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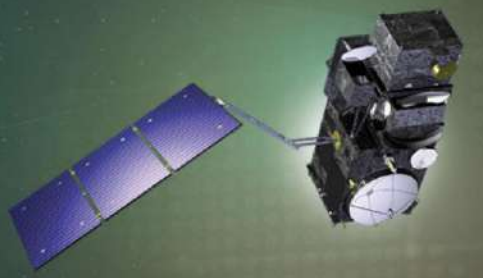

7th Sentinel-3 Validation Team Meeting 2022

18-20 October 2022 | ESA-ESRIN | Frascati (Rm), Italy

Sentinel-3 status and performance over ocean

F. Nencioli[1], E. Cadier[1], P. Prandi[1], P. Femenias[2], B. Lucas[3] and C. Nogueira-Loddo[3]

[1] Collecte Localisation Satellites, [2] ESA, [3] EUMETSAT

Overview

Regular monitoring of Sentinel-3 Surface Topography Mission (STM) performance over the oceans

Guaranteed from beginning of S3A mission to present by two distinct projects:

- S3-MPC (until December 2021)
- COPAS (from May 2022)

The monitoring activities in both projects includes:

- Calibration and characterization of S3 altimeter (SRAL) and microwave radiometer (MWR) performance
- Validation of the ground processing and final products
- Assessment of the overall mission performance
- Support for the continuous improvement of the S-3 STM performance

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Assessment of the overall mission performance

Analysis based on latest processing baseline => Currently **SM_WAT.005.01**

Comparison between SARM/PLRM modes and S3A/S3B/J3/S6 satellites

- **Data Availability**
  - Missing and edited measurements
- **Cal/Val results**
  - Focus on main geophysical variables => Sigma0, SWH, Wind, SLA
  - Global maps => Assess spatial distribution of anomalies
  - Full mission time-series => Identify drifts and anomalies
- **STM Error budget**
  - Different types of errors (sources and scales)
    - High-frequency
    - Low frequencies
    - Long-term trends

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Cyclic reports

Up to S3A cycle 78 and S3B cycle 59

https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-altimetry/data-quality-reports

From S3A cycle 79 and S3B cycle 60

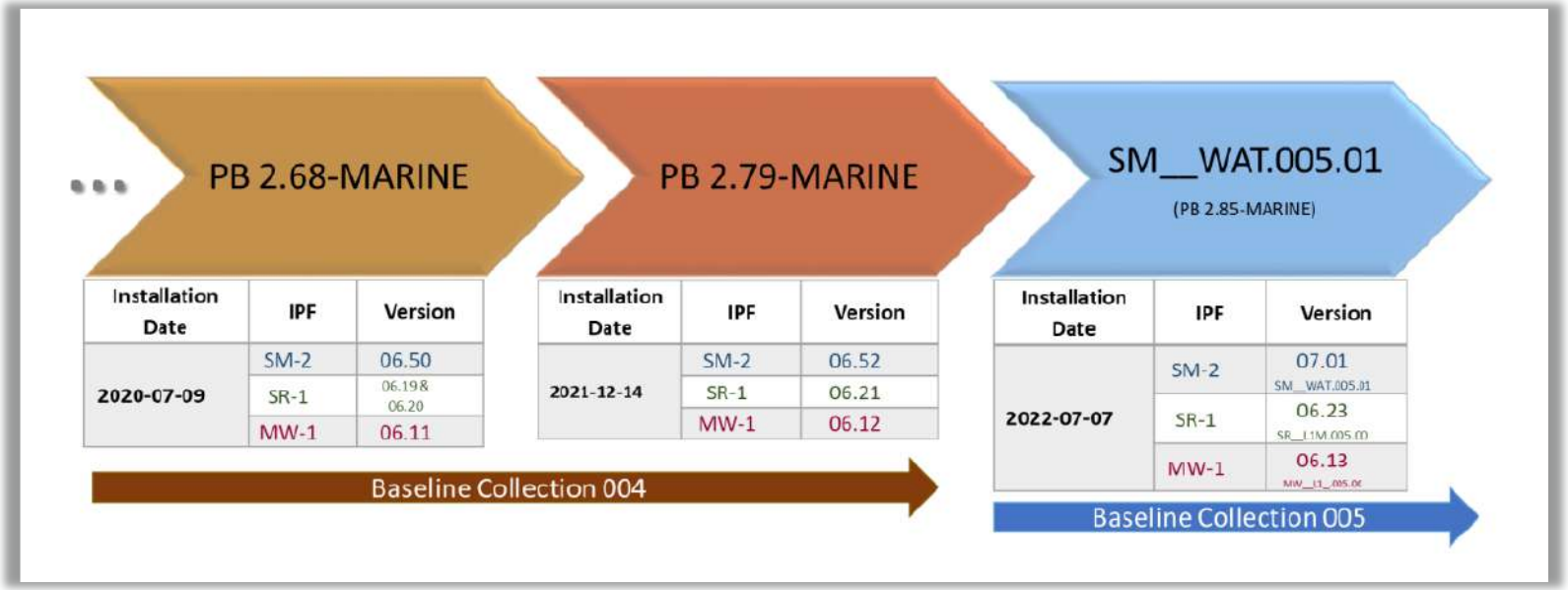
https://eumetsatspace.atlassian.net/wiki/spaces/PQ/pages/1828126721/Sentinel-3+cyclic+reports

S3MPC STM Error Budget

https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-altimetry/document-library

Processing baseline SM__WAT.005.01

- First PB of the new Baseline Collection 005 (BC 005)
- Deployed on 7 July 2022 (S3A cycle 86 pass 397; S3B cycle 67 pas 111)
- Before that Baseline Collection 004 (included PB 2.61, PB 2.68 Marine, and PB 2.79 Marine)
- PB name now contains all the changes for both L1 and L2



New naming convention

- SM__WAT.005.01.00 (SRAL/MWR L2 Marine)
- SR__L1M.005.00.00 (SRAL L1 Marine)
- MW__L1_.005.00.00 (MWR L1 Global)

https://www.eumetsat.int/new-sentinel-3-altimetry-processing-baseline-collection-005

Processing baseline SM_WAT.005.01

Updates to the SSHA

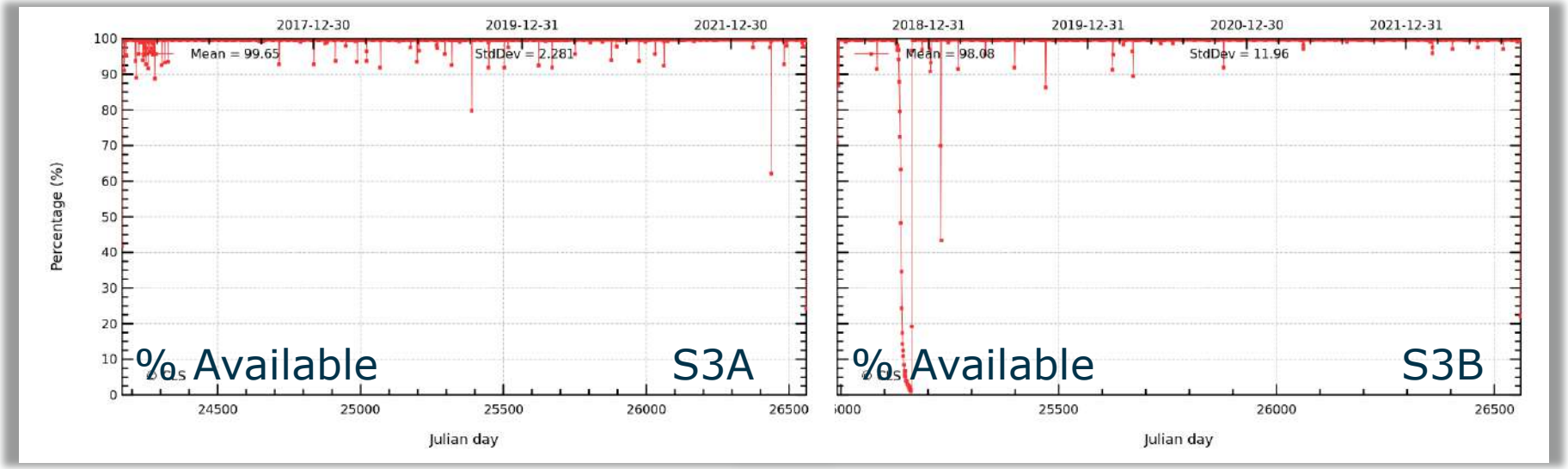
- New Mean Sea Surfaces (Combined MSS, CNES/CLS15, SIO, DUT15 new default MSS)
- New Pole Tide solution (Desai 2017).
- Internal tides and long tide non-equilibrium now applied to calculate SSHA.
- New Sea State Bias (Tran 2021) derived from S3A SAR/PLRM for Ku-band.
- Real Zero Masking from L1B data applied at SAR L2 (all timeliness).
- Range Walk (applied at SAR L1, only NTC).
- No-more (land-)ice variables being generated by Marine products.

➢ Impact on several SAR variables (e.g. SWH, wind and SSHA)

➢ Full mission reprocessing underway

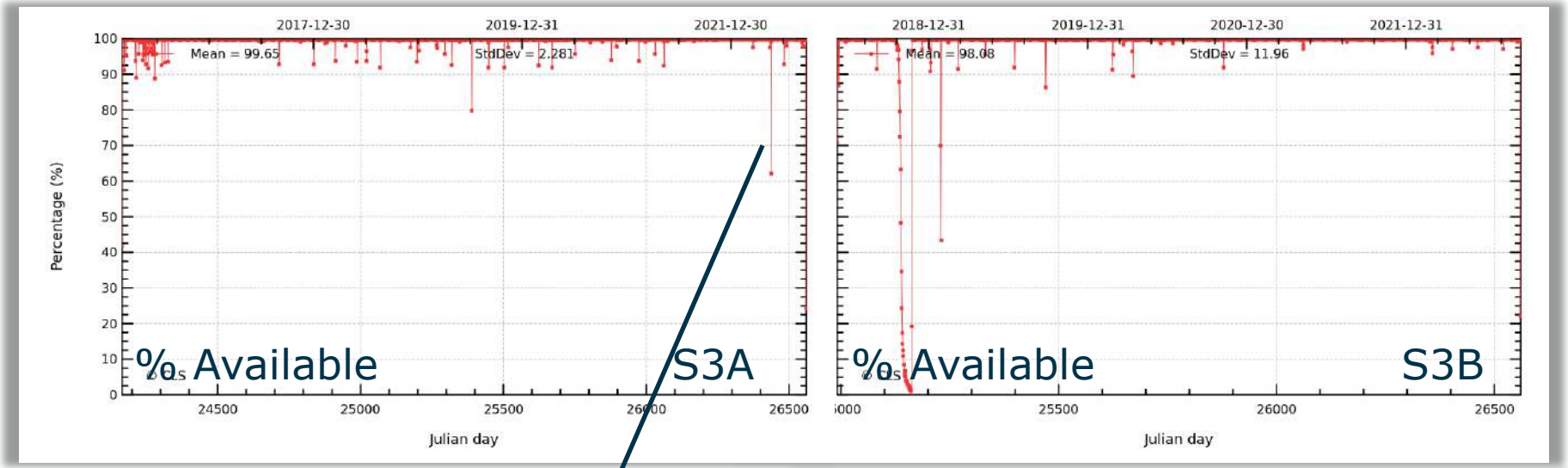
https://www.eumetsat.int/new-sentinel-3-altimetry-processing-baseline-collection-005

Data Availability: Missing Measurements

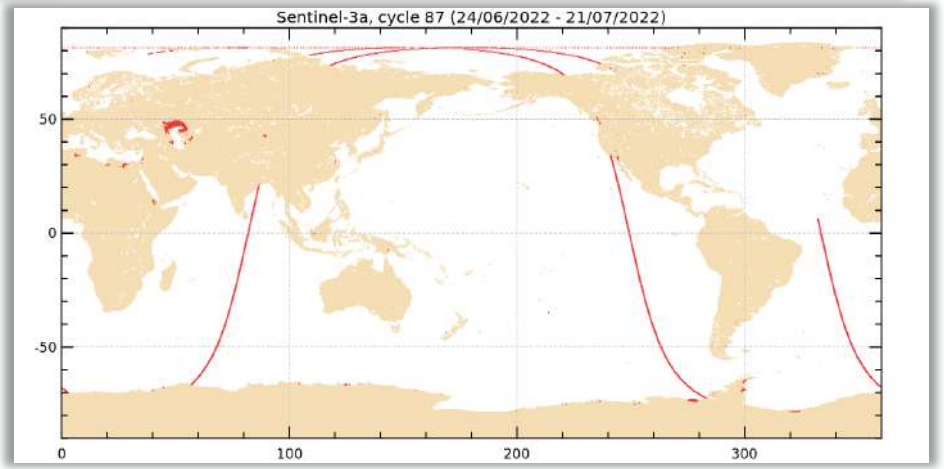


- Good measurements coverage/availability
- Occasional events with large loss of data

Data Availability: Missing Measurements



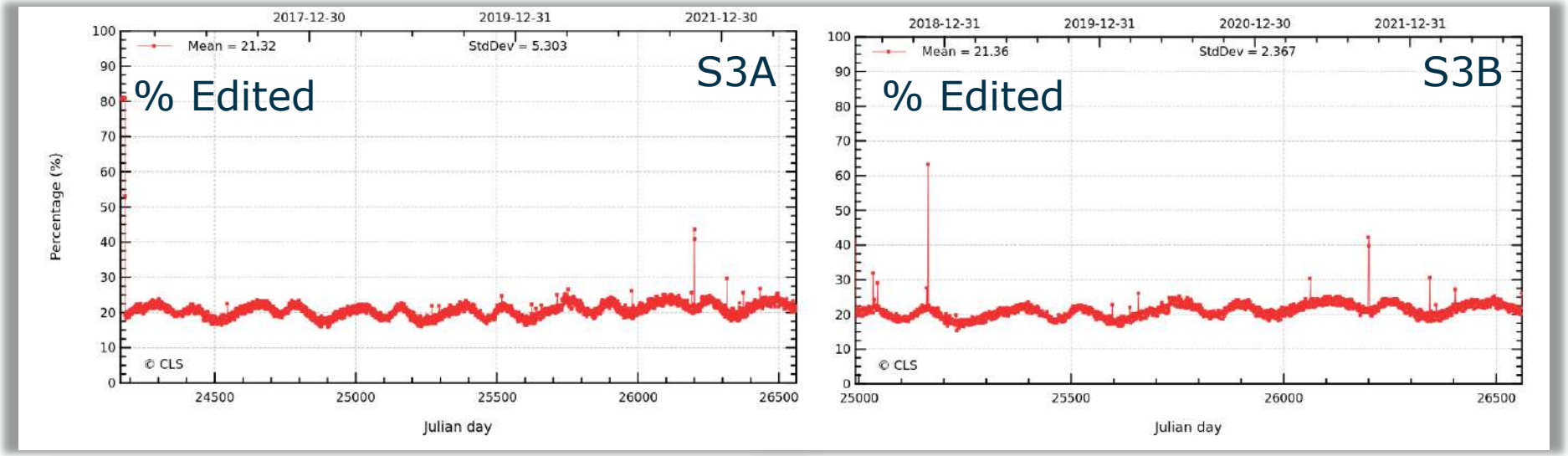
Type:	Service Alert
Ann Nr:	8398
Rev:	2
Start Time:	2022/07/05 03:52
End Time:	2022/07/05 05:47
Satellites:	
Subsystem:	
Component:	
Subject:	ground-segment-anomaly
Impact:	data-unavailable
Detail:	SLSTR data degraded from time 05:47 to 07:28.
Revision History:	[Original] Investigation is ongoing. [Rev.1] Service has been resumed. Impact changed to data unavailable.
Url:	
Orbits:	
Status:	recovered
Issue Time:	2022/07/07 08:34



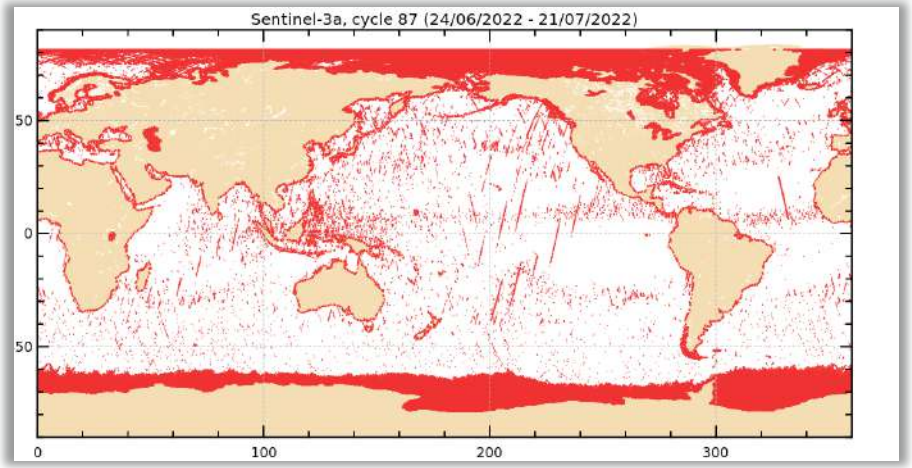
- Good measurements coverage/availability
- Occasional events with large loss of data

- Worst event in the last two years
- Usually ground segment anomalies, satellite maneuvers or spacecraft special operations

Data Availability: Edited Measurements

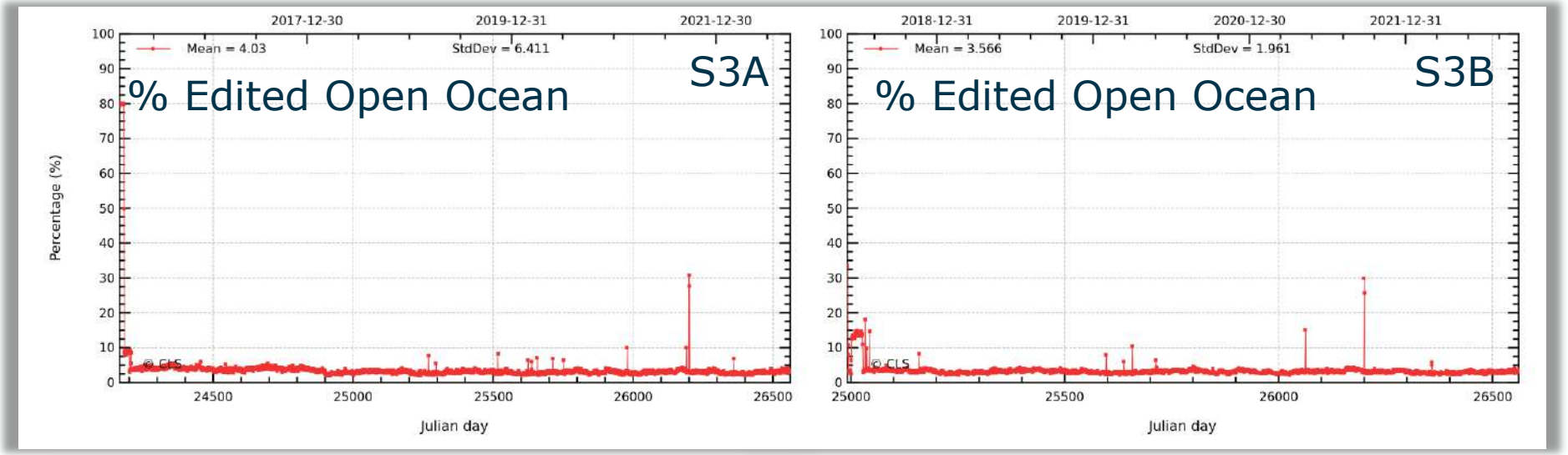


- Discarded available ocean measurements (ice, quality thresholds)

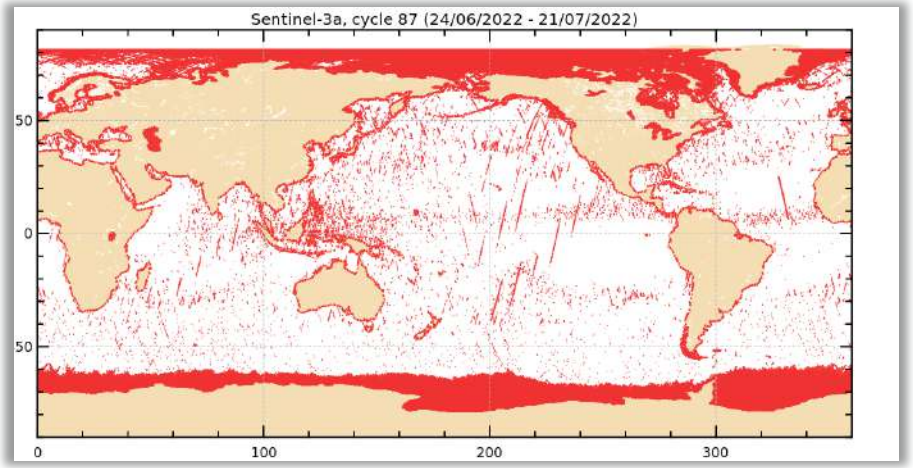


- Edited measurements mostly in polar regions
- Over ocean mostly due to swell and rain events
- Consistency between Sentinel-3A and 3B
- Percentage of edited measurements between 25 and 14 %
- Occasional larger edited events

Data Availability: Edited Measurements



- Discarded available ocean measurements (ice, quality thresholds)
- ~3 to 5% of open ocean measurements edited



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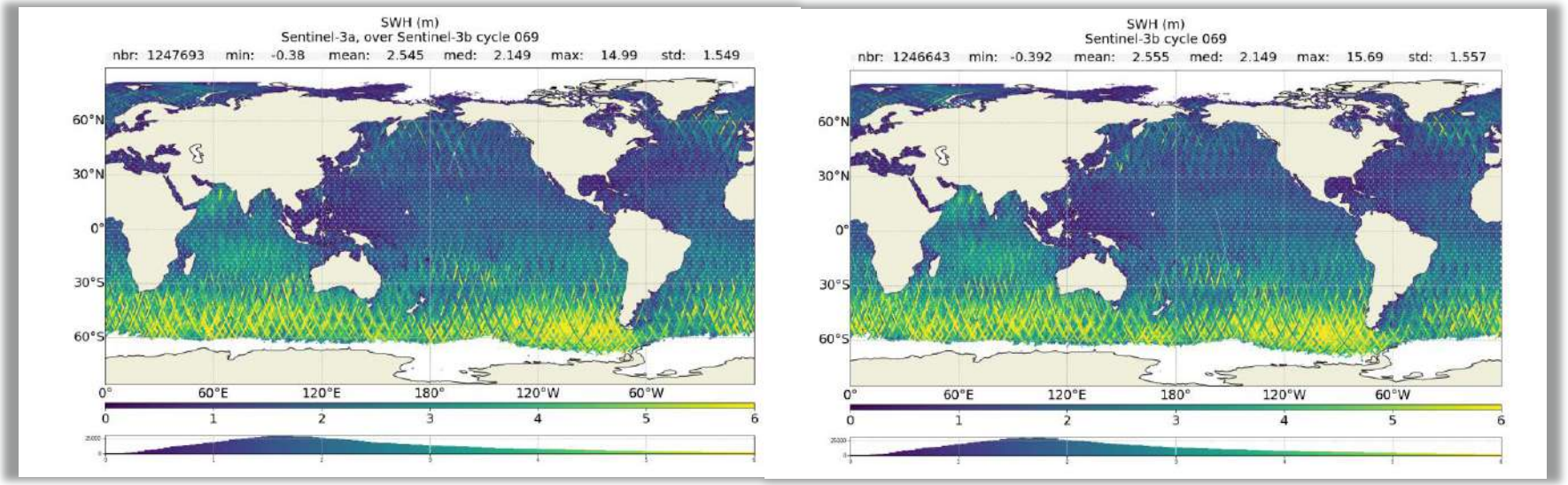
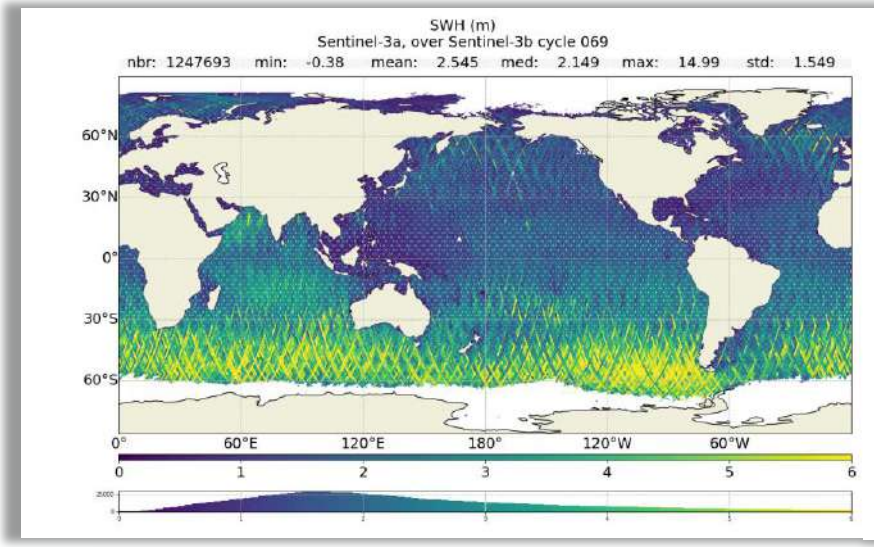
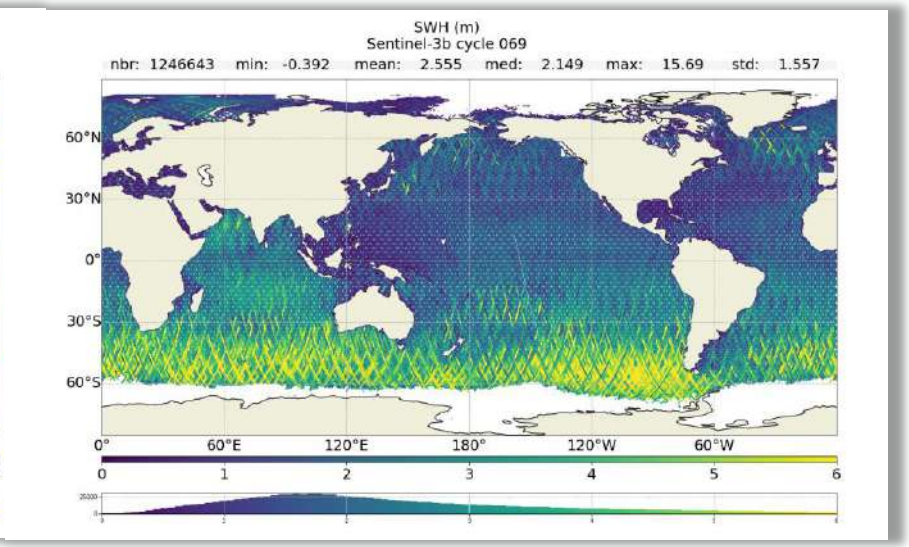
Cal/Val results: SWH (S3B cycle 69 – Jul 31 to Aug 27 2022)

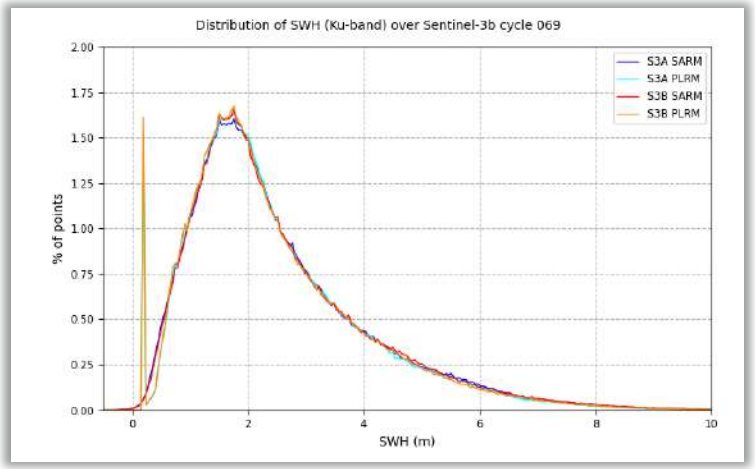


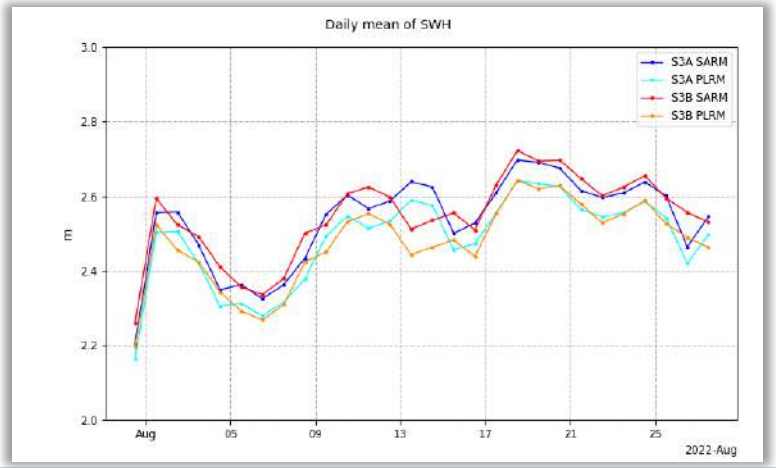
- Consistency between Sentinel-3A and 3B
- Expected geographical distribution

Cal/Val results: SWH (S3B cycle 69 – Jul 31 to Aug 27 2022)



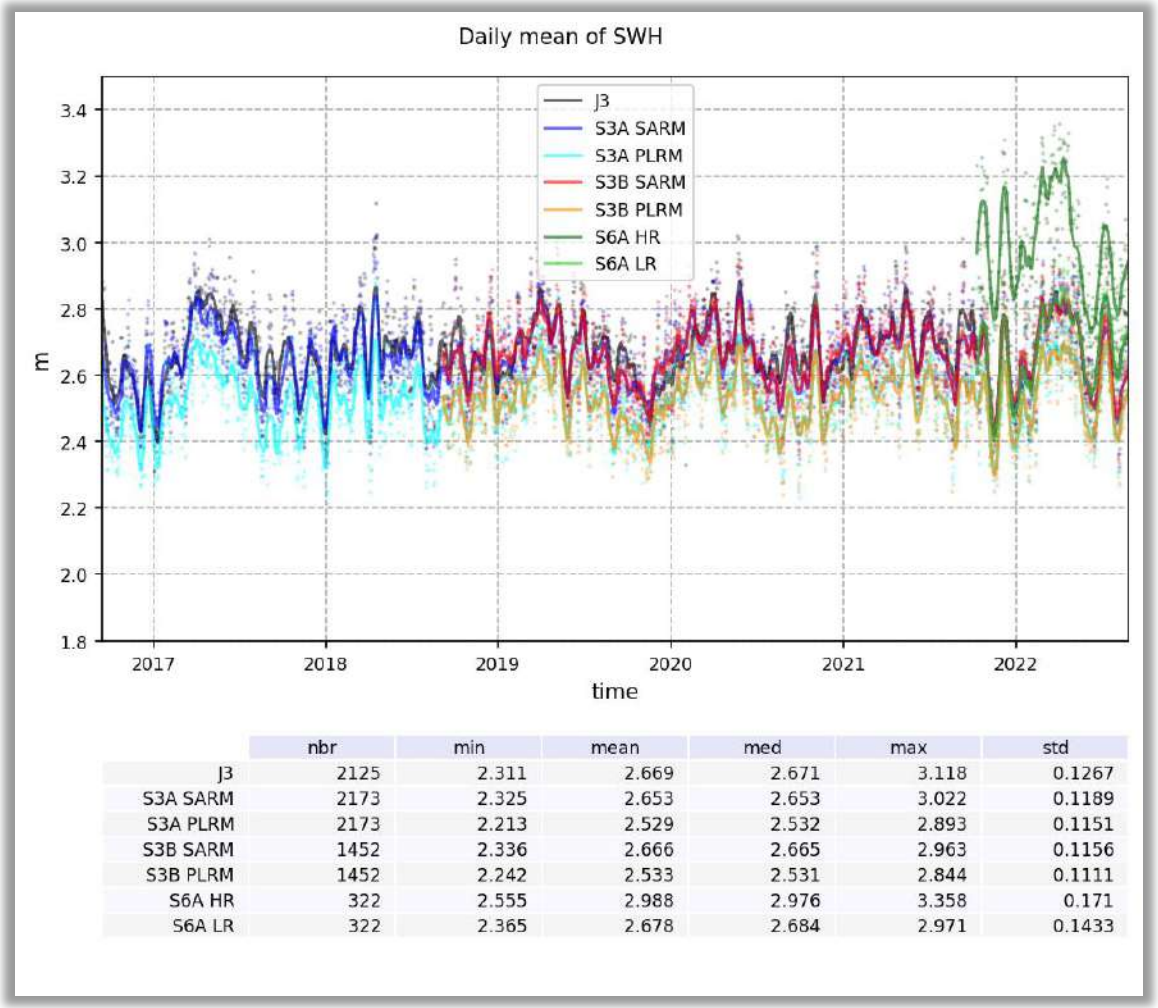






- Consistency between Sentinel-3A and 3B
- Expected geographical distribution
- Consistency between modes
- Small SARm/PLRM bias

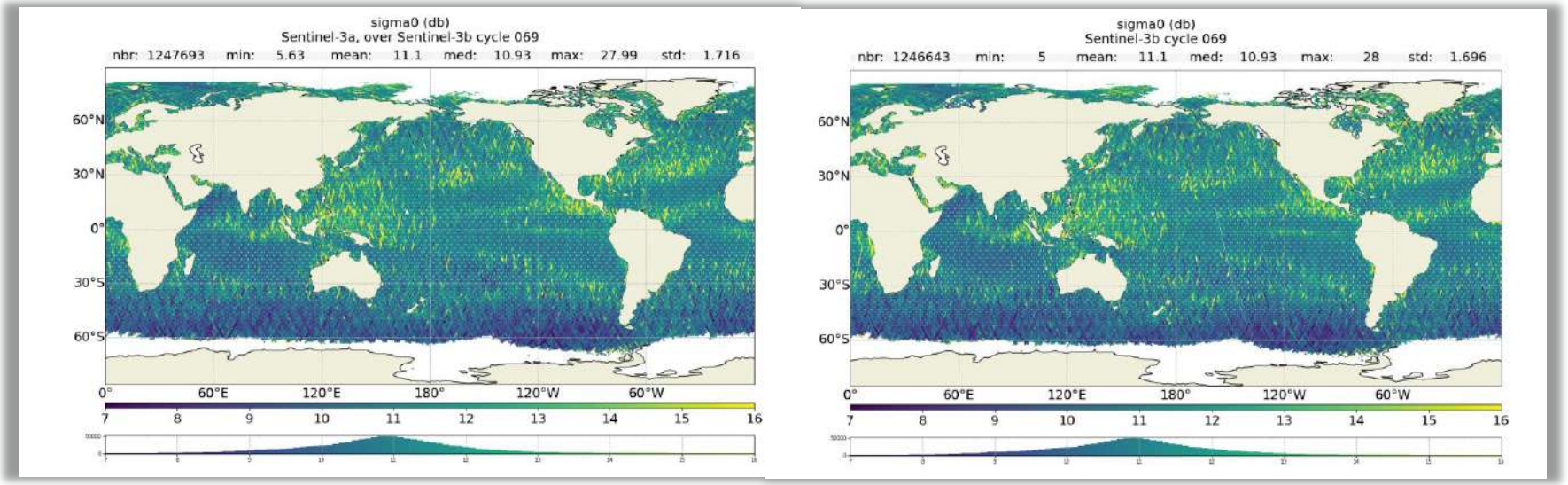
Cal/Val results: SWH (Full mission time series)



	nbr	min	mean	med	max	std
J3	2125	2.311	2.669	2.671	3.118	0.1267
S3A SARM	2173	2.325	2.653	2.653	3.022	0.1189
S3A PLRM	2173	2.213	2.529	2.532	2.893	0.1151
S3B SARM	1452	2.336	2.666	2.665	2.963	0.1156
S3B PLRM	1452	2.242	2.533	2.531	2.844	0.1111
S6A HR	322	2.555	2.988	2.976	3.358	0.171
S6A LR	322	2.365	2.678	2.684	2.971	0.1433

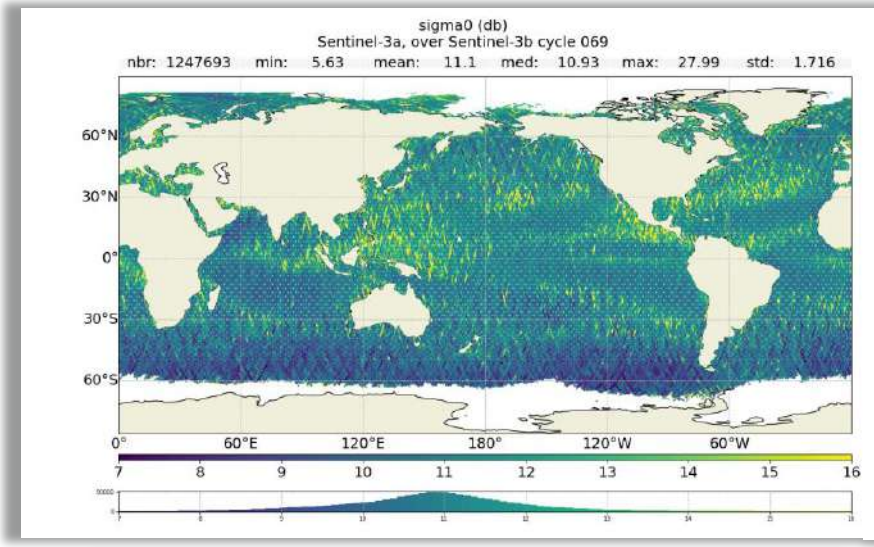
- Consistency between Sentinel-3A and 3B
- Expected geographical distribution
- Consistency between modes
- Small SARm/PLRM bias
- Stable time-series
- S3 consistent with J3 and S6A LR
- S6A HR shows some bias

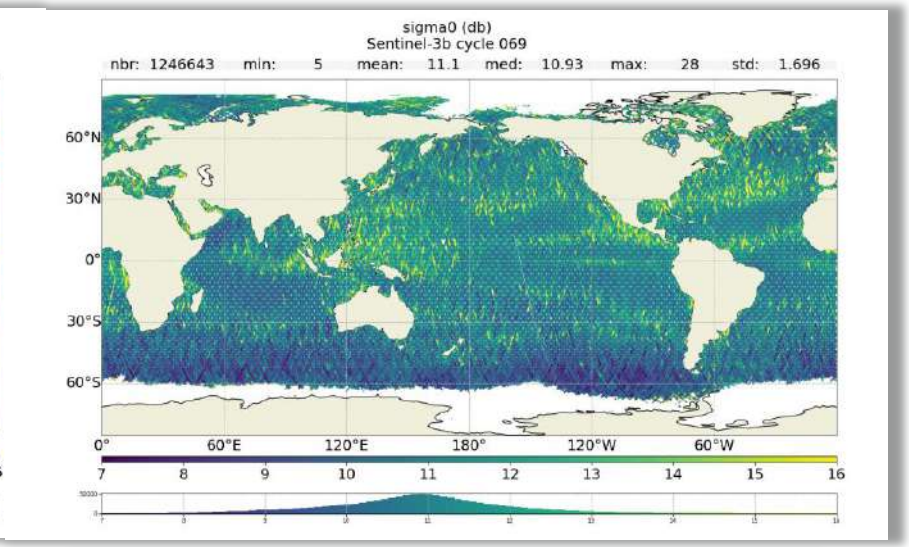
Cal/Val results: Sigma0 (S3B cycle 69 – Jul 31 to Aug 27 2022)

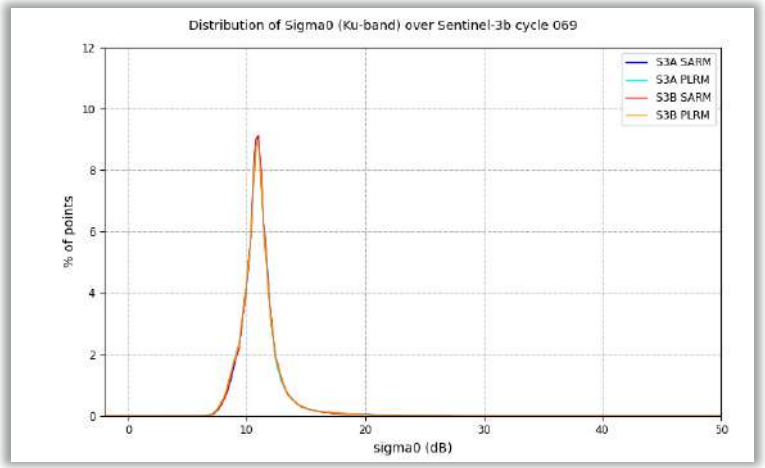


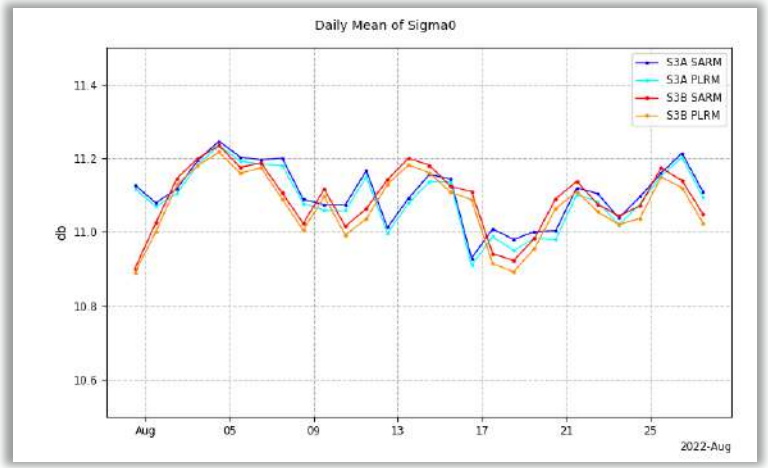
- Consistency between Sentinel-3A and 3B
- Expected geographical distribution

Cal/Val results: Sigma0 (S3B cycle 69 – Jul 31 to Aug 27 2022)



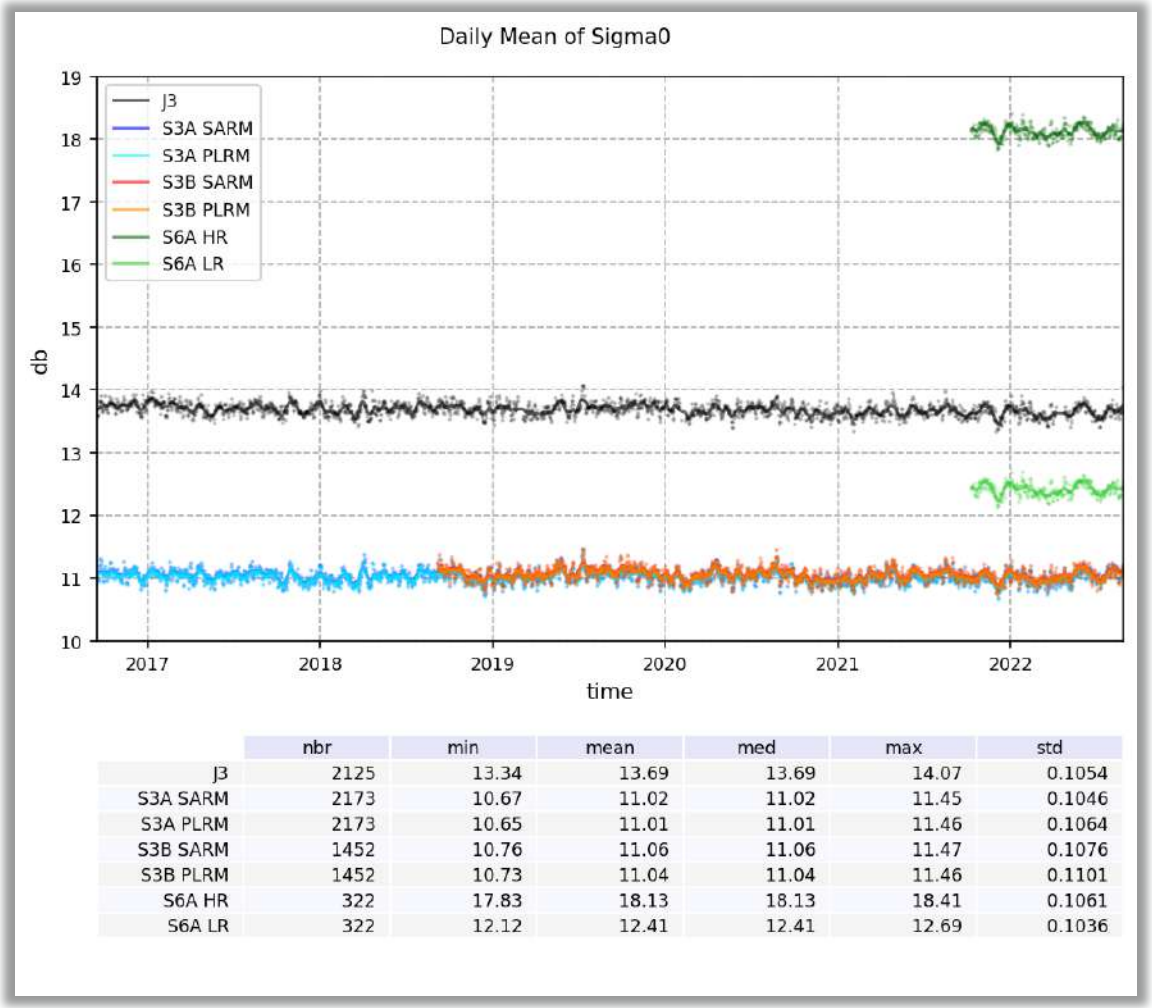






- Consistency between Sentinel-3A and 3B
- Expected geographical distribution
- Consistency between modes
- No SARm/PLRM bias

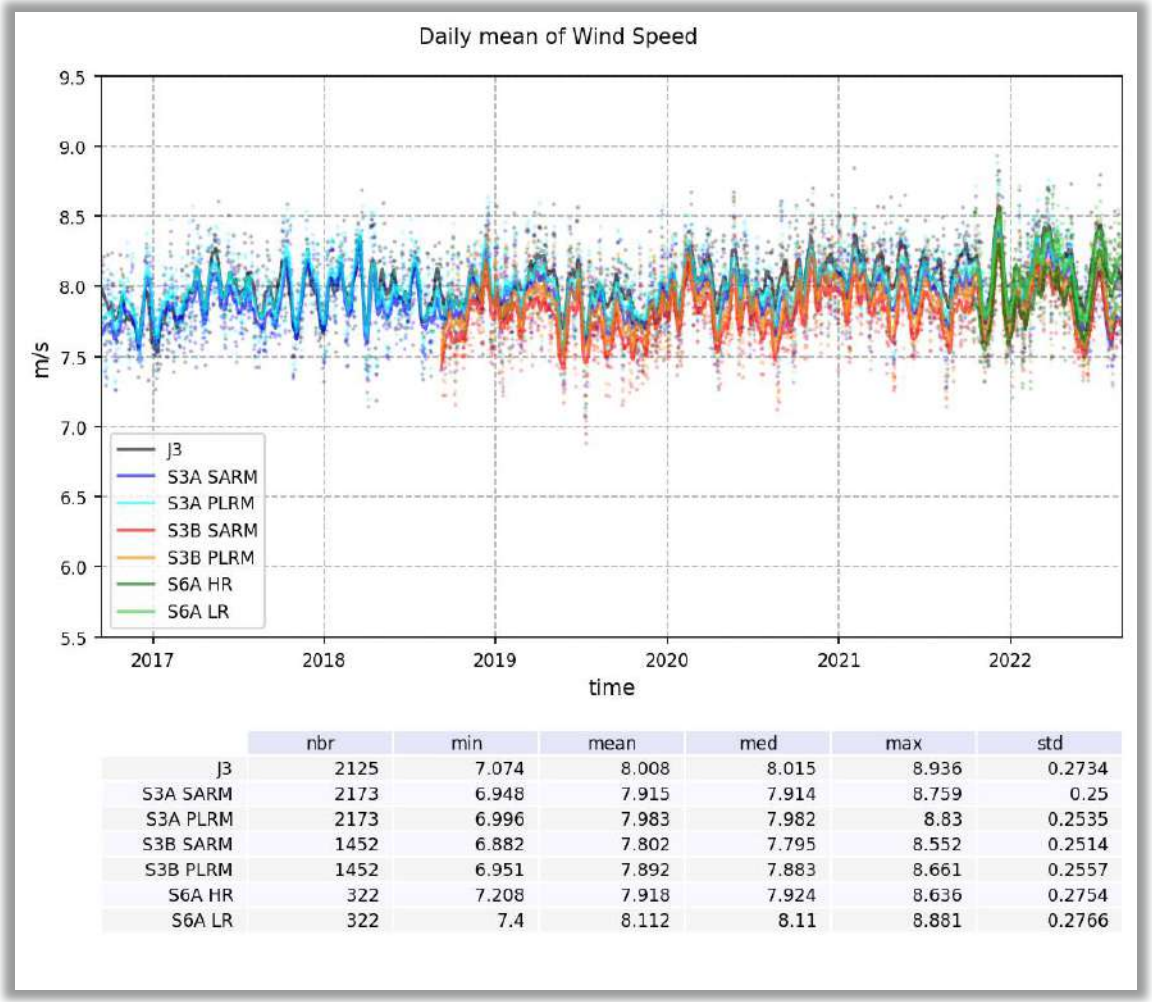
Cal/Val results: Sigma0 (Full mission time series)



	nbr	min	mean	med	max	std
J3	2125	13.34	13.69	13.69	14.07	0.1054
S3A SARM	2173	10.67	11.02	11.02	11.45	0.1046
S3A PLRM	2173	10.65	11.01	11.01	11.46	0.1064
S3B SARM	1452	10.76	11.06	11.06	11.47	0.1076
S3B PLRM	1452	10.73	11.04	11.04	11.46	0.1101
S6A HR	322	17.83	18.13	18.13	18.41	0.1061
S6A LR	322	12.12	12.41	12.41	12.69	0.1036

- Consistency between Sentinel-3A and 3B
- Expected geographical distribution
- Consistency between modes
- No SARm/PLRM bias
- Stable time-series
- **Bias** with respect to J3, S6A LR and S6A HR

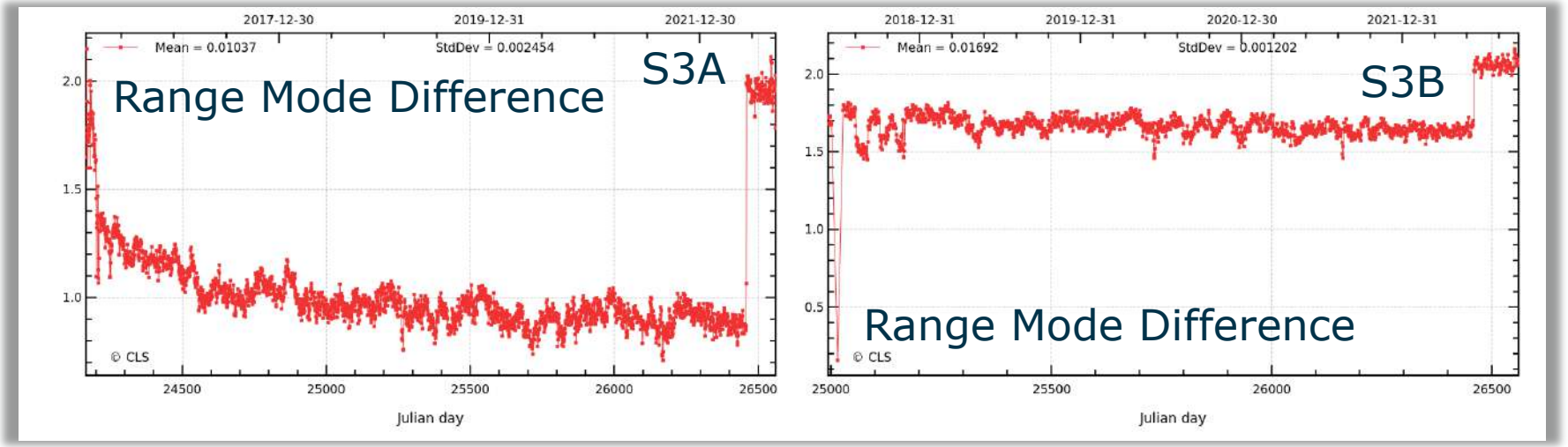
Cal/Val results: Wind (Full mission time series)

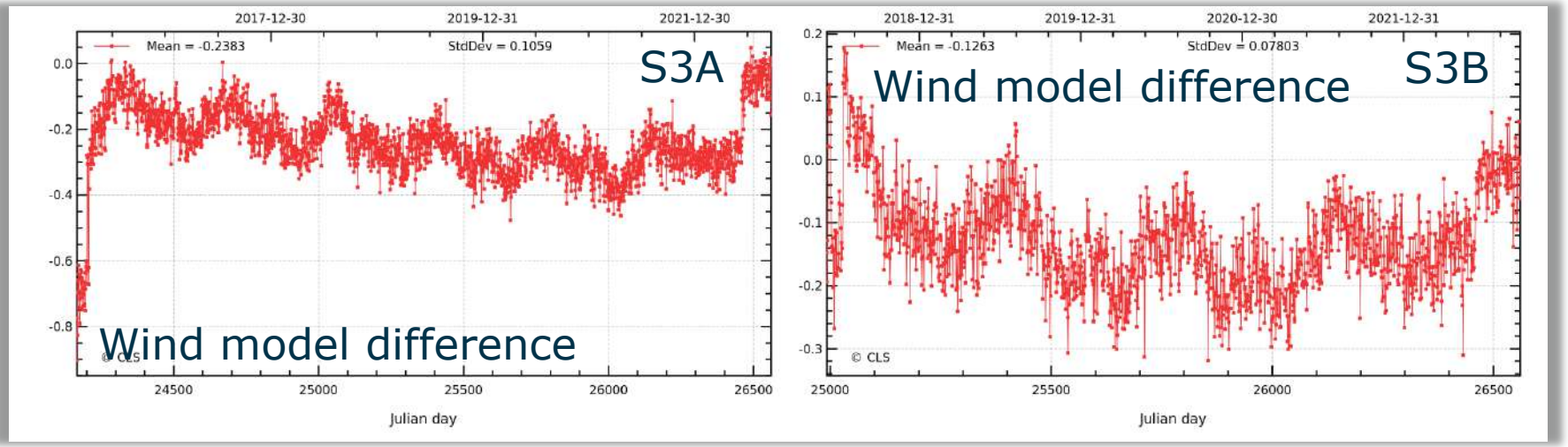


	nbr	min	mean	med	max	std
J3	2125	7.074	8.008	8.015	8.936	0.2734
S3A SARM	2173	6.948	7.915	7.914	8.759	0.25
S3A PLRM	2173	6.996	7.983	7.982	8.83	0.2535
S3B SARM	1452	6.882	7.802	7.795	8.552	0.2514
S3B PLRM	1452	6.951	7.892	7.883	8.661	0.2557
S6A HR	322	7.208	7.918	7.924	8.636	0.2754
S6A LR	322	7.4	8.112	8.11	8.881	0.2766

- Consistency between Sentinel-3A and 3B
- Expected geographical distribution
- Consistency between modes
- No SARm/PLRM bias
- Stable time-series
- **No bias** with respect to J3, S6A LR and S6A HR

Cal/Val results: Unstable time-series

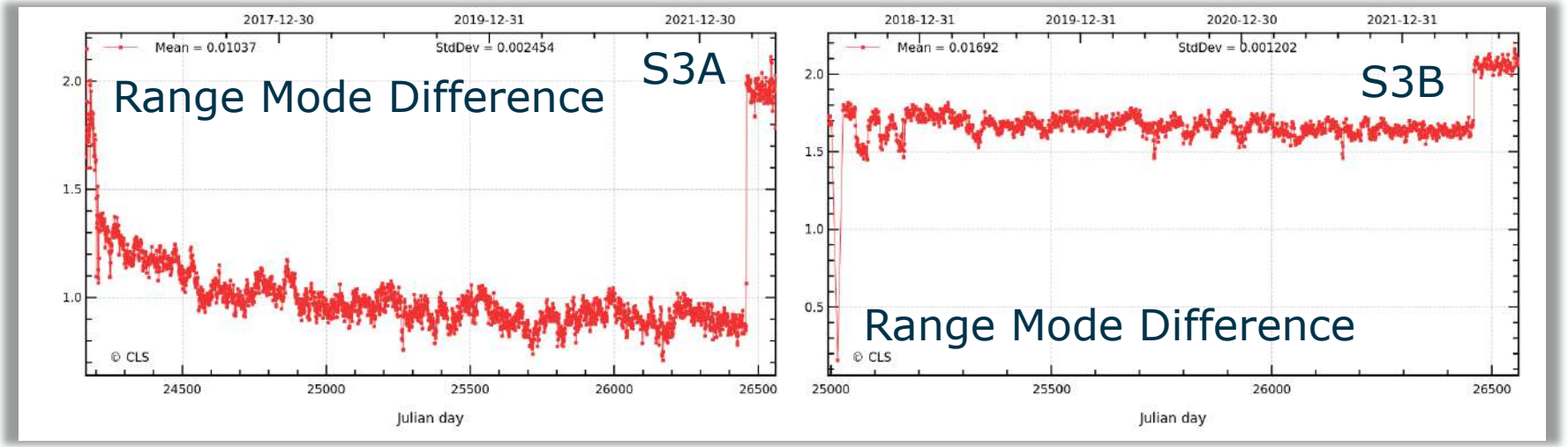


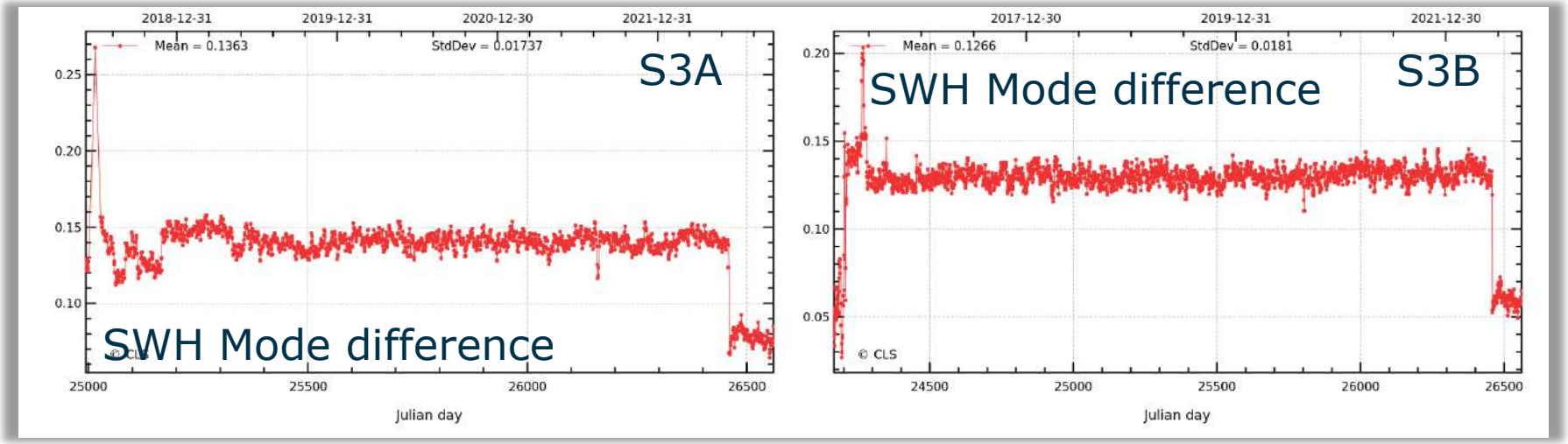


- **Not all time series are stable**
- Few parameters of the full stack regularly validated at the end of each cycle show unstable trends
- No clearly visible effect on the final geophysical parameters

➢ Jumps at the end of the series due to the change to SM__WAT.005.01

Cal/Val results: Unstable time-series





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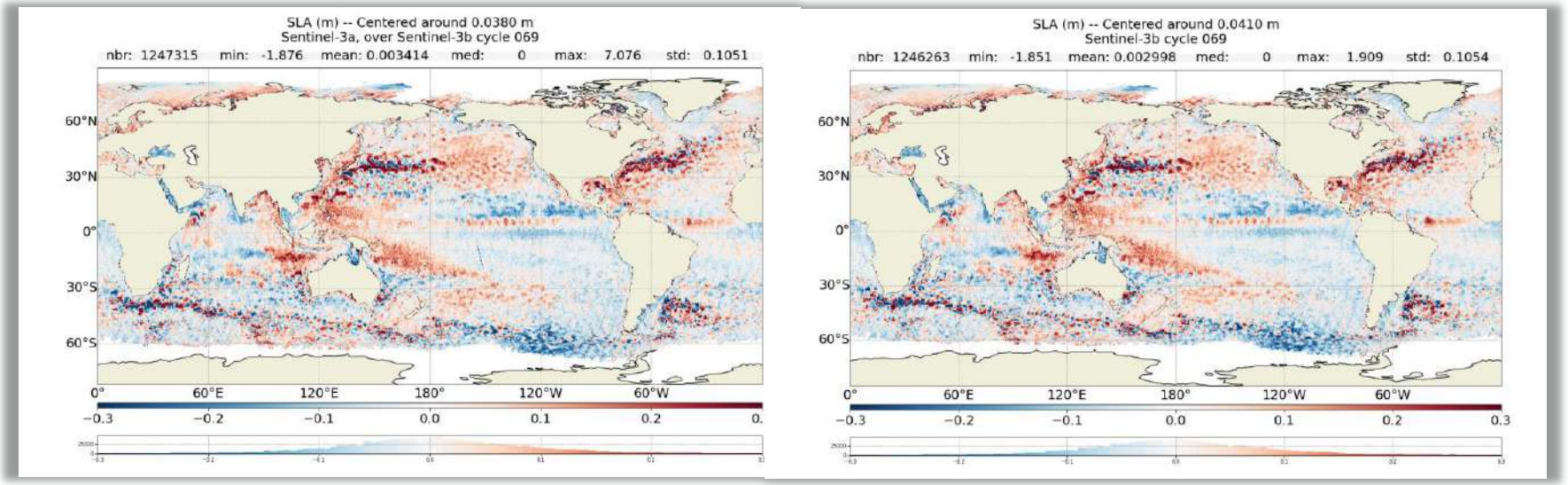
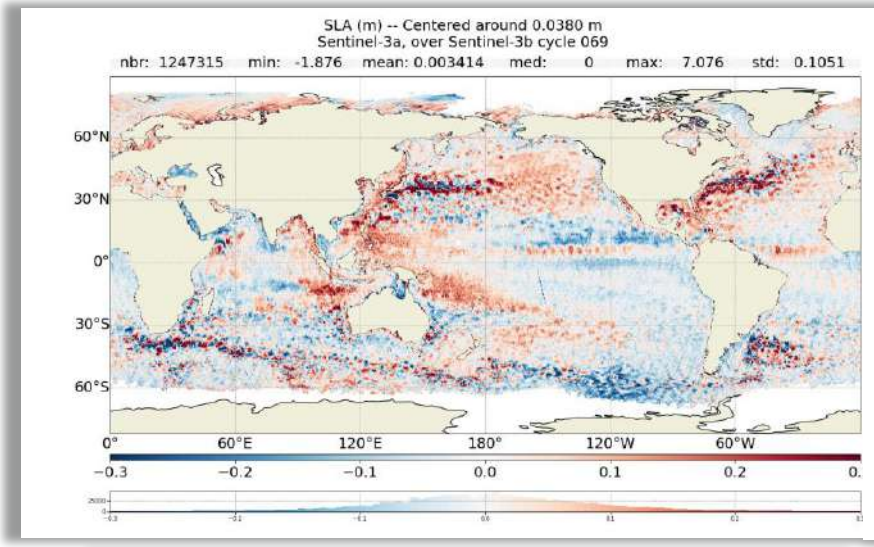
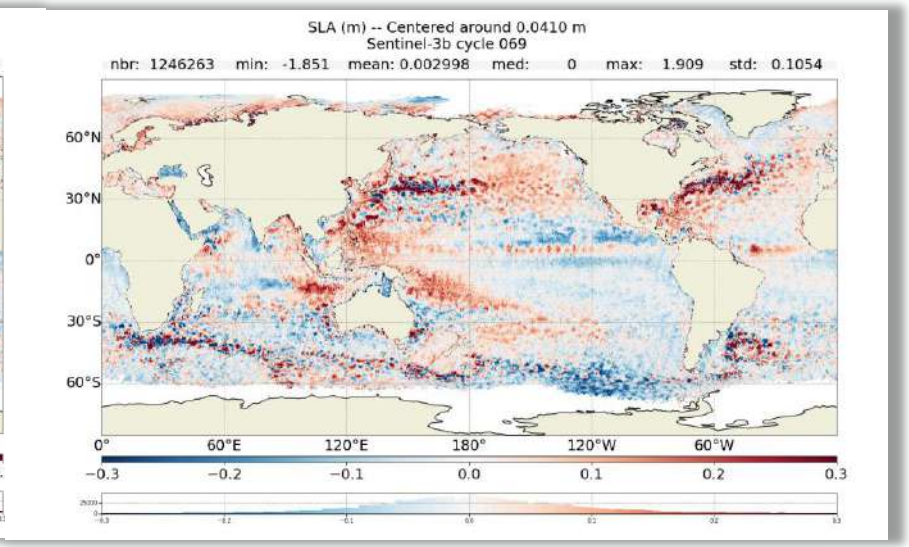
Cal/Val results: SSHA (S3B cycle 69 – Jul 31 to Aug 27 2022)

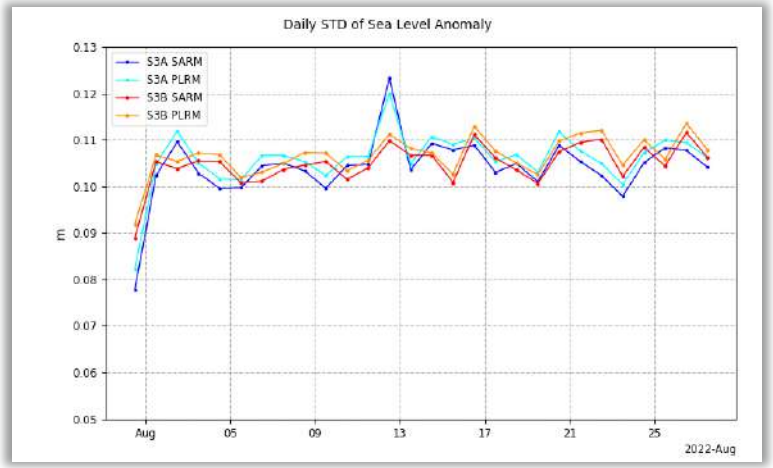


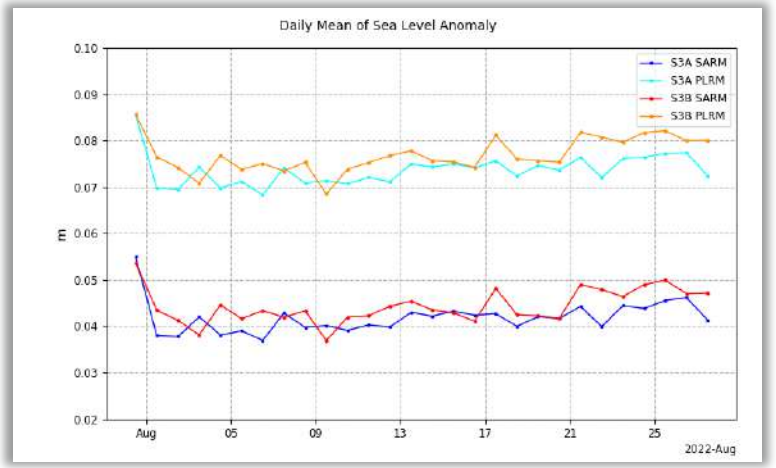
- Consistency between Sentinel-3A and 3B
- Expected geographical distribution
- Slight bias between satellites (much reduced since new PB)

Cal/Val results: SSHA (S3B cycle 69 – Jul 31 to Aug 27 2022)



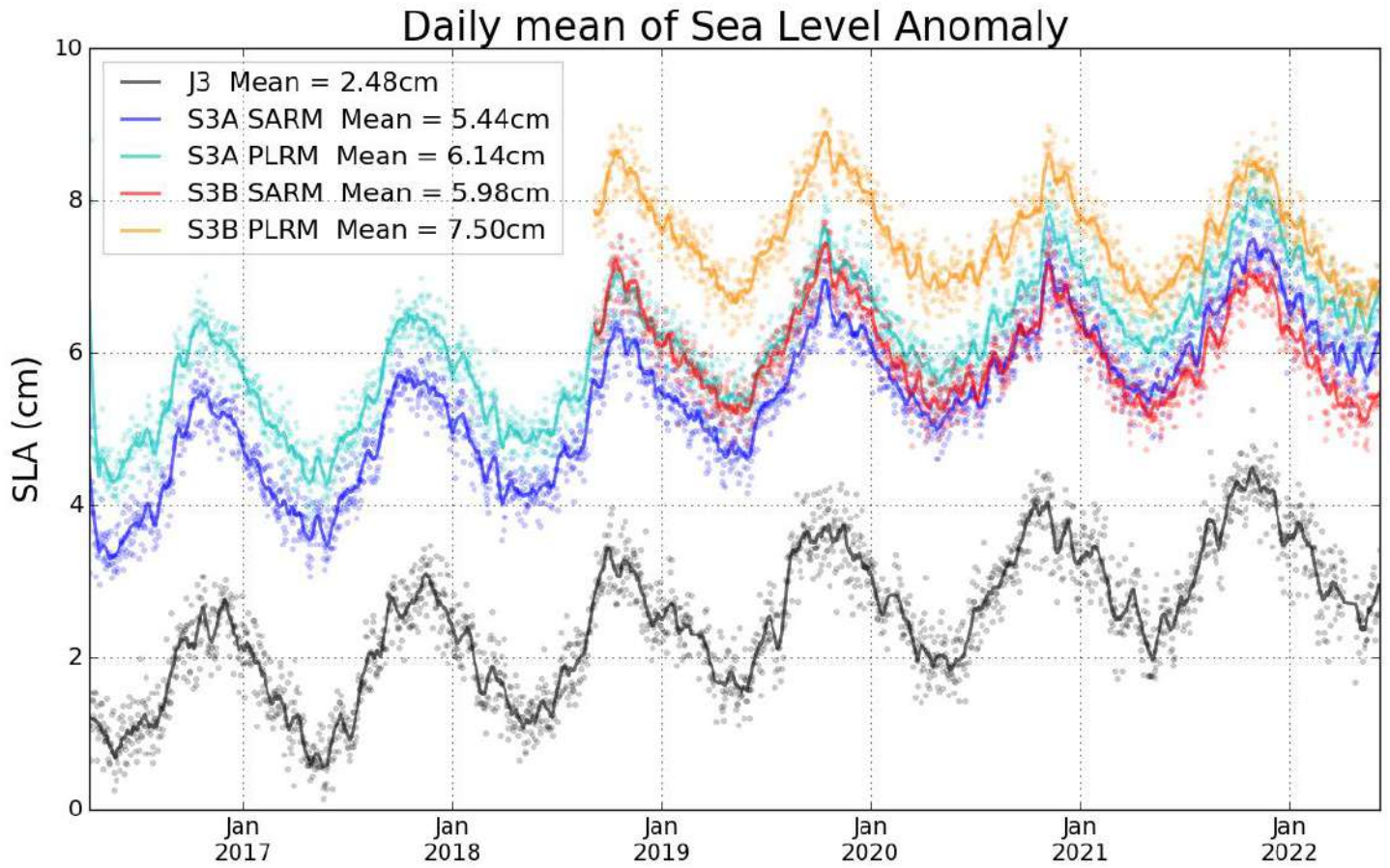






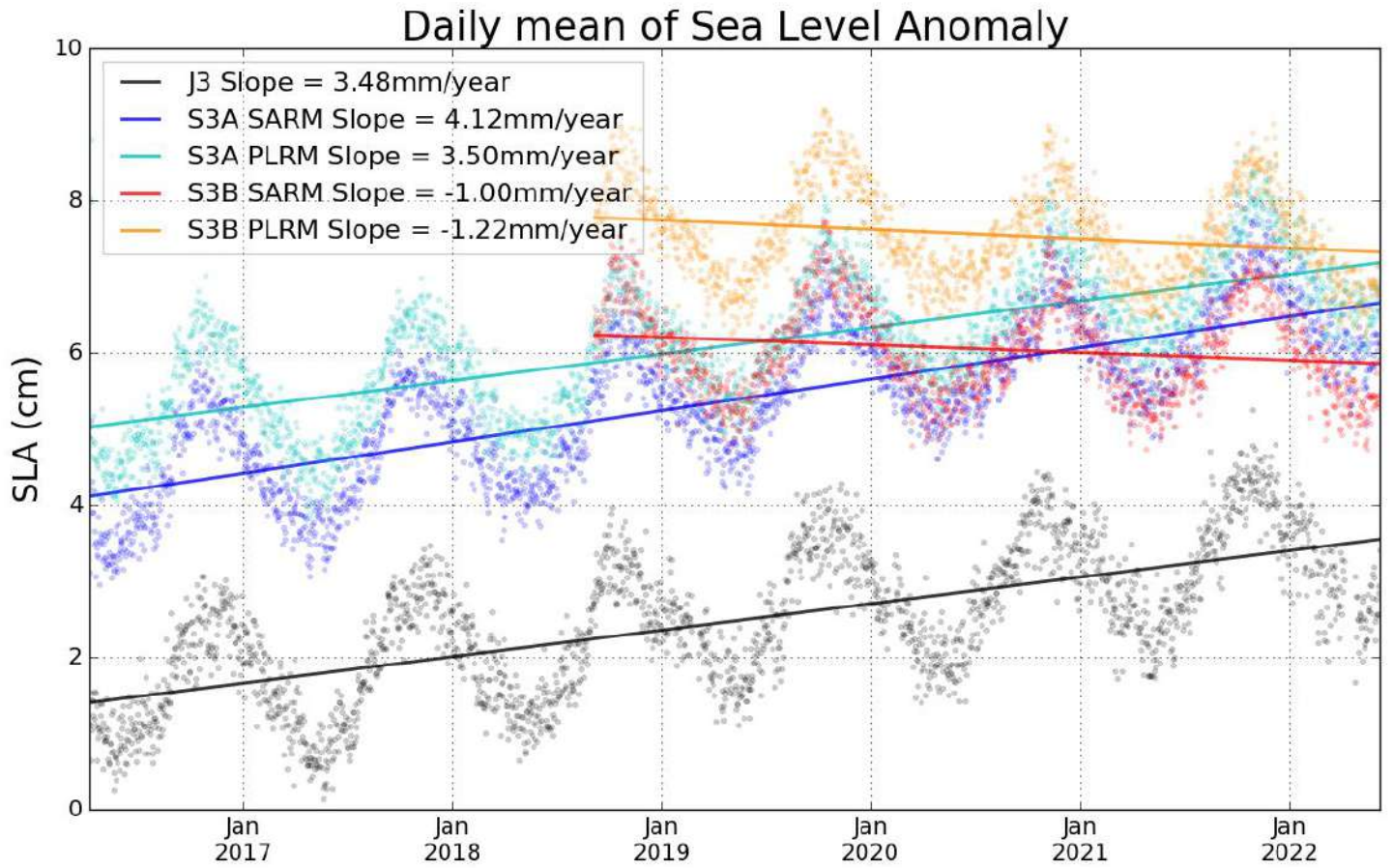
- Consistency between Sentinel-3A and 3B
- Expected geographical distribution
- Slight bias between satellites (much reduced since new PB)
- SARm/PLRM bias
- Stable observations (from STD time series)

Cal/Val results: SSHA (Full mission time series)



- Bias between modes
- Bias between satellites
- Bias wrt Jason-3

Cal/Val results: SSHA (Full mission time series)



- Bias between modes
- Bias between satellites
- Bias wrt Jason-3

- No positive trend for S3B
- S3A SAR trend steeper than Jason-3 (by ~1.2 mm/year)

SLA errors!!!

STM Error Budget

https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-altimetry/document-library

STM Error Budget

Different types of errors

Sources

- **Instrumental errors**
  - Intrinsic to the instrument
  - white noise
  - Impact on small-scale applications individual measurements

Spatio-temporal scales

- **High-frequency**
  (No spatial correlation)

STM Error Budget

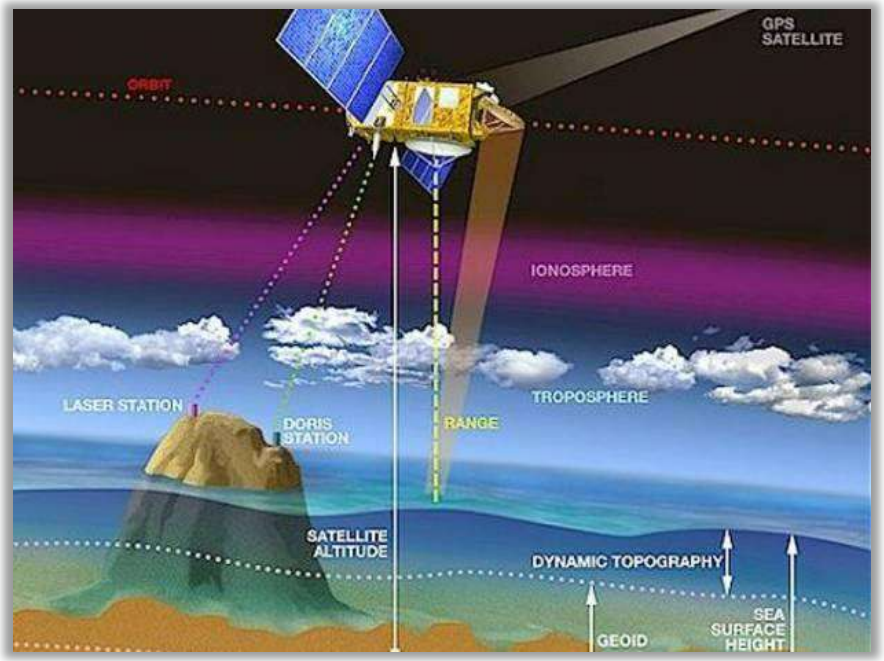
Different types of errors

Sources

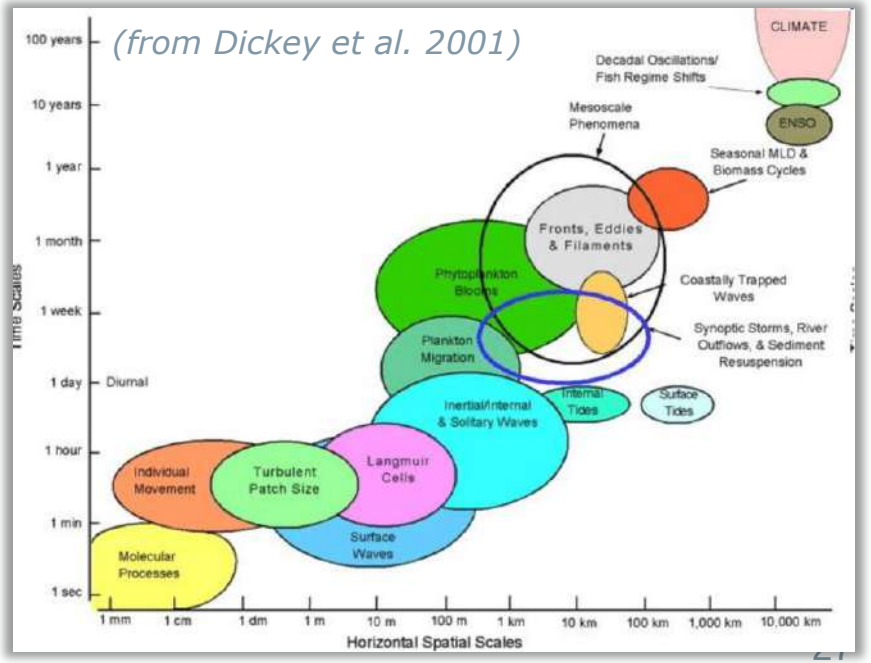
- **Correction errors**
  - Associated with SLA geophysical corrections
  - Broad range of scales
  - Impact on (sub)mesoscale to basin-wide applications

Spatio-temporal scales

- **High-frequency**
- **Low-frequency**
  10 km/1 week
  1000km/1 year



Corrections associated with specific geophysical processes: **Spatio-temporal correlations**

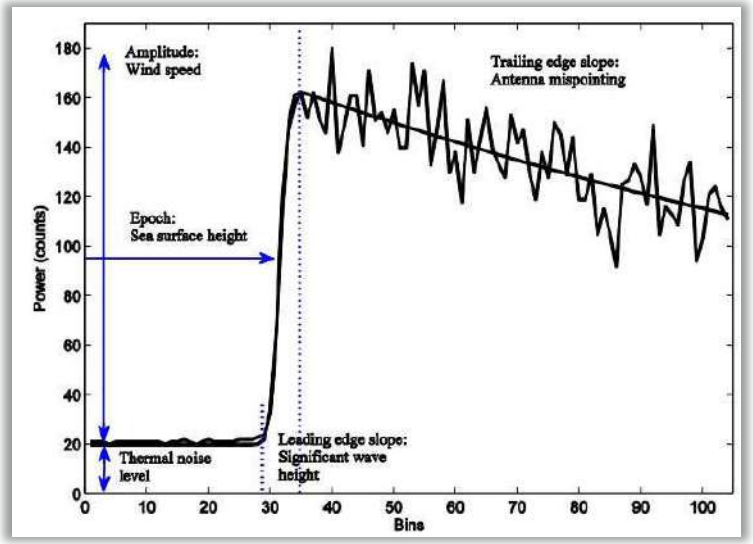


STM Error Budget

Different types of errors

Sources

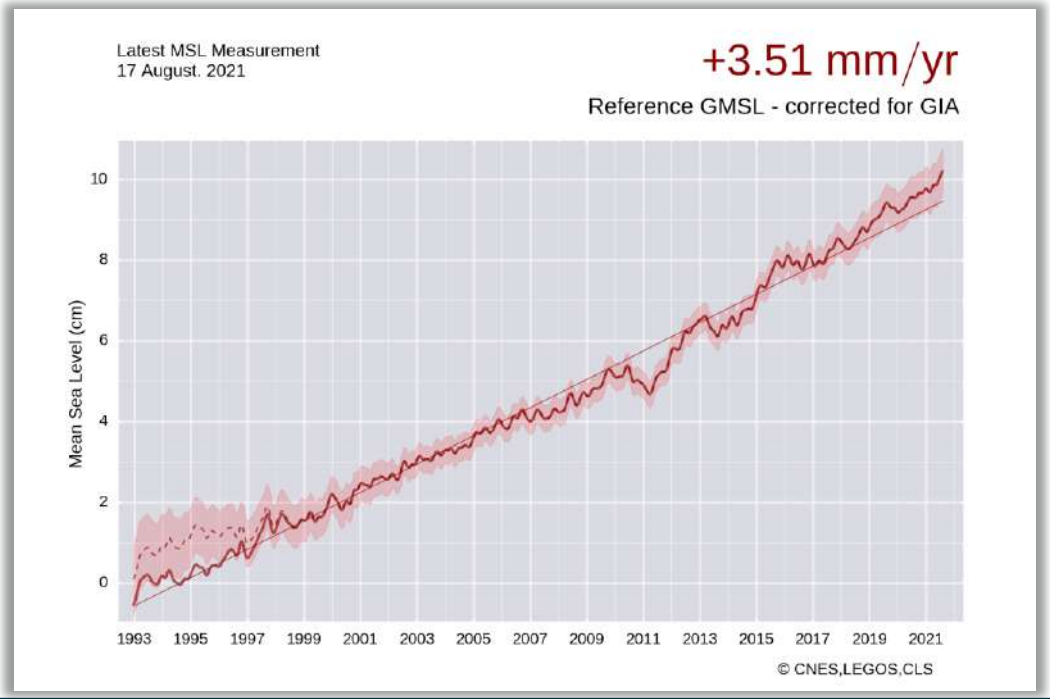
- **Retracking errors**
  - Associated with waveform retracking (algorithm + assumptions)
  - Smaller but broader errors
  - Impact on climate scale applications



Spatio-temporal scales

- **Low-frequency**
- **Long-term trends**

  Basin-scale variations



STM Error Budget

Different types of errors

Sources

- **Instrumental errors**
  - Intrinsic to the instrument
  - white noise
  - Impact on small-scale applications individual measurements

  ⇒ Spatio-temporal scales
  - **High-frequency**
    (No spatial correlation)

- **Correction errors**
  - Associated with SLA geophysical corrections
  - Broad range of scales
  - Impact on (sub)mesoscale to basin-wide applications

  ⇒ Spatio-temporal scales
  - **High-frequency**
  - **Low-frequency**
    10 km/1 week
    1000km/1 year

- **Retracking errors**
  - Associated with waveform retracking (algorithm + assumptions)
  - Smaller but broader errors
  - Impact on climate scale applications

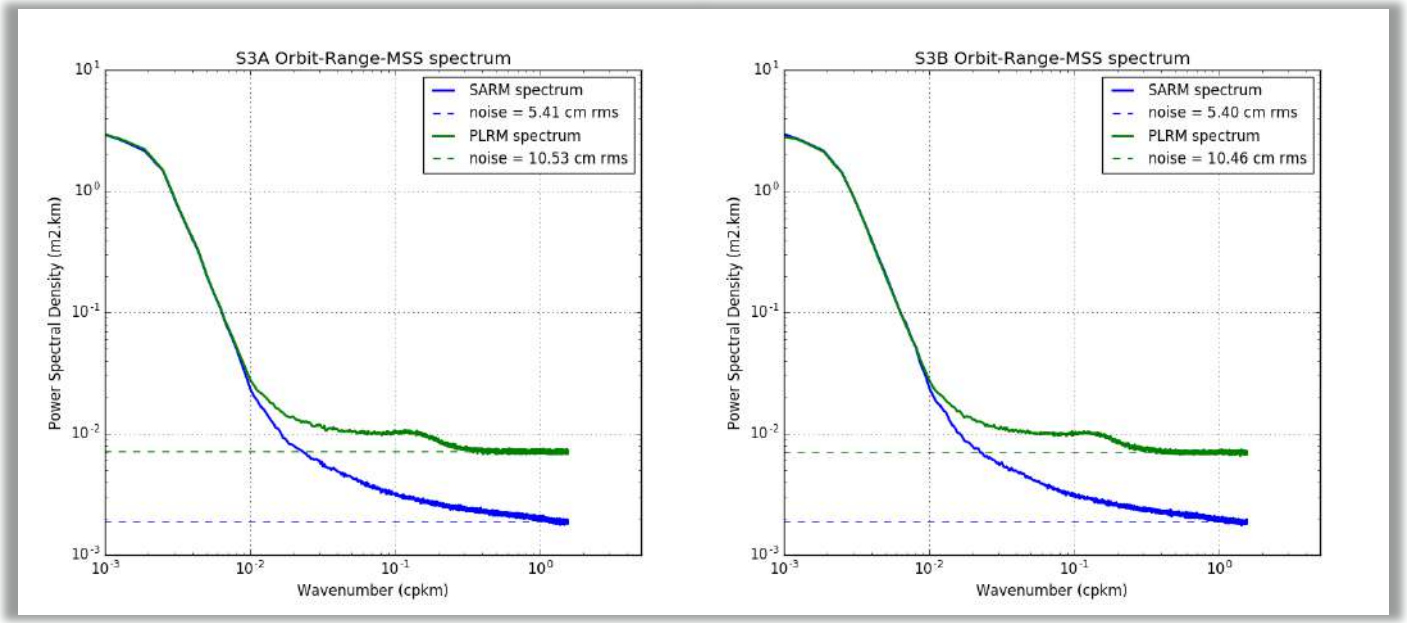
  ⇒ Spatio-temporal scales
  - **Low-frequency**
  - **Long-term trends**
    Basin-scale variations

STM Error Budget: High-frequency errors

Easy to quantify

1. 20Hz spectra (e.g. range)

Error derived from high-frequency white noise plateau



1Hz error = 20Hz error / sqrt(20)
[assumption of independent measurements]

All variables (SLA, SWH, Sigma0) within the requirements

SRAL MODE	Sentinel-3 Satellite	20Hz range white noise estimation	1Hz range white noise estimation	ESA requirements (1Hz observations)
SARM	S3A	5.41 cm	1.21 cm	1.3 cm
	S3B	5.40 cm	1.21 cm	1.3 cm
P-LRM	S3A	10.53 cm	2.35 cm	--
	S3B	10.46 cm	2.34 cm	--

STM Error Budget: High-frequency errors

Easy to quantify

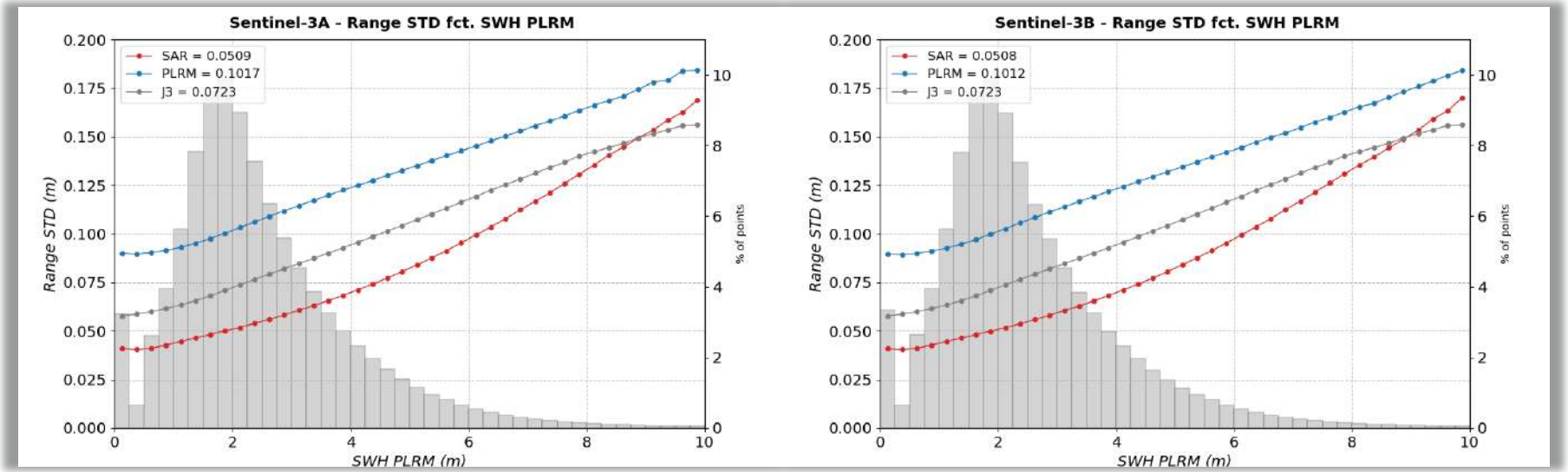
2. 20Hz STD (e.g. range)

Error derived from standard deviation of 20 Hz measurements averaged to 1 Hz

[assumption of no ocean variability within 1 Hz bin]

1Hz error = 20Hz error / sqrt(20)
[assumption of independent measurements]

All variables (SLA, SWH, Sigma0) within the requirements



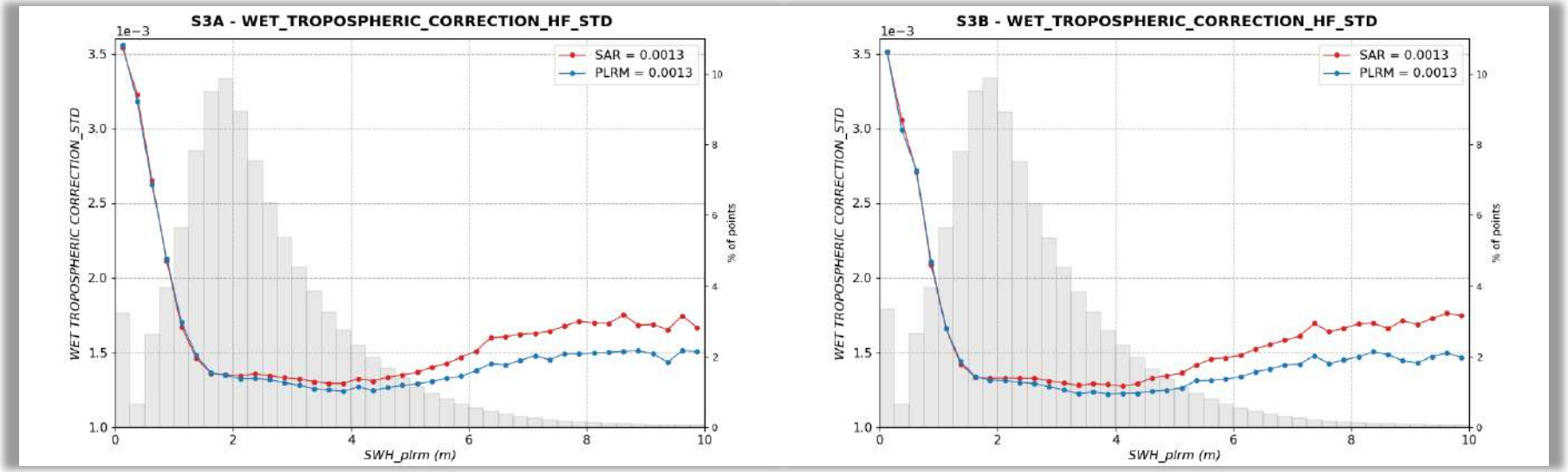
SRAL MODE	Sentinel-3 Satellite	20Hz range noise estimation (SWH = 2 m)	1Hz range noise estimation (SWH = 2 m)	ESA requirements (1Hz observations)
SARM	S3A	5.09 cm	1.14 cm	1.3 cm
	S3B	5.08 cm	1.14 cm	1.3 cm
P-LRM	S3A	10.17 cm	2.27 cm	--
	S3B	10.12 cm	2.26 cm	--

STM Error Budget: High-frequency errors

Easy to quantify

3. 1Hz filtered residuals (e.g. WTC)

Error derived from standard deviation of residuals within each SWH bin



- Corrections provided at only 1 Hz (so not 20 Hz approach possible)
- Lanczos2 filter with 40 km cutoff wavelength

All corrections errors small (<1cm) and within the requirements

SRAL MODE	Sentinel-3 Satellite	1Hz WTC white noise estimation	ESA requirements (1Hz observations)
SARM	S3A	0.13 cm	1.4 cm
	S3B	0.13 cm	1.4 cm
P-LRM	S3A	0.13 cm	--
	S3B	0.13 cm	--

STM Error Budget: Low-frequency errors

Hard to quantify (broad range of scales)

Mono-mission crossover maps

Range Mean Difference

Measurements from full missions

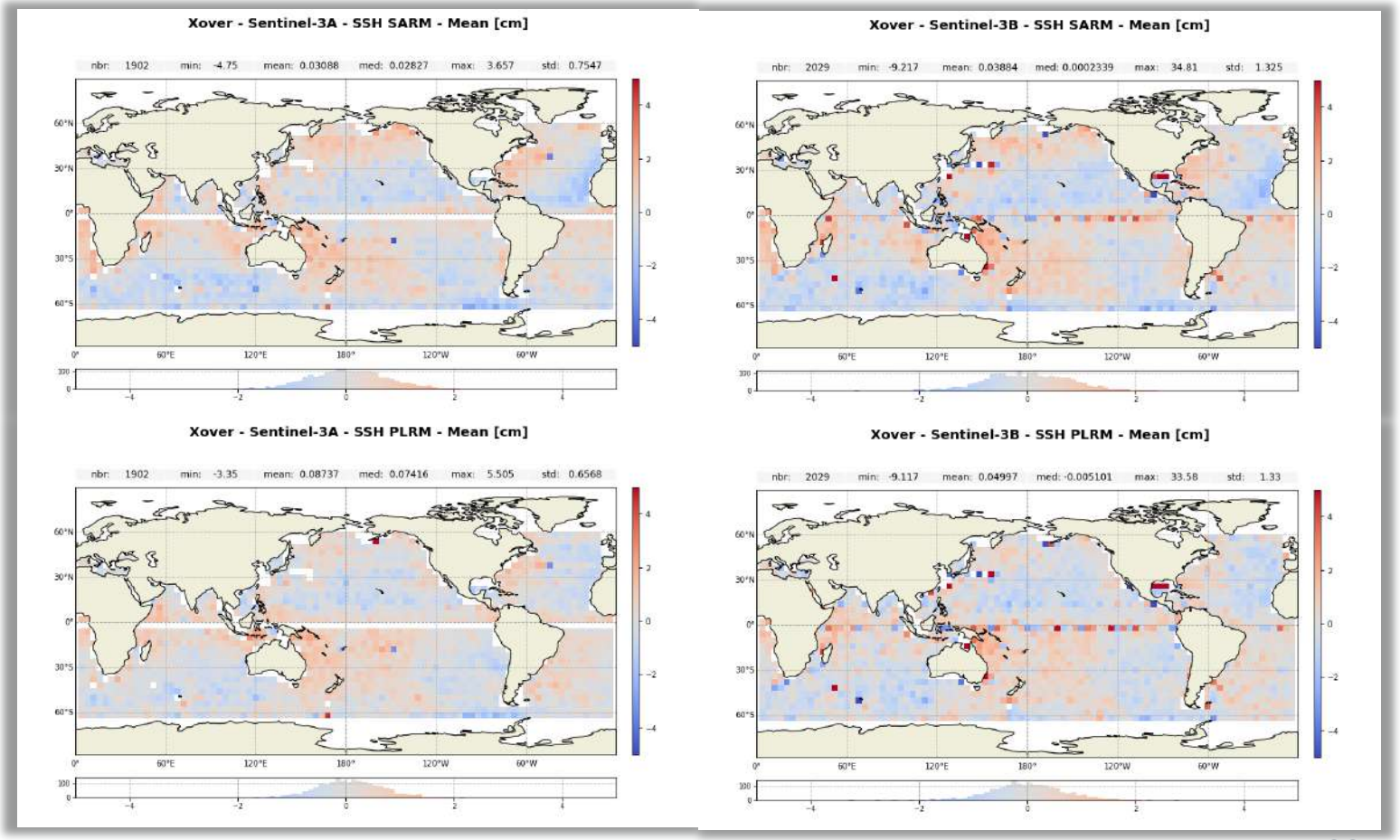
Differences only for time intervals at cross-overs <10 days (temporal scale)

[assumption of no ocean variations within that interval!!!]

- Consistency between modes and satellite

Values between -2 and 2 cm (S3A and S3B)

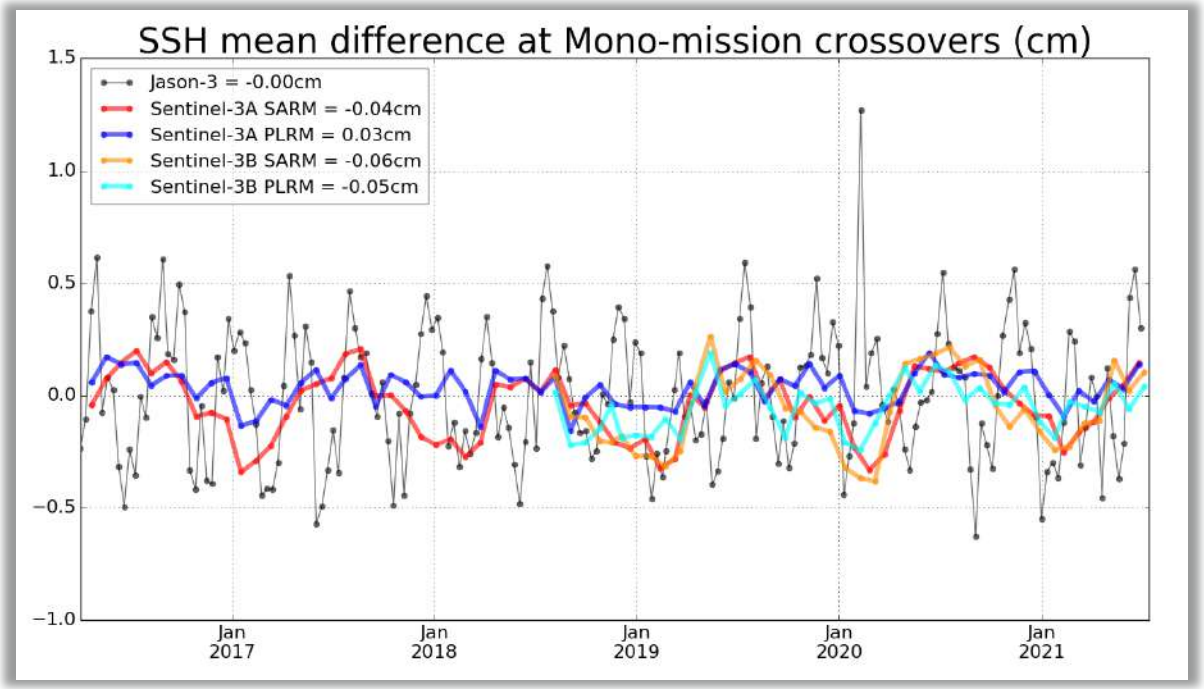
Large scale patterns: possible dependency on SWH and wind speed)



STM Error Budget: Low-frequency errors

Hard to quantify (broad range of scales)

Mono-mission crossover time-series



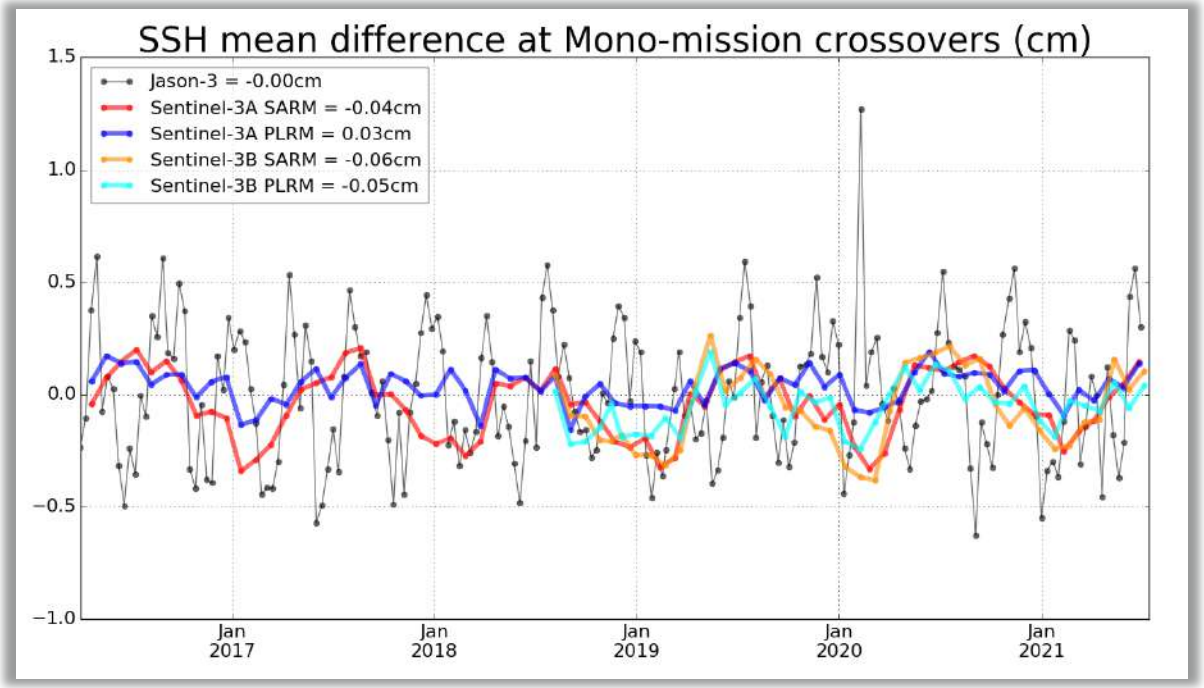
Mean values at cross-overs

- Annual cycles of ~0.5 cm in amplitude

STM Error Budget: Low-frequency errors

Hard to quantify (broad range of scales)

Mono-mission crossover time-series



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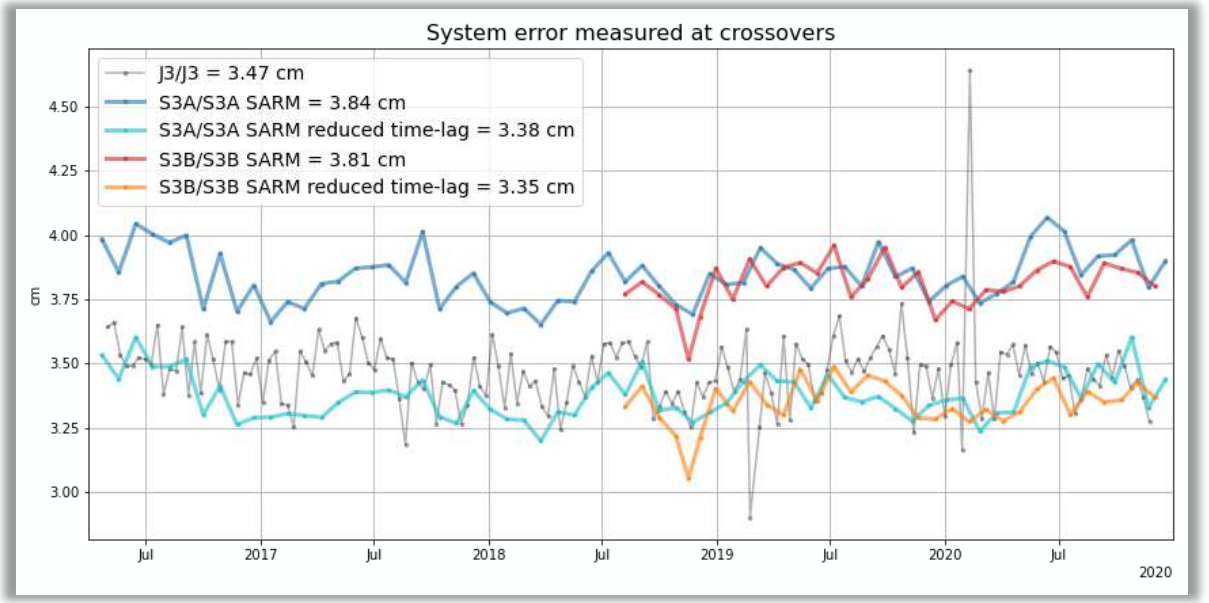

Standard deviation at crossovers

- Error variability decreases reducing time interval at cross-overs (limitations of ocean stationarity assumption)
- How to analyze longer frequency errors?

STM Error Budget: Low-frequency errors

Hard to quantify (broad range of scales)

Other approaches include:

1. Collocated mode difference (SAR-PLRM along track)
2. Double difference (asc-dsc difference of SARM-PLRM)

- Both approaches returns maps with large scale patterns which can be correlated to other geophysical or geometrical parameters
- Both approaches have the limitation of mixing spatial and temporal variability together

STM Error Budget: Low-frequency errors

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The key would be to have long, synoptic in-situ observations at the desired scales:

Not easy and very expensive !!!

SWOT experience will be very important:

- Strategy of observations (large multi-platform array: buoys, gliders, bottom pressure sensors…)
- New technologies for in-situ observations (e.g. airborne Lidar)

STM Error Budget: Long term trends

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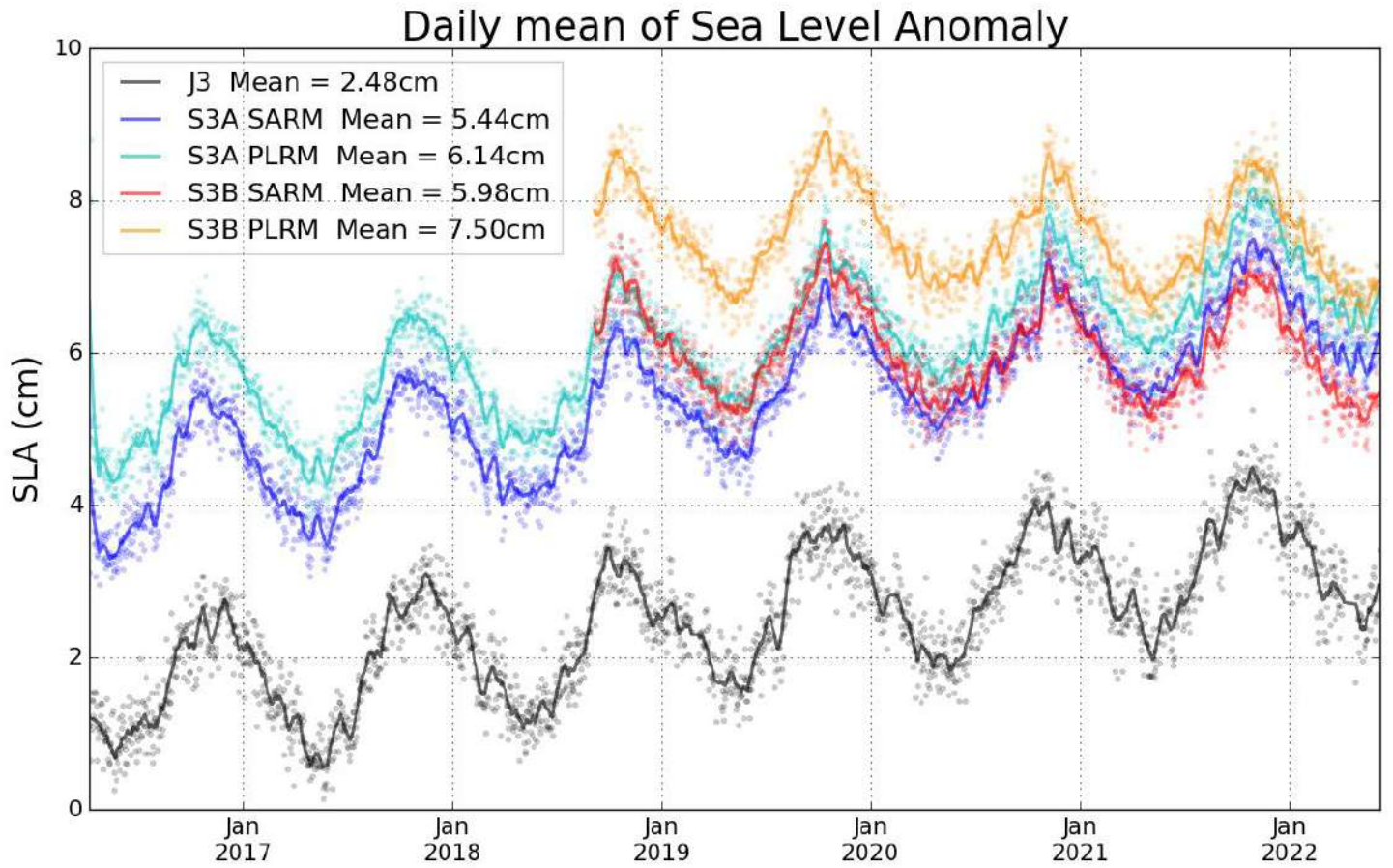
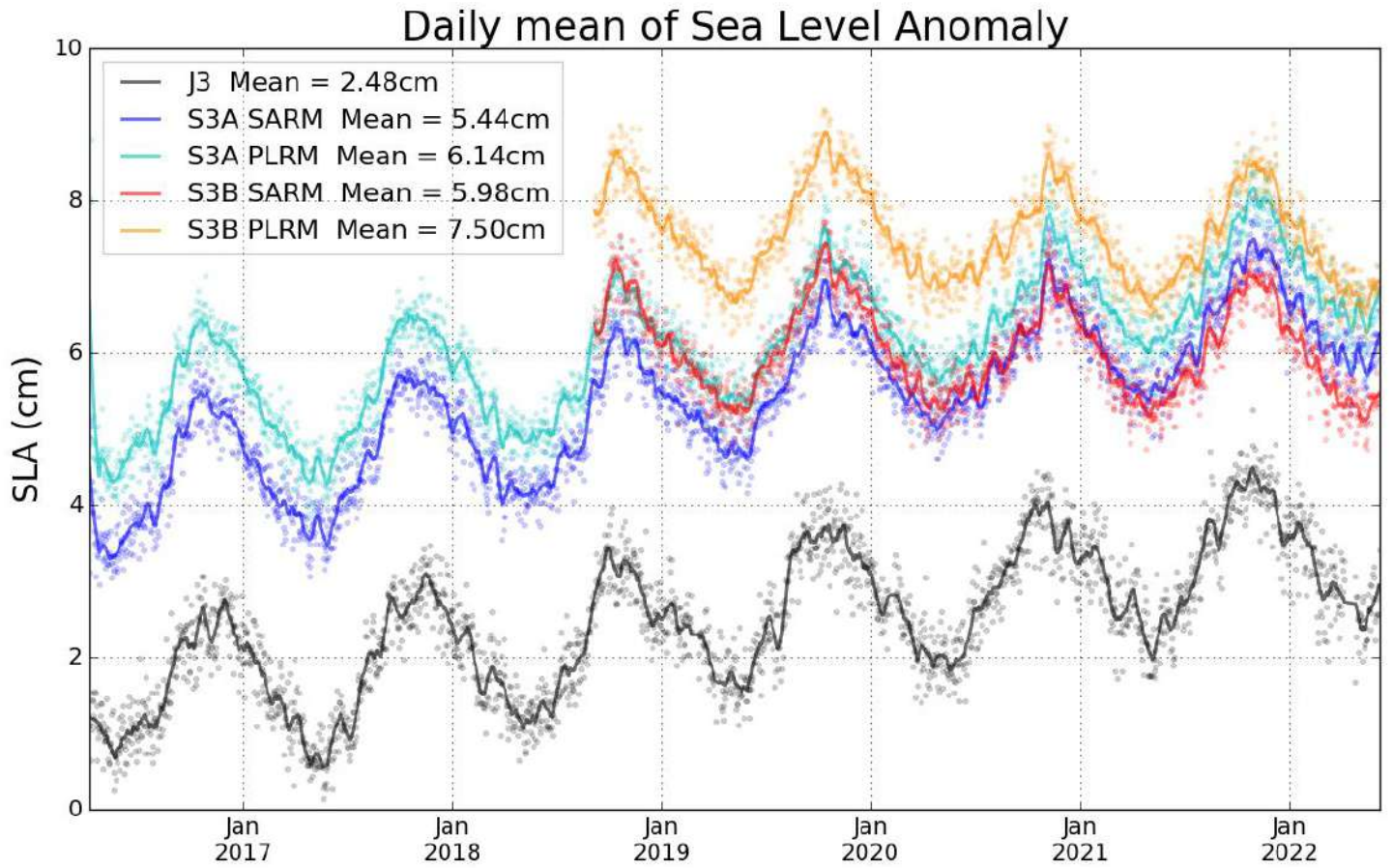
STM Error Budget: Long term trends

Multi-mission comparison



STM Error Budget: Long term trends

Multi-mission comparison

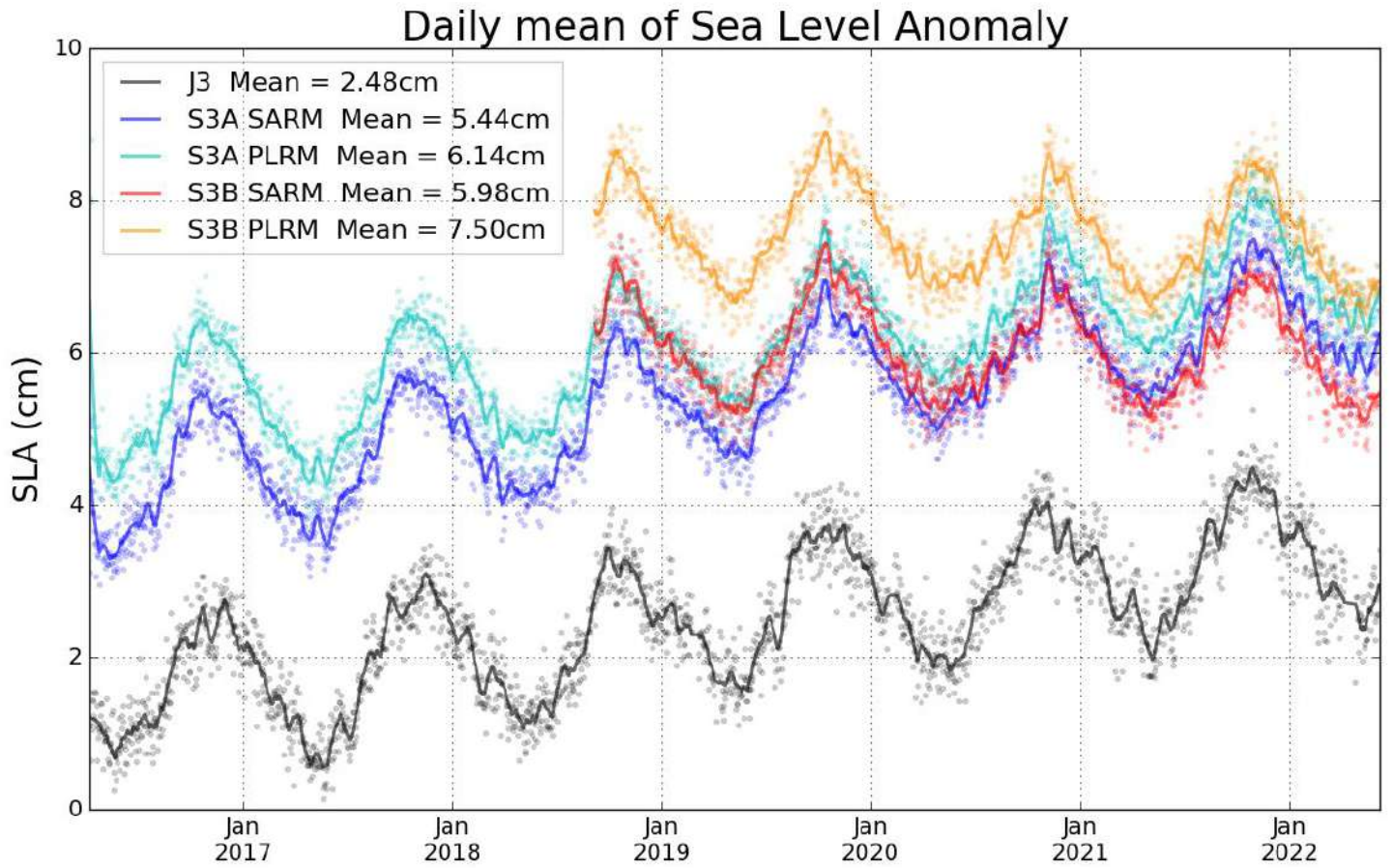


Sentinel-3A

- 0.3 mm/year trend error due to PTR approximation
- Can be corrected by including measured PTR in the retracking process (numerical retracker)
- 1.0 mm/year due to approximation in the lateral look range
- Can be corrected by introducing "range-walk" correction at level-1 before the beamforming

STM Error Budget: Long term trends

Multi-mission comparison

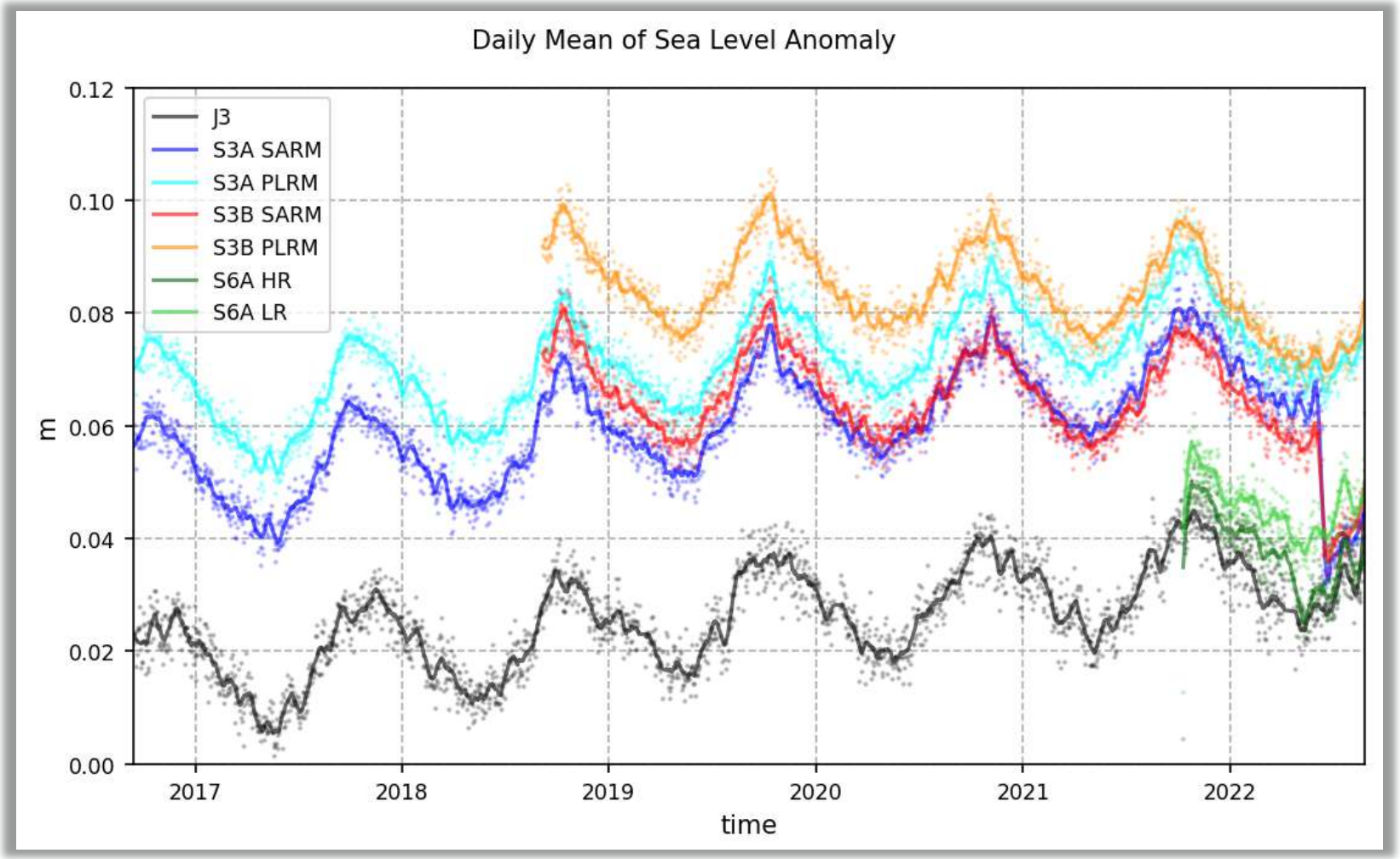


Sentinel-3B

- Processing error in the application of the USO correction

STM Error Budget: Long term trends

Multi-mission comparison



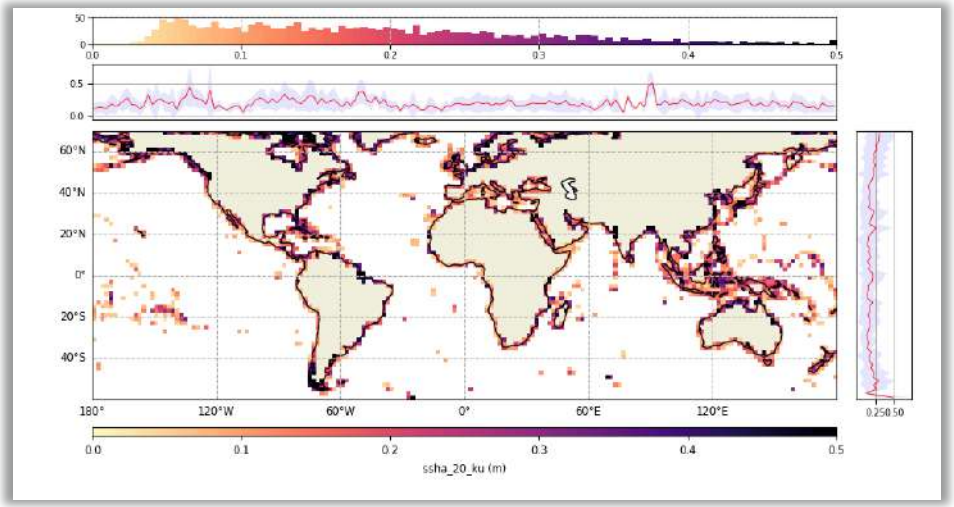
Sentinel-3B

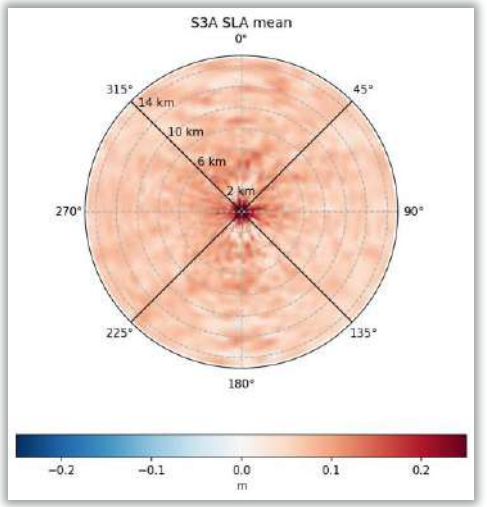
- Processing error in the application of the USO correction

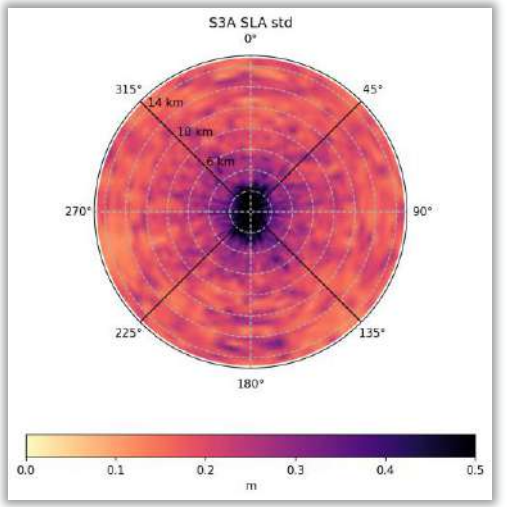
- Sentinel-3B correction already applied in the new PB
- Sentinel-3A corrections will be applied in the nex ones

Way forward: the COPAS project

1. Cyclic report analysis extended to 20Hz observations







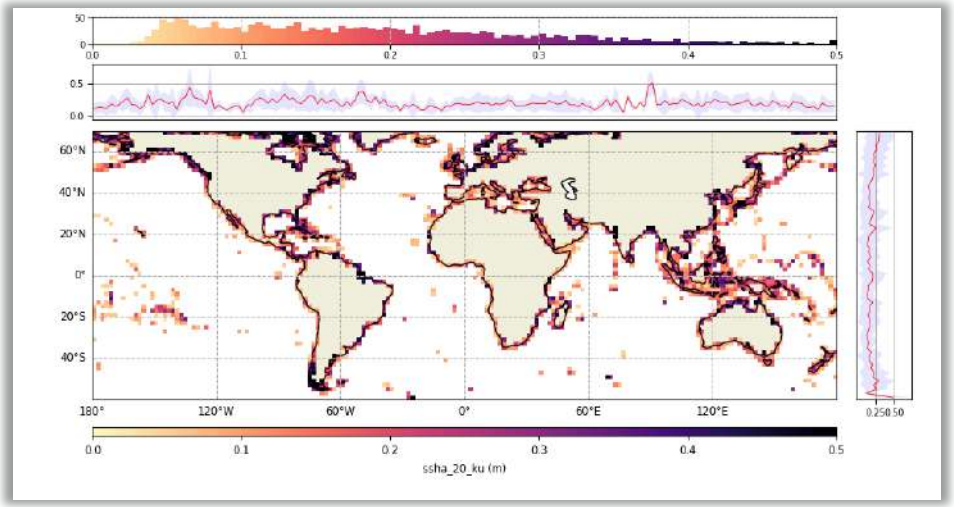
Coastal Oceans

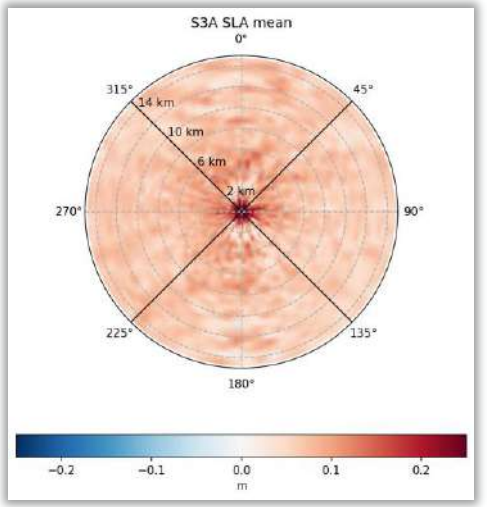
SLA mean and STD

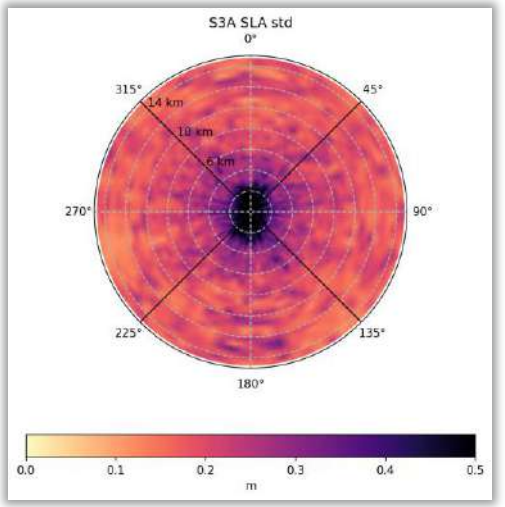
Way forward: the COPAS project

EUMETSAT

1. Cyclic report analysis extended to 20Hz observations

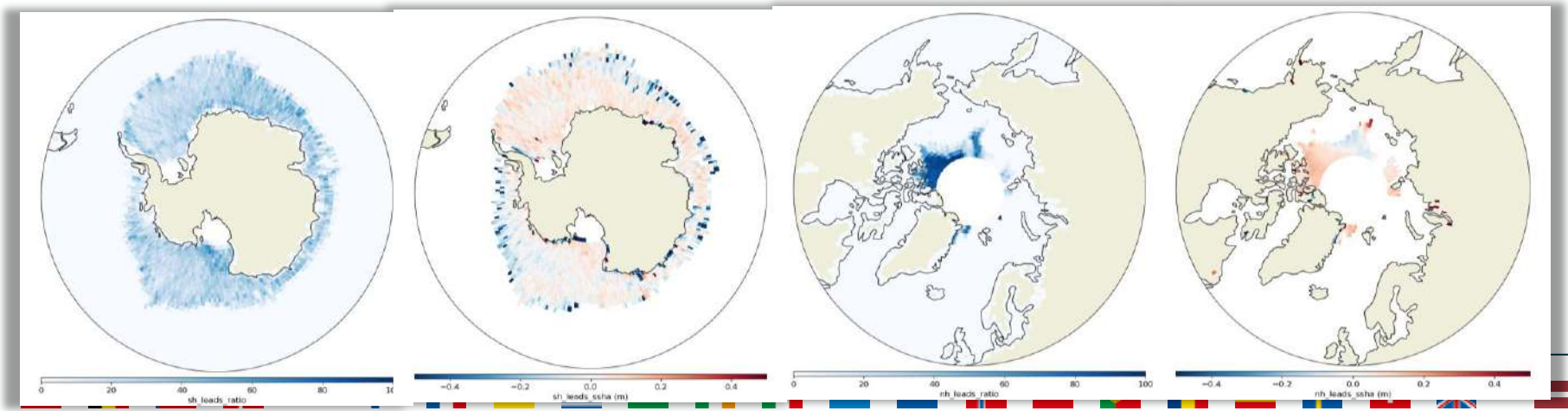






Coastal Oceans

SLA mean and STD

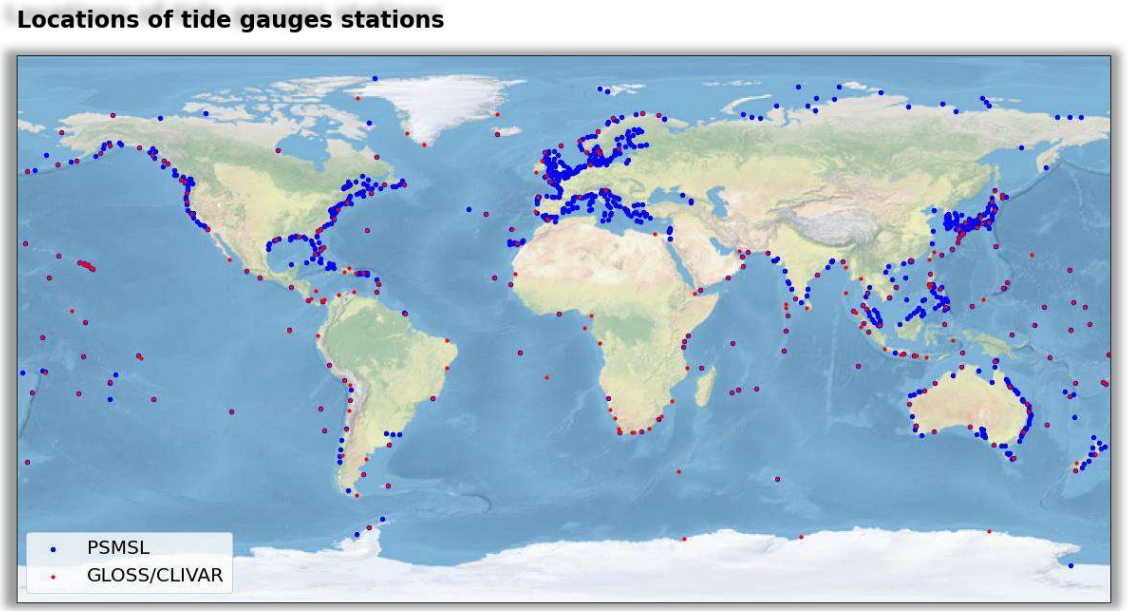


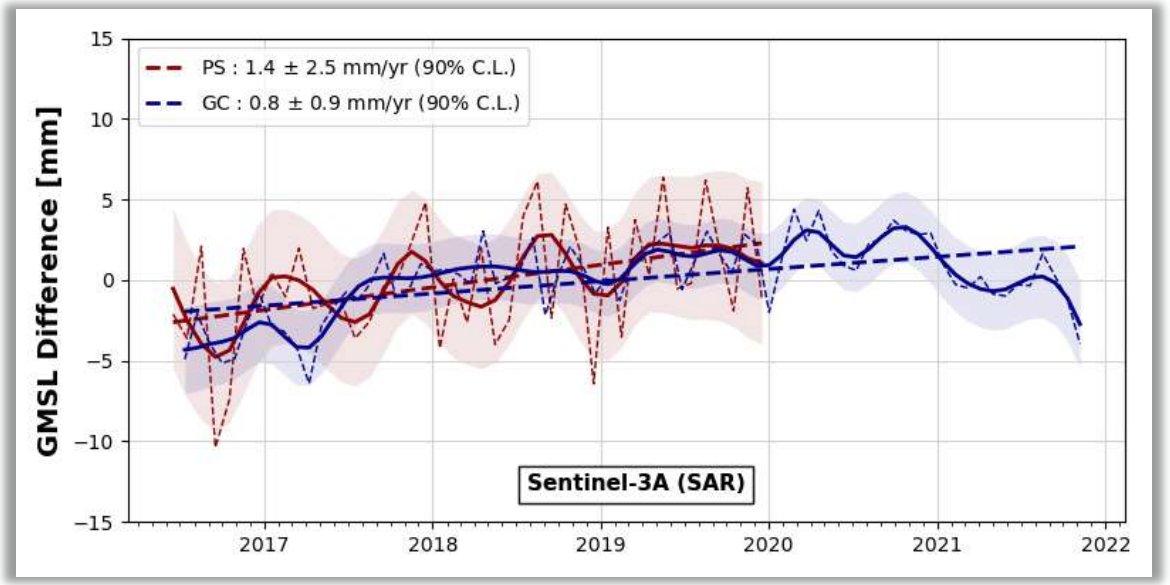
Polar Oceans

Lead SLA

Way forward: the COPAS project

2. Quarterly reports on instrument performance (SRAL, MWR)
3. Annual reports with comparison vs in-situ observations (e.g. tide-gauges, swh and wind…)





4. Dedicated scientific studies over key regions (e.g. coastal, high-latitudes…)

https://eumetsatspace.atlassian.net/wiki/spaces/PQ/pages/1828126721/Sentinel-3+cyclic+reports

CONCLUSIONS

EUMETSAT

Cal/Val

- ❑ Overall very good performance over the ocean
- ❑ Both in terms of data availability as well as data quality
- ❑ Cycle-to-cycle consistency between mission observations

Error budget

- High-frequency errors
  - ❑ All quantified errors within the requirements (geophysical parameters and corrections)
- Low-frequency errors
  - ❑ Limitations to quantify lower frequencies errors
- Long term trends
  - ❑ Sources of errors for S3A and S3B trends have been identified