SUMMARY OF 3rd COASTAL ALTIMETRY WORKSHOP[1]

The Workshop took place on 17-18 September 2009 in Frascati, Rome, Italy being hosted by the European Space Agency (ESA) with support from the National Oceanography Centre Southampton (NOCS), the Centre National d'Etudes Spatiales (CNES), the National Oceanic and Atmospheric Administration (NOAA) and the Consiglio Nazionale delle Ricerche (CNR).

WORKSHOP BACKGROUND

The first workshop in this series was held in Silver Spring, U.S.A. in February 2008 and charted the course for achieving a greater improvement of satellite altimetry and promoting its use in the Coastal Zone.

Please see the summary of the first workshop at:
http://www.coastalt.eu/pisaworkshop08/supplementary-EOS-WS-first-coastal-altimetry-30-sep-08.pdf

The second workshop, hosted in Pisa in November 2008, represented a consolidation of the rapid progress made in the field, also thanks to projects such as COASTALT (funded by ESA) and PISTACH (funded by CNES).

Please see the summary of the second workshop at:
http://www.coastalt.eu/pisaworkshop08/supplementary-EOS-WS-second-coastal-altimetry-30-June-09.pdf

WORKSHOP FOCUS

The 3rd Coastal Altimetry workshop was designed to review the latest advances in retrieving altimeter data in the Coastal Zone and to strengthen the links between the coastal altimetry community and the wider range of users, including scientists and those responsible for data integration. Scientific contributions were solicited in the following areas:

- Technical improvements (including retracking/corrections)
- Impact of new techniques and missions
- Integration of altimetry in coastal observing systems and examples of applications

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WORKSHOP FORMAT

The workshop was structured as a two-day event, with the first highlighting latest scientific results concerning coastal altimetry and the second providing a showcase of applications using traditional and improved altimeter data in the Coastal Zone. The workshop was organized around a series of plenary sessions with moderated roundtable discussions of current knowledge, gaps in that knowledge, and recommendations for future science needs. The workshop also featured a poster session.

WORKSHOP PROGRAMME

The Scientific Committee reviewed 47 abstracts; on the basis of these reviews the Organizing Committee designed the content of the programme, including topical sessions, moderators, and the allocation of contributions (talk or poster).

Sessions covered the following topics:

- Coastal waveforms and retracking
- Improvement of corrections in the coastal zone
- Sea level
- Waves
- Future of coastal altimetry
- New products
- Coastal applications still using traditional altimetry
- Applications using the new coastal altimetry data
- Capacity building in coastal altimetry

The complete agenda with copies of presentations and posters can be found on the COASTALT website (www.coastalt.eu).

The workshop attracted eighty-six attendees representing a variety of expertise and disciplines from around 20 different countries on six continents.

WORKSHOP OUTCOMES

The first and (overall) recommendation is to develop local solutions driven by local requirements. Many local areas require special treatment and special consideration. Some areas have large tides, or a complex coastline, or will be more affected by sea level rise. But none of the problems that apply in one case are unique to the single case. They apply elsewhere too. Thus coastal altimetry requires global sharing of expertise as well as global products.

Therefore the recommendation extends to integrating many local solutions into a global approach to building a global coastal zone product, which will eventually become finely-tuned for every local coastal area. It is a challenge for the years to come. The construction and improvement of the global product will be incremental, adding gradually improved local solutions. It will require an active international collaboration, and continuation of this series of workshops.

The workshops should bring successful applications of altimetry in coastal regions to the attention of a wider group of coastal oceanographers, managers and the general public. They should be complemented by specific outreach and capacity building activities, to remove the impression that altimeter data cannot be used in coastal regions, and replace it by a more complete understanding of the capabilities of altimeter data, both alone and in combination with other types of data and model fields.

Data from next-generation altimeters (especially SAR/DDA and possibly Ka-band) should be analysed as soon as they become available (early 2010), in order to derive and validate appropriate processing methods, adapted to the new observation techniques of these instruments.

Finally, the participants to the 3rd Coastal Altimetry workshop recommend the continuation of those initiatives (like PISTACH and COASTALT) aiming at the development and distribution of coastal altimetry products (from Jason-1, Topex/Poseidon and ERS-1/2 as well as Jason-2 and Envisat) and associated documentation.

Findings and recommendations from the workshop topics (sessions at the workshop):

1 – Coastal waveform and retracking

Status

Contributions focused on contamination of Envisat waveforms (case-study of Pianosa Island, NW Mediterranean), validation of Jason-1 retracked data with tide gauges (case-study of Australia) and novel algorithms to retrack waveforms (e.g., Synthetic, Brown-modified, Bayesian).

Open Issues

- What factors does contamination near the coast depend upon? (e.g., distance, sea state, coastal shape, what else?)
    - Can we give a minimum distance when nearer coast? We need a uniform metric. We may be able to see 4 km around Australia (Deng et al.) or even 2 km globally for both sea-land and land-sea transitions (Fairhead et al.).
    - How do different retrackers respond to different contamination? We have to consider that different sensors may have different waveforms.
    - Is there any effect from bathymetry? Initial answer: NO; but deserves additional analysis.
- What happens when the waveform is very far from the model? We need to know if useful information can be retrieved from specular waveforms. PISTACH products provide information on the echo shape by applying a classification algorithm. Therefore, an automatic and dynamic processing

can be performed to select desired waveforms (e.g., specular, Brown echoes, etc.). However, some processing with "human in the loop" was also suggested. We need more work on the operational processing of waveforms in the coastal zone. The various methods to detect unusual (bad) waveforms automatically should be intercompared.

- Which are the real limits (waveform shapes) for retrackers? No limits, but noisier waveforms might introduce additional random errors in the estimated parameters. Not all altimeters exhibit the same performance (e.g., Jason-1 noisier near coasts).
- How much is the improvement of the retracked outputs compared to original (SGDR) data? This should be assessed in terms of more data (%) and higher quality data (but we have to define how to measure quality).
- What about validation of retracking techniques? We need to explain what the sensor sees through independent measurements (e.g., tide gauges). We need to consider the context (e.g., point-wise vs footprint averages, colocation with the nearest point, etc.) and take care of differences in the measuring systems.
- Can specialized, coastal retracking only be done on the ground, limiting near real time data availability?
- Is intercalibration of retrackers still an issue? YES as we need to make sure that we set the right parameters.

Recommendations

There is no magic bullet, but a consistent methodology to be applied to each case separately is suggested:

- Using the fundamental Brown model, create a synthetic waveform for the local situation – shape, backscatter of land, water margin, water.
- Based on synthetic waveforms, develop an adaptive, iterative retracking method – reduce parameters estimated, use correlation, adjust weights on parts of waveforms, etc.; iterate and/or adjust model(s).
- Develop local corrections for wet troposphere, ionosphere, SSB, tides, IB.
- Evaluate relation of adopted method(s) to each other and to open ocean or other adjoining results/methods.
- Determine error bounds; validate results.

The first three items were covered by several presenters, but the last two items are still to be explored. The proposed methodology should be applied to more cases of oceanographic interest and findings reported at the next workshop.

The community recommends comparing open ocean retracking to the coastal method(s), developing error estimates for specialized retrackers (and corrections) and showing the relationship to standard products. We also suggest determining the distance from the coast for transition between specialized and standard methods. Specialized and standard retrackers should be validated through comparison with independent data sets on test sites (e.g. tide gauges, buoys, GPS).

More systematic investigations about effects of bathymetry are suggested. There is a desire for at least some full rate (i.e., 1-2 kHz) waveforms near coasts.

2 – Corrections

Status

Probably not an issue:

- Dry tropospheric correction
  - Based on sea level pressure
  - Worry about "elevation contamination" in pressure fields
- Ionospheric correction
  - Dual-frequency will be affected very near to coast
  - GPS-based 3-hourly TEC fields with high-enough resolution experience no coastal contamination
  - Pre-GPS: climatological TEC fields
- Solid earth tide
  - Well understood, might require better earth models in the future. No coastal issues
- Ocean loading tide
  - Relatively small, with small coastal gradients

More problematic:

- Wet tropospheric correction
  - Radiometer footprint size very large (up to 40 km)
  - Land contamination correction models have been developed / are being developed
- Inverse barometer correction
  - Now modelled dynamically, correcting high-frequency component
  - Higher-resolution models are under development.
- Mean sea surface
  - State-of-the-art models (based on altimetry) have very high resolution (1'x1')
  - Much less "trackiness" than previous models
  - Produce better mean ocean dynamics when compared to geoid
- Ocean tide correction
  - Global models generally do a well-enough job for the constituents that they already contain, but lack the more "esoteric" tides that are prominent in coastal areas
  - Local models still have benefits in terms of resolution and inclusion of locally important tidal constituents

Open Issues

- Corrections: multiple choices for the user - single or blended product?
- Tidal corrections: more work on global tidal models, blending in local tide models and constituents like M3.
- Ionospheric correction: the GPS method works fairly well. Can it be done in most/all cases of interest? Need for systematic procedure.

- Wet tropospheric correction: Possible further validation of the various methods with ground-based water vapour radiometers and GPS?
- Local corrections: make "library" of local models so many people can use them

Recommendations

The community asked for quality flags and some clear documentation on the characteristics and limitations of the individual corrections. Studies of the variability of all individual geophysical corrections in the coastal zone are recommended. The wet tropospheric correction derived from GPS/GNSS observations should be explored further and possibly included in future versions of the coastal altimetric products.

3 – SEA LEVEL

Status

Coastal areas around the world are presently undergoing rapid population growth and development, causing the threat of sea level rise to become an increasingly important societal issue. It is therefore consistent that this topic has been taken as a new session title at the 3rd Coastal Altimetry Workshop.

The sea level theme is strongly linked to a number of important climate phenomena, including the melting of mountain glaciers and continental ice sheets, the fingerprint of Global Isostatic Adjustment, the separation of ocean steric and mass change, coastal trapped Kelvin waves, and large scale changes in the atmosphere.

It is also strongly linked to geodesy, as a rise of a few mm/year can only be identified on the basis of a reference frame that provides a long-term stability. Reliable estimates of vertical tectonic motions from GPS or other global navigation satellite systems are needed in order to distinguish between relative sea level rise as seen by tide gauges and absolute sea level rise.

Open Issues

- There is still no clear explanation why coastal and island tide gauge measurements made over the past century show sea level rising at ~1.7 mm/yr, while satellite altimeter measurements made over the past 17 years give a rate of ~3.0 mm/yr, roughly 50% higher. Does this increase reflect a true long term acceleration, or simply decadal variability? Is there a significant long-term difference between coast and open ocean measurements? Recent studies comparing coastal and open ocean altimeter measurements (e.g. *Holgate and Woodworth* 2004, *Prandi, et al.*, 2009) show the rate in the coastal zone, defined as extending 200 km from land, is nearly twice as fast as in the open ocean in the interval 1993-2002. However, most of this difference is due to El Nino related warming events in the western tropical Pacific, included in the coastal calculation.

When the past 17 years are considered there is no significant difference between the coastal and open ocean rates.

- There are some questions regarding the use of coastal and island tide gauges to calibrate altimeter observations and whether the altimeter missions are sufficiently consistent and homogeneous to produce a multi-mission record. Because of land-water interference problems caused by the relatively large sizes of the radiometer and radar footprints, the comparison with tide gauges is never exactly coincident. The radar problem may become more complicated by on-going efforts to use special waveform re-tracking algorithms near the coast. These may make it possible to measure sea level altimetrically within 5-10 km of the coast but may also introduce subtle biases not present in open ocean tracking algorithms.
- Coastal hydrodynamics are very complex and occur on spatial and temporal scales that are small compared to most altimeter measurements. What are the best strategies for merging satellite altimetry with numerical models and other observations?

Holgate S.J. and Woodworth P.L. (2004), Evidence for enhanced coastal sea level rise during the 1990s, , Geophys. Res. Lett., 31, L07305, doi:10.1029/2004GL019626.

Prandi, P., A. Cazenave, and M. Becker (2009), Is coastal mean sea level rising faster than the global mean? A comparison between tide gauges and satellite altimetry over 1993–2007, *Geophys. Res. Lett.*, 36, L05602, doi:10.1029/2008GL036564.

Recommendations

There is a clear consensus that long, consistent time series of altimeter observations are required to understand the long-term evolution of sea level, both globally and in the coastal zone. Only long time series can make the findings independent from decadal variability and inter-annual events, like El-Niño.

The community recommends keeping “sea level” as a major topic in future workshops. In general, the problem of comparing altimeter and coastal tide gauge measurements needs to be thoroughly examined, in view of the growing importance of satellite altimeter measurements as a means of monitoring sea level rise. In particular, the effects of waveform re-tracking, tidal modelling, and wet troposphere correction need to be documented.

4 – Waves

Status

Along-track altimeter-derived estimates of waves at 1 Hz rate (7km spacing) are valuable information for SSB correction, wave model validation, extreme events studies, etc. The GLOBWAVE initiative (major details at www.globwave.info) will contribute to create a harmonised, quality controlled, multi-sensor set of satellite wave data (including altimetry at 1 HZ) and ancillary information in a common format, with consistent characterisation of errors and biases.

With reference to the along track profiles at 10/20 Hz rate, these data might contain physical information (at least till 5 km from the coast) below 7 km.

Open Issues

- Are the raw along-track high resolution data (output from standard retrackers) too noisy to retrieve good wave information? YES. We need some spatial filtering. However, correlation scales (scales of the physical process) may vary from region to region. A good trade-off between smoothing and signal (which might be different between applications) has to be achieved. Wave filtering would induce smoother SSB correction and smoother SSH. Recent retracking approaches adopting waveform filtering (developed within PISTACH project) look promising.
- Can altimetry contribute to wave models through improved coastal high resolution wave data for validation and assimilation? We need Operational Sensor Data Record (OSDR) products at higher resolution than 7 km but lower than 350 m (is 1 or 2 km resolution the trade-off?). Operational centers using altimeter-derived estimates of waves prefer processing raw data (e.g., by applying their own editing/filtering) rather than getting filtered waves (as said previously).
- How close to the coast can altimetry provide good wave measurements? Wave retrieval requires improvement of the retracking techniques (e.g., challenging to extract wave height from specular echoes).
- How can accurate wave models contribute to the empirical SSB modelling? We can get from accurate models better description of the wave age. Work has been done in open ocean (Vandemark, Tran) and would be feasible for coastal areas. There is a clear trade-off between operational models with global coverage and more accurate models that might be available on limited areas where refined bathymetry is available.
- Could other sources of data (e.g., SAR) help understanding wave physics in coastal areas?

Recommendations

The workshop community recommends that we reinforce the link between those estimating waves from altimetry and the wave modeling community. Both communities can contribute to the other, for example:

- Wave modelling can provide altimetry with wave model data of good quality and with better resolution in coastal zones. Wave model data are useful to improve our understanding of the physics in coastal areas and to improve the sea state description (and therefore the empirical SSB correction)
- Altimetry can provide high resolution along-track wave data in coastal zones, thanks to retracking efforts.

5 – New products

Status

The PISTACH and COASTALT products are still very new and assessment by users is still far from complete. Accordingly, exploitation for oceanographic research is still very limited.

Issues

- Short time span is general limiting factor for full exploitation. So far, PISTACH has only processed the Jason-2 data, not any of the Jason-1 data.
- Lack of documentation for the scientific community is a major concern
- Validation is a prerequisite for coastal applications and this has not yet been done
- Categories of users with different knowledge levels (e.g., light or expert) and different objectives (e.g. NRT or off-line)

Recommendations

It is overall agreed that the development of coastal altimeter products could and should be extended and enhanced. The community recommends the continuation of projects to produce these coastal altimeter products automatically and systematically. There is a general consensus that products must be simple to use for inexpert users. Production of a comprehensive User Manual should be an immediate priority. When methods are finalized and the value of the new products demonstrated, the existing archive of older altimetry data from all missions should also be processed.

6 – Future of coastal altimetry

Status

Next generation altimeters, particularly well suited to Coastal Altimetry, include AltiKA (ka-band, high resolution altimeter) and SAR/DelayDoppler altimeters.

Wide-Swath altimeter concepts currently envisaged suffer from the lack of accurate estimation of SWH, required for coastal applications.

Ka-band and SAR/DDA altimeters are already in development and expected to be operational in the period from 2010 to 2020. Their strength – compared to conventional Ku-band altimeters – is essentially linked to two aspects:

- A higher spatial resolution offered by these new concepts, providing better accuracy closer to the coast and the capability of resolving smaller scale topography, present in these areas.
- A higher "precision" of these systems compared with conventional altimeters, achieved by a higher measurement rate (higher number of looks or higher number of independently averaged pulses per time unit)

Recommendations

Some specific features related to the next generation of altimeters and in particular their effect on the accuracy of the measurements need to be investigated as early as possible, when first space-based data become available. This includes in particular the relative angle between the waves and the direction of the elongated resolution of the SAR/DDA altimeter.

7 and 8 – Applications using standard and coastal-processed products

Status

The coastal oceanography community makes use of existing satellite altimetry, even if not specifically processed properly for coastal regions. The impact is dependent upon the ability of users to process data of appropriate quality. Examples of best practices exist in this community, but there is a clear need for synergistic combinations of altimeter data with other data and model fields to address the needs in these regions.

Open Issues

- Knowledge of the altimeter error budgets in coastal regions remains an important topic of research and discussion. Estimates of the uncertainty in final altimeter fields (SLA, absolute SSH, etc.) are of particular concern for those assimilating altimeter data into coastal numerical models.
- For applications requiring absolute dynamic topography (and geostrophic currents), enhanced resolution of the geoid and Mean Dynamic Topography is needed for specific regions of interest.

Recommendations

Given the shorter spatial (across-shelf) and temporal scales in coastal regions, along-track altimeter data (SLA, SSH, "dynamic topography", etc.) are most useful in combination with ocean circulation models (using data assimilation to constrain the models) and/or other types of data (tide gauge, coastal radar, mooring data, etc.). These help to overcome under-sampling in time and space (horizontal and vertical).

Improvements in the components of along-track altimeter data (geophysical corrections, tracking algorithms, internal signal characteristics, etc.), as presently calculated by the PISTACH, COASTALT, and X-TRACK initiatives, are making progress, but still need a great deal of evaluation, analysis, calibration/validation, etc. for different types of coastal configurations.

Similarly, we need to entrain more research scientists in analysis and data assimilation of coastal altimetry, in order to build experience on the choices of "corrections" and correct interpretations with respect to tide gauge SSH and other types of data.

New data sets need documentation for the various corrections and guidance on the choices for each type of correction. Each new data set should provide a suggested “recipe” to construct a prototype (SSH, SLA, etc.) data product and examples of the final data set produced by each recipe, to allow users to validate their successful creation of specific data products.

9 – Capacity building

Status

Topic was added because of its strategic importance for the developing countries. New initiatives just started in Thailand, India and South Africa.

Open Issues

- Providing access to data in these countries is not the final solution, but there is a need to identify case-studies of coastal applications.
- The expertise of the users is a non-negligible (limiting) factor in the correct processing and exploitation of altimeter data in the coastal zone.

Recommendations

The community considers it very important that we increase the understanding of the information content of the coastal altimeter data products. A priority in capacity building priority concerns training in how to access and deal with data before exploiting scientifically correct information.