National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

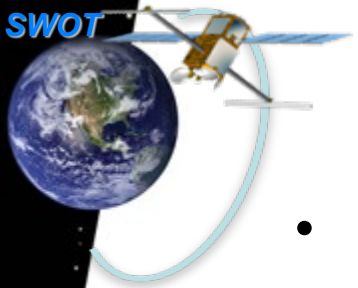# Surface Water and Ocean Topography (SWOT) Mission

Validation Meeting

June 18-19, 2024

KaRIn LR Features/Issues

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on behalf of JPL/CNES Algorithm and Cal/Val Team
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Introduction

- We discuss features/issues observed in KaRIn data over open ocean.
  - Roughly in order from most common to least common.
- Focus is on SSHA (sea surface height anomaly)
  - KaRIn SWH will be discussed separately.
  - KaRIn wind speed will be discussed separately.
  - LR data near/over land will be discussed separately.

L2_LR_SSH File	Grid	Posting
Basic, Expert, WindWave	Geographically Fixed	2 km
Unsmoothed	KaRIn native grid	250 meter

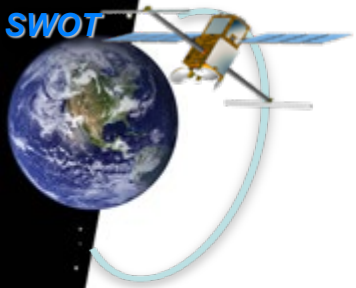| L2_LR_SSH Variables	Wet Troposphere Correction	Sea State Bias Correction
ssha_karin	Radiometer	Uses measured SWH and wind speed
ssha_karin_2	ECMWF	Uses model SWH and wind speed
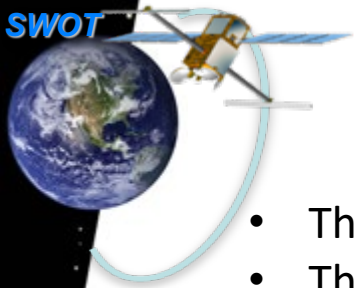
Cross-Over Correction

- The ssh and ssha variables have all corrections already applied, except the cross-over correction.
- The cross-over correction is reported in *height_cor_xover*. It should be added to the ssh or ssha variable.
- In the rest of this presentation, *ssha_karin(_2)* is always plotted with *height_cor_xover* applied.
- Users should check both quality flags (e.g. *ssha_karin_qual* and *height_cor_xover_qual*).

Example:
Cycle 004 Pass 293
around 34.5° S
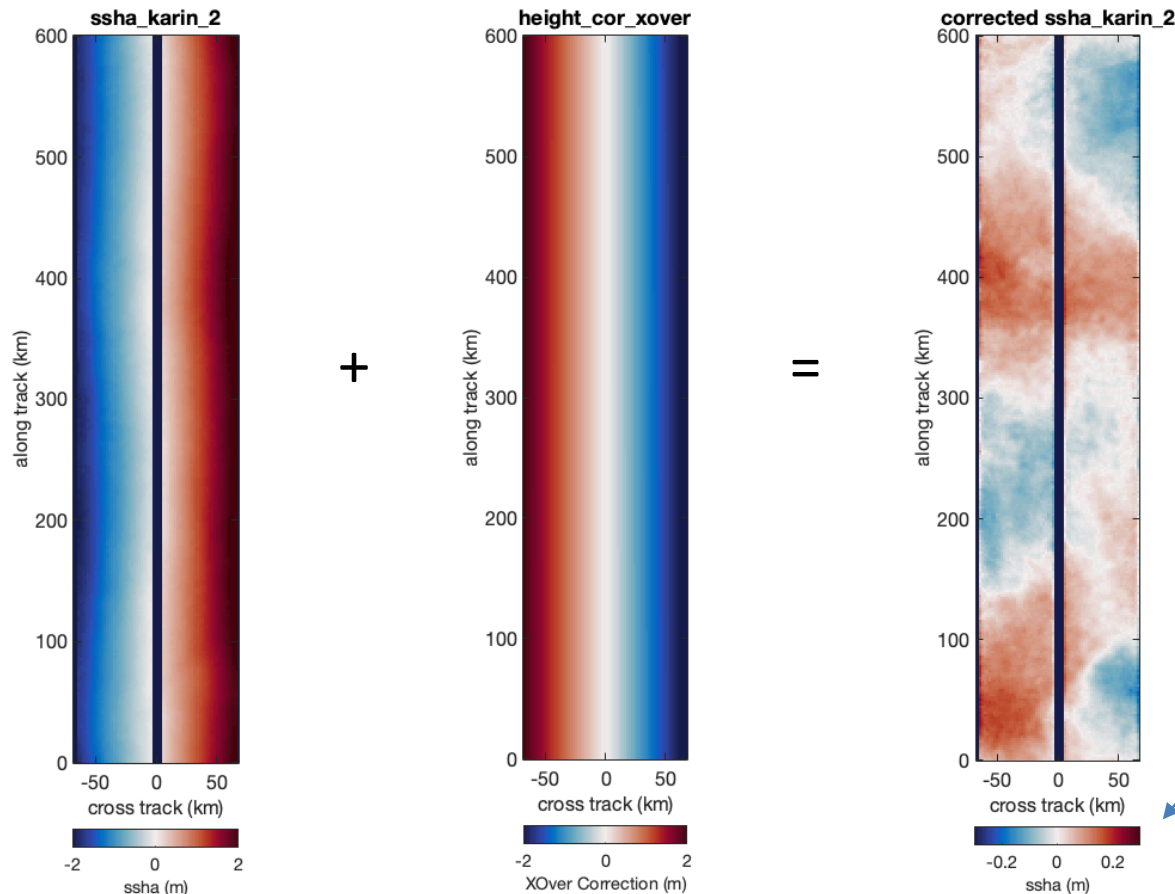
Note the colorbar. Meter-level systematic errors are removed, leaving decimeter-level SSHA signal.

Corrections Reported in Expert File

- Examining the corrections reported in the Expert product often shows the reason for artifacts.
- Example: discontinuity in SSB2 in circumpolar regions because *swh_model* has fill-values near ice.
- Users could also undo the reported corrections and apply their own, if desired.
- The *ssha_karin_2_qual* flag has the degraded_ssb_not_computable bit set in the affected region.

Cycle 003 pass 365, around 61°S
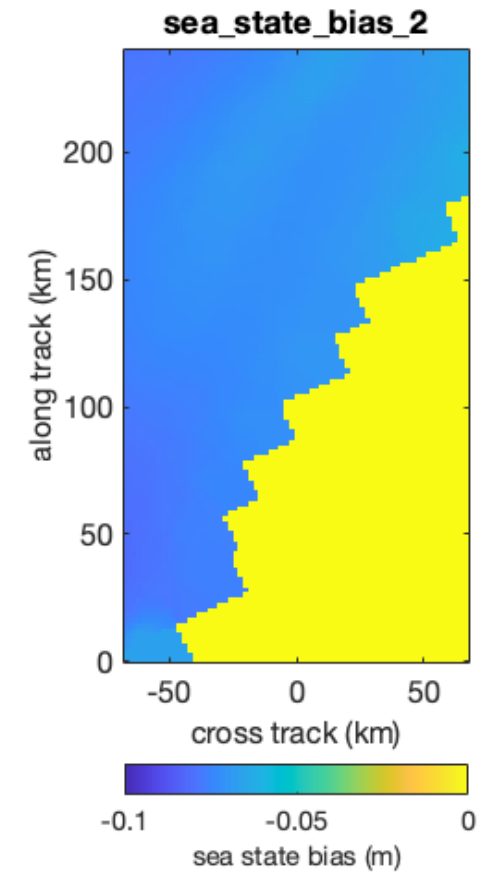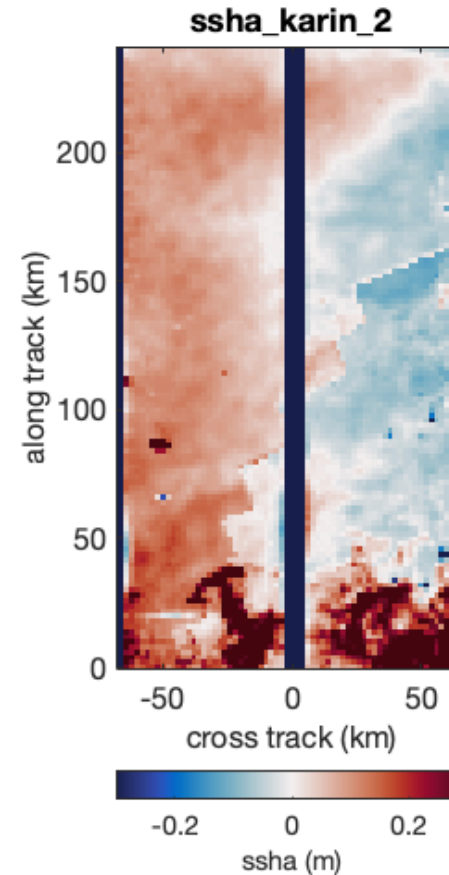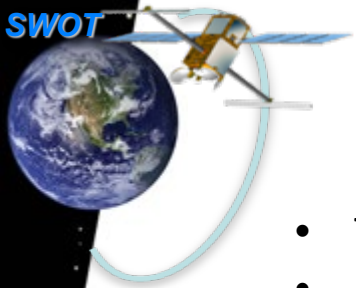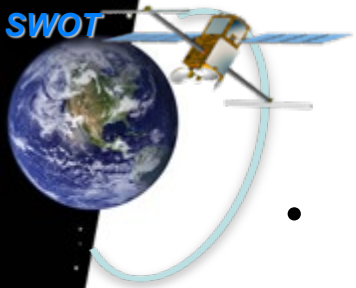
Unsmoothed product

- The Unsmoothed product contains *ssh_karin_2*, but not *ssha_karin_2*.
- Unsmoothed *ssha_karin_2* data shown in this presentation are computed by resampling the tides and cross-over correction from the Expert product to the Unsmoothed grid.
- In some places, individual ocean wave-fronts are resolved in the Unsmoothed product.

Zoom-in view of a portion of 010_037,
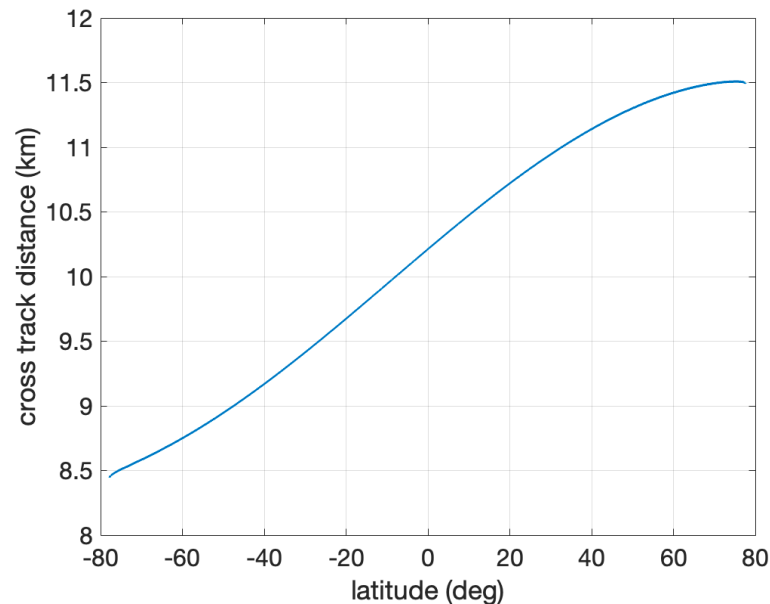right swath unsmoothed, near 25° S
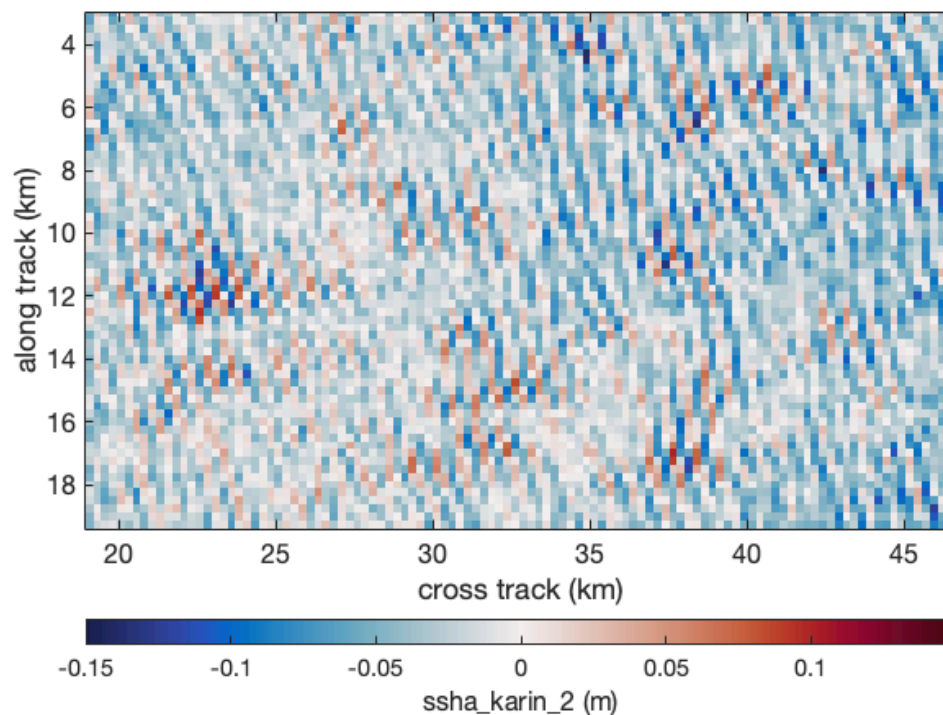
Unsmoothed file has 250m posting with ~500m resolution.

Amplitude of waves is attenuated by on-board processing averaging filters.

Cross-Track Distance

- In the Basic/Expert product, the actual cross-track distance for each pixel is reported in *cross_track_distance*.

- In the Unsmoothed product, cross-track distance is not reported. For pixels over open ocean, it is almost exactly ±(5 km + pixel_number × 0.25 km), with pixel_number ∈ [0, 1, 2, …].

Cycle 003 Pass 365

Cross-track distances for the pixels nominally at +10 km.

Basic/Expert: fixed grid
pixel 39

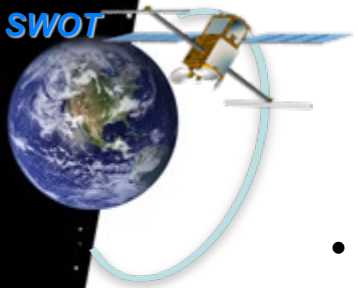

Unsmoothed: native grid
right swath pixel 20

Unreliable geolocation in Antarctic ice sheet.
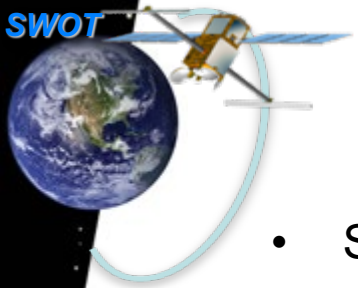
Waves

- SSH uncertainty only captures decorrelation, not waves, not systematic error.
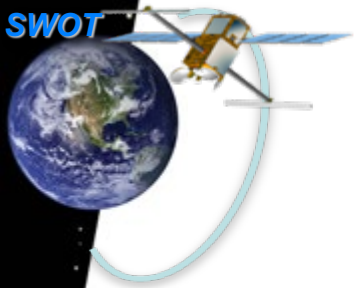- Smoothing to 2km makes a bigger difference at larger SWH.
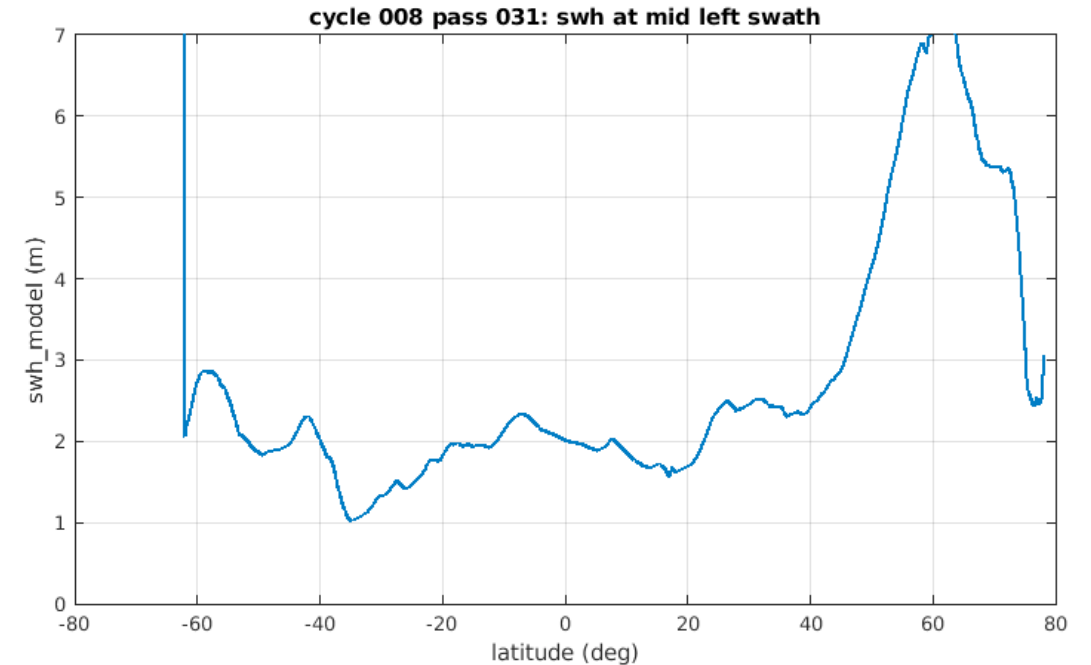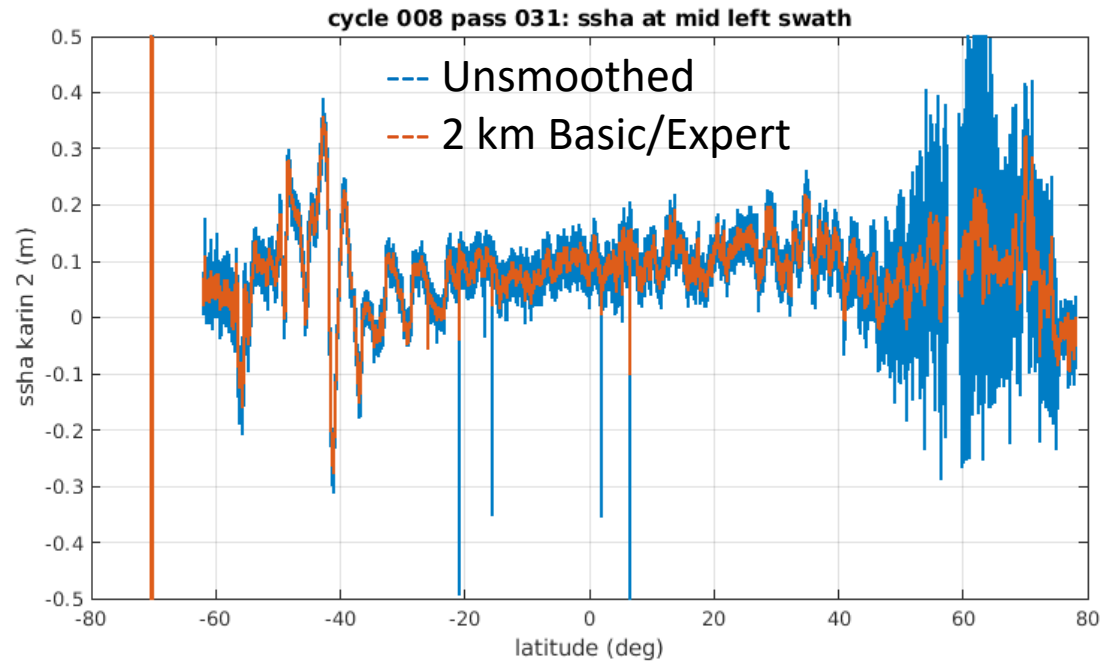
Residual Phase Screen

- The residual phase screen is stable, but it it is different for H and V swaths.
- Check *polarization_karin* variable to see if spacecraft is yaw-flipped.
- Future update to static calibration will reduce the residual phase screen.

Yaw-flip maneuvers

H swath   V swath
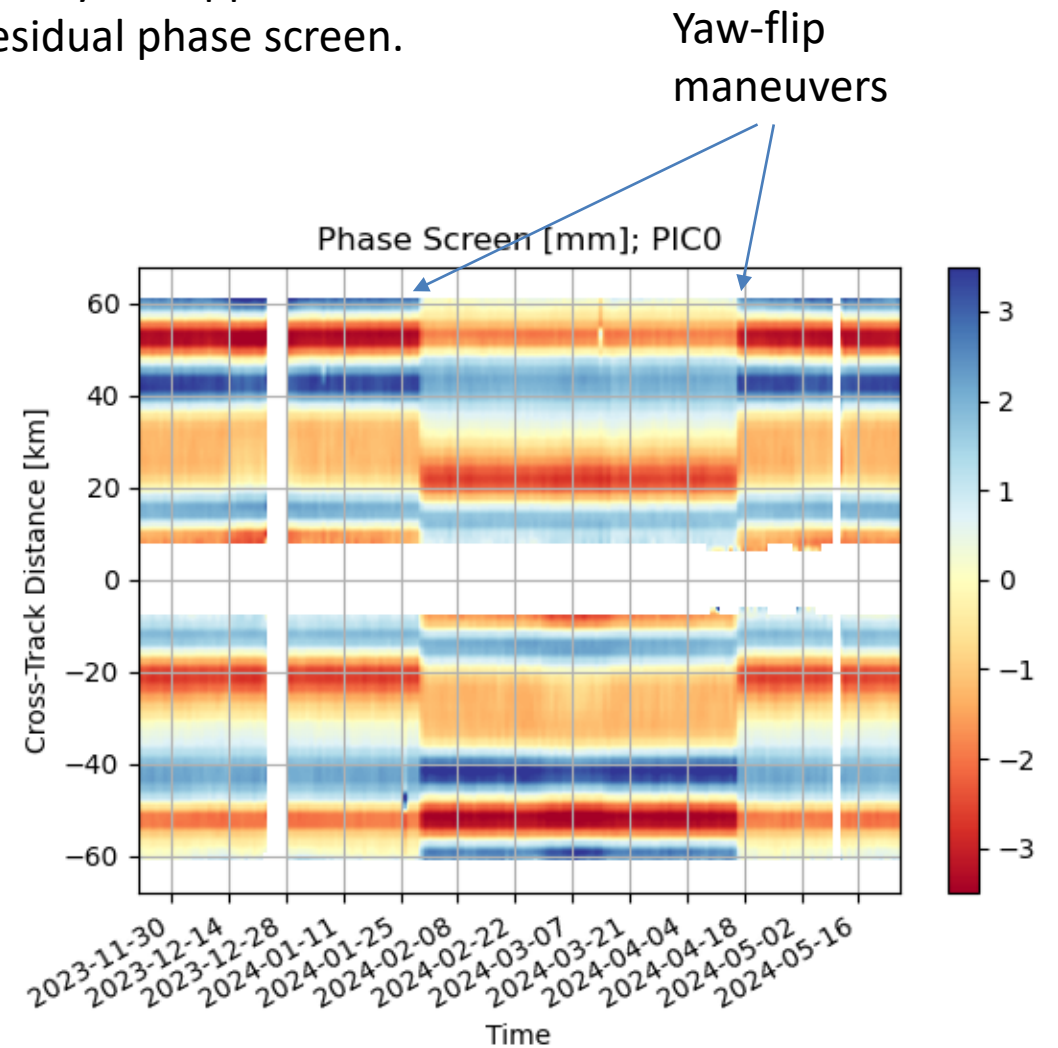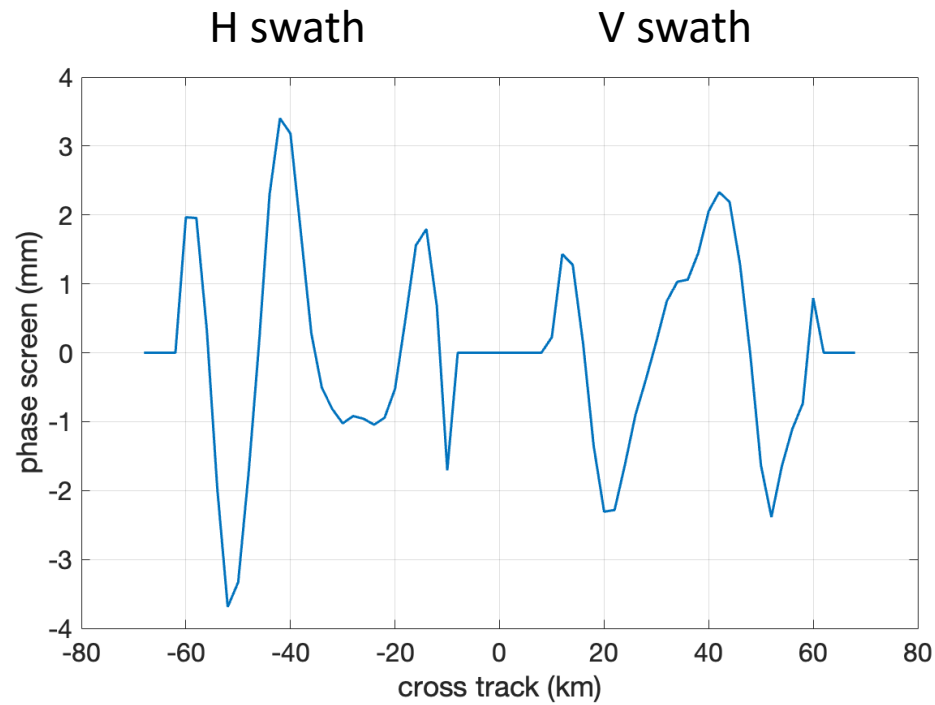
Eclipse Transitions

- Eclipse means Earth is between SWOT and the sun.
- Eclipse transitions happen when SWOT enters/exits eclipse.
- L2 data are flagged suspect for 2 minutes immediately following each eclipse transition, with the suspect_sc_event_flag bit set to 1 in *ssh_karin_qual*, *ssh_karin_2_qual*, etc.
  - Eclipses can be distinguished from other events by checking L1B *sc_event_flag* in *tvp_left* or *tvp_right*.
- Eclipse transitions will occur at characteristic latitudes. However, those latitudes vary with beta angle.

Cycle 012, passes 500-584
suspect_sc_event_flag == 1
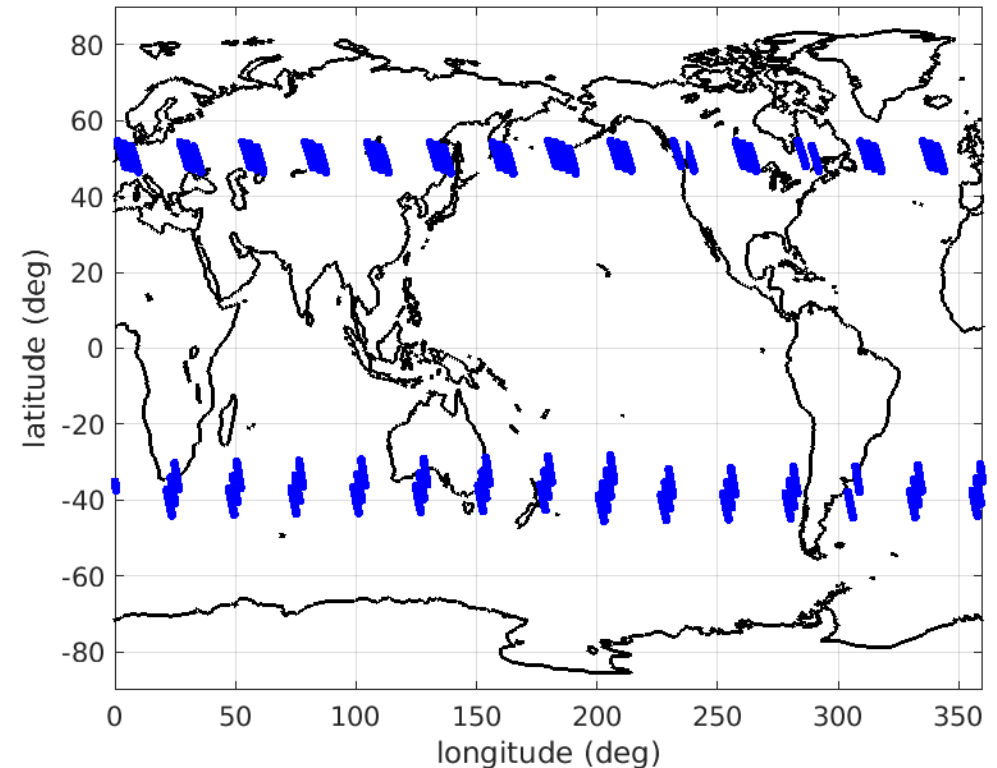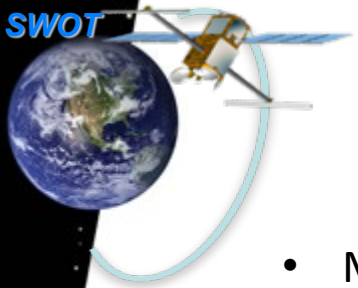
Eclipse Transitions

- Most data in eclipse transitions generally does not have obvious artifacts.
- Users may make application-specific decisions on whether to use or discard the data.
- ADT to further investigate how well KaRIn works around eclipse transitions and may flag the data differently in the future.

Cycle 012 pass 518, around 30° S

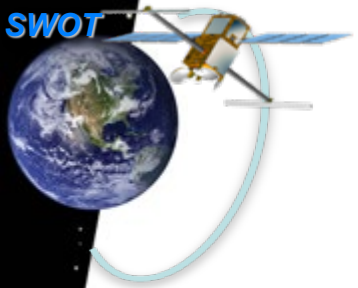Example of ssha data during eclipse transition.
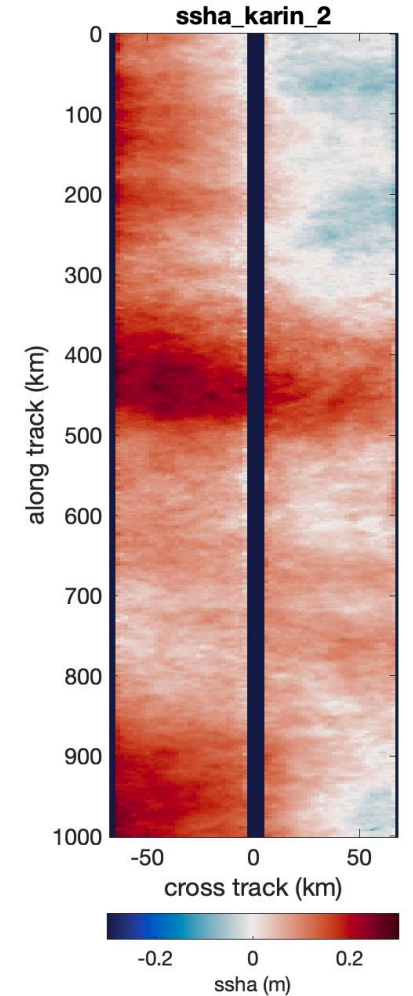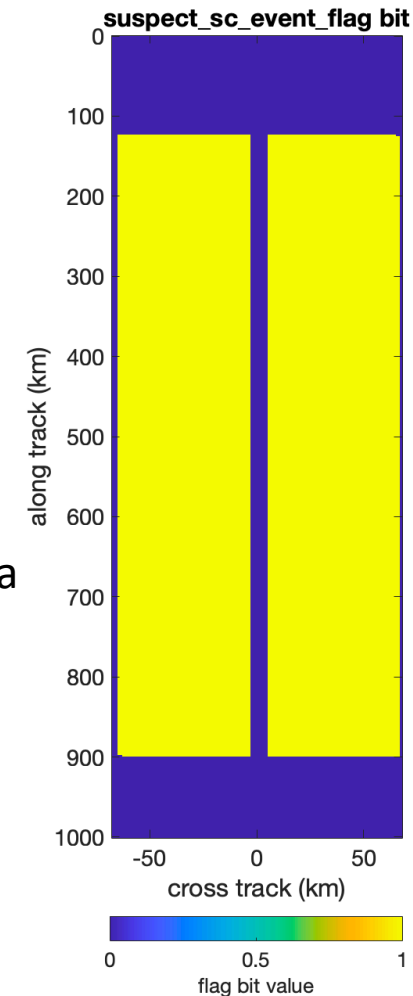
- Version C uses the CNES/CLS 2015 MSS for the L1B reference surface, even though the L2 processor uses the CNES/CLS 2022 MSS to compute SSHA from SSH.

- The 2015 MSS has some fill values in open ocean, which results in missing data in the L1B and L2 products.

  - Due to a bug in Version C, the MSS fill values resulted in more missing L1B and L2 pixels than in Version B.
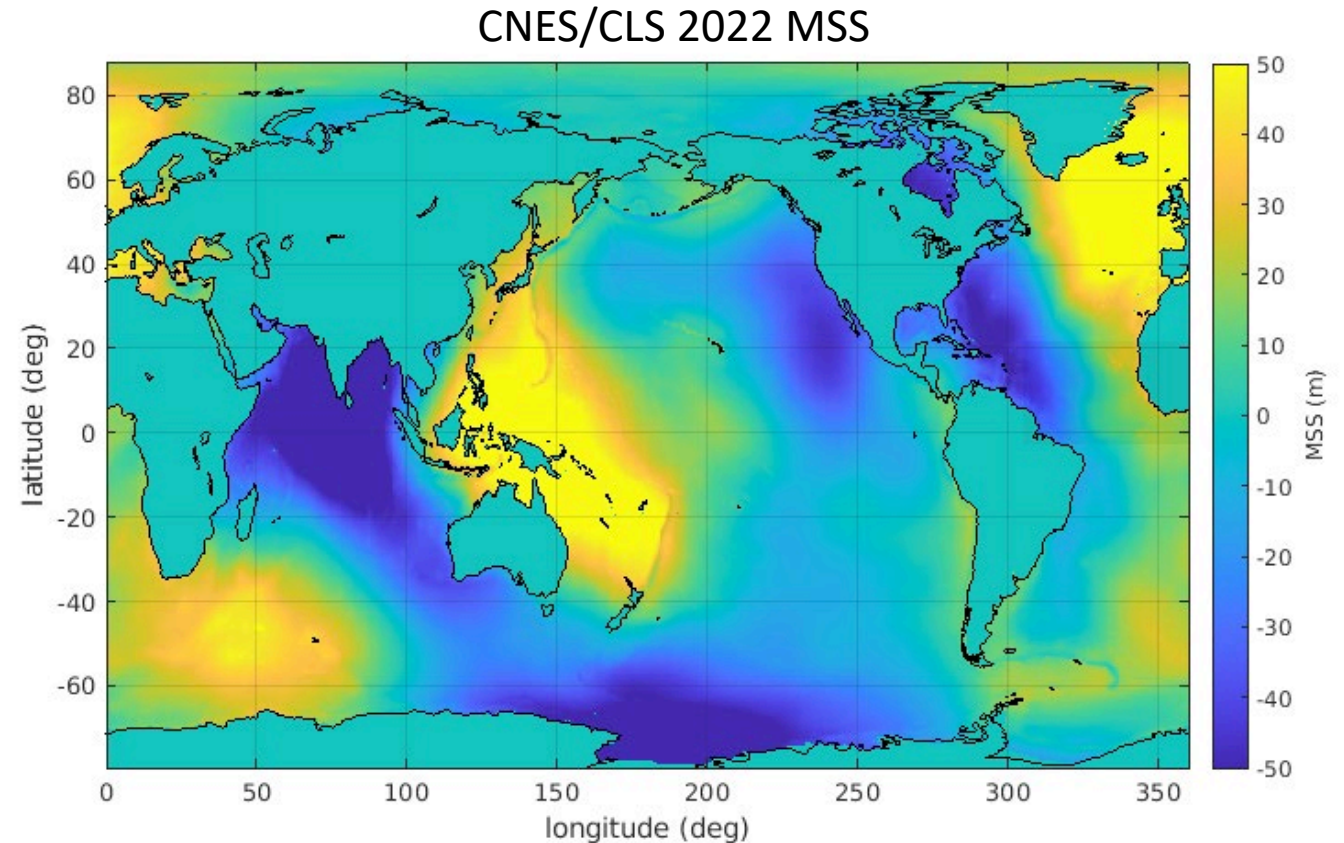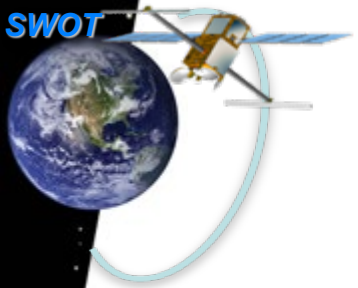
CNES/CLS 2015 MSS
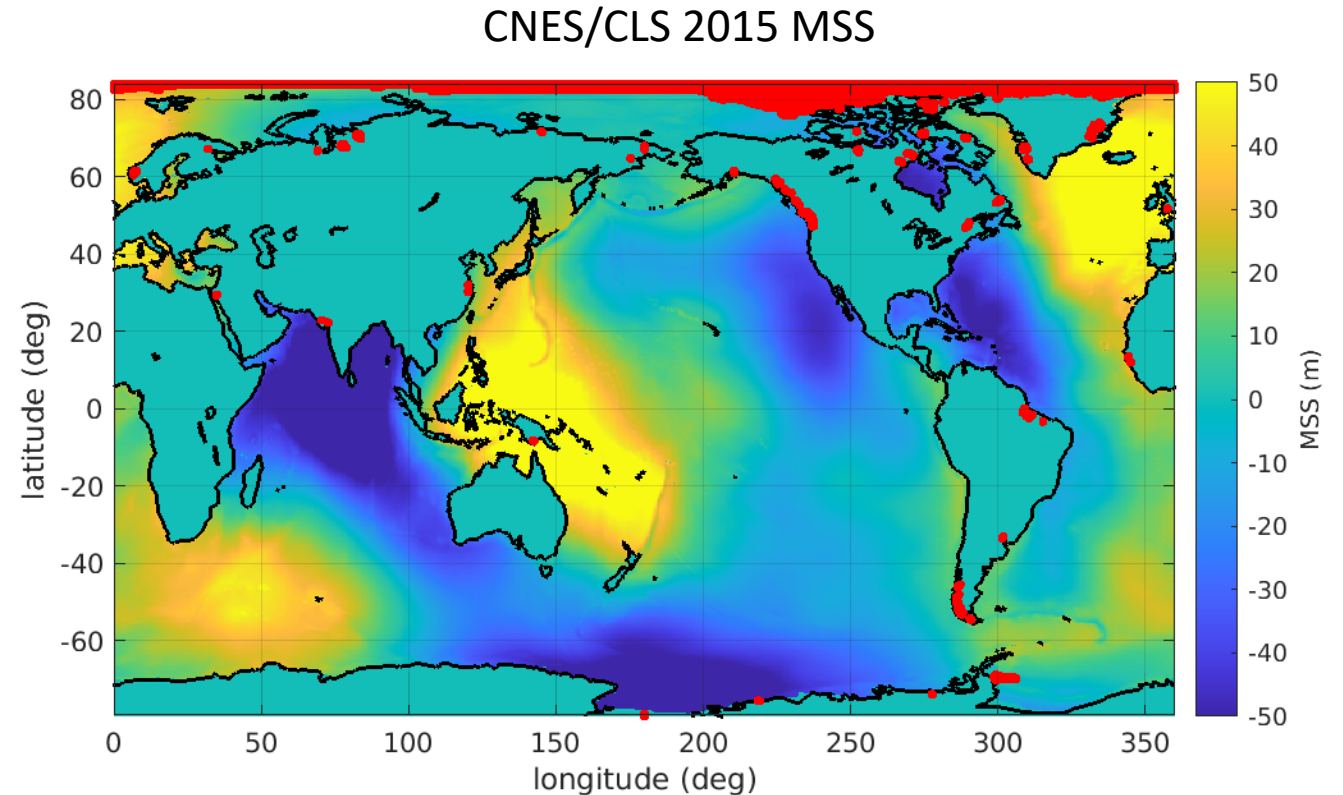
Red indicates fill values in open ocean.

Fill Values in Reference Surface

- The issues will be avoided in the next version by using CNES/CLS 2022 MSS as L1B reference surface.

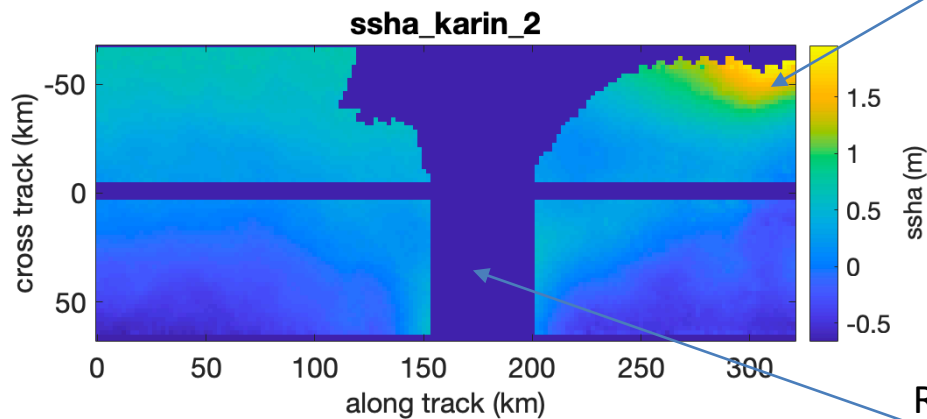- Note: Changing the L1B reference surface has negligible impact on SSHA in open ocean.

CNES/CLS 2022 MSS
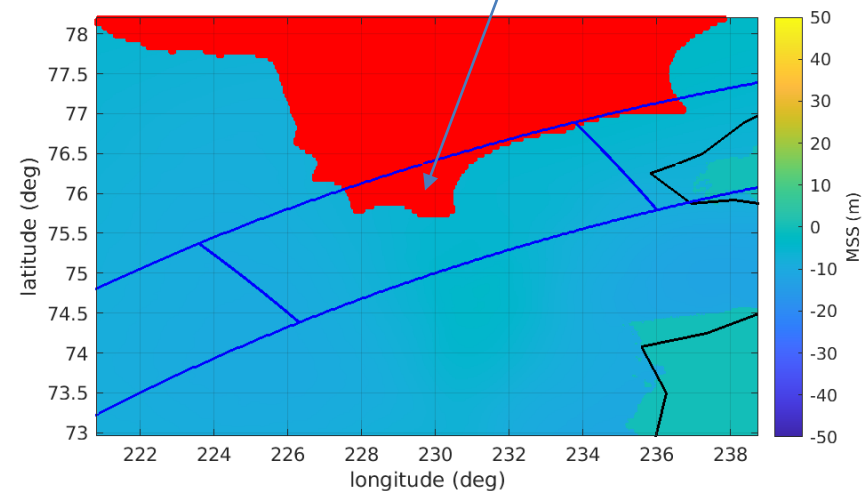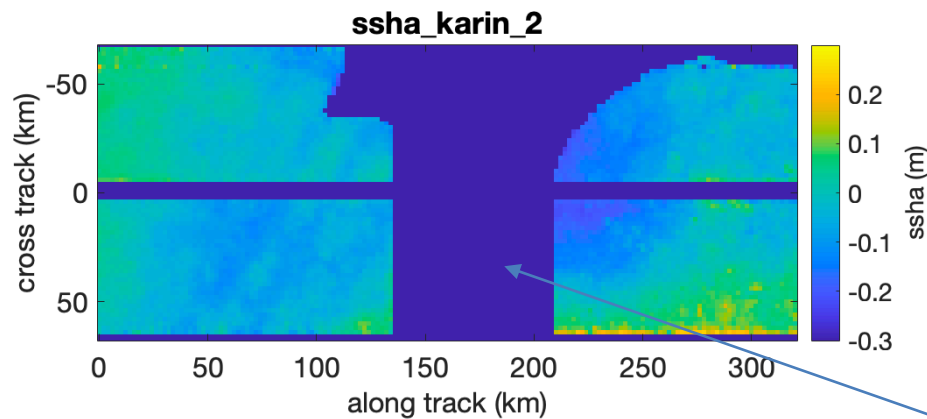
Fill Values in Reference Surface

Cycle 577 pass 017

Version B

ssha_karin_2

XOverCal less reliable in Version B

Fill values in L1B reference surface

Region of missing data typically larger than region of fill values.
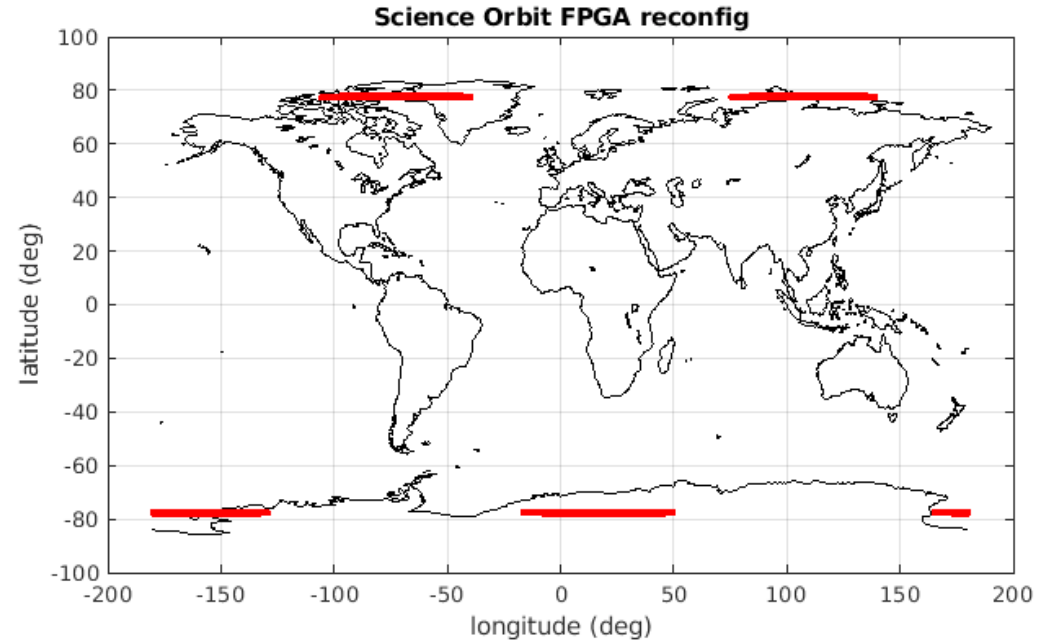
Version C

ssha_karin_2

More missing data than in Version B

Development Version

ssha_karin_2
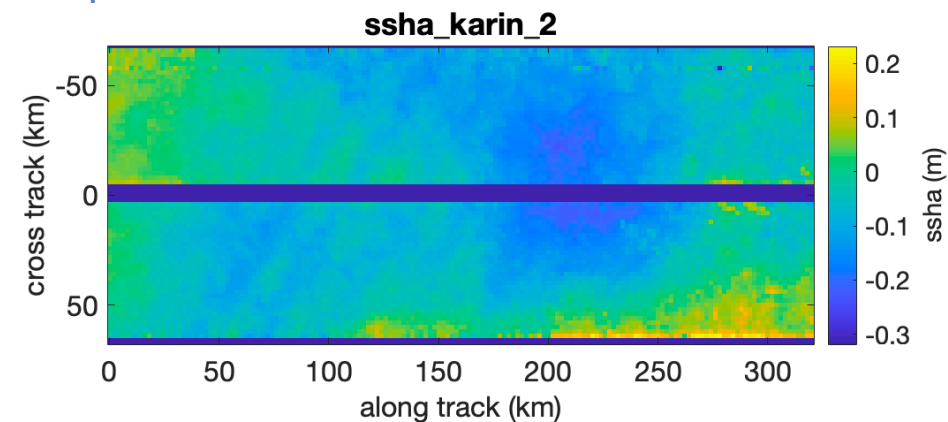
Missing Data when On-board Processor Resets

Calibration Orbit FPGA reconfig

Science Orbit FPGA reconfig
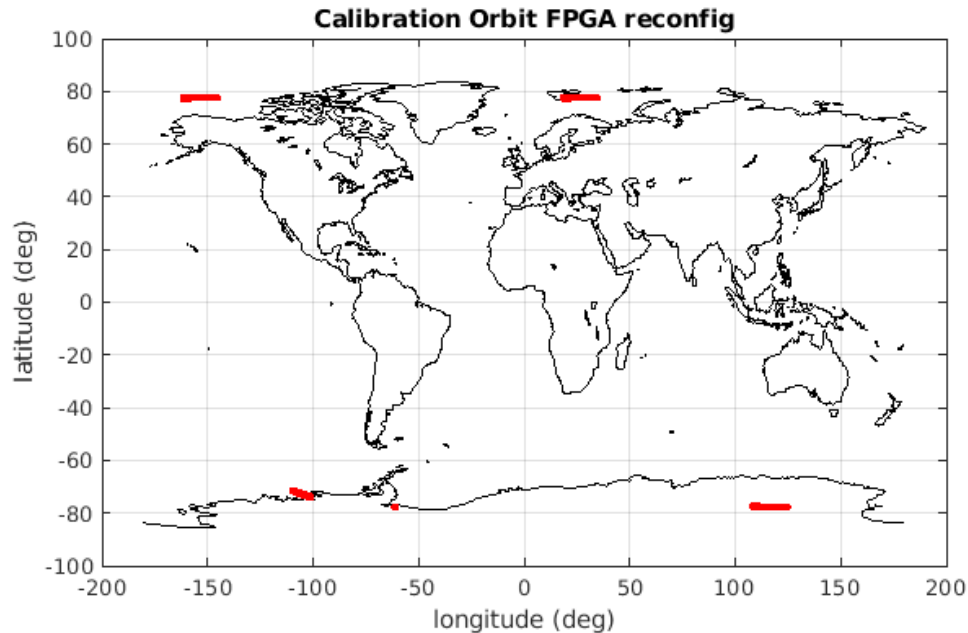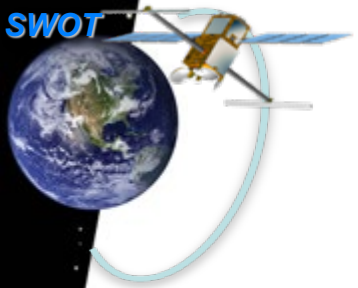
- On-board processor automatically resets every ~6 hours to clear any possible radiation corruption.
- Data is missing for ~1 minute when this occurs, always in the polar regions at/near LR granule boundaries.
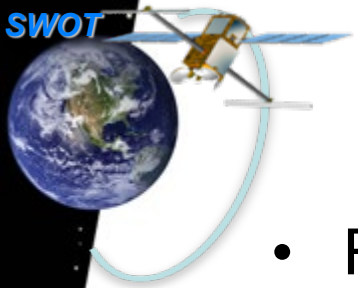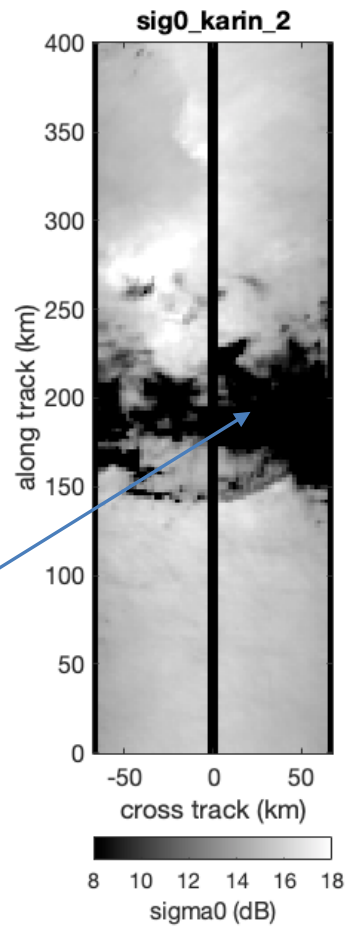
Rain

- Rain (or other precipitation) in the atmosphere causes significant Ka-band radar signal attenuation.

- The model atmospheric attenuation (*sig0_cor_atmos_model*) typically does not capture the signal attenuation.

  - The resulting estimates for *sig0_karin_2* are therefore often erroneously low.

- The radiometer atmospheric attenuation may have better information.

  - Thus *sig0_karin* and *sig0_karin_2* may differ significantly.

- The *rain_flag* is computed from a low-resolution model, not directly from KaRIn data.
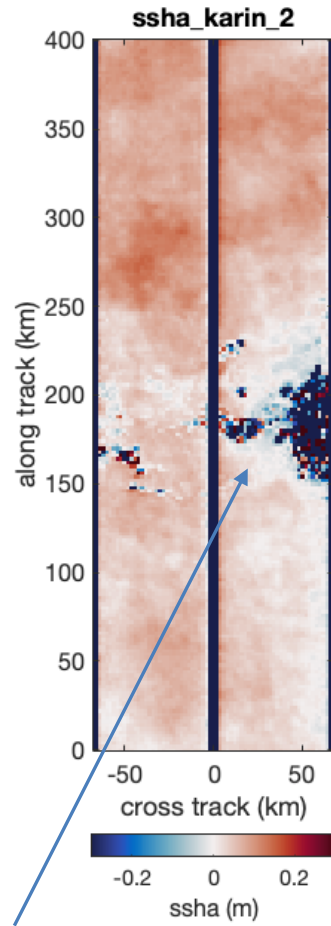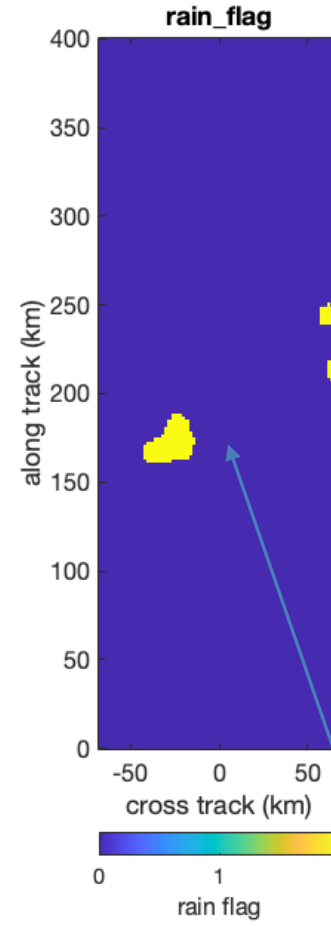
- See example, next slide.
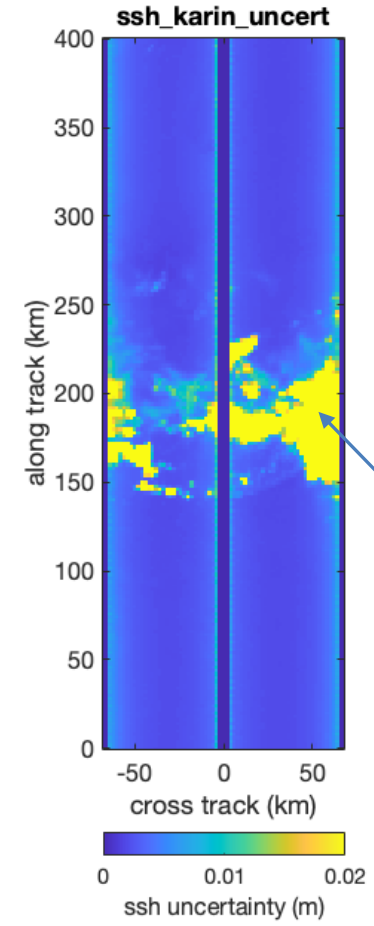
Rain

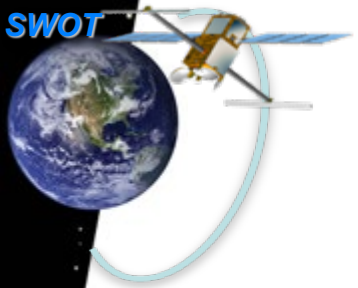Cycle 012 Pass 425, around 6.0° S

Low sigma0 due to rain attenuation

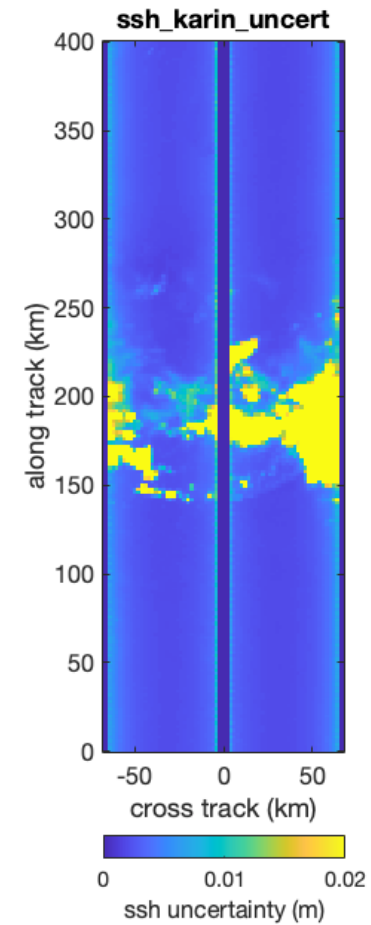Unreliable ssha

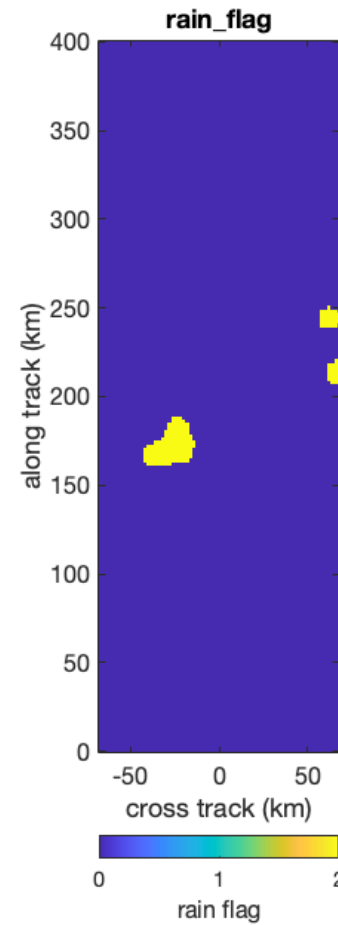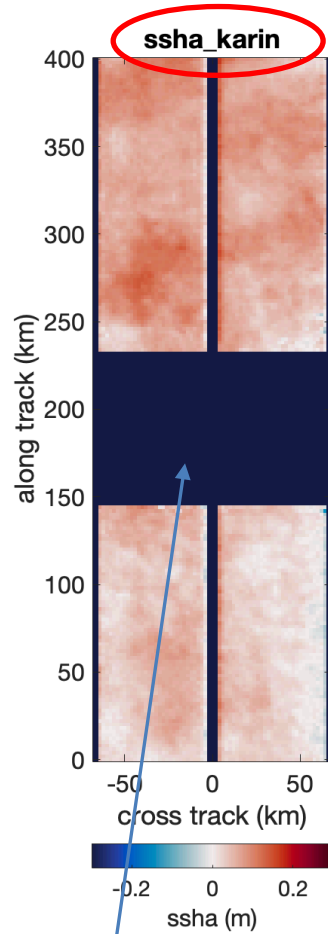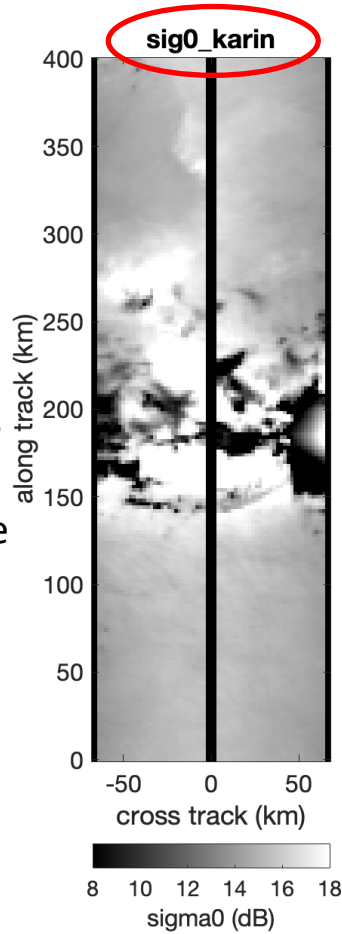Rain flag does not capture all affected pixels.

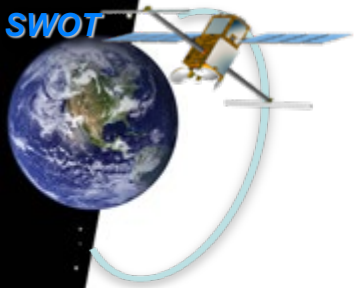Uncertainty is helpful for finding affected pixels.

Rain

Same example as previous slide.

Cycle 012 Pass 425, around 6.0° S

sig0_karin likely more realistic than *sig0_karin_2*, because radiometer attenuation is better than model here.
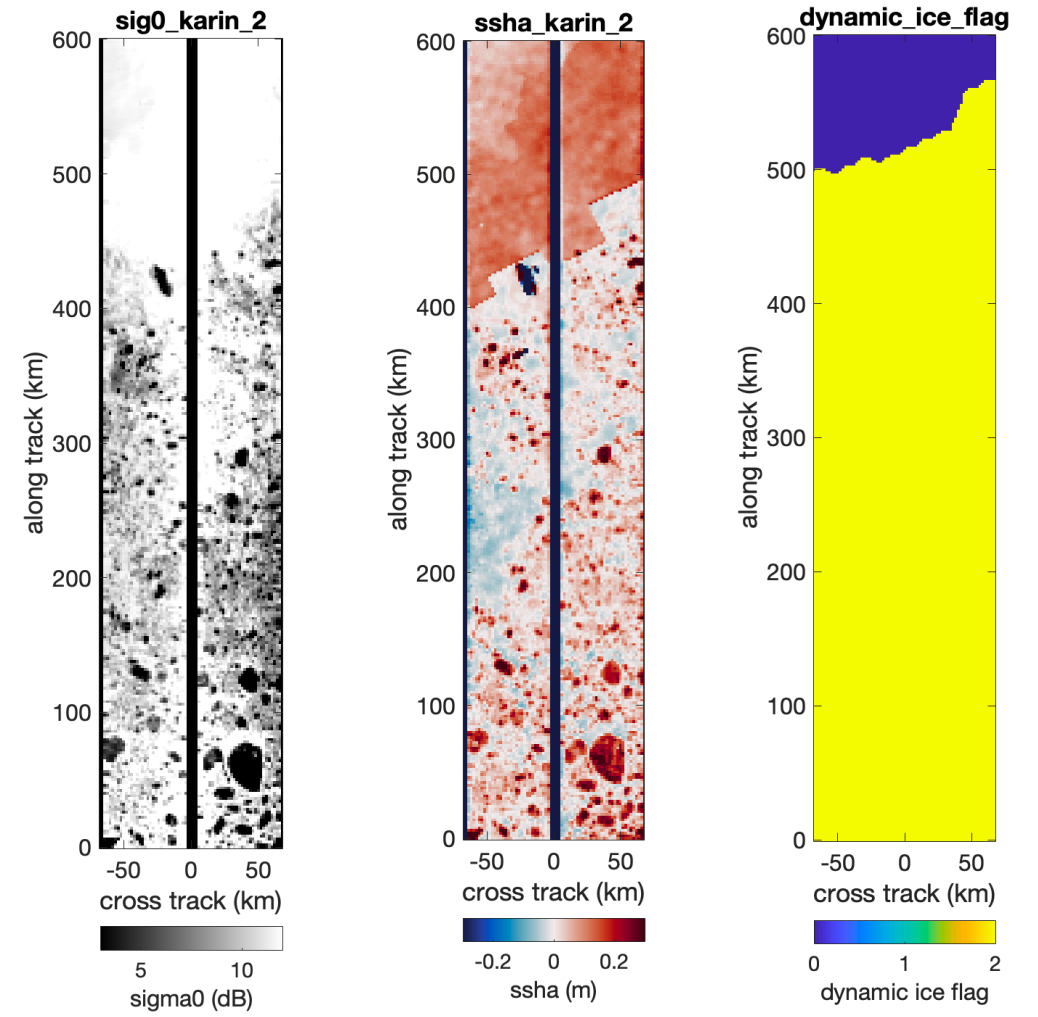
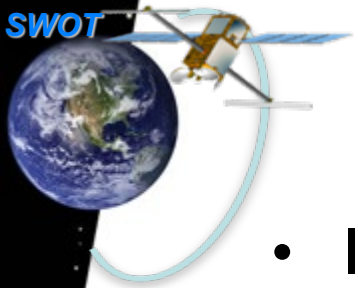ssha_karin is fill value (no *rad_wet_tropo_cor*)

Sea Ice

- The *dynamic_ice_flag* only approximately delineates boundary between sea ice and liquid ocean.
  - It is computed from a low-resolution model, not directly from KaRIn data.
- Sea ice phenomenology is complex and varied.
  - Sea ice sigma0 may be higher or lower than ocean.
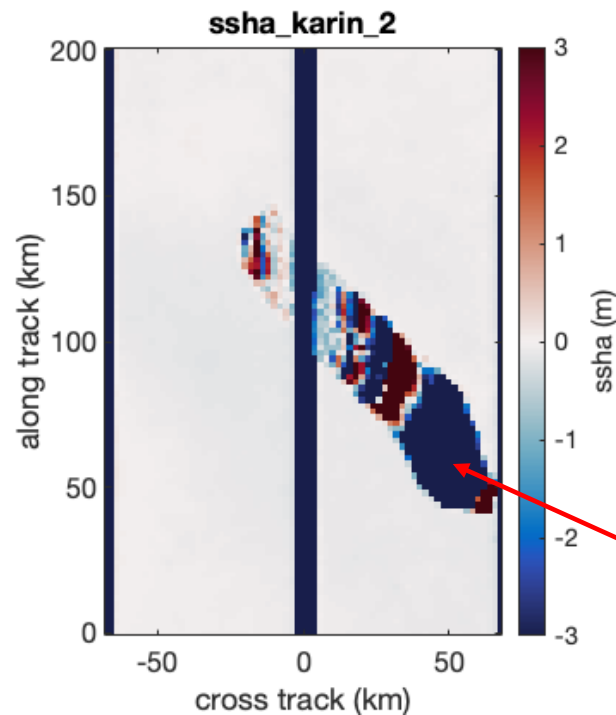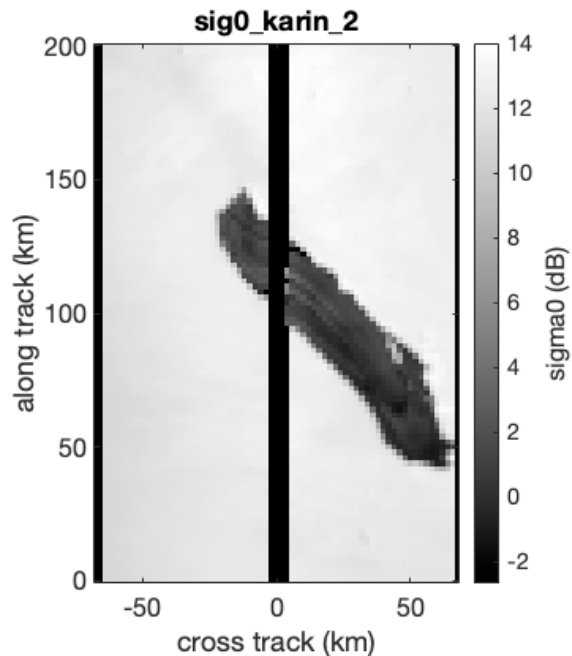
Cycle 009 pass 003, around 62° S

Icebergs and ships
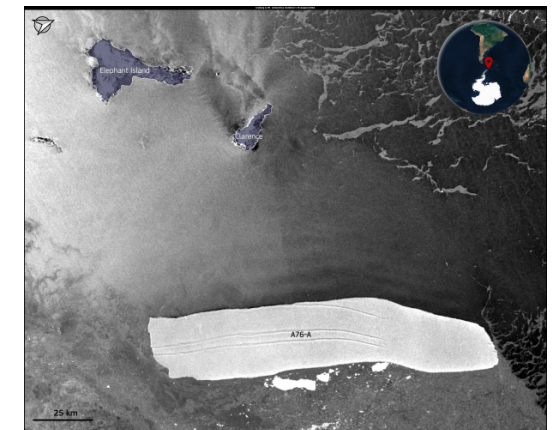
- Icebergs and ships are not always flagged.
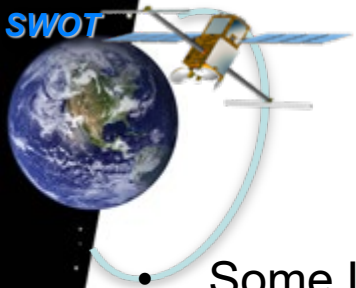
Cycle 505 pass 005 around 55.3° S

- Iceberg surface is high enough that interferometric phase wraps.
- Operational L2 processor does not do phase unwrapping.
- Iceberg height is unreliable.

Optical photo from www.copernicus.eu

Some pixels in this part of the iceberg are flagged `good`

Single Event Upset (SEU)

- Some LR data is affected by single event upsets (SEUs) in the on-board processor (OBP) hardware.
    - Caused by ionizing radiation in the space environment.
    - Sometimes called "radiation hits".
- Starts abruptly (but may start over land)
- Total duration may be longer than one granule.
- Ends when the on-board processor automatically resets itself to clear radiation corruption ("FPGA reconfig").
    - This is done every several hours at/near pass boundaries.
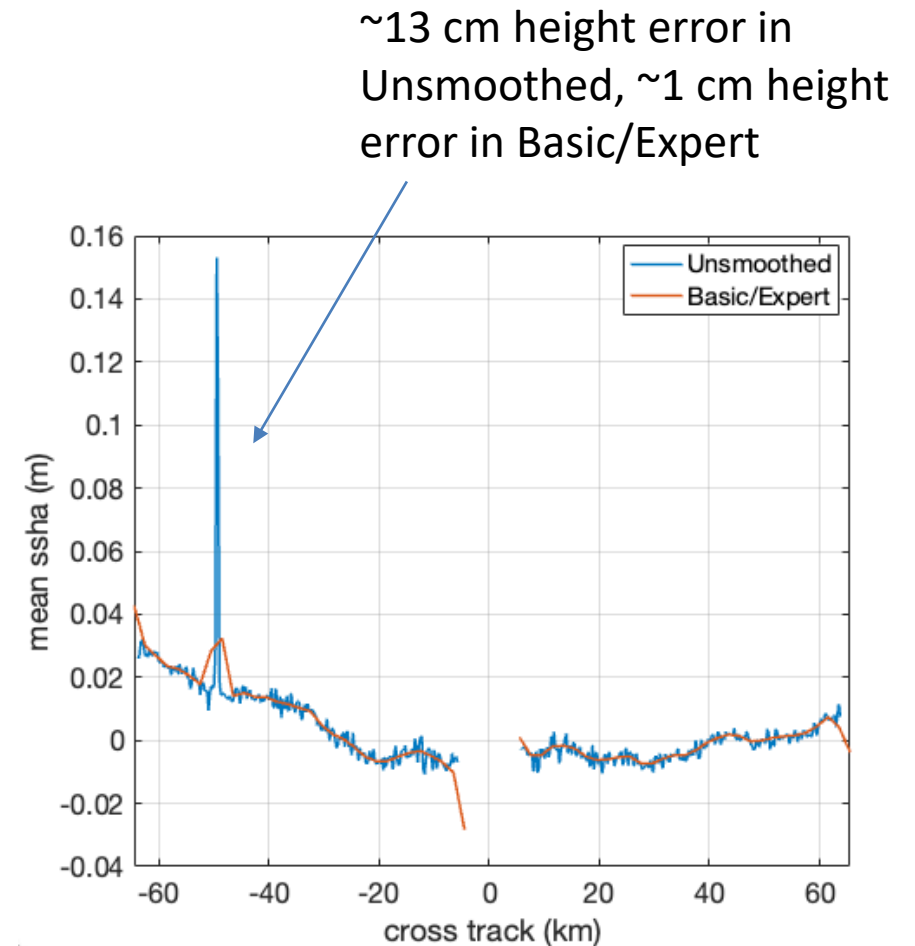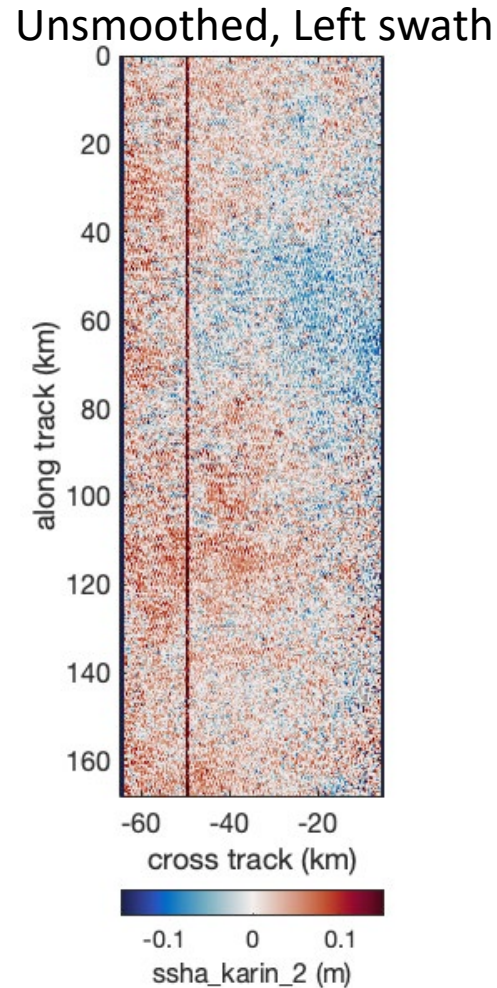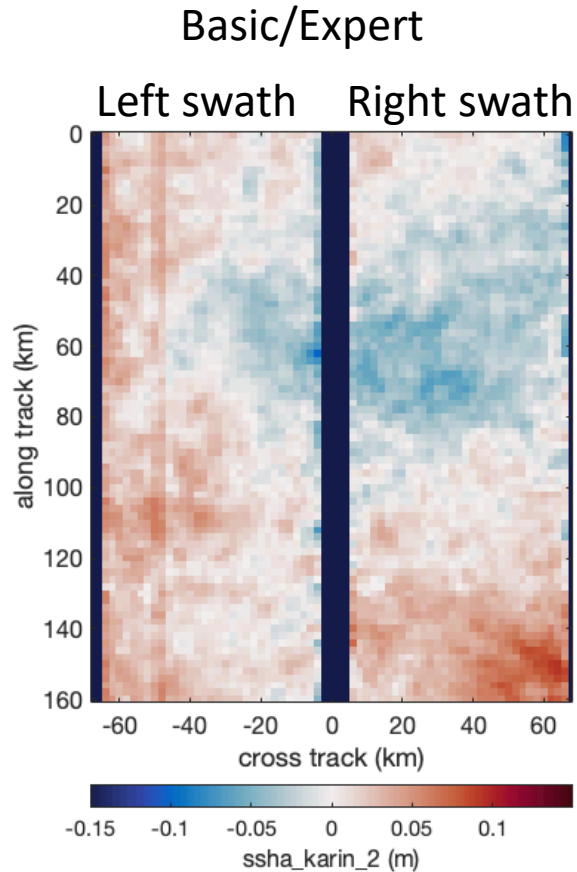- Version C flagging algorithm does not specifically detect these artifacts.
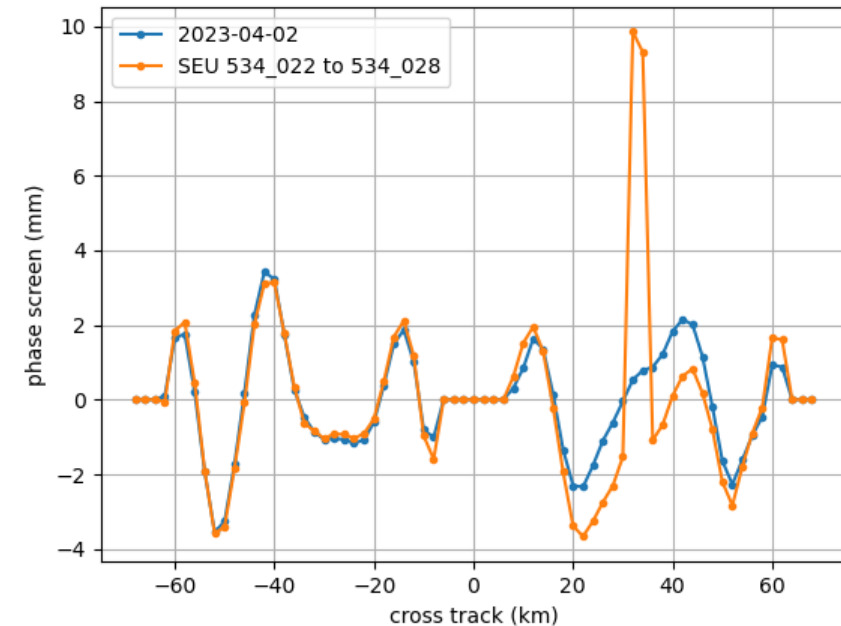
Phase screen computed from data affected by SEU differs from that of unaffected data.
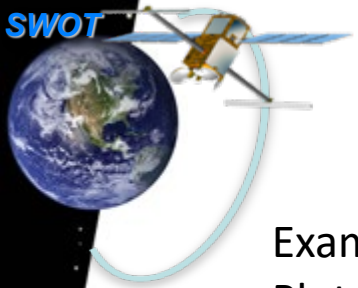
Single Event Upset (SEU)

Example SEU artifact, which affected cycle 010, pass 033 to 039.
Plots show Pass 037 around 32.7°

Basic/Expert

Left swath   Right swath

Unsmoothed, Left swath

~13 cm height error in Unsmoothed, ~1 cm height error in Basic/Expert
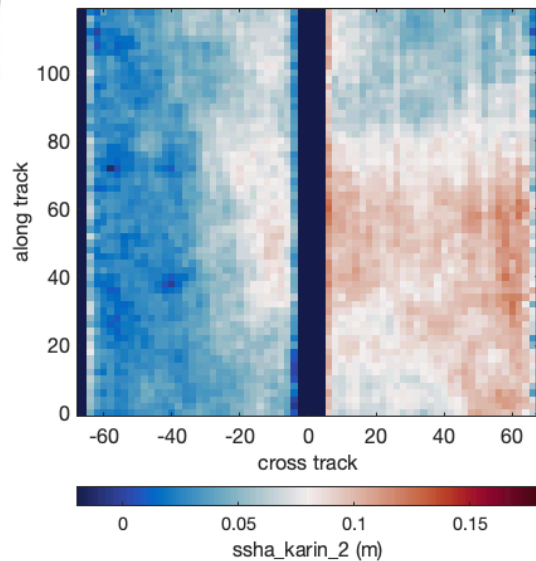
Single Event Upset (SEU)

Example SEU artifact, which affected cycle 003, pass 365 to 369.
Plots show pass 365 around 26.5° S, 36.3° W (in South Atlantic Anomaly)
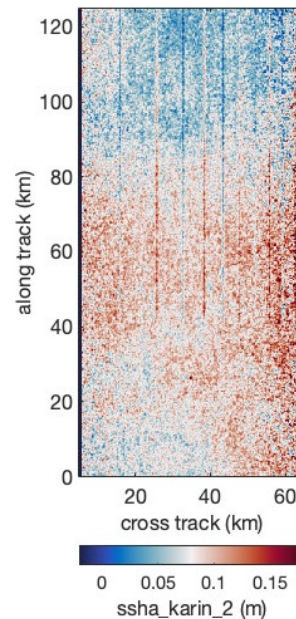

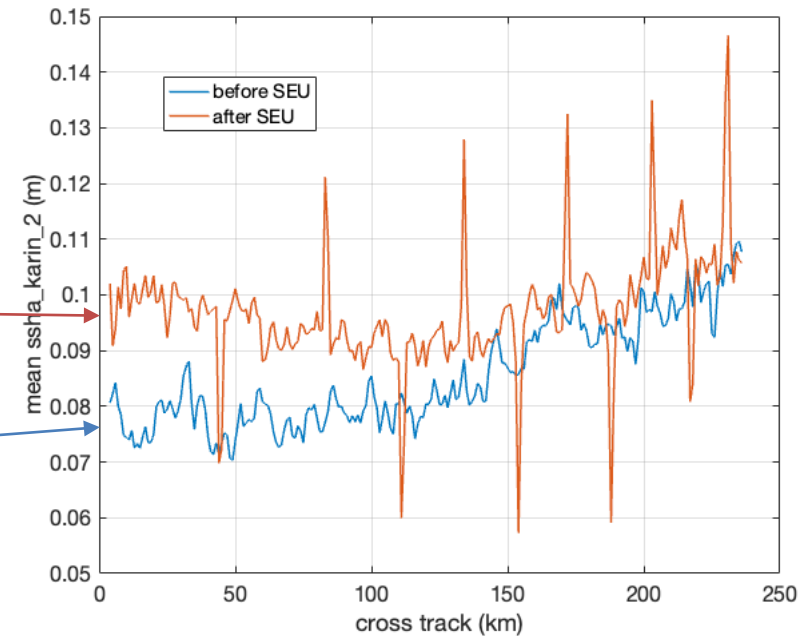Basic/Expert

Left swath   Right swath
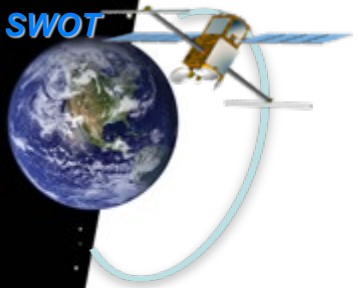
S/C flight direction

Unsmoothed Right swath

Start of artifact

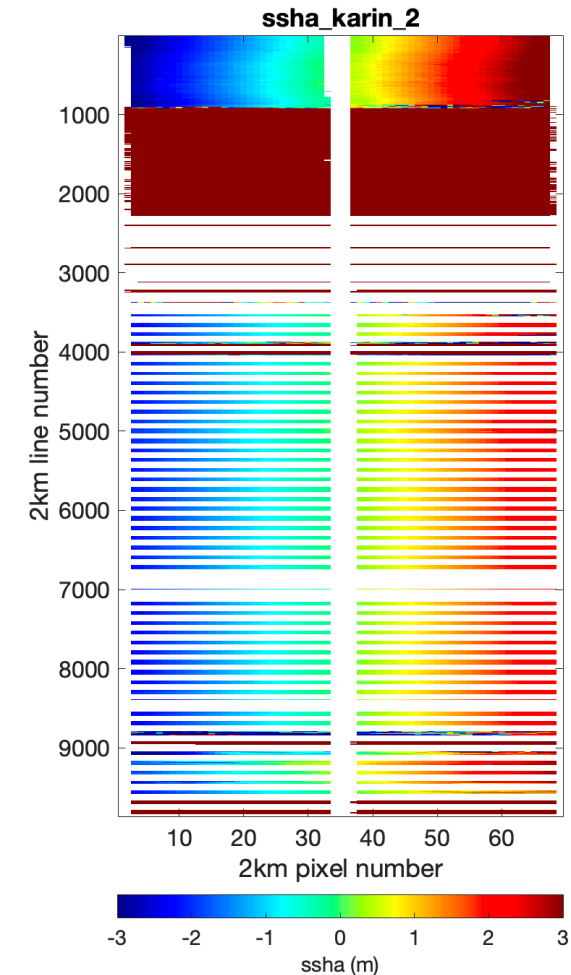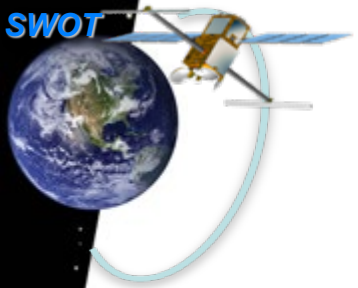Along-track mean of unsmoothed ssha, Right swath

Rare occurrences: Missing frames

- Parts of a granule are occasionally missing due to problems with the data downlink system.

- SSHA has many lines of fill values.

- Estimation of cross-over correction is hindered.

Cycle 506 pass 024

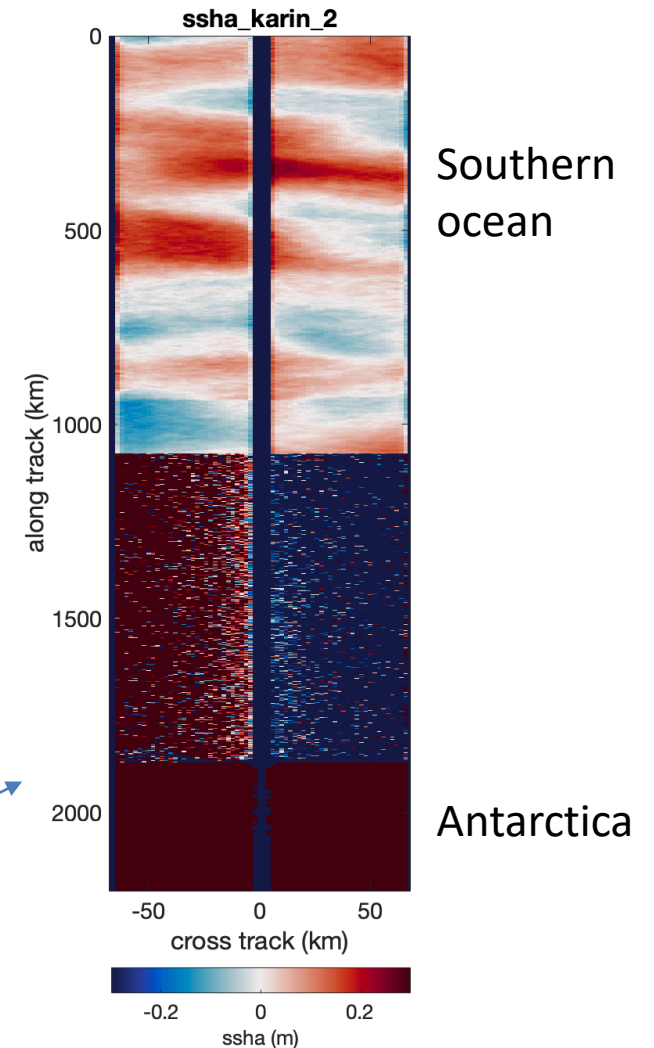ssha_karin_2

Rare Occurrences: HPA reset

- On rare occasions, KaRIn's high power amplifier (HPA) stops transmitting and resets.
  - This is normal and expected but happens very rarely.
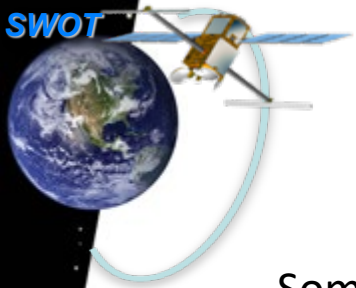- SSHA is very noisy, with very high uncertainty (> 0.1 m), and flagged 'suspect'.

Cycle 011 pass 484

HPA current trip

HPA not transmitting

HPA auto restart


Southern ocean

Antarctica

Other issues

Some other minor issues are present in Version C, but have been fixed in the Developmental Version:
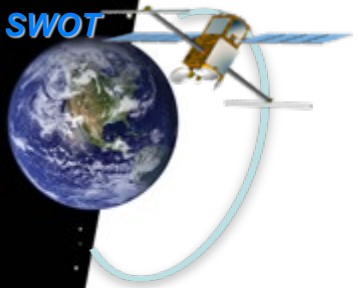
- Non-equilibrium ocean tide is not applied to SSHA
- Radiometer "pass-through" datasets are left/right flipped (*wind_speed_rad*, *rad_surface_type_flag*, *rad_tmb_187*, *rad_tmb_238*, *rad_tmb_340*, *rad_water_vapor*, *rad_cloud_liquid_water*)
  - *Note: rad_wet_tropo_cor and sig0_cor_atmos_rad not affected by this bug.*
- These variables sometimes have large values where fill-values were intended: *mean_wave_period_t02*, *mean_wave_direction*, and *swh_model*
- These quality flag bits are sometimes set incorrectly at processing boundaries: *suspect_large_ssh_delta*, *suspect_large_ssh_std*, *suspect_large_ssh_window_std*, *suspect_large_nrcs_delta*, *suspect_large_nrcs_std*, and *suspect_large_nrcs_window_std*

See Version C release notes.
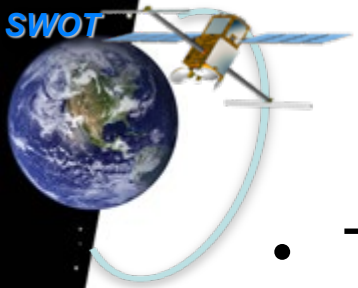
Summary

- The L2_LR_SSH products contain an excellent measurement of SSHA covering nearly the entire ocean, providing a rich and consistent data set for science users.

- There are some unique geophysical features, such as rain and ice, that users should be aware of.

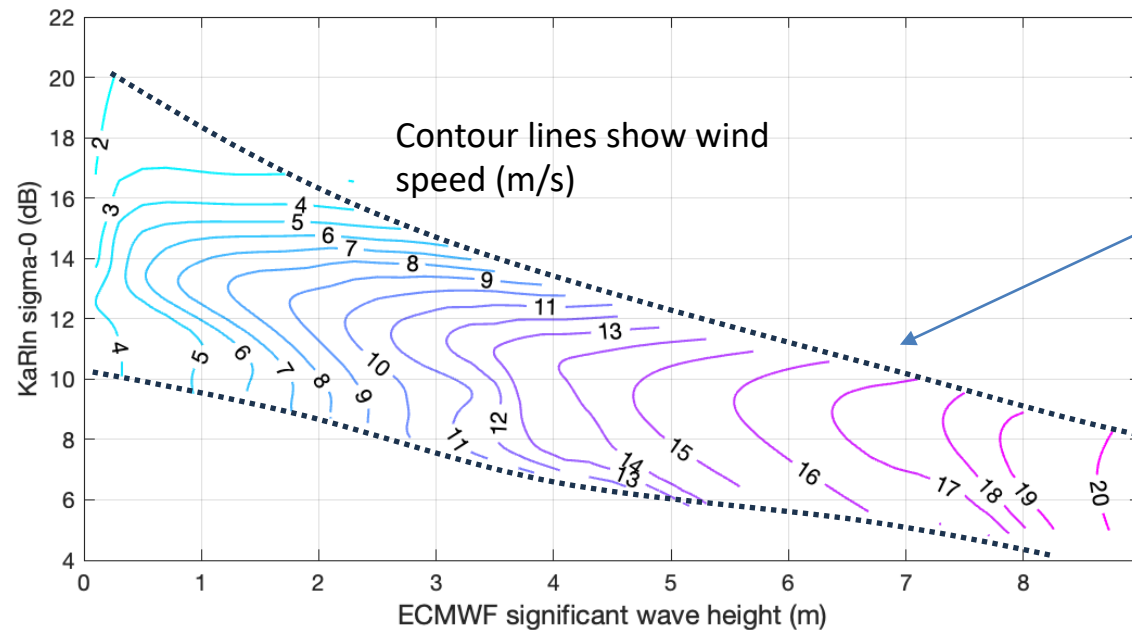- A small amount of data is affected by instrument-related artifacts.
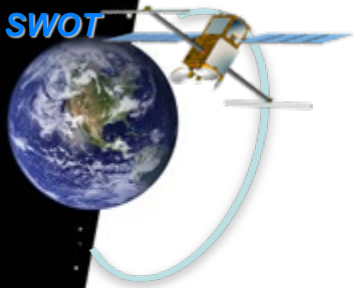
Wind Speed
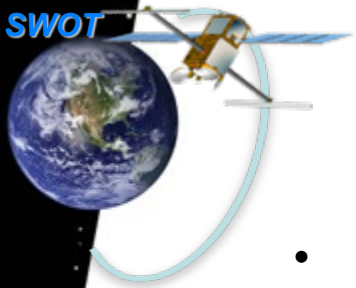
Wind Speed

- KaRIn wind speed is computed using an empirically-derived geophysical model function (GMF).
  - For Version C, the GMF was trained on ECMWF wind speed.
  - For the Developmental Version, the GMF is being further refined by training on Advanced Scatterometer (ASCAT) wind speed.
- The GMF gives wind speed as a function of sigma0, SWH, and incidence angle.

Version C Wind Speed GMF for incidence angle 2.5 deg
(approx. +/- 30 km cross-track)

Contour lines show wind speed (m/s)

~98% of data fall within the dotted lines. The GMF is still defined but less reliable outside this region.

wind_speed_karin uses *sig0_karin*.
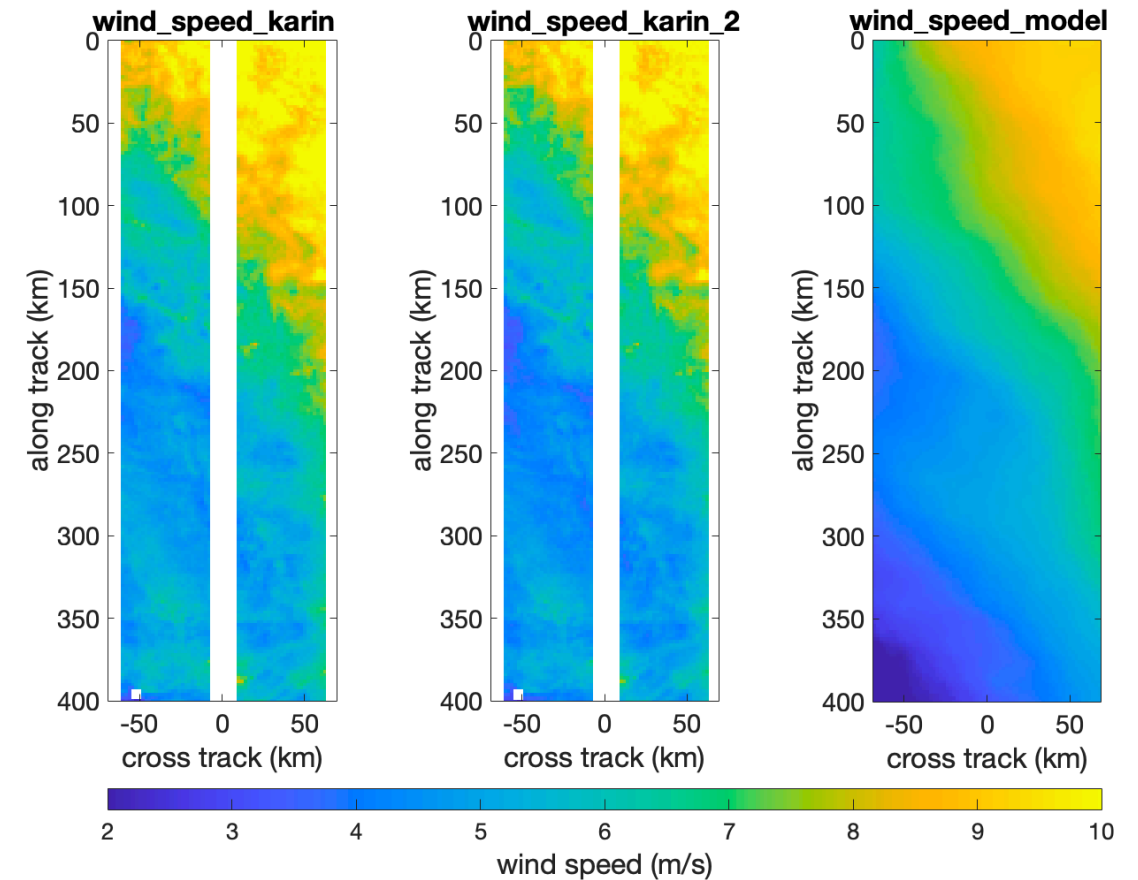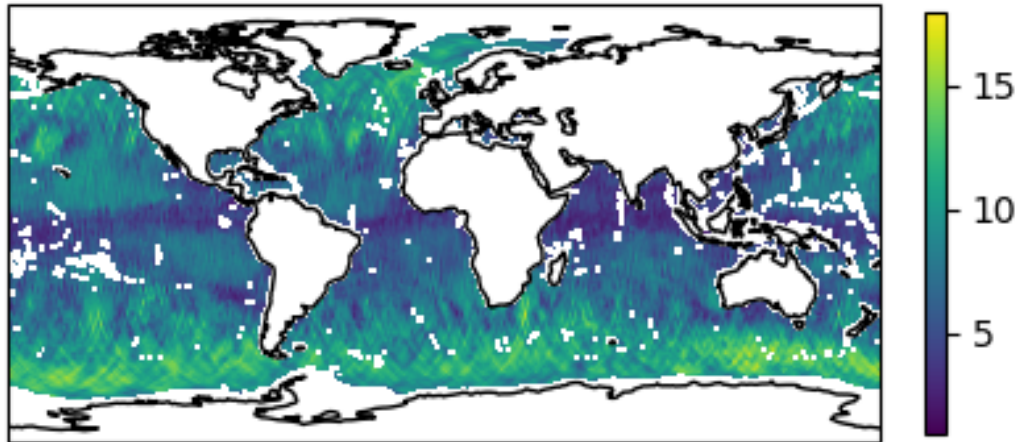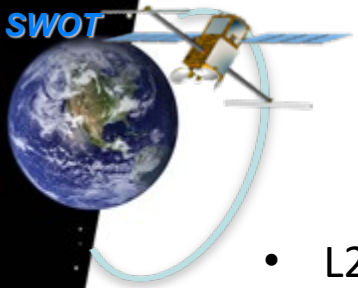*wind_speed_karin_2* uses *sig0_karin_2*.

Wind Speed

- KaRIn and model wind speeds typically show reasonable agreement.
- Global mosaic shows results generally consistent with other wind speed measurements.
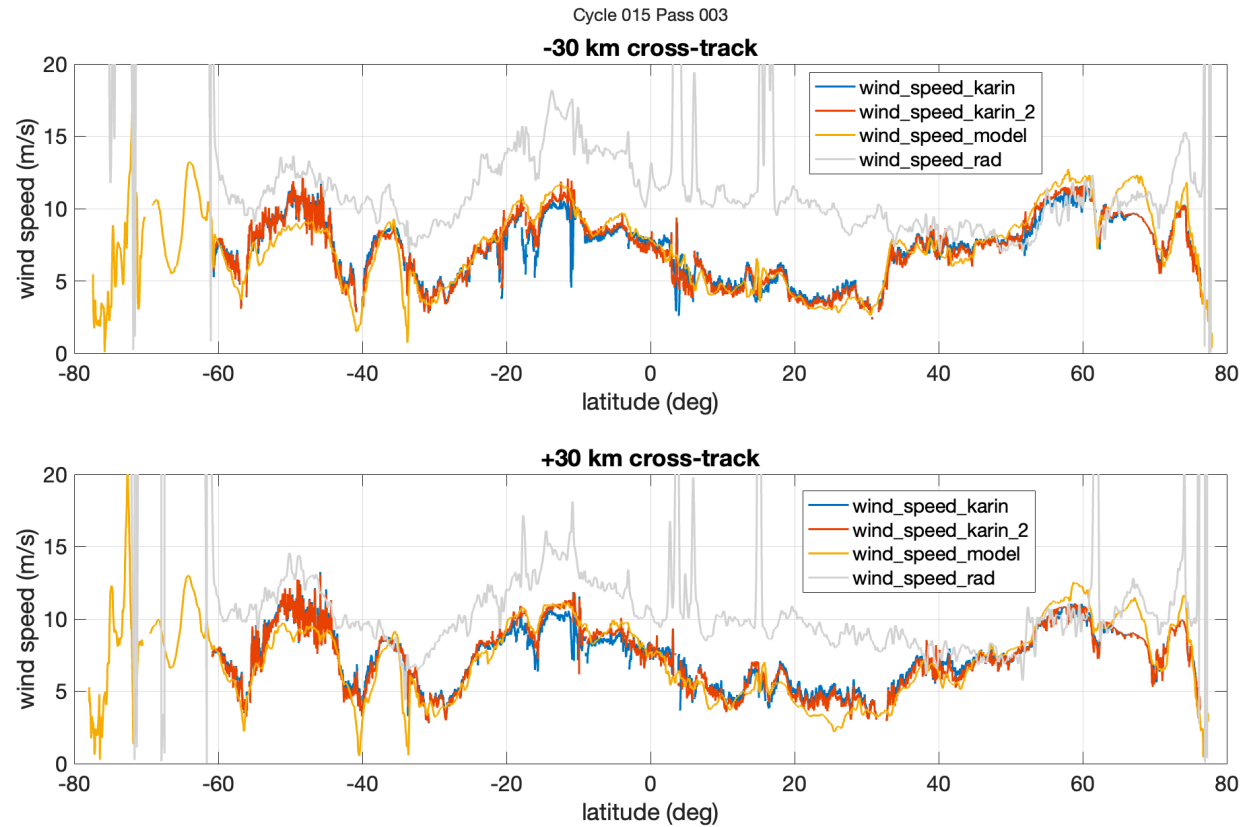
Cycle 015 pass 003, around 44.6° S
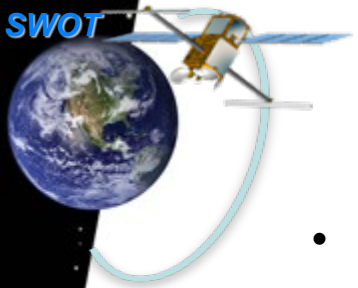

Mean wind_speed_karin_2 [m/s]; cycle 13

Wind Speed

- L2 product also contains radiometer wind speed, but this is less accurate due to radiometer limitations.
- In Version C, the reported radiometer wind speed is left/right flipped (fixed in Developmental Version).
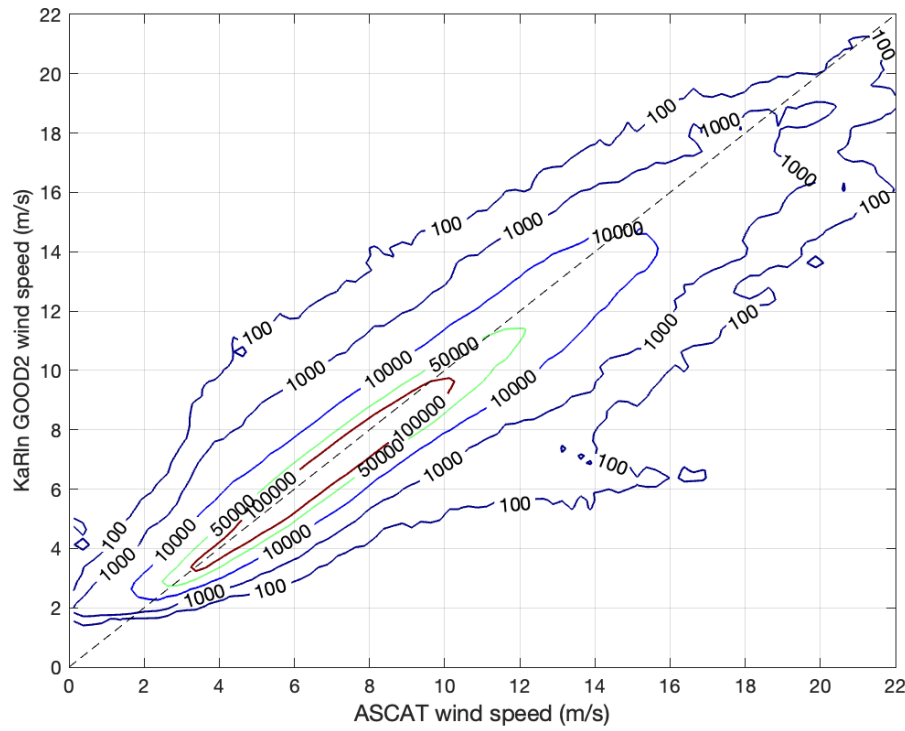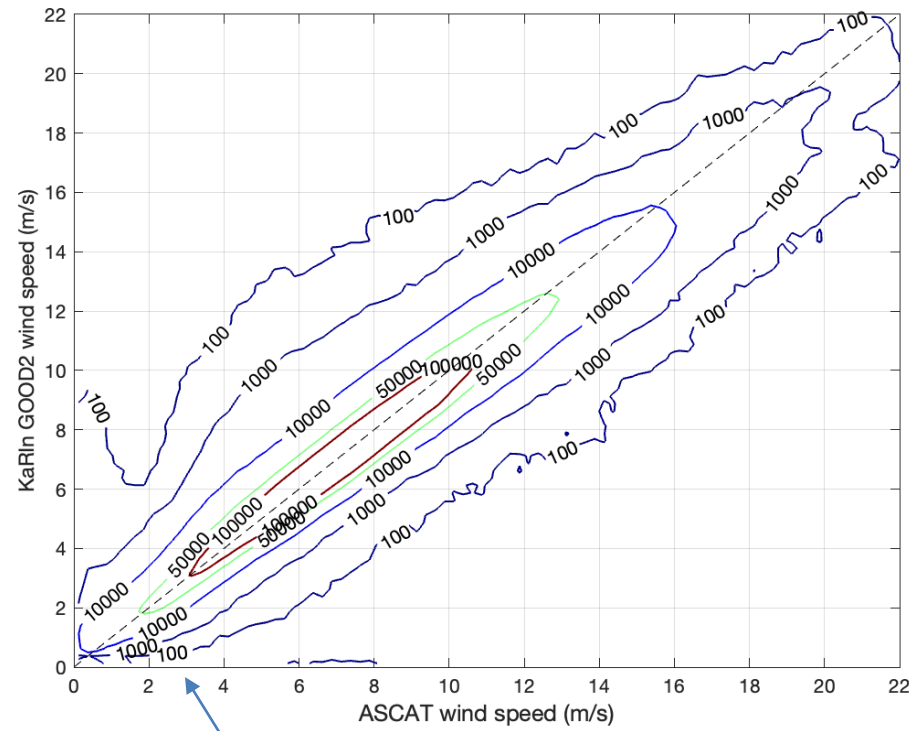

Cycle 015 Pass 003

Wind Speed

- KaRIn wind speed validated by comparison against co-located ASCAT wind speeds, with time differences <30 min.
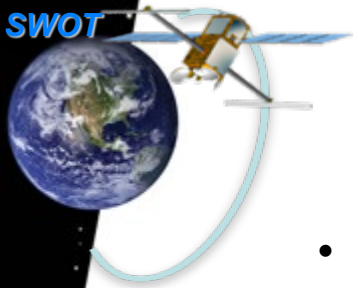- Crest of joint histogram falls close to 1-to-1 line.
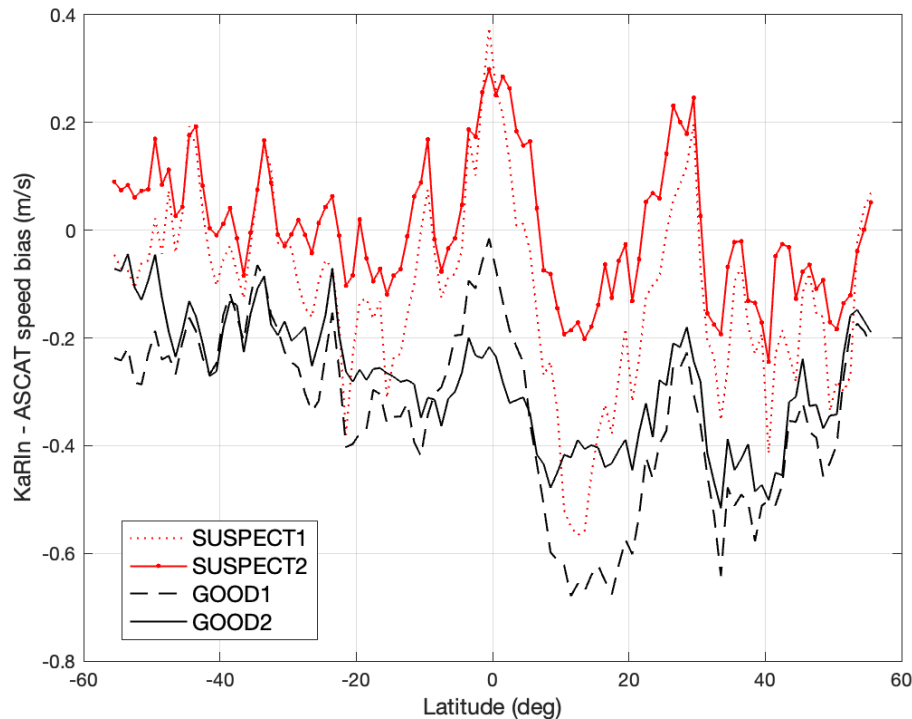
Version C

Developmental Version

Improvement most notable at lower wind speeds.

Wind Speed

- KaRIn wind speed performance shows minimal latitude dependence.
  - Bias between KaRIn and ASCAT has minimal latitude dependence.
  - Std.Dev. of difference has minimal latitude dependence.
- Validation focused on -55° S to 55° N, to avoid sea ice.

Bias between KaRIn and ASCAT
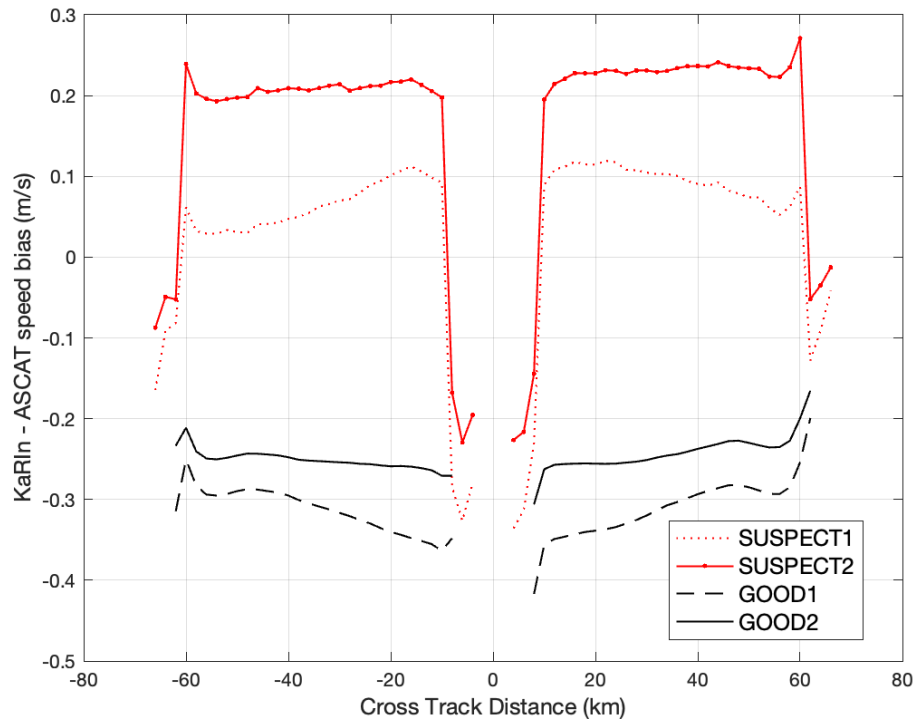
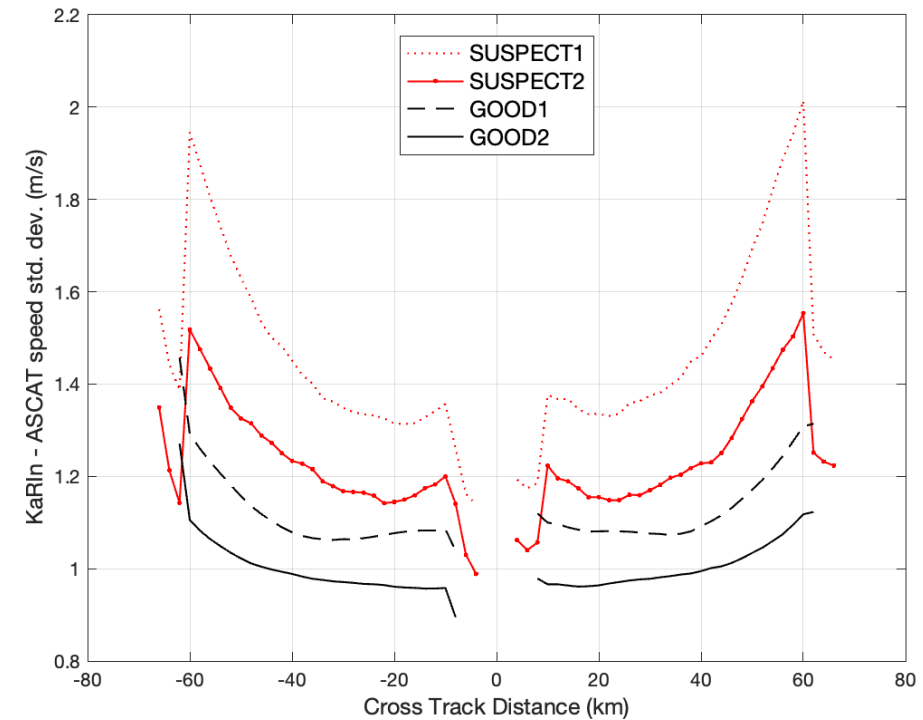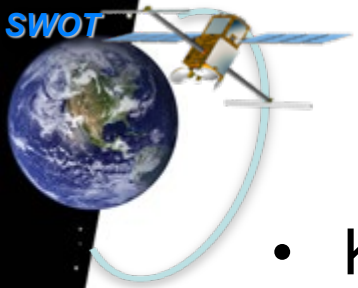Std.Dev. of difference between KaRIn and ASCAT
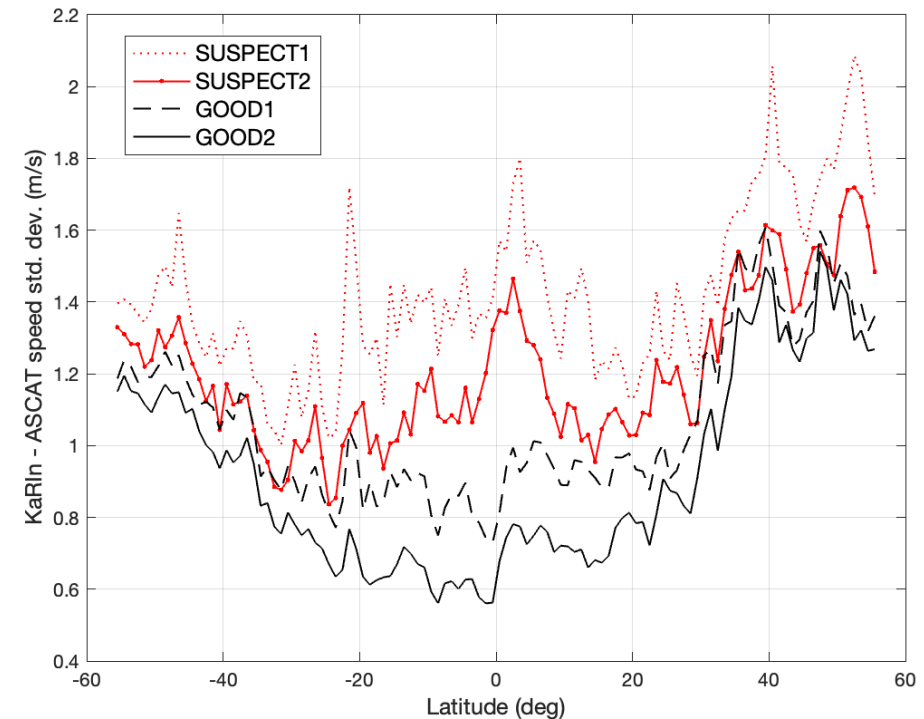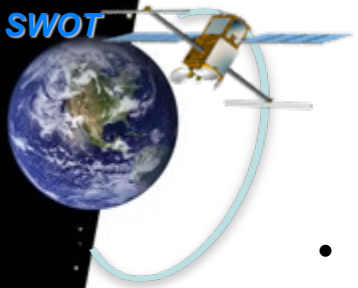
Wind Speed

- Bias between KaRIn and ASCAT has minimal cross-track dependence.
- Std.Dev. of difference is somewhat worse at outer edges of swath.
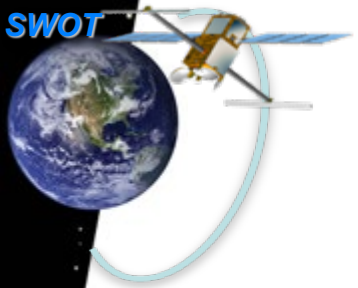
Bias between KaRIn and ASCAT

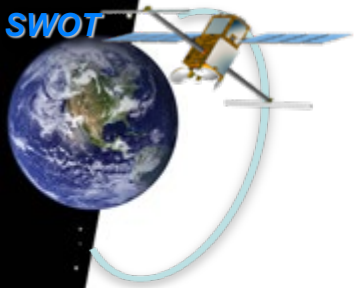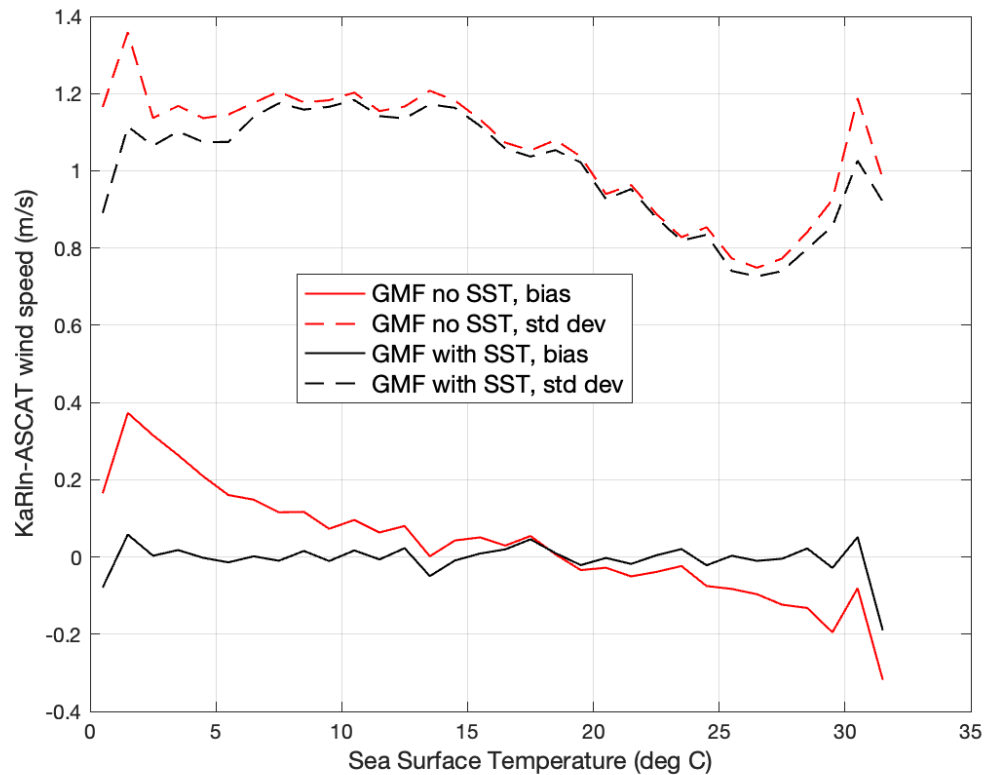Std.Dev. of difference between KaRIn and ASCAT

Summary

- KaRIn wind speed agrees well with ECMWF and has been validated by comparison against ASCAT.

- The KaRIn wind speed measurement will be further refined by improvements to the geophysical model function (GMF) in future releases.

Backup

Using SST for KaRIn wind speed

- To avoid sea-ice contamination the data used to make the plots excluded regions poleward of 55 degrees.
- The following data was also omitted
  - ASCAT/SWOT colocations separated by more than 30 minutes
  - Data with 20-km of coast or not over open ocean
  - Data with ssh_karin_2_qual > 0