Improving Sea Level Record in Arctic using Envisat Altimeter Measurements

P. Thibaut, JC. Poisson, D. Hoang
Collecte Localisation Satellite, Toulouse, France, pthibaut@cls.fr

G. Quartly, A. Kurekin
Plymouth Marine Laboratory, Plymouth, UK

J. Benveniste
ESRIN/ESA
The Arctic is an important component of the climate system whose exact influence on ocean circulation is still poorly understood. The Arctic is also very sensitive to global warming and some direct consequences like ice melting are particularly visible.

In this context, extending the knowledge of the sea level variability as far as possible in the Arctic Ocean is a valuable contribution to the understanding of rapid changes occurring in this region.

In the frame of the ESA Climate Change Initiative (Sea Level ECV), Collecte Localisation Satellite and Plymouth Marine Laboratory have been funded by ESA to improve the Sea Level closure budget in particular estimating the Sea Level Anomaly over arctic iced regions.

10 years of Envisat/RA-2 altimeter data have been reprocessed to deliver an improved long MSL record in Arctic.
3 main steps:

1) Floe / Lead / Ocean discrimination
   - Editing criteria
   - Waveform peakiness
   - NN classification on waveform shapes
   - Validation wrt NSIDC
   - Validation with TerraSARX images

2) Sea Level Height estimation with waveform retracking
   (over water surfaces – leads or open water)

3) Sea Level Editing/Smoothing/Mapping
**Step 1 : Floe / Lead / Ocean discrimination**

Two competing techniques have been implemented to identify leads on which sea level will be computed:

**Lead filtering (PML):**
- rise rate of the leading edge
- strength of echo signal ($\sigma_0$)
- position of tracking bin
- power in echo tail
- discrepancy with model waveform

**Neural Network for waveform classification (CLS):**
(supervised classification)
Waveform classes for the Neural Network

- 12 classes are defined to describe the main observed waveforms.
- Knowing that the classification is performed on all ENVISAT measurements, it is important to define a class not only for waveform shapes of interest but also for all other waveforms.

<table>
<thead>
<tr>
<th>Class</th>
<th>Waveform Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brownian</td>
<td></td>
</tr>
<tr>
<td>Brown + pic</td>
<td></td>
</tr>
<tr>
<td>Multi peak</td>
<td></td>
</tr>
<tr>
<td>Distorted Brownian</td>
<td></td>
</tr>
<tr>
<td>Peaky</td>
<td></td>
</tr>
<tr>
<td>Shifted</td>
<td></td>
</tr>
<tr>
<td>2 Leading Edge</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
</tr>
</tbody>
</table>
Ocean measurements are identified by class 1.

Measurements affected by sea ice are mainly identified by classes 4, 6 (and a class 5 at borders). The different classes correspond to different types of surface backscattering.

Peaky echo (corresp. to leads) are identified by class 2.

The sea ice is detected and discriminated from ocean.
Evolution of sea ice types and leads with time

Class 4 ➔ sea ice waveforms with high backscattering

Class 2 ➔ leads / peaky waveforms
Seasonal variations

- Sea ice extent is maximum in February / March, the minimum is in September / October.
- The proportion of peaky waveforms strongly increases during the sea ice melting and decreases as the freeze-up begins.

**Ocean waveforms (class 1)**
**Peaky waveforms / leads (class 2)**
**Sea ice waveforms (classes 4, 5 and 6)**

![Percentage of Sea Ice over the Arctic Ocean above 60 degrees](image)

- Brownian waveforms / Ocean (class 1)
- Peaky waveforms / Leads (class 2)
- Ice waveforms (classes 4, 5, 6)

---

P. Thibaut & al, Improving Sea Level Record in Arctic using Envisat Altimeter Measurements, EGU Wien, April 2015

Courtesy Dave McAdoo, 2010
Very good consistency with the same proportion of leads except one region at very high latitudes (red circle)

(All leads identified by PML are identified by CLS)
Patterns of leads concentration logically evolve with sea ice melting. The maximum proportion of leads is reached in June/July when melting is maximum.

Leads are always found in all seasons but not in all regions.

Issues to extend sea level estimates in certain regions/periods...
Step 2 : Range estimation - retracking

Different retrackers have been implemented based on models able to adapt from ocean waveforms (Brown model) to waveforms obtained over leads and ice floes (in addition to the classical sea ice retracker).

PML and CLS retrackers are based on the same approach → continuity between ocean and leads (no biases)

\[
p(t) = P_N + \frac{1}{2} A \left[ 1 + \text{erf} \left( \frac{t-t_0 - F\sigma^2}{\sqrt{2}\sigma^2} \right) \right] \exp \left[ -F(t-t_0 - \frac{F\sigma^2}{2}) \right]
\]

where \( F = \left( \frac{4}{\gamma} + \alpha \right) \frac{c}{h(1+h/R)} \).

\( \alpha \) – scattering term

P. Thibaut & al, Improving Sea Level Record in Arctic using Envisat Altimeter Measurements, EGU Wien, April 2015
The off-nadir correction

The echo returned back by leads at some angle can produce hyperbolic signatures. This is known as off-nadir effect that adversely affects retracking accuracy of the neighbour waveforms.

A new method for off-nadir correction has been developed at PML

2D waveforms, corrected for tracker range and AGC

The off-nadir correction

Waveforms

Correction for AGC

Estimation of across track peakiness

Detection and flagging waveform anomalies

Floe/Lead/Ocean Discrimination

The off-nadir filtering
The off-nadir correction
SLA monthly gridded products

- Monthly SLA gridded maps have been produced for the entire period of Envisat.

- They have been computed from Envisat/RA-2 measurements over ocean and leads after editing/filtering (hooking effects for example).
Similar work has been undertaken with Altika measurements (CNES Peachi project)

- Saral/AltiKa altimetry mission has been launched in 2013
- Works in Ka band on the historical Envisat tracks
- Better spacial sampling of the AltiKa measurements (40Hz along track, reduced waveform footprint)
- Similar SLA mapping over the arctic regions has been implemented producing SLA gridded maps.
Conclusions

- A discrimination of ocean / ice floe / leads has been implemented from RA-2 waveforms (based on a Neural Network or editing approach) and run over the entire ENVISAT period.

- Waveforms identified as coming from leads have been retracked and the results filtered to derive

- The quality of SSH measurements has been improved by improving:
  - the accuracy of classification into leads, floes and open ocean
  - the properties of retracker applied to each class

- Monthly gridded Sea Surface Height maps have been produced over the Envisat / RA-2 period (2002 – 2012)

- Comparison with existing products (from DTU) will be done in the frame of the CCI

- A similar processing has been developed from AltiKa data in the frame of the CNES PEACHI project with Ka-band advantages: lower microwave penetration, better precision, higher sampling rate, …
Thank you for your attention