Comment on ‘The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL): Expected Mission Contributions’

Laurence Gray, University of Ottawa, March 2020

The CryoSat SARIn mode has been successful in demonstrating that coherent interferometric radar altimetry is better than traditional radar altimetry in monitoring change in glacial height, particularly at the periphery of the large ice caps and for glaciers and smaller ice caps. The problem remains that often the point-of-closest-approach (POCA) in these areas is at a cross-track look angle greater than that corresponding to a differential phase of -π to +π radians. For the CryoSat baseline this look angle is ±0.54°. A reference digital elevation model (DEM) can be used to help resolve the 2π phase ambiguity but height blunder errors can still exist, particularly with cross-track slopes of greater than 1°. However, if the Ka-band channel on CRISTAL could be made interferometric then there is a straightforward approach which would remove the need for a reference DEM and allow an improved and more reliable mapping solution.

The steps in the process would be:

1. Create three look-angle solutions using the Ku-band SARIn phase χ, and that phase ±2π.
2. Calculate the equivalent Ka-band phase for each of the three Ku-band look angle solutions.
3. Using the three Ku-band look angle solutions calculate the number of 2π’s to be added or subtracted to the (wrapped) Ka phase from the Ka interferometric altimeter.
4. Compare the three possible look-angle solutions from the corrected Ka phase above with the three Ku look-angle solutions. With a normal level of phase noise, one of the comparisons will match much more closely than the other two.

To demonstrate the potential of this approach, I have used the GIMP DEM of Greenland and randomly picked a sub-satellite track (Fig. 1; CryoSat descending pass on April 8, 2012) over the western periphery of the Greenland Ice Cap. The POCA position is calculated for each along-track sampling position allowing an estimation of the look-angles. Independent Gaussian distributed phase noise was added to simulate the POCA differential phase for both frequencies, calculated on the basis of the look-angles. The POCA height range along the line in Fig. 1 is from around 500 m to 2000 m and, as is normal here, many of the POCAs subtend a look-angle greater than 0.54°. The look-angle range is from 0.15° to 1.54°. The Fig. 1 upper plot illustrates the good agreement between the derived solution for the Ku and Ka look-angles. The middle plot illustrates the look-angle errors and shows that, as expected, the Ka error is significantly less than the Ku error. The lower plot illustrates the phase clustering for the three solutions and shows that the correct solution clustered around 0 can be readily picked. The standard deviation of added noise for this plot was 0.08 radians, which I think is larger than the phase noise in the processing scheme I use.

Further work could evaluate the extent to which random and bias phase errors, uncertainty in baseline attitude, and differences in radar response at the two frequencies could limit this approach. Note this approach is not new, two frequencies were used in the first demonstration of airborne repeat-pass interferometry and the movement of a radar reflector was recovered without concern of the multiple solutions due to 2π phase ambiguities (Gray and Marris-Manning, IEEE TGRS, 31, no. 1, pp 180-191, 1993).

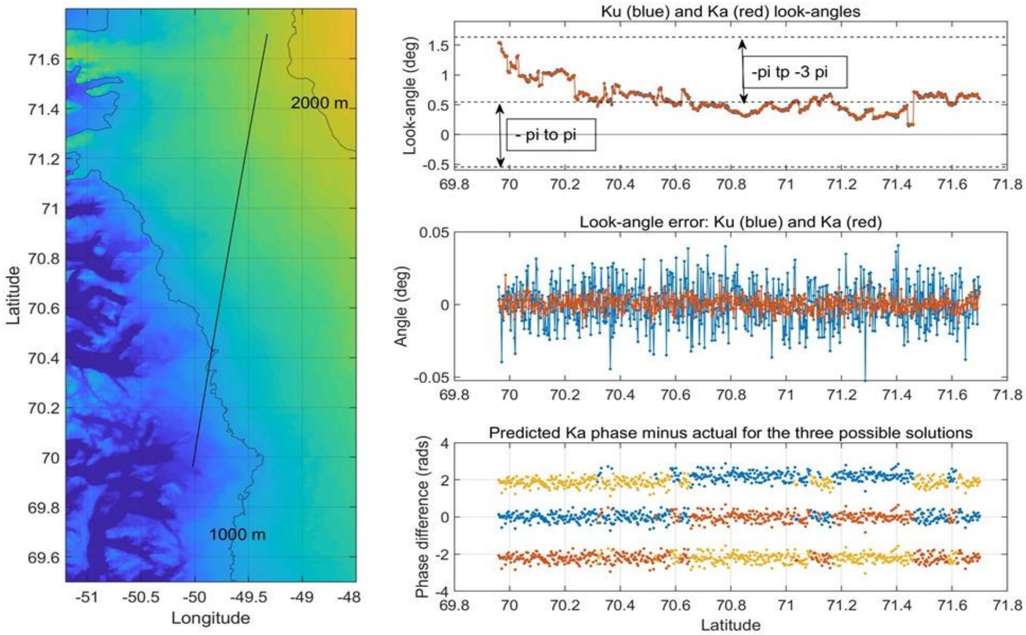

Fig. 1 Left: Position of the track used to calculate the POCA look-angles superimposed on the GIMP DEM. Upper plot: Ku and Ka solutions for the POCA look-angles with (middle plot) the errors (Ka: red and Ku: blue). The lower plot illustrates the phase difference between the Ka-band phase derived from the three possible look-angle solutions and the Ka-band 'wrapped' phase.

The advantages of this approach to the mapping of glacial height and height change are very significant:

1. There is no need for a reference DEM.
2. There will be two solutions, both more reliable than that possible from a single frequency system, therefore, a more precise and accurate result. The Ka result in particular should be more accurate then the Ku.
3. The possibility of serious mapping errors which exist with a single frequency SIRAL-like system will be reduced.
4. The approach can also be used to improve the reliability of swath mode results.
5. Having two SARIn frequencies will also improve the ability to calibrate both systems.

I don't see any insurmountable complications re the satellite hardware. I assume that there will be a spare Ka receiver. I also assume there will be a composite multi-frequency horn feed, this will have to illuminate only part of the two parabolic dishes at Ka-band as there would be the requirement that the cross-track antenna pattern be comparable to that at Ku-band. This may require a re-think of the Ka-band link budget and the Ka burst frequency must adequately sample the azimuth Doppler bandwidth. I hope that the CRISTAL programme is still at a stage where ESA can study this option. If it can be implemented, it will make a huge improvement to the utility of CRISTAL for mapping of change in glacial ice. NASA has made a significant step forward in going from IceSAT-1 to IceSAT-2, ESA can make a comparable step forward in monitoring change in glacial ice around the world with the CRISTAL satellite if this option can be implemented.