

# DEVELOPING PRINCIPLES FOR THE INTER-COMPARISON OF AIRBORNE DELAY/DOPPLER PHASE MONOPULSE RADAR ALTIMETER AND LIDAR MEASUREMENTS OVER SVALBARD LAND- AND SEA-ICE

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## Background

This poster discusses some preliminary work undertaken as part of a project to investigate the potential of a CryoSat SIRAL-like airborne radar altimeter (the JHU/APL D2P Delay/Doppler Phase monopulse) to study Arctic ice masses on Svalbard through an inter-comparison with contemporarily acquired laser altimetric data. The objectives of this project are to:

- Gain a better understanding of the ice mass surface and sub-surface characteristics that lead to a bias between the radar and laser altimeter returns
- Use this understanding to develop techniques for the acquisition of accurate elevation measurements
- Consider the problems that may be experienced by CryoSat when studying smaller ice masses (Svalbard ice caps and glaciers)

This poster discusses some of the techniques developed and results achieved using calibration and test flight data collected over the Wallops Flight Facility runway



Fig.1: NASA P-3 aircraft

## Introduction to the instrument

- The D2P uses Doppler frequency shifts in the signal returning from points away from the minimum radar range to partition the return signal by along-track location. This acts to reduce the size of the effective along-track radar footprint [1]. A second antenna (receive-only) is used to measure the phase difference between the return signal received at the two antenna in order to calculate the cross-track location of the measured range [2]

## Introduction to the mission

- The D2P was flown aboard the NASA P-3 aircraft in conjunction with the ATM 2/3 (Airborne Topographic Mapper) laser altimeters as part of the LaRA (Laser-Radar Altimetry) mission
- On 3<sup>rd</sup> May 2002, the NASA P-3 made two calibration and test flights over the Wallops Flight Facility runway; one at 300 m and the other at 600 m altitude. This was followed by overflights of Svalbard land- and sea-ice during 20<sup>th</sup> – 23<sup>rd</sup> May 2002. Navigation data was provided by the NASA P-3 GPS.

## Methodology

### Delay/Doppler and other pre-Processing

Including:

- Correction for aircraft movement
- Correction for offset between position of D2P and GPS antenna
- Effect on cross-channel phase measurement of aircraft roll

### Retracking

- D2P cross-channel waveforms resampled by factor 50
- Peak power retracking over runway

### Cross-track slope angle

- Calculated from 'maximum likelihood estimate' of cross-channel phase at retracked surface range
- Takes into account effect of antenna gain on observed phase [2]
- Slope angle used to correct the cross-track position of the D2P footprint

### Quality assessment

- Generation of waveform 'descriptor' variables, e.g. location of leading edge (LEP) and trailing edge position (TEP)
- Along-track 'Blunder point' check [3]
- 'Multiple peak' flag
- Calculation of 'leading edge noise'
- Removal of LEP and TEP falling outside certain limits (abnormal or 'no return' check)
- Calculation of phase coherence and effect of coherence on slope angle measurement

### Intercomparison of D2P and ATM

- Identification of all ATM measurements falling within calculated pulse-limited D2P footprint
- Average ATM elevation in footprint weighted by the antenna gain

### References

1. Raney R.K. The Delay/Doppler Radar Altimeter *IEEE Trans. Geos. RS*, Vol. 36, No.5, 1578-1588, 1998.
2. Jensen J.K. Angle measurement with a phase monopulse radar altimeter *IEEE Trans Ant. Prop.*, Vol. 47, No.4, 715-724, 1999.
3. Cudlip W. and Milnes M. Overview of altimeter data processing at the U.K. Earth Observation Data Centre *Int. J. RS*, Vol. 15, No.4, 871-887, 1994
4. Townsend W.F., et al. Satellite Radar altimeters – present and future oceanographic capabilities. In Gower J.F.R. *Oceanography from Space*, Marine Science 13, Plenum Press, 1981
5. Martin T.V. et al Analysis and retracking of continental ice sheet radar altimeter waveforms *J. Geophys. Res.*, Vol. 88, No.C3, 1608-1616, 1983
6. Raney R.K. and C. Leuschen 2002 LaRA 2002 – Data Format Report JHU/APL SRO-02-17

## Results

### 1. Removal of 'junk' data

The success of the quality assessment (QA) routines were tested on poor quality data at the beginning and end of the runway overflights.

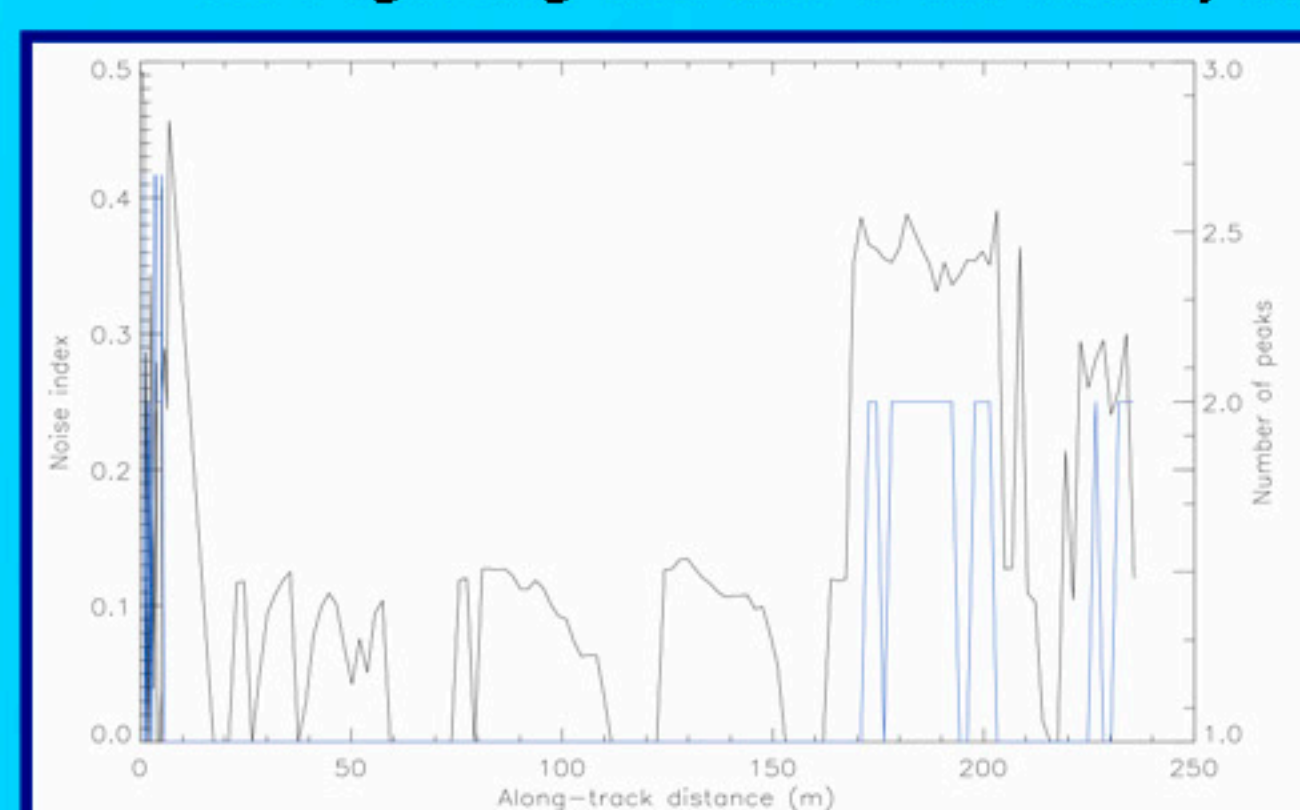


Fig. 2: Noise of leading edge (black) and number of peaks (blue) for the 600 m runway overflight. 3 areas of 'noisy' and multiple peaked waveforms are visible.

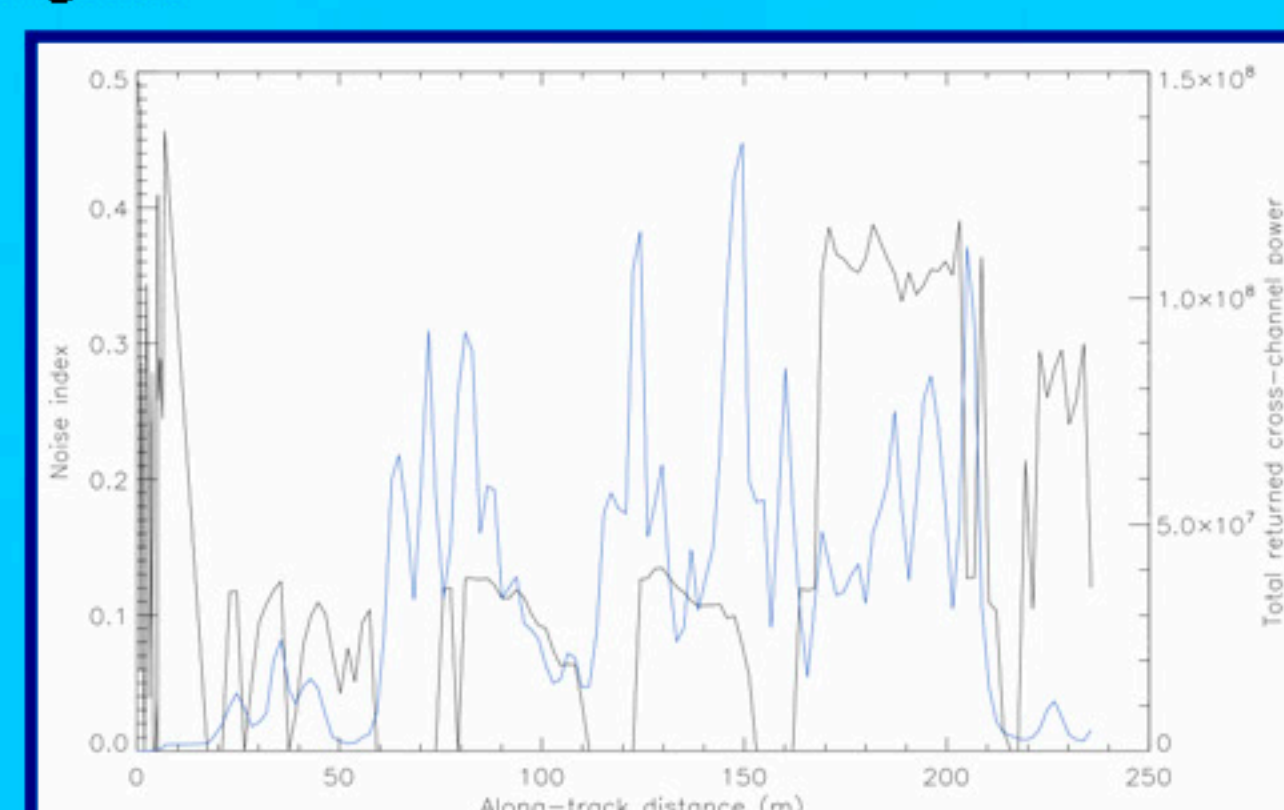


Fig. 3: Noise of leading edge (black) and relative cross-channel total returned power (under waveform) (black) for the 600 m runway overflight. Poor quality data at the beginning and end of the flight is noisy and has a low relative cross-channel total returned power. The 'noisy' area between 160 and 215 m is due to a series of double-peaked waveforms

### 3. Analysis of double-peaked waveforms

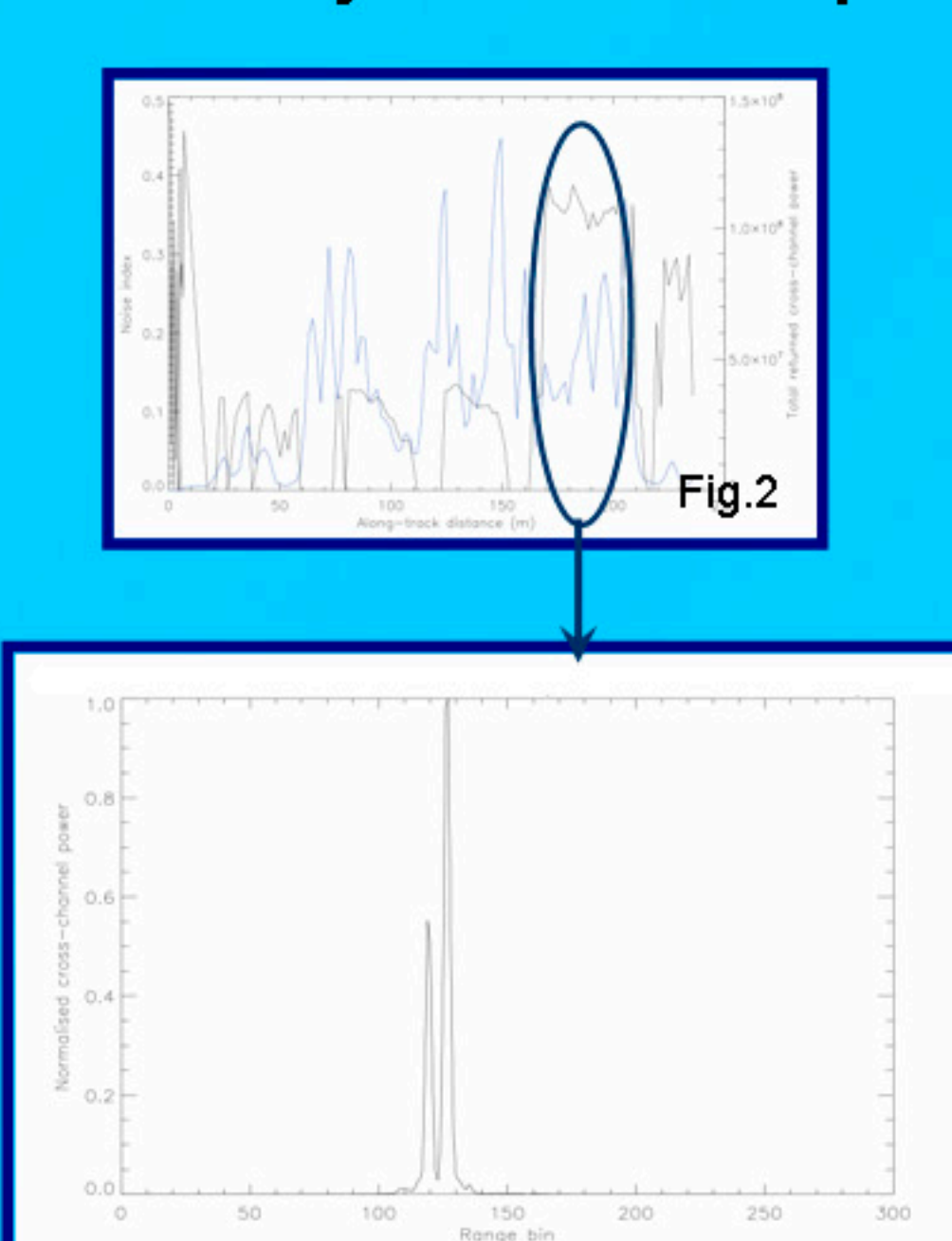


Fig. 5: Double-peaked waveform from 600 m overflight located at 284.53051 lng, 37.932787 lat, 174.56835 m along-track

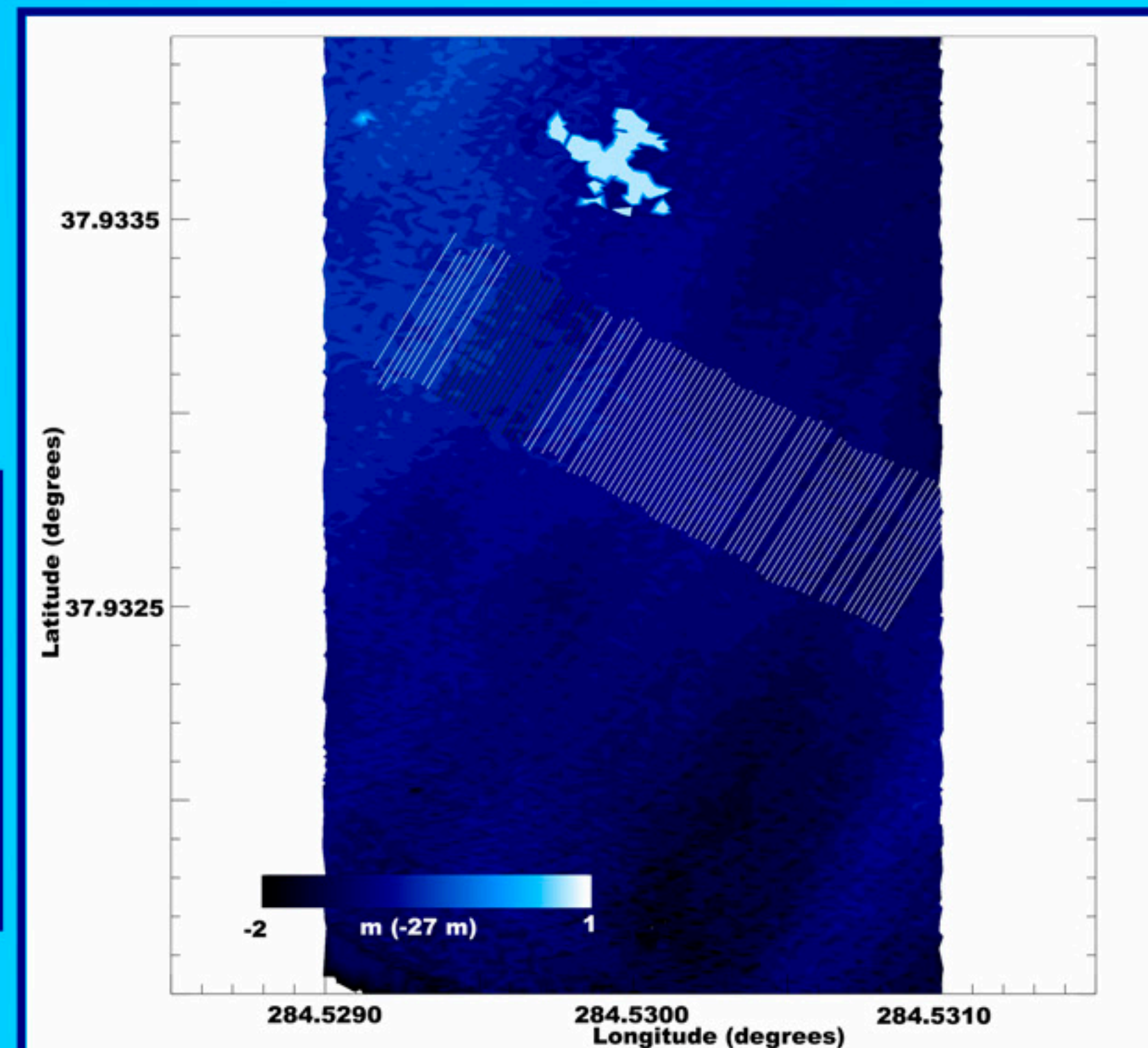


Fig. 6: Contoured ATM elevations (blue) overlaid with width of D2P pulse-limited footprint (white). Double-peaked waveforms are shown in black. Pulse-limited footprint ~30 m, plane is 60 m away

- Around 16% of the retained data from the 600 m runway overflight consisted of double-peaked waveforms
- The 'early' return was on average 1.58 m above the 'later' return. Phase measured at the 'early' peak was large and likely to be incoherent
- Double-peaked waveforms can be caused by surface undulations and may represent two spatially distinct reflecting surfaces within the beam-limited footprint [5]
- A C-130 plane was found to be parked on the runway ~60 m from the location of the D2P track. The pulse-limited footprint of the D2P is around 30 m

### 5. Coherence of phase measurement

- The coherence of the cross-channel phase measurement was calculated on data from the 300 m runway overflight
- The coherence was used to correct for the bias to the phase measurement due to the antenna beam pattern [2]
- The difference between the corrected and uncorrected slope correction was negligible for the overflight (RMS difference of ~0.007 m)

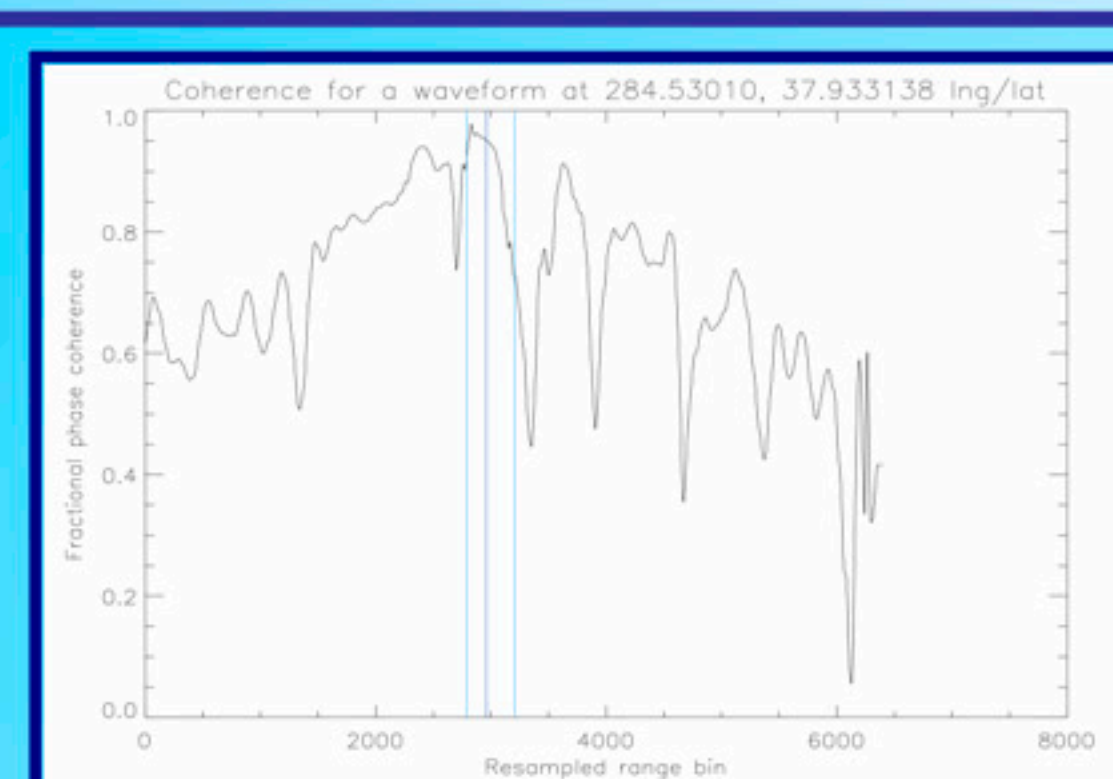


Fig. 7: Coherence for waveform from 300 m runway overflight. LEP and TEP (light blue) and retracked point (dark blue) marked

### 2. D2P and ATM inter-comparison

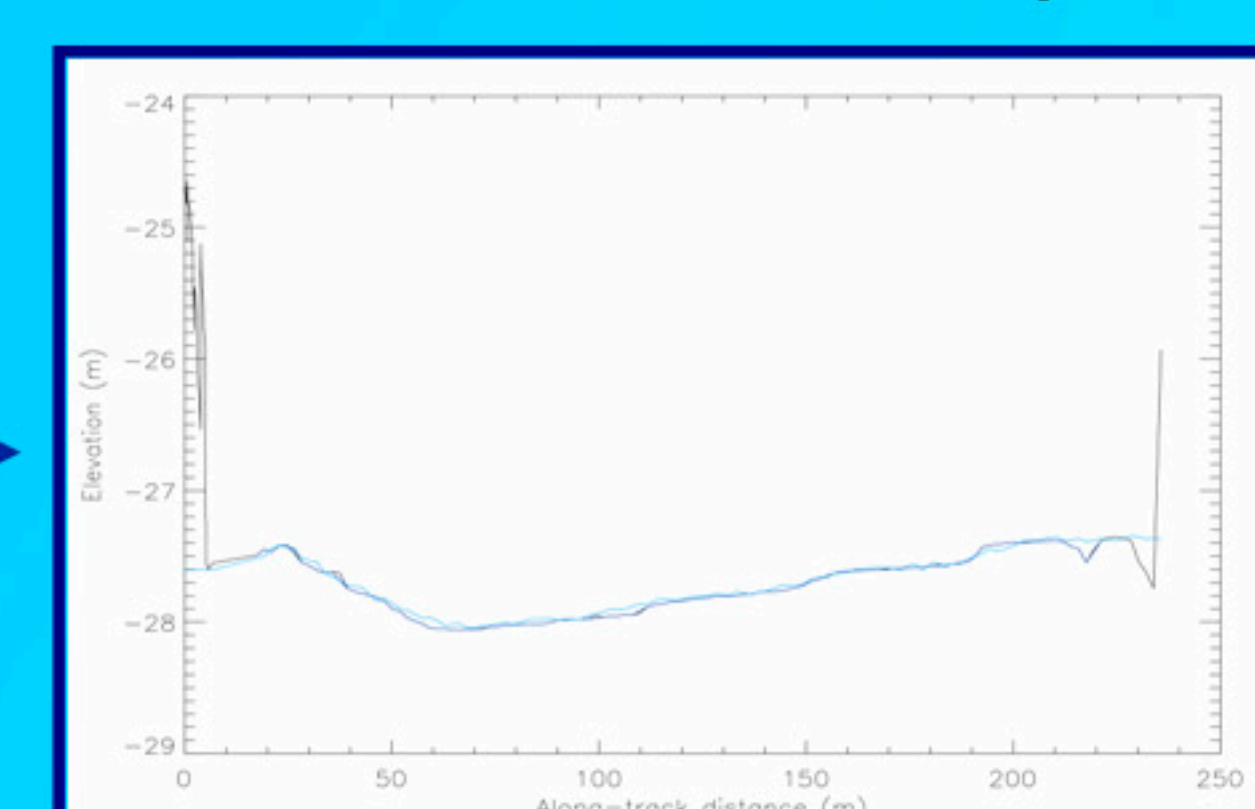


Fig. 4: 600 m overflight showing 'junk' data at beginning and end of track (black). Dark blue line shows data remaining after all QA procedures have been applied. Pale blue line shows ATM measured heights

- For the 600 m overflight, the mean difference between the ATM and D2P data for the 600 m runway overflight was 0.017 m. The RMS difference was 0.0345 m
- The D2P should tend to underestimate surface height due to its 2.5° mispointing angle [4]
- The RMS difference between the ATM elevation measured in each D2P footprint and elevation measurements made by a GPS truck survey was found to be 0.0162 m and the mean difference was 0.009 m.

### 4. Elevation precision issues due to low altitude airborne survey

- The low altitude of the survey compared with the nominal CryoSat altitude means that the D2P data have only imperfect Doppler structure [6]
- Preliminary estimates suggest that the number of looks at each along-track position (reducing the need for averaging and the 'smearing' of the effective footprint along-track) may be somewhat lower than expected for CryoSat

### 6. Future work

- Testing of the performance of the D2P compared to the ATM over Svalbard ice surfaces with different surface- and sub-surface characteristics
- Development of non-physical/non-model based retracking techniques for different surface types.
- Use of the waveform 'descriptor' variables to automatically categorise different types of ice mass surface for appropriate retracking

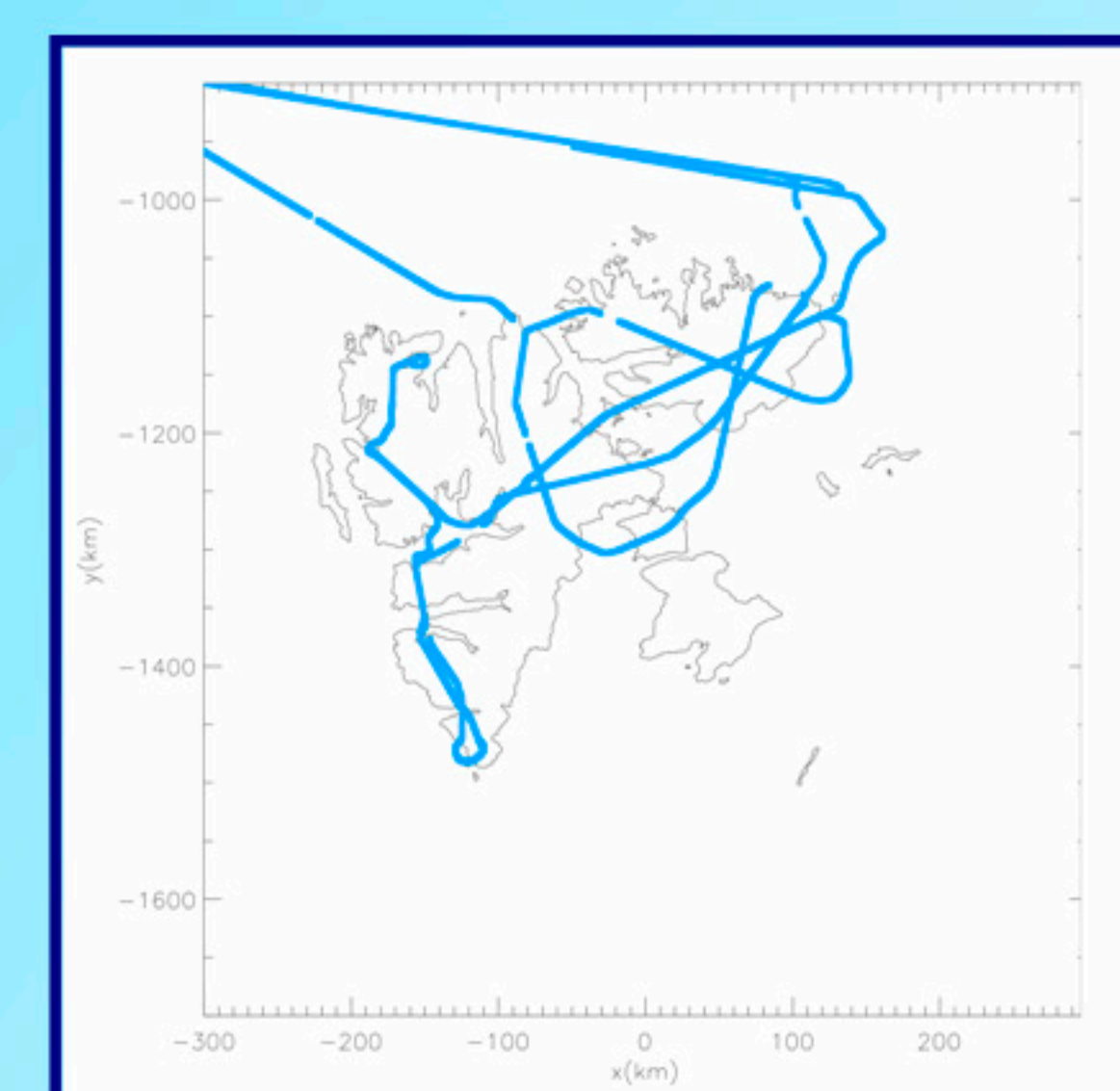


Fig. 8: Tracks flown by the D2P over Svalbard in May 2002