WP 5000

Open Ocean Validation of Test Data Set -- Phase 1 & 2

Data reference performances in SAR/PLRM Assessment of alternative SAR altimetry algorithms and improved WTC

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Input data

- **Test Data Set:** 2-years L2 data (TDS phase 1&2 in PLRM/SARM)
- **CPP product** [Boy et al., 2017]: CNES Cryosat-2 Processing Prototype L2 data for comparison / validation
- Atm/env corrections from CLS database used as a reference for CPP bias characterization
- **WTC from U. Porto**
- WP3000/WP4000 PSD, ATBD and POCCD

Deliverable

- Product Validation Plan, D2.4 – **Completed**
- Product Validation Report (Phase 1&2), D2.5 – **On-going**

Methodologies

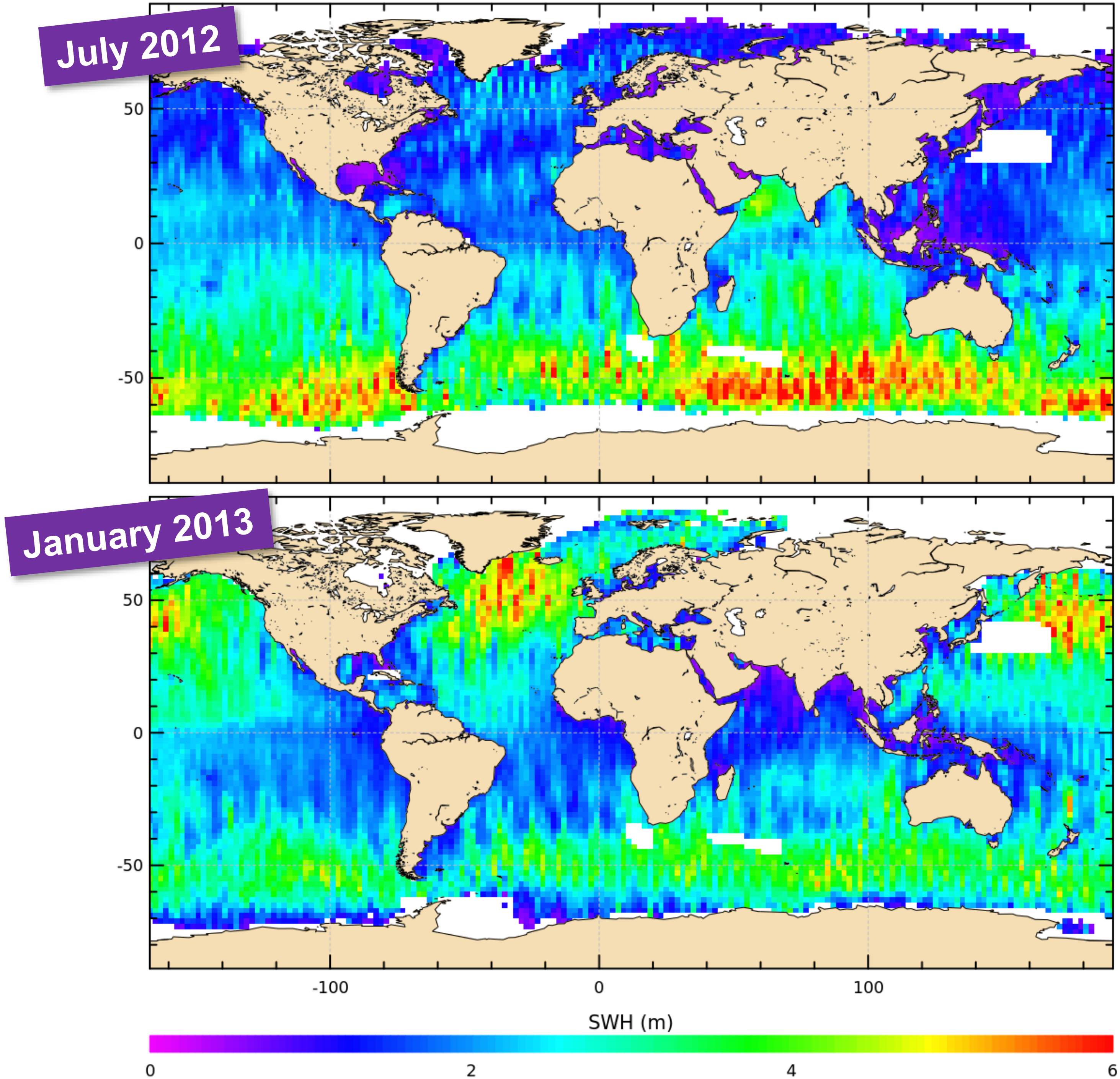
- **Phase 1: Assessment of the reference Test Data Sets**
  - Relative validation of SAR-mode TDS (GPOD) by comparison with CPP SARM [Raynal et al., 2018]
  - Relative validation of PLRM dataset (from TU-Delft) by comparison with CPP PLRM [Raynal et al., 2018]
  - Large amount of observations shall permit to make a deep assessment with reliable statistic even though CY2 SAR mode is not operated in global

- **Phase 2: Assessment of alternative SAR altimetry + improved WTC**
  - Validation of innovative SAR-mode TDS (from IsardSAT) by comparison with the reference (GPOD)
  - Validation of GPD WTC by comparison with ECMWF Operational model

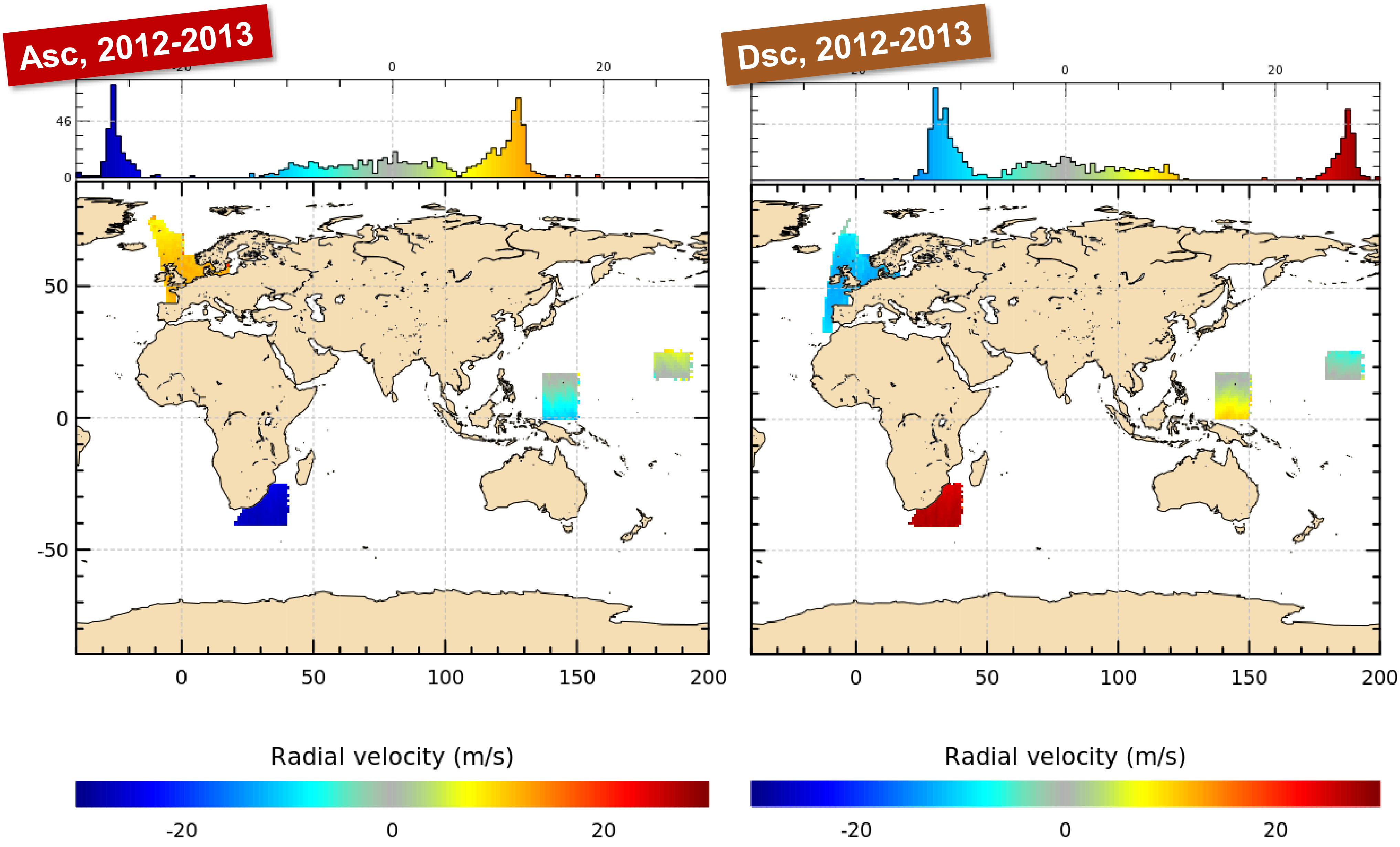
- **TDS and CPP data are co-dated with less than 0.5s of time difference which is acceptable for the analysis of large-scale errors**

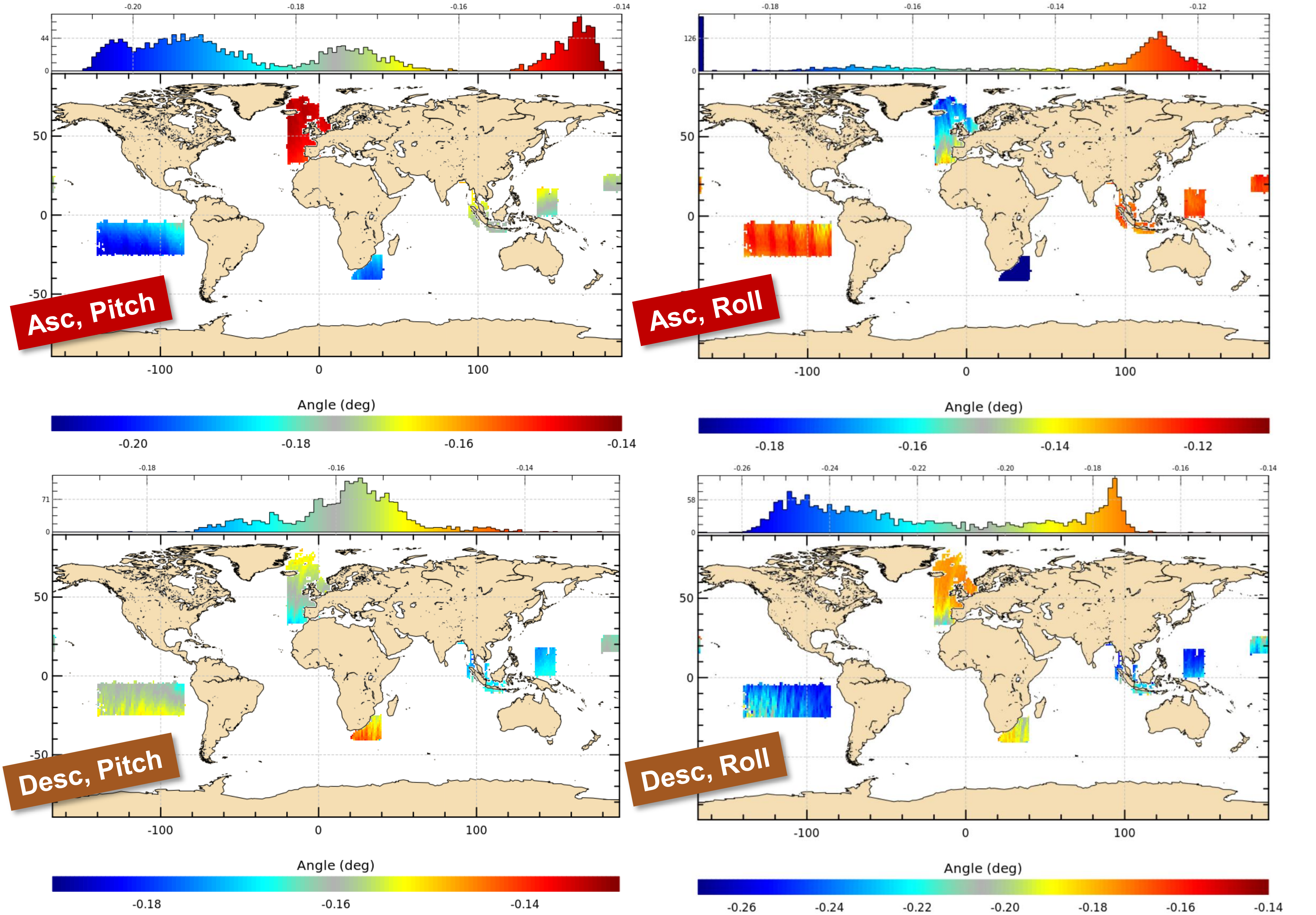
FIRST ANALYSIS OBJECTIVE

- **Analysis to be done to assess the consistency of the combined L1b/L2 processing**
  - TDS/CPP differences sensitivity to
    - Varying sea state conditions: SWH, Sigma0
    - Orbital/platform parameters: radial velocity, roll/pitch, altitude
  - Diagnosis to detect correlation errors at large scale
    - Cartography: to visualize geographically potential correlated discrepancies
    - Diagram Dispersion: to assess dependencies of their difference wrt the identified parameters
  - Different scenario may be addressed regarding the detected issues
    - L1b processing inconsistency (radial velocity)
    - L2 backscattered waveform model inconsistency (sea states)
    - Or inhomogeneity between L1b and L2 processing (mismatched roll/pitch, inconsistent number of looks or range correction between data/model, ..)



July 2012
January 2013
50
0
-50
-100
0
100
SWH (m)
0
2
4
6


Asc, 2012-2013
0
20
46
0
50
0
-50
0
50
100
150
200
Radial velocity (m/s)
-20
0
20
Dsc, 2012-2013
0
20
0
50
100
150
200
Radial velocity (m/s)
-20
0
20

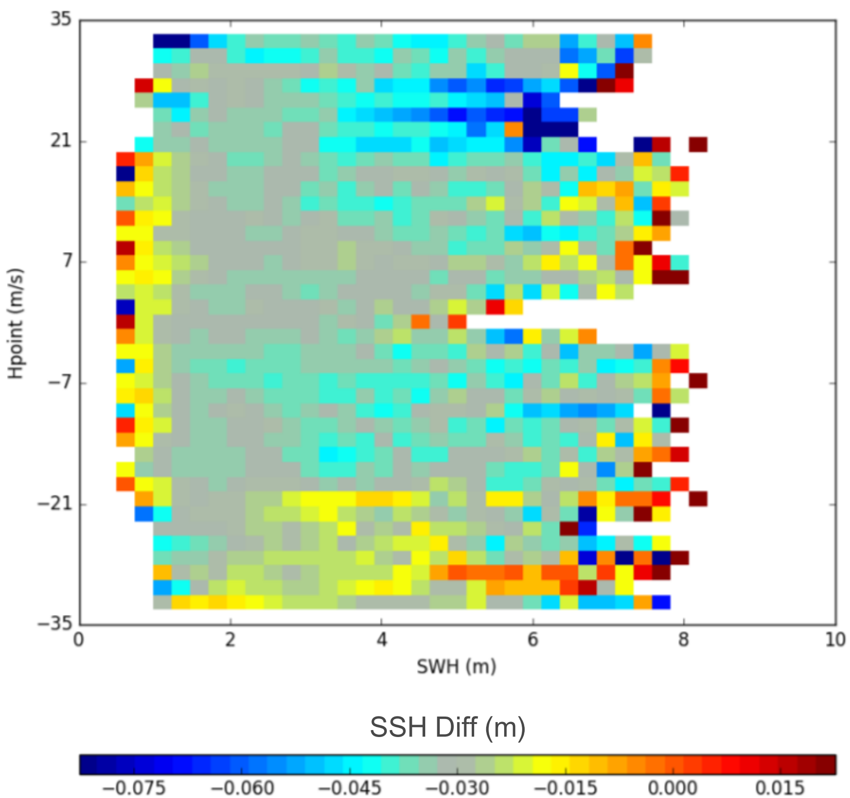


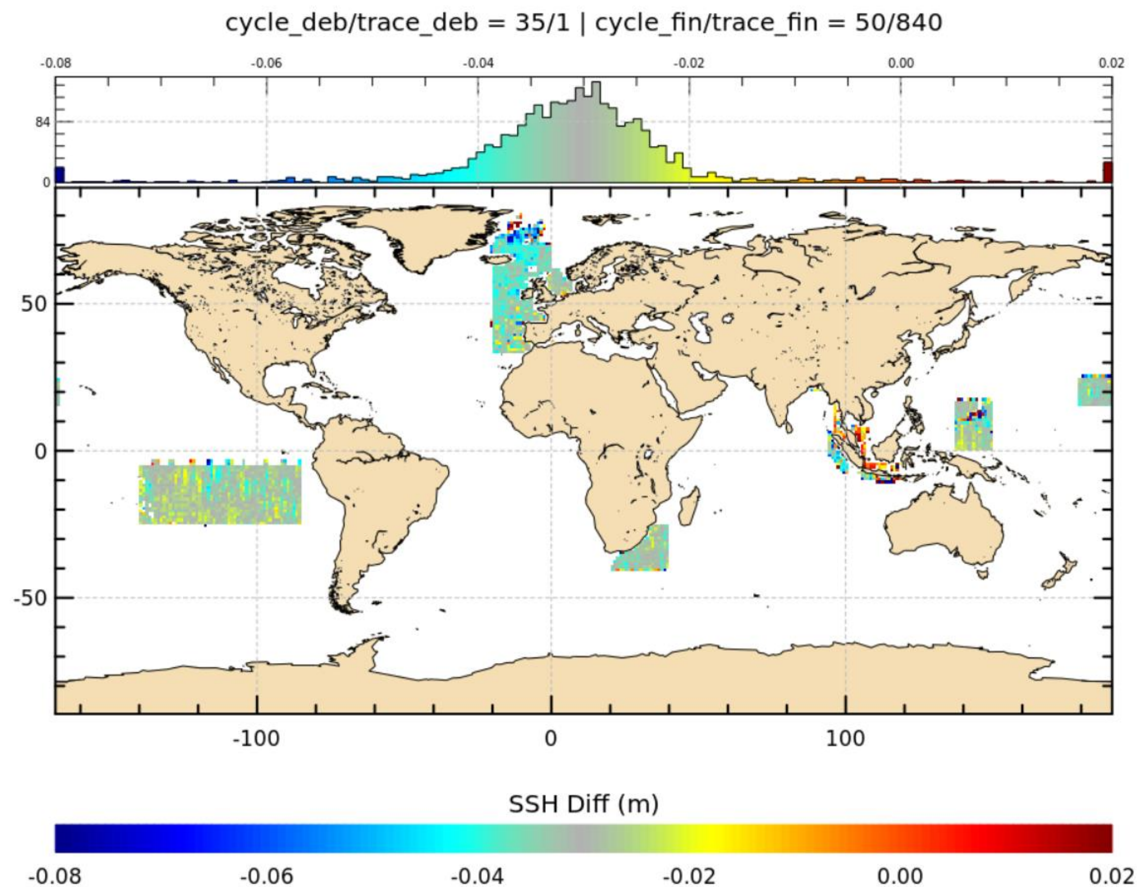
Asc, Pitch
Asc, Roll
Desc, Pitch
Desc, Roll
Angle (deg)
-0.20
-0.18
-0.16
-0.14
-0.12
-0.26
-0.24
-0.22
-100
0
100
50
-50

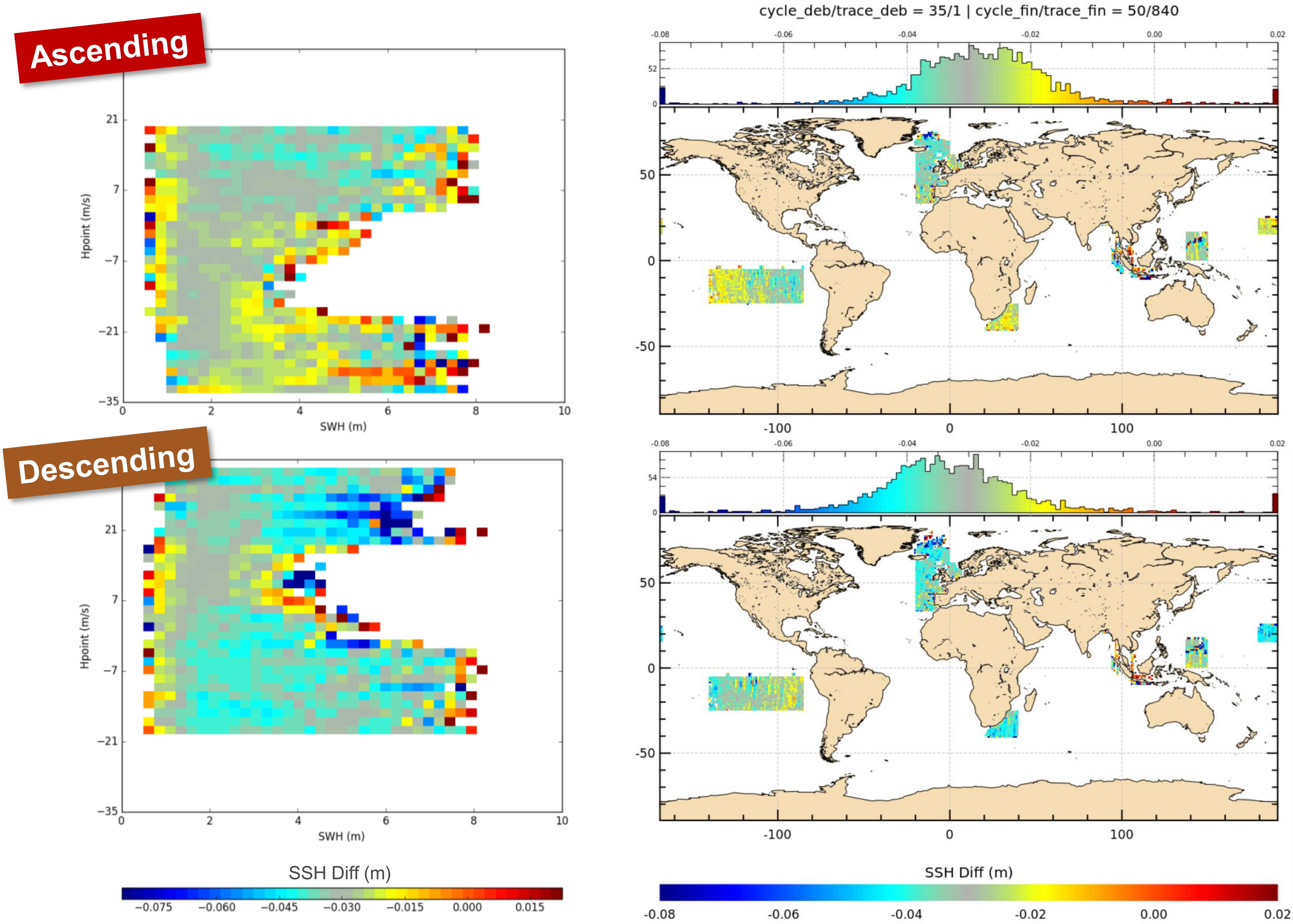
VALIDATION
TU-DELFT PLRM / CPP
AT LARGE SCALES

PLRM SSH DIFFERENCES

- Mean: -3.1cm
- Std: 5.6 cm



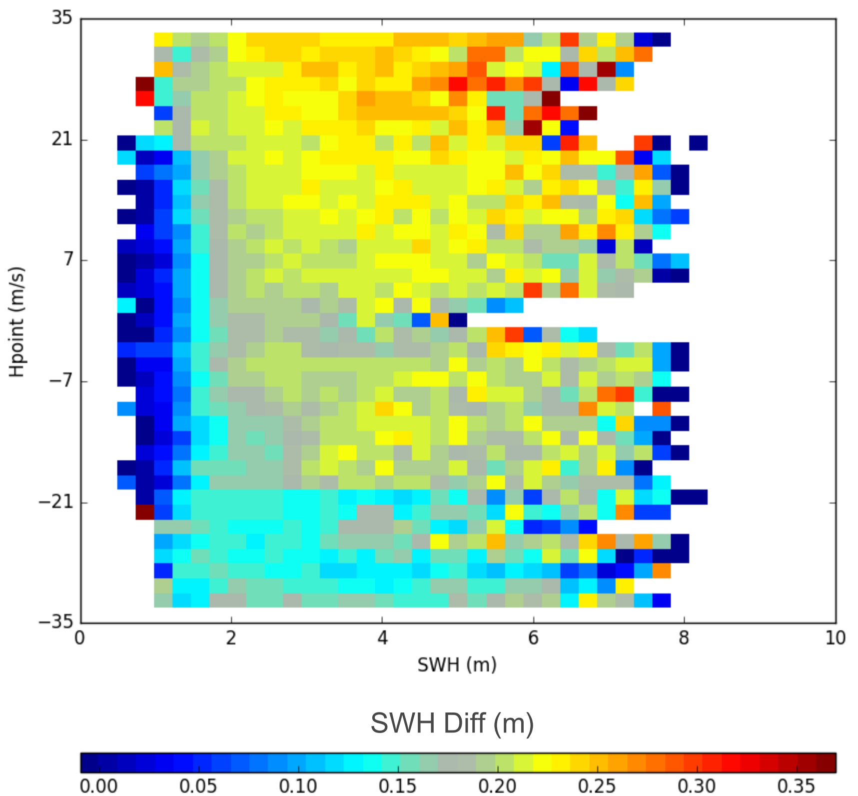


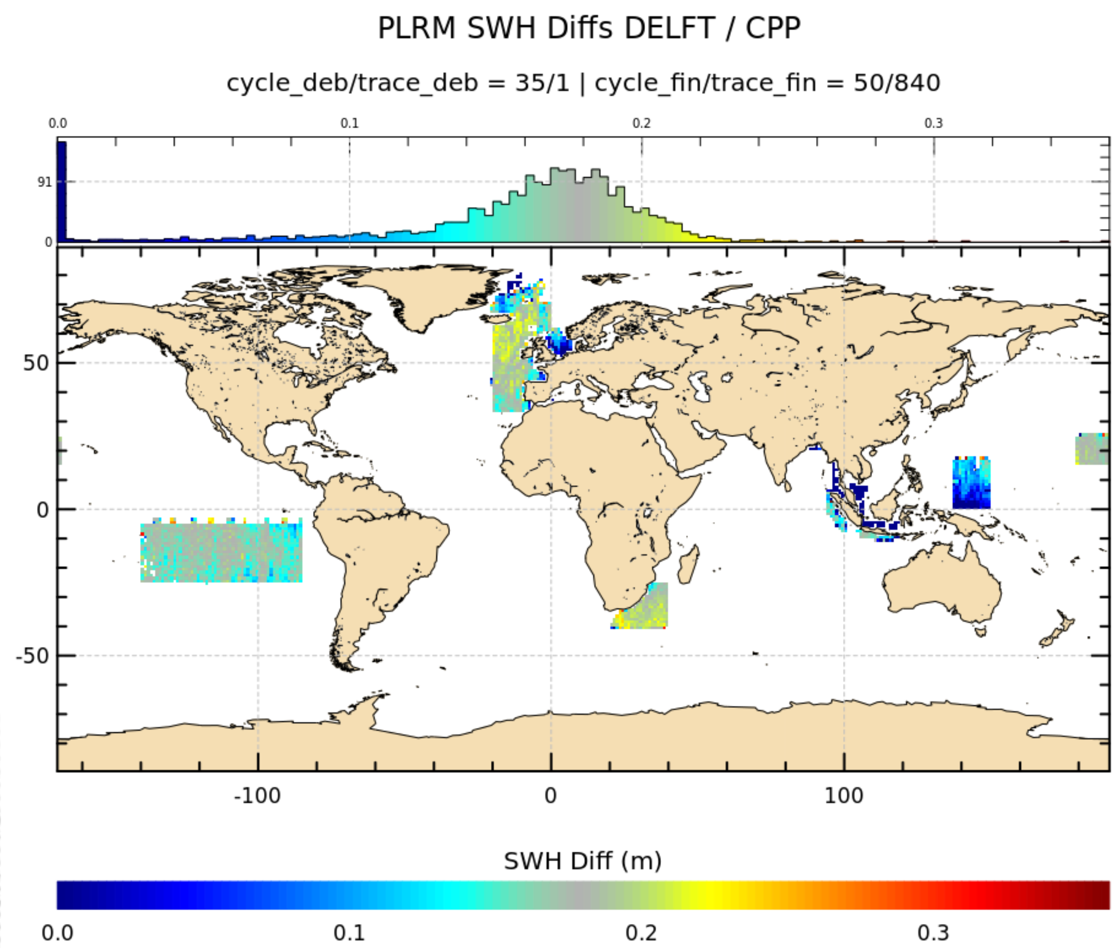


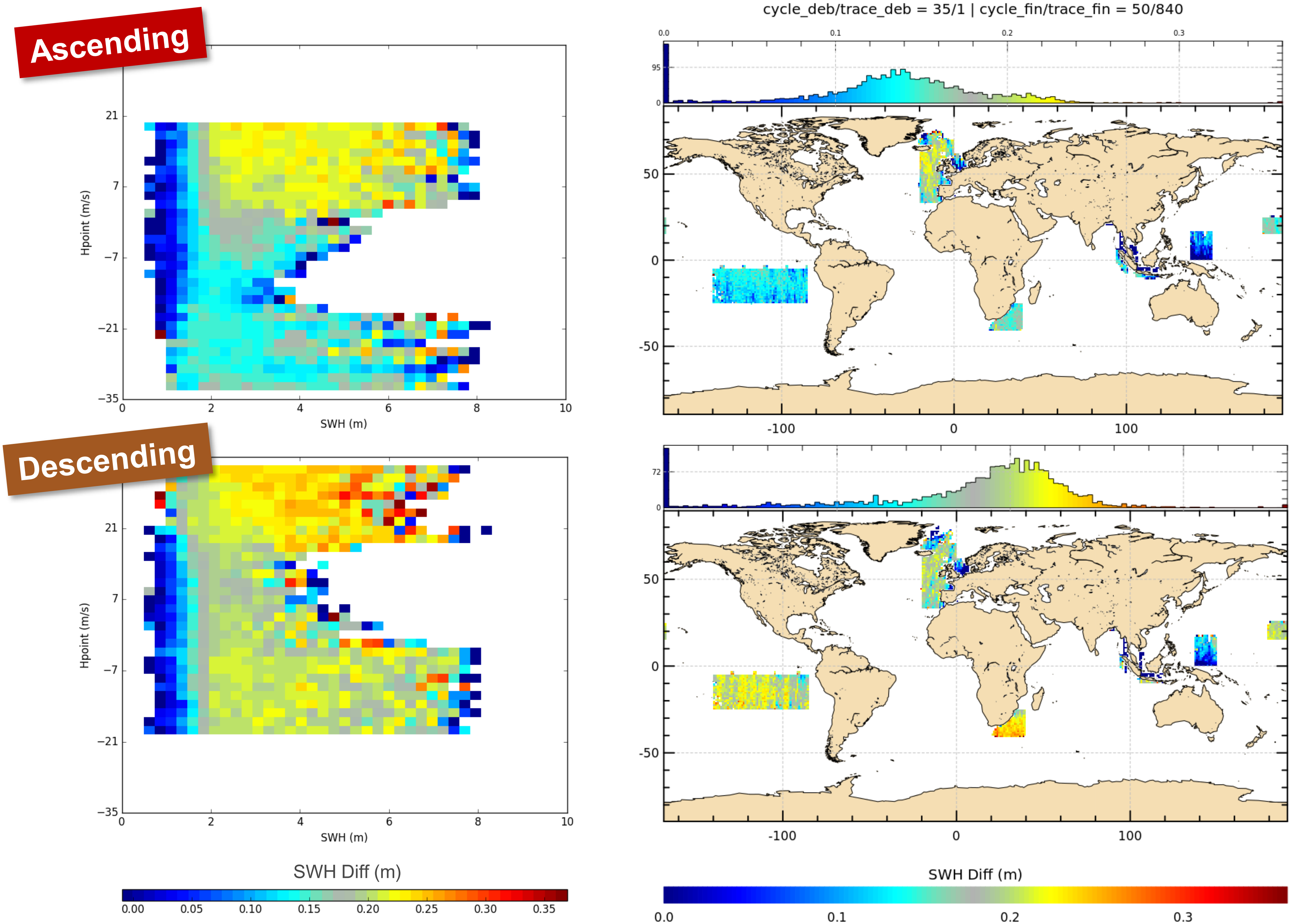
Ascending
Descending
Hpoint (m/s)
SWH (m)
SSH Diff (m)
−0.075
−0.060
−0.045
−0.030
−0.015
0.000
0.015
cycle_deb/trace_deb = 35/1 | cycle_fin/trace_fin = 50/840
-0.08
-0.06
-0.04
-0.02
0.00
0.02
-100
0
100
50
-50

PLRM SWH DIFFERENCES

- Mean: 15.1 cm
- Std: 22.0 cm



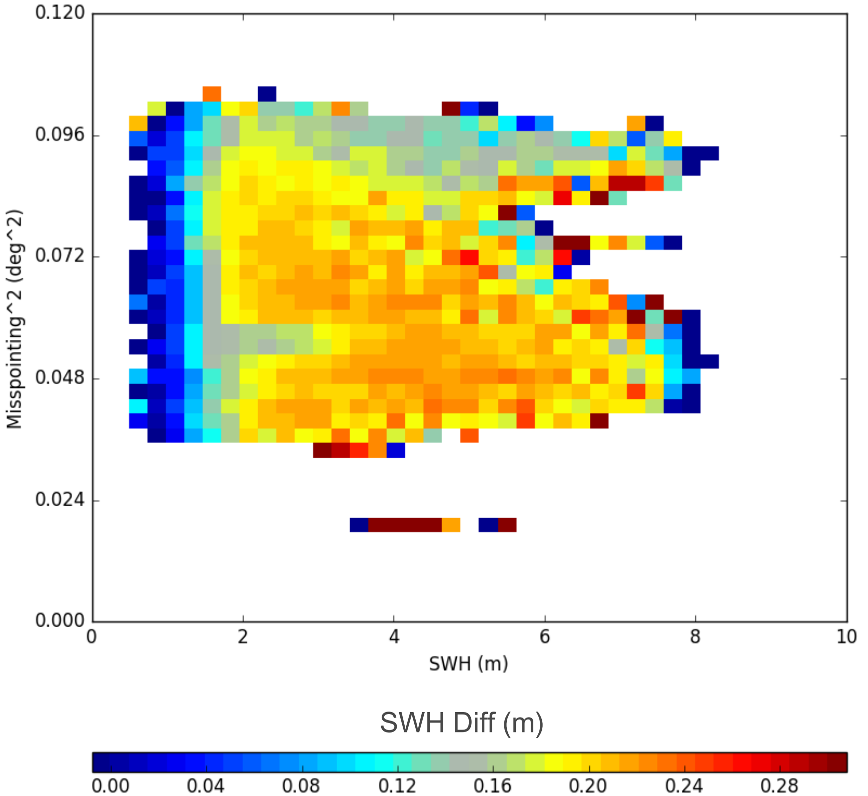


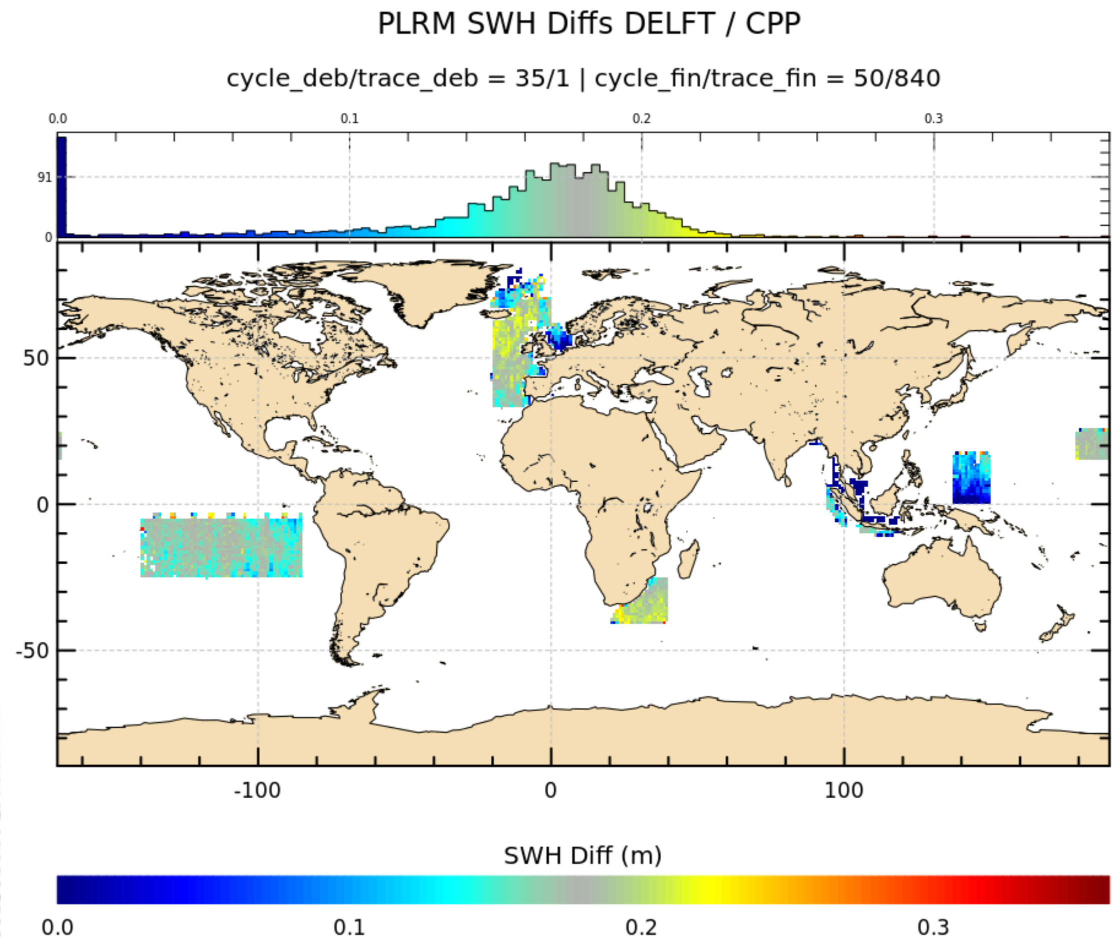


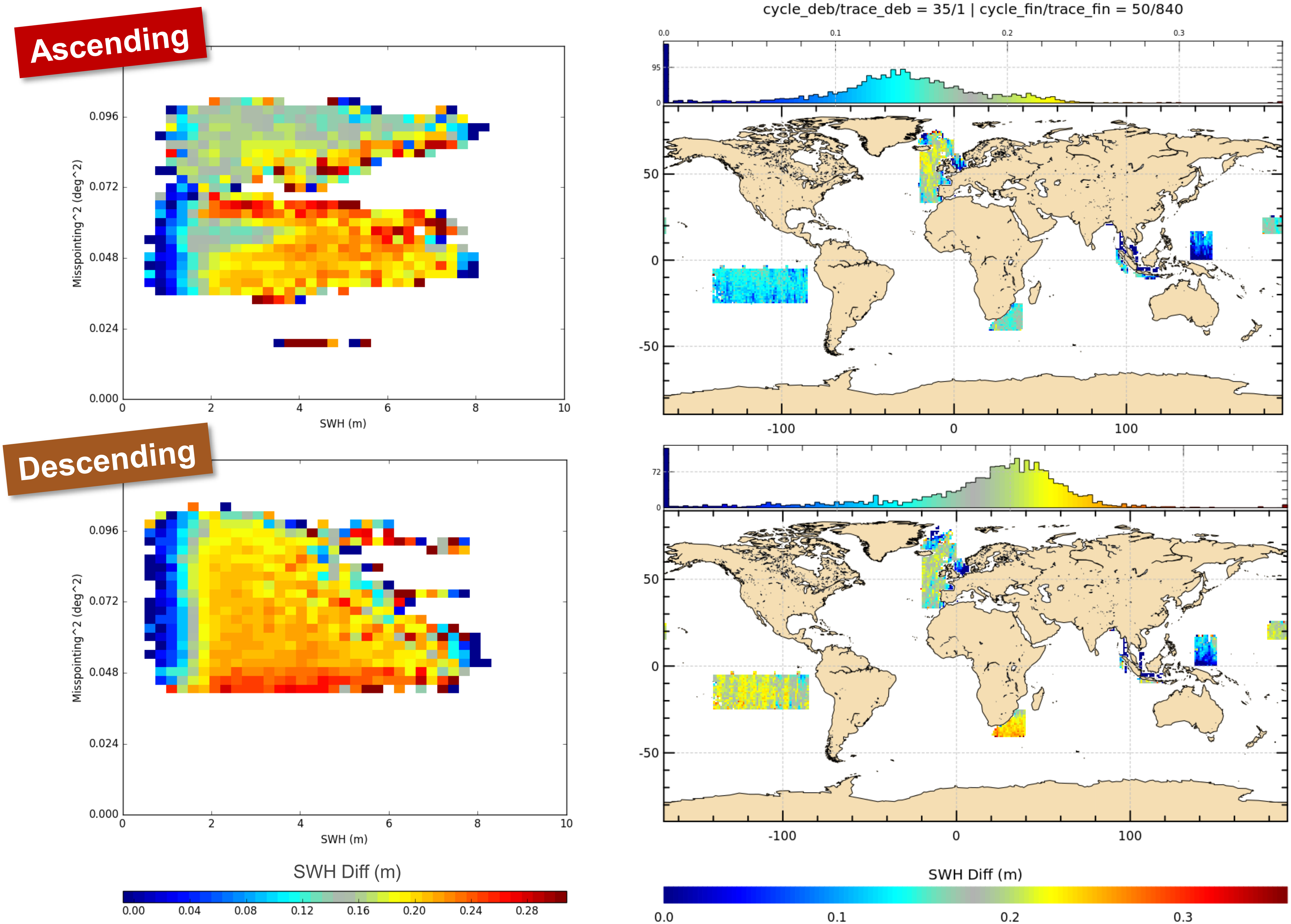
Ascending
Descending
cycle_deb/trace_deb = 35/1 | cycle_fin/trace_fin = 50/840
Hpoint (m/s)
SWH (m)
SWH Diff (m)

PLRM SWH DIFFERENCES

- Mean: 15.1 cm
- Std: 22.0 cm

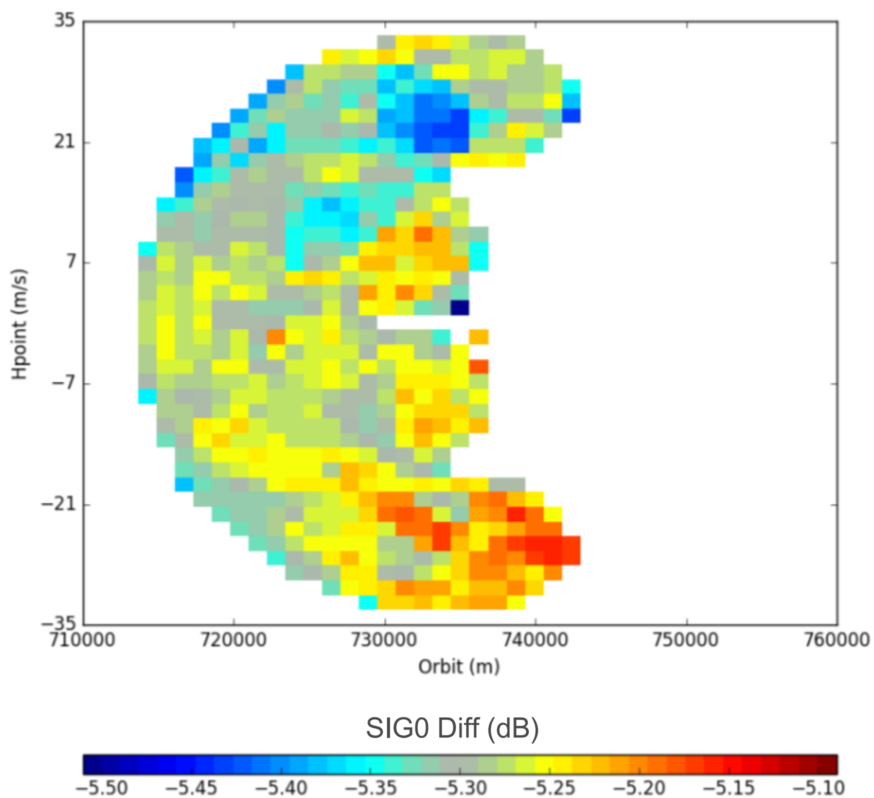


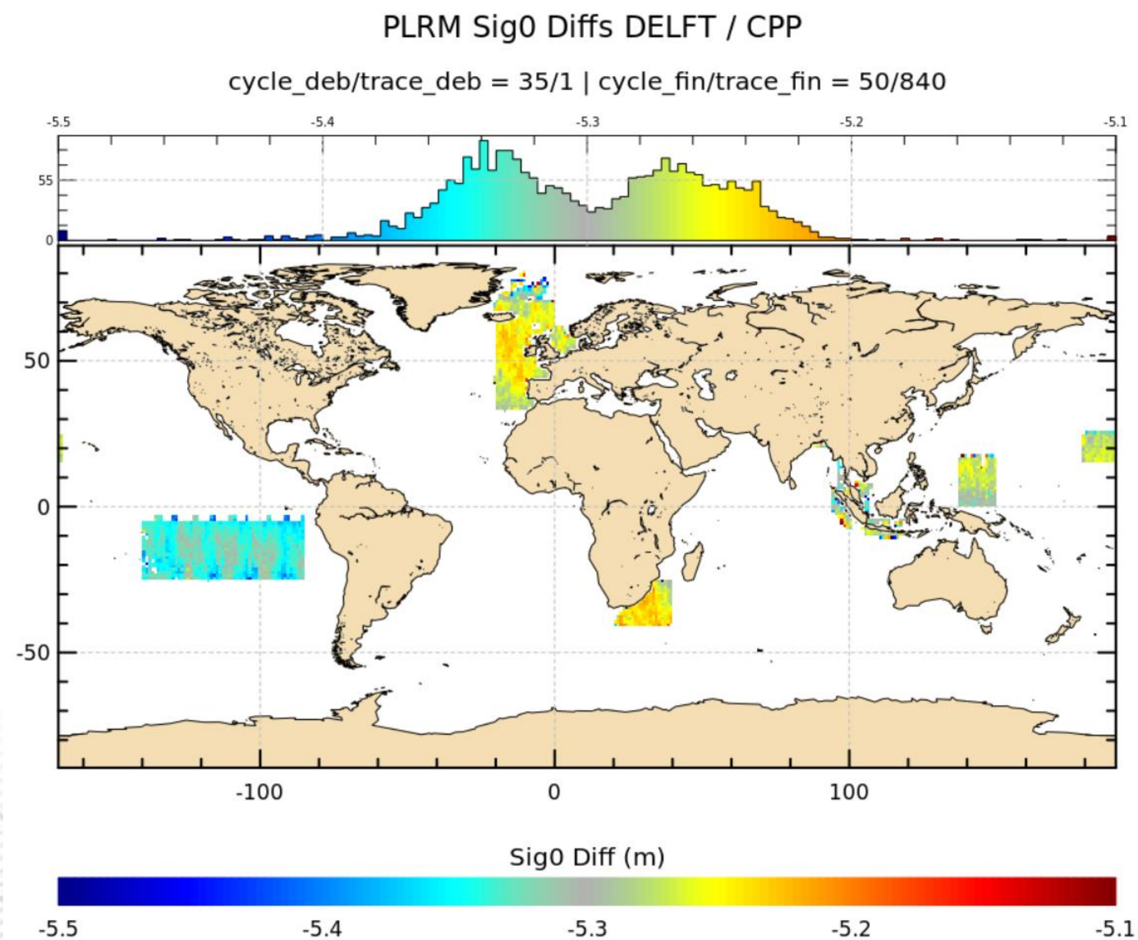


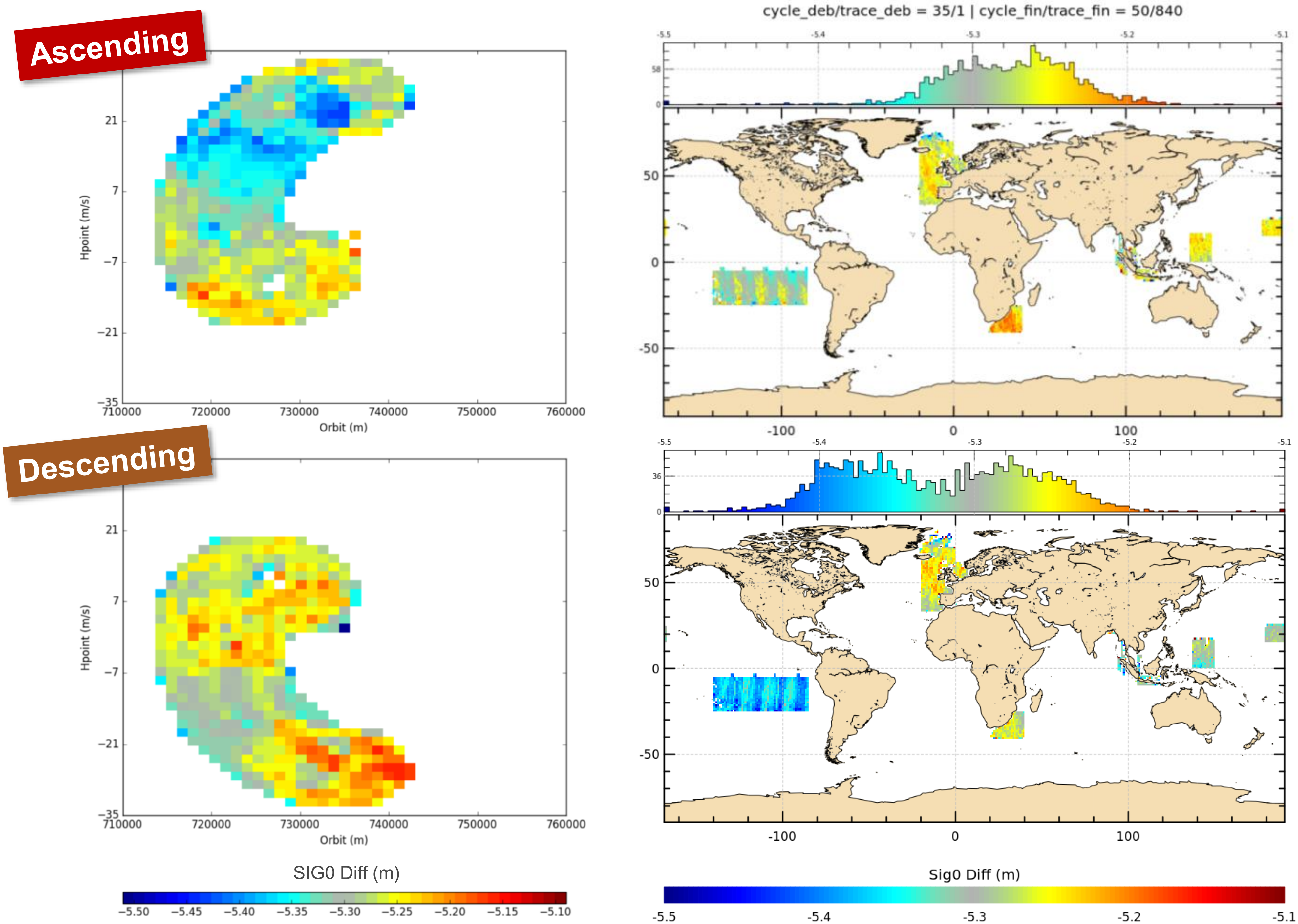

Ascending
Descending
cycle_deb/trace_deb = 35/1 | cycle_fin/trace_fin = 50/840
Misspointing^2 (deg^2)
SWH (m)
SWH Diff (m)
SWH Diff (m)

PLRM SIG0 DIFFERENCES

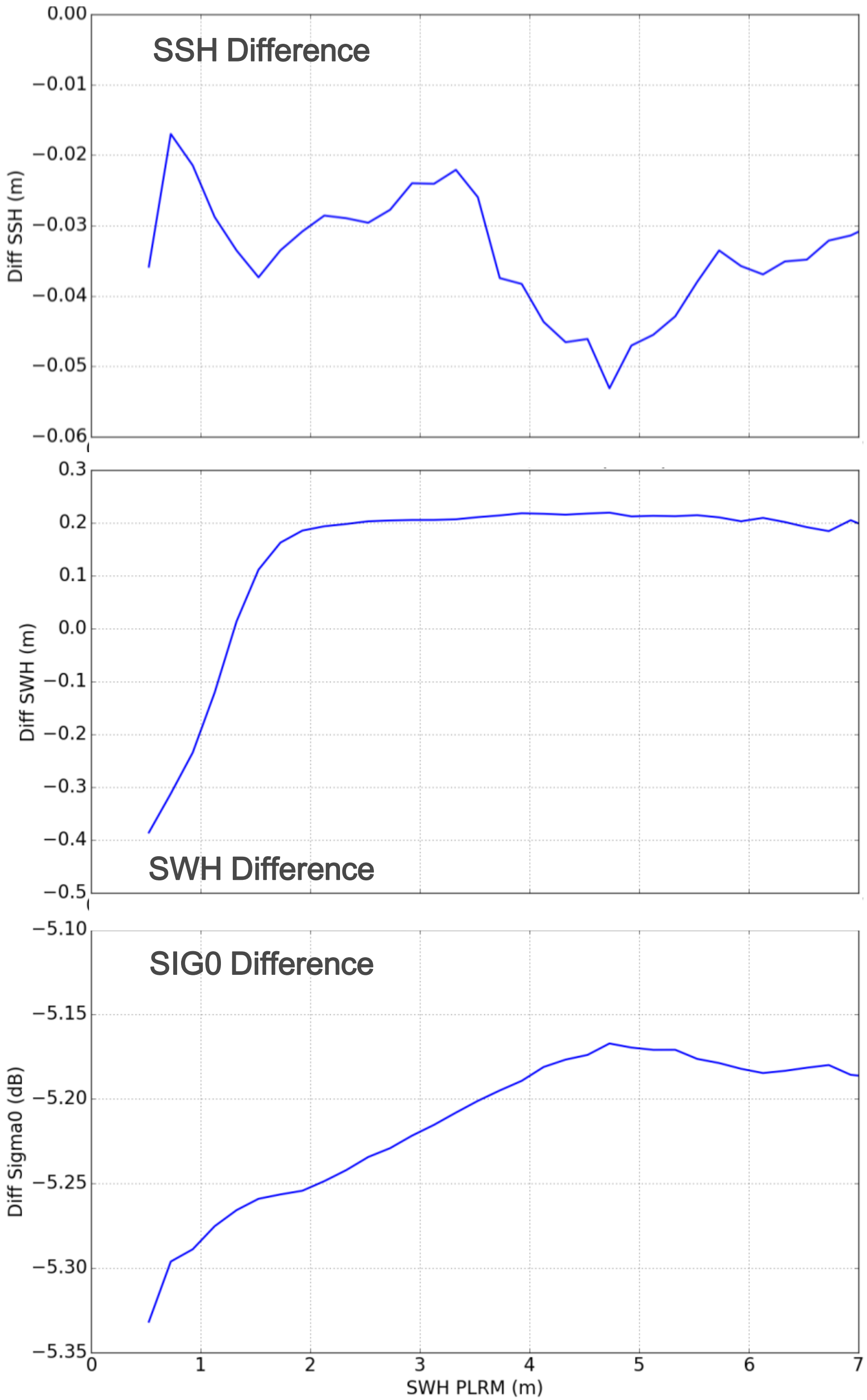
- Mean: -5.28 dB
- Std: 0.37 dB







Ascending
Descending
Hpoint (m/s)
Orbit (m)
21
7
−7
−21
−35
710000
720000
730000
740000
750000
760000
cycle_deb/trace_deb = 35/1 | cycle_fin/trace_fin = 50/840
-5.5
-5.4
-5.3
-5.2
-5.1
58
36
0
50
-50
-100
100
SIG0 Diff (m)
−5.50
−5.45
−5.40
−5.35
−5.30
−5.25
−5.20
−5.15
−5.10
Sig0 Diff (m)



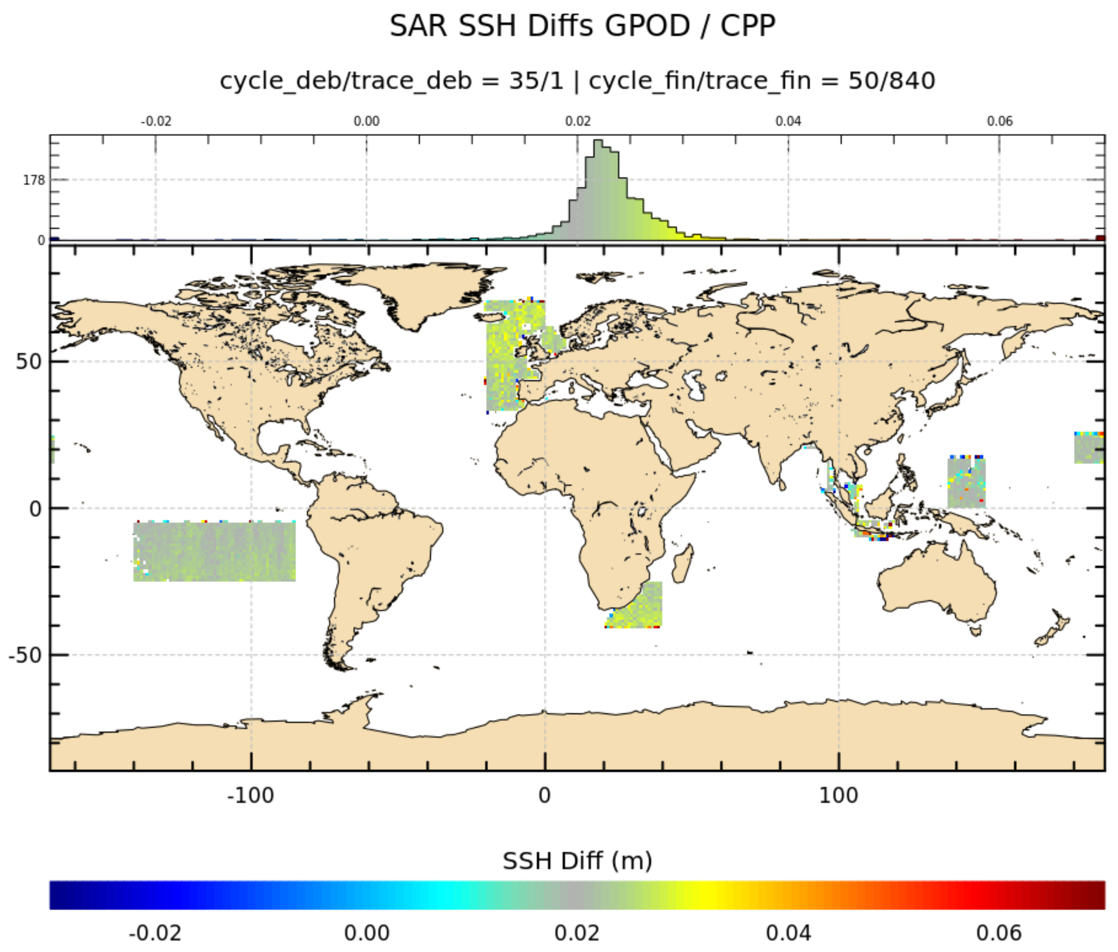
TU-Delft PLRM analysis at large scales :

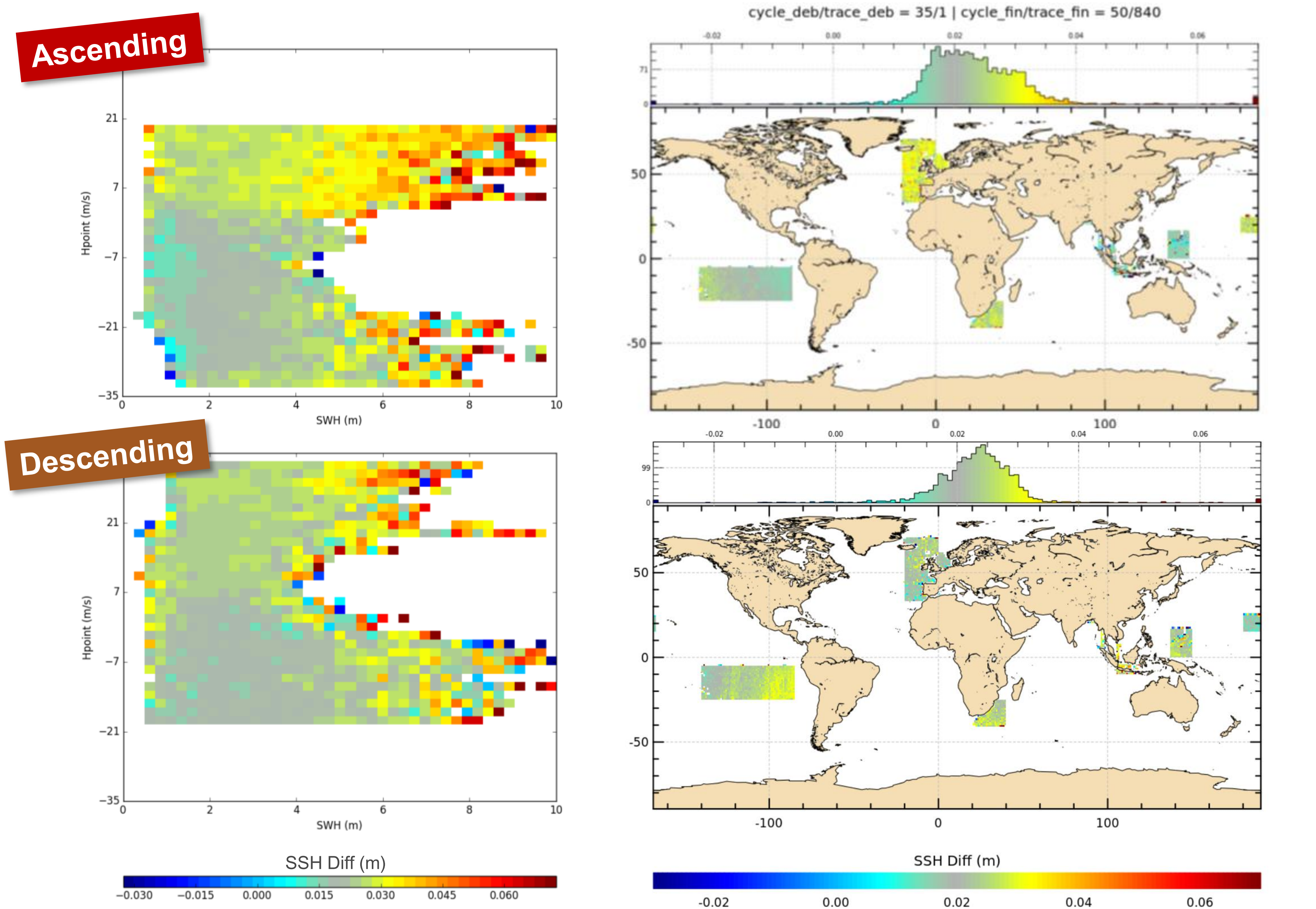
- Non-observable SSH difference related to SWH
  But low dependency of SSH difference on radial velocity, more likely correlated to antenna mispointing angles
  (3-parameter model requires accurate antenna pointing information but not needed by MLE4)
- Non-negligible SWH difference (correction for Gaussian approximation of PTR applied ?)
- Low dispersion of sig0 difference (apparently correlated to mispointing angles)

VALIDATION
SARM GPOD / CPP
AT LARGE SCALES

SARM SSH DIFFERENCES

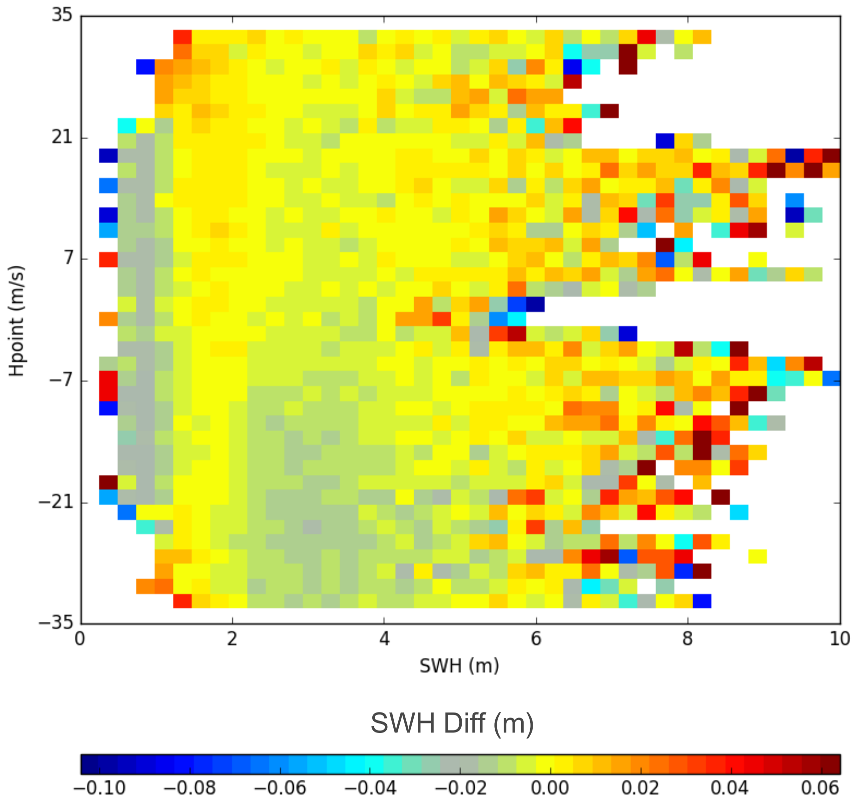
- Mean: 2.3 cm
- Std: 4.9 cm

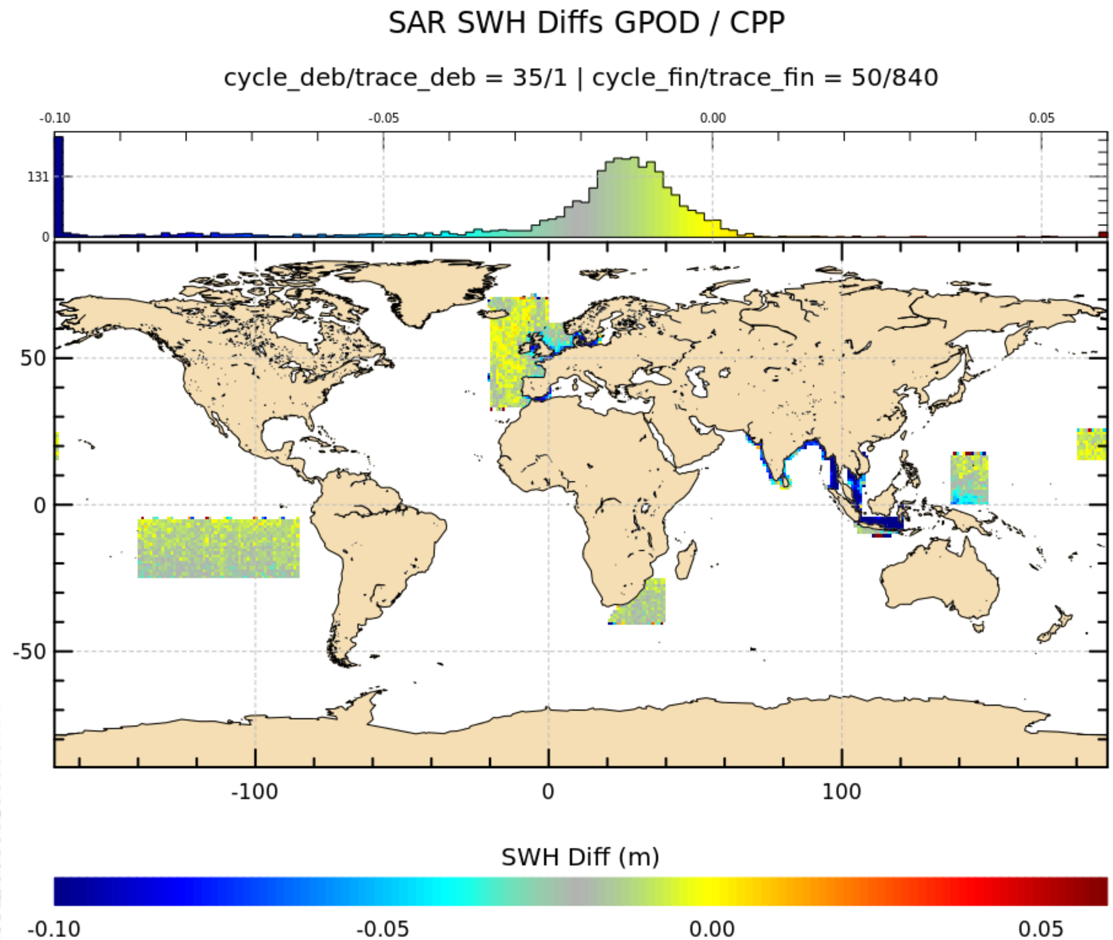


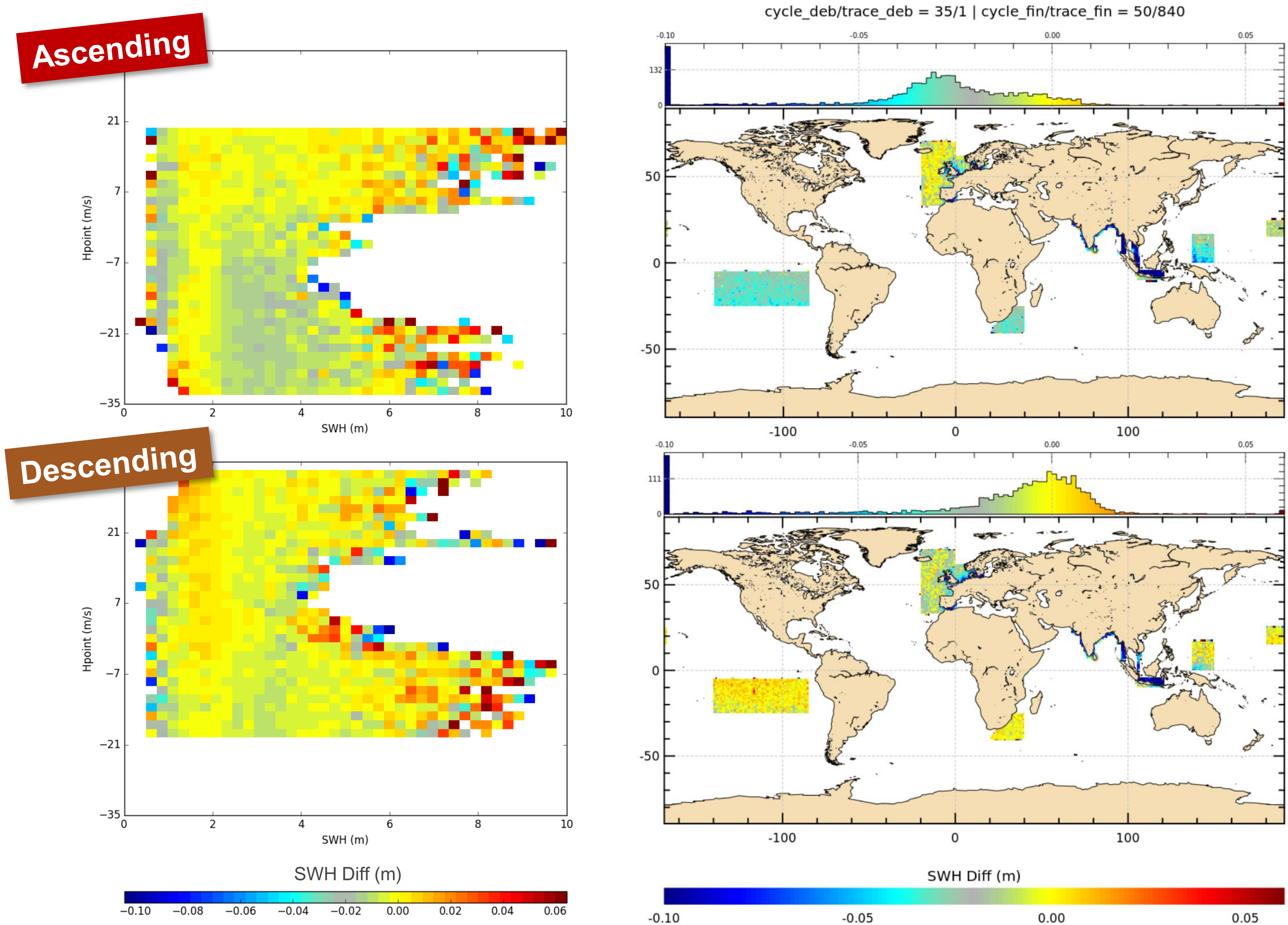

Ascending
Descending
Hpoint (m/s)
21
7
−7
−21
−35
0
2
4
6
8
10
SWH (m)
cycle_deb/trace_deb = 35/1 | cycle_fin/trace_fin = 50/840
-0.02
0.00
0.02
0.04
0.06
71
99
0
50
-50
-100
100
SSH Diff (m)
−0.030
−0.015
0.000
0.015
0.030
0.045
0.060

SARM SWH DIFFERENCES

- Mean: -1.9 cm
- Std: 12.3 cm

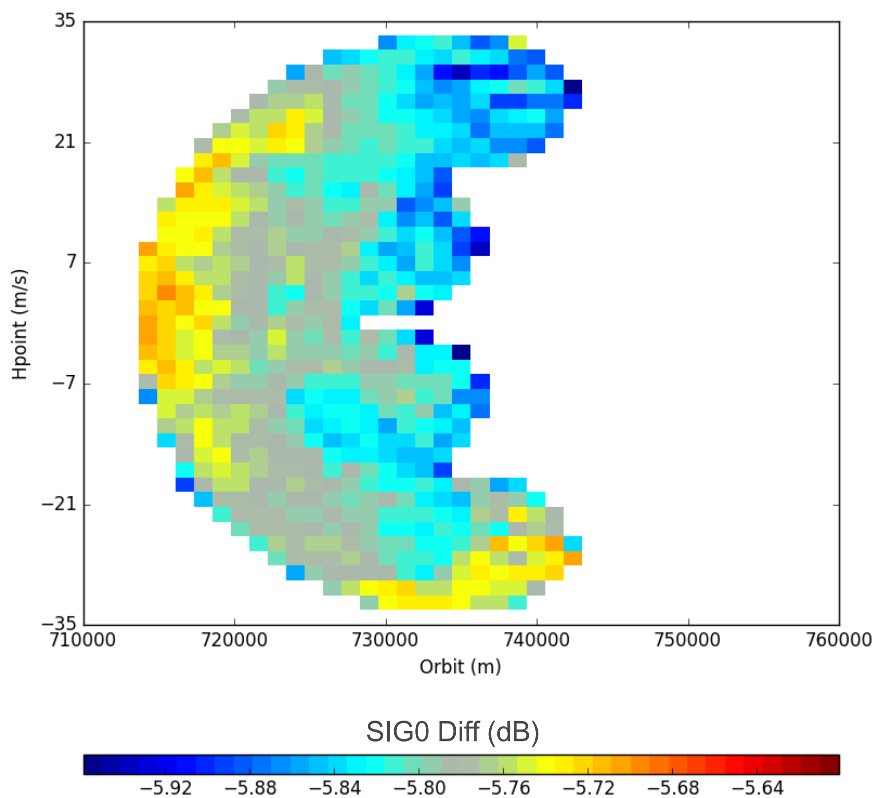


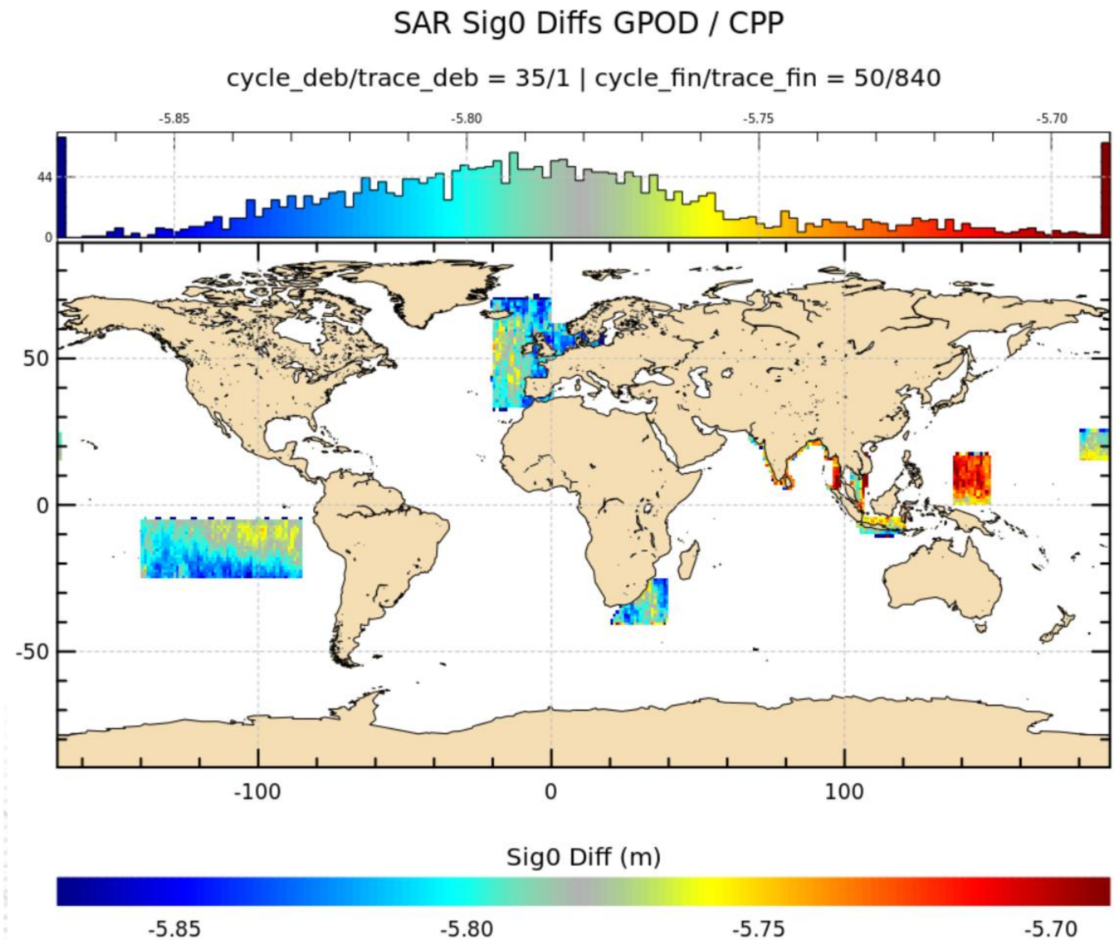


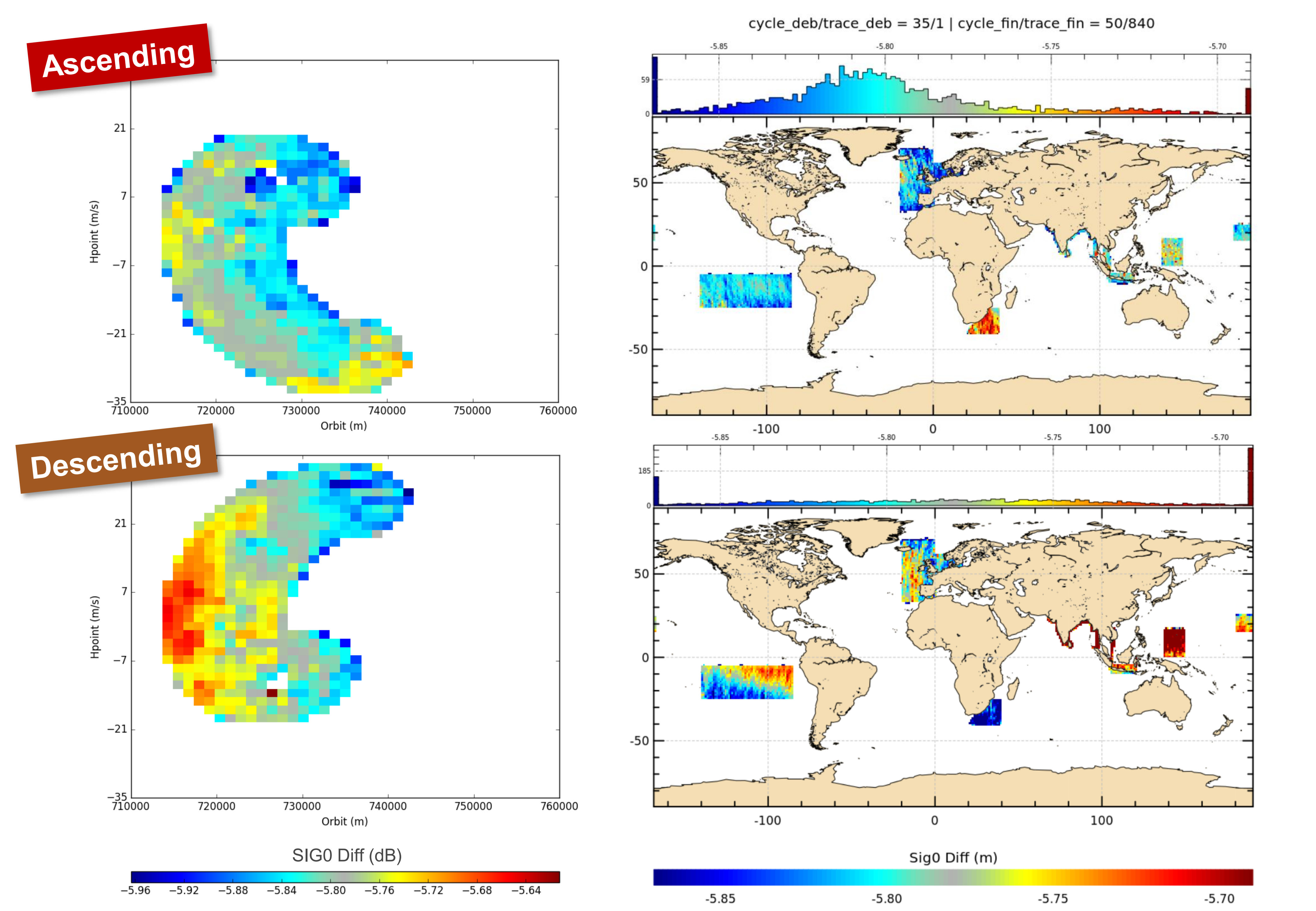

Ascending
Descending
cycle_deb/trace_deb = 35/1 | cycle_fin/trace_fin = 50/840
Hpoint (m/s)
SWH (m)
SWH Diff (m)
21
7
−7
−21
−35
0
2
4
6
8
10
-0.10
-0.05
0.00
0.05
132
111
50
0
-50
-100
100
−0.10
−0.08
−0.06
−0.04
−0.02
0.00
0.02
0.04
0.06

SARM SIG0 DIFFERENCES

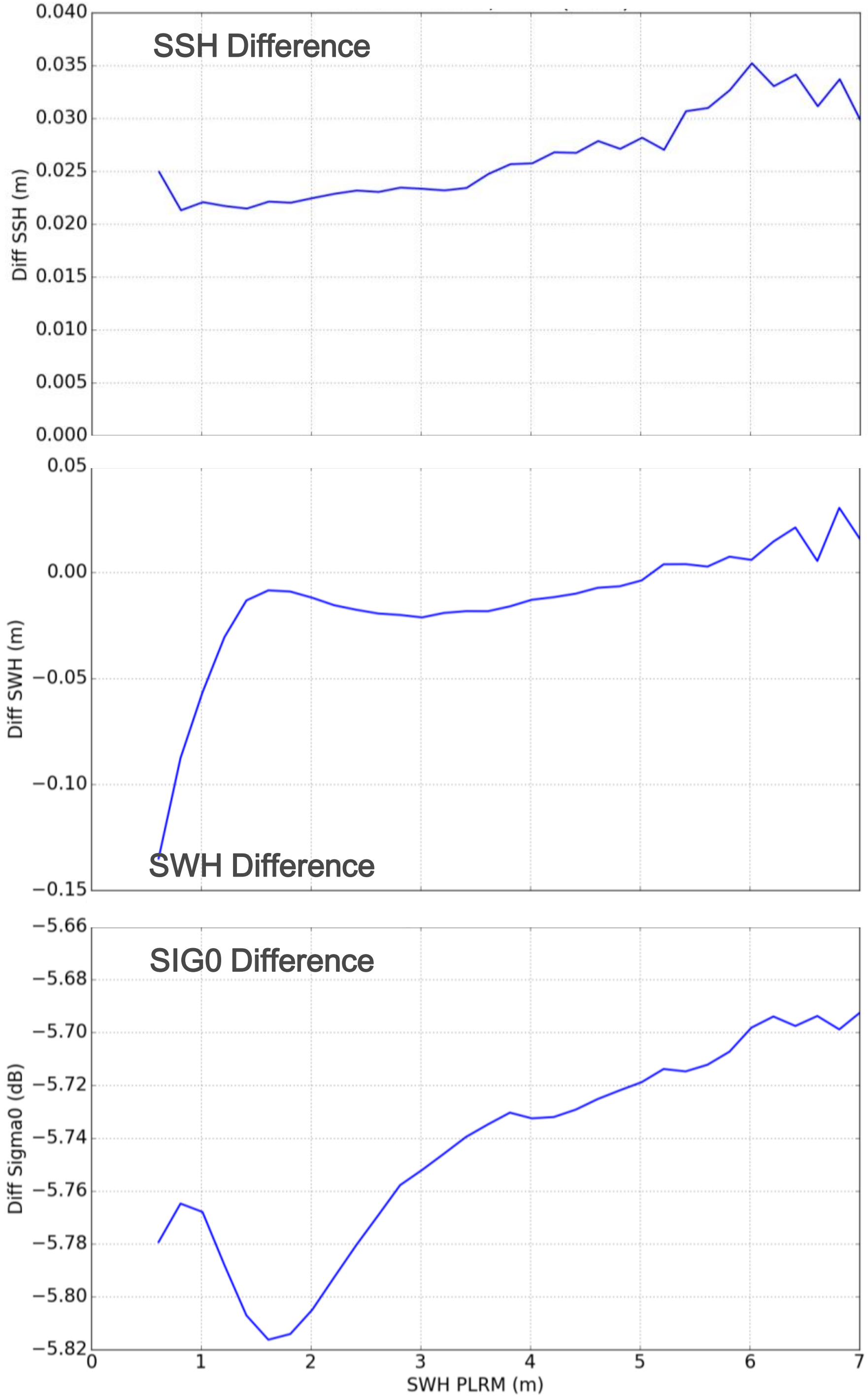
- Mean: -5.79 dB
- Std: 0.15 dB







Ascending
Descending
cycle_deb/trace_deb = 35/1 | cycle_fin/trace_fin = 50/840
Hpoint (m/s)
Orbit (m)
21
7
−7
−21
−35
710000
720000
730000
740000
750000
760000
-5.85
-5.80
-5.75
-5.70
59
185
0
50
-50
-100
100
SIG0 Diff (dB)
−5.96
−5.92
−5.88
−5.84
−5.80
−5.76
−5.72
−5.68
−5.64
Sig0 Diff (m)



GPOD SARM analysis at large scales:

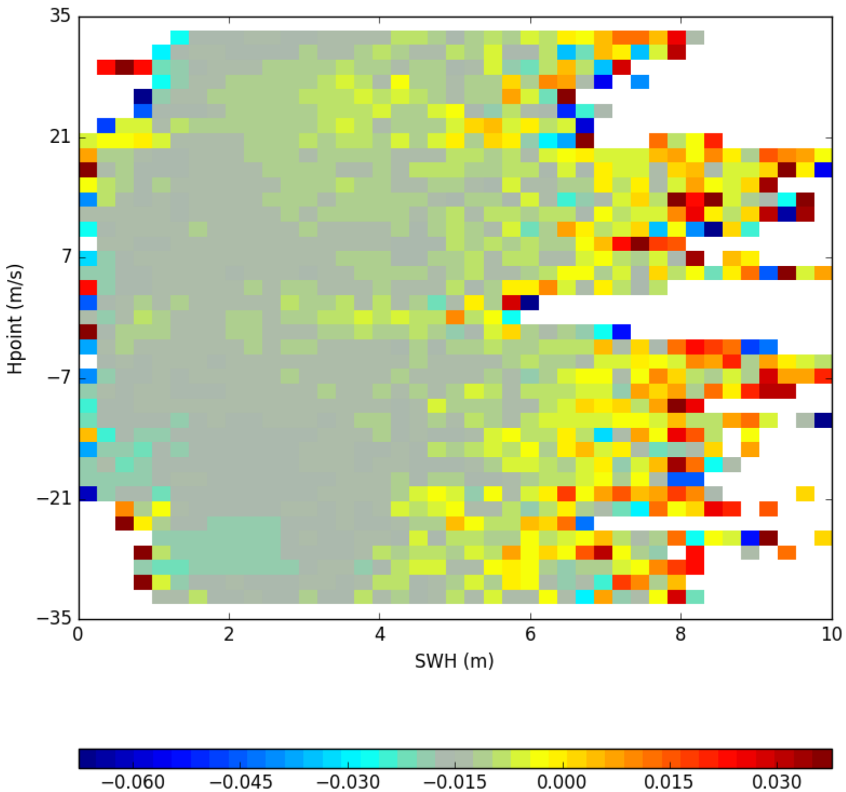
- Very consistent SSH
- Noticeable SWH difference at very low wave height only
- Low dispersion of sig0 difference likely correlated to orbit (modelisation of SAR altimeter backscattered waveform at different altitudes in CPP or GPOD ?)

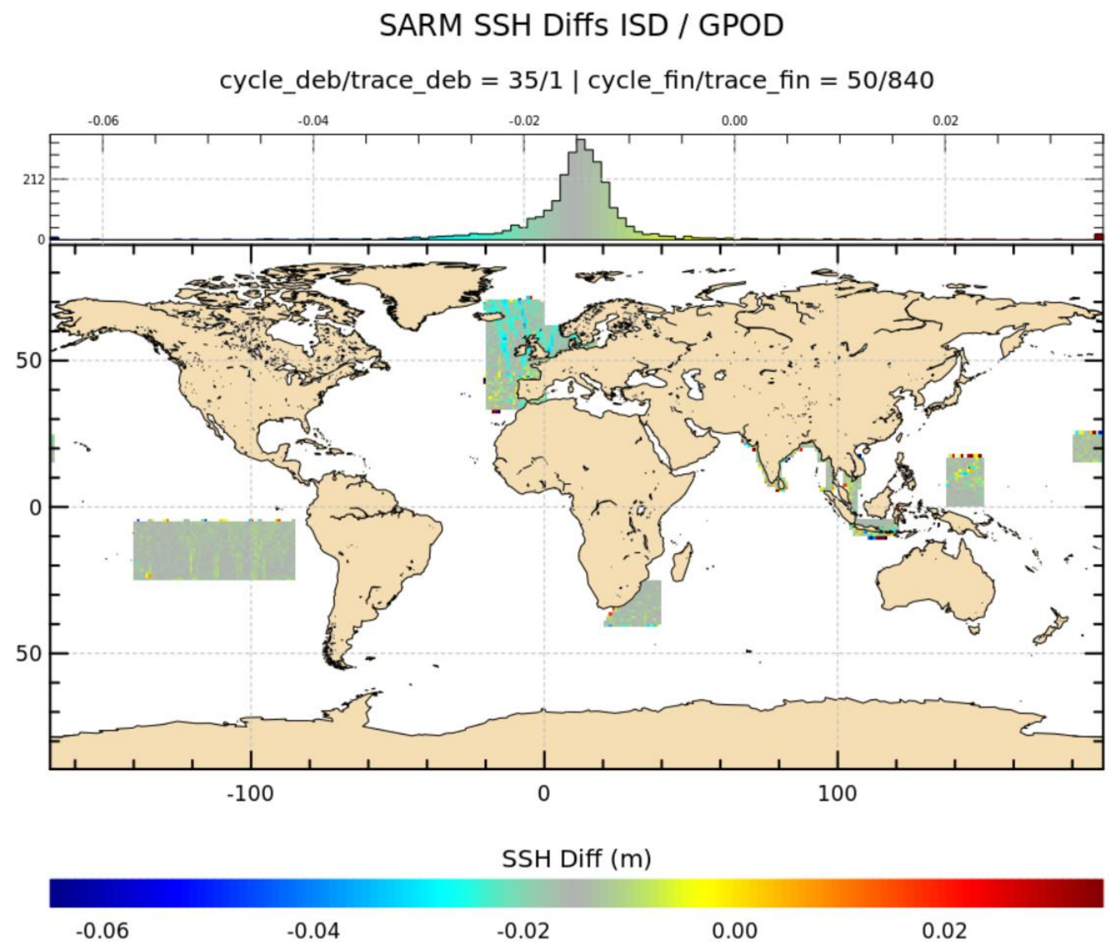
➔ Very good agreement between SARM GPOD and CPP products

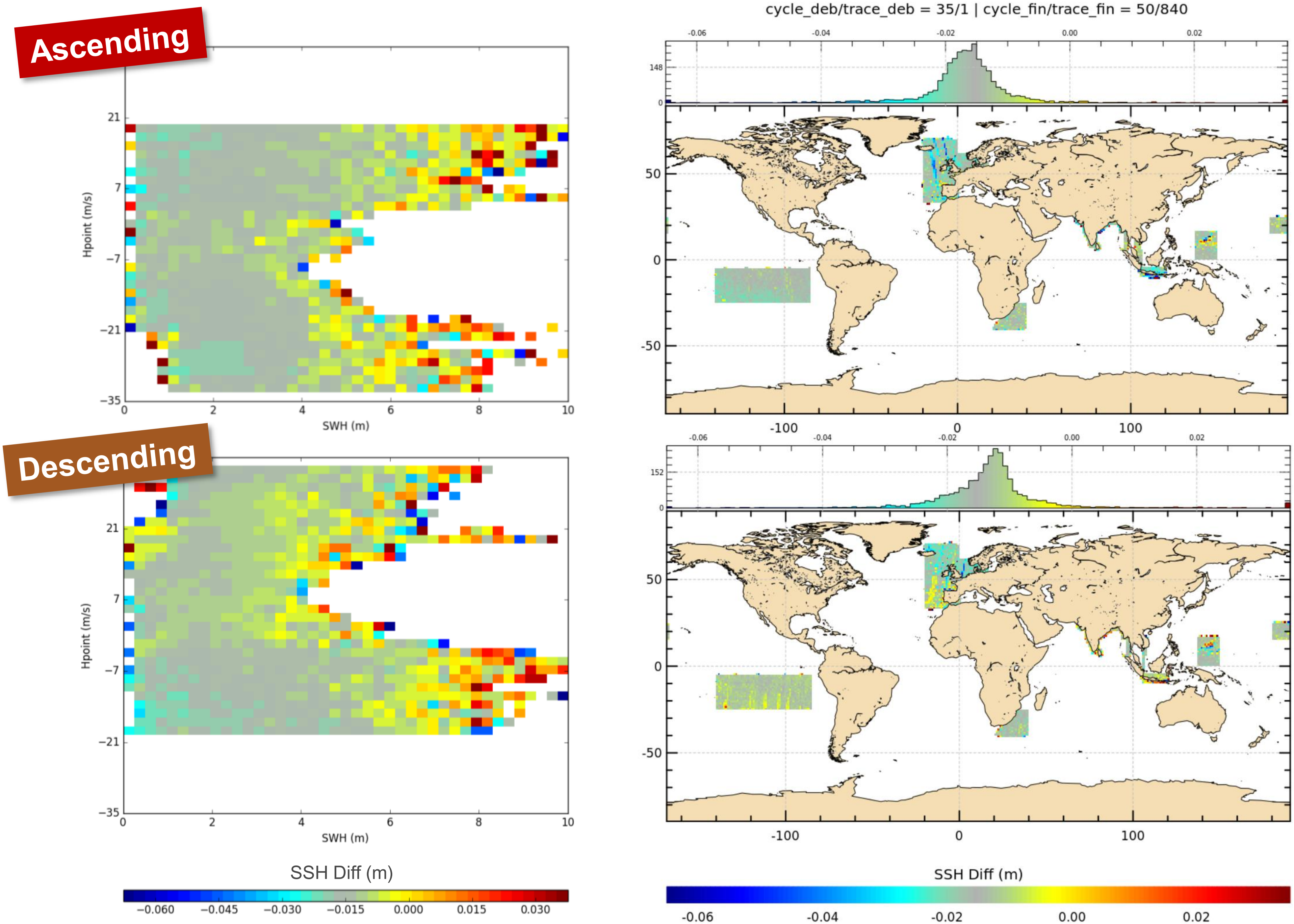
VALIDATION
ALTERNATIVE SAR ALGO / GPOD
AT LARGE SCALES

SARM SSH DIFFERENCES

- Mean: -1.5 cm
- Std: 4.9 cm

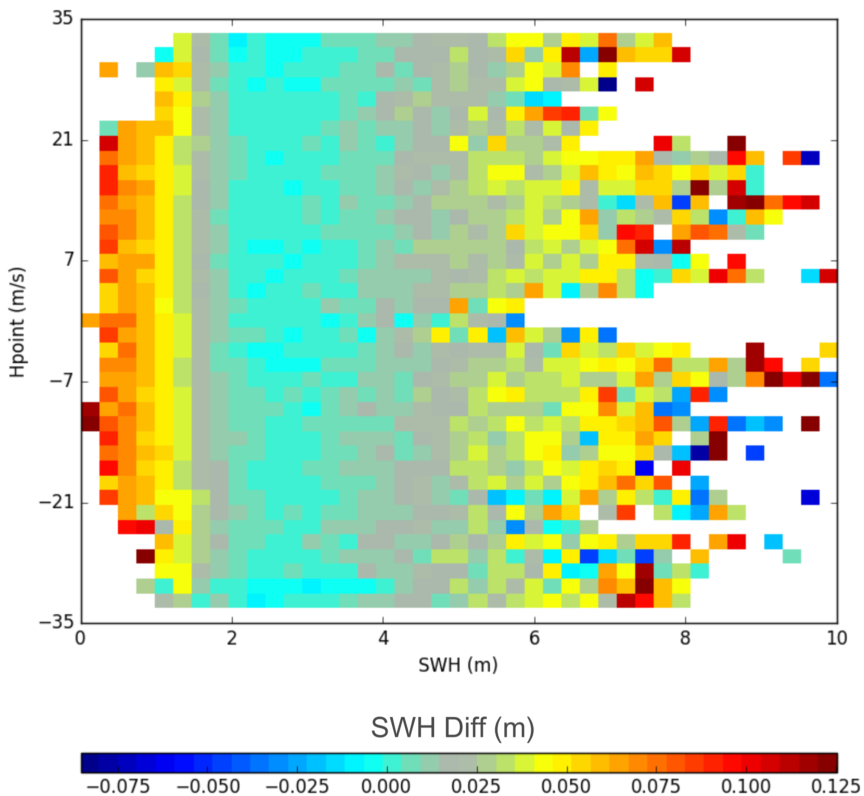


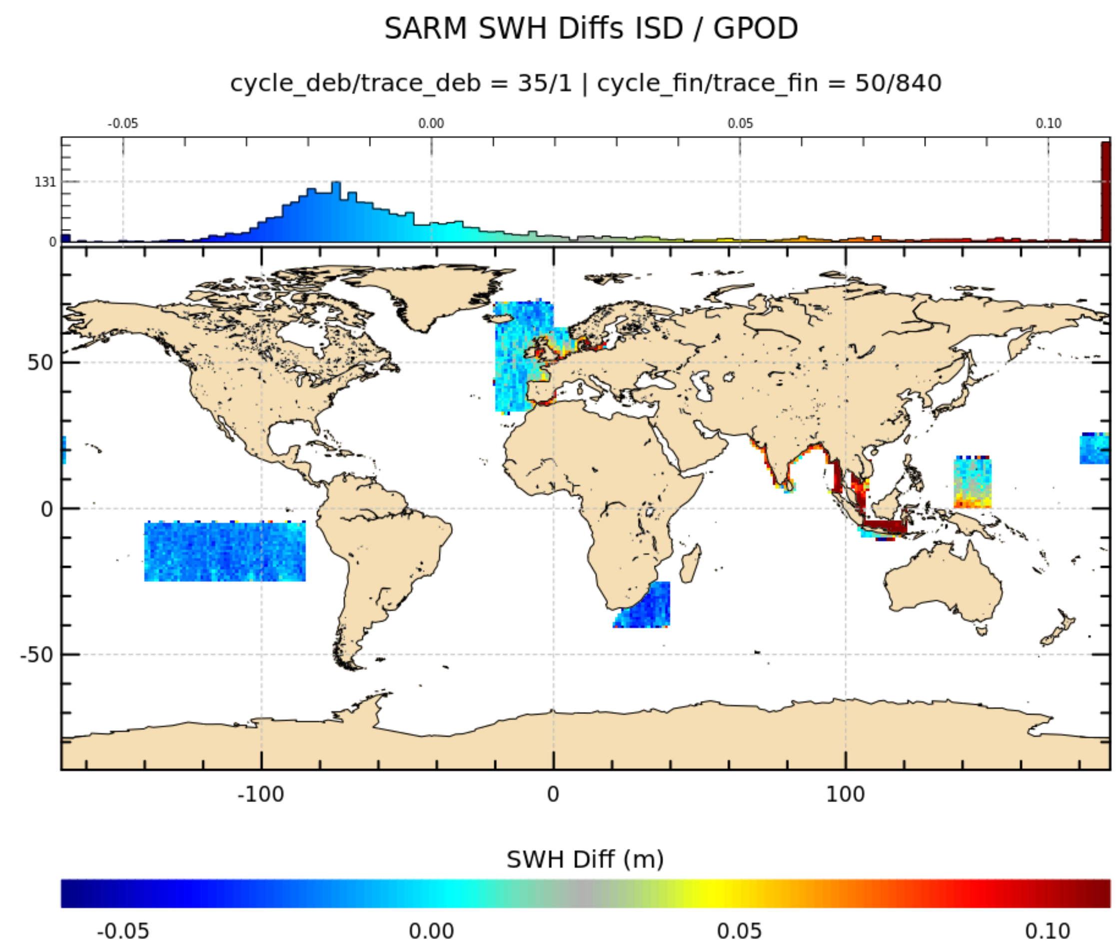



Ascending
Descending
Hpoint (m/s)
SWH (m)
SSH Diff (m)
cycle_deb/trace_deb = 35/1 | cycle_fin/trace_fin = 50/840
-0.060 -0.045 -0.030 -0.015 0.000 0.015 0.030
-0.06 -0.04 -0.02 0.00 0.02

SARM SWH DIFFERENCES

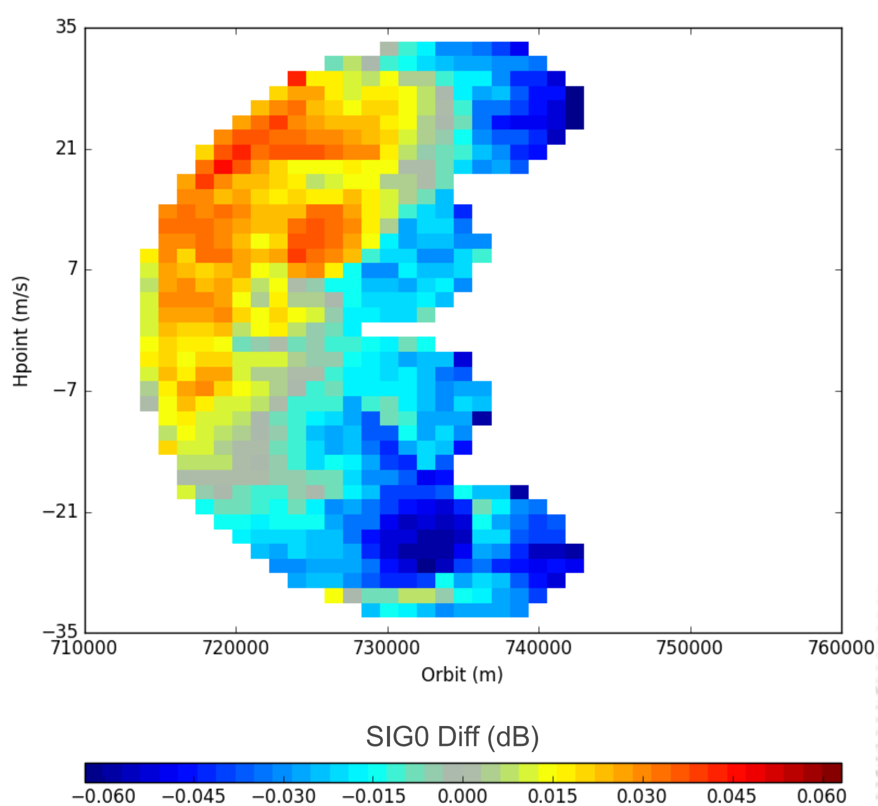
- Mean: 0.0 cm
- Std: 13.0 cm

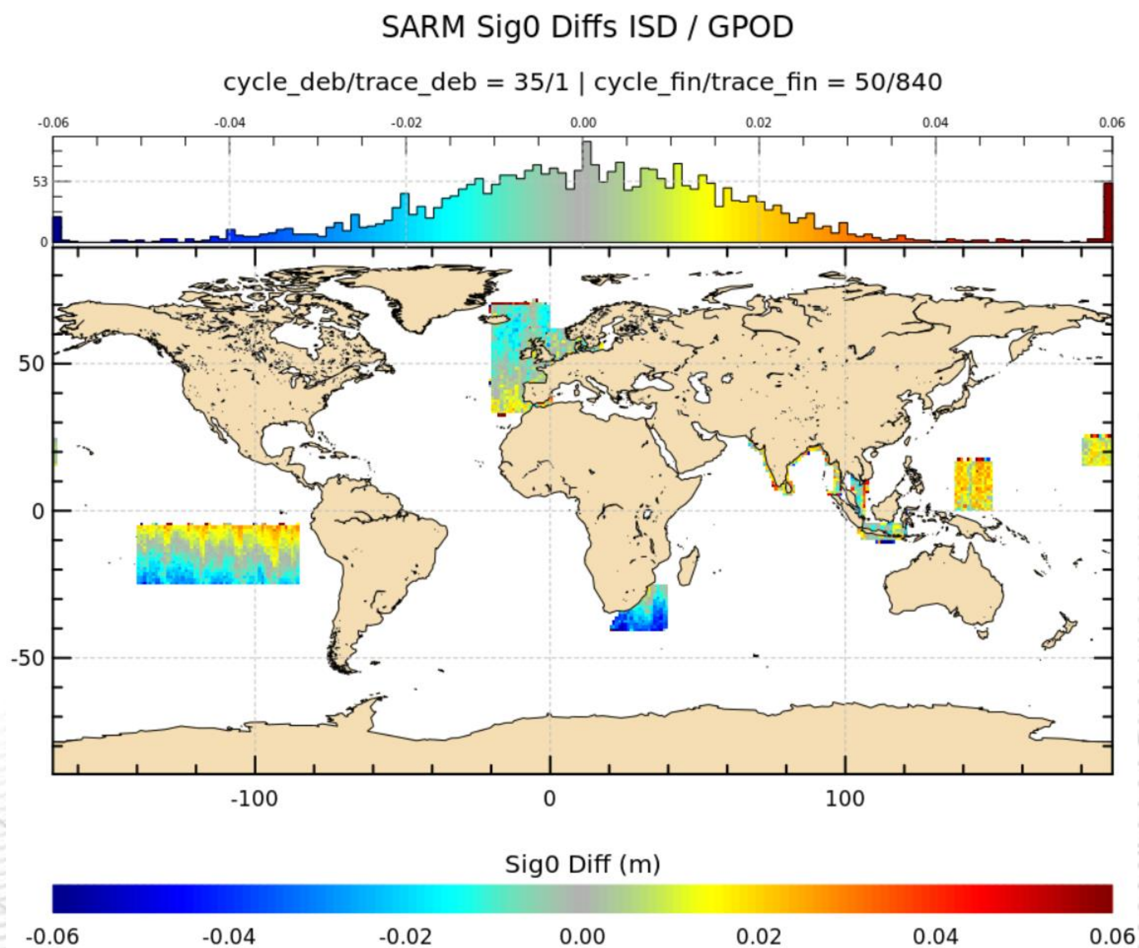


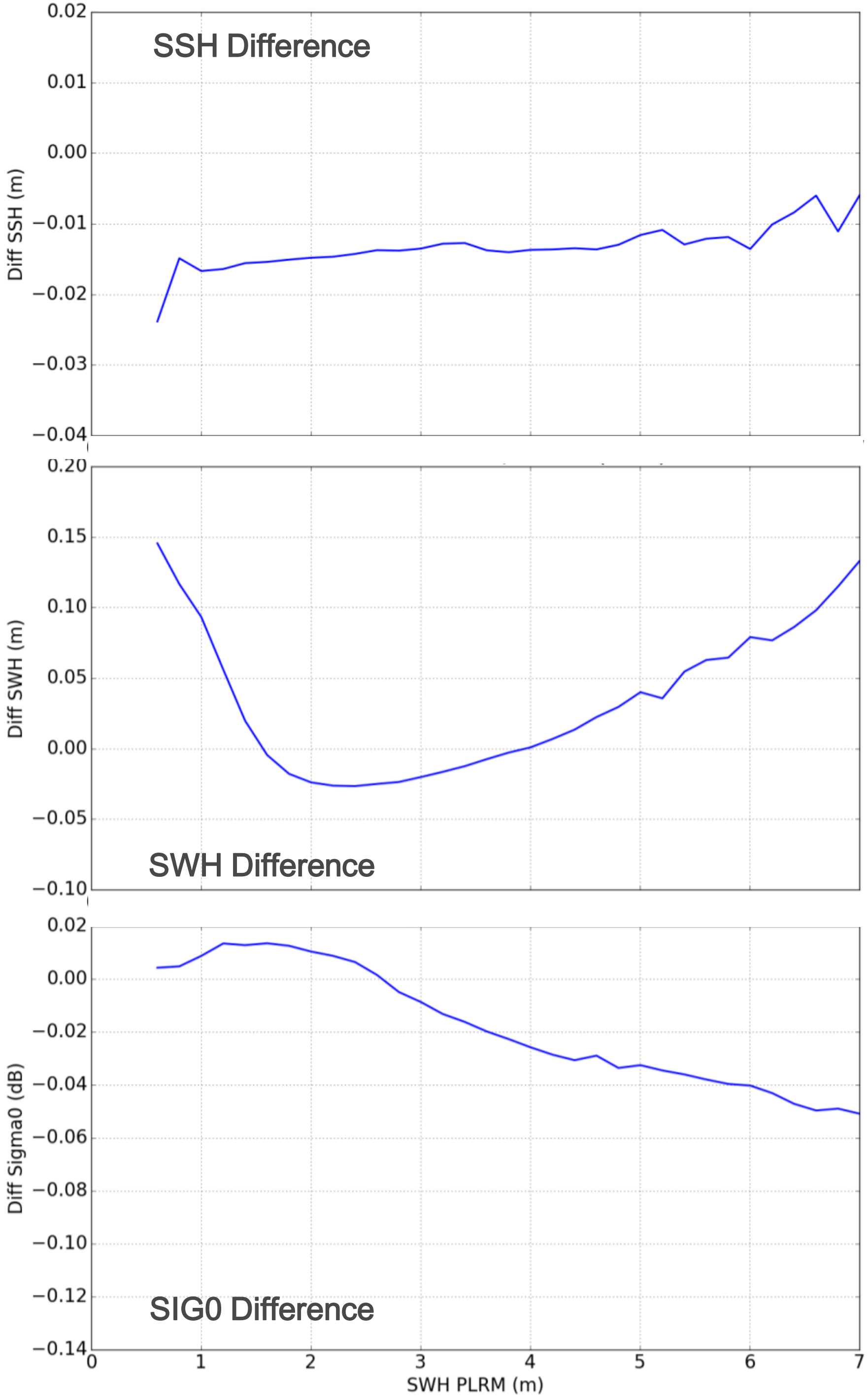


SARM SIG0 DIFFERENCES

- Mean: 0.0 dB
- Std: 0.1 dB







Alternative SARM algorithm (IsardSAT) analysis at large scales:

- Very consistent SSH
- Noticeable correlation of SWH difference on wave height (alpha_p correction to be adjusted for along-track Hamming weighting function ?)
- Very low dispersion of sig0 difference

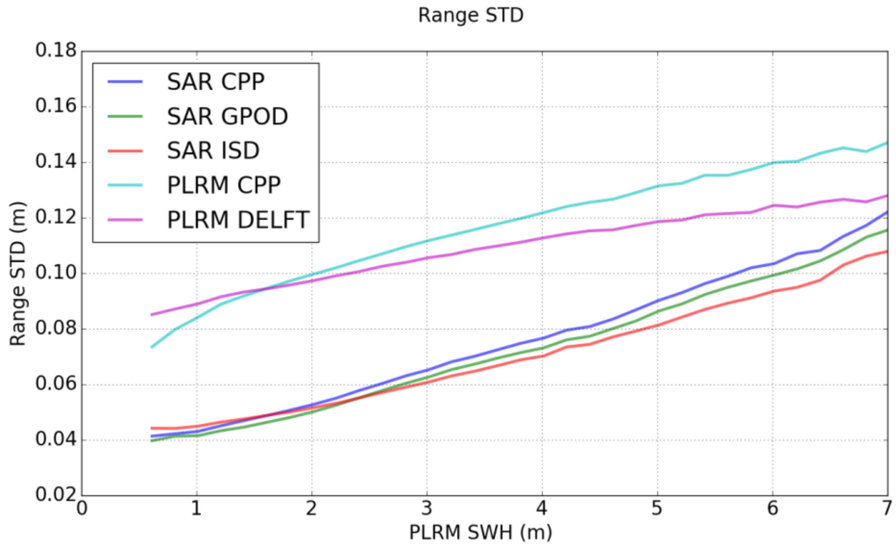
➔ Good agreement between SARM GPOD and the alternative SARM algorithm

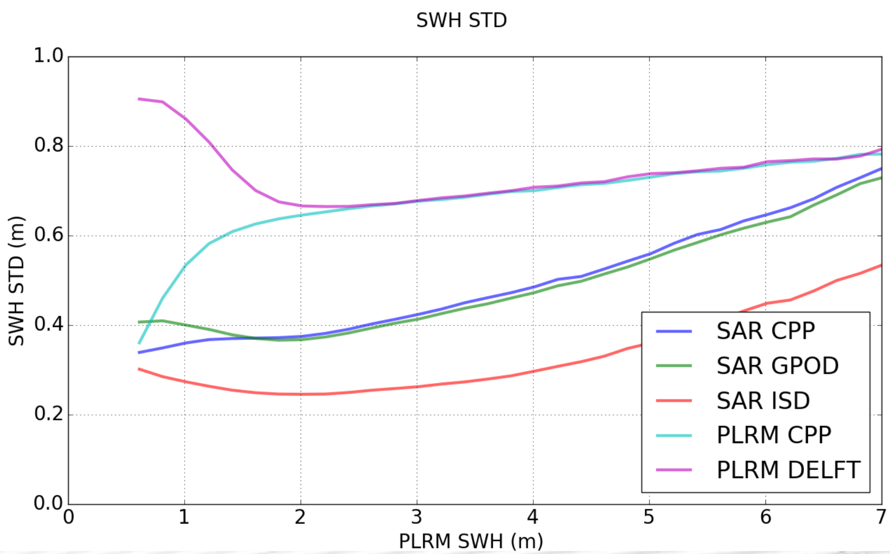
HIGH-FREQUENCY ANALYSYS

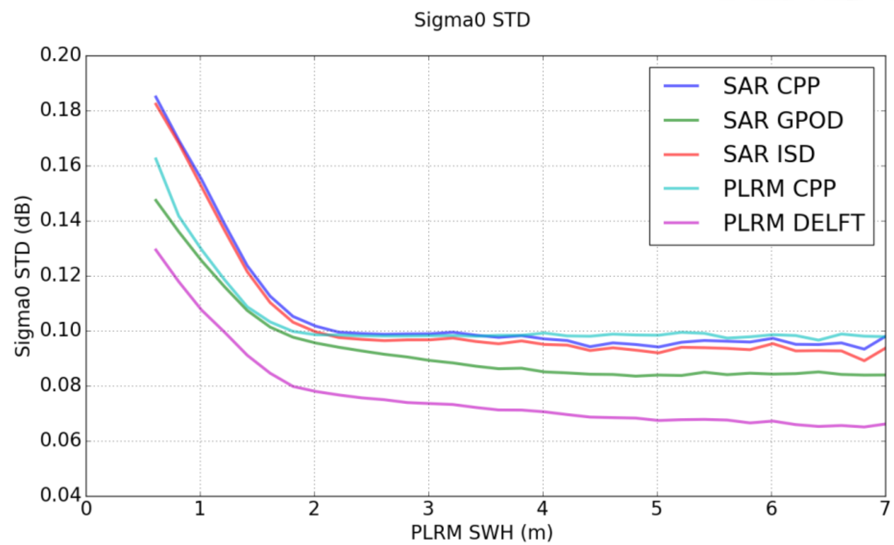
20-HZ NOISE ANALYSIS

Alternative SARM algorithm:

- Range STD: improvement brought by Hamming window at medium/large wave height (but degraded at low swh)
- High noise reduction in SWH (> 35% @2m) better than CY2 Baseline B/C (also including zero-pading x2 and azimuth window)
- No improvement for sig0

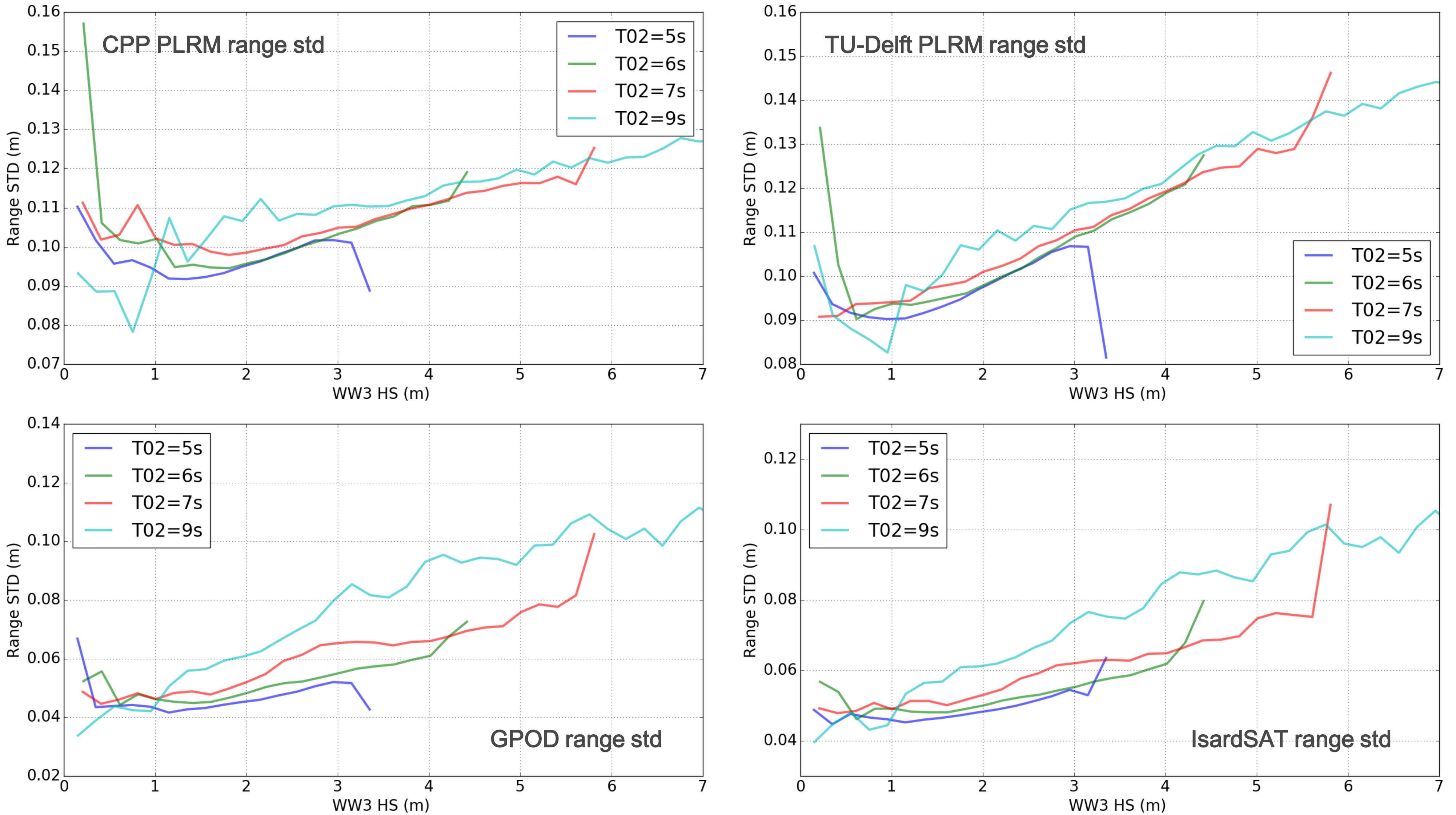




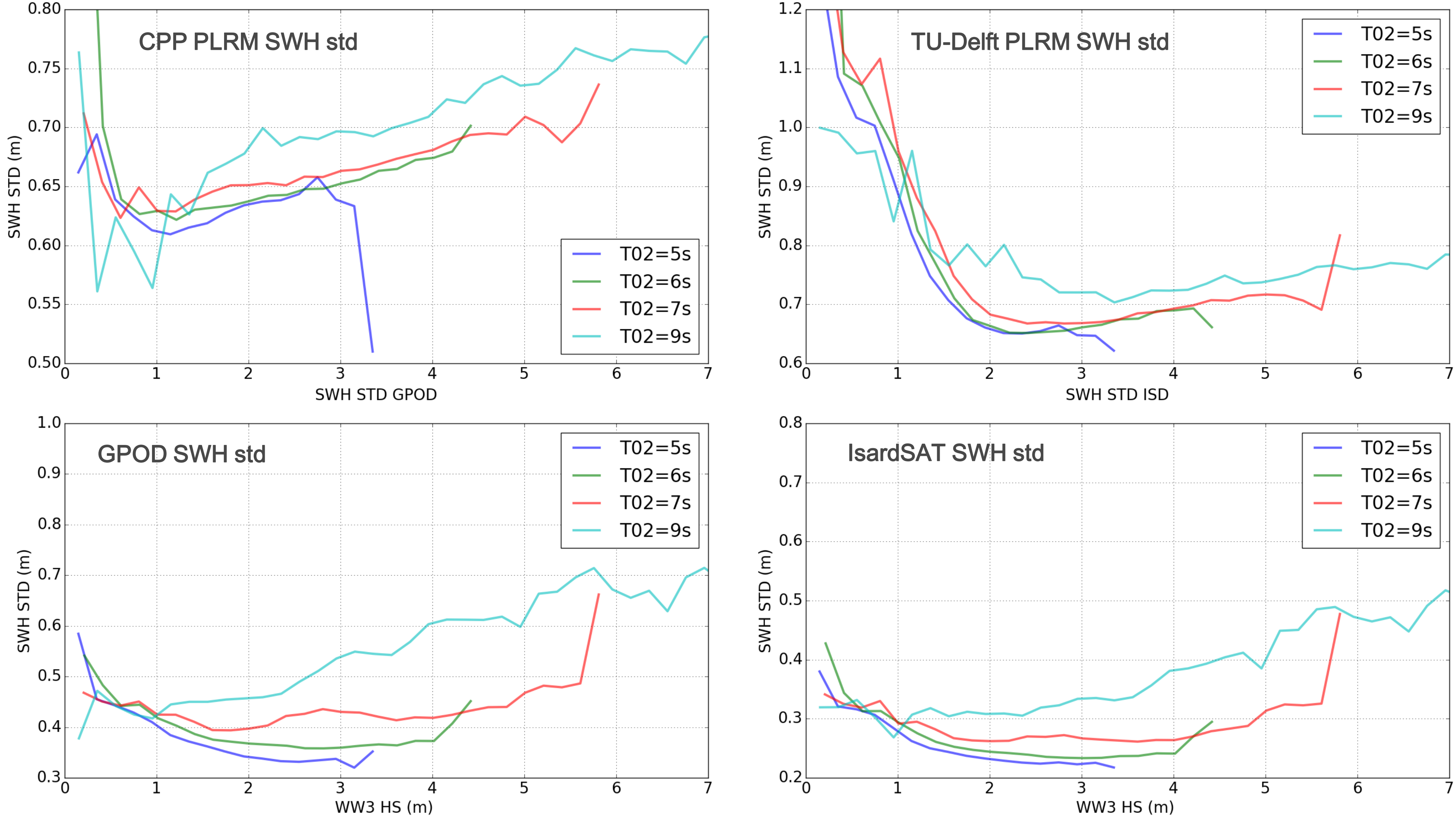


SENSITIVITY TO SUB-MESOSCALES

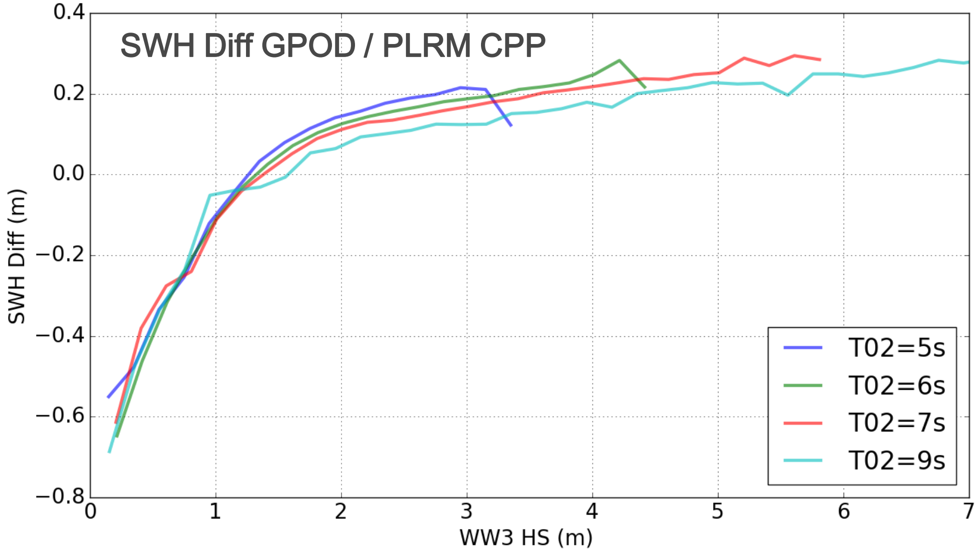
LONG OCEAN WAVES IMPACT ANALYSIS

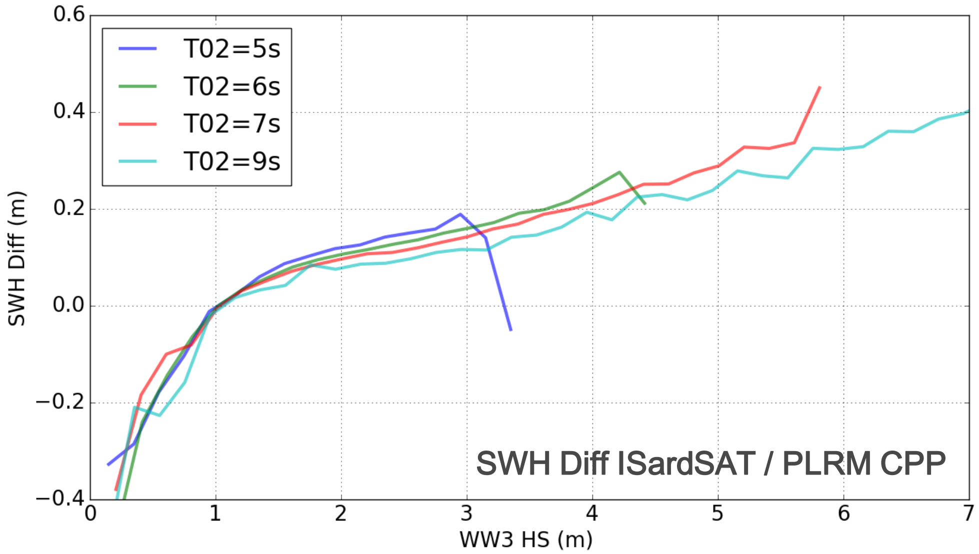


LONG OCEAN WAVES IMPACT ANALYSIS



LONG OCEAN WAVES IMPACT ANALYSIS

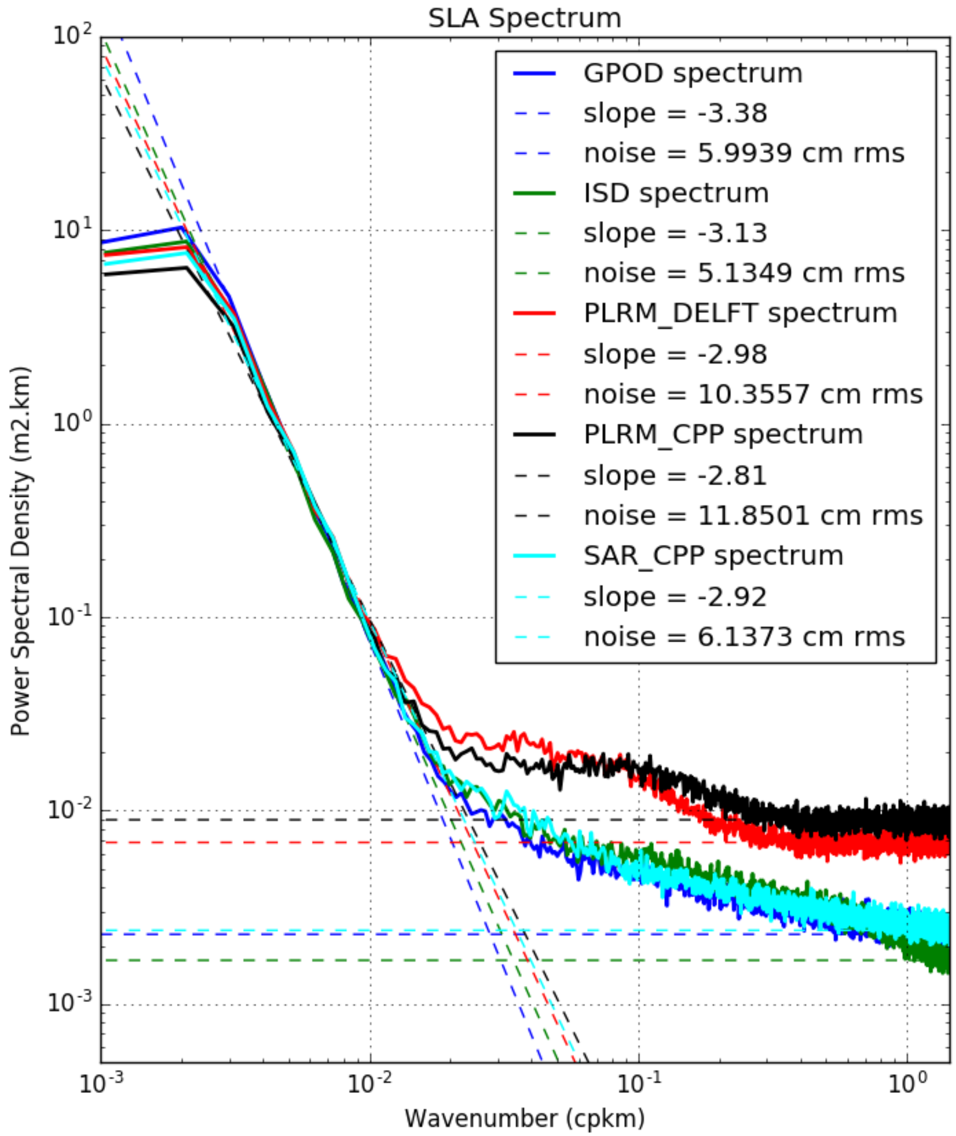




- Estimated parameters from SAR altimetry (GPOD / alternative SARM algo) waveforms are particularly noisy under long-wave conditions
- Also SWH in SAR mode are biased wrt conventional altimetry data
- No noticeable bias found in range

POWER SPECTRAL DENSITY OF SLA

PSD ANALYSIS OVER AGULHAS IN 2013

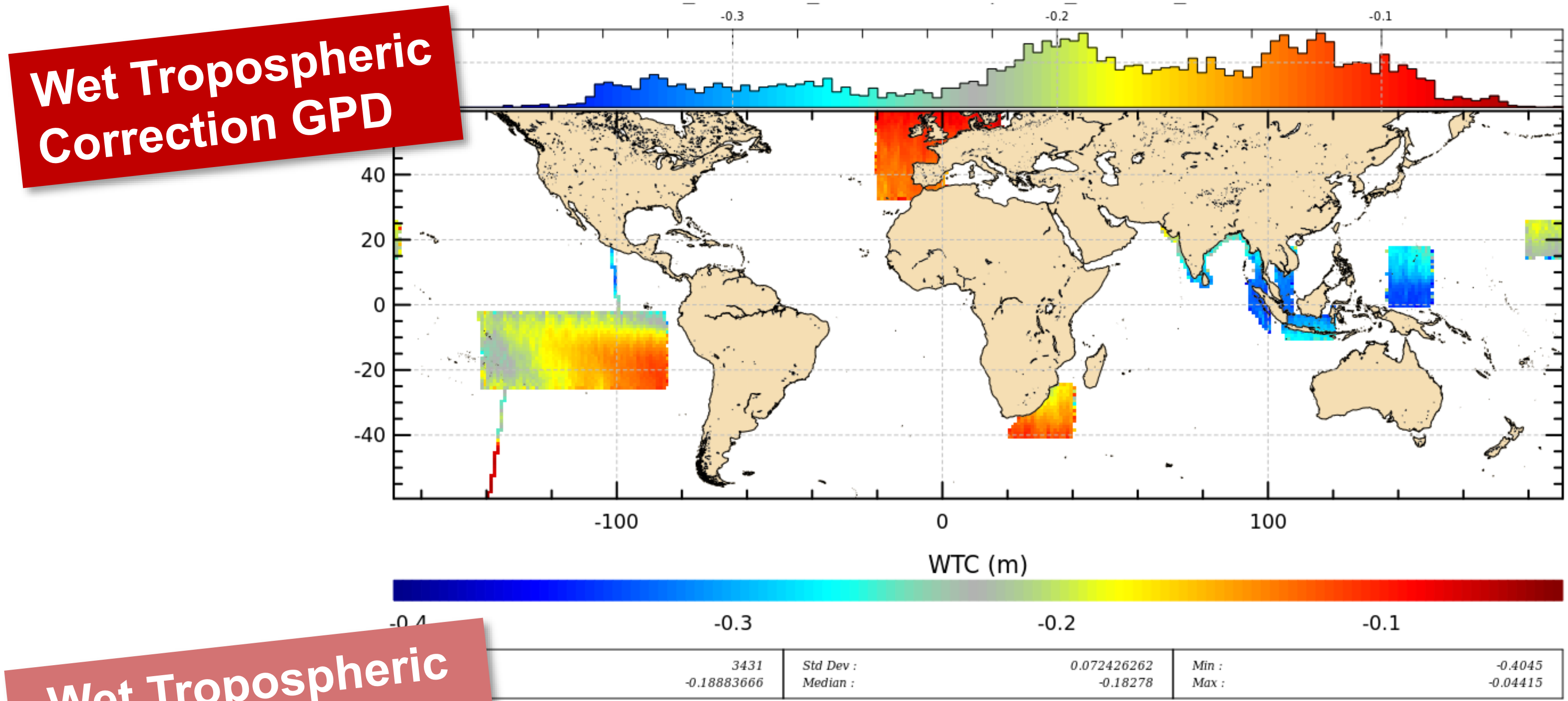


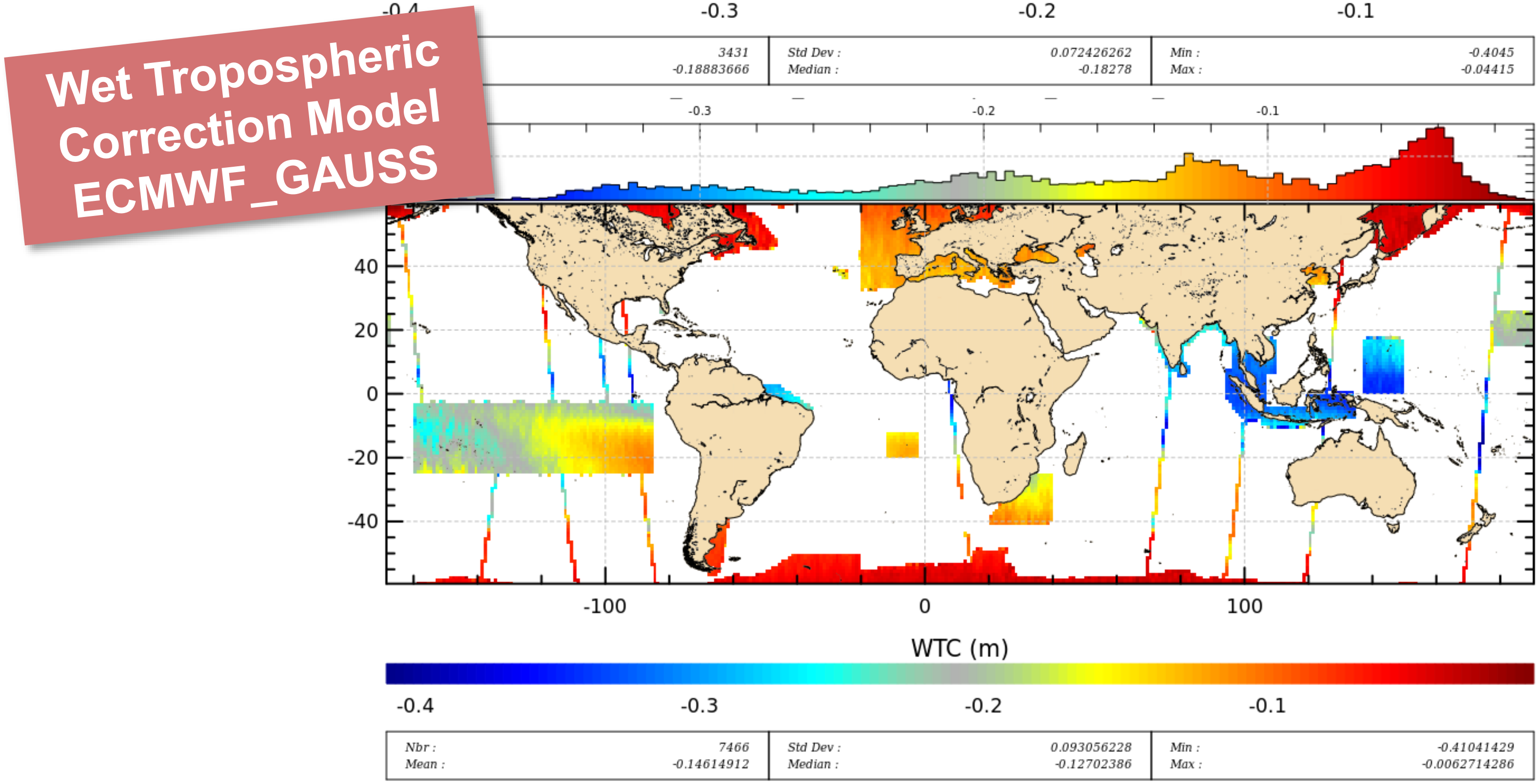
- Same behavior on large scales
- Short wavelength correlated errors (*bump*) affecting conventional altimetry from 7 to 50 km
  A little hump also observed in PSD from alternative SARM data most probably linked to Hamming window (that creates low spatial correlation between samples)
- Swell-induced effects (*red noise*) at sub-mesoscales (from 30 km to smaller scales) affecting SAR altimetry
- Large noise reduction on HF content brought by SAR mode (➔ better observability of small scale oceanic signals)

Assessment GPD Wet Tropospheric Correction wrt ECMWF Operational model

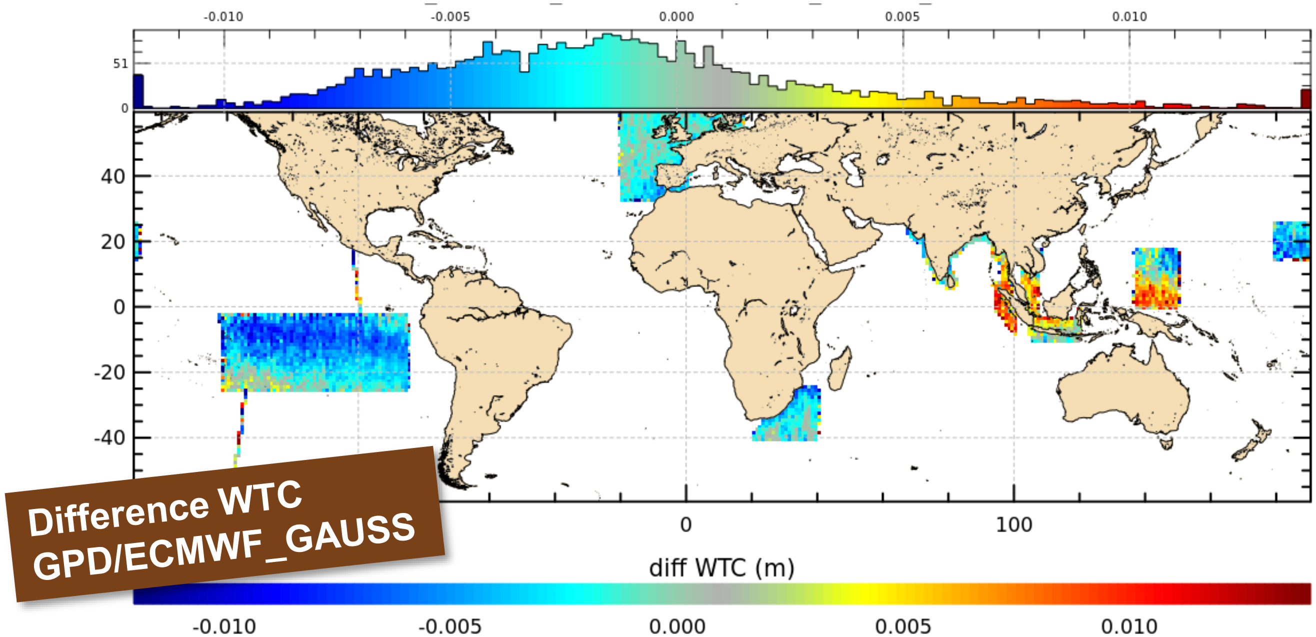
Period: 01/2012 – 12/2013

Mission CY2, sub-cycles 26 to 49

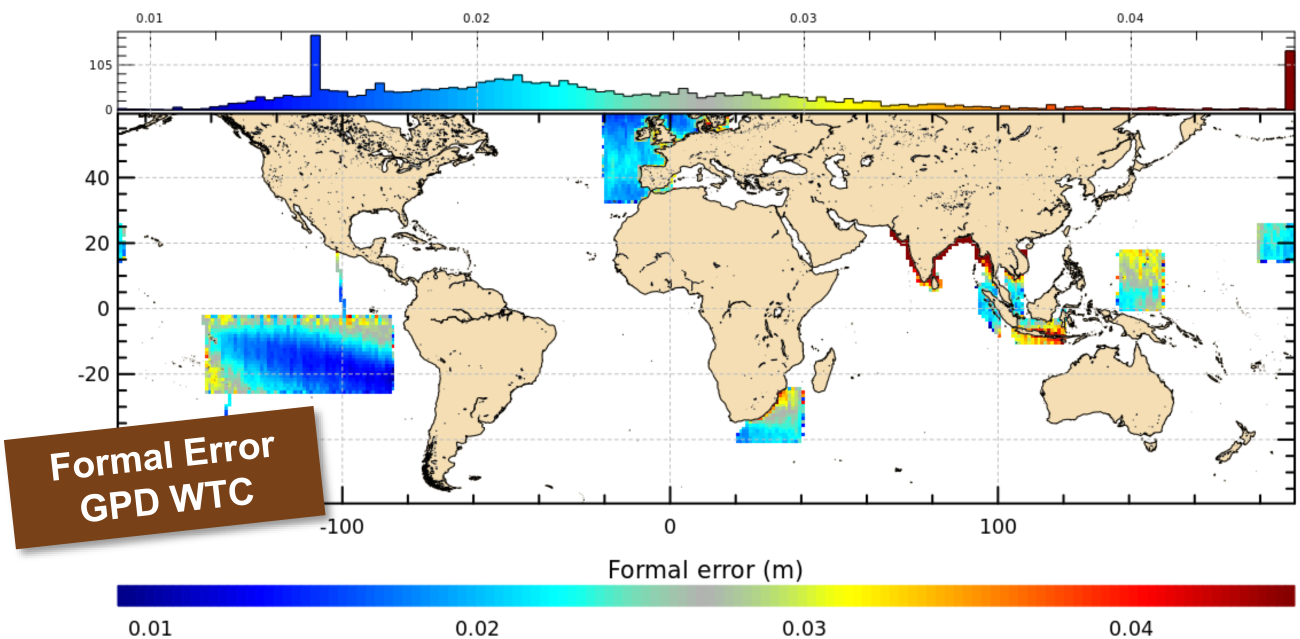

Wet Tropospheric Correction GPD
-0.3
-0.2
-0.1
40
20
0
-20
-40
-100
0
100
WTC (m)
-0.4
-0.3
-0.2
-0.1
3431
-0.18883666
Std Dev :
Median :
0.072426262
-0.18278
Min :
Max :
-0.4045
-0.04415


Wet Tropospheric Correction Model ECMWF_GAUSS
-0.3
-0.2
-0.1
40
20
0
-20
-40
-100
0
100
WTC (m)
-0.4
-0.3
-0.2
-0.1
Nbr :
Mean :
7466
-0.14614912
Std Dev :
Median :
0.093056228
-0.12702386
Min :
Max :
-0.41041429
-0.0062714286

ALONG-TRACK



Nbr :	3431	Std Dev :	0.004884935	Min :	-0.0303
Mean :	-0.0014967392	Median :	-0.001767462	Max :	0.0468

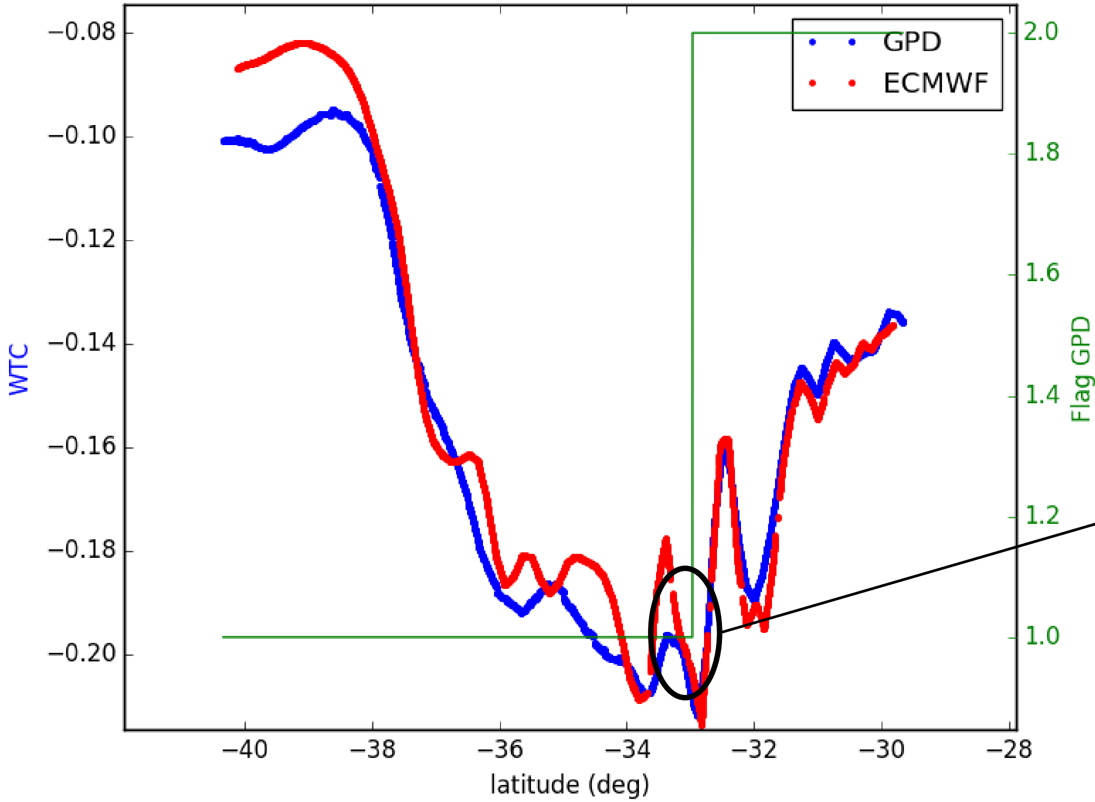


Nbr :	3431	Std Dev :	0.010617071	Min :	0.00734
Mean :	0.024244971	Median :	0.021993505	Max :	0.10711818

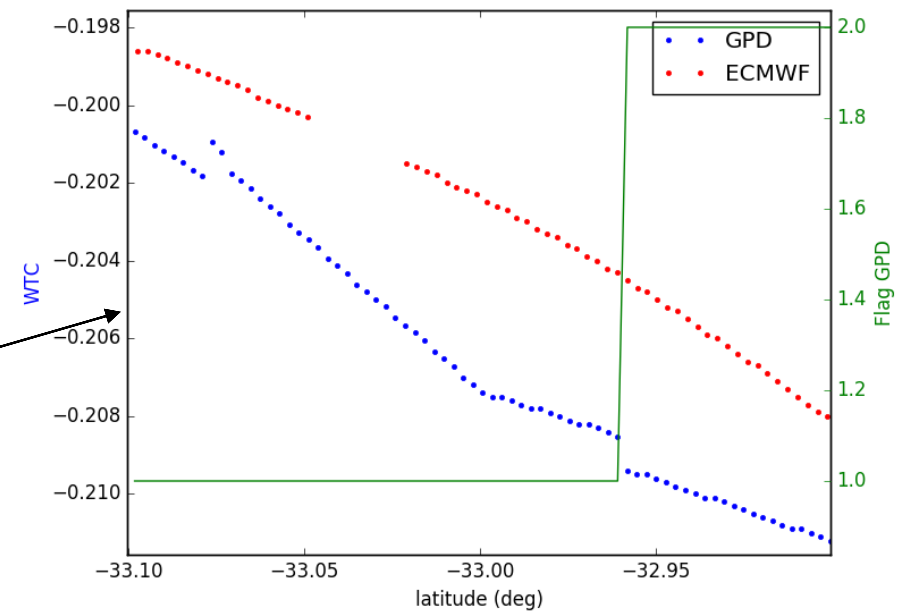
Differences between the two corrections:

- Mean Value: 0.149 cm
- Std dev: 0.488 cm
- Higher differences where formal error is higher i.e.: West Pacific and Indonesia

ALONG-TRACK



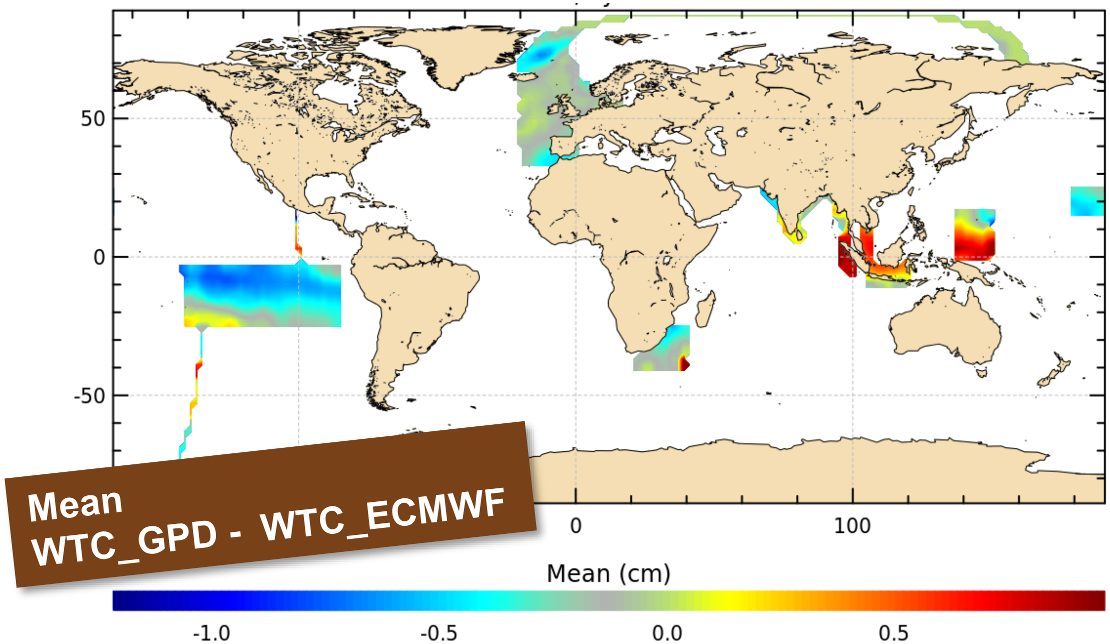
Discontinuity of around 1 mm in flag GPD transition



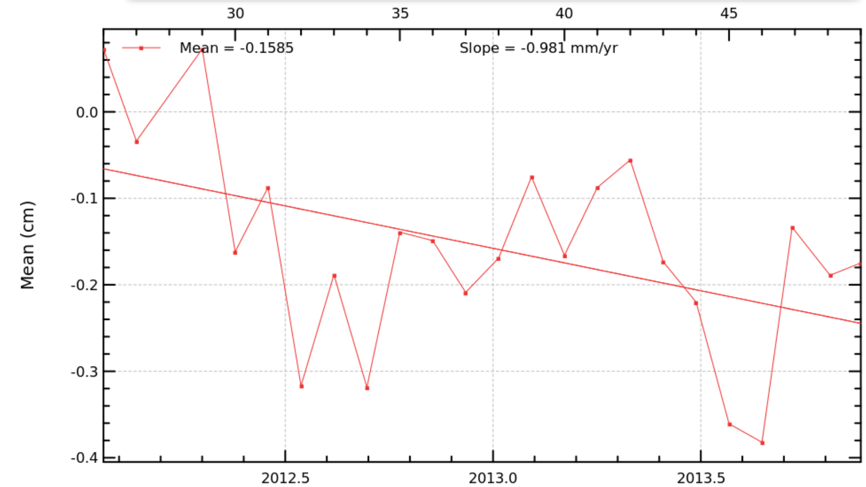
Description of Flag_GPD:

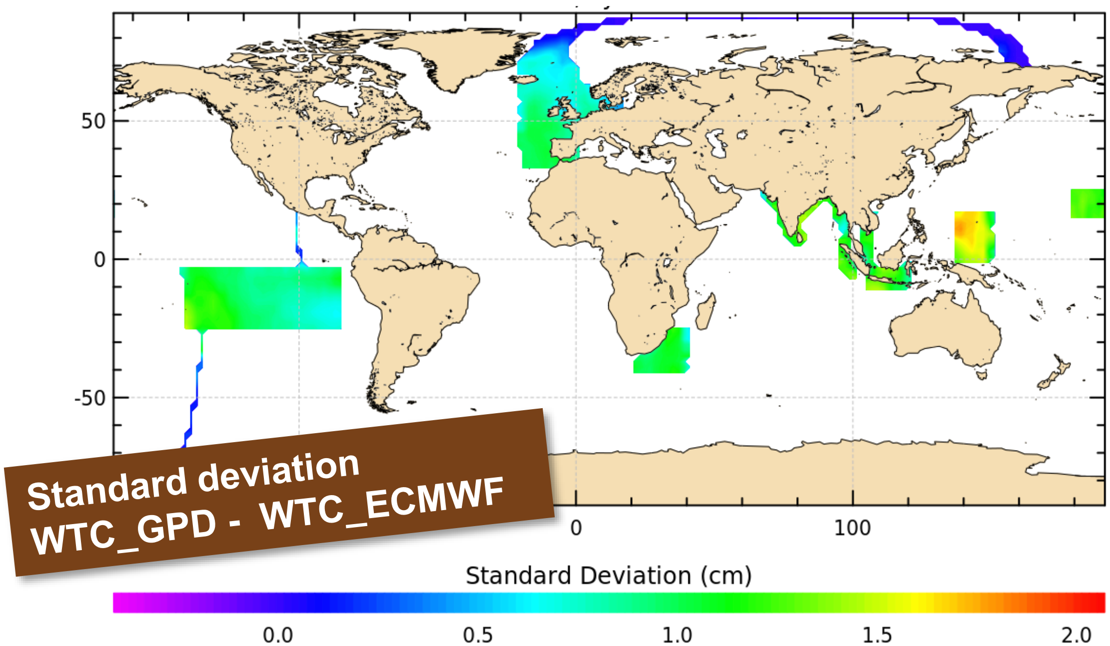
- 0 = point for which the radiometer correction (rad_wet_tropo_cor) is valid - for these points wet_GPD=rad_wet_tropo_cor – not applicable for CryoSat-2
- 1 = wet_GPD is a valid estimate
- 2 = there were no observations for this point. In this case wet_GPD equals the model value (ERA Interim or ECMWF Op.) – always ECMWF OP for CryoSat-2
- 3 = unreliable wet_GPD estimate, according to algorithm internal criteria
- 4 = wet_GPD was outside the interval [-0.5, 0.0], In this case the values -0.5 and 0.0 were
- attributed to the correction

ALONG-TRACK

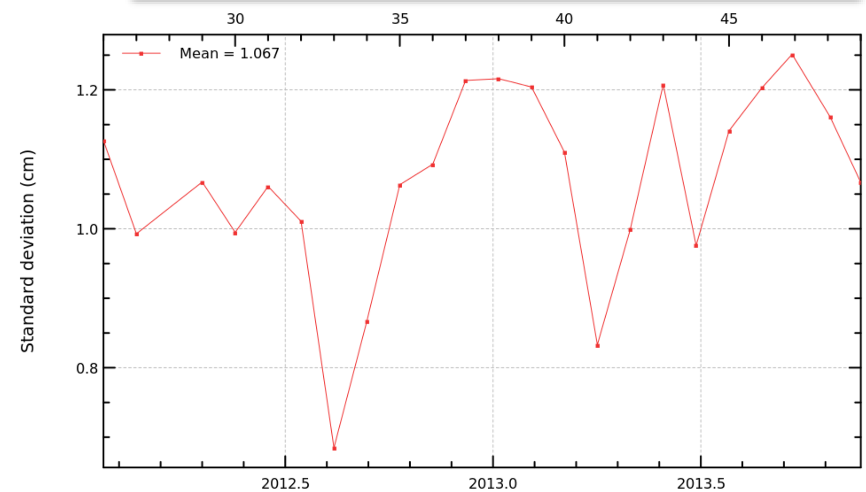


Temporal evolution of mean difference

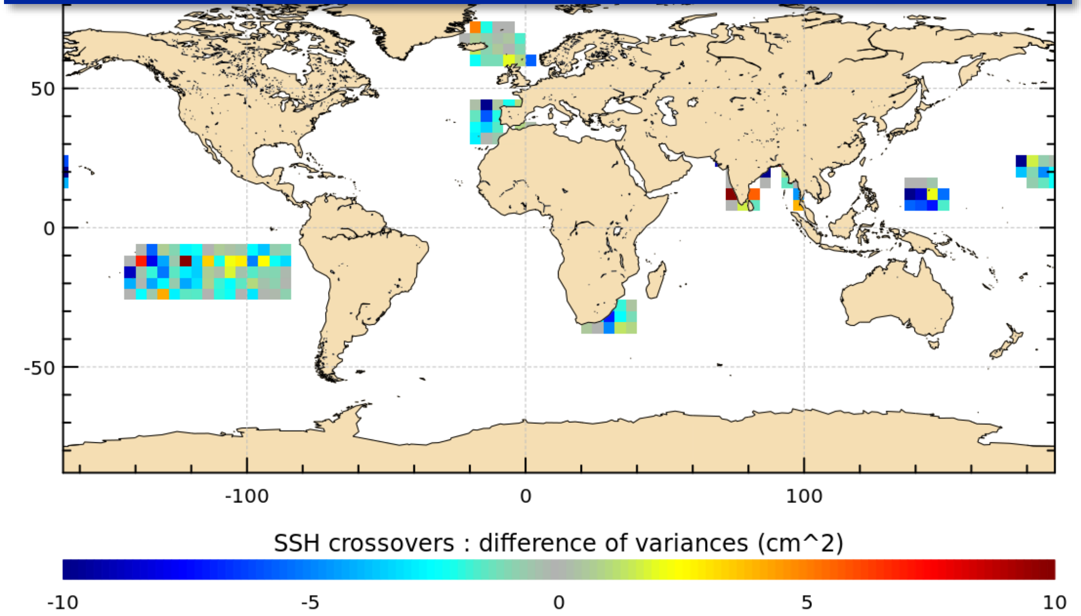




Temporal evolution of std of difference

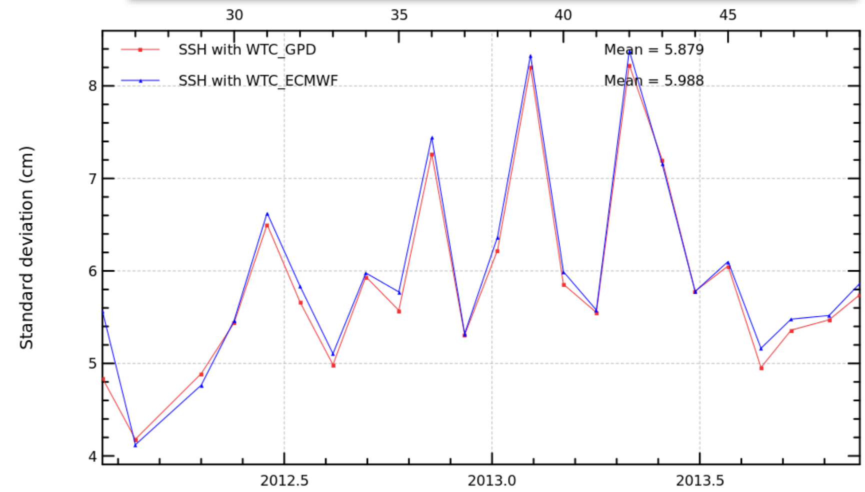


VAR(SSH with WTC_GPD) – VAR(SSH with WTC_ECMWF)

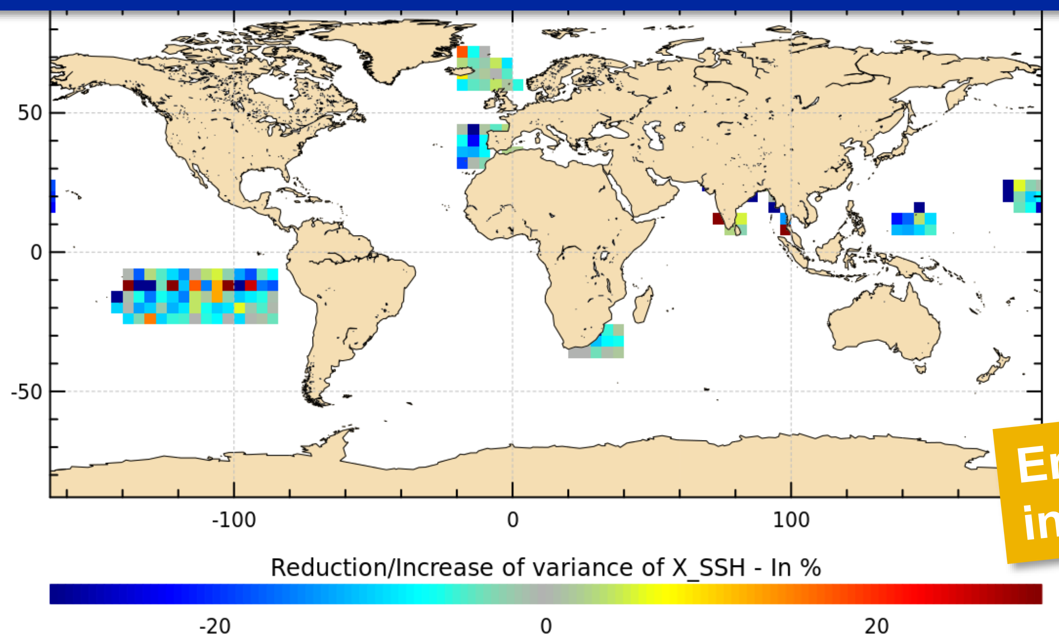


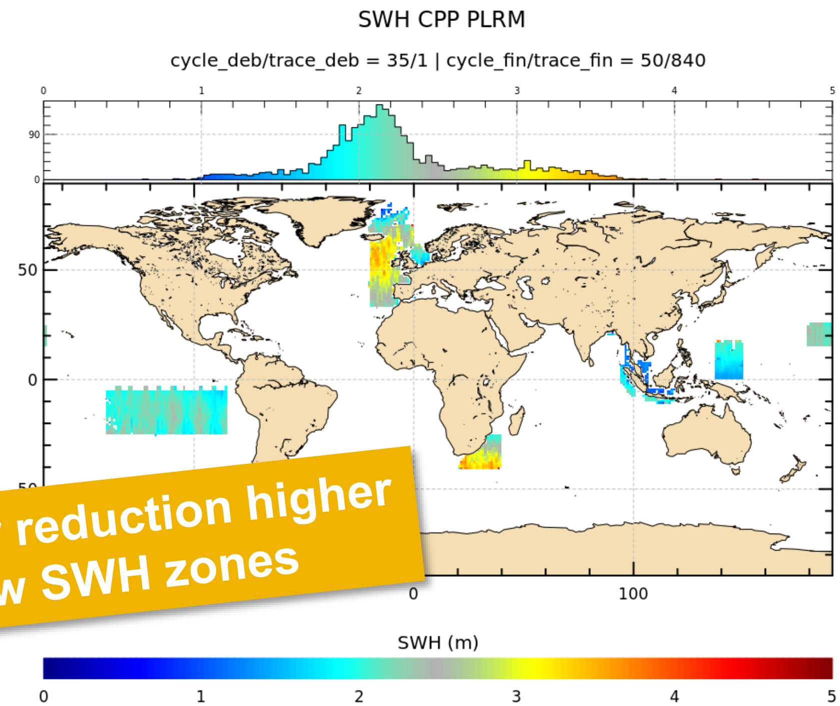
XOVERS

Standard deviation of SSH crossovers



(VAR(SSH with WTC_GPD)–VAR(SSH with WTC_ECMWF))/VAR(SSH with WTC_ECMWF)

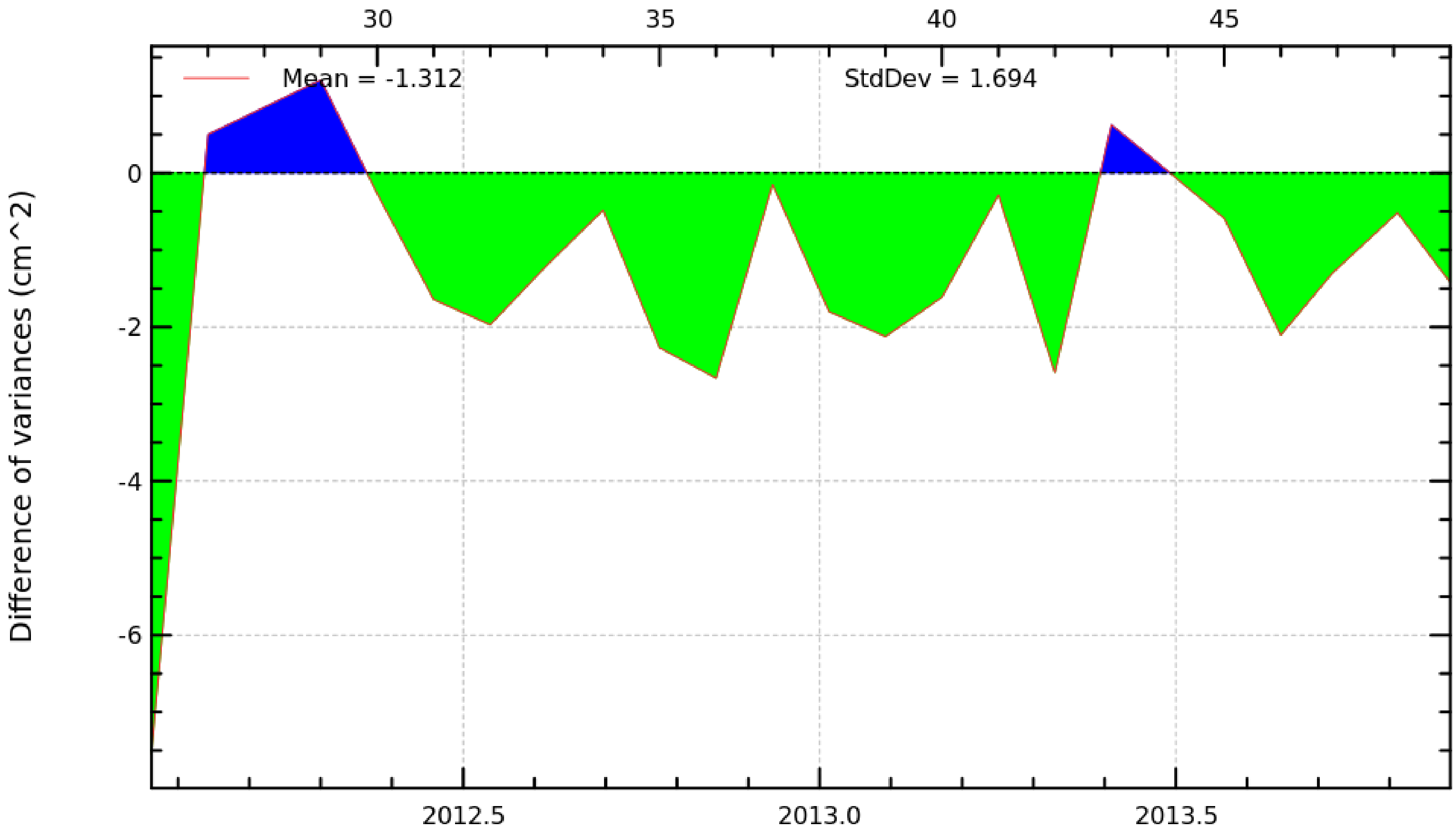




Error reduction higher in low SWH zones

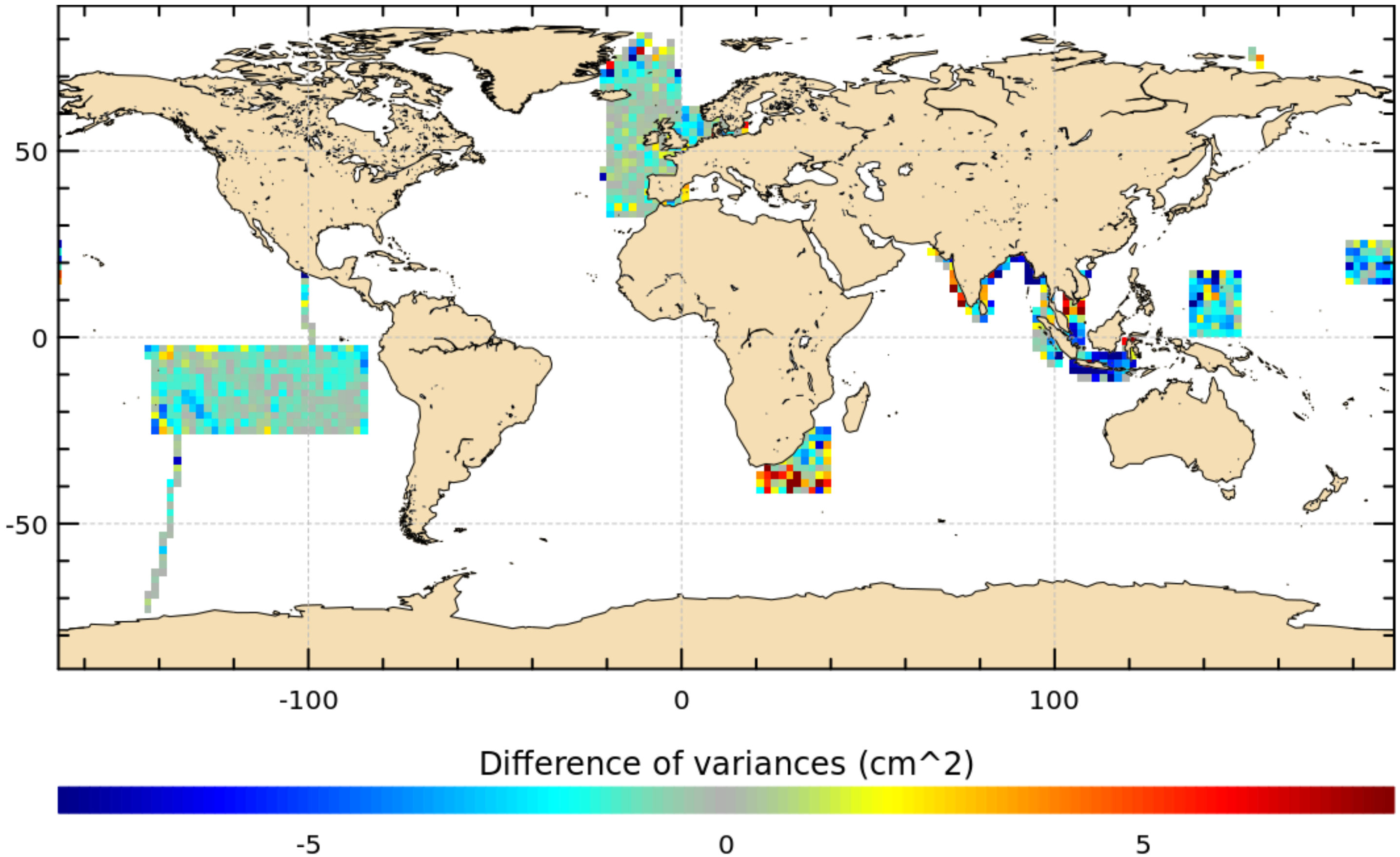
XOVERS

SSH crossovers:
VAR(SSH with WTC_GPD) – VAR(SSH with WTC_ECMWF)



ALONG-TRACK

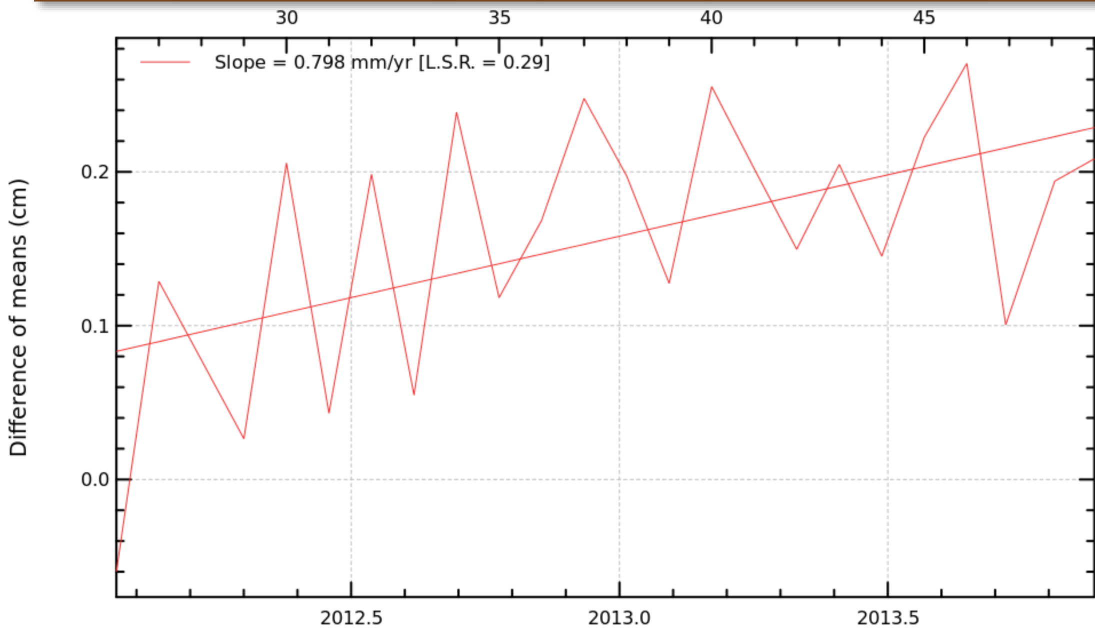
VAR(SLA with WTC_GPD) – VAR(SLA with WTC_ECMWF) ALONG SATELLITE TRACK



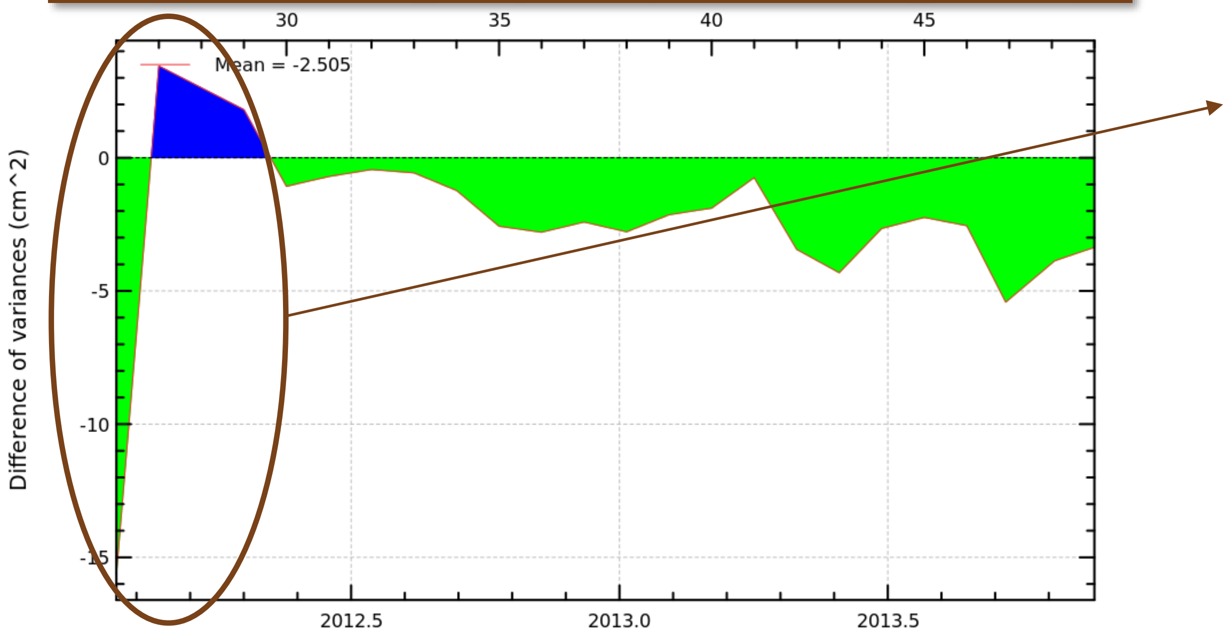
– Higher reduction variance brought by GPD model wrt ECMWF mainly in coastal areas (e.g. Indonesian sea)

ALONG-TRACK

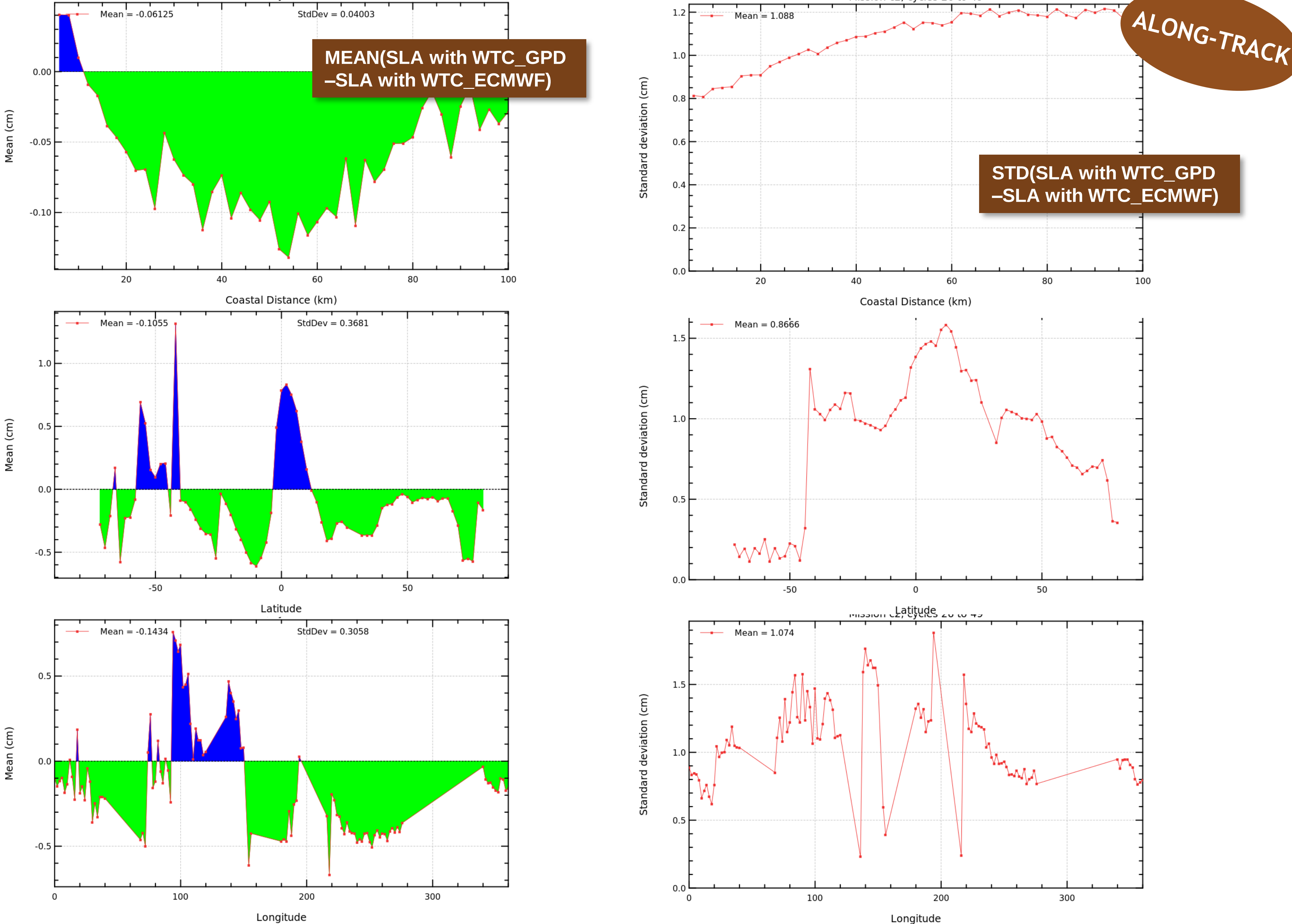
MEAN(SLA with WTC_GPD) – MEAN(SLA with WTC_ECMWF)



VAR(SLA with WTC_GPD) – VAR(SLA with WTC_ECMWF)

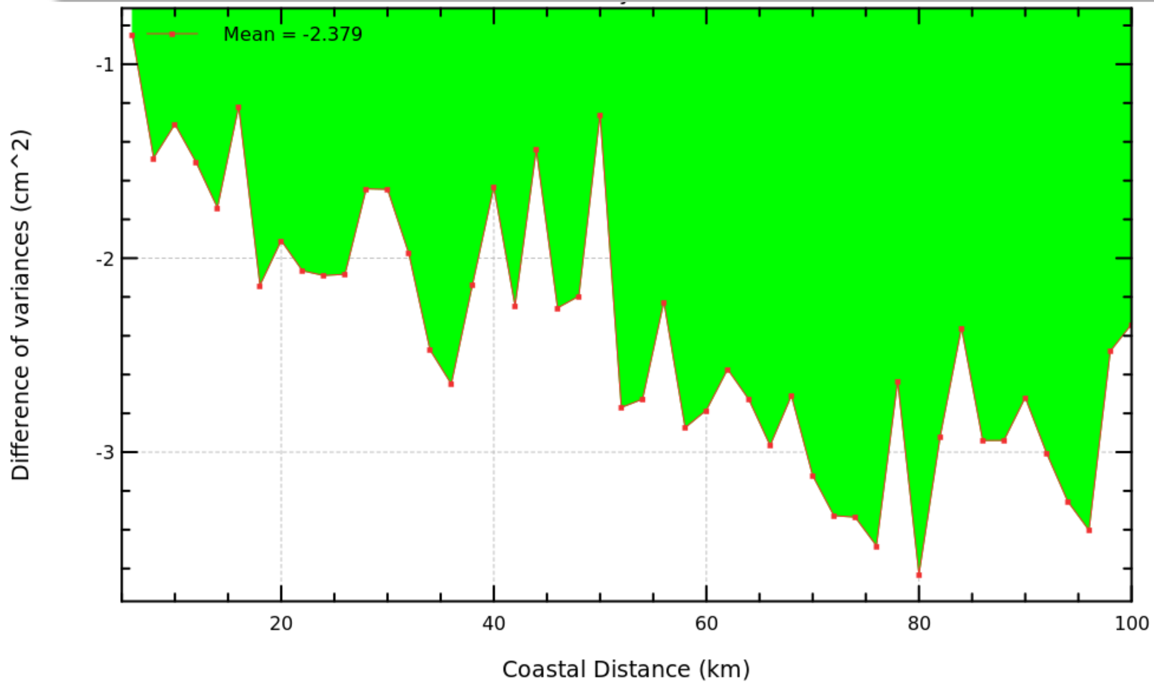


- Only 8 days for first cycle
- Data are missing in some areas in the first few months of the studied period

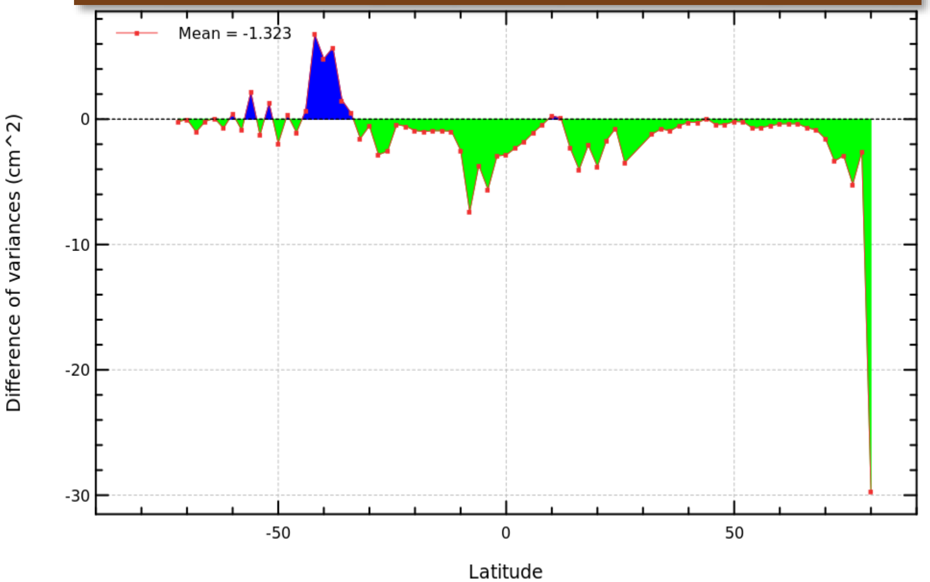

ALONG-TRACK
MEAN(SLA with WTC_GPD
–SLA with WTC_ECMWF)
STD(SLA with WTC_GPD
–SLA with WTC_ECMWF)
Mean = -0.06125
StdDev = 0.04003
Mean (cm)
Coastal Distance (km)
Mean = 1.088
Standard deviation (cm)
Coastal Distance (km)
Mean = -0.1055
StdDev = 0.3681
Mean (cm)
Latitude
Mean = 0.8666
Standard deviation (cm)
Latitude
Mean = -0.1434
StdDev = 0.3058
Mean (cm)
Longitude
Mean = 1.074
Standard deviation (cm)
Longitude

ALONG-TRACK

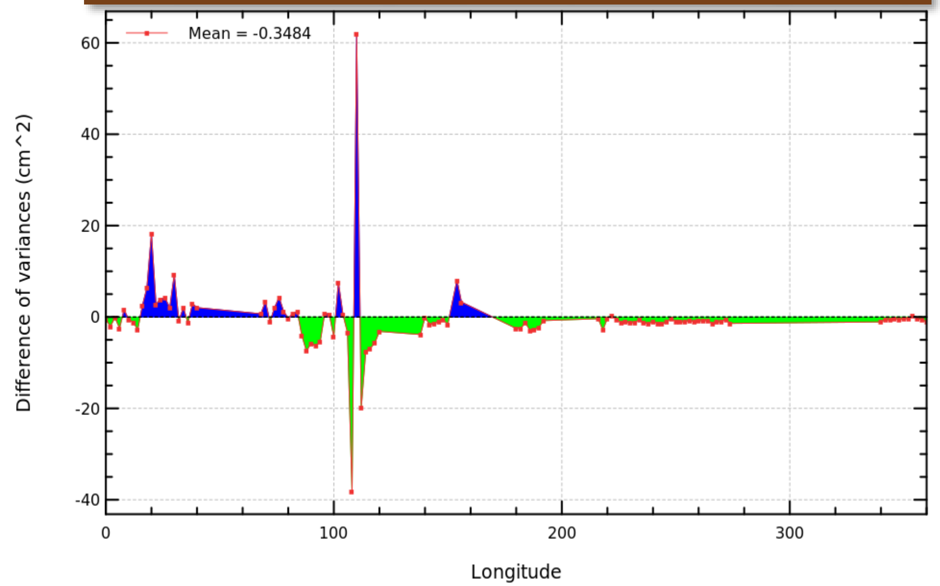
VAR(SLA with WTC_GPD) – VAR(SLA with WTC_ECMWF)



VAR(SLA with WTC_GPD) – VAR(SLA with WTC_ECMWF)



VAR(SLA with WTC_GPD) – VAR(SLA with WTC_ECMWF)



GPD WET TROPOSPHERIC CORRECTION

- GPD WTC reduces the sea level anomaly variance with respect to the ECMWF operational model correction from both colinear analysis and cross-overs by ~2 cm^2
- Results evidence significant improvement in open ocean (particularly for low sea states) and coastal areas (not assessed in polar regions)
- Such WTC product is an added value for both open ocean and coastal studies

CONCLUSIONS

- The alternative SARM algorithm (including zero-padding and along-track weighting window) shows very consistent results at large scales (compared to GPOD)
- The alternative SARM algorithm shows improved noise reduction performance in range (after 2m SWH crossing point) and more importantly in SWH (> 35% @2m)
- Further analysis in global (S3) would confirm these results and also mitigate/explain all possible mispointing dependencies observed with PLRM data
- The improved GPD WTC clearly outperforms the model in open ocean and coastal regions

➔ **We advocate the use of these innovative/improved algorithms for Sentinel-3 mission to enhance altimeter ocean products to users**