National Aeronautics and Space Administration

Jet Propulsion Laboratory
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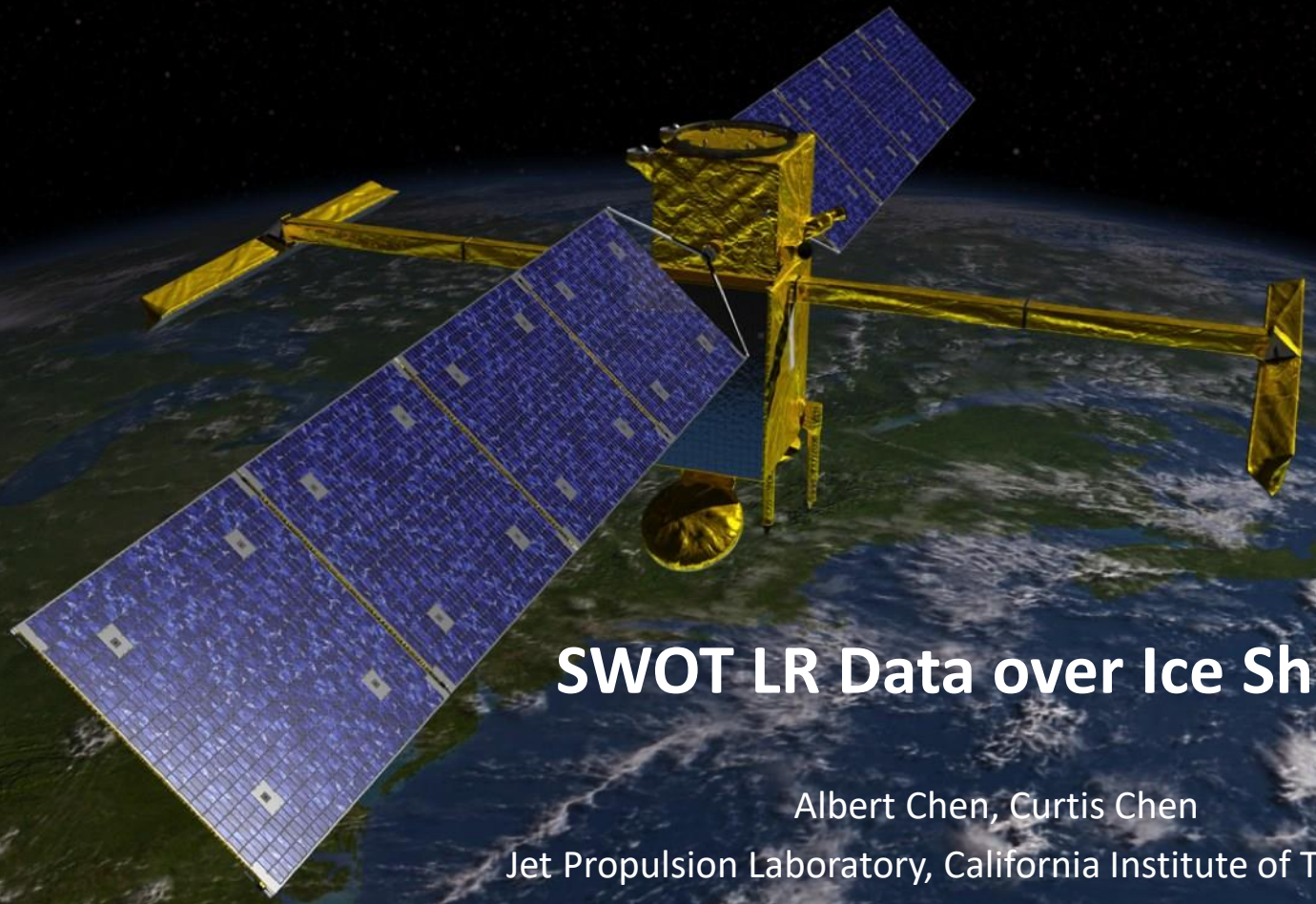
Pasadena, California

Surface Water and Ocean Topography (SWOT) Mission



SWOT LR Data over Ice Sheets

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Overview

- We discuss the use of KaRIn LR data to measure ice sheet elevation
  - Greenland and Antarctica: large and flat on top, and large areas where HR data not available
  - Not alpine glaciers, etc.
- We explain the phase unwrapping issue and show some example data/results from Greenland.

LR Ice Sheet Elevation Measurements

- L2_LR_SSH consists of 4 files:
  - Unsmoothed (250 m posting, “native grid”)
  - Expert, Basic, and WindWave (2 km posting, fixed grid)
    - Basic and WindWave contain subsets of the data in Expert
- Expert contains more information than Unsmoothed, due to space limitations
- LR data is available globally (including ice sheets), except during OBP reconfig, which occurs at polar regions in certain passes

- Expert and Unsmoothed files contain two elevation measurements:
  - ssh_karin: Not available over ice sheets, because it uses radiometer wet troposphere correction
  - ssh_karin_2: Available over ice sheets, uses ECMWF model wet troposphere correction

- Use ssh_karin_2 + height_cor_xover for elevation measurement relative to WGS84 ellipsoid.
- Use ssha_karin_2 + height_cor_xover for elevation measurement relative to EGM2008 geoid, with solid-Earth tide correction.

- Users are advised to check both ssh(a)_karin_2_qual and height_cor_xover_qual flags.

Limitations and Issues

- LR data works best in the regions with lower surface slopes (KaRIn was optimized for measuring water surfaces)
- On-Board Processor (OBP) algorithm was optimized for ocean surfaces
  - Check obp_ref_surface variable in Expert file. Best performance is when obp_ref_surface is close to true ice sheet elevation.
- LR processor limitations
  - No phase unwrapping as of Version D (see following slides).

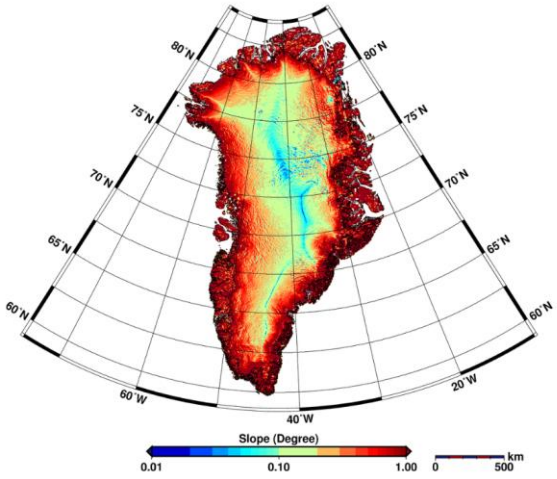


Figure 8. Surface slopes, estimated from the new elevation model of Greenland.

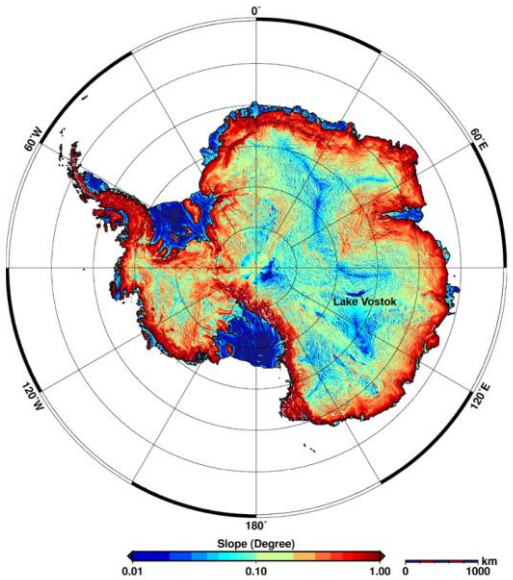


Figure 6. Surface slopes, estimated from the new elevation model of Antarctica.

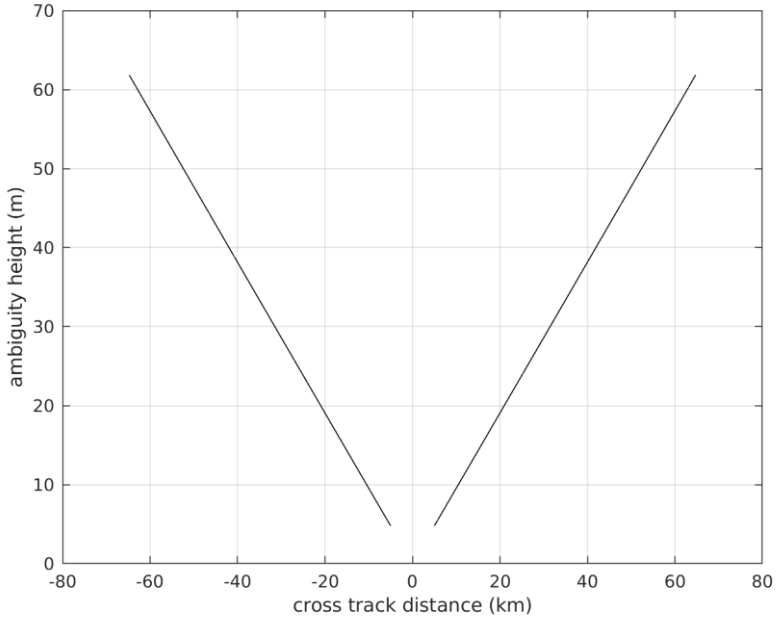
V. Helm, A. Humbert, and H. Miller, "Elevation and elevation change of Greenland and Antarctica derived from CryoSat-2," The Cryosphere, vol. 8, pp. 1539–, 08 2014.

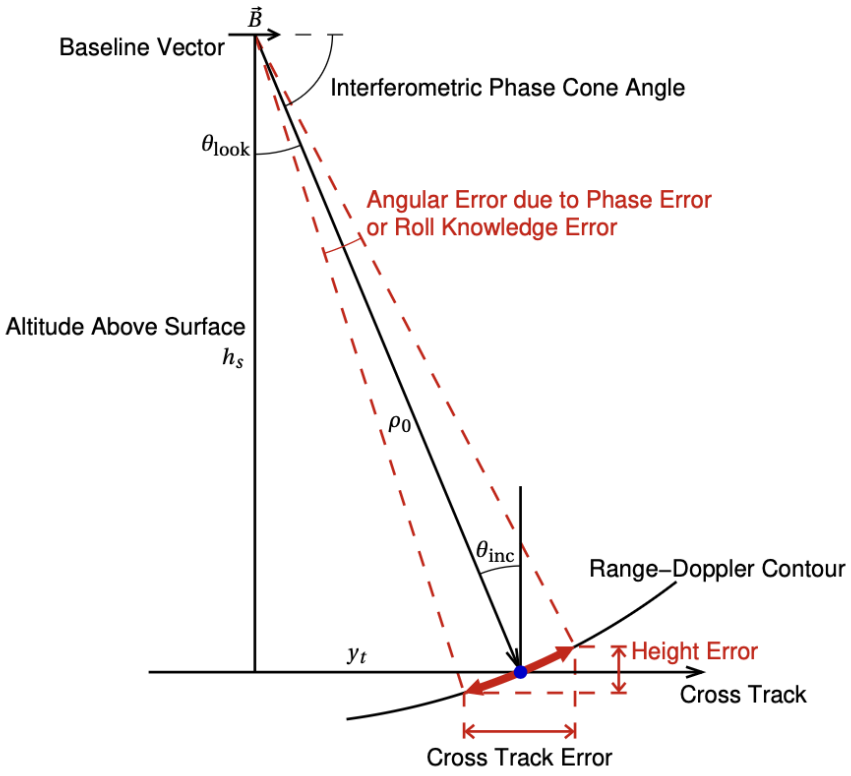
Phase Unwrapping

- Phase unwrapping is needed because interferometric phase can only be measured modulo 2π
  - Thus $\phi = \phi_{measured} + 2\pi n$
  - Over ocean, OBP and L1B_LR_INTF reference surfaces ensure that $n = 0$
  - As of Version D, we also assume $n = 0$ for all ice sheet pixels, but this is not always valid, resulting in phase unwrapping errors.
- In the Basic/Expert files, unwrapping errors have been averaged over by the 2km averaging kernel.
- Unwrapping errors cause SSH error (magnitude depends on cross-track distance) and geolocation error.
- See SWOT User Handbook Sec. 8.3.5

Phase unwrapping illustration

Ambiguity height is SSH error corresponding to n off by 1.





From SWOT User Handbook, Fig. 8.14

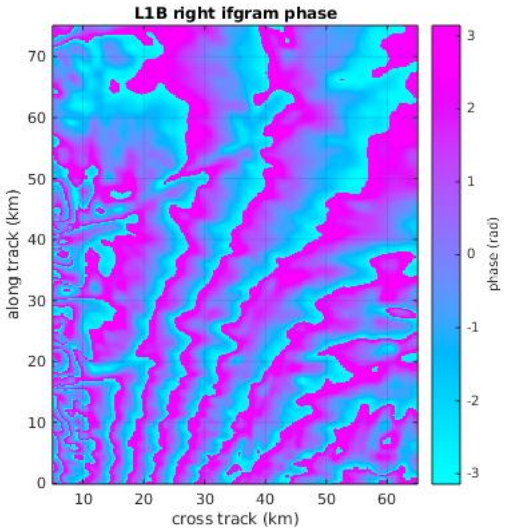
Height error will be a multiple of the ambiguity height.

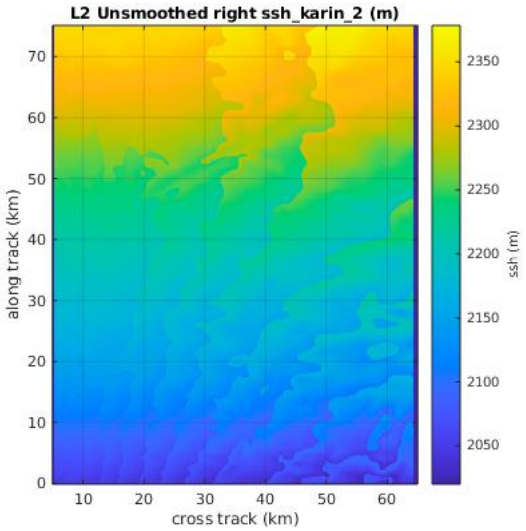
Cross-track error will be a multiple of ~750 meters.

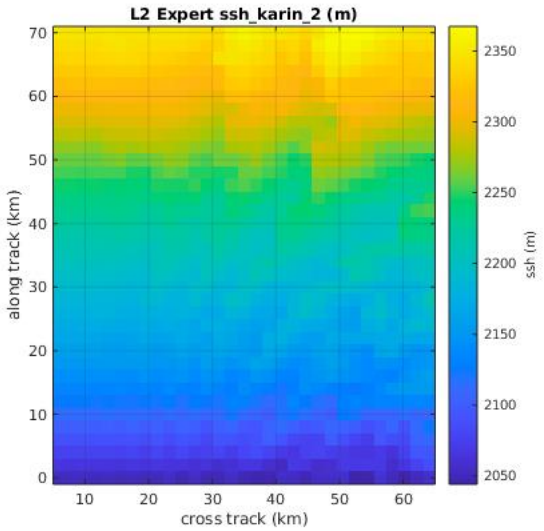
Proposed L2 processor update

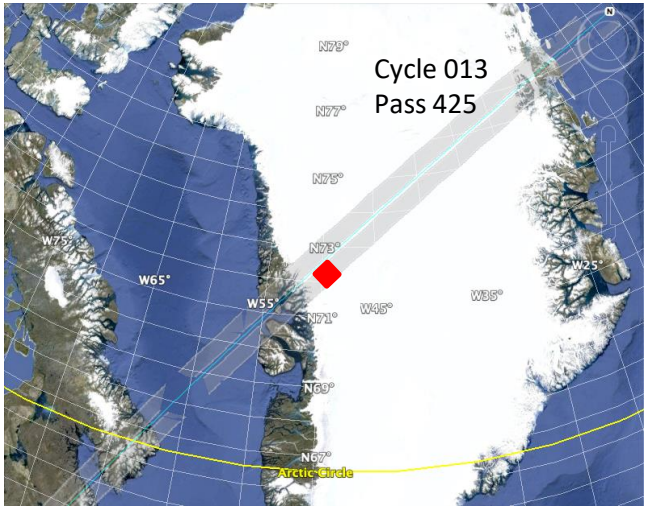
- We are investigating an update to the height reconstruction in the L2_LR_PreCalSSH processor to estimate phase unwrapping ambiguity
  - Two options being considered:
    - Estimate ambiguity on a pixel-by-pixel basis by comparison against a reference DEM (no 2-D phase unwrapping).
    - Use a 2-D spatial phase unwrapping algorithm, similar to HR processing. Reference DEM is still used to assist with absolute ambiguity.
  - Reference DEM is based on MERIT for Greenland, and REMA for Antarctica.
- To avoid possible errors over ocean, ambiguity is forced to be zero outside of ice sheets.

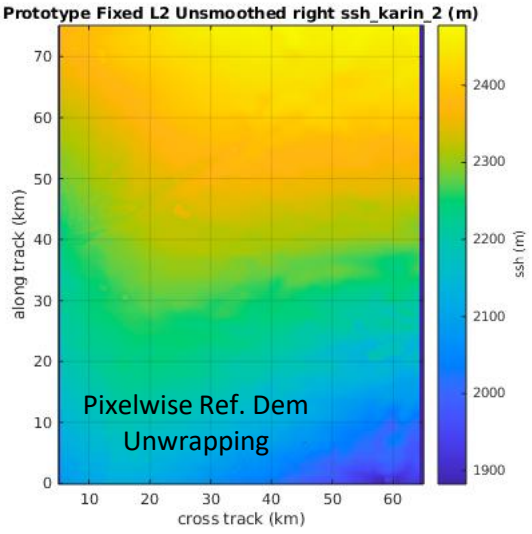
Phase Unwrapping errors in Version D







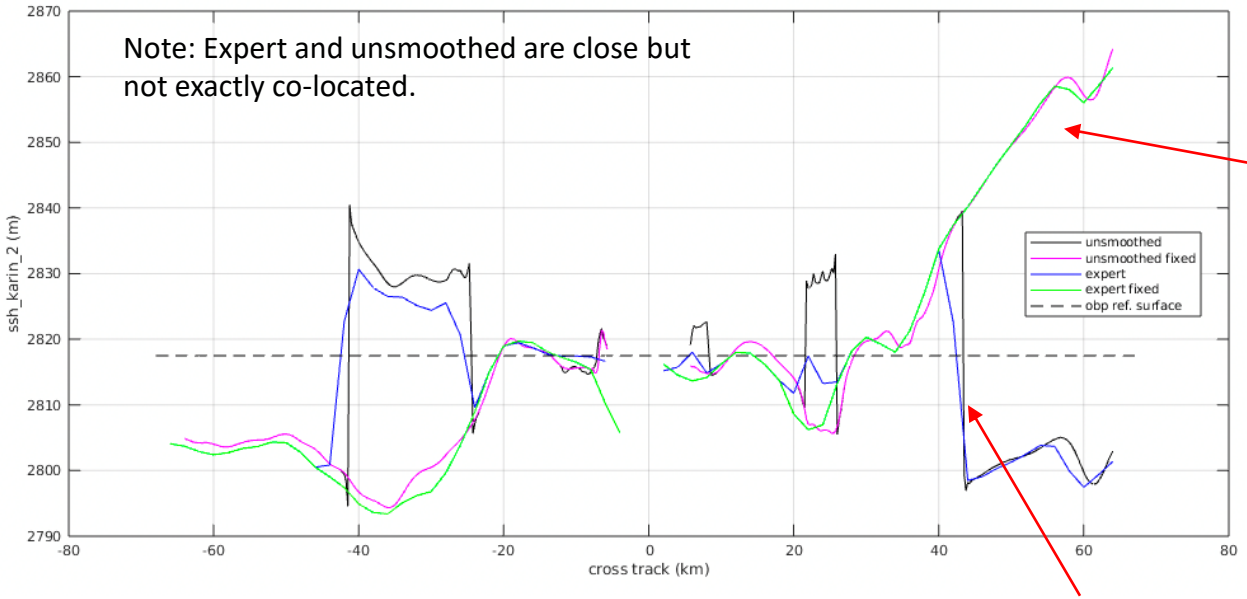




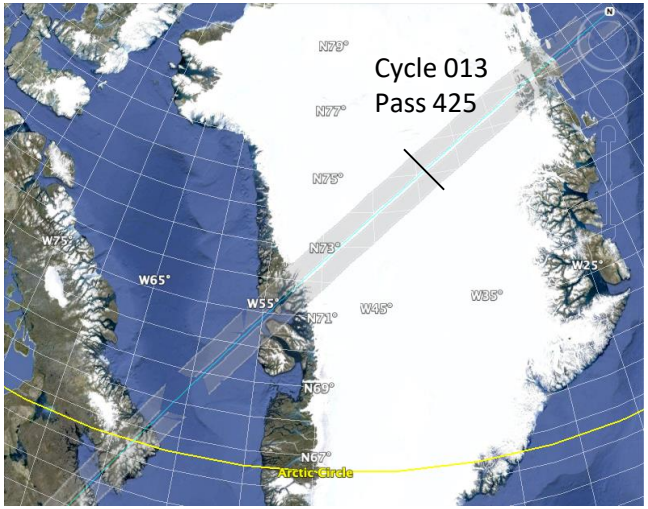
- SNR is generally very good
- Random noise is typically < 3 cm for unsmoothed product (see ssh_karin_uncert).
- Note the examples shown here are processed off-line using the same code and configuration as Version D data.

Phase Unwrapping errors in Version D

80 meters



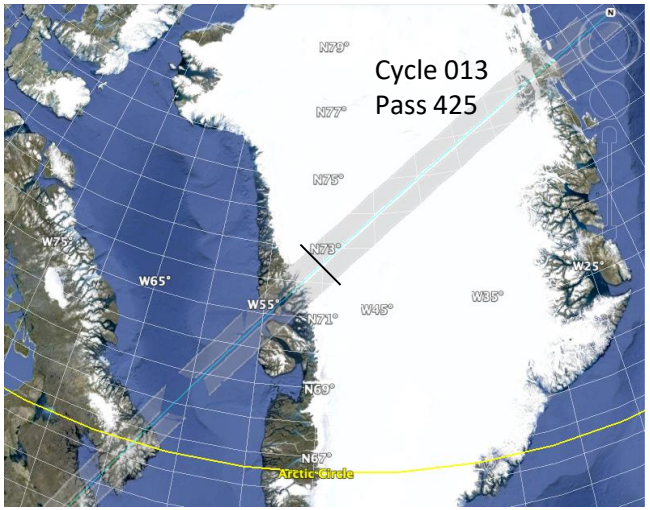
Corrected SSH after implementing phase unwrapping algorithm.

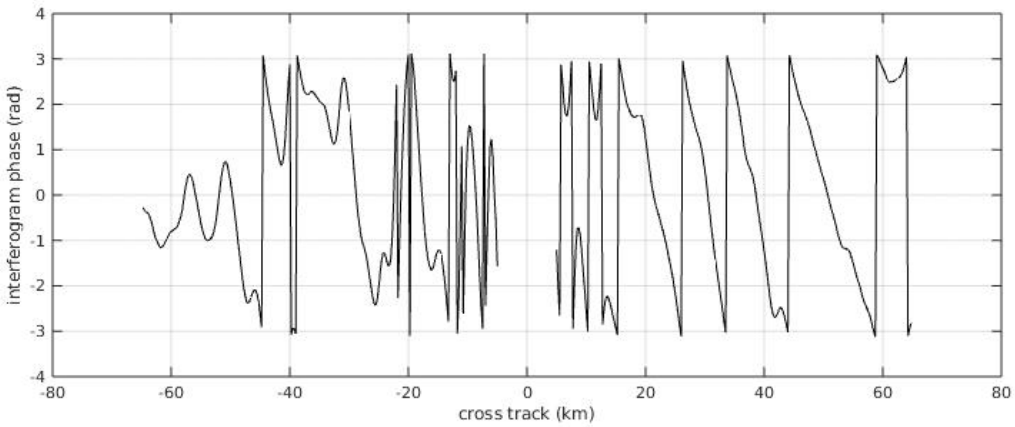


Large abrupt jumps in SSH due to phase unwrapping errors.

Performance is generally better at the center of the ice sheet where surface slope is lower. (Next slide shows a more challenging example.)

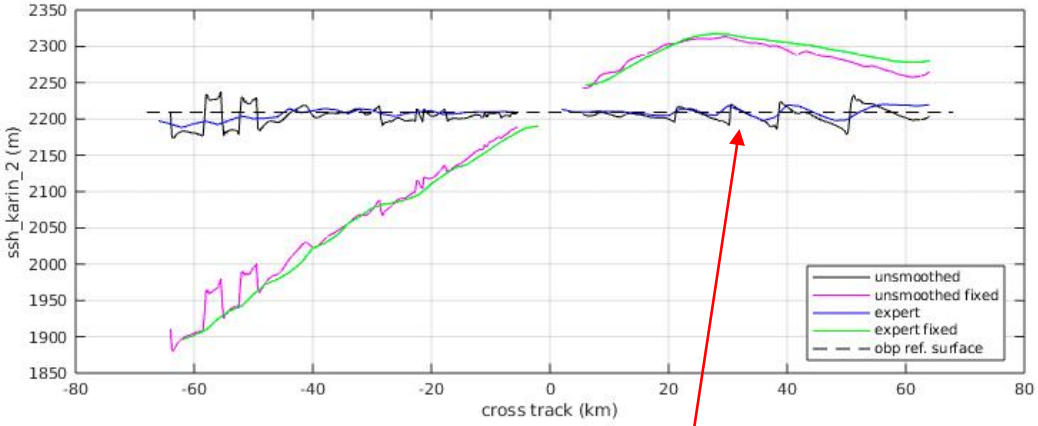
Phase Unwrapping errors in Version D





- Unwrapping errors in L2_LR_SSH products don't exactly correspond to wraps in L1B_LR_INTF phase, because phase calibration has not been applied in L1B_LR_INTF product.
- OBP reference surface assumes a flat ice sheet at the nadir elevation.
- In this example, performance is worse on the left swath, as it deviates more from OBP assumption
- Note the unsmoothed and expert curves are close but not exactly co-located.

500 meters



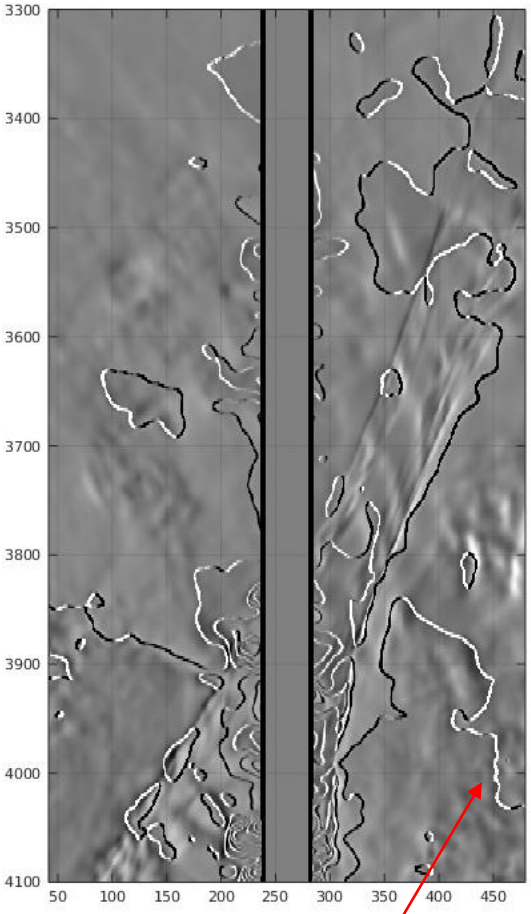
Curves labeled "fixed" have pixelwise ref. DEM unwrapping applied. Most unwrapping errors resolved, but some aphysical jumps remain.

Large abrupt jumps in SSH due to phase unwrapping errors.

Unwrapping Results near NEGIS

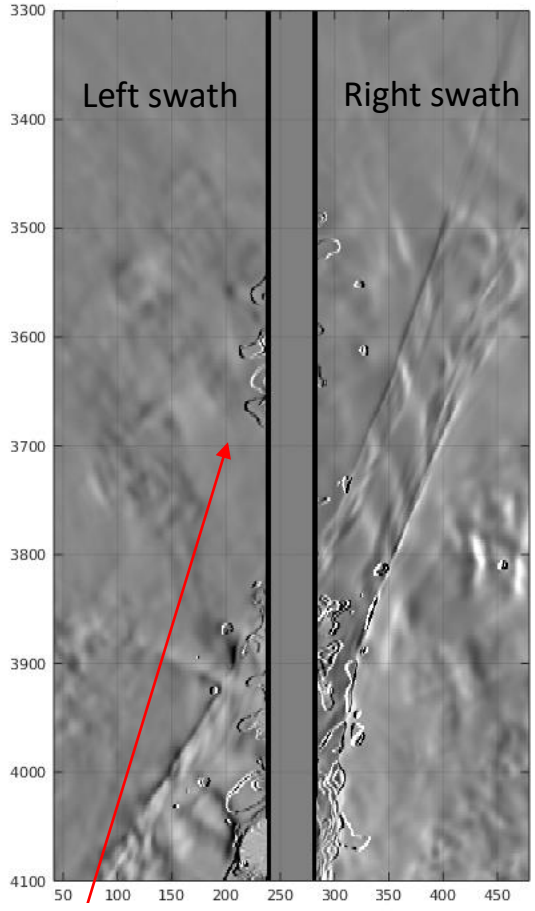
The figure shows a shaded relief image of ssh_karin_2 around the Northeast Greenland Ice Stream (NEGIS).

Version D



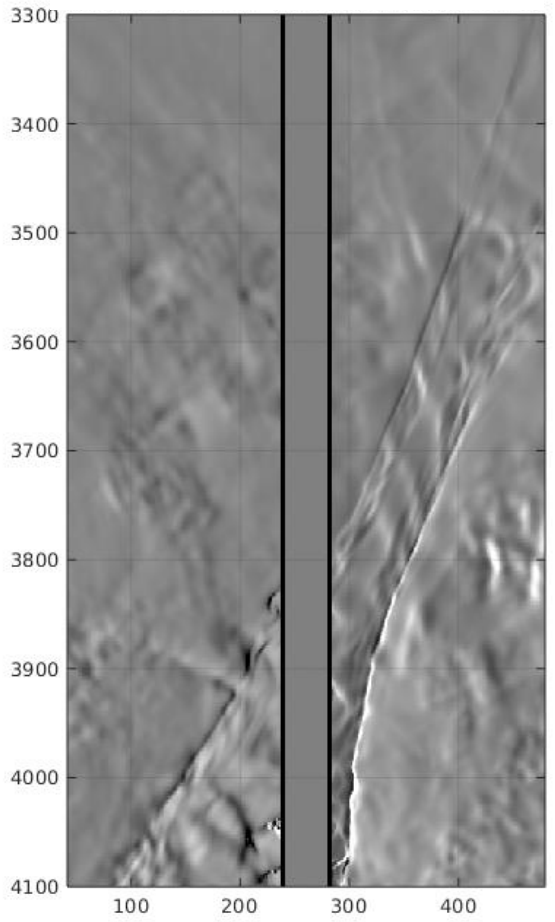
Unrealistic edges (phase unwrapping errors)

Ref. DEM unwrapping



Unwrapping errors mainly near nadir.

Ref. DEM & 2D unwrapping



Better performance / higher complexity

User Considerations

- The most useful data are those for which the surface is within half an ambiguity height of obp_ref_surface.
- It may be possible to make approximate corrections for unwrapping errors in post-processing.
  - However, because the errors are large (many meters) and cross-track dependent, it will be hard to do a very exact correction.
- Beware of other potential error sources
  - Phase bias correction assumes land has uniform sigma0.
  - Residual cross-over correction errors.
  - Etc.

Summary

- KaRIn LR data gives potentially useful measurements of ice sheet surface elevations
- Many phase unwrapping errors remain in Version D, particularly closer to nadir
- ADT is developing methods that could be used in future product versions to resolve some of the unwrapping errors.