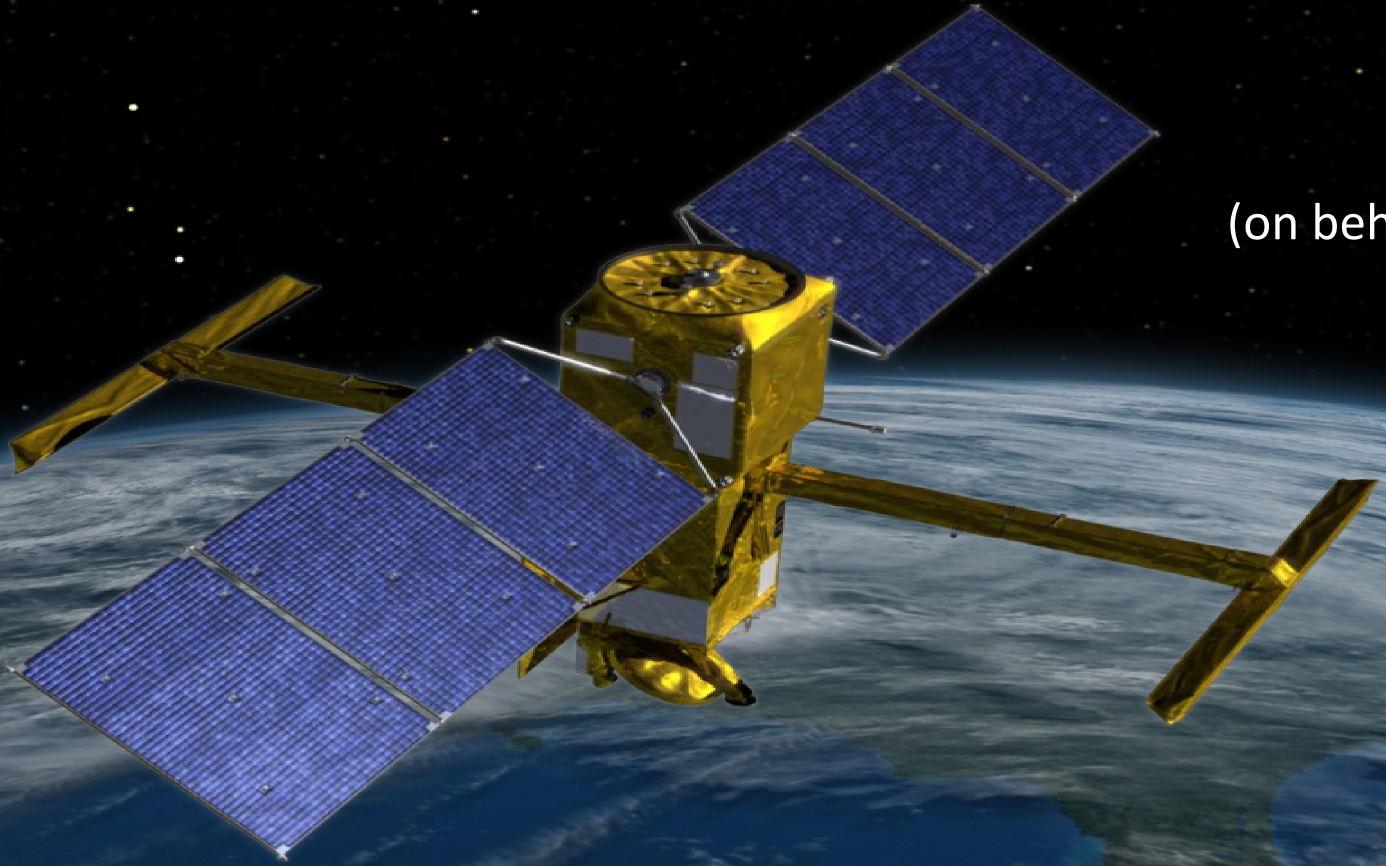


Surface Water and Ocean Topography (SWOT) Mission

September 2023

Alejandro Bohe

(on behalf of the JPL/CNES ADT team)

SWOT LR products

Versions of the LR products

The code used to process the data continuously evolves as the algorithms are improved, configuration parameters (e.g. calibration parameters) get refined and bugs are fixed.

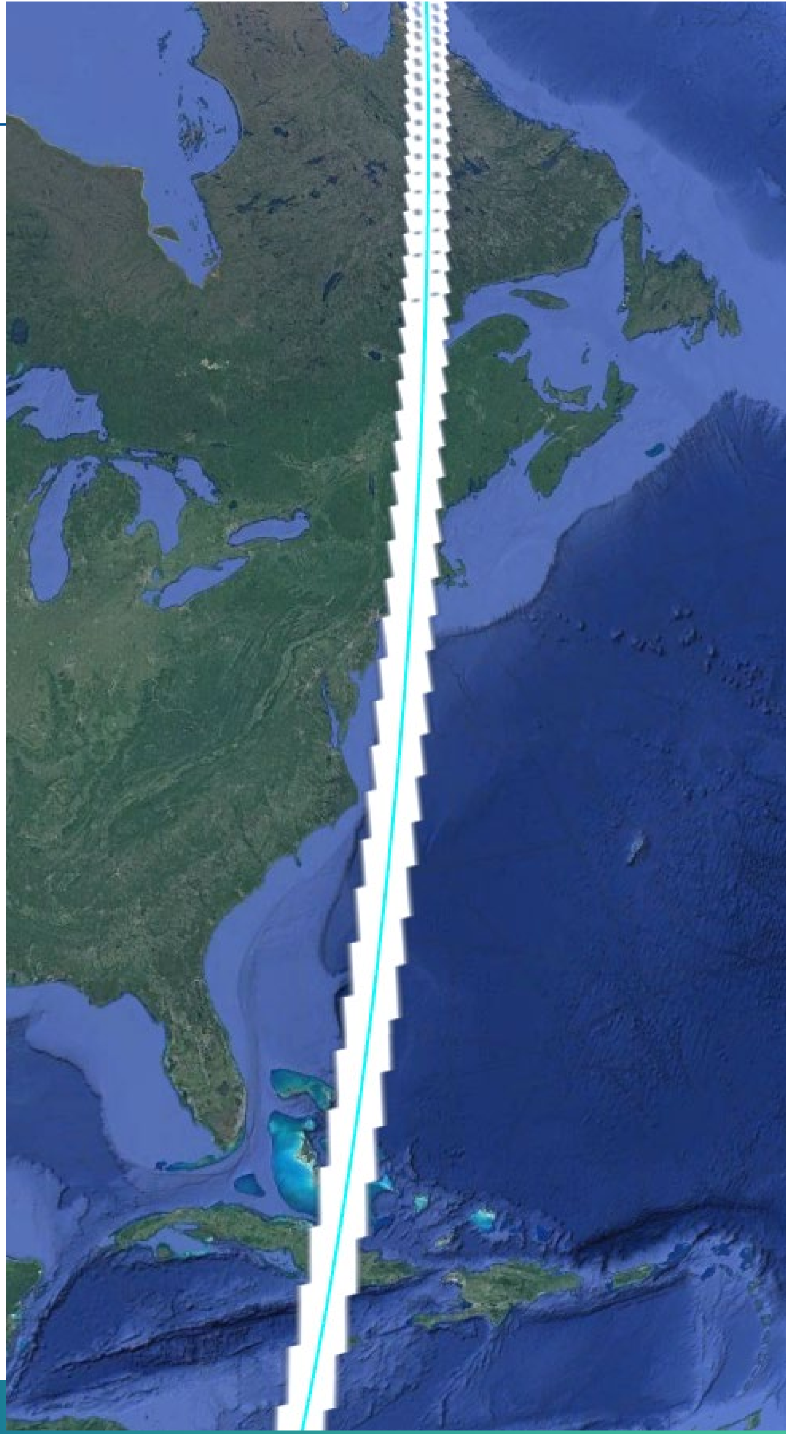
- « Forward » processing
  - Data is processed by SDS ~3 days after the acquisition
  - Discontinuities when new version of the code is replaces an older one
- « Summer » RE-processing
  - Uses the version of the code in operation at the end of the 1-day sampling phase
  - Homogeneous dataset over the entire 1-day sampling phase : March 30th – July 10th
- « Fall » RE-processing
  - will use a newer version of the code, with improved algorithms (in particular wind and SWH)

Product	File	Target User	Contents	Measurement grid	MB/granule
L2 (4 files)	**Basic**	All SSH/SSHA users	SSA, SSHA and most geophysical corrections	2km geographically fixed	32
	Wind and Wave	All SWH and wind speed users	Wind speed, SWH, sigma0 and intermediate quantities		36
	Expert (includes copies of Basic and Wind and Wave)	Expert users who want all corrections	All corrections applied in Basic, alternate corrections and intermediates		122
	Unsmoothed	Expert users who want full downlinked resolution	500m resolution SSH and sigma0	250m, "native" (center beam)	1624
L1B		Expert users who want to redo height reconstructio n, beam combine	Interferograms, sigma0 and volumetric decorrelation for all 9 beams on reference grids, and all geometry	9 reference grids with ~250m posting	~42000

LR products : contents and illustrations

The next slides illustrate the main variables available in the L2 and L1B products on an example from April 14th (data available to the ST) in the Gulf Stream

Cycle 490, Pass 9



LR products : contents and illustrati

L2_LR_SSH product

« **Basic** » file

2 km x 2km geographically fixed grid

surface height

context

flags

(some of the) corrections

► Dimensions: (num_lines: 9866, num_pixels: 69, num_sides: 2)

▼ Coordinates:

latitude	(num_lines, num_pixels)	float64	...
longitude	(num_lines, num_pixels)	float64	...

▼ Data variables:

time	(num_lines)	datetime64[ns]	...
time_tai	(num_lines)	datetime64[ns]	...
ssh_karin	(num_lines, num_pixels)	float64	...
ssh_karin_qual	(num_lines, num_pixels)	float64	...
ssh_karin_uncert	(num_lines, num_pixels)	float32	...
ssha_karin	(num_lines, num_pixels)	float64	...
ssha_karin_qual	(num_lines, num_pixels)	float64	...
ssh_karin_2	(num_lines, num_pixels)	float64	...
ssh_karin_2_qual	(num_lines, num_pixels)	float64	...
ssha_karin_2	(num_lines, num_pixels)	float64	...
ssha_karin_2_qual	(num_lines, num_pixels)	float64	...
num_pt_avg	(num_lines, num_pixels)	float32	...
distance_to_coast	(num_lines, num_pixels)	float32	...
heading_to_coast	(num_lines, num_pixels)	float32	...
ancillary_surface_...	(num_lines, num_pixels)	float32	...
dynamic_ice_flag	(num_lines, num_pixels)	float32	...
rain_flag	(num_lines, num_pixels)	float32	...
rad_surface_type...	(num_lines, num_sides)	float32	...
mean_sea_surfac...	(num_lines, num_pixels)	float64	...
mean_sea_surfac...	(num_lines, num_pixels)	float32	...
geoid	(num_lines, num_pixels)	float64	...
internal_tide_hret	(num_lines, num_pixels)	float32	...
height_cor_xover	(num_lines, num_pixels)	float64	...
height_cor_xover...	(num_lines, num_pixels)	float32	...

► Indexes: (0)

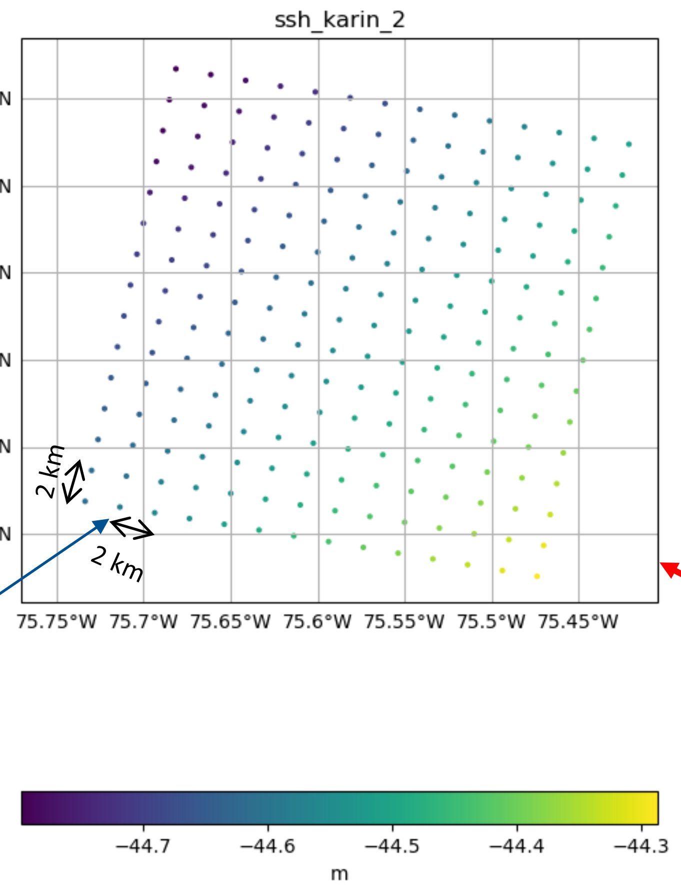
► Attributes: (60)

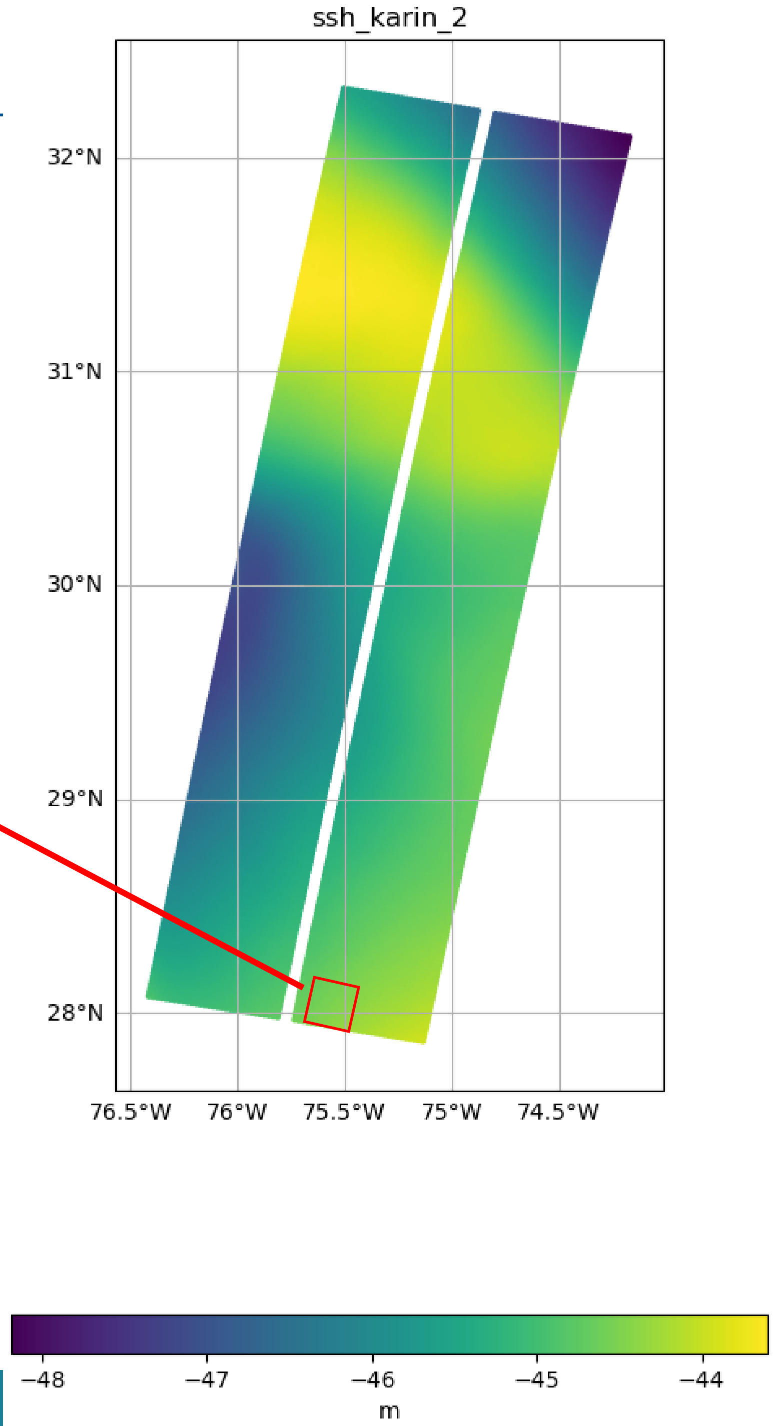
LR products : contents and illustrations

L2_LR_SSH product

« **Basic** » file
2 km x 2km geographically fixed grid

Each individual measurement always has the same geographical coordinates, for all cycles

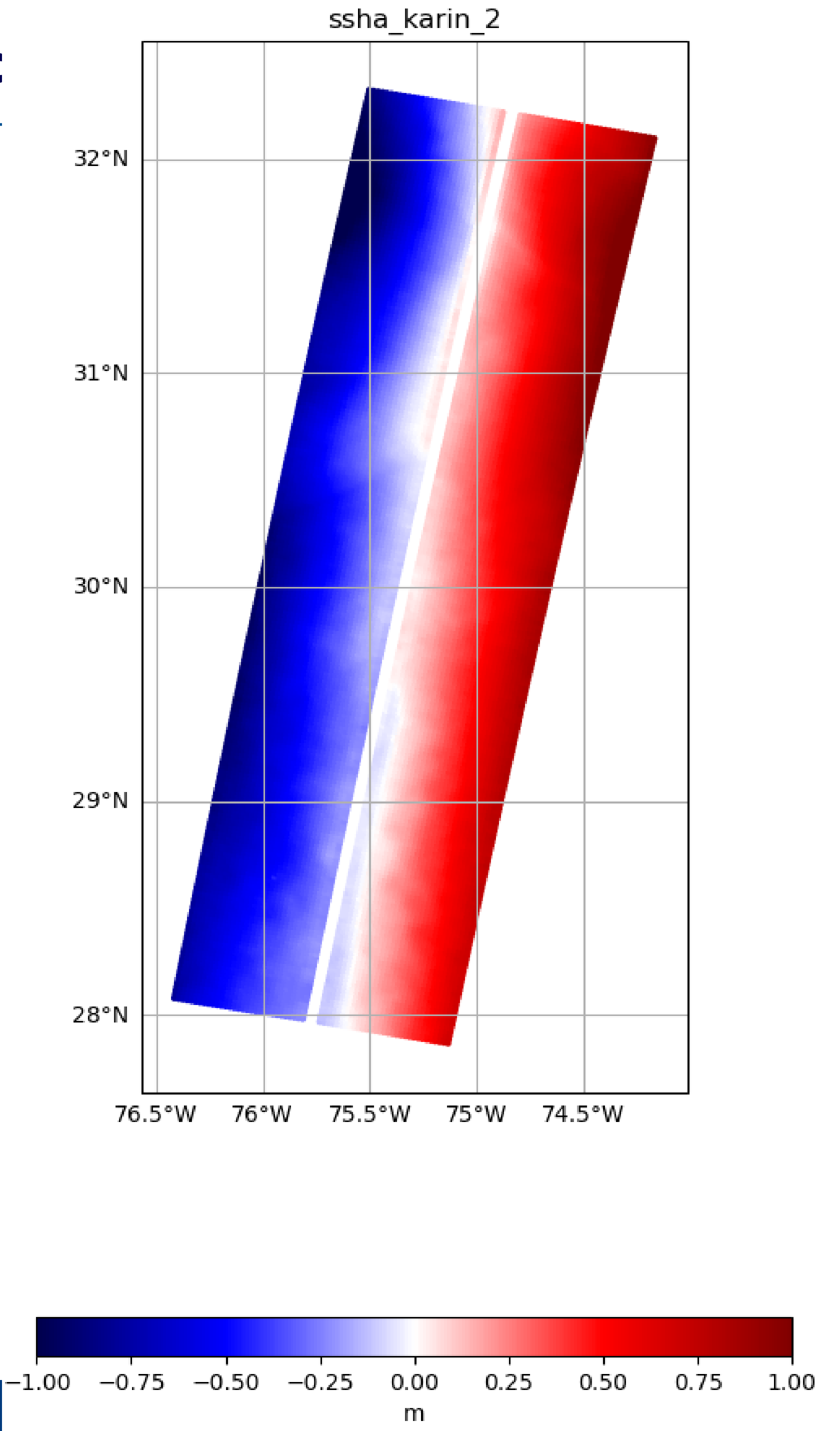




LR products : contents and

L2_LR_SSH product

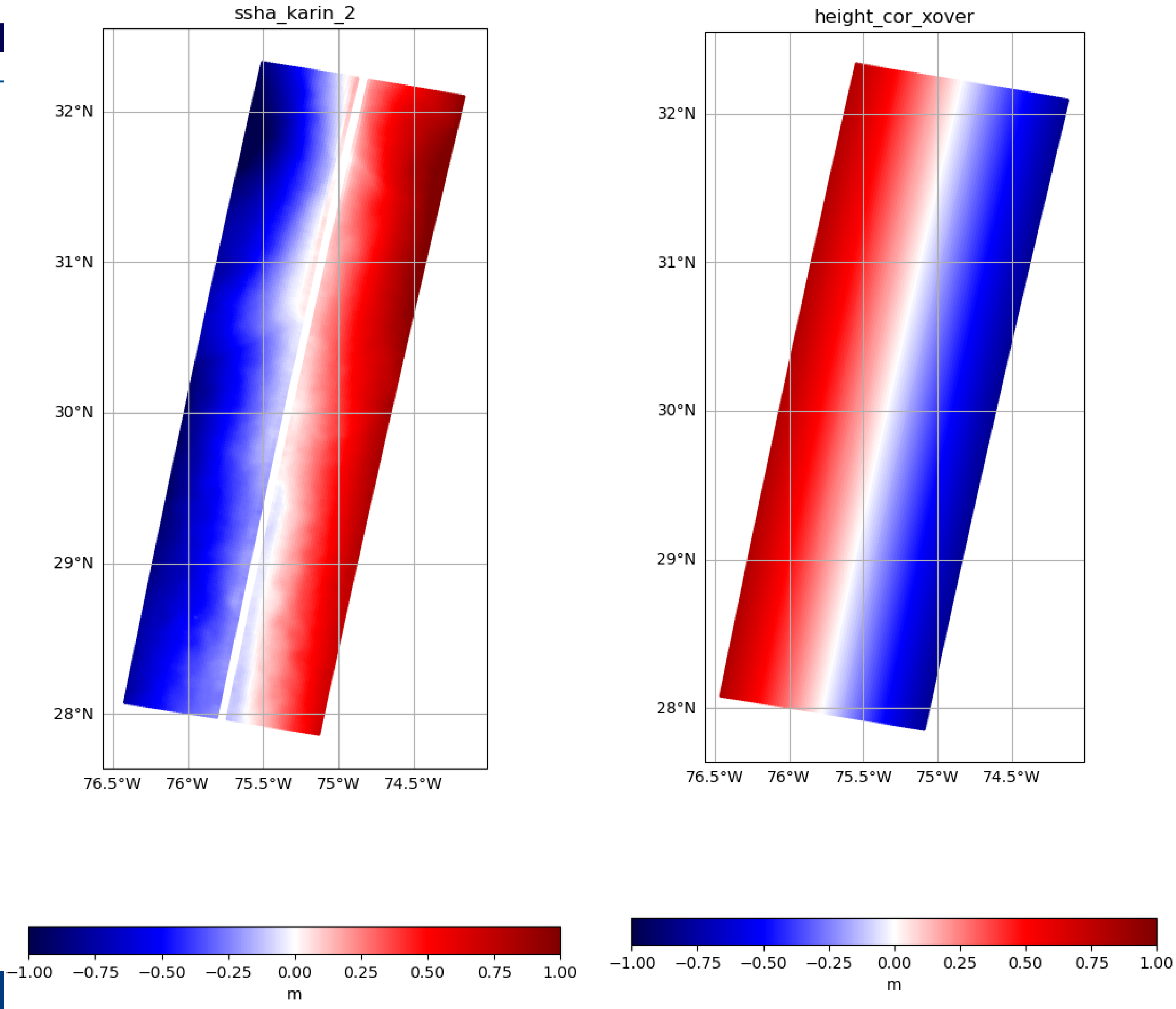
« **Basic** » file
2 km x 2km geographically fixed grid



LR products : contents and

L2_LR_SSH product

« **Basic** » file
2 km x 2km geographically fixed grid

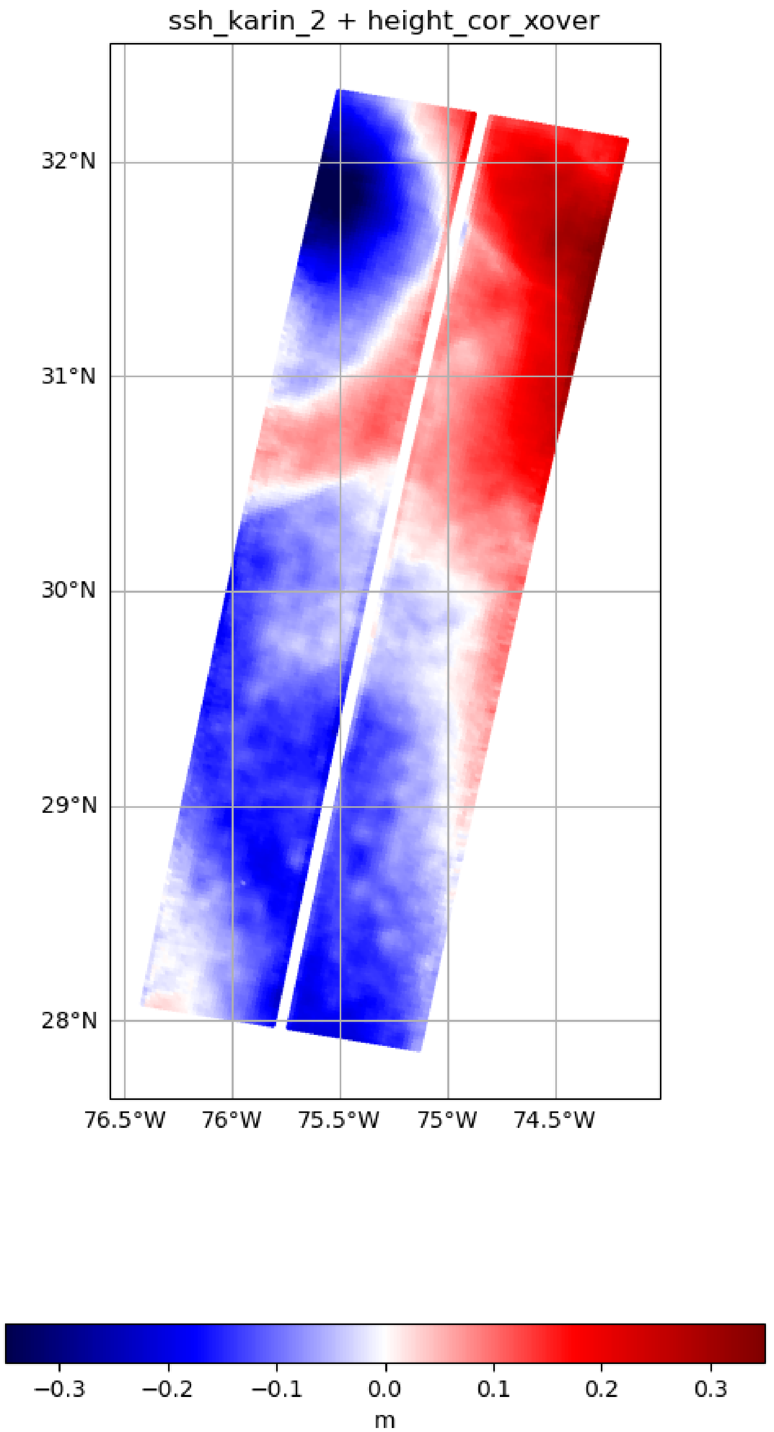


LR products : contents and illustrations

L2_LR_SSH product

« **Basic** » file
2 km x 2km geographically fixed grid

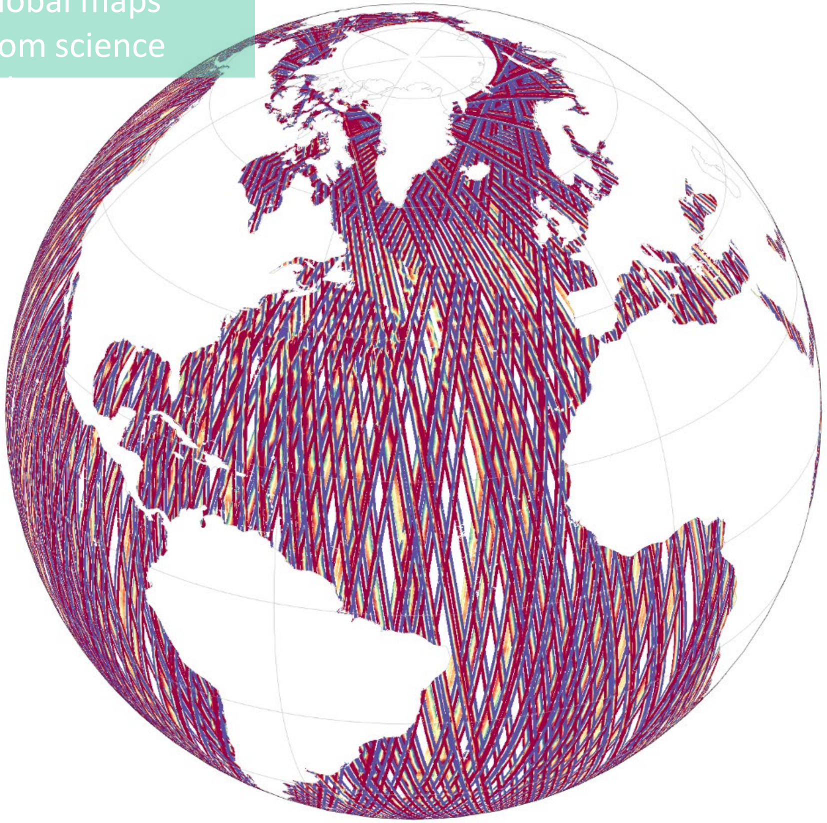
ssh_karin_2 + height_cor_xover



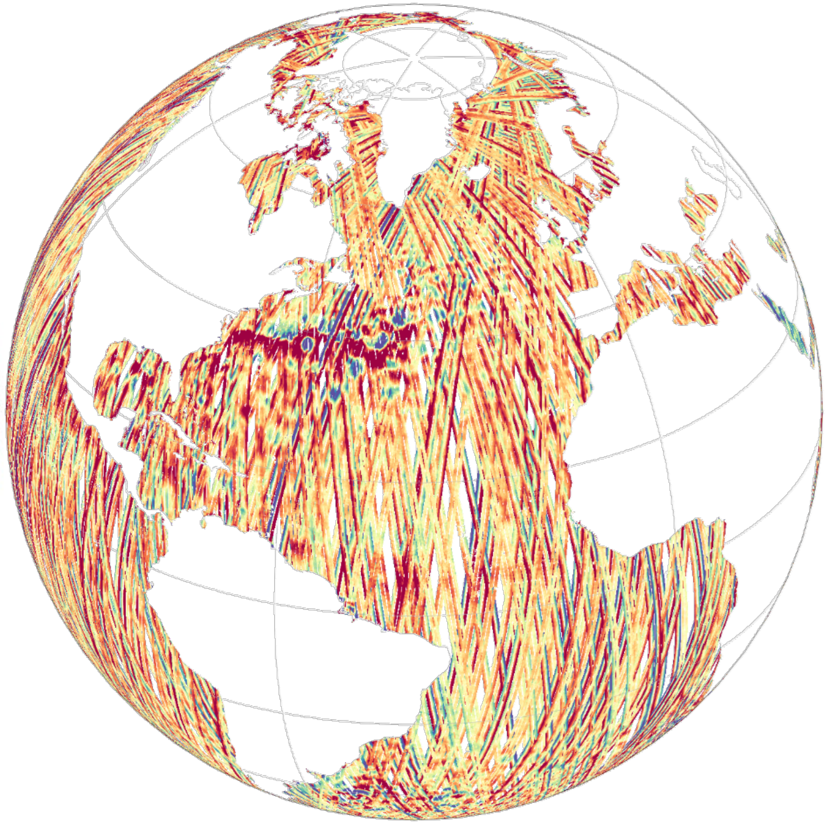
KaRIn SSHA preliminary assessment

Global maps from science

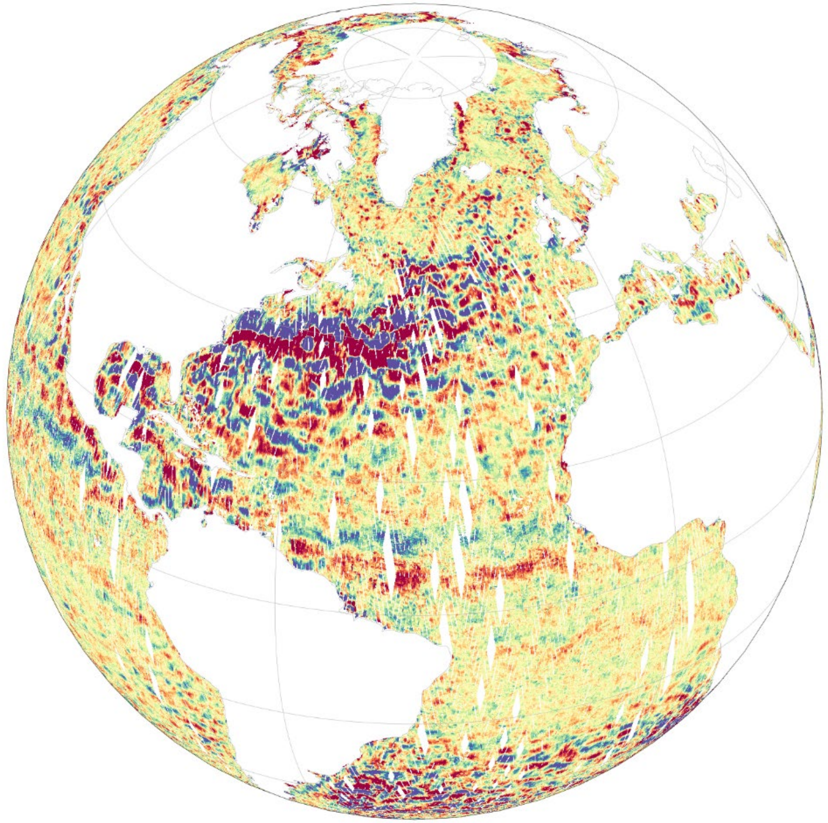
Ssha_karin_2



Ssha_karin_2 + height_cor_xover



Ssha_karin_2 high pass filter (< 1000km)



- **REMINDER:**
  - ✓ L2 SSHA long wavelengths are affected by « systematic errors » (e.g. from roll error knowledge)
  - ✓ The « crossover » correction will remove most of this error (see G. Dibarboure presentation)
  - ✓ Below1000 km, these systematic errors are much smaller than the oceanic signal

LR products : contents and illustrations

SWH measurement

sigma0 measurement

L2_LR_SSH product

« **WindWave** » file
2 km x 2km geographically fixed grid

wind speed measurement

wind & wave models

ancillary information

► Dimensions: (num_lines: 9866, num_pixels: 69, num_sides: 2)

▼ Coordinates:

latitude	(num_lines, num_pixels)	float64	...
longitude	(num_lines, num_pixels)	float64	...

▼ Data variables:

time	(num_lines)	datetime64[ns]	...
time_tai	(num_lines)	datetime64[ns]	...
polarization_karin	(num_lines, num_sides)	object	...
swh_karin	(num_lines, num_pixels)	float32	...
swh_karin_qual	(num_lines, num_pixels)	float64	...
swh_karin_uncert	(num_lines, num_pixels)	float32	...
sig0_karin	(num_lines, num_pixels)	float32	...
sig0_karin_qual	(num_lines, num_pixels)	float64	...
sig0_karin_uncert	(num_lines, num_pixels)	float32	...
sig0_karin_2	(num_lines, num_pixels)	float32	...
sig0_karin_2_qual	(num_lines, num_pixels)	float64	...
wind_speed_karin	(num_lines, num_pixels)	float32	...
wind_speed_kari...	(num_lines, num_pixels)	float64	...
wind_speed_kari...	(num_lines, num_pixels)	float32	...
wind_speed_kari...	(num_lines, num_pixels)	float64	...
num_pt_avg	(num_lines, num_pixels)	float32	...
swh_wind_speed...	(num_lines, num_pixels)	float32	...
swh_wind_speed...	(num_lines, num_pixels)	float32	...
swh_nadir_altime...	(num_lines, num_pixels)	float32	...
swh_model	(num_lines, num_pixels)	float32	...
mean_wave_dire...	(num_lines, num_pixels)	float32	...
mean_wave_peri...	(num_lines, num_pixels)	float32	...
wind_speed_mod...	(num_lines, num_pixels)	float32	...
wind_speed_mod...	(num_lines, num_pixels)	float32	...
wind_speed_rad	(num_lines, num_sides)	float32	...
distance_to_coast	(num_lines, num_pixels)	float32	...
heading_to_coast	(num_lines, num_pixels)	float32	...
ancillary_surface_...	(num_lines, num_pixels)	float32	...
dynamic_ice_flag	(num_lines, num_pixels)	float32	...
rain_flag	(num_lines, num_pixels)	float32	...
rad_surface_type...	(num_lines, num_sides)	float32	...

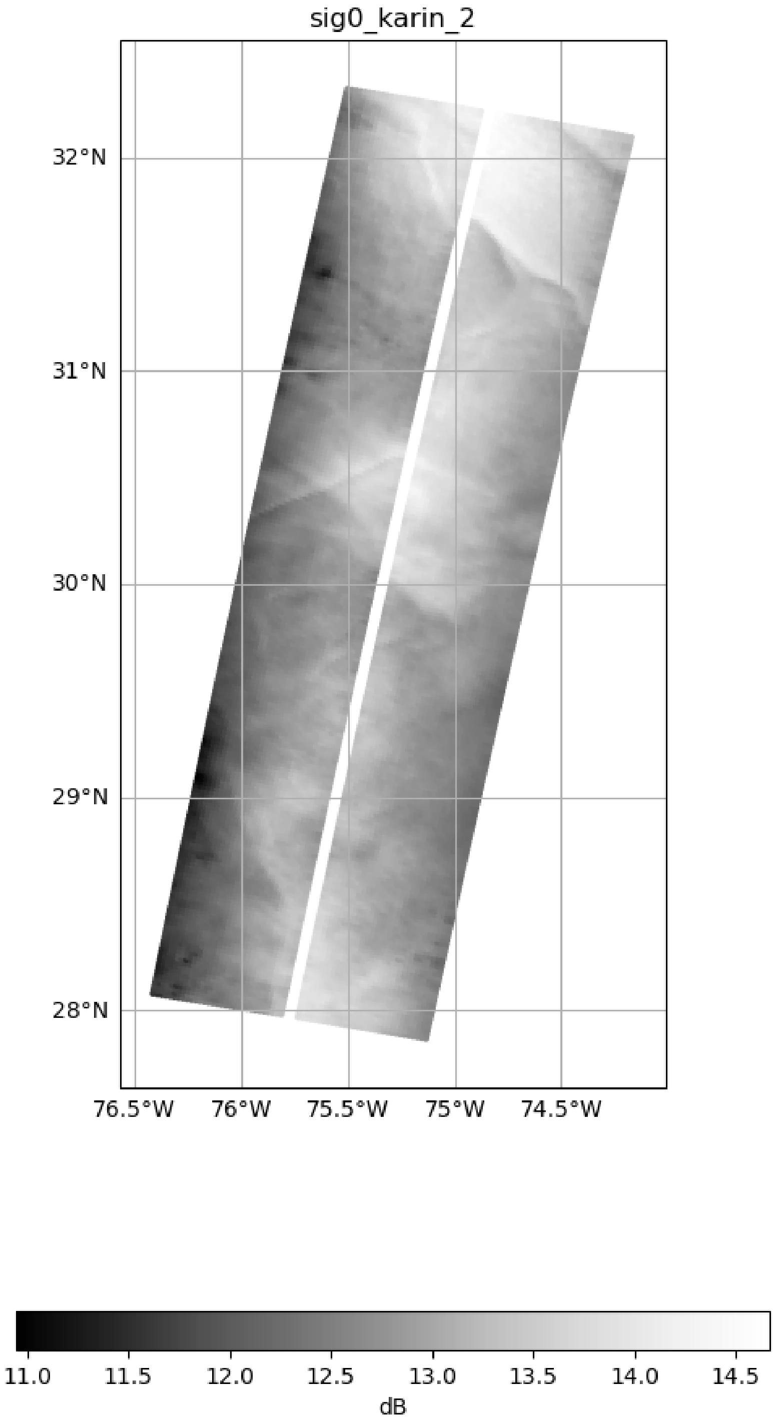
► Indexes: (0)

► Attributes: (60)

LR products : contents and illustrations

L2_LR_SSH product

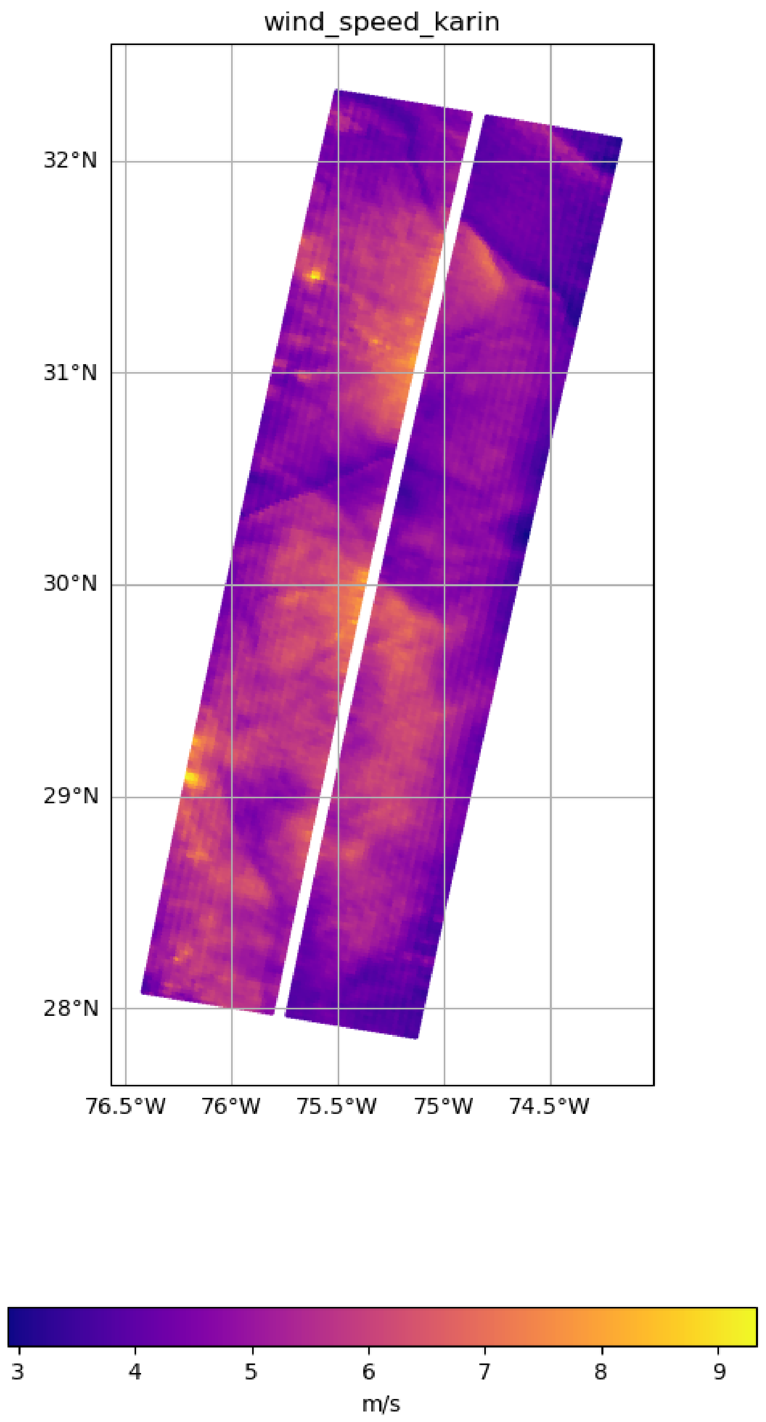
« **WindWave** » file
2 km x 2km geographically fixed grid



LR products : contents and illustrations

L2_LR_SSH product

« **WindWave** » file
2 km x 2km geographically fixed grid



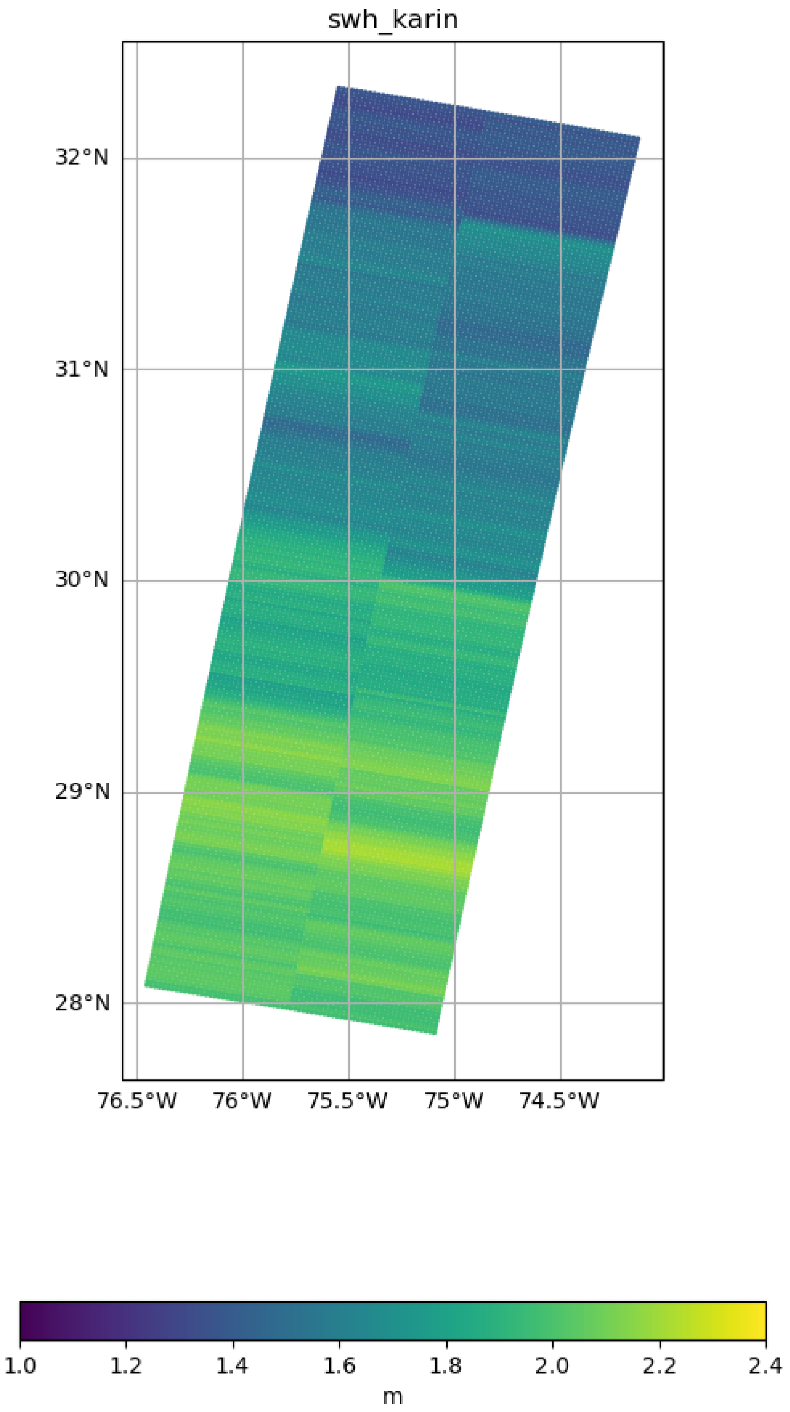
« Fall reprocessing » will use an improved GMF (cf presentation in Waves/air-sea interaction WG)

LR products : contents and illustrations

L2_LR_SSH product

« **WindWave** » file
2 km x 2km geographically fixed grid

« Summer reprocessing » has one measurement per swath, every 2km in along-track

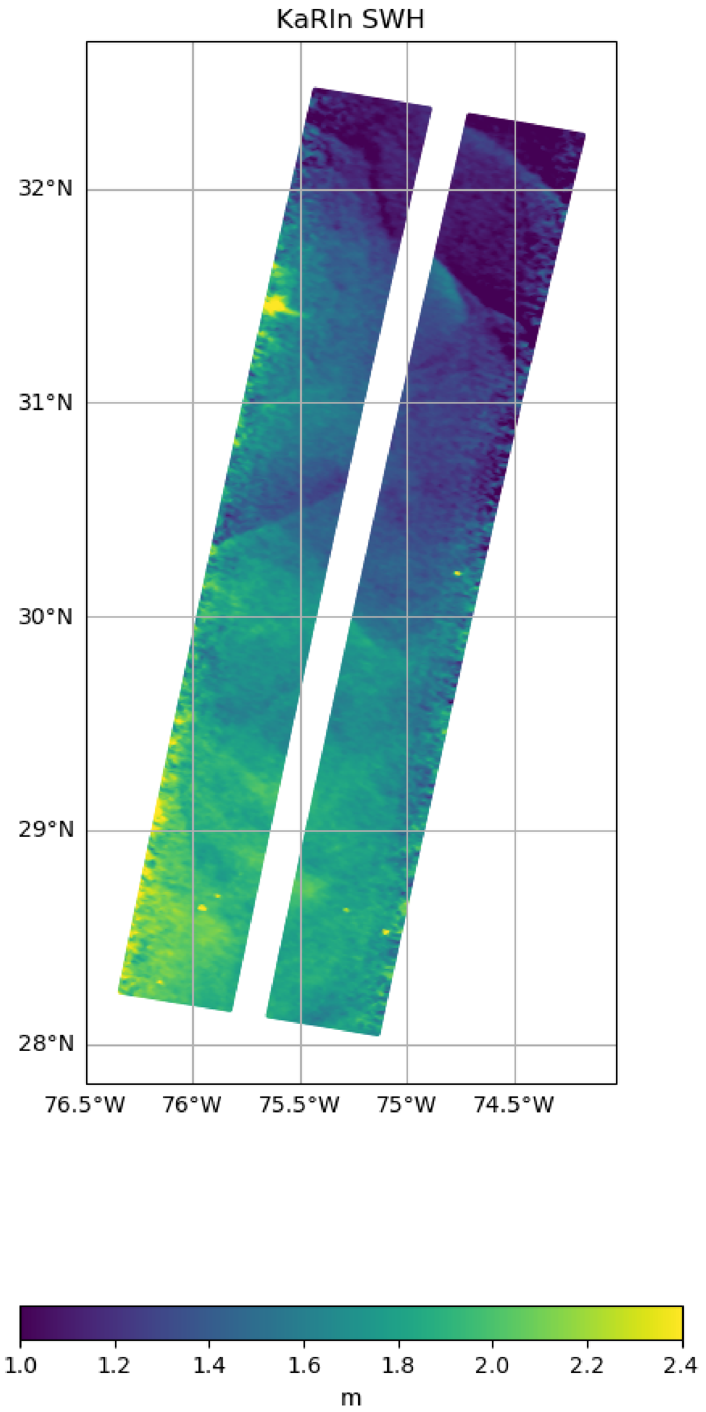


LR products : contents and illustrations

L2_LR_SSH product

« **WindWave** » file
2 km x 2km geographically fixed grid

« Fall reprocessing » will use calibration and 2D inversion (cf presentation in Waves/air-sea interaction WG)



LR products : contents and illustrations

L2_LR_SSH product

« **Expert** » file
2 km x 2km geographically fixed grid

contains a copy of the Basic and WindWave datasets, as well as :

sc_altitude	(num_lines)
orbit_alt_rate	(num_lines)
cross_track_angle	(num_lines)
sc_roll	(num_lines)
sc_pitch	(num_lines)
sc_yaw	(num_lines)
velocity_heading	(num_lines)
orbit_qual	(num_lines)
latitude_avg_ssh	(num_lines, num_pixels)
longitude_avg_ssh	(num_lines, num_pixels)
cross_track_dista...	(num_lines, num_pixels)
x_factor	(num_lines, num_pixels)
sig0_cor_atmos_...	(num_lines, num_pixels)
sig0_cor_atmos_r...	(num_lines, num_pixels)
doppler_centroid	(num_lines, num_pixels)
phase_bias_ref_s...	(num_lines, num_pixels)
obp_ref_surface	(num_lines, num_pixels)
rad_tmb_187	(num_lines, num_sides)
rad_tmb_238	(num_lines, num_sides)
rad_tmb_340	(num_lines, num_sides)
rad_water_vapor	(num_lines, num_sides)
rad_cloud_liquid_...	(num_lines, num_sides)
mean_sea_surfac...	(num_lines, num_pixels)
mean_sea_surfac...	(num_lines, num_pixels)
mean_sea_surfac...	(num_lines, num_pixels)
mean_sea_surfac...	(num_lines, num_pixels)
geoid	(num_lines, num_pixels)

mean_dynamic_t...	(num_lines, num_pixels)
mean_dynamic_t...	(num_lines, num_pixels)
depth_or_elevati...	(num_lines, num_pixels)
solid_earth_tide	(num_lines, num_pixels)
ocean_tide_fes	(num_lines, num_pixels)
ocean_tide_got	(num_lines, num_pixels)
load_tide_fes	(num_lines, num_pixels)
load_tide_got	(num_lines, num_pixels)
ocean_tide_eq	(num_lines, num_pixels)
ocean_tide_non_...	(num_lines, num_pixels)
internal_tide_hret	(num_lines, num_pixels)
internal_tide_sol2	(num_lines, num_pixels)
pole_tide	(num_lines, num_pixels)
dac	(num_lines, num_pixels)
inv_bar_cor	(num_lines, num_pixels)
model_dry_tropo...	(num_lines, num_pixels)
model_wet_trop...	(num_lines, num_pixels)
rad_wet_tropo_cor	(num_lines, num_pixels)
iono_cor_gim_ka	(num_lines, num_pixels)
height_cor_xover	(num_lines, num_pixels)
height_cor_xover...	(num_lines, num_pixels)
rain_rate	(num_lines, num_pixels)
ice_conc	(num_lines, num_pixels)
sea_state_bias_cor	(num_lines, num_pixels)
sea_state_bias_c...	(num_lines, num_pixels)
swh_ssb_cor_sou...	(num_lines, num_pixels)
swh_ssb_cor_sou...	(num_lines, num_pixels)
wind_speed_ssb_...	(num_lines, num_pixels)
wind_speed_ssb_...	(num_lines, num_pixels)

LR products : contents and illustrations

L2_LR_SSH product

« **Unsmoothed** » file
approximately 250m x 250m grid
exact location depends on actual observation geometry at the time of the measurement

One netcdf group per side (left/right)

► Dimensions: (num_lines: 82249, num_pixels: 240)

▼ Coordinates:

latitude	(num_lines, num_pixels)	float64	...
longitude	(num_lines, num_pixels)	float64	...

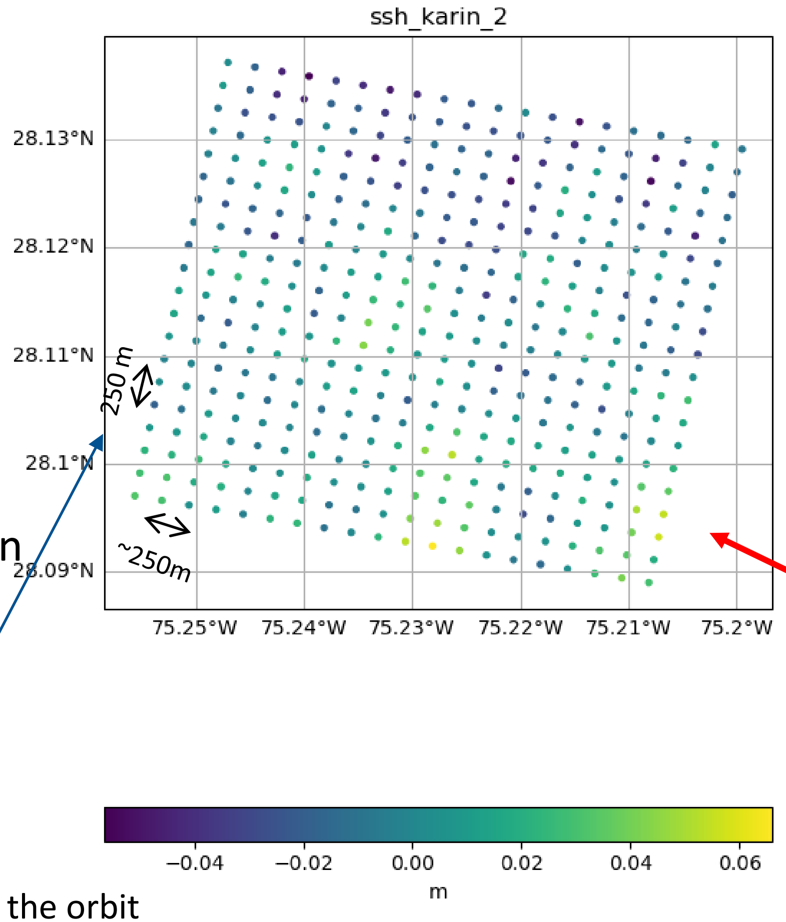
▼ Data variables:

time	(num_lines)	datetime64[ns]	...
time_tai	(num_lines)	datetime64[ns]	...
latitude_uncert	(num_lines, num_pixels)	float32	...
longitude_uncert	(num_lines, num_pixels)	float32	...
polarization_karin	(num_lines)	object	...
ssh_karin_2	(num_lines, num_pixels)	float64	...
ssh_karin_2_qual	(num_lines, num_pixels)	float64	...
ssh_karin_uncert	(num_lines, num_pixels)	float32	...
sig0_karin_2	(num_lines, num_pixels)	float32	...
sig0_karin_2_qual	(num_lines, num_pixels)	float64	...
sig0_karin_uncert	(num_lines, num_pixels)	float32	...
total_coherence	(num_lines, num_pixels)	float32	...
mean_sea_surfac...	(num_lines, num_pixels)	float64	...
miti_power_250m	(num_lines, num_pixels)	float32	...
miti_power_var_...	(num_lines, num_pixels)	float32	...
ancillary_surface_...	(num_lines, num_pixels)	float32	...

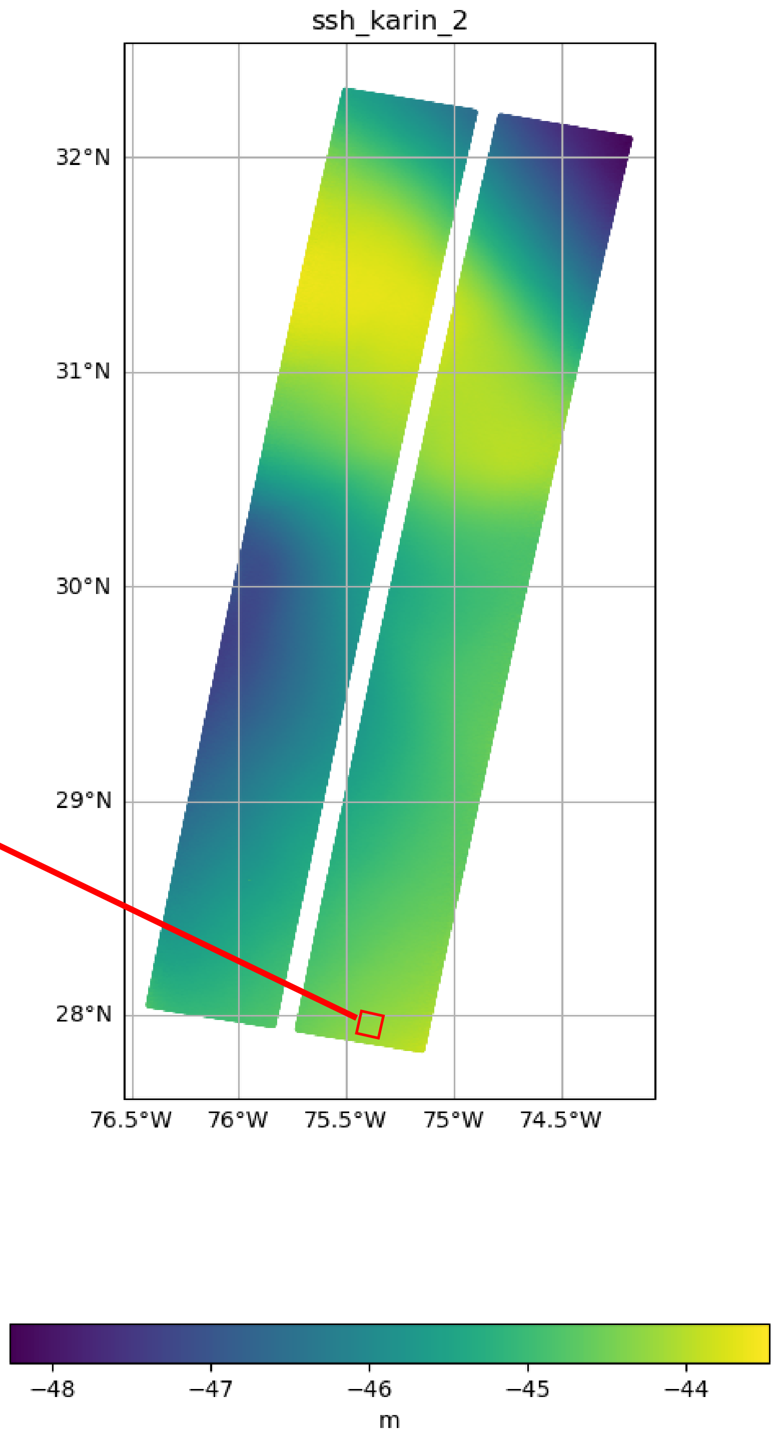
LR products : contents and illustrations

L2_LR_SSH product

« **Unsmoothed** » file
approximately 250m x 250m grid
exact location depends on actual observation geometry at the time of the measurement



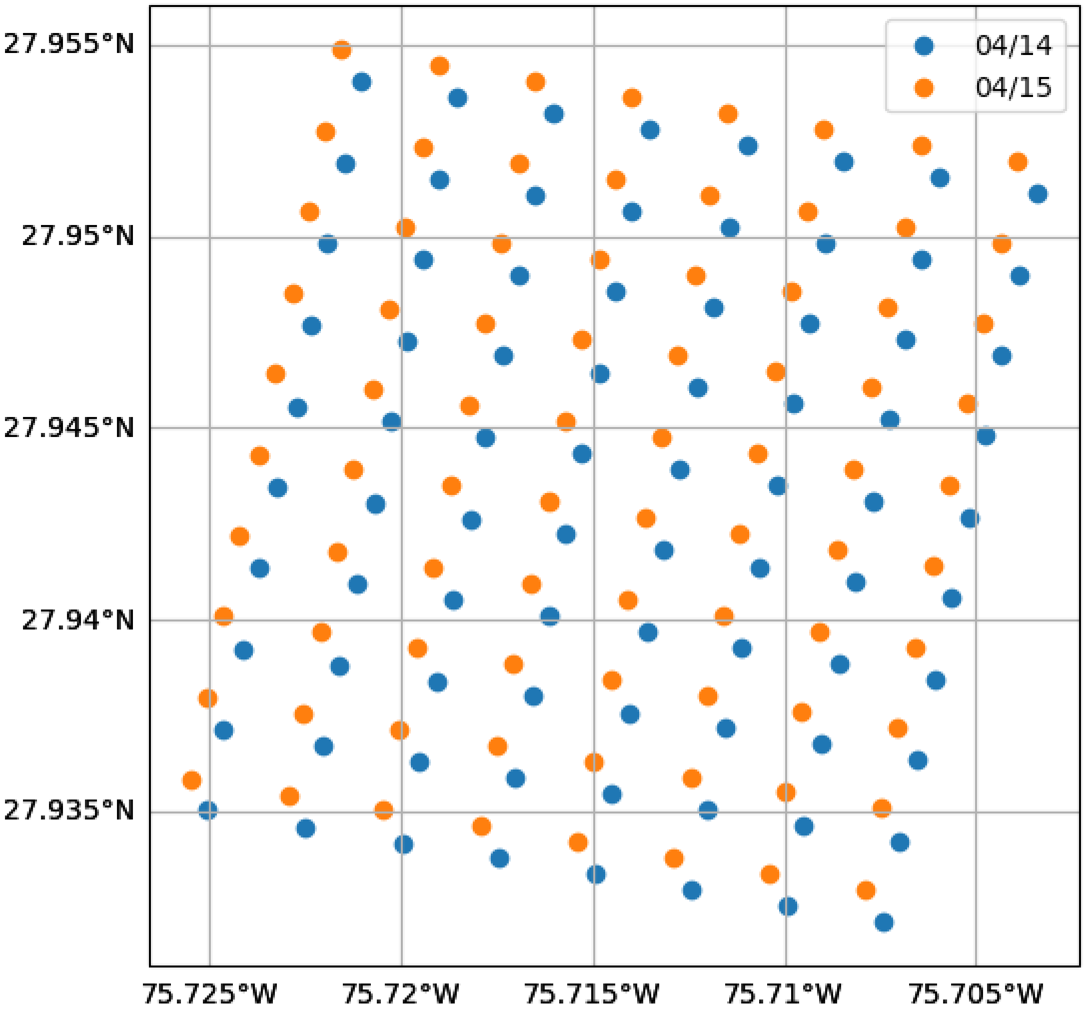
varies by a few m along the orbit



LR products : contents and illustrations

L2_LR_SSH product

« Unsmoothed » file
approximately 250m x 250m grid
exact location depends on actual observation geometry at the time of the measurement

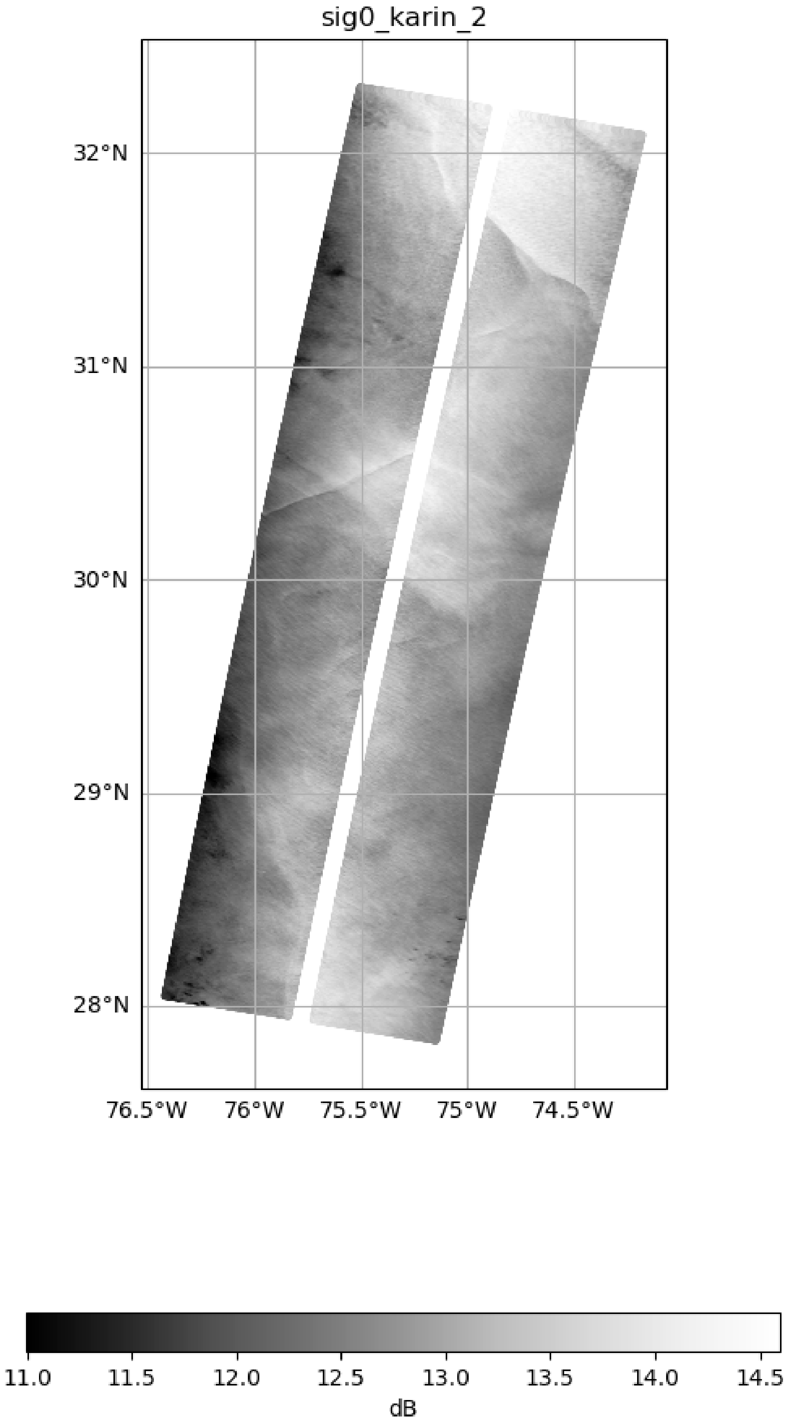


Be careful when computing 1-day differences for example

LR products : contents and illustrations

L2_LR_SSH product

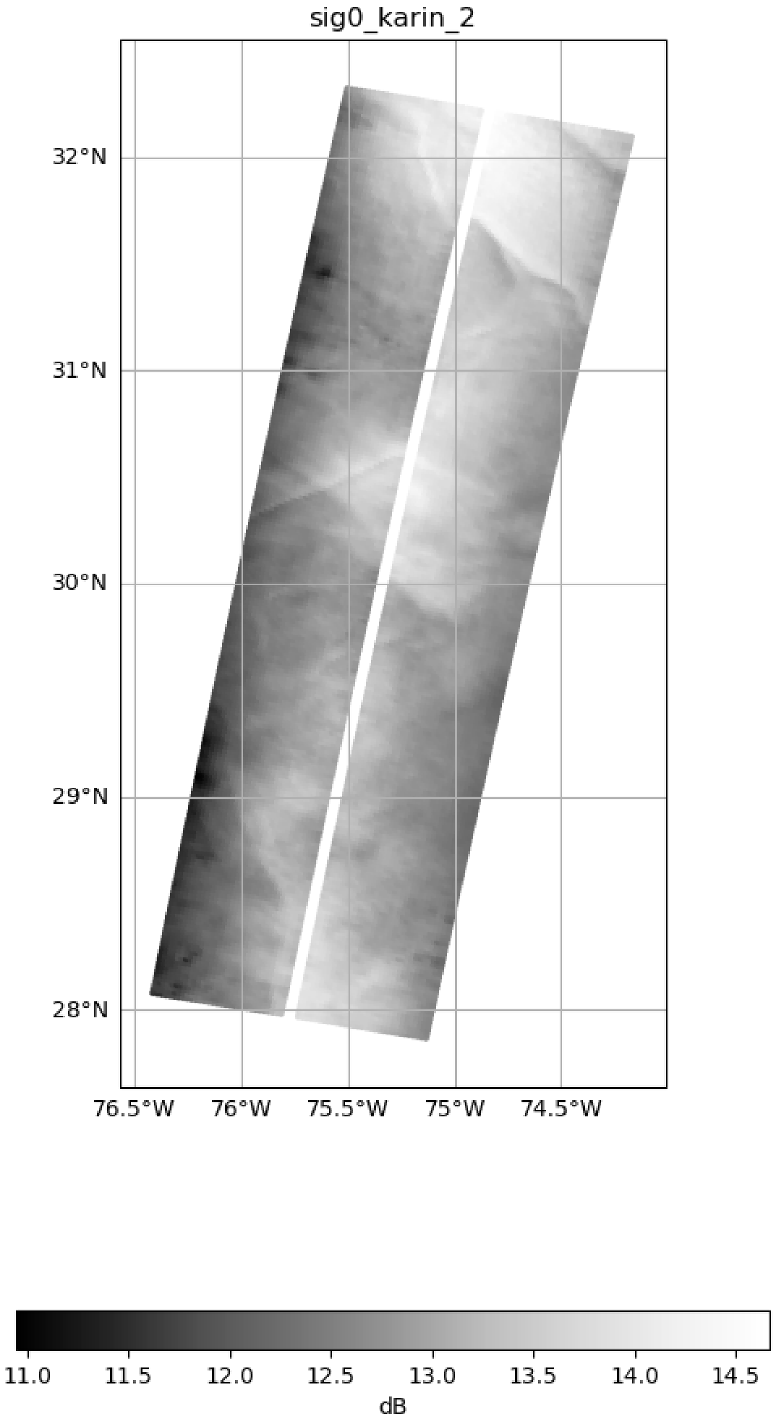
« Unsmoothed » file
approximately 250m x 250m grid
exact location depends on actual observation geometry at the time of the measurement

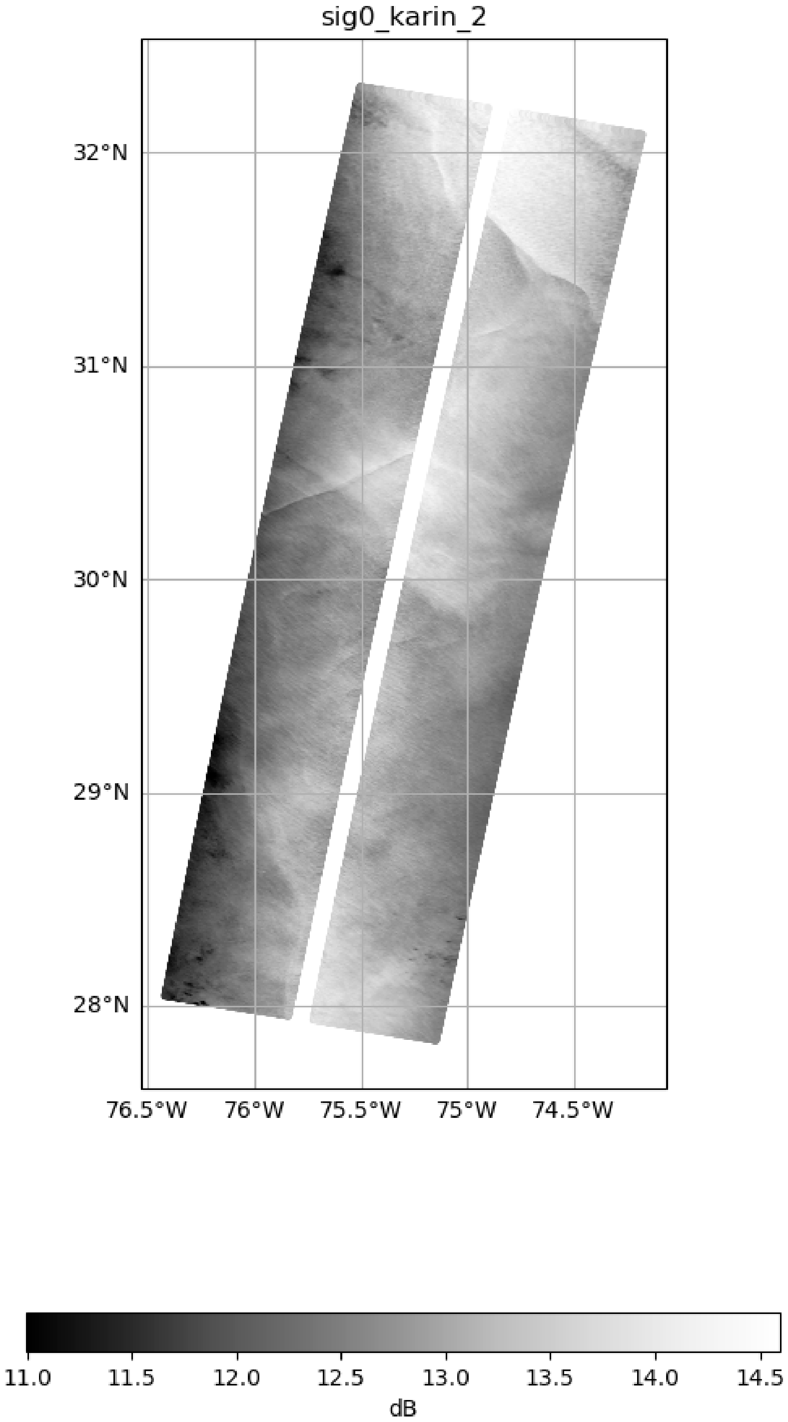


LR products : contents and il

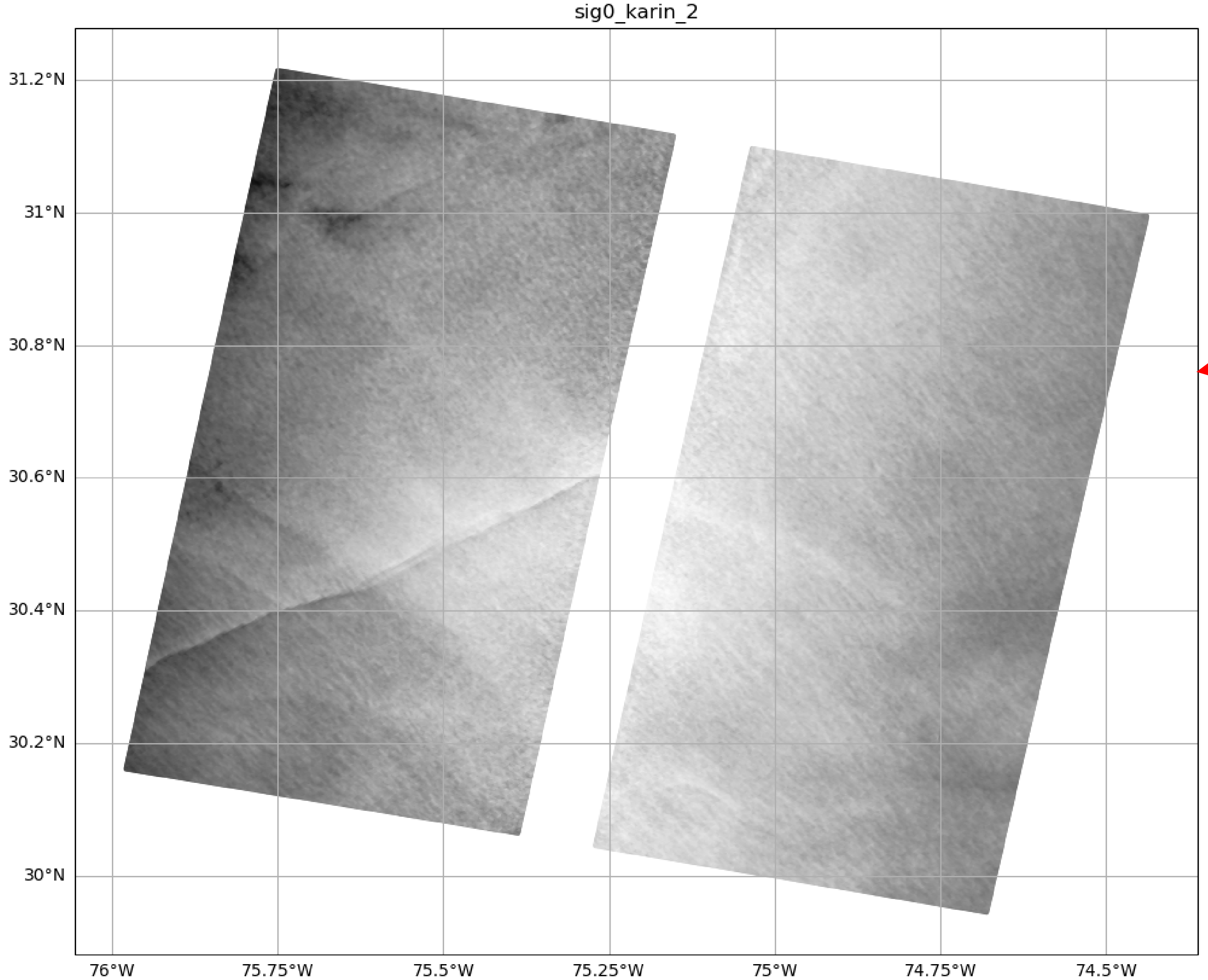
L2_LR_SSH product

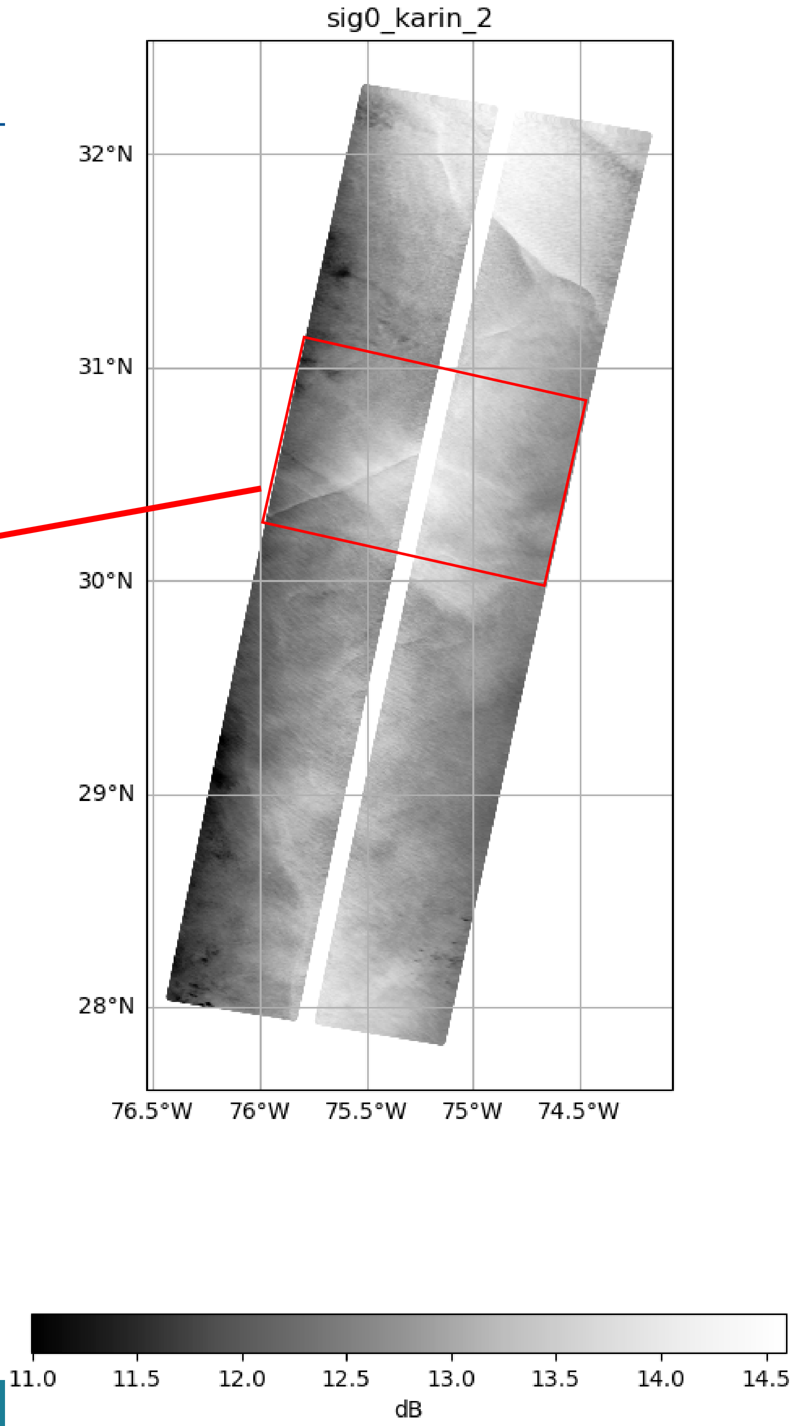
« Unsmoothed » file
approximately 250m x 250m grid
exact location depends on actual observation geometry at the time of the measurement



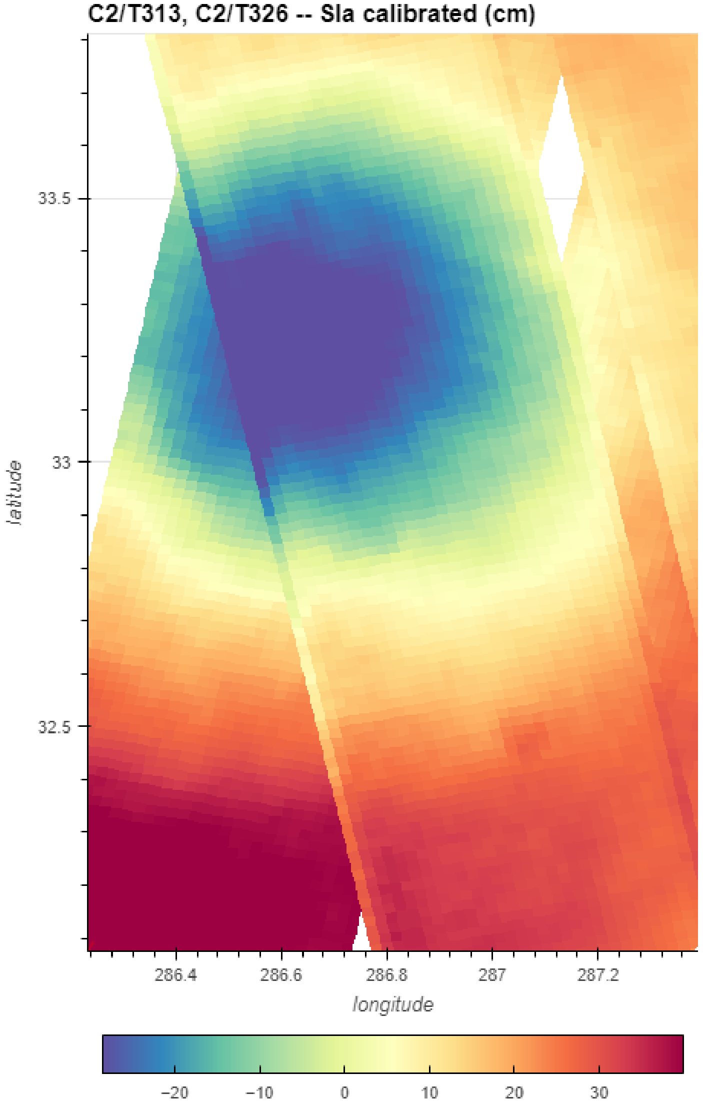


LR products : contents and illustrations

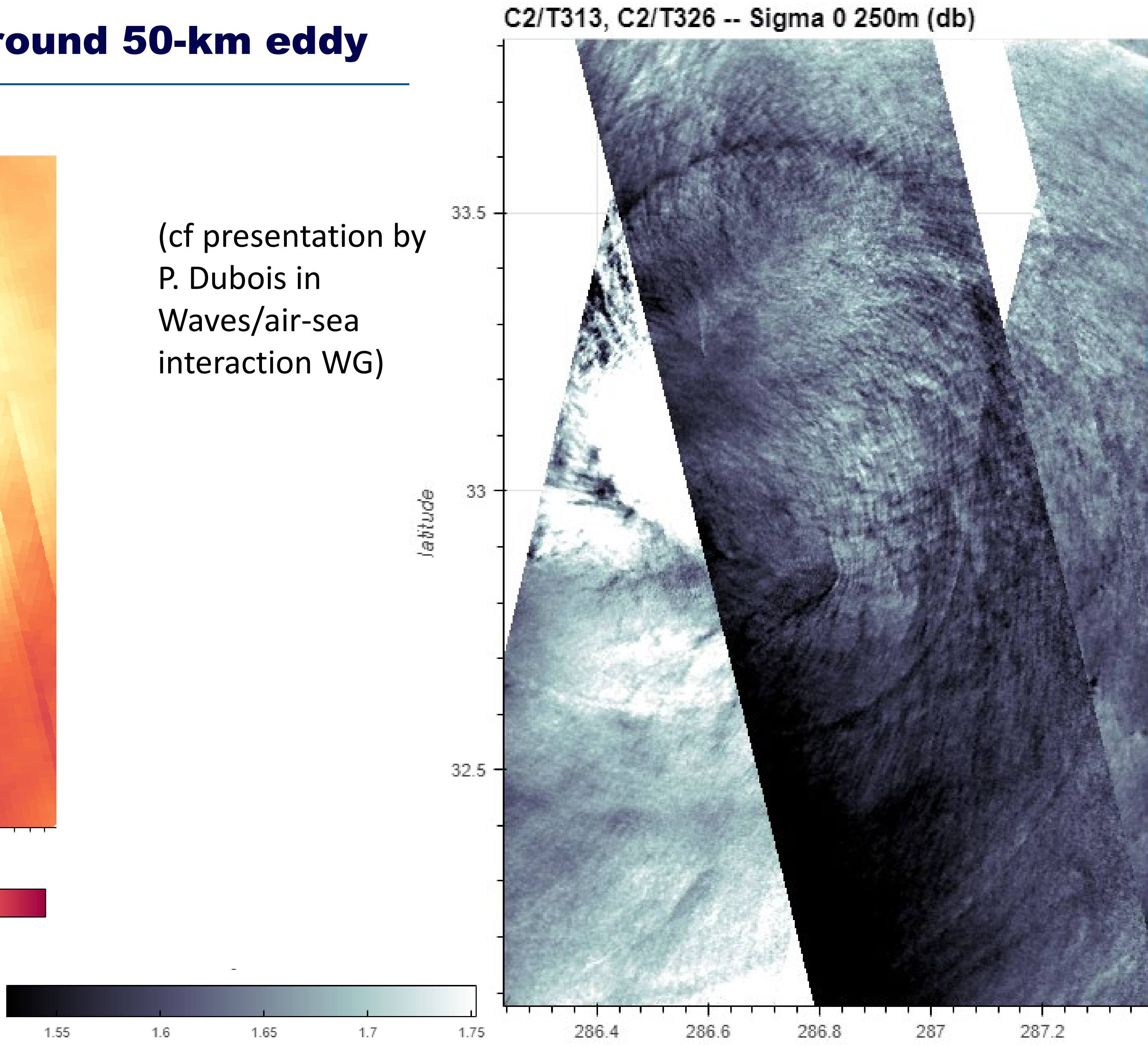




Small scale surface roughness around 50-km eddy



(cf presentation by P. Dubois in Waves/air-sea interaction WG)



LR products : contents and illustrations

L1B_LR_INTF product

Single file, ~20GB, one netCDF group per side
« radar » variables, not geolocated
Before combining the 9 doppler beams

► Dimensions: (num_beams: 9, num_lines: 82457, num_pixels: 240, num_coord: 3, complex_depth: 2, num_doppler_miti_lines: 10384, num_doppler_miti_pixels: 24)

▼ Coordinates:

reference_latitude	(num_beams, num_lines, num_pixels)	float64
reference_longitu...	(num_beams, num_lines, num_pixels)	float64

▼ Data variables:

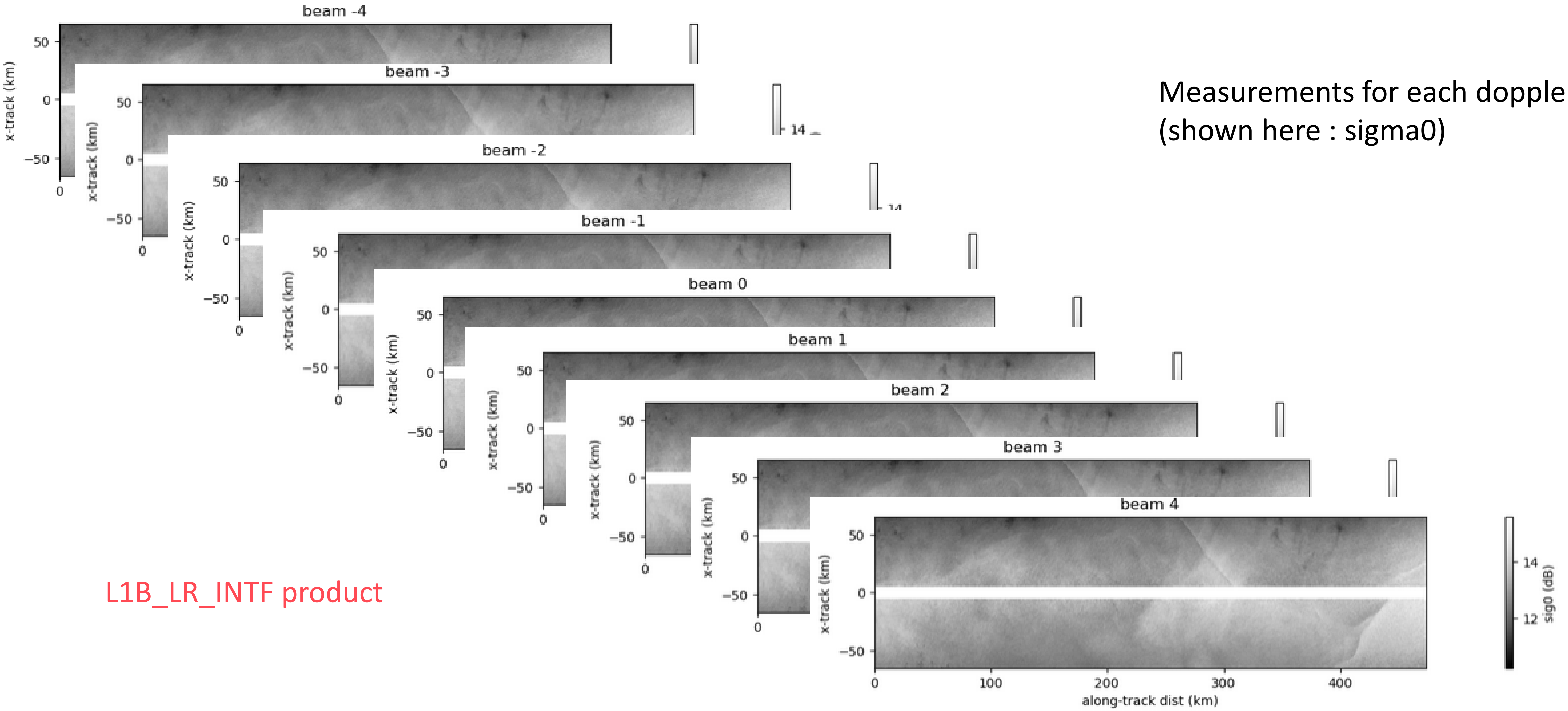
reference_location	(num_beams, num_lines, num_pixels, num_coord)	float64
interferogram	(num_beams, num_lines, num_pixels, complex_depth)	float32
phase_uncert	(num_beams, num_lines, num_pixels)	float32
sig0	(num_beams, num_lines, num_pixels)	float32
sig0_uncert	(num_beams, num_lines, num_pixels)	float32
volumetric_correl...	(num_beams, num_lines, num_pixels)	float32
volumetric_correl...	(num_beams, num_lines, num_pixels)	float32
angular_correlati...	(num_beams, num_lines, num_pixels)	float32
geometric_correl...	(num_beams, num_lines, num_pixels)	float32
noise_correlation	(num_beams, num_lines, num_pixels)	float32
x_factor_plus_y	(num_beams, num_lines, num_pixels)	float32
x_factor_minus_y	(num_beams, num_lines, num_pixels)	float32
uncalibrated_po...	(num_beams, num_lines, num_pixels)	float32
uncalibrated_po...	(num_beams, num_lines, num_pixels)	float32
noise_power_plu...	(num_beams, num_lines, num_pixels)	float32
noise_power_min...	(num_beams, num_lines, num_pixels)	float32
model_dry_tropo...	(num_beams, num_lines, num_pixels)	float32
model_wet_trop...	(num_beams, num_lines, num_pixels)	float32
iono_cor_gim_ka	(num_beams, num_lines, num_pixels)	float32
phase_bias_cor	(num_beams, num_lines, num_pixels)	float32
interferogram_q...	(num_beams, num_lines, num_pixels)	float64
snr	(num_beams, num_lines, num_pixels)	float32
num_looks	(num_beams, num_lines, num_pixels)	float32
sig0_cor_atmos_...	(num_beams, num_lines, num_pixels)	float32
doppler_centroid	(num_lines, num_pixels)	float32
obp_ref_surface	(num_lines)	float32
pulse_repetition_...	(num_lines)	float32
power_miti	(num_lines, num_pixels)	float64
power_squared_...	(num_lines, num_pixels)	float64
time_doppler_miti	(num_doppler_miti_lines)	datetime64[ns]
time_tai_doppler...	(num_doppler_miti_lines)	datetime64[ns]
doppler_miti	(num_doppler_miti_lines, num_doppler_miti_pixels, complex_d...	float64

► Indexes: (0)

▼ Attributes:

description : KaRIn bias-corrected interferogram and associated information for the half swath to the righ t (when facing the velocity direction) of the nadir track.

LR products : contents and illustrations

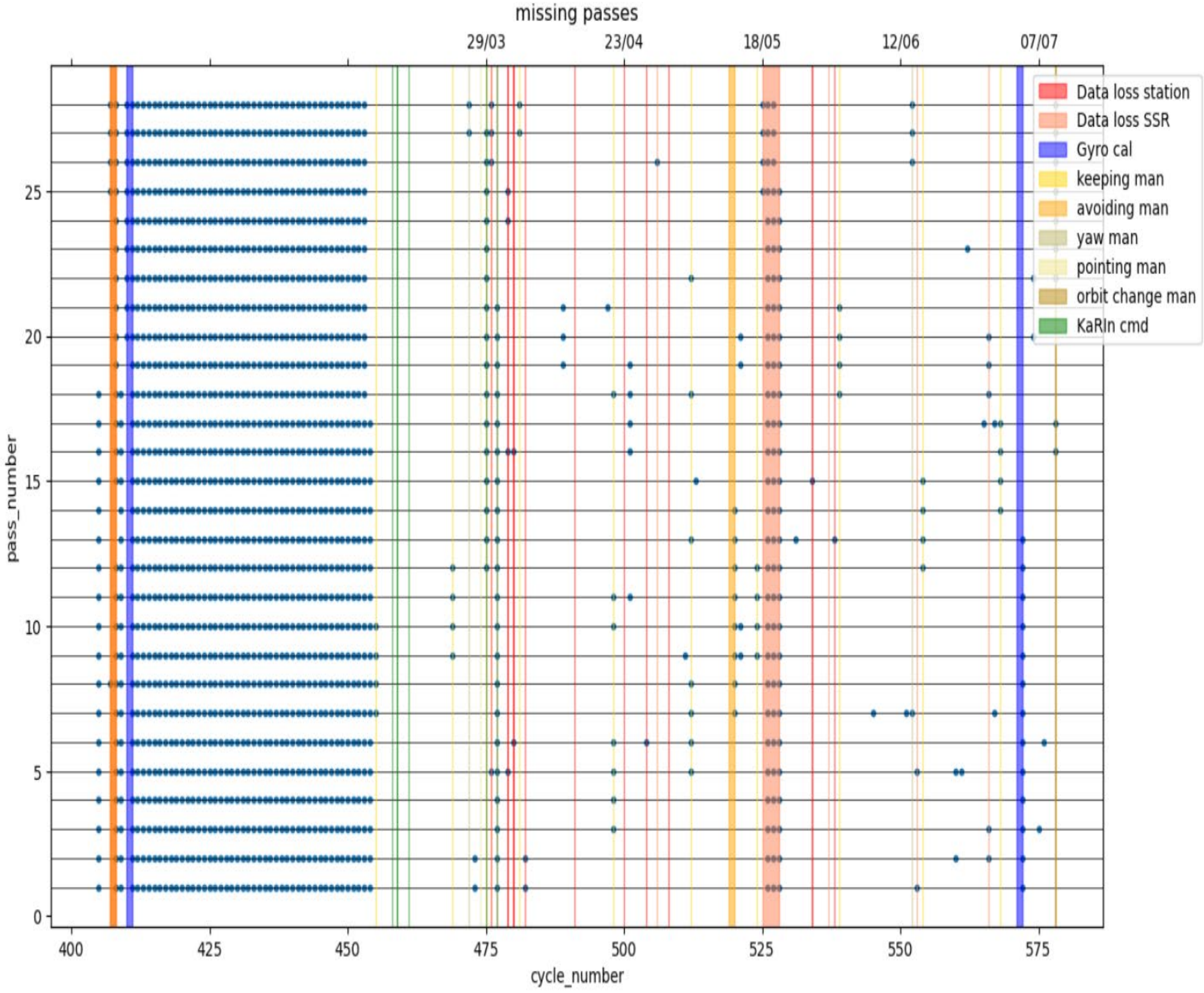


Measurements for each doppler beam (shown here : sigma0)

L1B_LR_INTF product

Data availability (forward processing)

- **Missing products monitoring (FWD production).**
- **Almost all of them are related to specific events**
- **After HPA- restart (cycle 454 / March 9th) 82% of the products are nominally produced in FWD mode.**
- **A few of these missing products will be available in the « Fall » reprocessing**



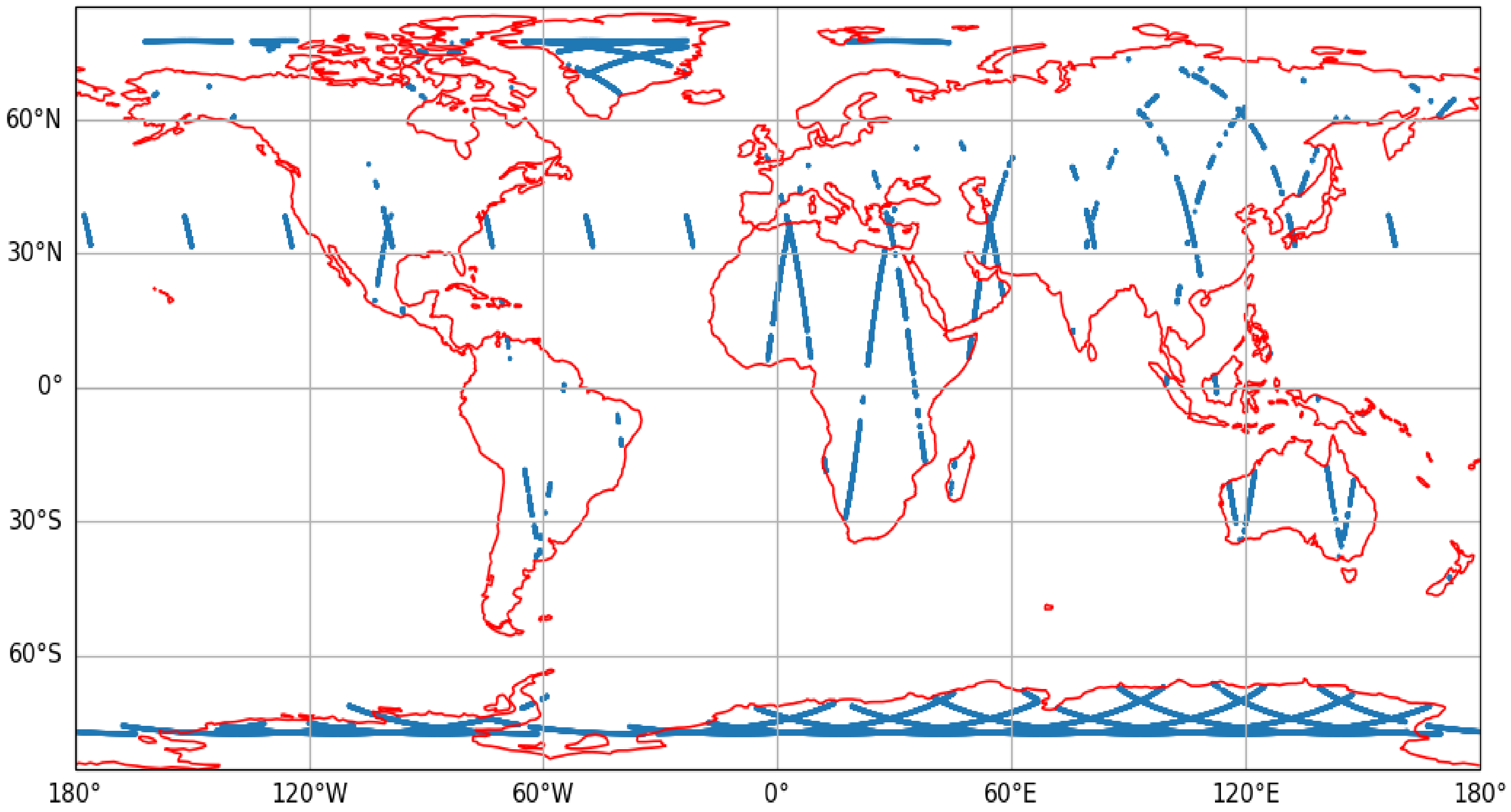
SSHA KaRIn availability: missing measurements

- **Data availability over open ocean is excellent:**
  - ✓ 0,03 % of missing measurements over Ocean (for swath ranged [10;60]km and excluding eclipse events.

- **Missing segments at eclipse location.**
  - ✓ conservative choice before launch to flag data close to eclipse entries/exits as bad.
  - ✓ Up to now, L2 processing discards those segments
  - ✓ For « fall » reprocessing, will be kept, processed (and flagged suspect as quality still has to be examined; first inspections do not show visible artifacts).

- **Missing measurements over land**
  - ✓ Time, and most of variables regularly set to default values. Up to now, processing discarded data when distance to water is >10 km.
  - ✓ For « Fall » reprocessing, will now be kept, but quality of data over land/ice/… has not been thoroughly investigated

Cycle 549



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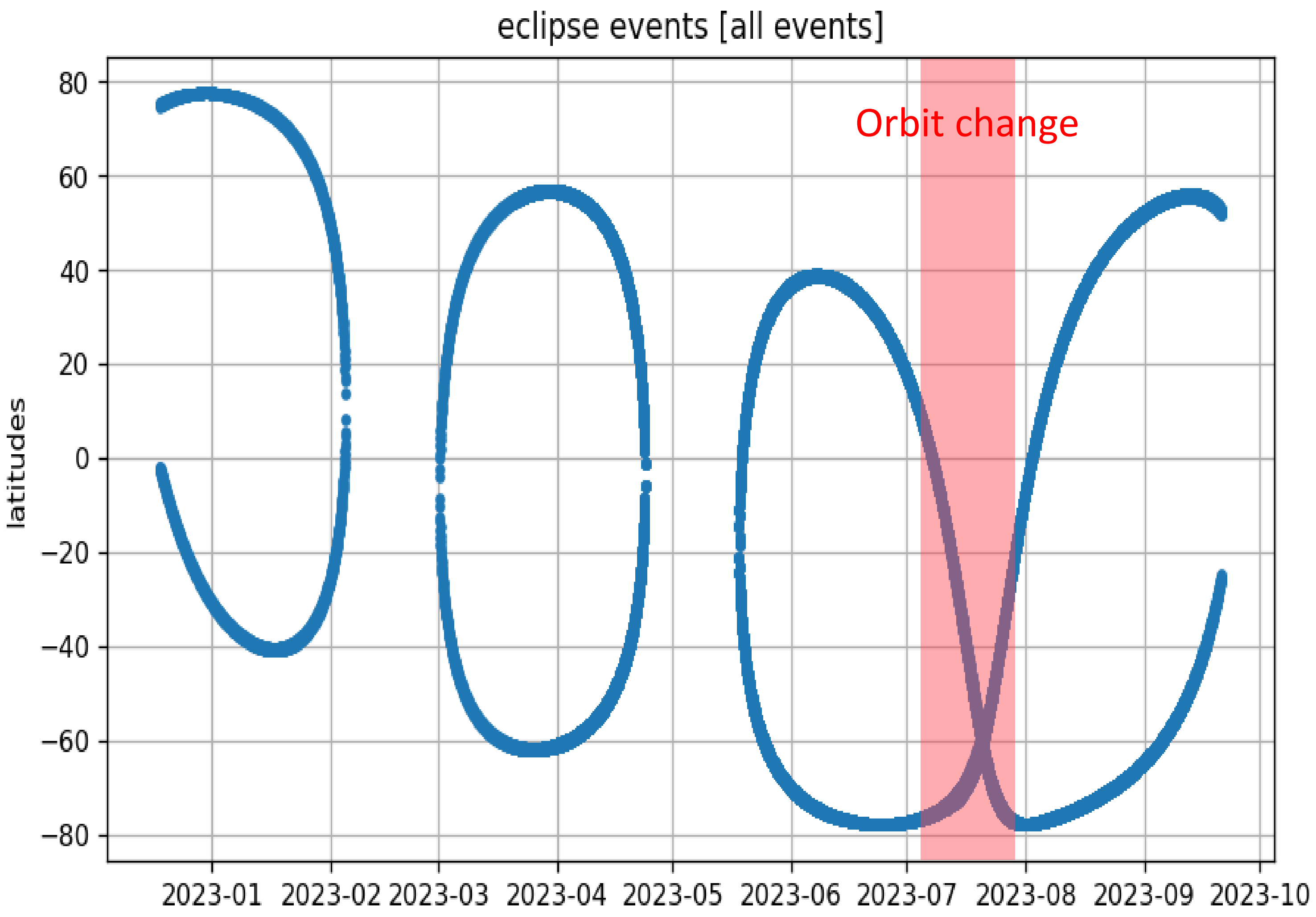
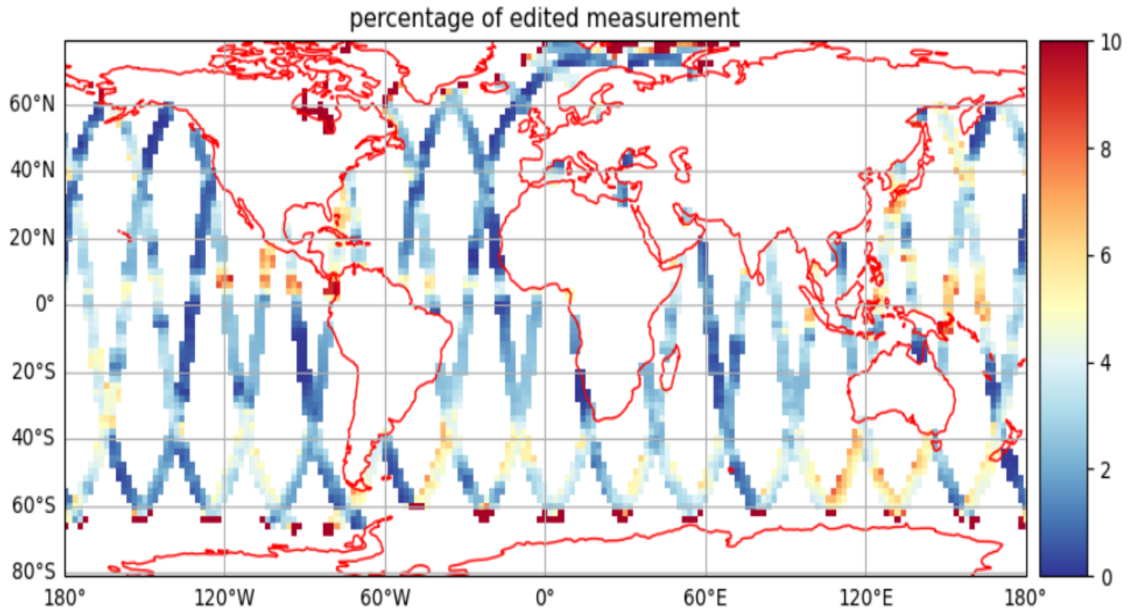
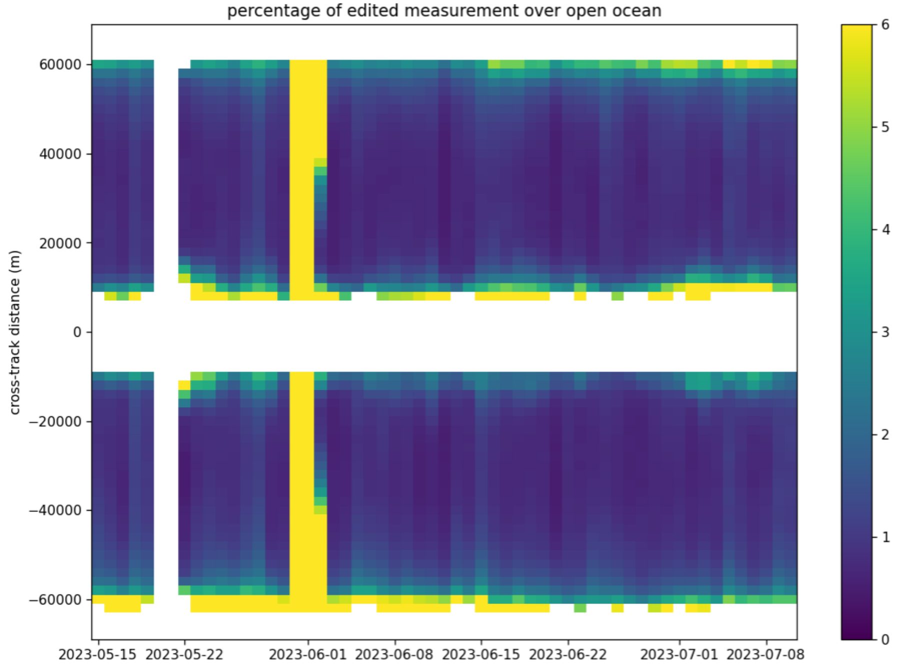


Editing & data quality

- **2% of edited measurements on average over open ocean.**
  - ✓ 3.2 % for Jason class altimeters.
  - ✓ A little more data edited at the edge of the swath ([10;60]km)
- **Most of rejected measurements are located in heavy rain areas (up to 8% in specific areas)**



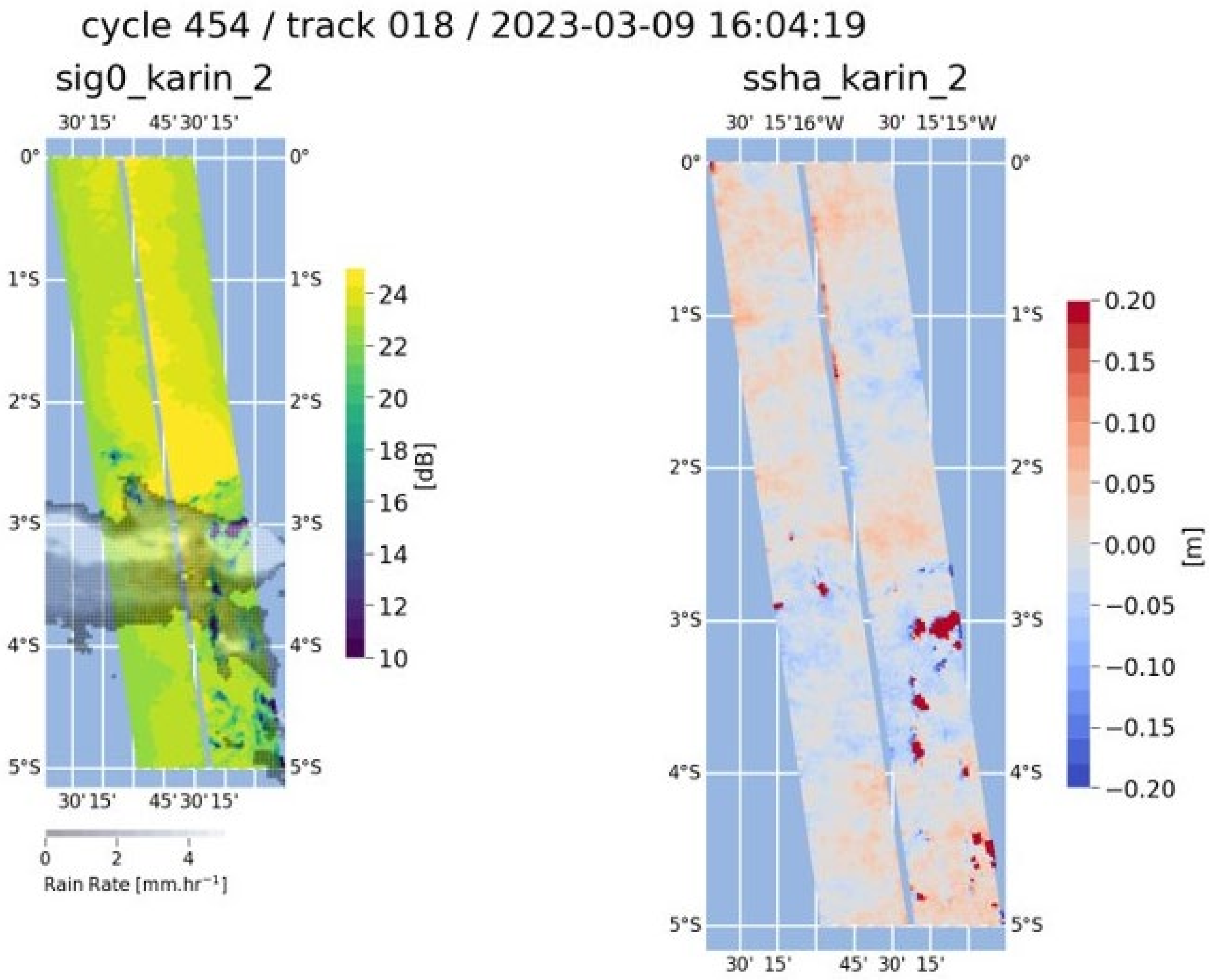


Editing & data quality: rain impact

- **Rain events impact the Ka Band radar signal.**
  - ✓ Sigma0 attenuation observed
  - ✓ SSHA is biased (not systematically) ➔ ongoing studies to caracterise relationship between sigma0 attenuation and impact on the SSHA.

- **Rain flag available in L2 products (derived from ECMWF model) is not accurate enough**

- **New offline flag definition based on sigma0 attenuation improves significantly the rain detection (but may flag other phenomena)**



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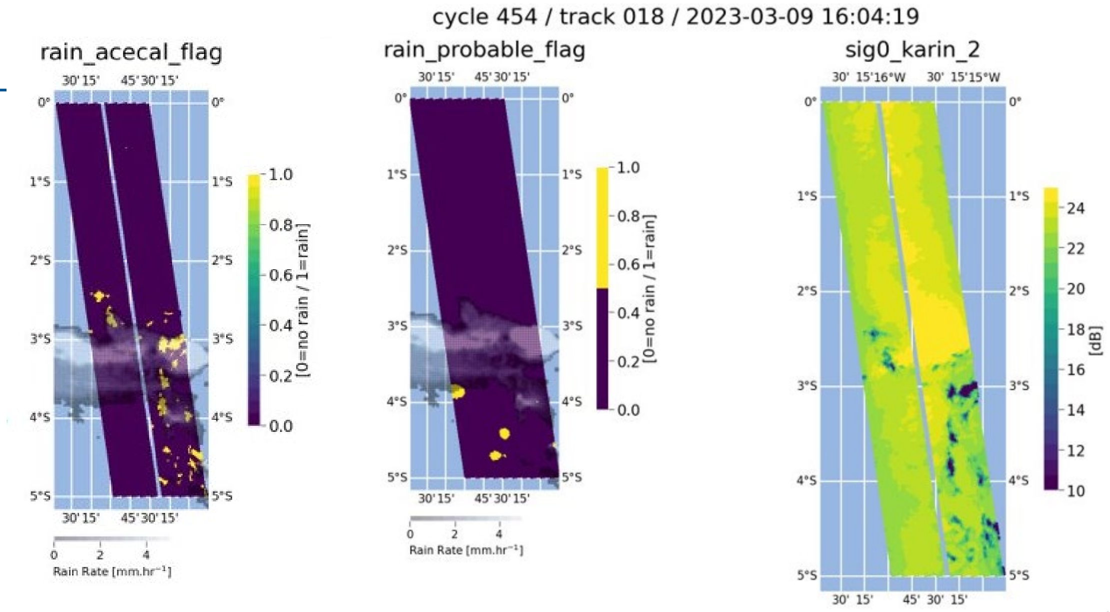
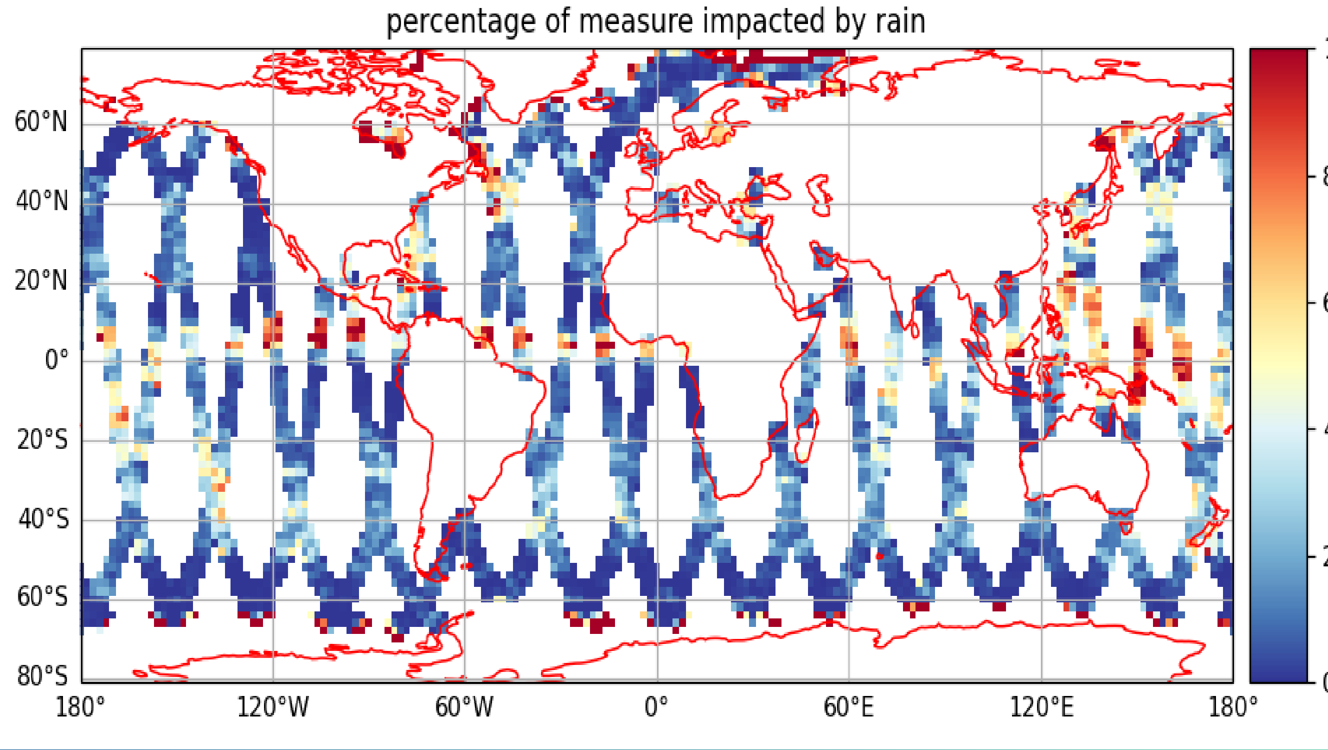
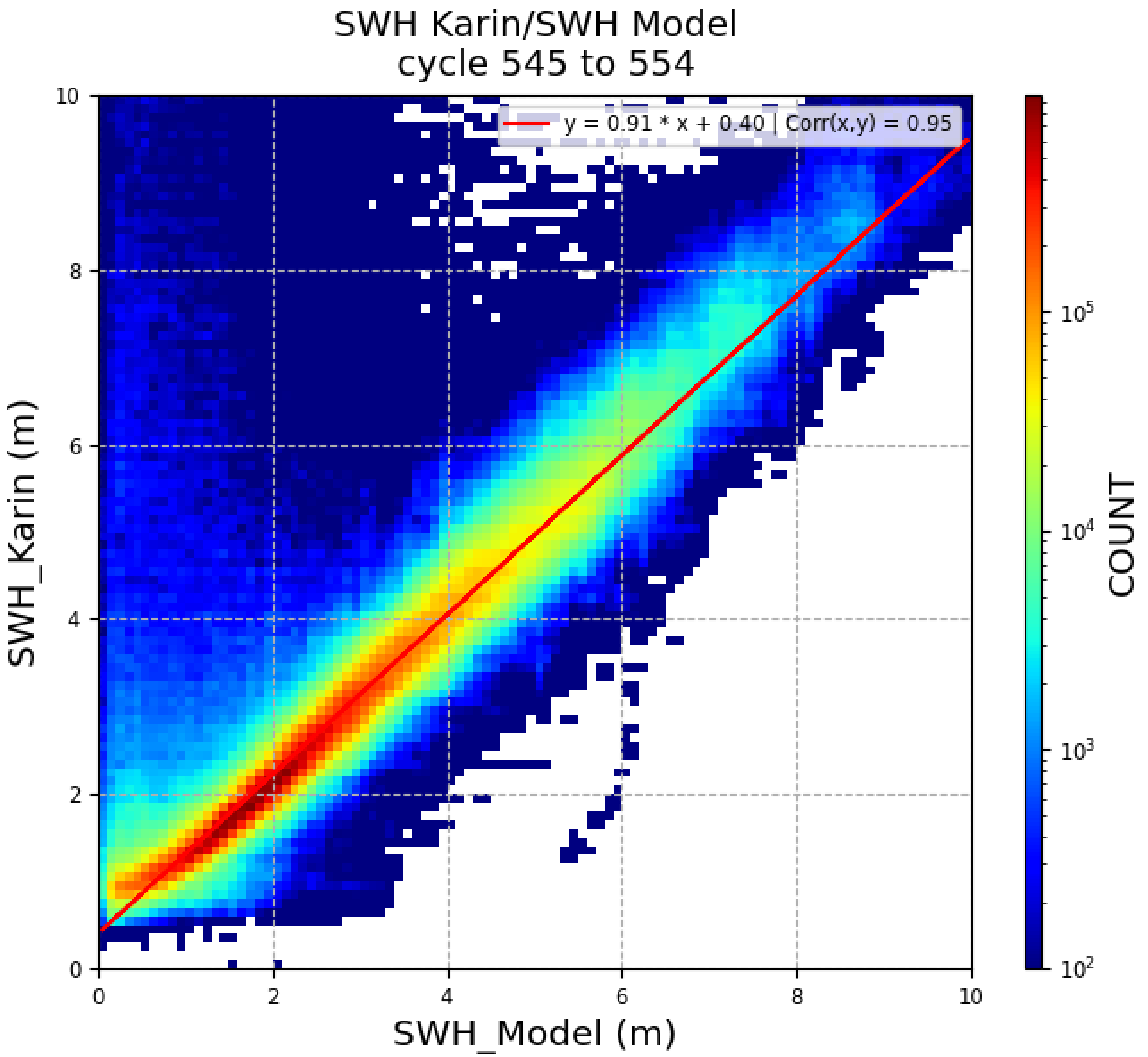




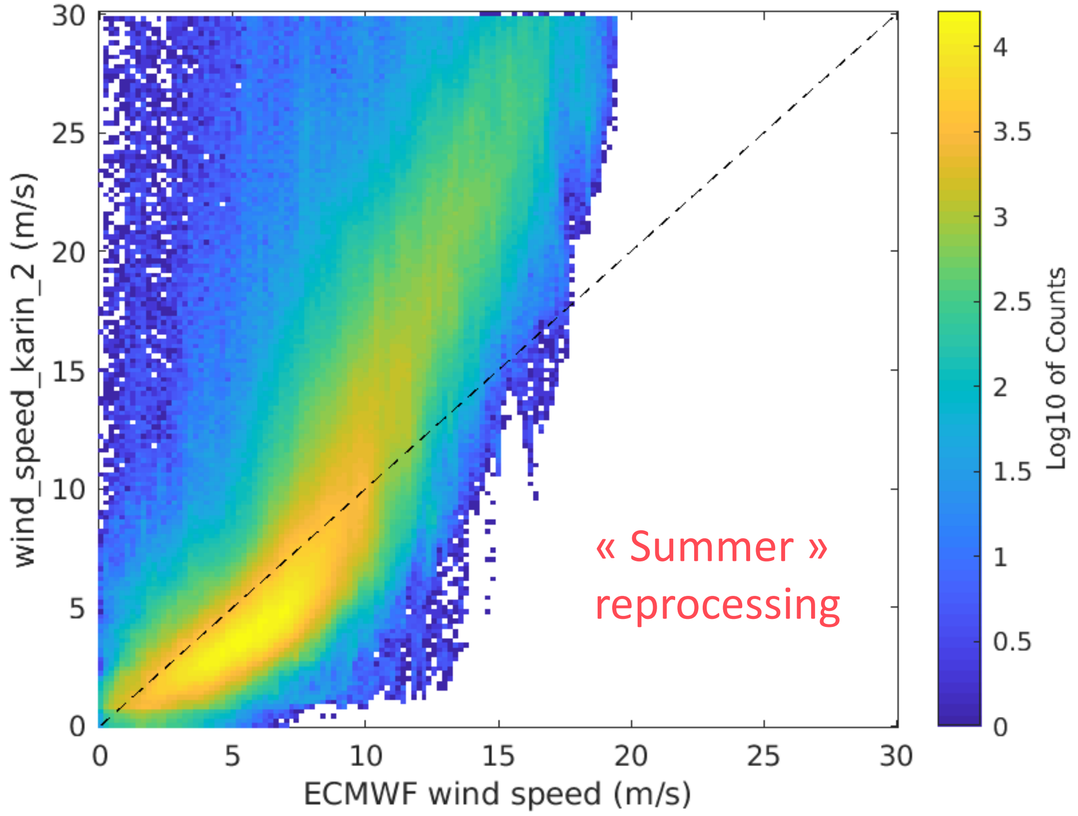
KaRIn SWH preliminary Assessment

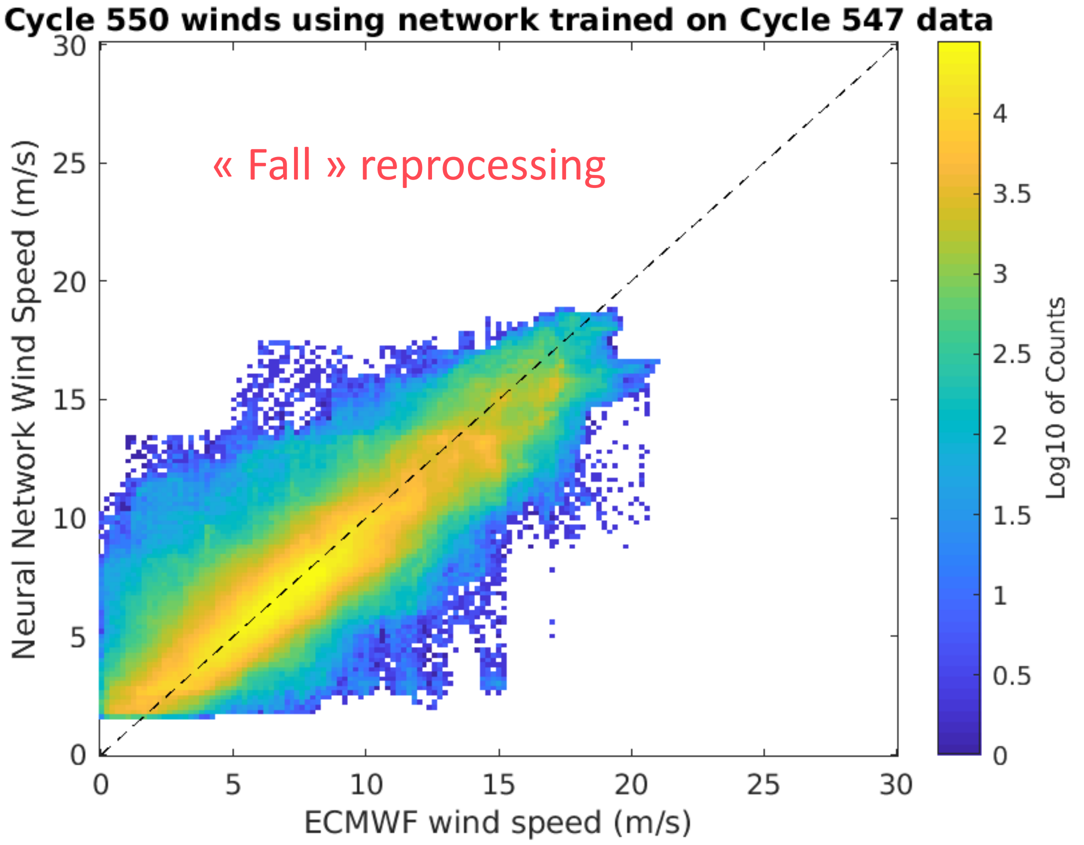
- Current KaRIn SWH (1 estimate for each swath) is produced without any calibration of volumetric decorrelation.

- Fall reprocessing will add a calibration and use a new algorithm providing 2D maps of SWH at 2km resolution. (cf A. Bohe presentation in Waves Working Group)



KaRIn wind preliminary Assessment



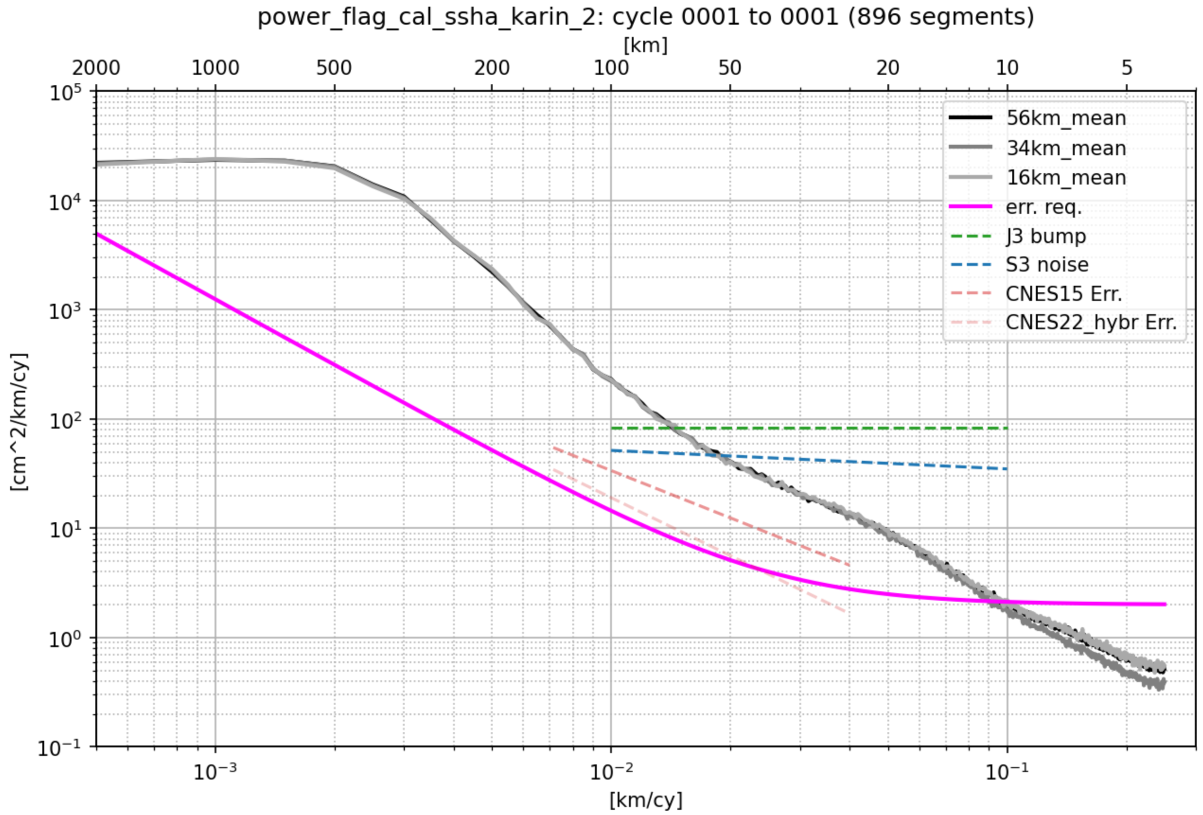


Pre-launch GMF used for wind inversion up to now leads to underestimates at low (<10m/s) winds and overestimates at high wind.

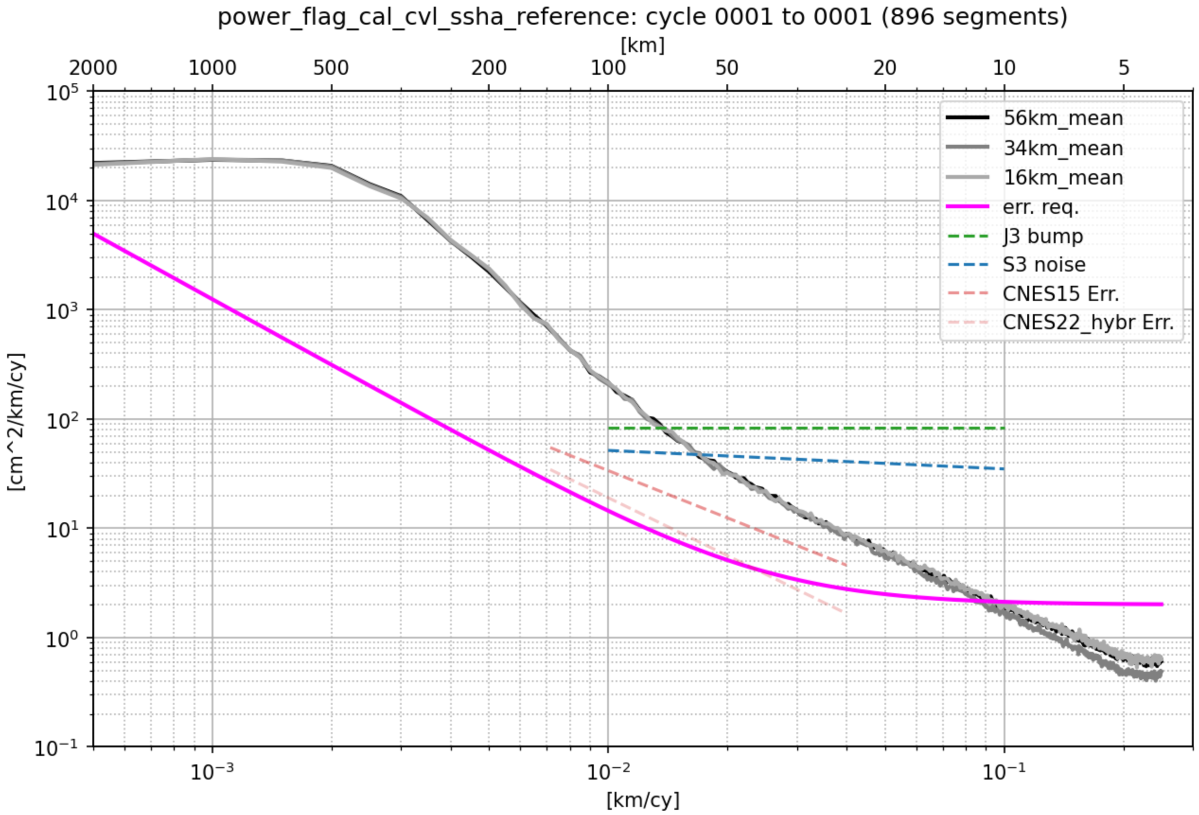
Fall reprocessing will use a new GMF (cf A. Bohe presentation in Waves Working Group)

SSHA PSD : MSS errors

Science Orbit: SSHA KarIn_2 with MSS model from 2015



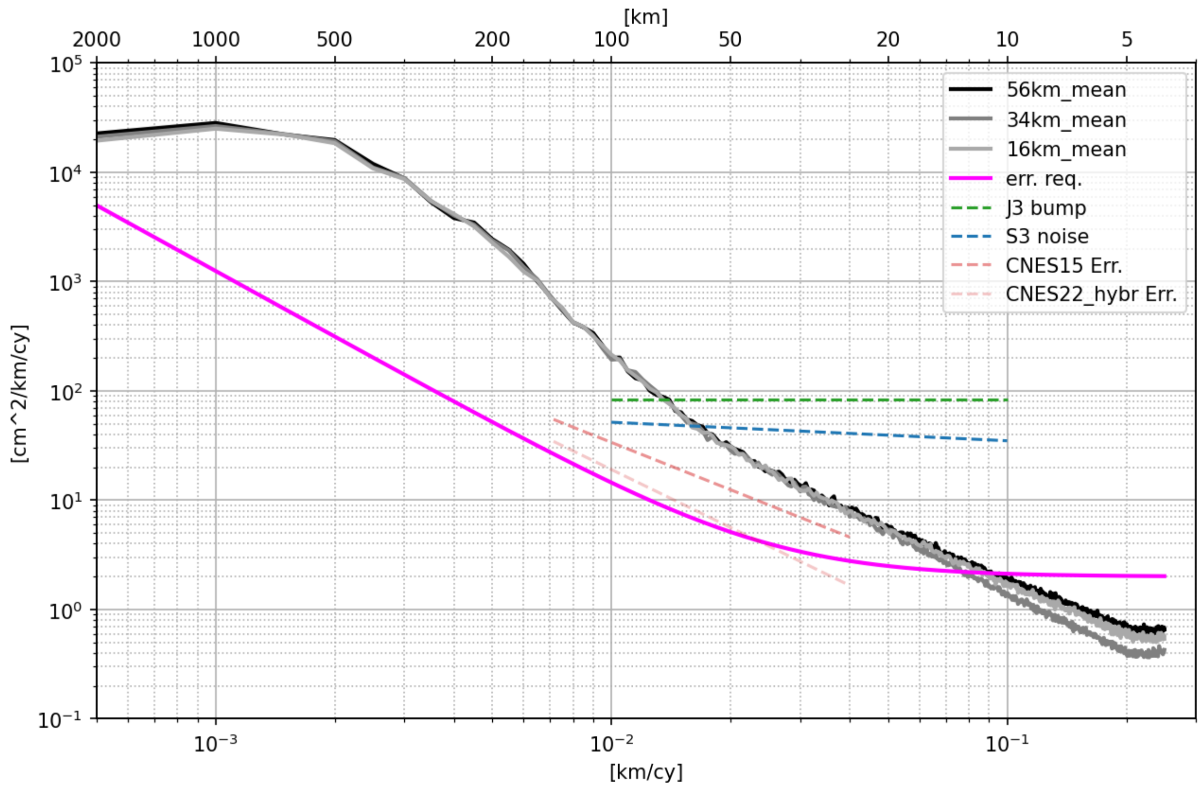
Science Orbit (MSS updated 2023H-alpha2)



- Smaller scales of the geoid are poorly known in many regions: the error is correlated (fake eddies are seen in KaRIN SSHA)
- The MSS model is currently a major contributor to the SSHA : hump-shaped artifact from 15 to 50 km
- For smaller scales, the geoid error is likely still here but hidden by ocean geophysical signals & errors
- With the most recent MSS model (SIO/CLS/DTU hybrid v2023, in development) the hump disappears (geoid error divided by 3)
- The SSHA spectrum is then perfectly linear and well-behaved : not dominant error anymore, but MSS errors are still visible locally in many places

SSHA PSD : CalVal vs Science orbit

CalVal Orbit (MSS updated 2023H-alpha2)



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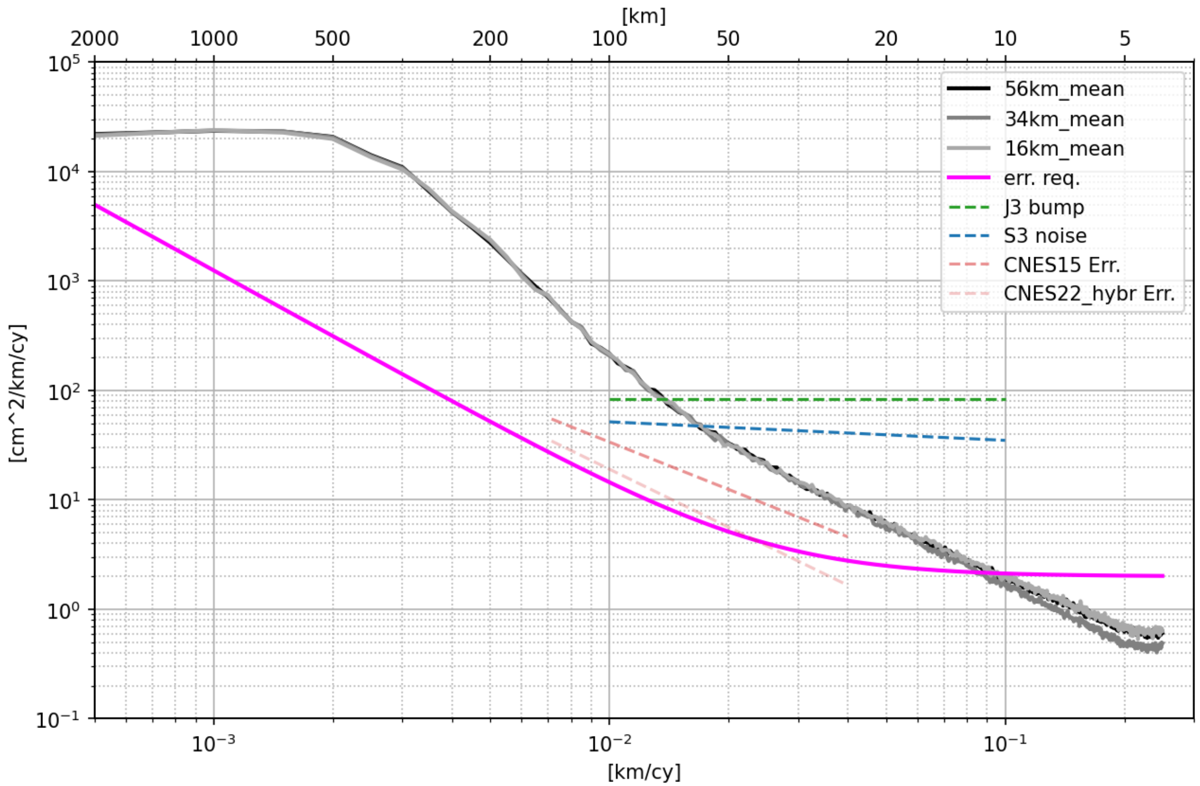
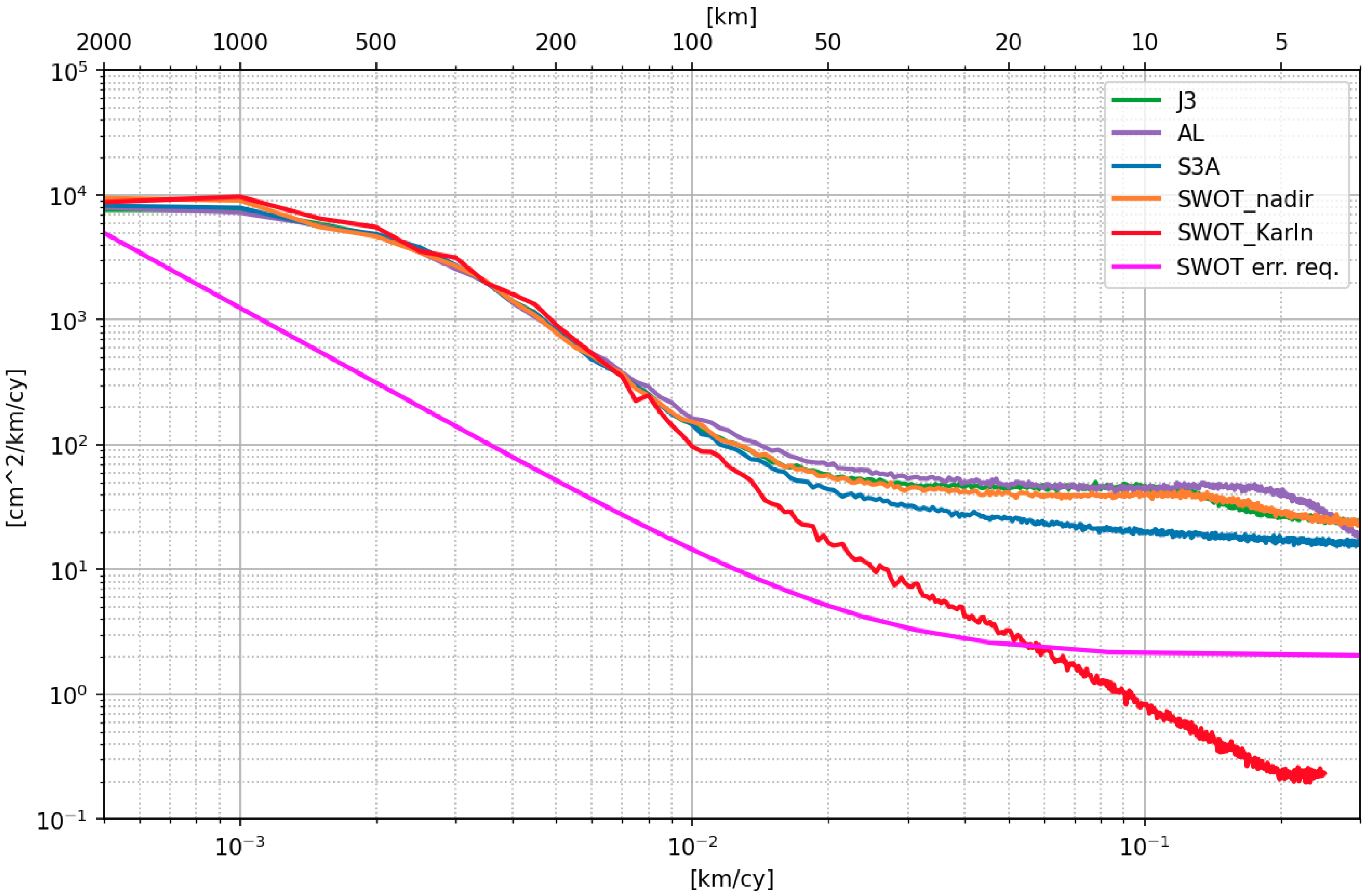


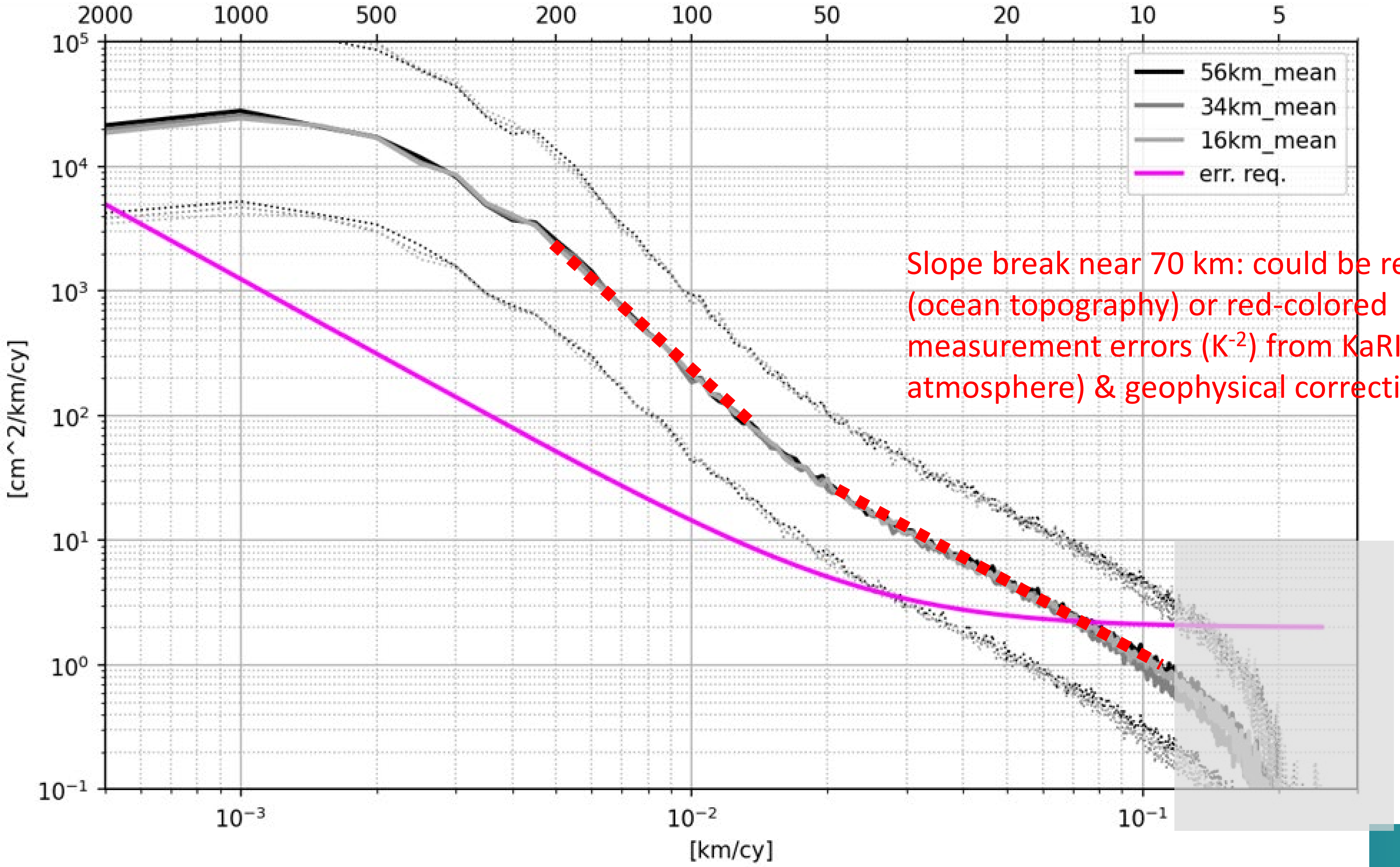
- Both orbits yield very consistent SSHA spectra (KaRIn still performing well)
- The random noise plateau changes on 21-day orbit (more noise in swath center & near-range)
- The 1-day orbit has some near/range PSD discrepancies from mesoscale as expected: eddies repeatedly sampled on 1day orbit
- The 21-day PSD is smoother and consistent: global ocean, PSDs reflect the mean ocean variability
- The near/medium/far range are not aligned (because of random noise, more energy on the swath edges)

SSHA PSD : comparison with nadir altimetry

KaRIn SSHA power spectrum compared with other missions

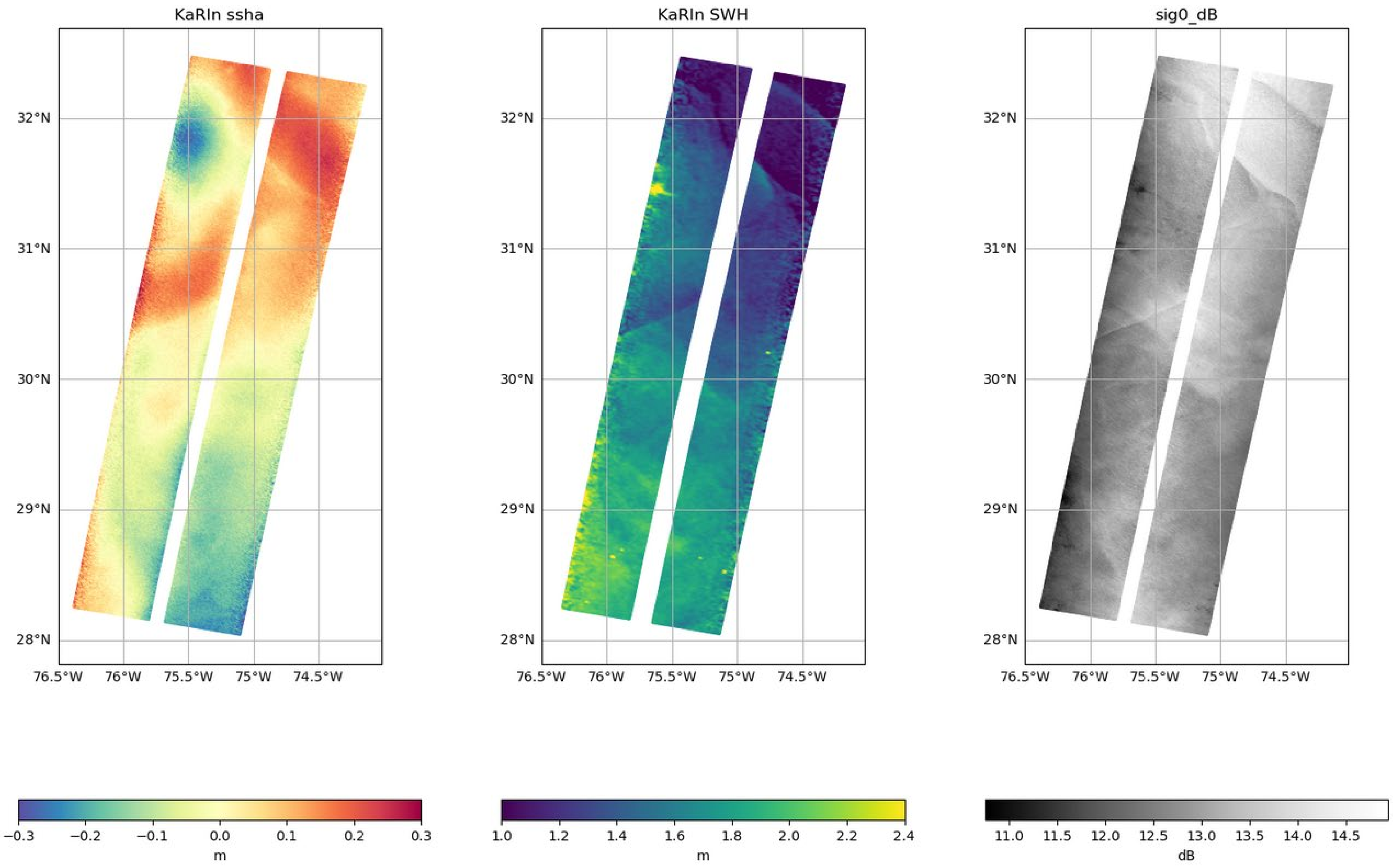


SSHA PSD : slope break near 70 km



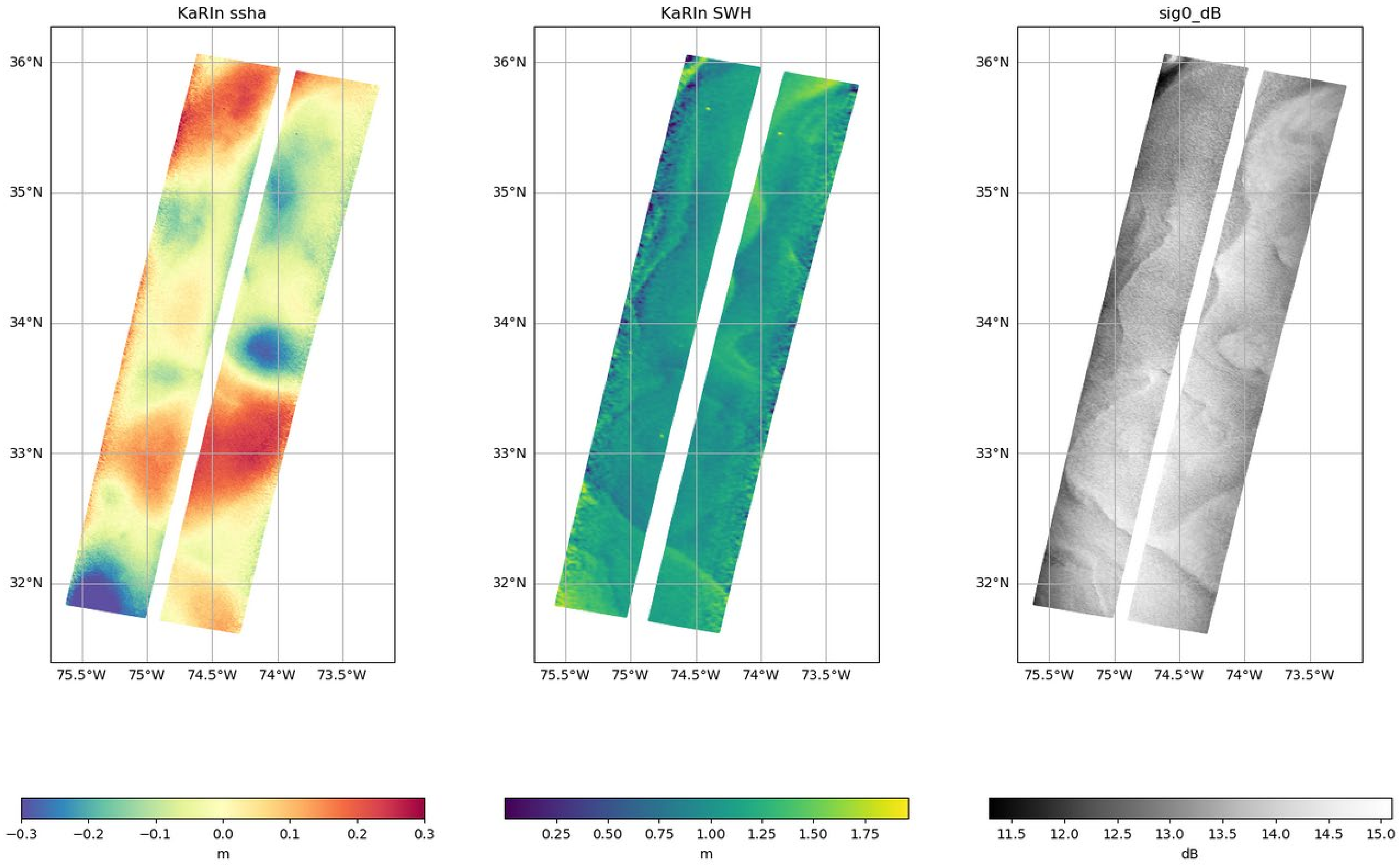
In the grey box a constant scalar value was estimated (noise floor) and removed from each PSD. When this is done, the grey & black spectra align very well below 100 km (i.e. the slope break and k^{-2} signal is the same in near and far range). That might tend to rule out waves as the cause since they tend to have range-specific behavior.

A rich new phenomenology to understand



Understanding to what extent these correlations are geophysical or errors from the measurement (SSB, wet tropo etc…) is likely a topic for a long time !

A rich new phenomenology to understand



Large scale of SSH looks trustworthy

Thin bright lines in σ0 also visible in SSHA