1. Summary of Lecture at CAW February 2017: SAR Altimetry Processing for Open Ocean Sea Level Monitoring/SLCCI Multi Mission Datasets

This Lecture has two main aims.

First aim is to we address the Sea Level Monitoring over the complete altimetric mission period showing applications of the ESA Sea Level Climate Change Initiative (SLCCI) database which is a dataset very suitable for sea level change studies.

Second aim is to outline the advantages and the possible improvement in sea level change analysis made possible by the new SAR methodology on open sea, which was treated in the Tuesday lessons this week. We discuss here some further details on the dedicated processing for open Sea, the novelty in SAR for sea level monitoring, improvement assessment / validation and finally few results.

1. 1 Sea Level Monitoring

Satellite altimetry has here a very important contribution to sea level monitoring. The ocean is the largest storage of energy and the largest water reservoir. Monitoring of sea level change is therefore of primary importance for understanding climate and water cycle changes. Observation of past sea level change before the altimetric era rely on tide gauges since middle of the 19th Century. Since the few long records available the error bars of the derived sea level are much larger than for the altimetry era.

We also know that both the annual global mean surface temperature (0.6 degrees since 1950) and that the CO_2 concentration have increased since middle of the 19th century. Their increase is very much correlated to sea level change.

There is no doubt that Climate is changing and that we are contributing to this change. The recently published 5th Assessment Report of the Intergovernamental Panel on Climate Change (IPCC) (1) confirms a warming of the climate system which has an impact on all the components of the water cycle (atmosphere & ocean are warming, ice and glaciers are melting, sea level is rising), (2) explicitly suggests them to have an anthropologic component and (3) foresee social impacts. Satellite geodetic observations can significantly contribute to the :

(a) measuring, (b) understanding of processes, (c) assessment of risks related to changes in water cycles caused by climate change.

Satellite Geodetic Observations allow to quantify the changes with a unprecedent accuracy thanks to the (a) variety of the measurements available, (b) their precision and accuracy and to (c) their global coverage. By integration of the various measurements we can better understand the causes and attempt a closure of the water budget. Satellite altimetry provides a geometric information, which is just one the 3 geodetic observables in Geodesy, the other being Earth orientation, Gravity and geoid. Satellite gravimetry provides information on mass change. The third component of sea level is the steric component that can be derived by Argo data (temperature and salinity at depth).

The CCI database provides data with homogeneous correction. Only sea level information is available, that is only sea surface height (SSH) and no significant wave height (SWH) or wind (U10) parameters. There are two type of data available: the Fundamental Climate Data Record (FCDR), along-track data resolution of 1Hz (distance 6km), Essential Variable Climate (ECV), gridded data ¼ x ¼ degree, which includes Monthly averaged Sea Level Anomalies (SLA) and Mean Sea Level changes indicators. The indicators are : Global trend, Grid of trends, Grids of

Amplitude, Semi-annual periodic signals. Data from all missions are included, data are in netcdf format. The actual version 2.0 show very good results both at global and regional scale. Data have been used within the SLCCI project in a Water Mass Budget estimation (ECV) and in in-situ validations against geodetic data (FCDR and ECV) to assess regionally the quality of the data. Examples are give for analysis in Mediterranean Sea and Bay of Bengal.

1.2. SAR altimetry processing in Open Sea

SAR Satellite altimetry has here a very important contribution to sea level monitoring. The Synthetic Aperture Radar (SAR) mode in CryoSat-2 is expected to provide higher resolution long-track and altimeter-derived parameters of higher accuracy, thanks to the reduced along-track footprint. In CryoSat-2 SAR model covers only selected regions of the world. We have shown results in the German Bight region, where model and in-situ data are available for validation (Fenoglio-Marc et. al, 2015, 2015s). Here we regionally quantify the skills of CryoSat-2 SAR altimetry at different time and special scales by comparing SAR altimetry and conventional altimetry in open ocean, defined as the locations having distances to coast larger than 10 km. The validated geophysical altimeter parameter is sea surface ellipsoidal height (SSH). Results are from Fenoglio et al., 2015, with SAR from GPODC and PLRM from RADS. The precision of 1Hz data are in SAR: 0.9 cm, 6.6 cm, 6 cm/s (SWH@2m), the accuracy of 1Hz SAR is 7 cm, 14 cm, 1.3 m/s. The cross-validation of PLRM and SAR gives no bias, STDD 3.1 cm, 21 cm, 0.263 m/s (SSH,SWH,U10).
More recent results using the GPODC (Table 1) options and the TALES retrackers for PLRM (Dinardo et al., submitted, Buchhaupt et al., sub) shows better agreement for SSH and SWH with the TALES retracker for PLRM, with STDD 2.6 cm, 17.5 cm, 0.264 m/s. In open ocean the GPODO and GPODC products are very similar, with STDD of 5 cm. The precision remains unchanged. Also the histgram of SAR and PLRM show a good agreement in open ocean. The in-situ analysis shows STDD of around 9 cm in SAR and 11 in PLRM.

GPODO/SAM2	**Common options in GPOD**	**GPODC/SAM+**
	20 Hz	
	Hamming in coastal only	
	Exact beam forming approximated	
	FFT Zero-Padding	
128 range bins (radar receiving window)		256 range bins (radar receiving window)
	No antenna path correction	
	LUT	
SAMOSA2 (SAM2)		SAMOSA+ (SAM+)

Table 1: GPOD options used in GPODO and GPODC

References

Buchhaupt C., Fenoglio-Marc L., Dinardo S. (submitted). Retracking CryoSat-2 data with pulse limited processing, AdSR special session CryoSat-2

Dinardo S., Fenoglio-Marc L. Buchhaupt C., Becker M., Scharroo R., Fernandez J., Benveniste J. (submitted). CryoSat-2 performance along the german coasts, AdSR special session CryoSat-2

Fenoglio-Marc, L., S. Dinardo, R. Scharroo, A. Roland, M. Dutour Sikiric, B. Lucas, M. Becker, J. Benveniste, R. Weiss (2015). The German Bight: A validation of CryoSat-2 altimeter data in SAR mode, Advances in Space Research, 55, 11, 2641-2656, 2015. http://dx.doi.org/10.1016/j.asr.2015.02.014

Fenoglio-Marc L., R. Scharroo, A. Annunziato, L. Mendoza, M. Becker, and J. Lillibridge (2015a). Cyclone Xaver seen by geodetic observations, Geophys. Res. Lett., 42, 9925–9932, http://dx.doi.org/10.1002/2015GL065989.

Fernandes M. J., Lázaro C. (2016). GPD+ Wet Tropospheric Corrections for CryoSat-2 and GFO Altimetry Missions, Remote Sensing 2016, 8(10), 851, 2016. http://dx.doi.org/10.3390/rs8100851

Passaro, M. et al. (2015). ALES: A multi-mission adaptive subwaveform retracker for coastal and Remote Sensing of Environment, 4 April, pp. 173-189, 2014.

Scharroo, R. (2016). , RADS RDSAR Algorithm Theoretical Basis Document, Version0.3, CP4O Project Report, 2014 - updated May 2016. URL: http://www.satoc.eu/projects/CP4O/docs/tud_rdsar_atbd.pdf