90% of the polygons are caught regardless of CRISTAL orbit.

Summary for sea-ice

Case-1 (7 days subcycle): Optimal
Case-G2 (5 days sc): Sub-optimal*
Case-3 (4 days sc): Sub-optimal*
Case-5 (7 days sc): Optimal
ICESat-2 (4 days sc) : Sub-optimal*
CLS1 (7 days sc) : Optimal
CLS2 (5 days sc) : Sub-optimal*
CLS3 (7 days sc) : Optimal

**** NOTE - if co-operation with Sentinel-3 satellites is expected, all of the orbits are optimal.***

Land Ice Performance Metrics

***MRD-070:** The orbit spatial sampling pattern shall be repetitive to achieve discrimination of trends of first and multi-year sea-ice thickness and land ice elevation.*

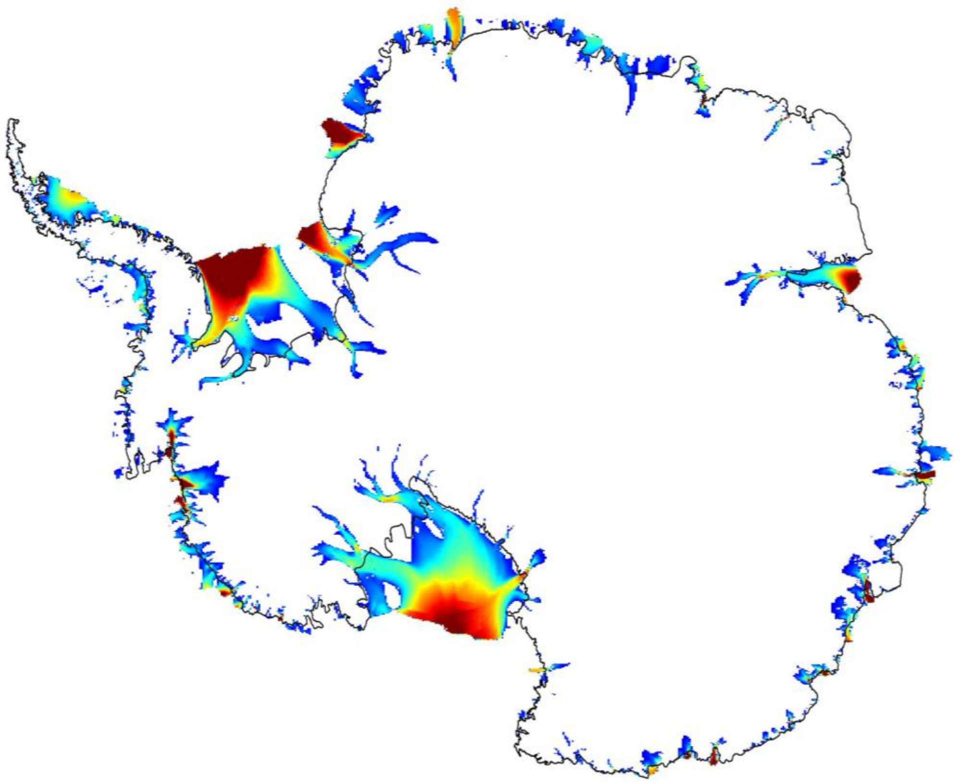
***MRD-350:** The system shall be capable of delivering surface elevation with a temporal sampling of at least 30 days.*

***Note 1:** Lower temporal sampling sufficient for terrain with gentle topography in the interior of the ice sheets.*
***Note 2:** Major changes in surface elevation are observed at outlet glaciers and boundaries of Greenland and Antarctica. In these regions, monthly to seasonal maps of surface elevation are needed.*

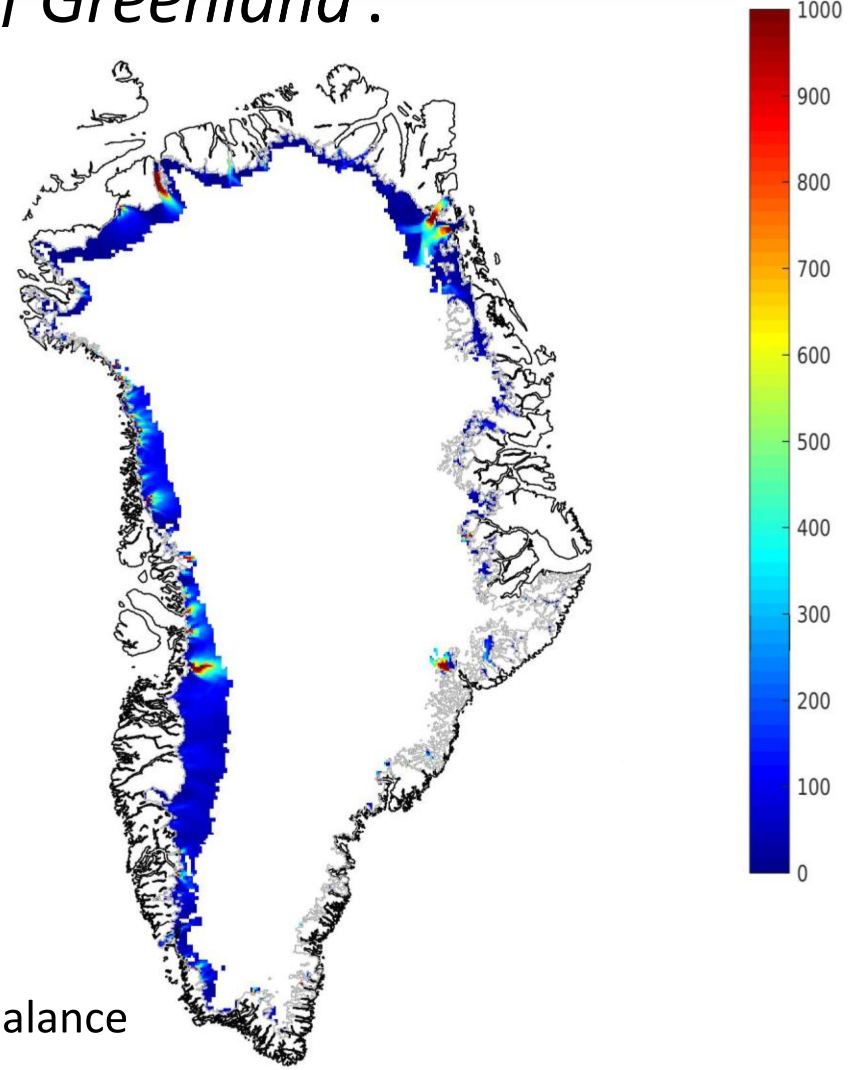
- Ability to sample dynamic regions of the ice sheets at 30-day frequency.
- Metrics:
  - Average area sampled per 30-day epoch.
  - Consistency of sampling in all 30-day epochs.

+ Quarterly sampling

Definition of ‘*Outlet Glaciers and Boundary Areas of Greenland*’.



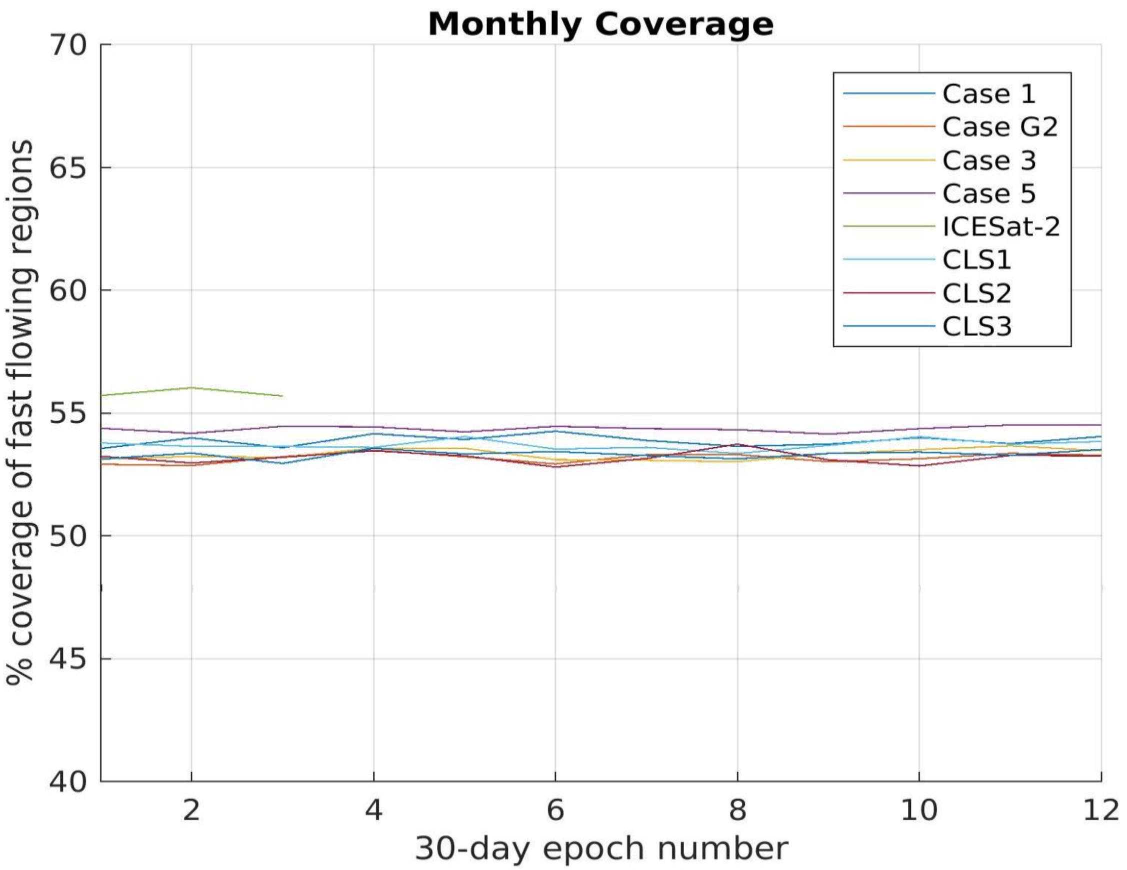
Velocity > 100 m/yr

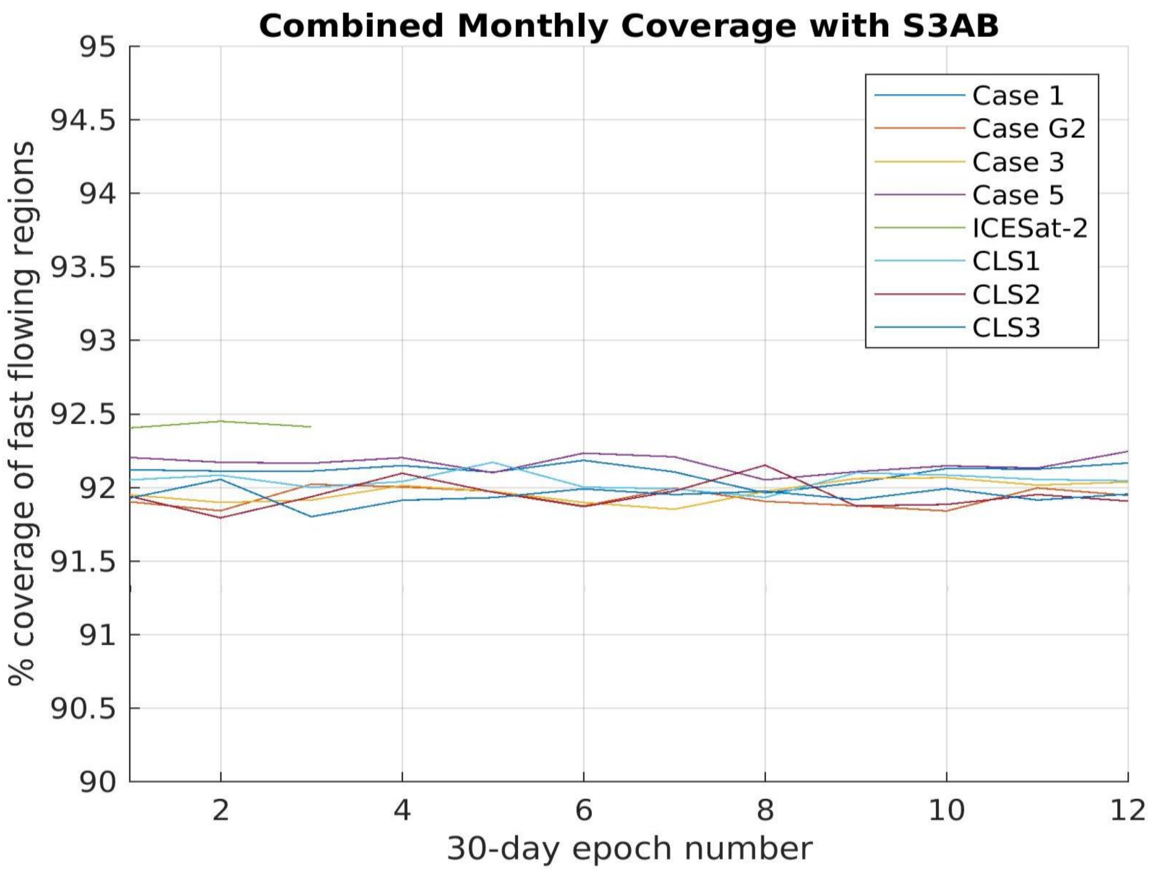


Ablation zone + areas of dynamic imbalance

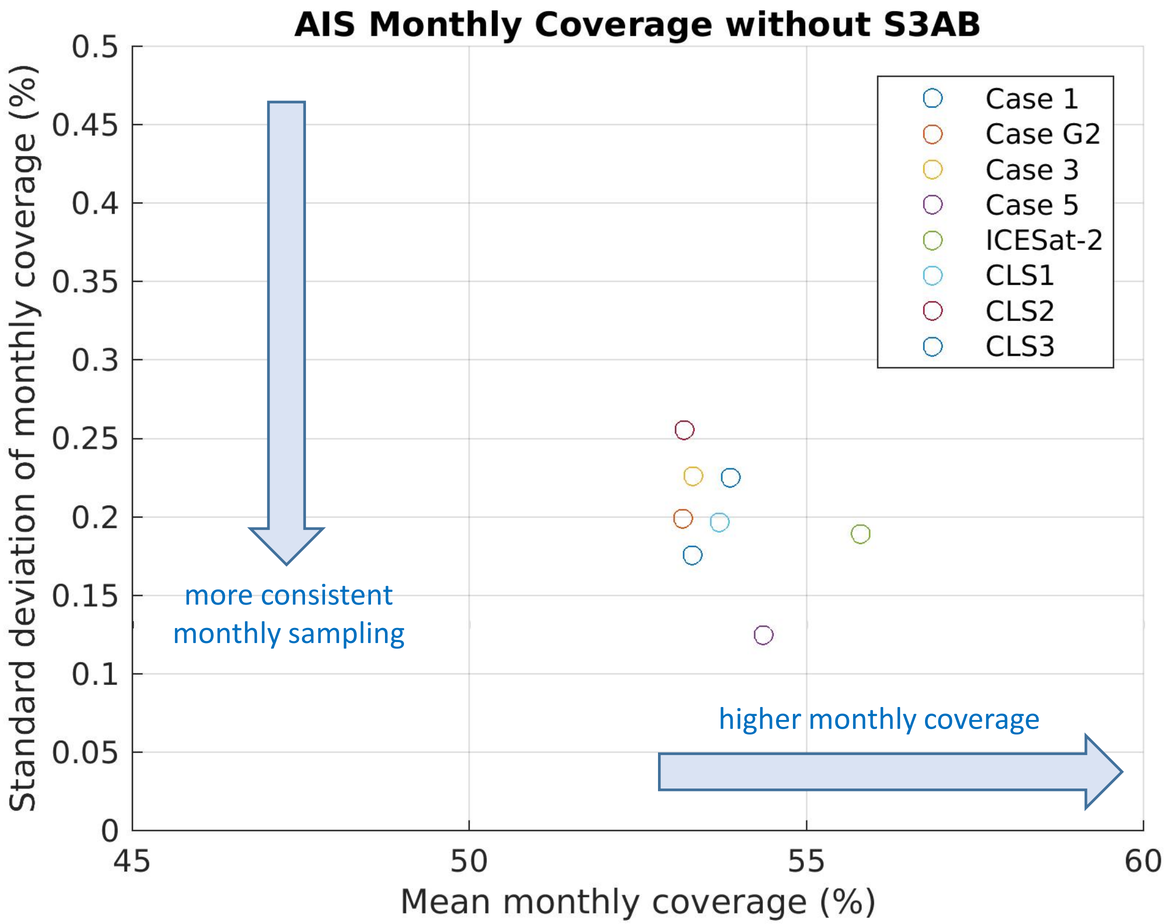
Antarctica -- Monthly

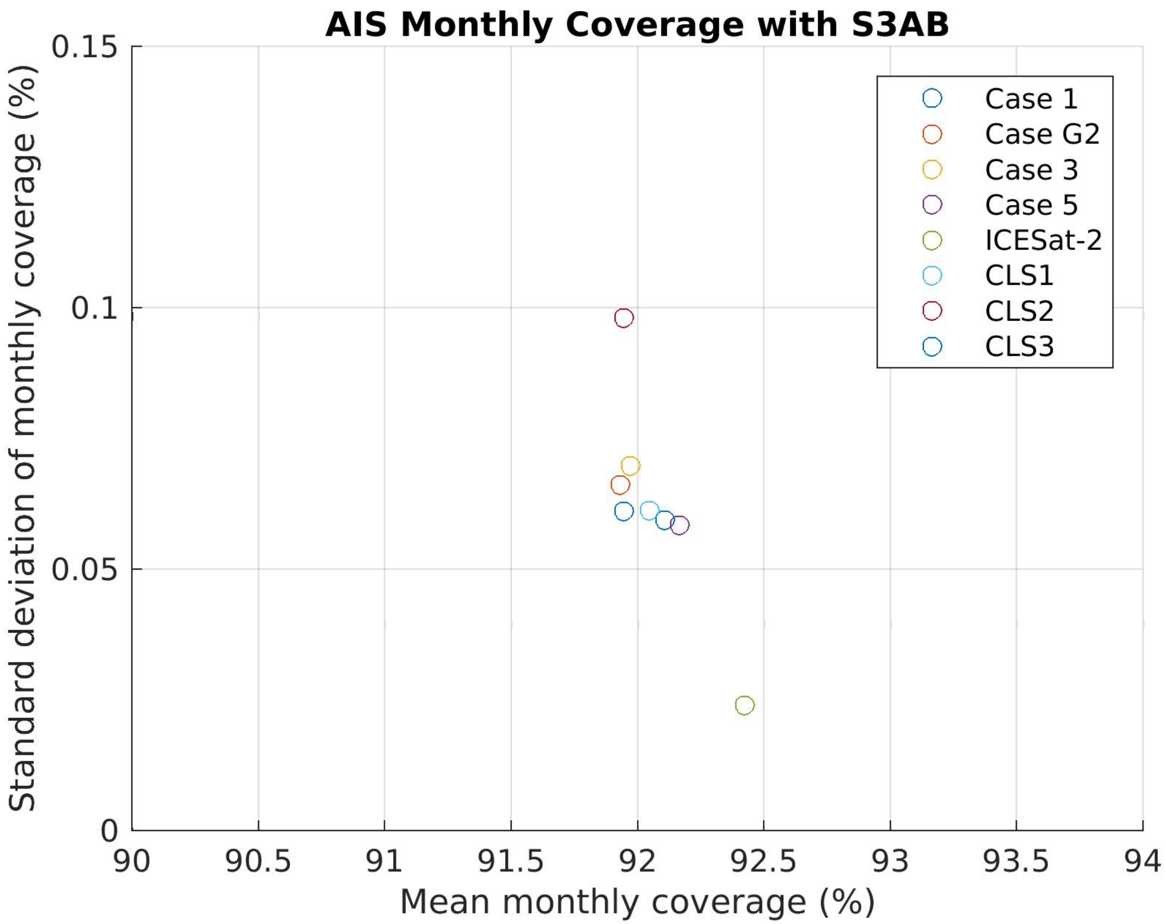
CRISTAL Orbits Analysis – Monthly Coverage – Antarctica





CRISTAL Orbits Analysis – Monthly Coverage – Antarctica





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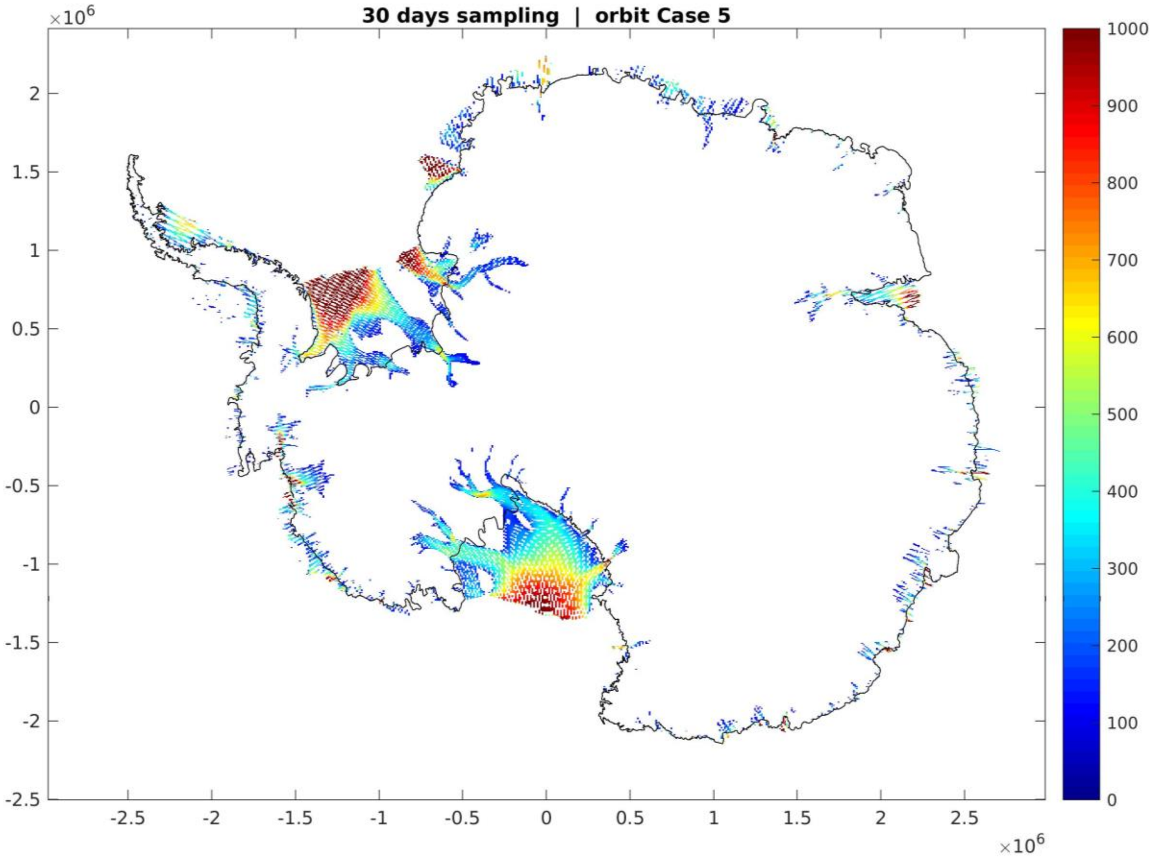
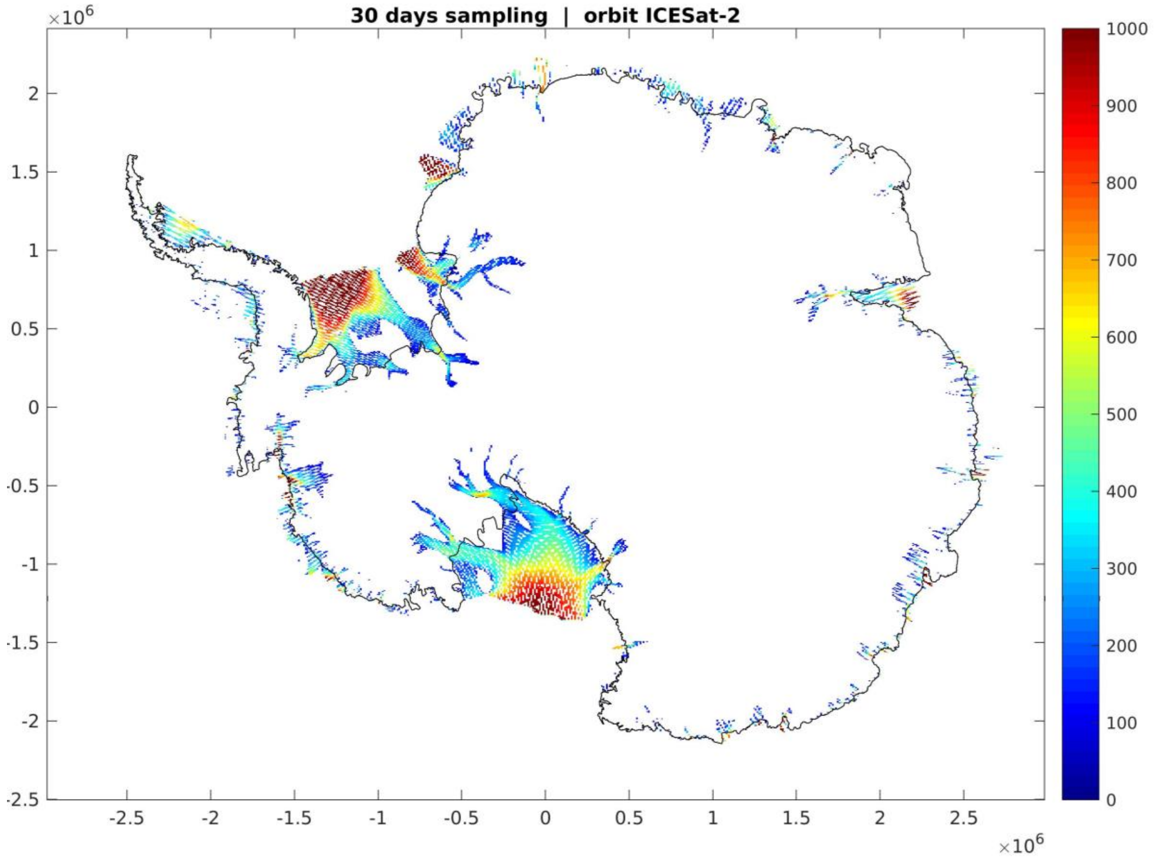
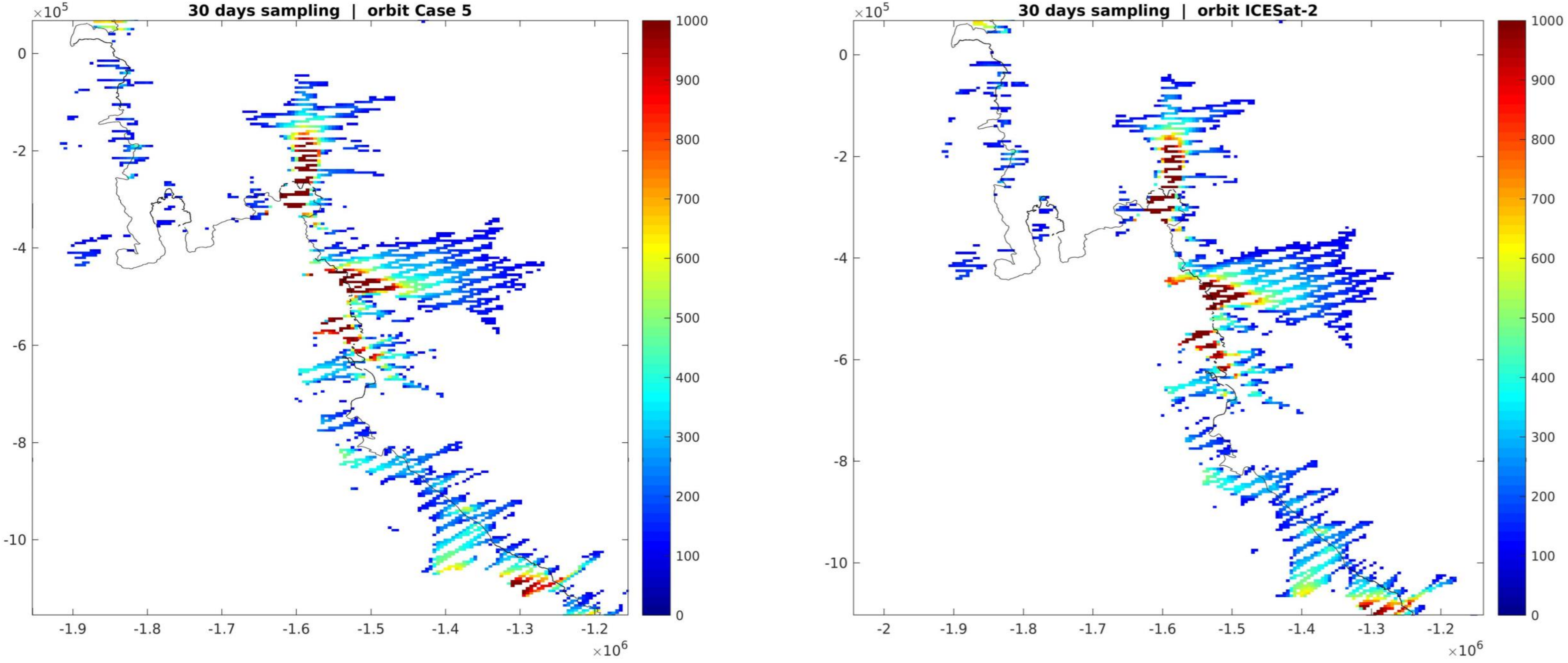


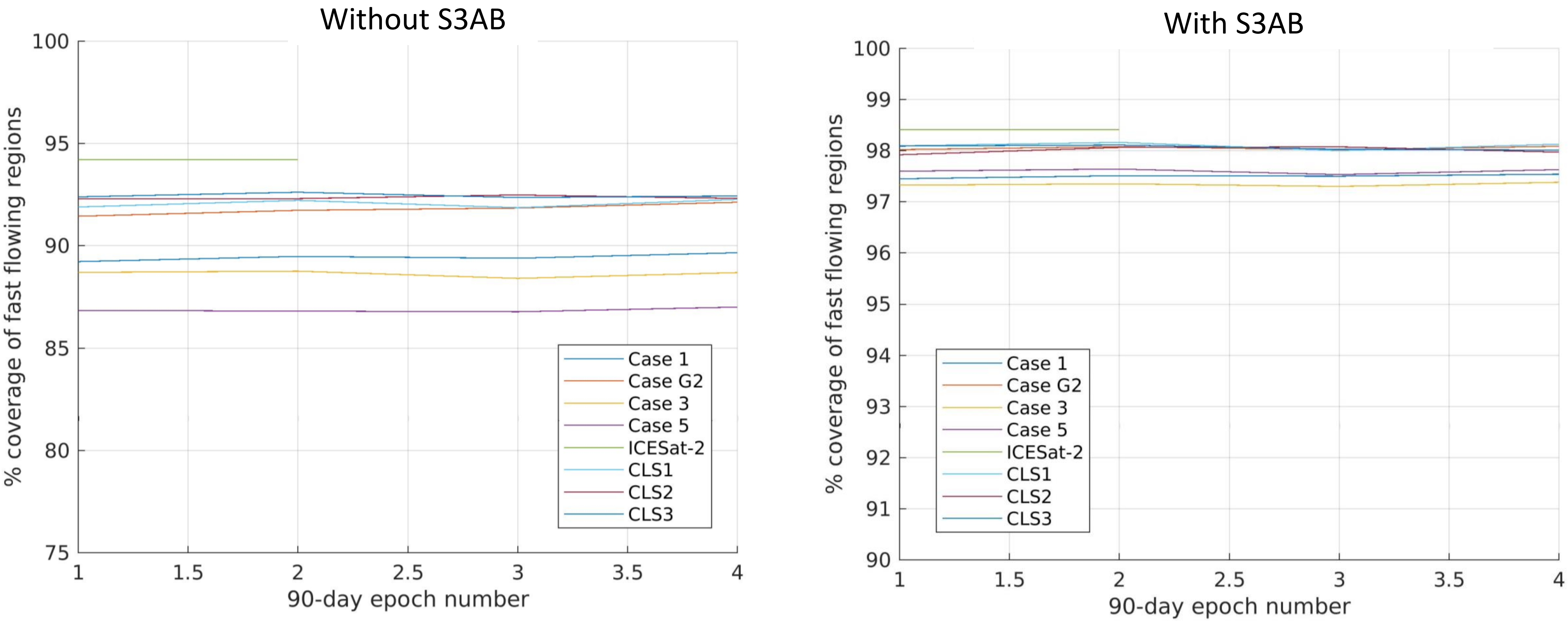


CRISTAL Orbits Analysis – Monthly Coverage – Amundsen Sea

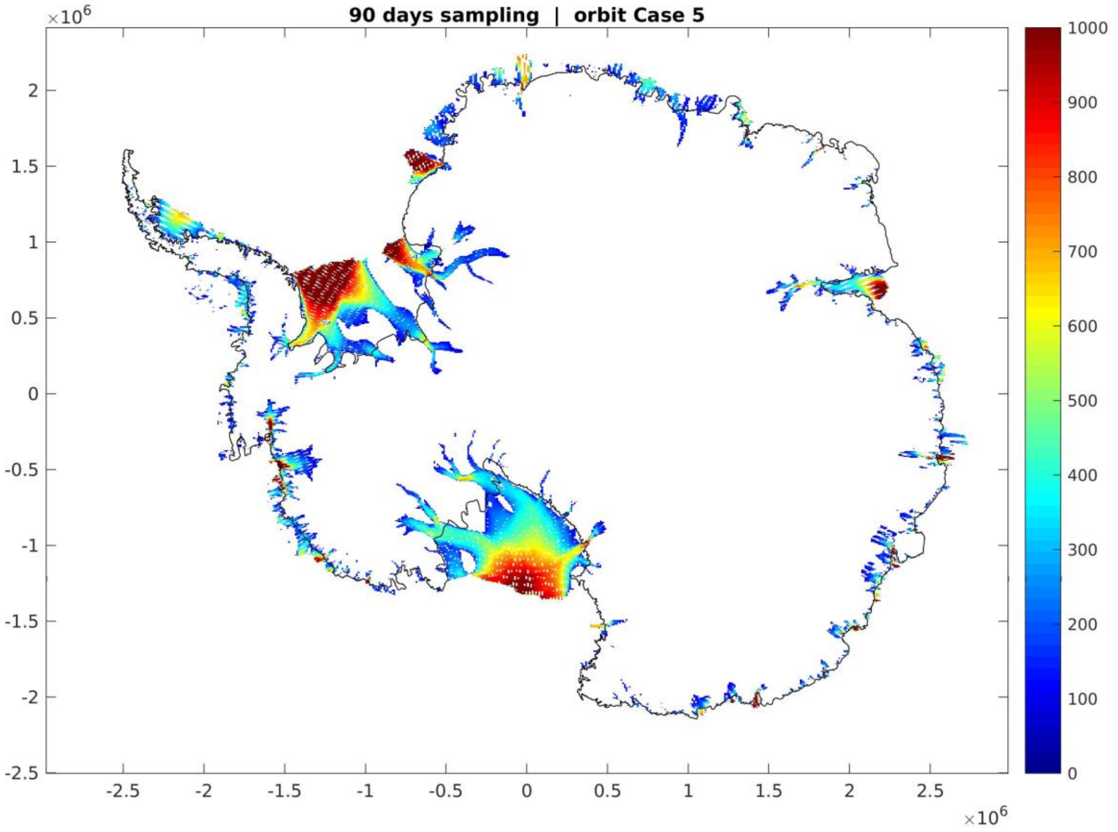


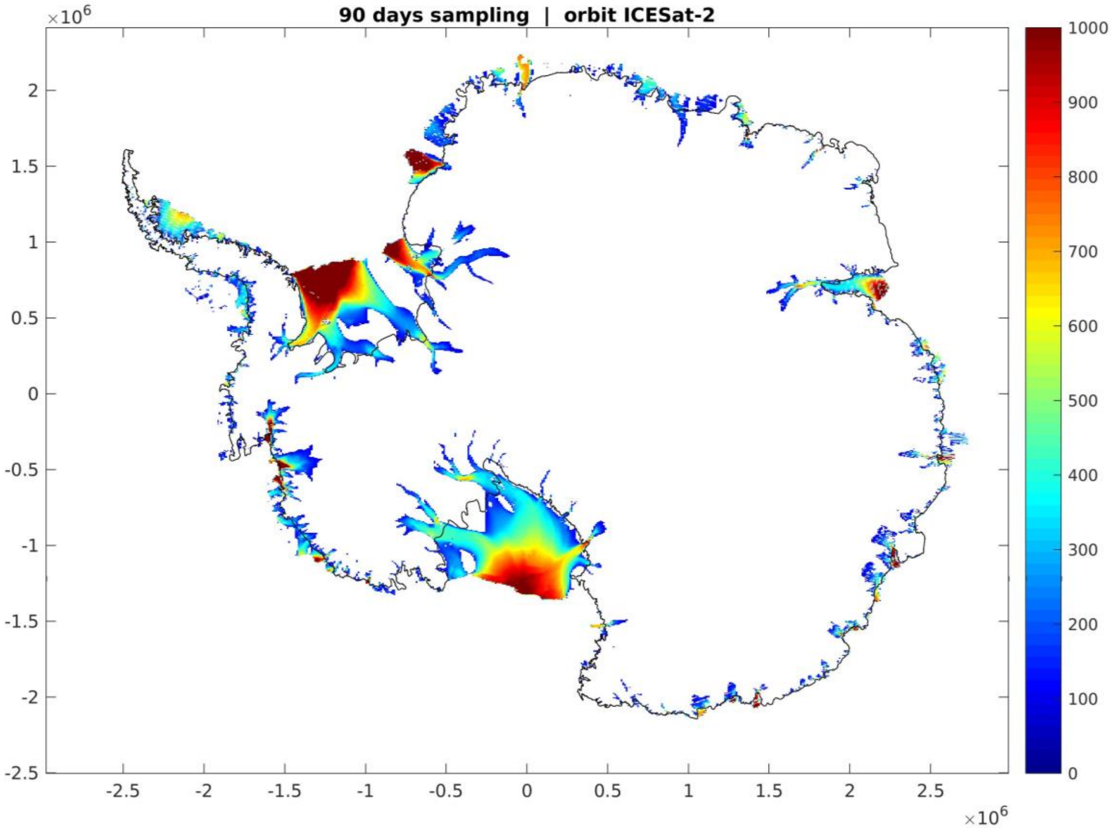
Antarctica -- Quarterly

CRISTAL Orbits Analysis – Quarterly Coverage – Antarctica

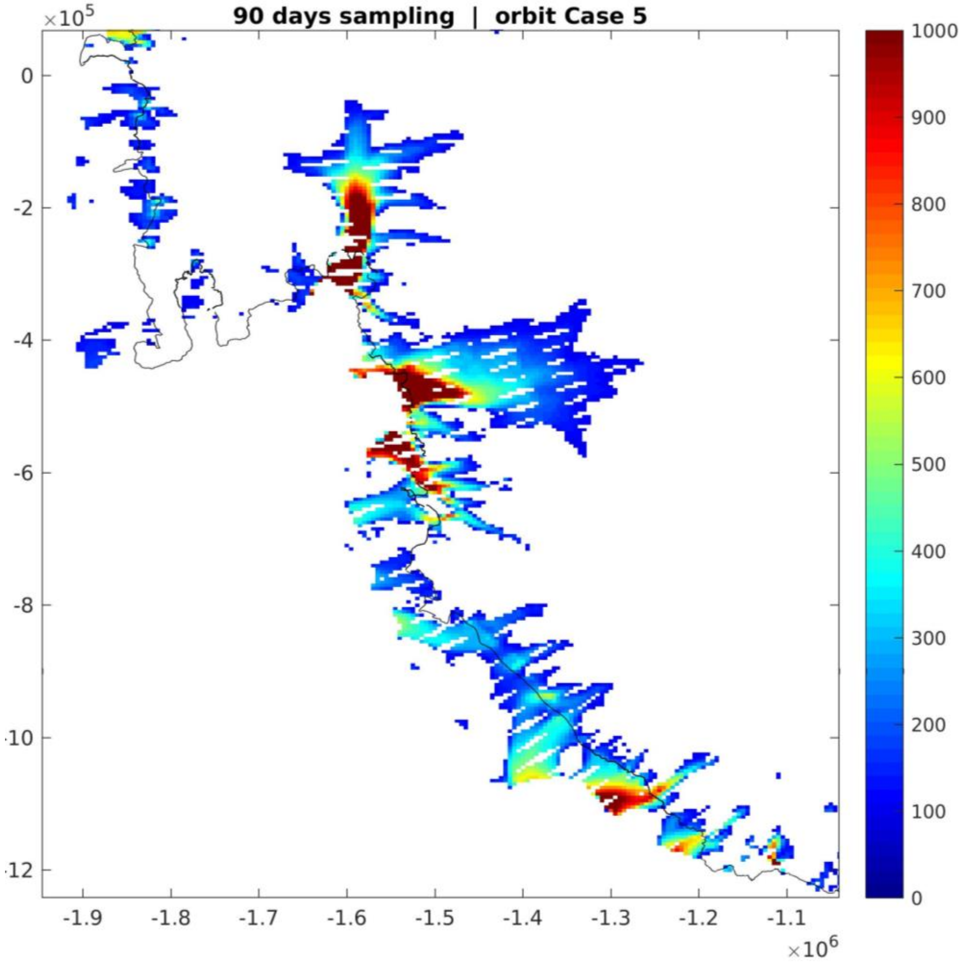


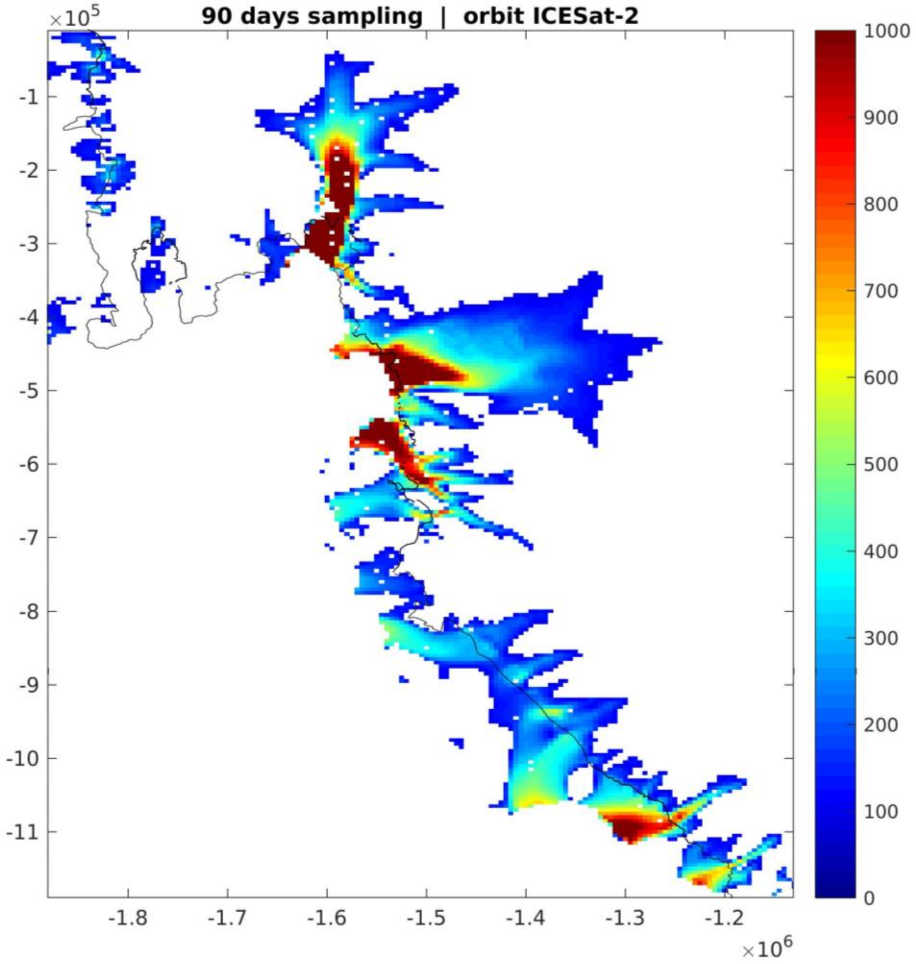
CRISTAL Orbits Analysis – Quarterly Coverage – Antarctica


90 days sampling | orbit Case 5


90 days sampling | orbit ICESat-2

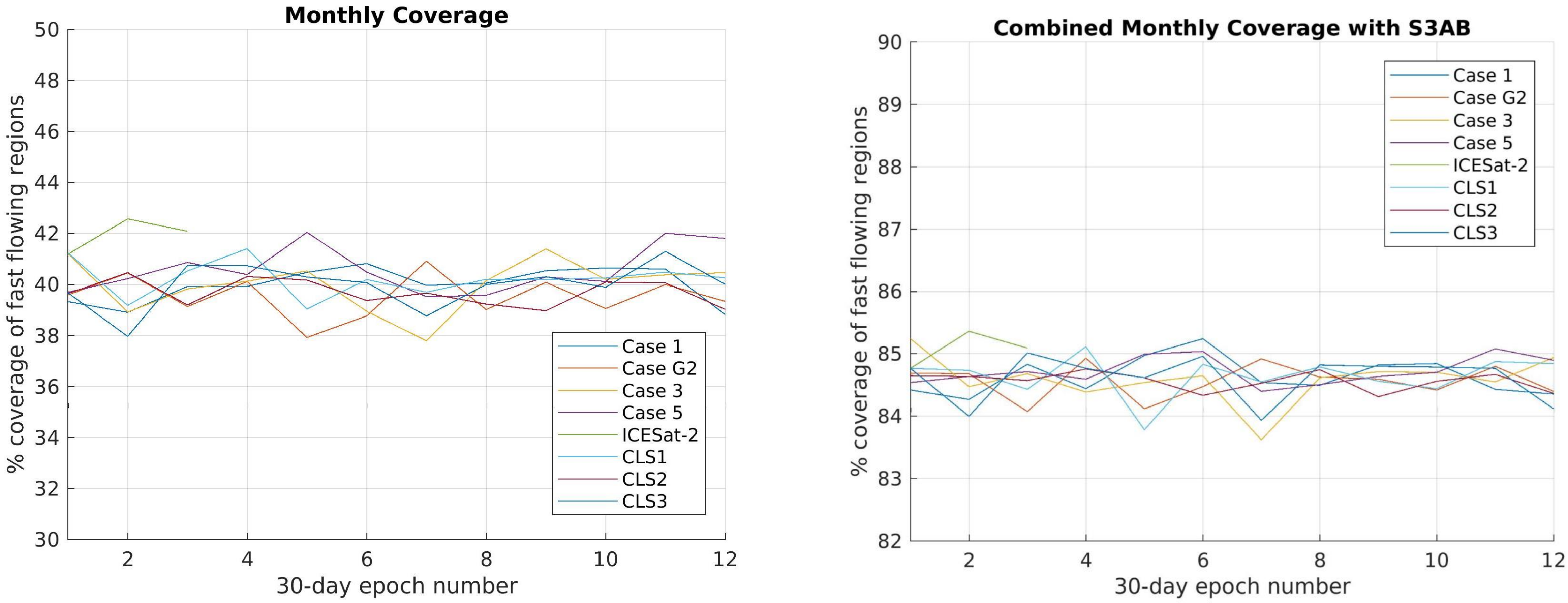
CRISTAL Orbits Analysis – Quarterly Coverage – Antarctica





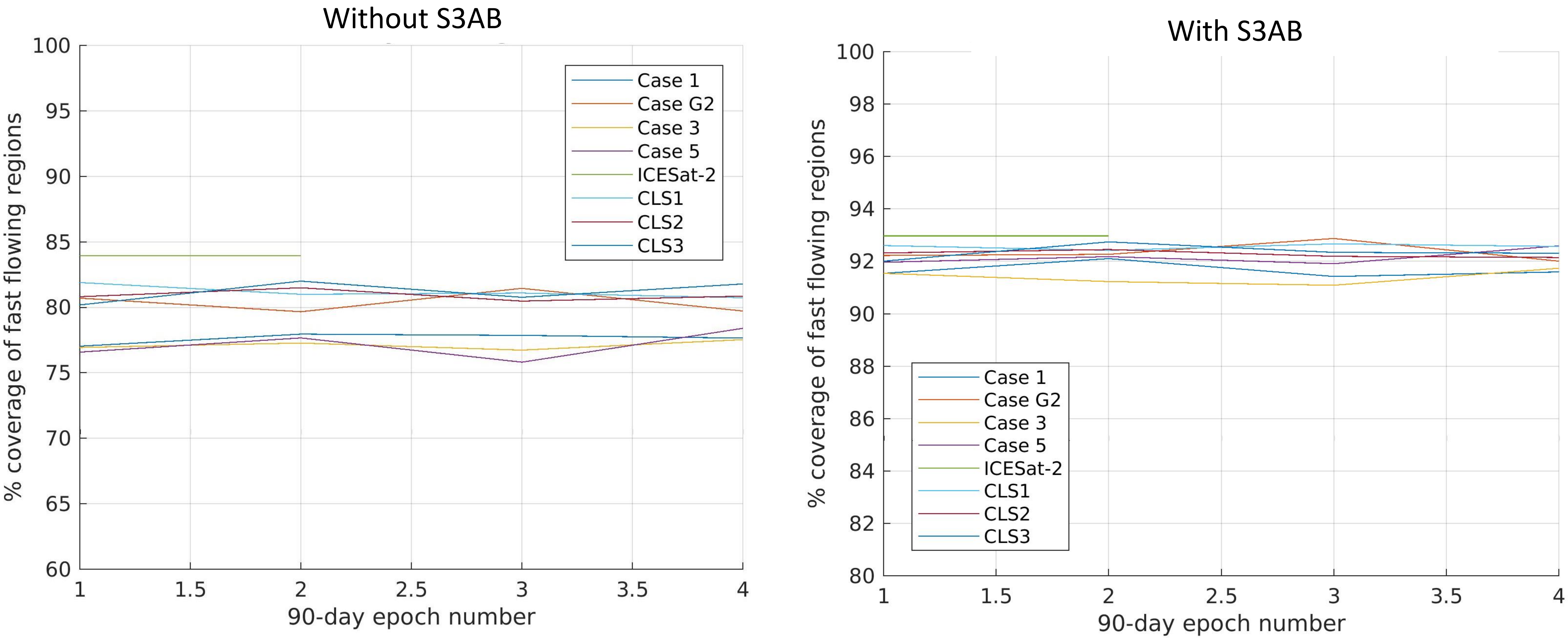
Greenland -- Monthly

CRISTAL Orbits Analysis – Monthly Coverage – Greenland

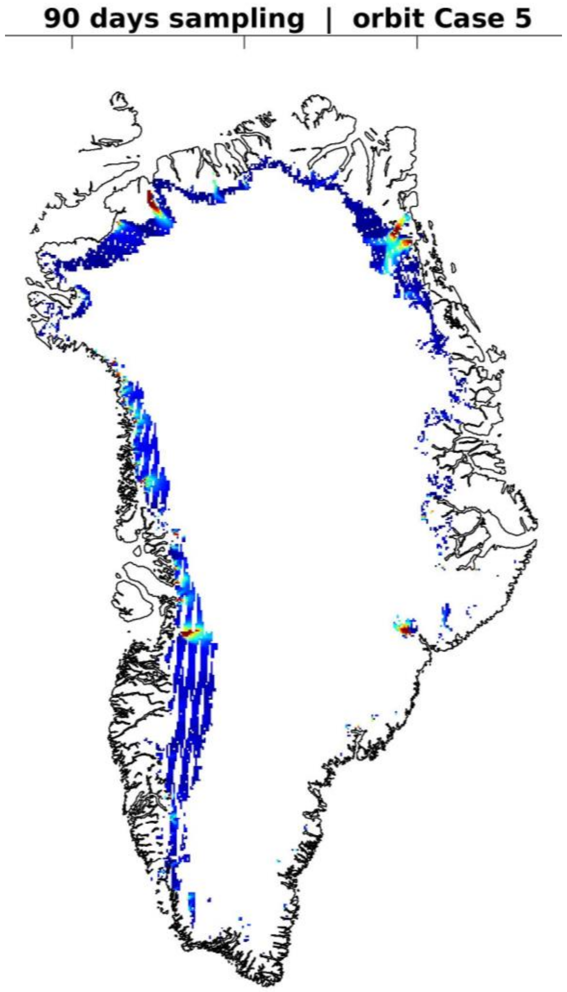


Greenland -- Quarterly

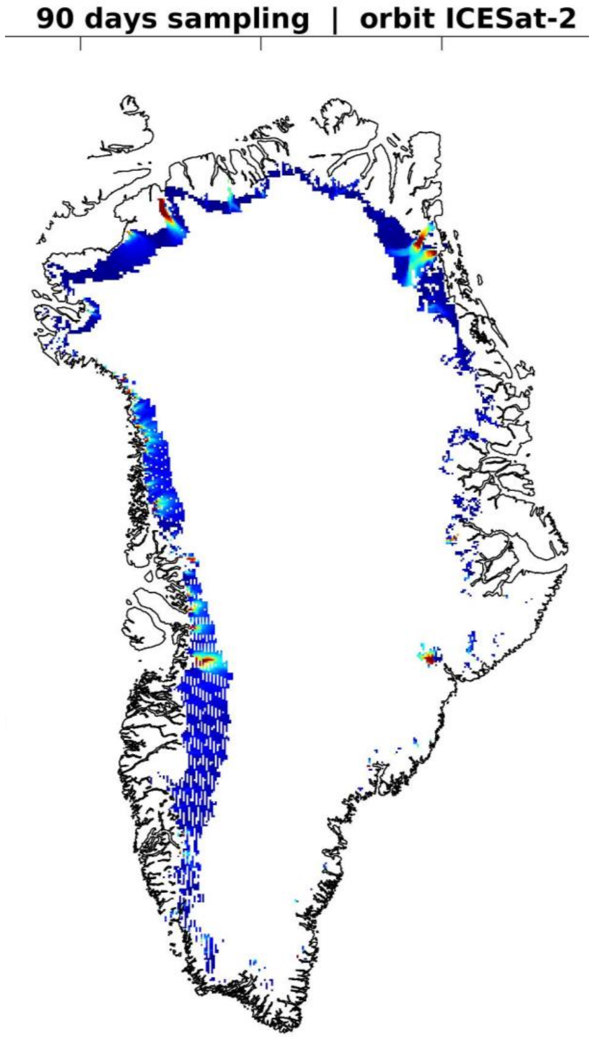
CRISTAL Orbits Analysis – Quarterly Coverage – Greenland



CRISTAL Orbits Analysis – Quarterly Coverage – Greenland

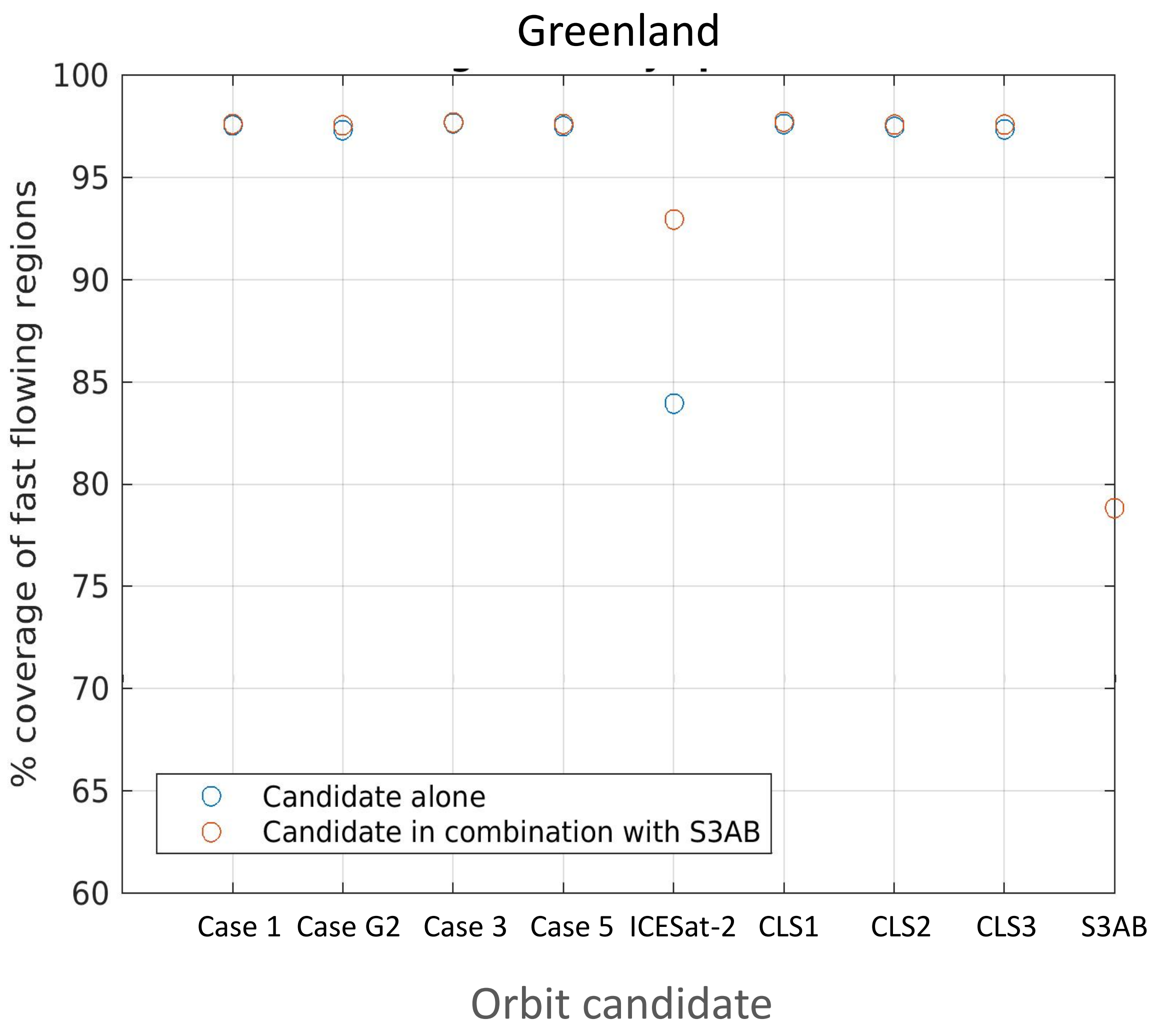


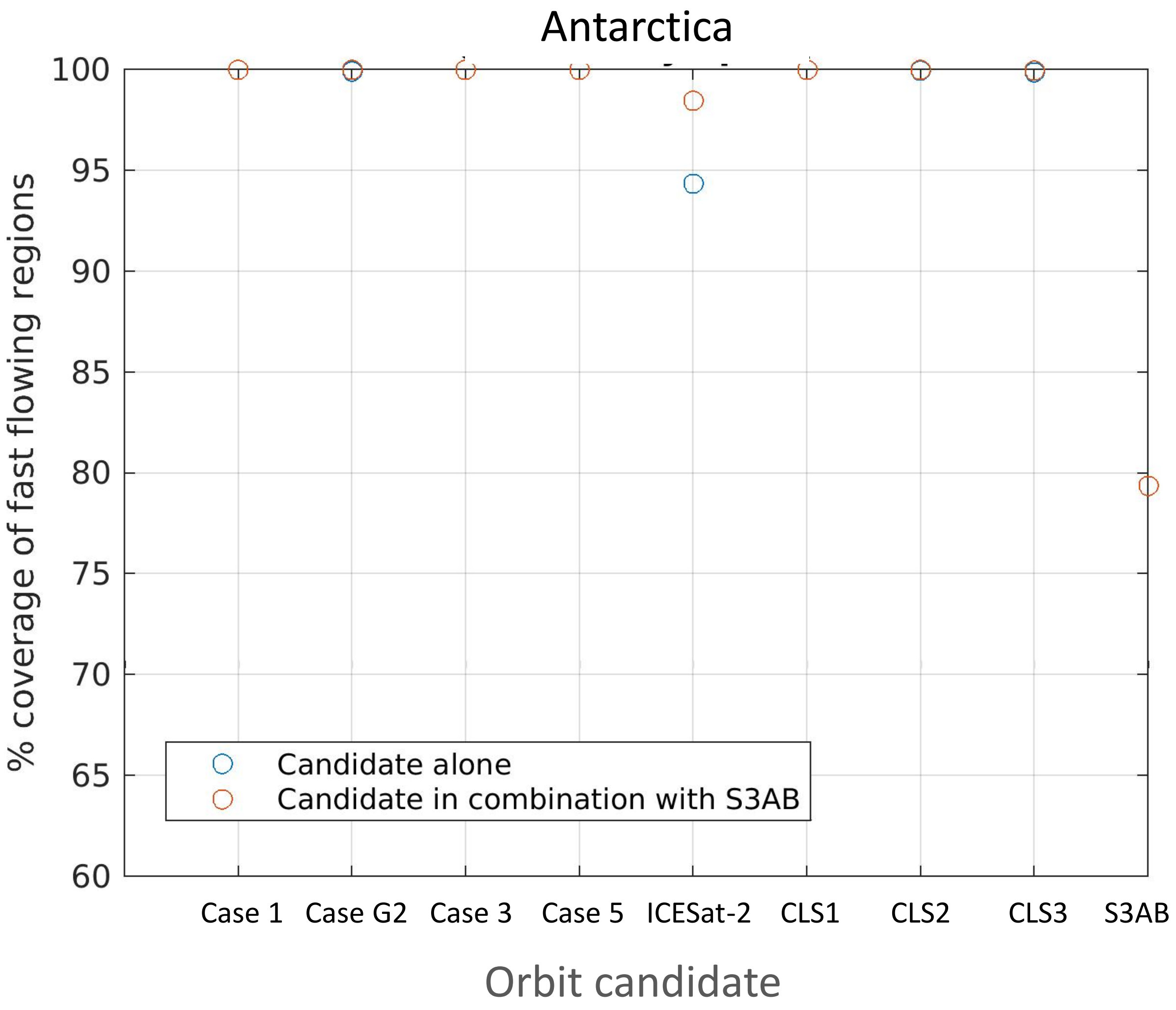
90 days sampling | orbit Case 5



90 days sampling | orbit ICESat-2

CRISTAL Orbits Analysis - fast flow - 365-day coverage





Summary

1. When considered in conjunction **with S3AB**, there is no clear ”optimal” candidate. All perform well.

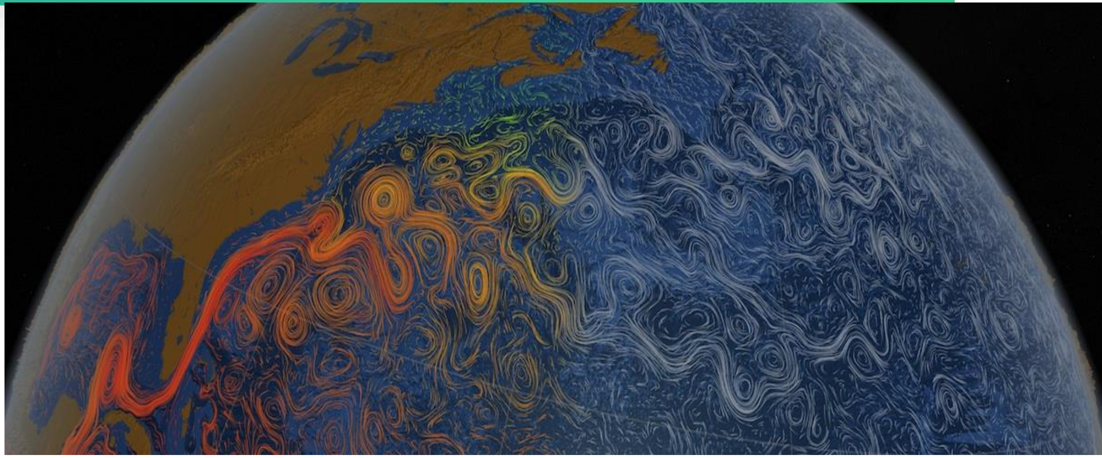
2. When considered **without S3AB** then the following 5 options are “optimal”. Within these 5, performance depends upon the priority timescale.

	ICESat-2	Orbit 5	CLS-1	CLS-2	CLS-3
Antarctica Monthly	56 %	54 %	53%	53%	53%
Antarctica Quarterly	94%	87%	92 %	92 %	92 %
Antarctica Annual	95 %	100 %	100 %	100 %	100 %
Greenland Monthly	42 %	41 %	40 %	40 %	40 %
Greenland Quarterly	84 %	77 %	81 %	81 %	81 %
Greenland Annual	84 %	97 %	97 %	97 %	97 %

Which is most important?

- **+ 2-3 % @ quarterly &**
- **+ 2 % @ monthly**
  - ➢ IS-2

- **+ 5-13 % @ annual:**
  - ➢ CLS1-3 (quarterly + annual)
  - ➢ Orbit 5 (monthly + annual)

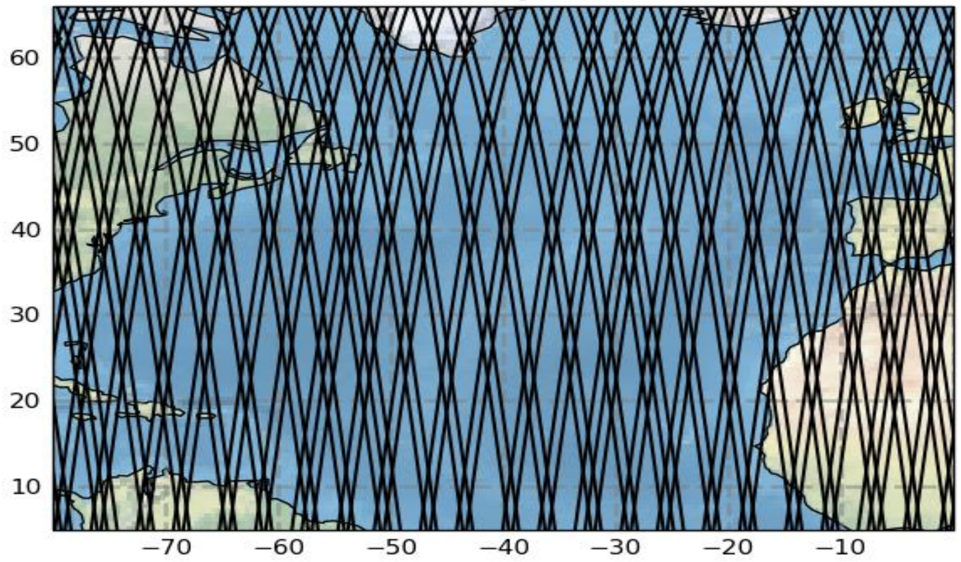


Global oceanic mesoscale

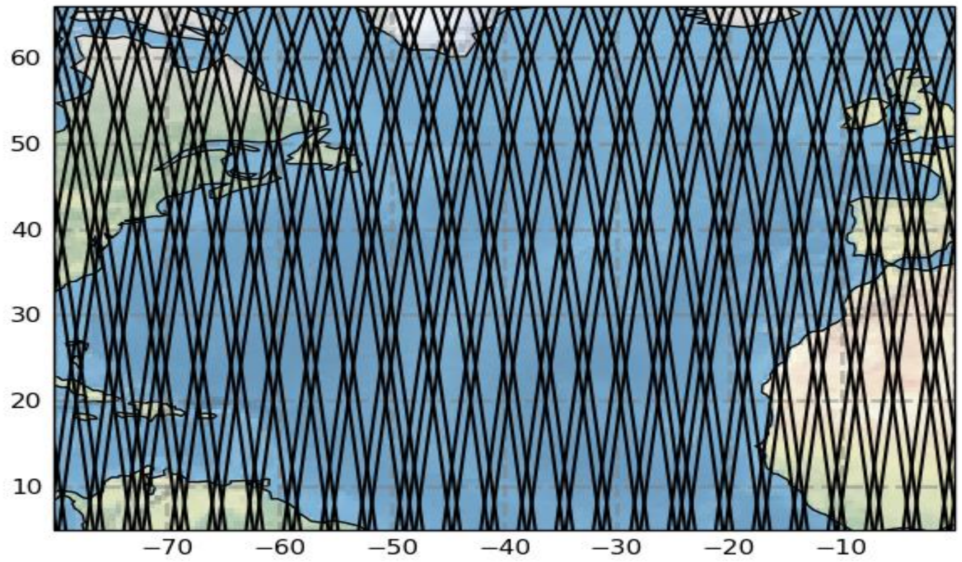
- Mesoscale ocean eddies are characterized by currents that flow in a roughly circular motion around the center of the eddy
- Mesoscale ocean dynamics have scales ranging from 150 to 500 km and 15 to 50 days [Morrow et al., 2017]**. Typical decorrelation scale days of ocean mesoscale is 150km / 15 days.**
- Two operational altimeters are required to monitor ocean mesoscale variability in delayed time, and up to four are needed in near real time [Chelton et al., 2003]
- **Geodetic orbits can be compatible with mesoscale monitoring, by including intermediate sub-cycles maximizing the ocean mesoscale sampling over a period of 15 to 20 days.** [Dibarboure et al., 2012]

Sampling after 15 days – worst cases

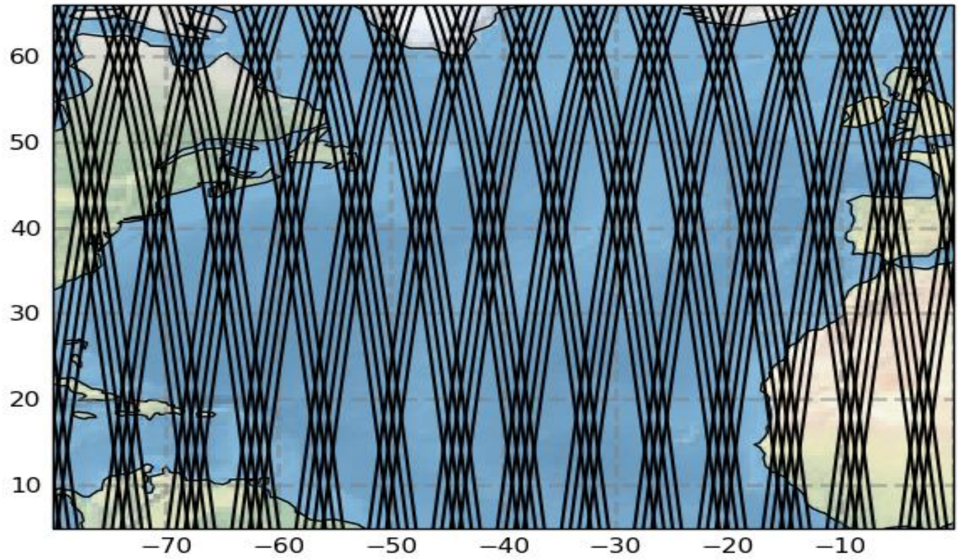
CLS3 option



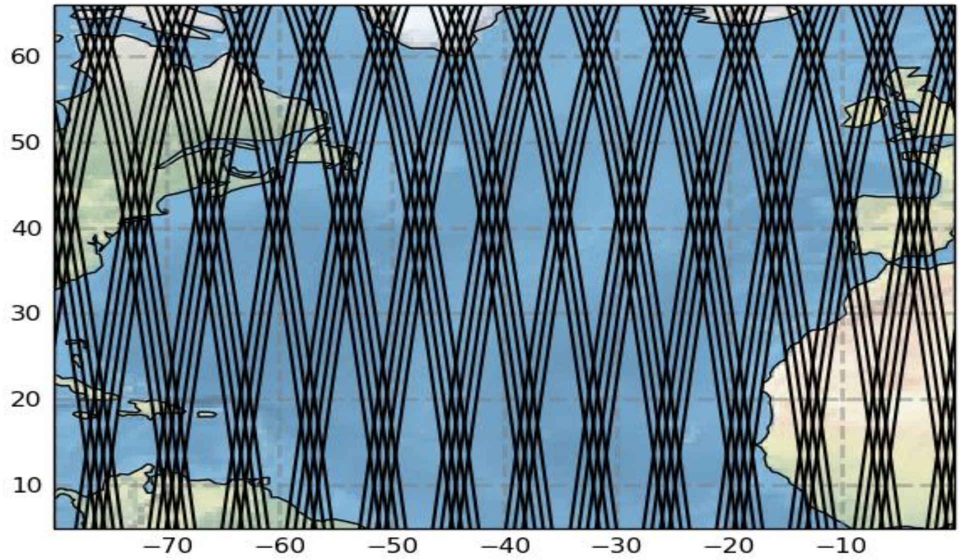
Case 5



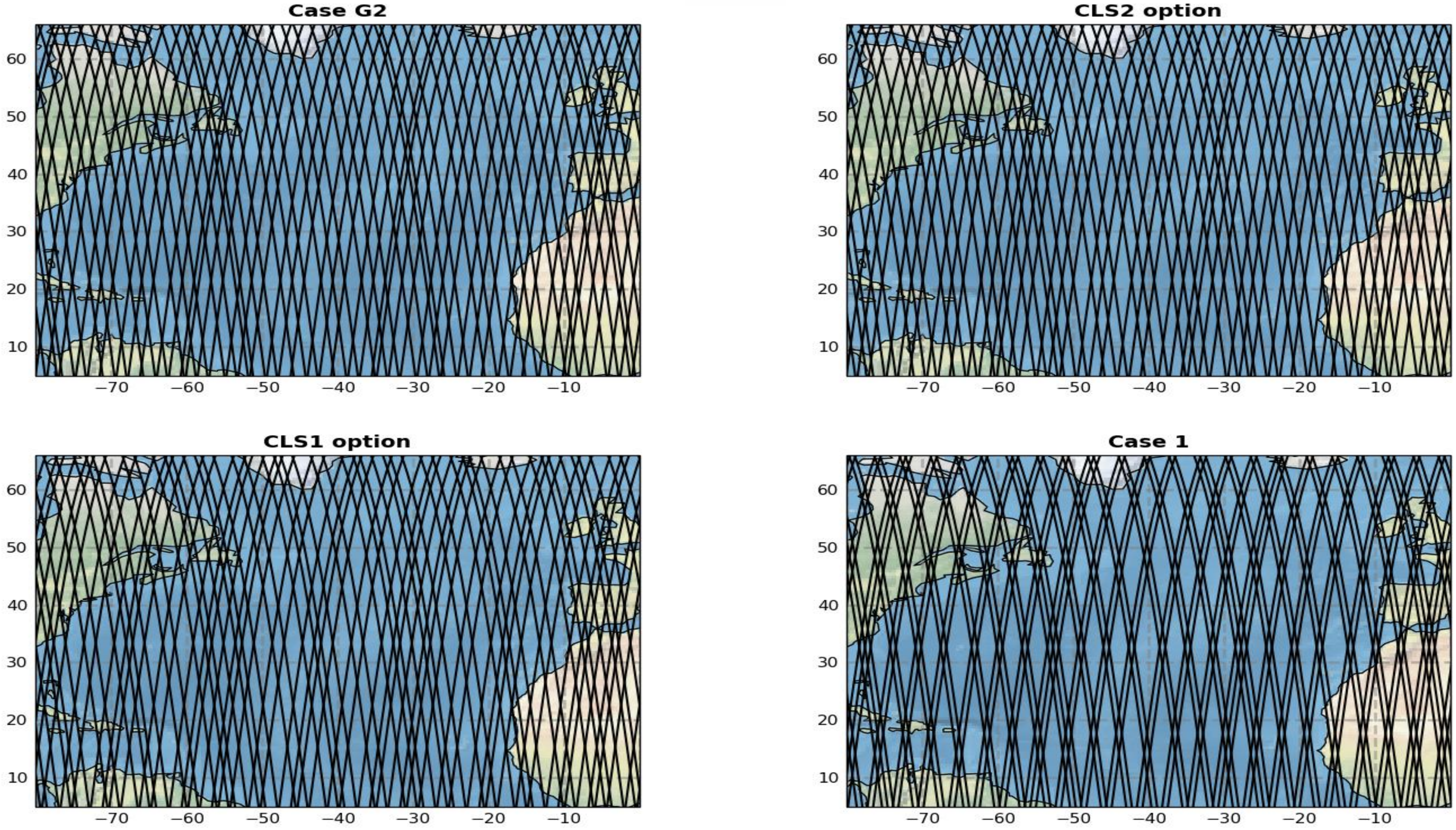
ICESat-2



Case 3



Sampling after 15 days – better cases (except Case-1)

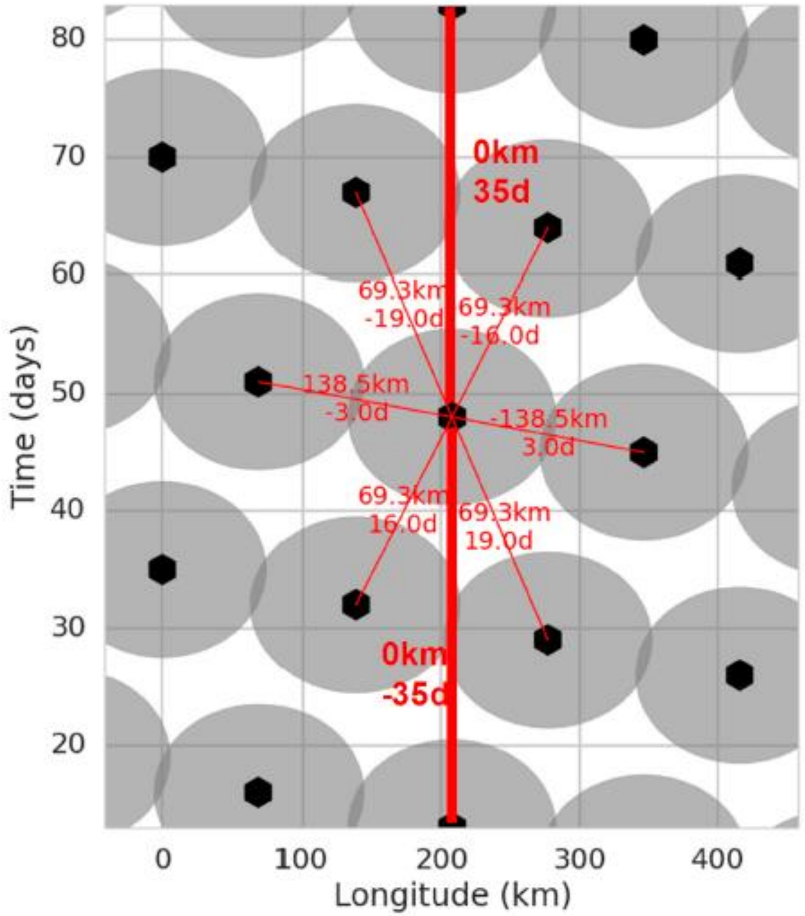


We use the methodology of Dibarboure et al. [2018] to evaluate the orbit candidates wrt oceanic mesoscale sampling capabilities

Directly from the publication:

"Right figure shows the distribution of the satellite tracks for the ***ERS/ENVISAT orbit.*** *Each black dot is one satellite track. The vertical alignment of the black dots corresponds to the 35-day exact repeat cycle of this orbit. The grey circles are 150 km by 15 days. This is an approximation of the decorrelation scale of mesoscale eddies at mid-latitudes."*

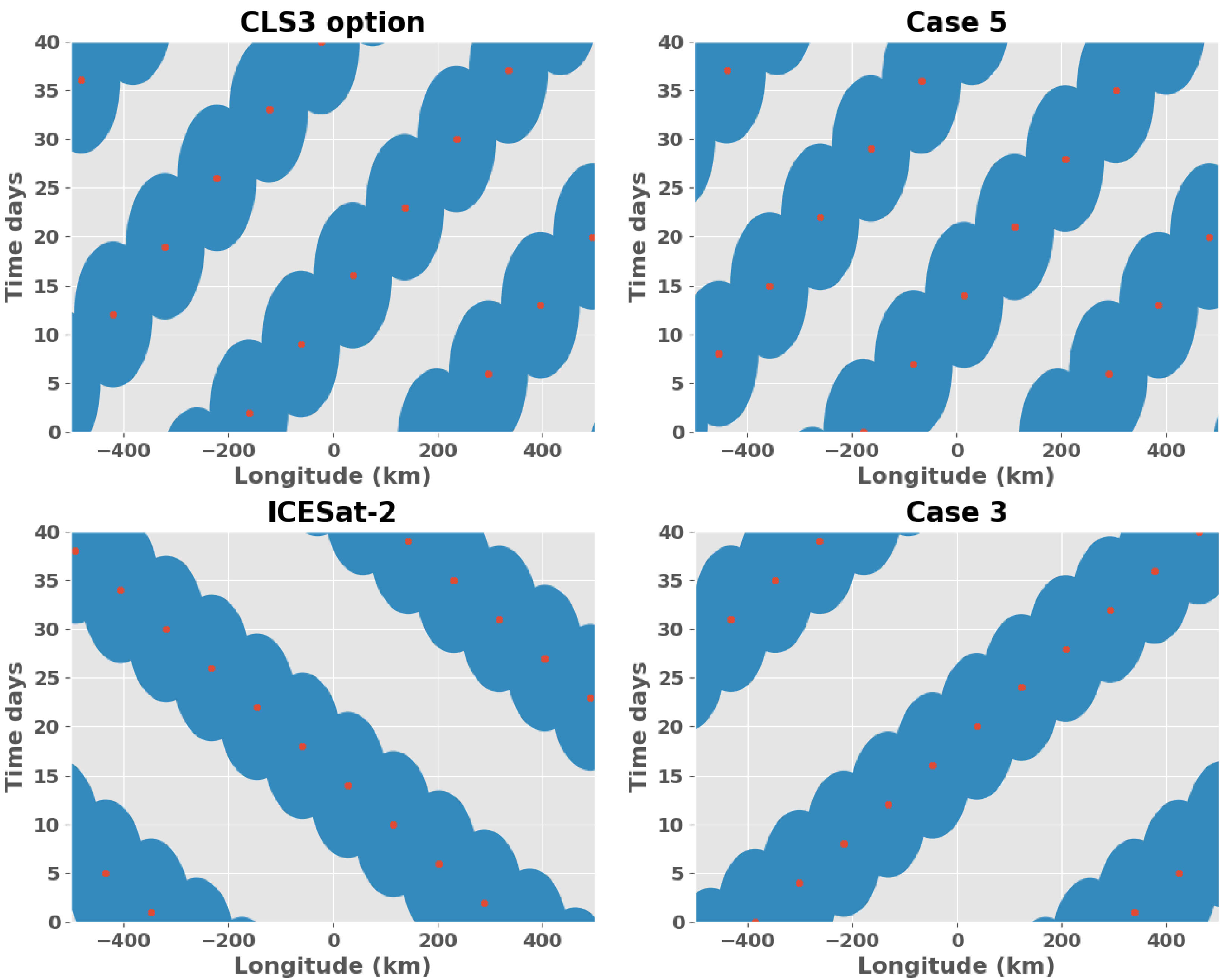
if two grey circles overlap, then the corresponding satellite tracks are too close in space or in time: their measurements are correlated and in turn other regions of the space/time plane are completely unobserved.



Oceanic mesoscale assessment

- Each red marker displays a single satellite track, computed here at 30°N
- blue circles are 150 km by 15 days, ~decorrelation scale of mesoscale eddies at mid-latitudes
- if two circles overlap, then the altimetry measurements are correlated in space/time

None of these orbits are adapted for oceanic mesoscale sampling. Case-3 & ICESat-2 being the worst.



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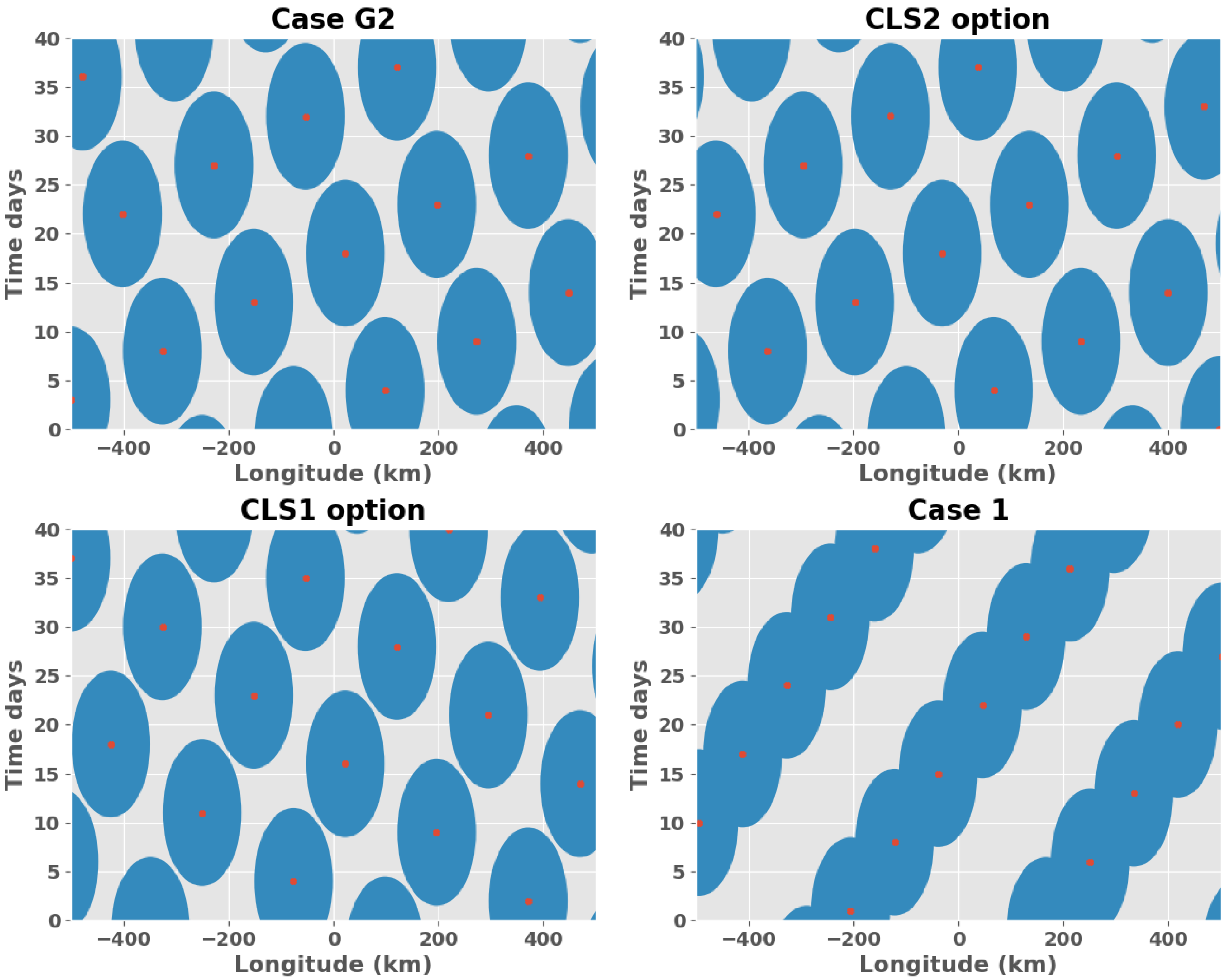
Case G2, CLS1, CLS2 optimal for oceanic mesoscale

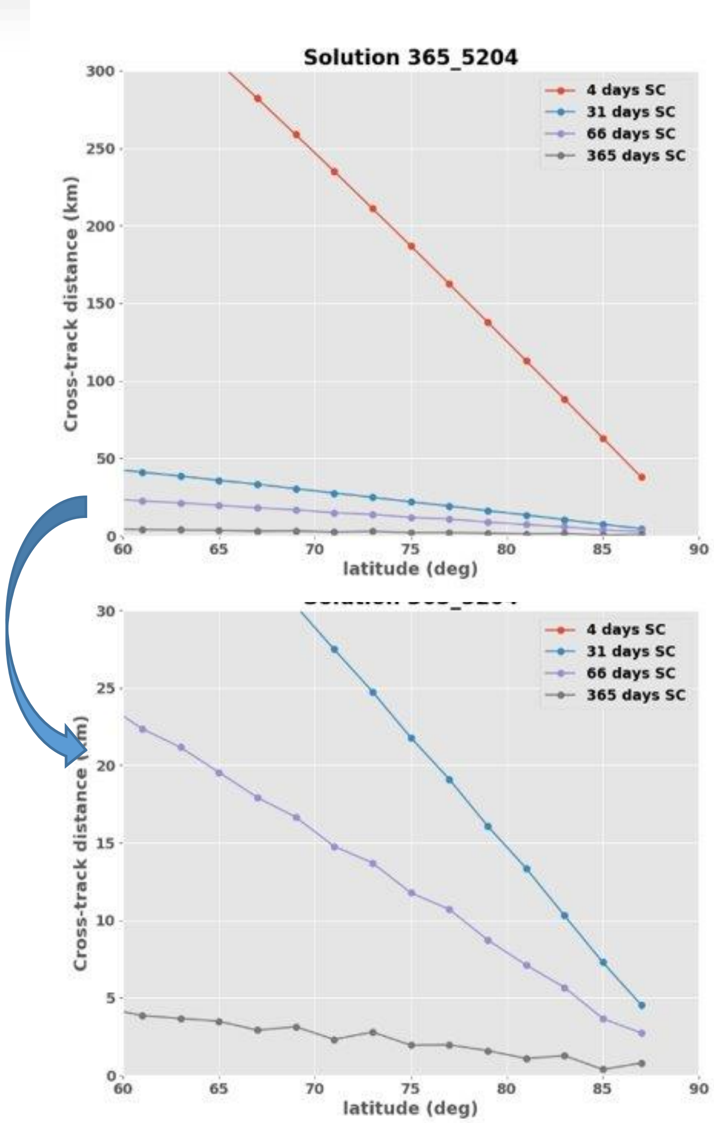


Polar mesoscale

- Oceanic eddies get smaller & faster with latitude because Coriolis force increase. **Typical eddy radius is 5 - 15km over polar ocean**. Two grid-points per eddy radius necessary to 'resolve' eddies adequately, one grid-point to 'permit' them [Timmermans et al., 2007 ; Nurser & Bason, 2014]

- Right figures show the across-track distance between tracks, as function of latitude, for each sub-cycle of Case-5 (taken as example). Bottom figure is a zoom to look more specifically at the small across-track distances

- **Except for extreme high latitudes, only a yearly (sub)-cycle is capable to reach these spatial scales (5-15km).** The strategy for polar ocean must be to consider CRISTAL as part of a global constellation.



Polar mesoscale strategy from G.Dibarboure

- Achievable sampling goals
    1. To collect independent (decorrelated) L3 measurements every 1 to 5 days for CMEMS model assimilation
    2. To assemble low spatial resolution L4 maps for rapid signals (e.g. 2 to 3 days)
    3. To collect denser homogeneous (albeit insufficient) sampling for slower eddies in bimonthly to monthly maps
    - Compatible with glaciology orbit requirements

- Goals #2 and #3 should be discussed with CMEMS
    - Finding sample orbits with these properties is simple
    - But product interest should be confirmed (e.g. not done routinely with CryoSat-2)

- In practice for CRISTAL orbit
    - **First sub-cycle : 2 to 4 days** (also useful for assimilation of SWH in wave models anyway)
    - **Second sub-cycle : ~15 days** (also useful for global mesoscale anyway)
    - **Third sub-cycle : ~30 days** (also useful for other monthly products such as Icebergs anyway)
    - **Other sub-cycles (60 days or more)** can be added
    - Does not constrain the repeat cycle

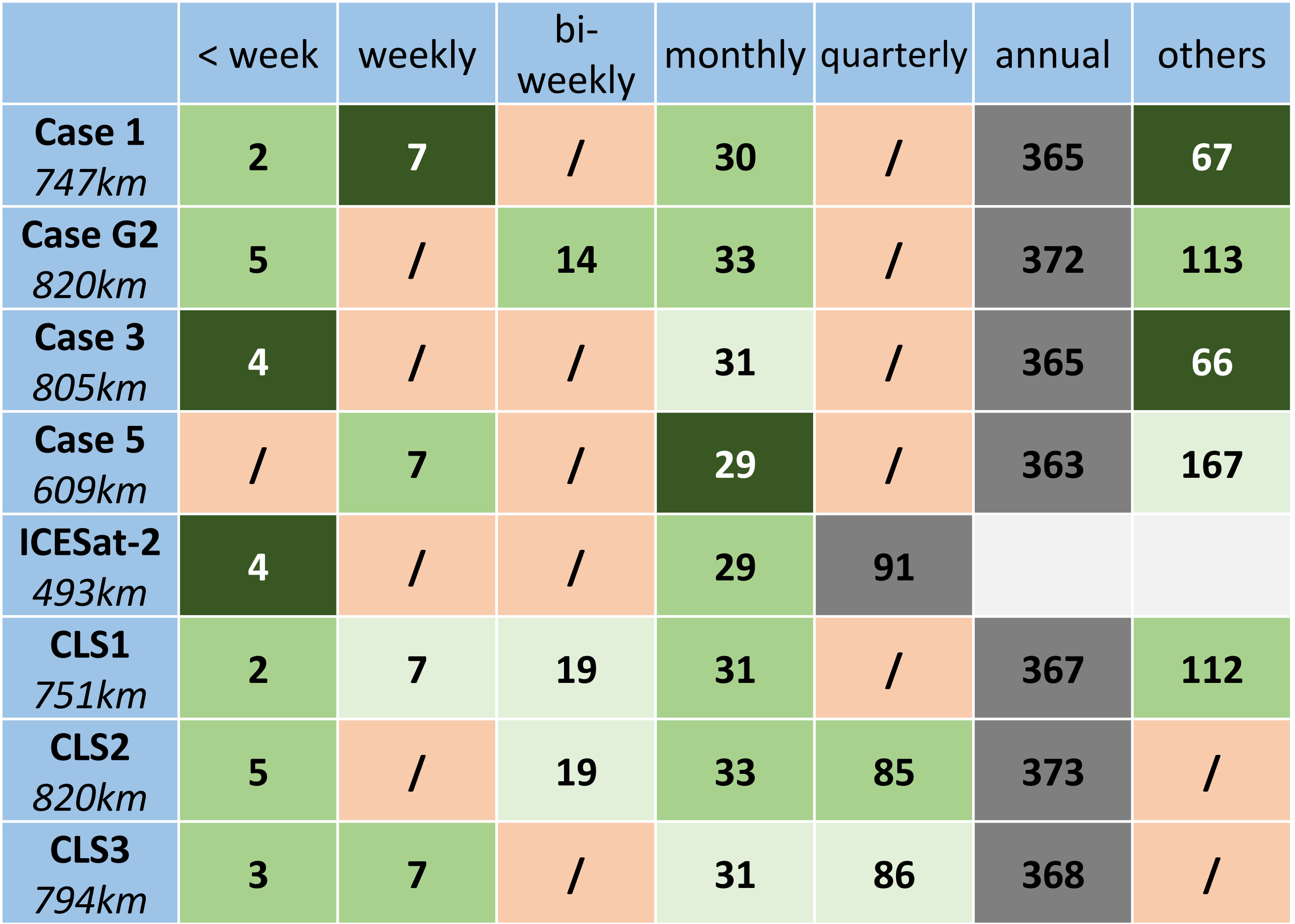
- Possible way forward:
    - Prototype these L4 products (with non-standard R&D Level-3 from CryoSat-2 , or simulated data)
    - Determine if this should be a PIST and/or CMEMS requirement

In practice for CRISTAL orbit

- **First sub-cycle : 2 to 4 days** (also useful for assimilation of SWH in wave models anyway)
- **Second sub-cycle : ~15 days** (also useful for global mesoscale anyway)
- **Third sub-cycle : ~30 days** (also useful for other monthly products such as Icebergs anyway)
- **Other sub-cycles (60 days or more)** can be added

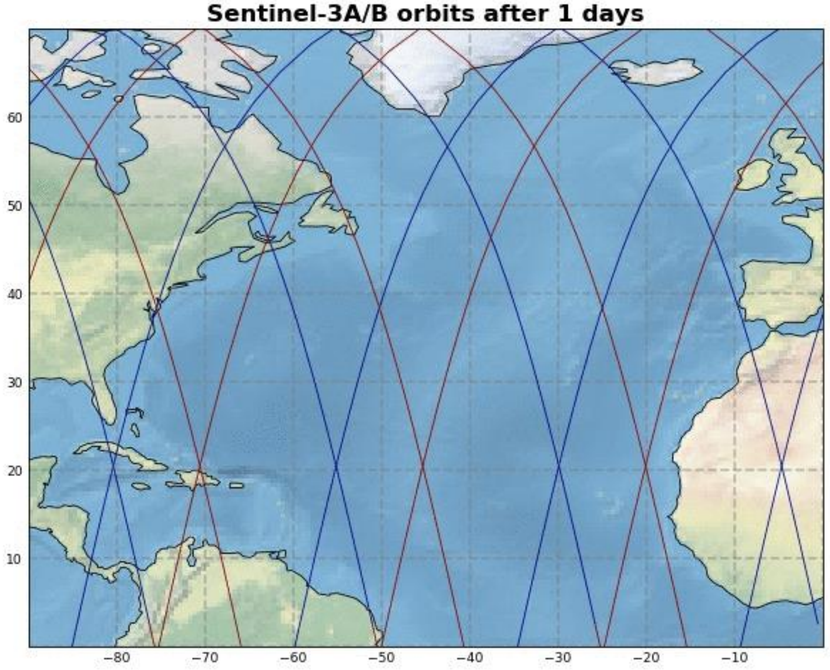
Evaluation of orbit candidates

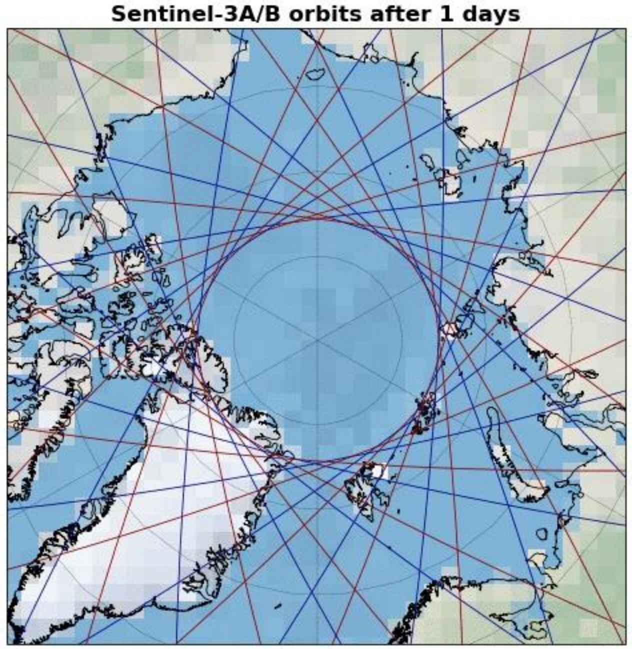
- ➢ **Sub-optimal: G2 , CLS1 & CLS2** (bi-weekly sub-cycle)
- ➢ **Average: Case-1 ; CLS2 ; Case-3 ; ICESat-2** (no bi-weekly sub-cycle)
- ➢ **Not adapted: Case-5** (no 2-4 days & bi-weekly sub-cycles)

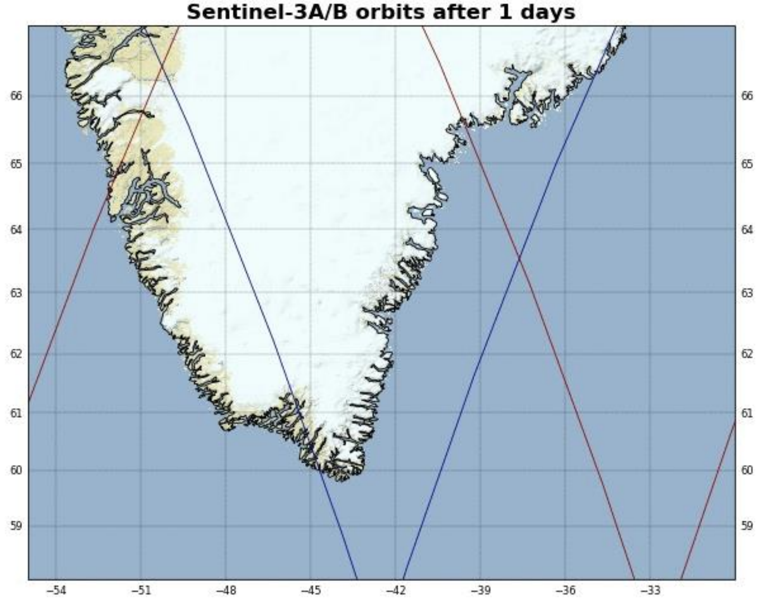


	< week	weekly	bi-weekly	monthly	quarterly	annual	others
Case 1 *747km*	**2**	**7**	**/**	**30**	**/**	**365**	**67**
Case G2 *820km*	**5**	**/**	**14**	**33**	**/**	**372**	**113**
Case 3 *805km*	**4**	**/**	**/**	**31**	**/**	**365**	**66**
Case 5 *609km*	**/**	**7**	**/**	**29**	**/**	**363**	**167**
ICESat-2 *493km*	**4**	**/**	**/**	**29**	**91**		
CLS1 *751km*	**2**	**7**	**19**	**31**	**/**	**367**	**112**
CLS2 *820km*	**5**	**/**	**19**	**33**	**85**	**373**	**/**
CLS3 *794km*	**3**	**7**	**/**	**31**	**86**	**368**	**/**

Complementarity with Sentinel-3X + Sentinel-3Y


Sentinel-3A/B orbits after 1 days


Sentinel-3A/B orbits after 1 days

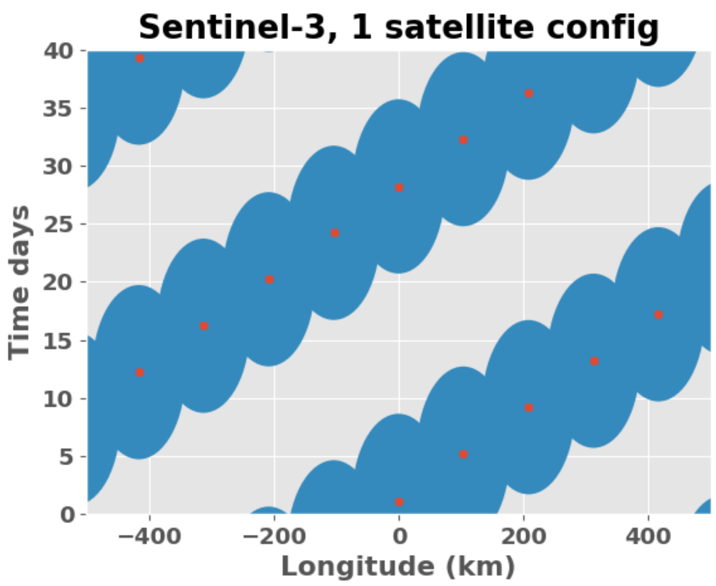

Sentinel-3A/B orbits after 1 days

Sentinel-3A has an inclination of 98.65° (max. latitude = **81.35°).** The orbit reference altitude is 814.5 km (orbit similar to ERS/Envisat to continue the time series).

Sentinel-3B's orbit is identical to Sentinel-3A's orbit but flies +/-140° out of phase with Sentinel-3A

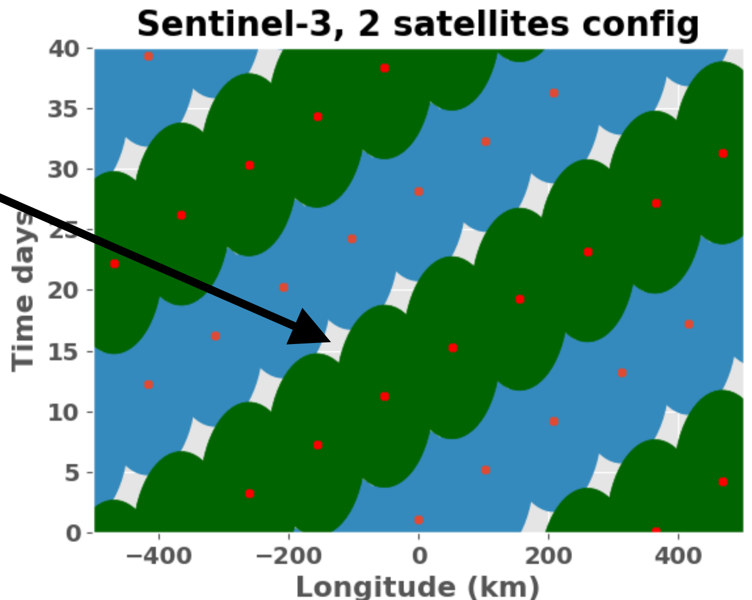
Complementarity with Sentinel-3A for oceanic mesoscale

- **By 2025/2026, we can expect at least 2 Sentinel-3 flying coincidently.**
- **Sentinel-3 orbit is very well optimized for oceanic mesoscale when two missions are operationals.** The tracks are almost perfectly distributed in space & time to avoid correlation between measurement (bottom right figure)



There is still a little room for optimization, but this would require an orbit fully designed for that purpose (out of scope of CRISTAL)

Regarding oceanic mesoscale, recommendation to optimize CRISTAL orbit alone, as presented slides 19-20



Summary table – CRISTAL alone

	Sea-ice	Ice sheets	Ocean	
	Weekly products & ice charting	Monthly + Quarterly products	Polar mesoscale	Global mesoscale
Case-1	optimal	optimal -	average	not adapted
Case G2	optimal -	optimal -	optimal -	optimal
Case-3	optimal -	optimal -	average	not adapted
Case-5	optimal	optimal	not adapted	not adapted
ICESat-2	optimal -	optimal	average	not adapted
CLS1	optimal	optimal	optimal -	optimal
CLS2	optimal -	optimal	optimal -	optimal
CLS3	optimal	optimal	average	not adapted

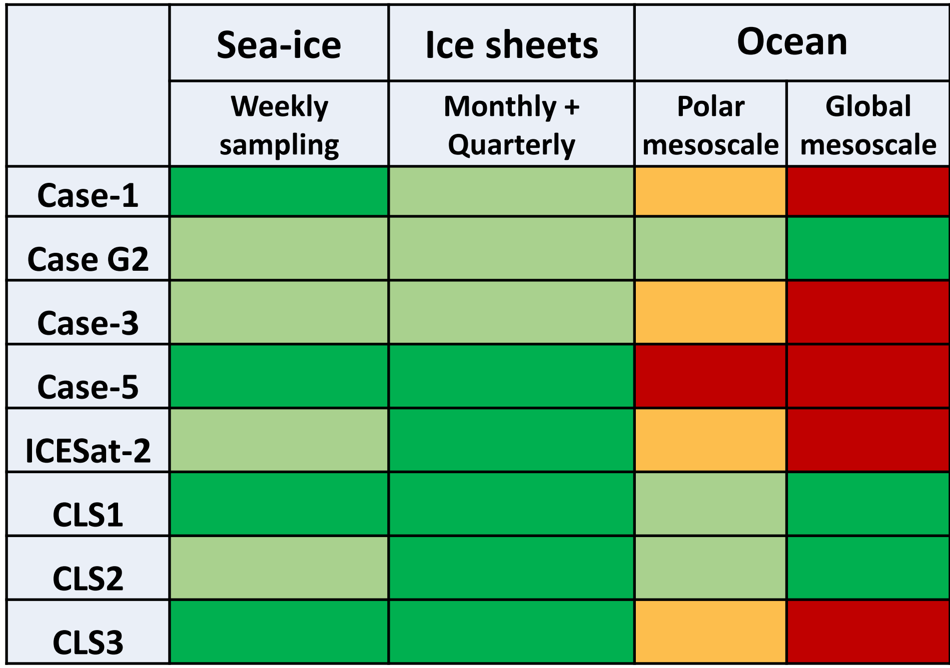
🟩 optimal

🟧 average

🟩 optimal -

🟥 not adapted

Conclusions



	Sea-ice	Ice sheets	Ocean	
	Weekly sampling	Monthly + Quarterly	Polar mesoscale	Global mesoscale
Case-1	🟩	▨	🟧	🟥
Case G2	▨	▨	▨	🟩
Case-3	▨	▨	🟧	🟥
Case-5	🟩	🟩	🟥	🟥
ICESat-2	▨	🟩	🟧	🟥
CLS1	🟩	🟩	▨	🟩
CLS2	▨	🟩	▨	🟩
CLS3	🟩	🟩	🟧	🟥

- ➢ Overall all orbit candidates are well designed to address mission requirements over ice surfaces.

- ➢ **<u>For sea-ice</u>, best candidates are Case-1 ; Case-5 ; CLS1 & CLS3,** thanks to the 7 days sub-cycle

- ➢ **<u>For ice-sheets</u>, best candidates are Case-5 ; ICESat-2 ; CLS1 ; CLS2 ; CLS3**
  - ⇒ Best adapted to monthly & quarterly sampling: **ICESat-2**
  - ⇒ With a yearly sub-cycle:
    - ⇒ Case-5 most performant for monthly sampling
    - ⇒ CLS1**,** CLS2, CLS3 very close with a better quarterly sampling

- ➢ **<u>For ocean,</u> Case G2 ; CLS1 & CLS2 are the best candidates. Case-5 is the worst.**

  (more time necessary to refine polar mesoscale strategy & potentially look at tide aliasing)

- ➢ We remind these analyses do not account for technical feasibility (station visibility, altitude conflicts…) that must be checked

Trade-off considerations – open questions

sampling after 15 days

- **When Sentinel-3 is added in the analyses, all the candidates are optimal for** **ice sheet & sea ice surfaces,** which is good news! *Nevertheless is that adequate to consider that CRISTAL & S3 will be complementary over cryosphere surfaces regarding the improvements bring by CRISTAL ? (Ku/Ka, SARIn)*

- **For ice-sheets should we prioritize monthly sampling wrt quarterly sampling**?
  - ☐ Case-5 has the most performant monthly sampling, but the worst quarterly sampling
  - ☐ CLS1 ; CLS2 ; CL3 have a better quarterly sampling, and are very close to Case-5 for monthly sampling

- **Do we need a 4 days sub-cycle, and for what purposes?**
  - ☐ If yes and if we consider a 5 days sub-cycle remains suitable for sea-ice, CLS2 & G2 are good trade-offs

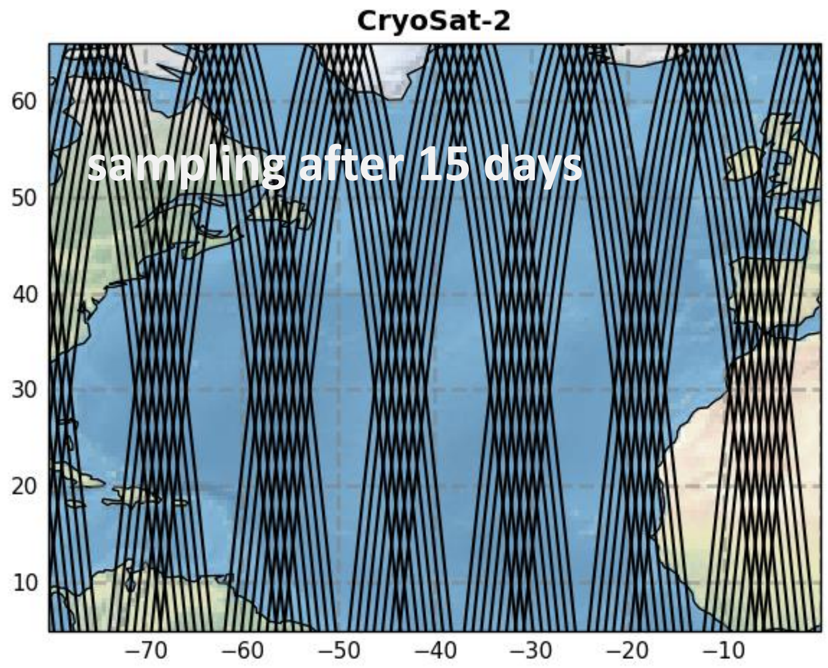
- **If we want to make a trade-off with ocean (global & polar),** then CLS1, CLS2 & G2 are the possible options. **Case-5 has clearly to be avoided (cryosat like).**

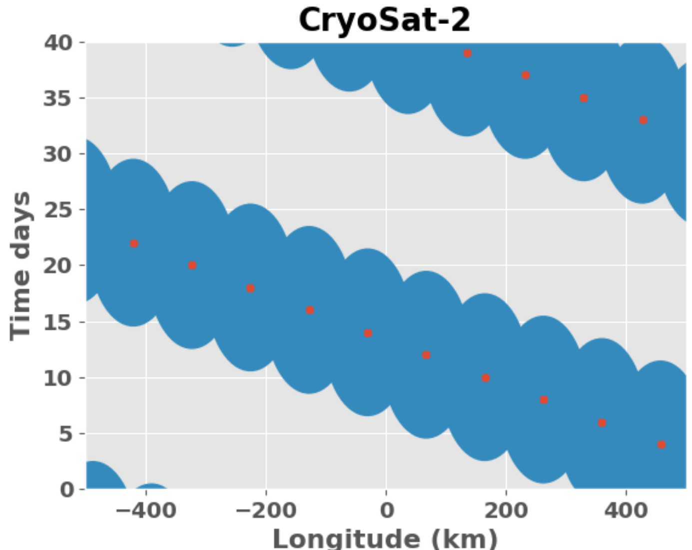
BACK UP

Oceanic sampling capabilities of CryoSat-2

- CryoSat-2 sub-cycles are 2, 29, 85 & 369 days. CryoSat-2 lacks a bi-weekly sub-cycle for the oceanic mesoscale

- On the other hand the yearly geodetic orbit is highly valuable for resolving **Mean Sea Surface (MSS)** over the open & polar ocean, which in the end is useful for all the other altimetry missions (as Sea Level Anomaly (SLA) is relative to MSS)





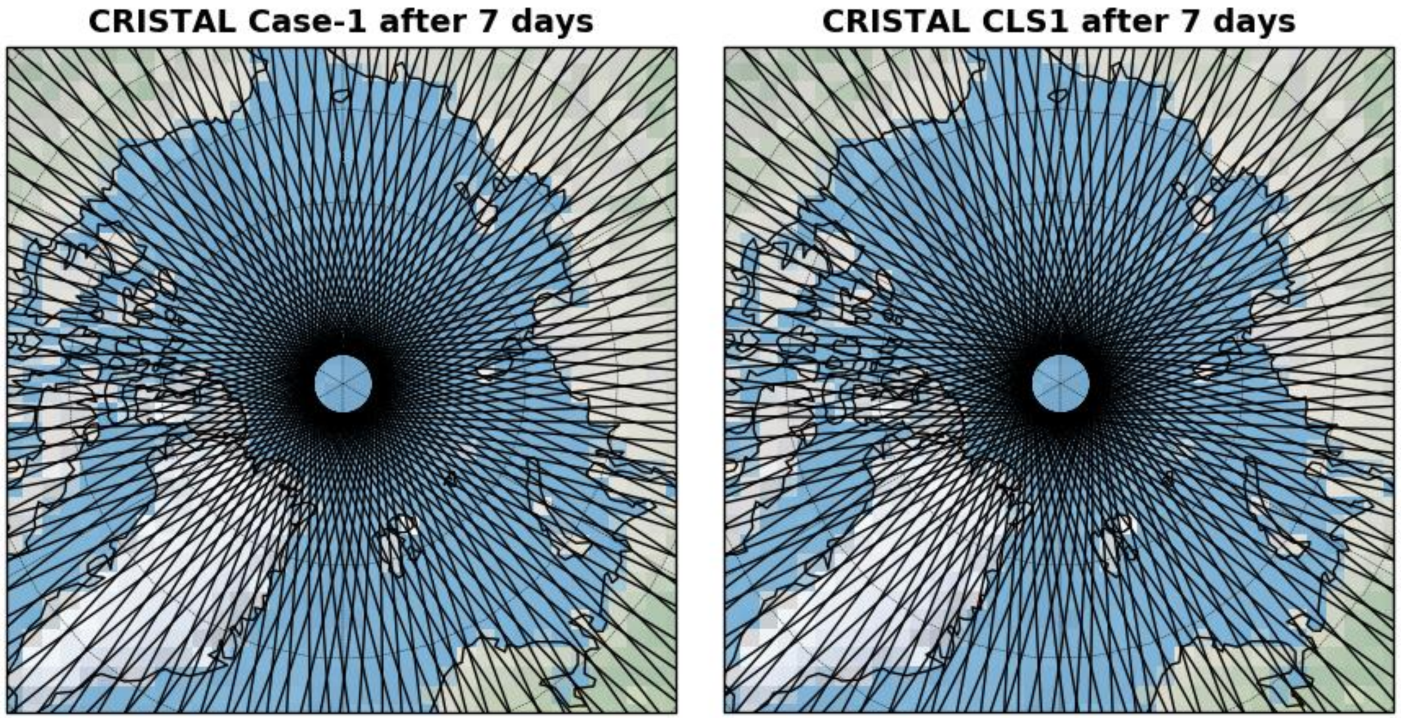
Sub-cycle sampling differences

- Case-1 & CLS1 are two close orbits, both having a 7 days sub-cycle

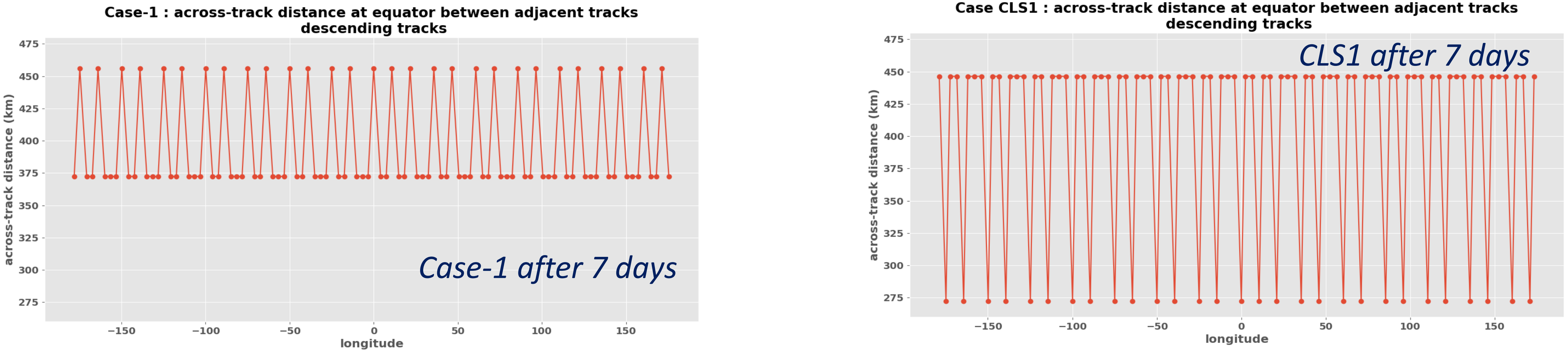
- But the sampling homogeneity is not completely identical. Visually Case-1 pattern is more uniform.

- Across-track distance between adjacent tracks is more “stable” with Case-1: it ranges between **372km – 456 km** VS **272km – 446 km** for CLS1**.**

- But CLS1 brings others benefits : among them a 19 days sub-cycle.



Sub-cycle sampling differences



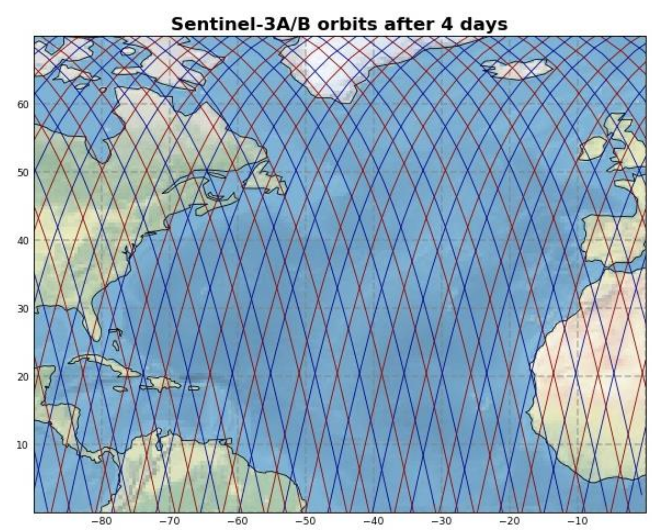
Across-track distance at equator between adjacent tracks, as function of longitude, after 7 days for Case-1 (left) & CLS1 (right)

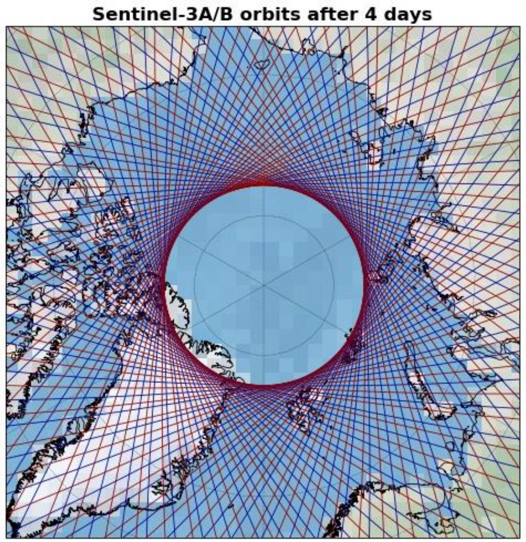
- The mean equatorial across-track distance is almost the same for both orbits, but the distribution of these distances is not. Much more variations with CLS1 ranging from **272km – 446km** VS **372km – 456 km** for Case-1.
- To account for this sampling homogeneity difference between sub-cycles, we defined a “homogeneity ratio” for each sub-cycle => *ratio between maximum/minimum across-track distance, and referred as “**sampling-ratio**” thereafter.*
- **Case-1 sampling-ratio is 1.23 ; CLS1 sampling-ratio is 1.64 (for the 7 days sub-cycle)**

Discussions around Sentinel-3 complementarity for polar mesoscale (& cryosphere)

- **Sentinel-3 constellation provides a rapid homogeneous sampling thanks to the 4 days sub-cycle** (*~400km average across-track resolution with 2 Sentinel-3)*
- Shall we also seek for a 4 days sub-cycle ?

More time needed to look at potential Moiré patterns for each orbit cases



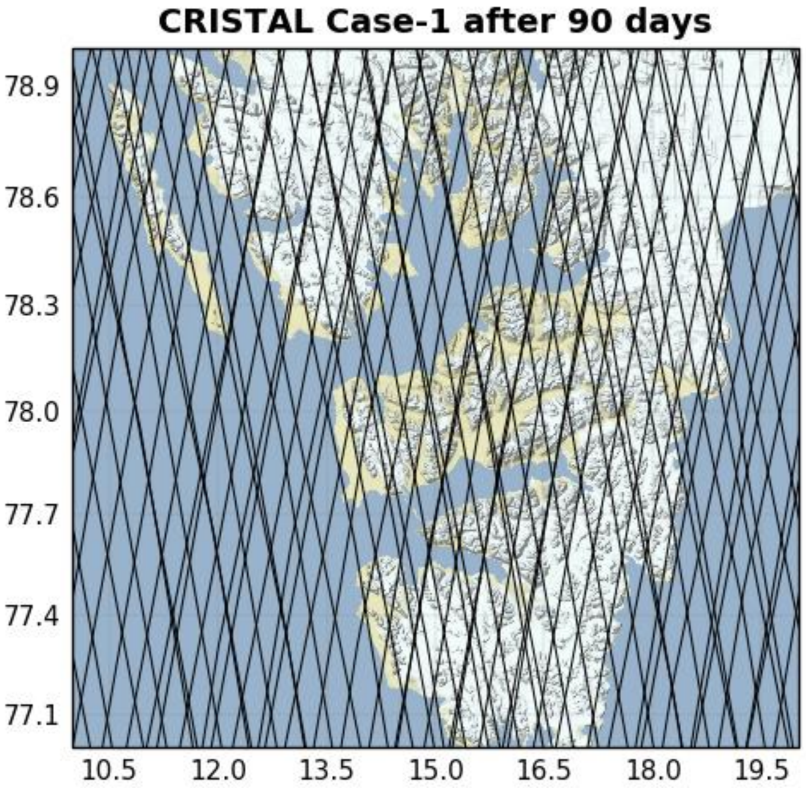


Summary table

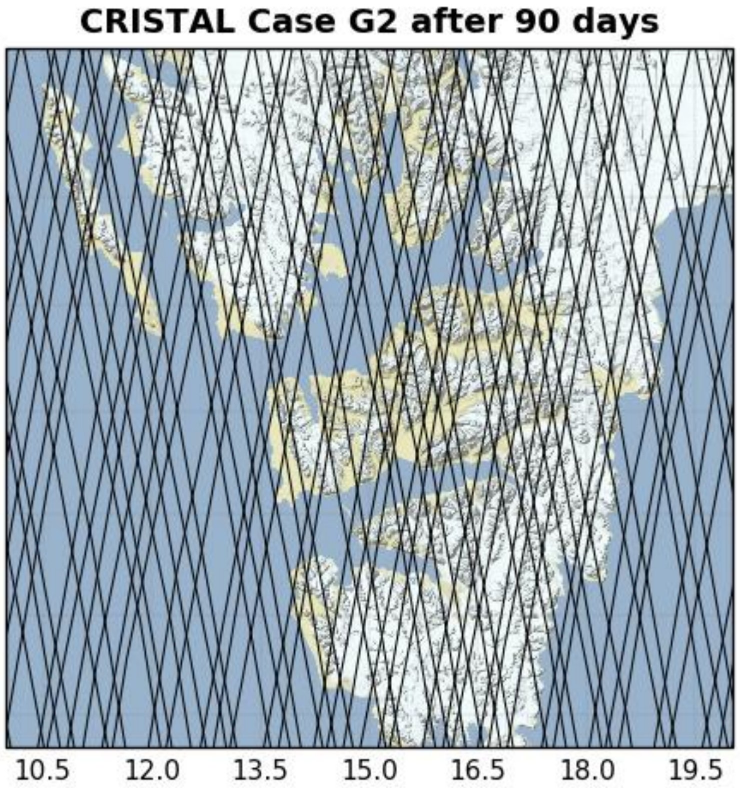
	< week	weekly	bi-weekly	monthly	quarterly	annual	others
Case 1 *747km*	**2** *[1201 - 1572]*	**7** *[372 - 456]*	**/** *[84 - 372]*	**30** *[84 - 122]*	**/** *[8 - 46]*	**365**	**67** *[38 - 46]*
Case G2 *820km*	**5** *[598 - 424]*	**/** *[174 - 598]*	**14** *[174 - 250]*	**33** *[76 - 98]*	**/** *[23 - 53]*	**372**	**113** *[23- 30]*
Case 3 *805km*	**4** *[638 - 723]*	**/** *[85 - 638]*	**/** *[85 - 469]*	**31** *[46 - 85]*	**/** *[7 - 46]*	**365**	**66** *[38 - 46]*
Case 5 *609km*	**/**	**7** *[371 - 467]*	**/** *[96 - 275]*	**29** *[82 - 96]*	**/** *[15 - 67]*	**363**	**167** *[14 - 22]*
ICESat-2 *493km*	**4** *[635 - 722]*	**/** *[87 - 635]*	**/** *[86 - 462]*	**29** *[87 -115]*	**91**		
CLS1 *751km*	**2** *[1165 - 1611]*	**7** *[272 - 446]*	**19** *[98 -174]*	**31** *[76 - 98]*	**/** *[23 - 53]*	**367**	**122** *[23 - 30]*
CLS2 *820km*	**5** *[430 - 597]*	**/** *[166 - 597]*	**19** *[98 -166]*	**33** *[68 - 98]*	**85** *[30 - 38]*	**373**	**/**
CLS3 *794km*	**3** *[814 - 1172]*	**7** *[358 - 457]*	**/** *[99 - 358]*	**31** *[61 - 99]*	**86** *[23 - 38]*	**368**	**/**

[min – max] equatorial across-track distance indicated in brackets

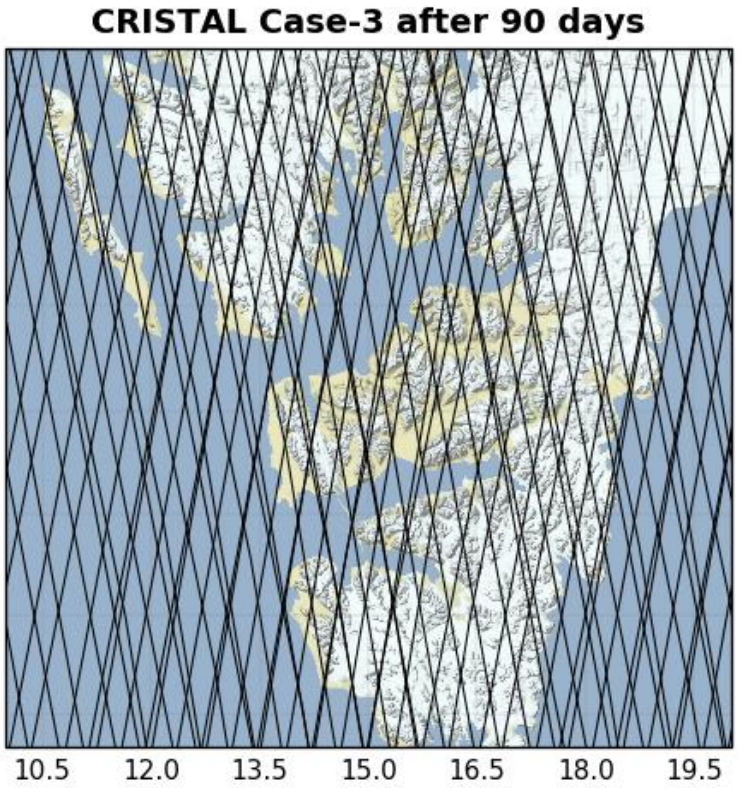
Quarterly sampling (90 days)



Min-Max inter-track distance at equator (km)
[8 - 46]

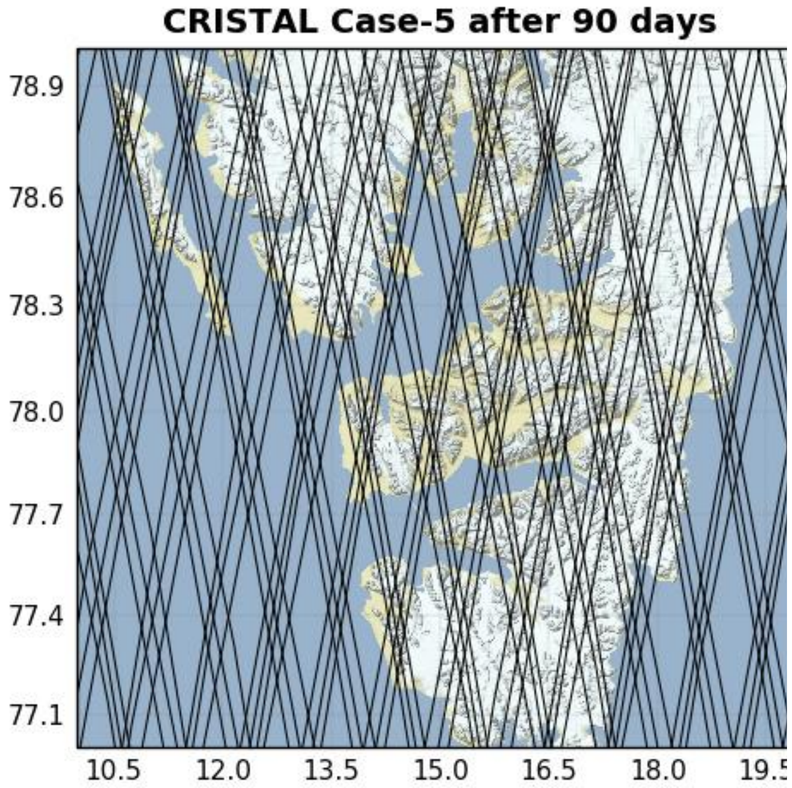


Min-Max inter-track distance at equator (km)
[23 - 53]



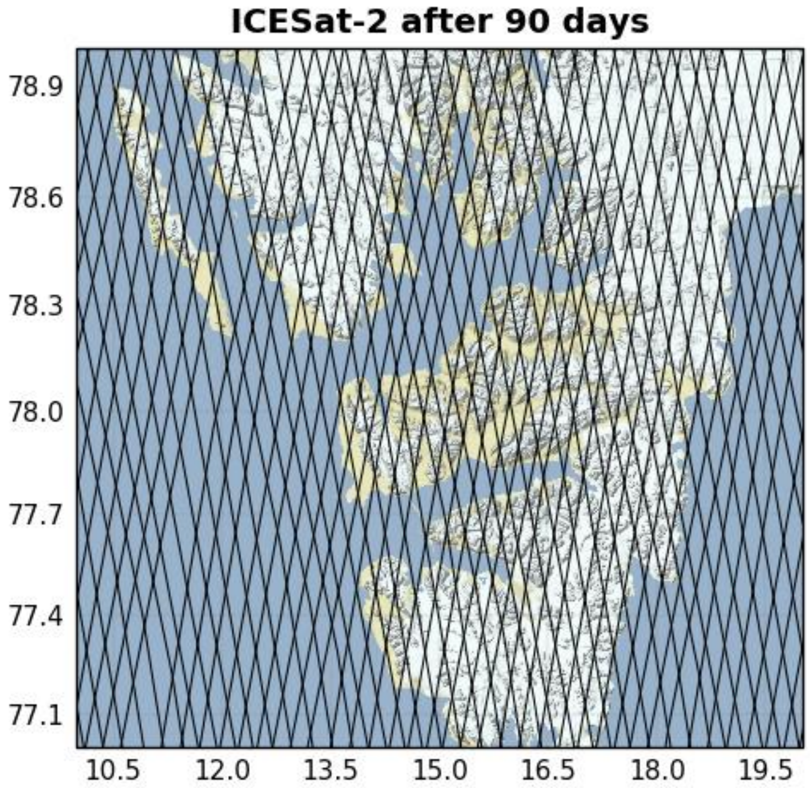
Min-Max inter-track distance at equator (km)
[7 - 46]

Quarterly sampling (90 days)



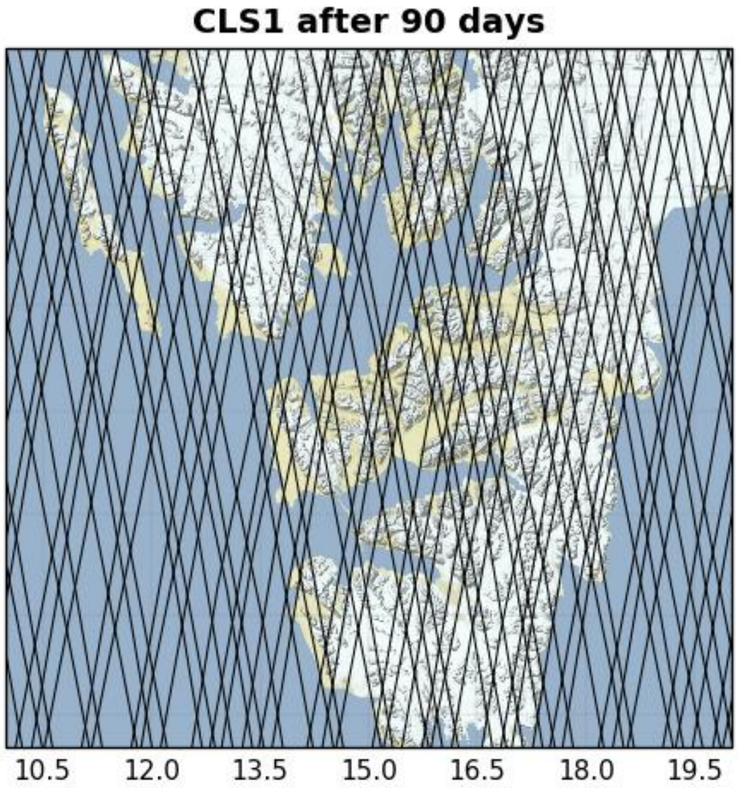
CRISTAL Case-5 after 90 days

Min-Max inter-track distance at equator (km)
[15 - 67]



ICESat-2 after 90 days

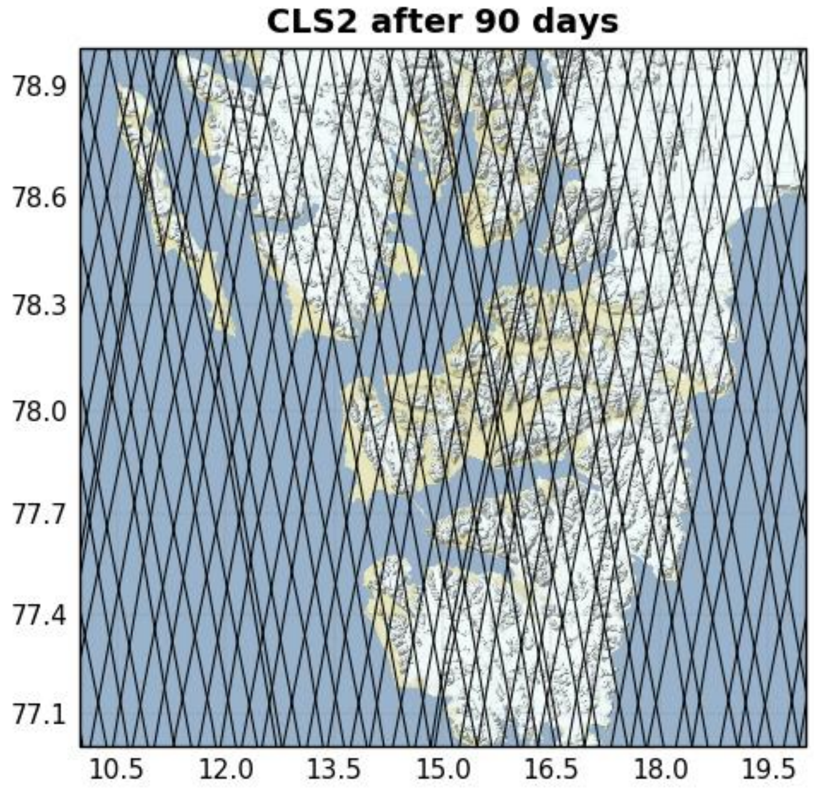
inter-track distance at equator (km)
29km
Cycle after 91days



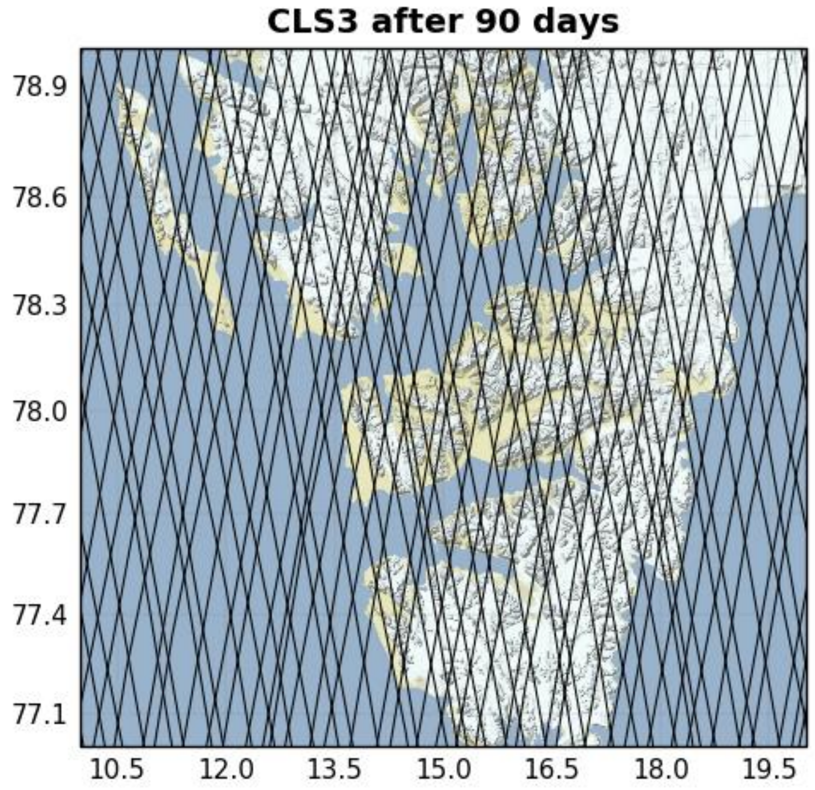
CLS1 after 90 days

Min-Max inter-track distance at equator (km)
[23 - 53]

Quarterly sampling (90 days)



Min-Max inter-track distance at equator (km)
[30 - 38]
Subcycle after 85 days



Min-Max inter-track distance at equator (km)
[23 - 38]
Subcycle after 86 days