TECH NOTE

Subject : **New Mean Sea Surface for the CryoSat-2 L2 SAR Chain**

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1) Introduction

CPOM were asked to supply a new mean sea surface for use in sea ice freeboard retrieval in the second pass of the Baseline-C L2 SAR chain. The mean sea surface used in previous releases of the L2 SAR chain was constructed by UCL in 2004 for use with CryoSat-1. It was anticipated that this first mean sea surface would not be of high enough quality in the far north of the Arctic for accurate freeboard retrieval so running the second pass of the L2 SAR chain was delayed until sufficient CryoSat-2 data had been acquired to build a mean sea surface of sufficient accuracy. This tech note explains how this new mean sea surface was constructed and fulfils QWG Action 5-8.

Please note that the new mean sea surface has been specifically tuned to improve sea ice freeboard retrieval and will not be the ideal one to use for any other applications.

2) Current Mean Sea Surface

The mean sea surface used in all pre-Baseline-C releases of the L2 SAR data was constructed by UCL in 2004 for use with CryoSat-1. Figure 1 shows the different sources of data used and the regions over which they were applied. At the time the most up-to-date radar altimetry data available was from ERS-2 and this only extended as far north as 81.5 degrees latitude. The only option available to fill the region not covered by satellite data from 81.5N to the Pole was to construct a mean sea surface from a model of the geoid and the mean dynamic topography. Figure 2 shows some CryoSat-2 results using the 2004 mean sea surface. The sea level anomaly plot in the region north of 81.5N shows permanent features caused by previously unseen gravity anomalies not present in the geoid and mean dynamic topography models used to construct the mean sea surface. When the mean sea surface is removed from sea and floe surface heights prior to interpolating the sea surface height beneath floe locations in the freeboard calculation, these high frequency signals are not removed. The effect on the final freeboard map can be seen clearly. A new mean sea surface is therefor required to improve freeboard retrievals in the high Arctic.

3) Data Used

To build the new mean sea surface we used two complete 369 day repeat cycles of CryoSat-2 data running from 24th September 2011 to 30th September 2013. We took the L1b SAR and SARIN mode data and computed lead and open ocean elevations; the leads were retracked using a Gaussian fit with an exponential tail to the specular echoes and an OCOG retracker was applied to diffuse open water returns to get the open ocean surface heights. In regions within the LRM mask we used sea surface heights directly from the L2 data. We found that we needed to remove 48cm from the L2 ocean surface elevations to bring them into line with the UCL results. All data comes from the Baseline-B reprocessing run processed partly at ESA and partly at UCL to fill the gaps which were present in the ESA reprocessed dataset at the time. Outside the polar regions the separation of the CryoSat-2 ground tracks becomes rather large so we used the latest CLS 2011 mean sea surface in the mid and low latitudes. We also used the CLS 2011 model in the Southern Ocean down to Antarctica. Full details of how the CLS model was merged with the CryoSat-2 data are given in the next section.

4) Construction of the New Mean Sea Surface

In order to remove the residual high frequency sea level anomaly pattern seen in Figure 2 the first step in our processing was to measure this pattern as accurately as possible. We first took every sea surface height in the two year period and removed the old mean sea surface to give us a dataset of sea level anomalies with respect to the old mean sea surface. We then went through every sea level anomaly measurement in turn and used the surrounding values to interpolate the sea level anomaly at that location using the same operator as is used to interpolate sea level anomaly when computing freeboard. The difference between the original and interpolated sea level anomaly is a measurement of the residual high frequency sea level anomaly pattern seen in Figure 2. We then averaged all these differences on to a 0.05 degree latitude by 0.2 degree longitude grid using a circular averaging operator of radius 5km and applying a 2σ outlier filter. The grid extended from 50 degrees North to 88 degrees North. The gridded high frequency sea level anomalies can be seen in Figure 3. We then added the old mean sea surface height to the average anomaly in each grid cell to make a new mean sea surface including the previously unseen high frequency signal.

Since the 2004 mean sea surface was generated with ERS-2 data mostly from the 1990s, we decided to bring the low frequency part of it into alignment with more recent data. To do this we took all the interpolated sea level anomalies calculated above for a single month of data and gridded them with a coarse Gaussian weighted operator of radius 300km and σ for the Gaussian weights set to 100km. As with the high frequency interpolation a 2σ outlier filter was applied, σ here being the standard deviation of the input heights. The month of July 2012 was chosen for this because there was not much variation in the oceanography over the month and it had the highest number of lead measurements of any month during our two year period of CryoSat-2 data. These gridded values were also added into the new mean sea surface. The gridded low frequency sea level anomalies can be seen in Figure 4. Note that this last step is purely cosmetic and will have no effect on the freeboard obtained with the new mean sea surface. This low frequency component will be completely filtered by the interpolator used to compute the sea surface heights at the floe locations.

The next step was to merge our new mean sea surface with the CLS 2011 model. Figure 5 shows spatially how they were fitted together. The CLS 2011 mean sea surface is supplied relative to the Topex ellipsoid so it was first converted to WGS84 and then interpolated onto a 0.05 degree latitude by 0.2 degree longitude grid. This is the same grid as described above except the grid extends from 80 degrees South to 60 degrees North. The CryoSat-2 mean sea surface was then raised by 67.3cm to account for the range bias which is present in the Baseline-B data but will not be present in Baseline-C. It was then raised by a further 2.2cm to bring it into alignment with the CLS model in the merge zone. Finally the two models were linearly merged together in the region between 50 degrees North and 60 degrees North.

Figure 6 shows the same CryoSat-2 results as Figure 2 but using the new mean sea surface. The problems caused by the poor quality of the old mean sea surface in the high Arctic have been removed.

5) Conclusion

The new mean sea surface using 2 years of CryoSat-2 data considerably improves freeboard retrievals in the Arctic, especially in the far North which has not previously been observed by satellite radar altimetry. The resolution of the new mean sea surface is about 5km which is approximately the same scale as the smallest possible ocean surface feature that can be caused by gravity anomalies given the Arctic Ocean depth. It must again be stressed that this mean sea surface has been specifically tuned to improve sea ice freeboard retrieval and should not be used for any other application. It should also be noted that there is room for improvement in the Antarctic. Figure 7 shows the same results as Figure 6 but for September 2012 in the Antarctic. The new mean sea surface considerably improves the Antarctic results but they could be improved further by the addition of some CryoSat-2 data.

Figure 1: Composition of the original 2004 mean sea surface. Region (A) was built by combining a geoid model with a mean dynamic topography model. Region (B) was constructed using 8 years of ERS-2 data. Region (R) uses an old version of the CLS mean sea surface from 2003. In Region (C) the CLS model is linearly merged with the ERS-2 mean sea surface.

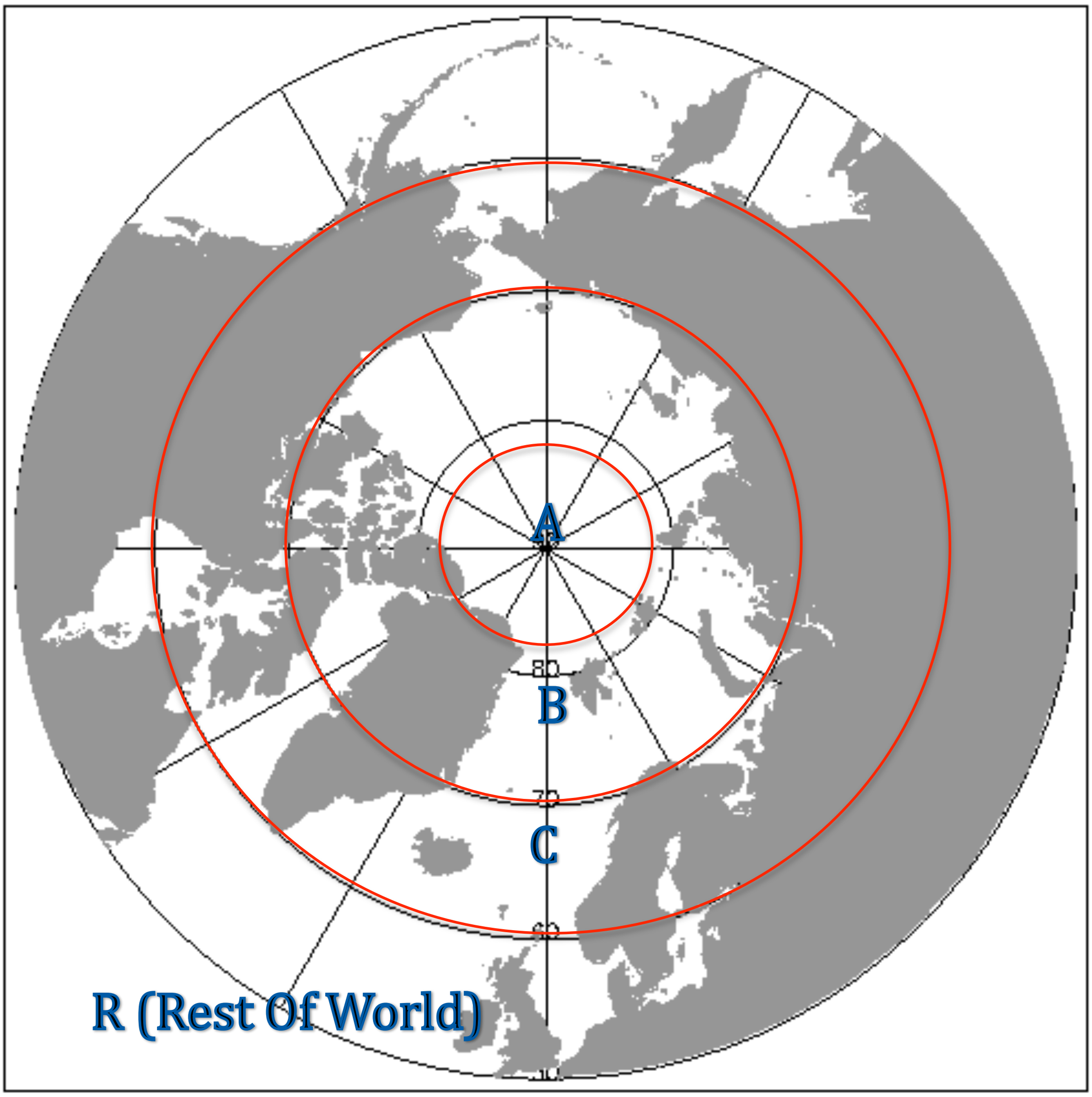

Figure 2: CryoSat-2 sea surface heights and freeboard results using the 2004 mean sea surface. The figure on the left shows the March 2012 sea level anomaly low pass filtered to remove any long wavelength oceanography. The residual high frequency signal seen north of 81.5N is due to previously unseen gravity anomalies not present in the geoid and mean dynamic topography models used to construct the mean sea surface in this region. This signal folds directly into the freeboard map seen on the right.

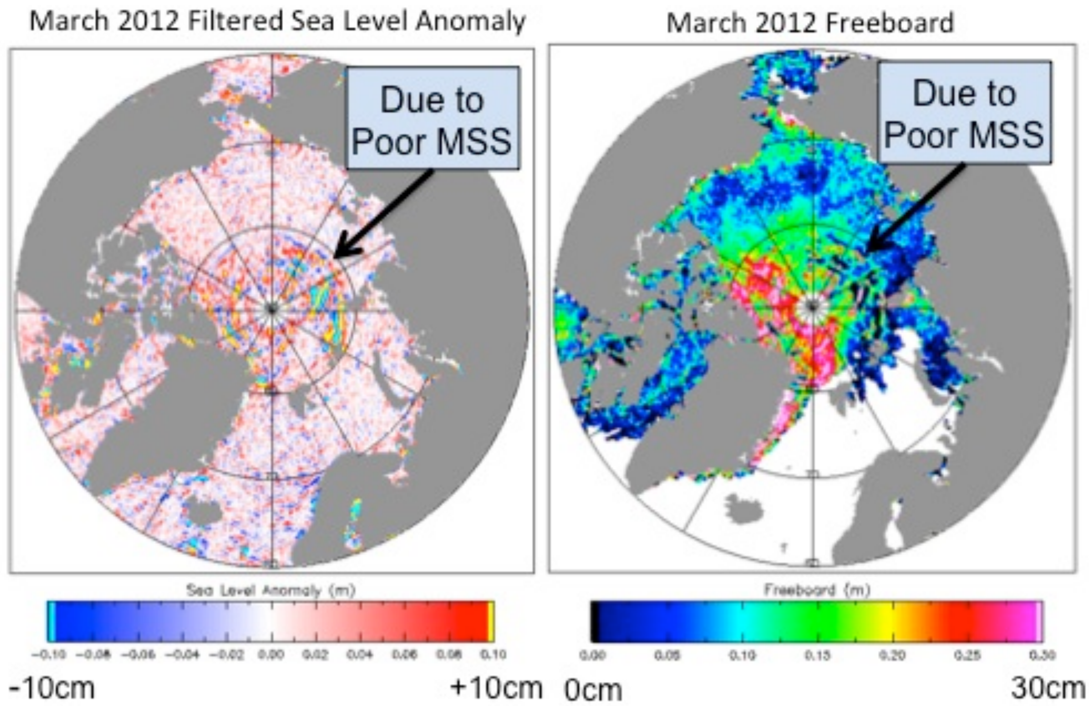

Figure 3: Two years of high frequency sea level anomalies with respect to the old mean sea surface gridded onto a 0.05 degree latitude by 0.2 degree longitude grid using a circular averaging operator of radius 5km. This grid is added to the old mean sea surface to remove the high frequency signal.

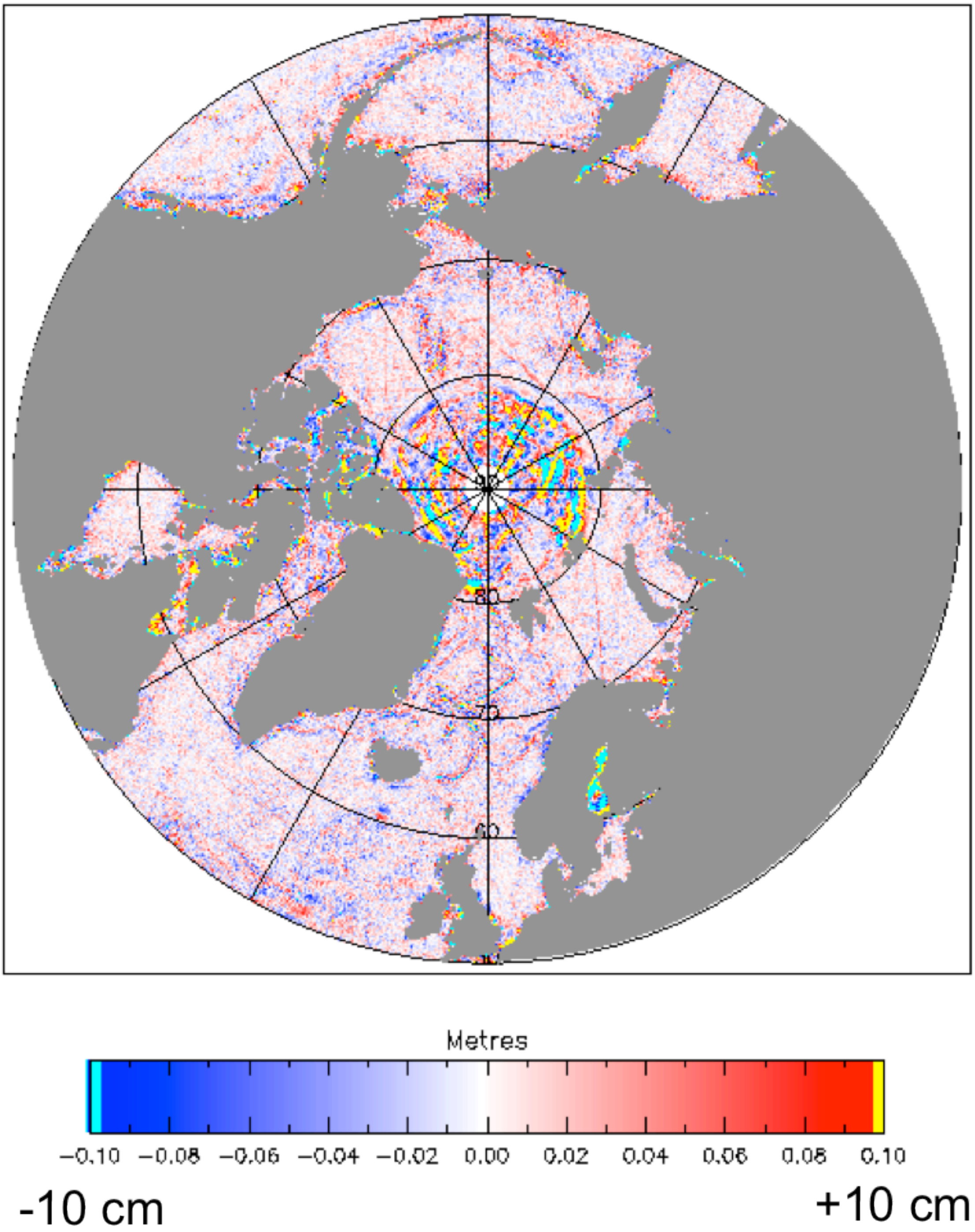

Figure 4: Low frequency sea level anomaly from July 2012 smoothed with a Gaussian weighted operator of radius 300km and σ for the Gaussian weights set to 100km. 67.3cm has been added to account for the range bias which is present in the CryoSat-2 Baseline-B data.

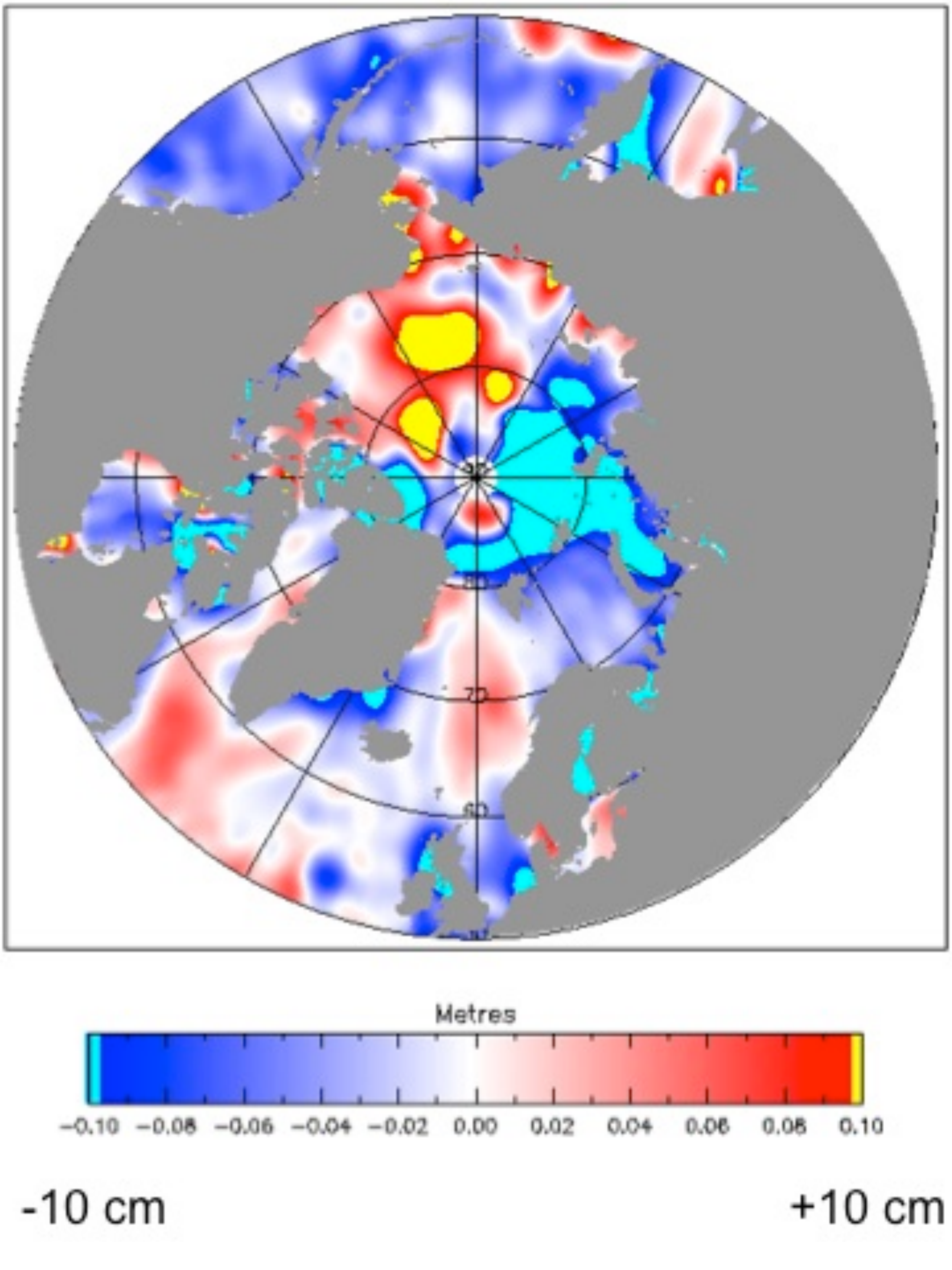

Figure 5: Composition of the new mean sea surface. Region (A) contains the mean sea surface built from 2 years of CryoSat-2 data as described in Section 4. Region (R), the rest of the world, is covered by the CLS 2011 mean sea surface. In Region (C) the CLS model is linearly merged with the CryoSat-2 mean sea surface.

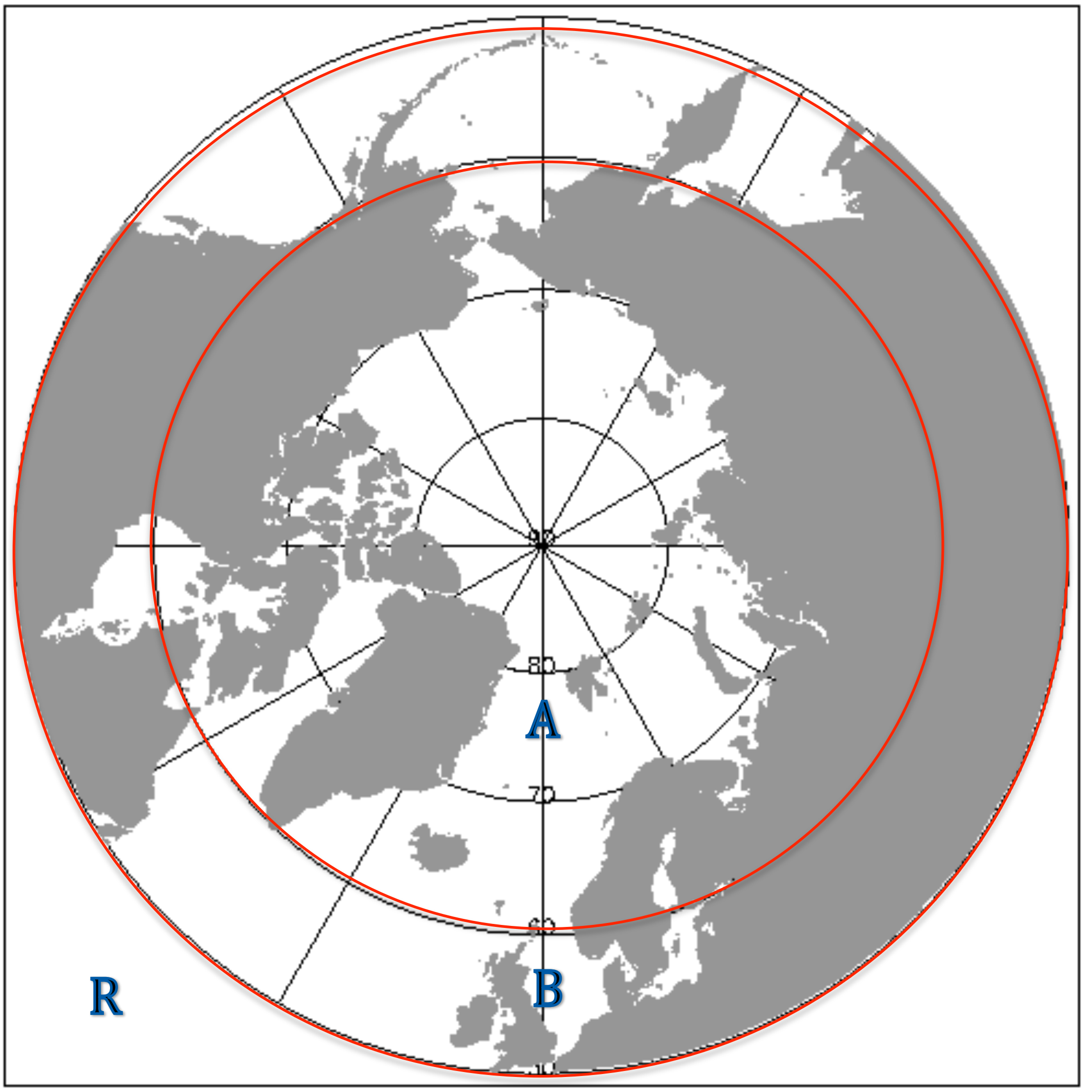

Figure 6: The same results as in Figure 2 but using the new mean sea surface. The problems caused by the poor quality of the old mean sea surface in the high Arctic have been removed.

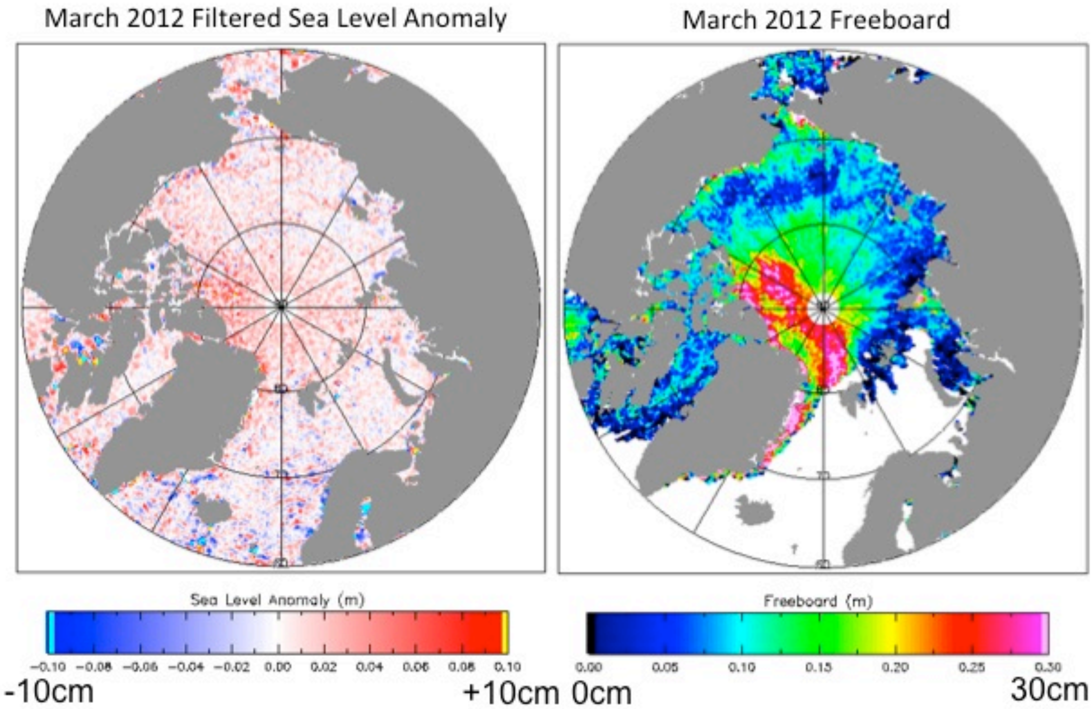

Figure 7: Same results as Figure 6 but for September 2012 in the Antarctic. The new mean sea surface considerably improves the Antarctic results but they could be improved further by the addition of some CryoSat-2 data.