Recent Progresses in Coastal and Open Ocean Altimetry and their Possible Applications for Circulation Studies

Passaro, Marcello (1); Boergens, Eva (1); Cherreskin, Teresa K (2); Dettmering, Denise (1); Gille, Sarah (2); Gomez-Enri, Jesus (3); Müller, Felix L (1); Piccioni, Gaia (1); Quartly, Graham D (4); Schwatke, Christian (1); Smith, Walter HF (5)

1: Technische Universität München, Germany; 2: Scripps Institution for Oceanography, USA; 3: University of Cadiz, Spain; 4: Plymouth Marine Laboratory, UK; 5: National Oceanic and Atmospheric Administration, USA

22.02.2019
Introduction

- Coastal Altimetry data (last ~25 km, but also shelf seas in general) suffer from signal perturbations, problems in geophysical corrections, poor knowledge of tides and mean sea surface -> lower precision and lower accuracy

- Tremendous improvement in the last decade means availability of dedicated reprocessing spanning all the altimetry era and better performances from new missions (AltiKa, Cryosat-2, the Sentinels)

- Several of these improvements have also an impact on open ocean data

- Here some progresses (from our own research) that can be useful for coastal circulation studies… and some open questions

- Many more progresses, such as in the Wet Tropospheric Correction, attend CAW for more news
Summary

1) De-noising Satellite Altimetry

2) Improving the accuracy: tide models and coastal mean sea level / dynamic topography

3) Improving the synergies for coastal/regional observing systems
De-noising satellite altimetry: SAR missions

(geostrophic) currents are obtained using the derivative of sea level data. The higher the noise, the stronger the filtering.

SAR precision improvement -> 0.3 cm w.r.t. Envisat at 1 Hz

Passaro et al. (2016), ASR
De-noising satellite altimetry: Sea State Bias

Improvement of precision of 30% for standard altimetry (including high frequency data)

To understand the physics of SSB, we need to decouple it from correlated errors of SLA-SWH estimation, which are contained in any empirical SSB model.

Is a global model representative enough for coastal altimetry? e.g. the parametric Fu-Glazman model, recomputed at regional scale, significantly decreases noise and its dependency on wave height.

Passaro et al. (2018), RSE Quartly et al. (2019), IEEE TGRS
De-noising satellite altimetry: Sea State

„Exploiting the link between currents and wave height variability may be a powerful way to diagnose the current variability at scales not accessible from sea level measurements“ Ardhuin et al., 2017, JGROceans

ESA’s Sea State CCI Initiative effort in progress to improve precision in SWH.
High-rate noise: Decrease of ~60% in terms of variance (median values of the std in the 1Hz records are shown)

Several algorithms working towards this objective. Examples are WHALES from DGFI-TUM (in the example), Adaptive Numerical Retracker from CLS
Summary

1) De-noising Satellite Altimetry

2) Improving the accuracy: tide models and coastal mean sea level / dynamic topography

3) Improving the synergies for coastal/regional observing systems
Improving the accuracy: tide models

What happens when you base your tidal model on coastal altimetry instead of standard data? [Example with EOT11a, Jason-1 & Jason-2]

“In the global average, results based on ALES are superior to results based on SGDR for every constituent.”

Piccioni et al. (2018), RS

<table>
<thead>
<tr>
<th>Constituents</th>
<th>$RMS_{ALES}$ (cm)</th>
<th>$RMS_{SGDR}$ (cm)</th>
<th>$\Delta RMS$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2</td>
<td>8.0</td>
<td>8.2</td>
<td>2.4</td>
</tr>
<tr>
<td>N2</td>
<td>2.1</td>
<td>2.3</td>
<td>8.7</td>
</tr>
<tr>
<td>S2</td>
<td>3.5</td>
<td>3.7</td>
<td>5.4</td>
</tr>
<tr>
<td>K2</td>
<td>1.4</td>
<td>1.6</td>
<td>12.5</td>
</tr>
<tr>
<td>K1</td>
<td>2.1</td>
<td>2.2</td>
<td>4.5</td>
</tr>
<tr>
<td>O1</td>
<td>1.4</td>
<td>1.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Q1</td>
<td>0.8</td>
<td>1.1</td>
<td>27.3</td>
</tr>
<tr>
<td>P1</td>
<td>1.2</td>
<td>1.4</td>
<td>14.3</td>
</tr>
</tbody>
</table>
Improving the accuracy: mean sea surface

Bormans and Garret (1989), Ross et al. (2000) and Stanichny et al. (2005) reported that in normal conditions there is a lower sea level on the northern side of the Strait, respectively.

Average SLA using valid ERS2+Envisat cycles…

…using MSS DTU15

…using locally recomputed along-track MSS from ALES
Improving the accuracy: mean sea surface

An ad-hoc local along-track MSS (based on ERS2/Envisat using the ALES retracker) gives a more realistic cross-strait variability in the Strait.

This improves the analysis of the oceanographic processes in the area: inversion of Absolute Dynamic Topography (SLA+Local MDT) slope due to Ekman Transport during strong easterlies.
Summary

1) De-noising Satellite Altimetry

2) Improving the accuracy: tide models and coastal mean sea level / dynamic topography

3) Improving the synergies for coastal/regional observing systems
Spatial scales

From the Altimetry point of view: „spectral bump“ (spectral variation in slope of 20-70 km spatial scales) is problem in signal-to-noise ratio.
Can be reduced with improved retracking or Delay-Doppler missions (…but probably only on a global average)

Smith et al., OSTST 2017

Raynal et al., OSTST 2016
Spatial scales

From ADCP: Strong ageostrophic contribution starts at ~70km scale

From Altimetry: change in slope starts at ~70km, S3 does not improve SNR

Chereskin et al., accepted in JGR

Limit for geostrophic analysis set by regional ocean dynamics rather than altimetry resolution? Waiting for SWOT…

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM) | Technische Universität München
Geostrophic Currents – blending with models

Limitations:
- Sparse spatial coverage due to satellite orbits
- Data gaps in polar areas due to sea ice

Solution:
- Combining the observations with an ocean model (FESOM) to fill the data gaps

Goals:
- Bridging periods and areas, where Altimery is missing
- Spatio-temporal consistent representation of DOT and geostrophic currents

Study area: northern Nordic Seas (Greenland Shelf circulation) and sea-ice coverage between 2003-2009 (Müller et al., 2019)

Multi-mission satellite gridded DOT and absolute geostrophic velocity provided by CMEMS for 2009-Apr-15.
Geostrophic Currents – blending with models

- Consistent high-frequency along-track sea surface heights, but irregular sampling
- SSH – geoid model $\rightarrow$ DOT

- Model includes Sea-Ice component reproducing the major sea-ice drift patterns
- Differential water heights w.r.t ocean bottom topography $\rightarrow$ ~DOT

Poster: 14
Felix L. Müller et al.

Combined-DOT

Combined-GC
Conclusions/Recommendations

- Higher precision and better accuracy can be reached with dedicated approaches in „problematic“ areas (coastal zone, shelf seas, high latitudes)

- Coastal altimetry is a part of a coastal observing system including in-situ data and circulation models. To understand the circulation in areas of high variability (and to interpret SWOT…) we need synergies

- Dedicated regional studies can exploit advanced pre-and-post-processing techniques that are not yet the standard in the available products. Collaboration between „expert altimetry users“ and oceanographers can be achieved with pilot projects that start from lower levels of processing to improve our understanding of the ocean dynamics

OUR RESEARCH:
- Quartly G.D., Smith W., Passaro M.: Removing Intra-1-Hz Covariant Error to Improve Altimetric Profiles of $\sigma^o$ and Sea Surface Height. IEEE Transactions on Geoscience and Remote Sensing, 1-12, 10.1109/tgrs.2018.2886998, 2019
- Smith W.H.F., Leuliette E.W., Passaro M., Quartly G., Cipollini P.: Covariant errors in ocean retrackers evaluated using along-track cross-spectra. OSTST Meeting 2017, Miami, USA, 2017-10-23
- Müller F., Wekerle C., Dettmering D., Passaro M., Bosch W., Seitz F.: Dynamic Ocean Topography of the northern Nordic Seas: a comparison between Satellite Altimetry and Ocean Modelling (accepted in The Cryosphere)
- Chereskin T.K., Rocha C.B., Gille S.T., Menemenlis D., Passaro M.: Characterizing the transition from balanced to unbalanced motion in the Souther California Current (under review)
SPARE SLIDES
De-noising satellite altimetry: Sea State

“Exploiting the link between currents and wave height variability may be a powerful way to diagnose the current variability at scales not accessible from sea level measurements“ Arduing et al., 2017, JGROceans

![Graphic showing scatter plot]

Correlation = 0.64
STD = 1.70 m
Slope = 0.83
Bias = -0.03
Entries = 28047
De-noising satellite altimetry: Sea State

“Exploiting the link between currents and wave height variability may be a powerful way to diagnose the current variability at scales not accessible from sea level measurements” Arduing et al., 2017, JGROceans

Correlation = 0.93
STD = 0.61 m
Slope = 0.93
Bias = -0.06
Entries = 27900