Exploiting the potential of an improved multi mission altimetric dataset over the coastal ocean

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[1] Until now, most satellite altimetry studies of the coastal ocean have been based on along-track data from a single mission, whereas up to four missions were operative in 2002–2005. Here, to monitor the coastal ocean we have applied specialized corrections and dedicated processing strategies to compute a multimission data set at a mean distance of 32 km of the coast. The resulting altimetric data set is compared with sea level data from three in situ stations over a coastal zone of the northwestern Mediterranean. The mean rms difference between this data set and the sea level stations is 2.9 cm against 3.7 cm when using the AVISO altimetric product. Comparison of altimeter-derived geostrophic velocities with a mooring also shows that the spatial and temporal variability of the surface current field is well reproduced. The agreement with in situ measurements extends to intraseasonal time scales showing a significant improvement compared to previous studies in the 50 km coastal-band. **Citation:** Bouffard, J., S. Vignudelli, P. Cipollini, and Y. Menard (2008), Exploiting the potential of an improved multimission altimetric data set over the coastal ocean, *Geophys. Res. Lett.*, *35*, L10601, doi:10.1029/2008GL033488.

1. Introduction

[2] Radar altimeters measure sea surface topography, which responds directly to internal ocean dynamics. As such, they should be very useful for capturing the complexity of the coastal ocean [*Strub*, 2001] — by coastal ocean we mean the region extending from the coast to offshore, including the shelf, the shelf break and the open sea closer than 50 km to the shelf break. However, all current altimeter missions have been designed to operate over open ocean and have significant problems in coastal regions; these include insufficient sampling, the corruption of radiometer and altimeter waveforms due to land contamination and the inaccuracy of geophysical corrections. Sampling can be augmented by using more than one mission, whereas corrections can be improved by using specific algorithms and control quality procedures optimized for coastal targets [see *Vignudelli et al.*, 2005].

[3] A decade of altimetric research in the northwestern Mediterranean (hereafter NWM) has allowed us to develop data recovery strategies for single altimetric missions, namely TOPEX/Poseidon (hereafter T/P). In particular, the ALBICOCCA (ALtimeter-Based Investigations in COrsica, Capraia and Contiguous Area) project illustrated a number of improvements such as better de-aliasing of tides and atmospheric effects using local modelling, reconstruction of data drop-outs using Bezier polynomial techniques, and the derivation of an accurate mean sea surface using inverse methods [see *Vignudelli et al.*, 2005]. Recently, *Madsen et al.* [2007] have studied the North Sea and Baltic Sea coastal regions using a two-altimeter data set (tandem T/P and Jason-1 configuration). Between 2002 and 2005, a constellation of four satellite altimeters (Envisat, GFO, T/P and Jason1) were flying together. *Pascual et al.* [2007] have investigated the increased resolution provided by this configuration at basin scales and showed that it allows a much better monitoring of the mesoscale. However, the problem of near-shore data recovery and relevant geophysical corrections remains.

[4] Here we will assess the performance of a new multimission data set, processed with specialized routines in order to improve the data accuracy and resolution in the coastal ocean. After a presentation of the data used and of the study area characteristics, we will focus on a diagnostic evaluation of the new data set and show an application using altimetry to monitor a narrow current over a marginal zone of the coastal ocean.

2. Data and Methods

[5] The availability of four different altimetric missions in 2002–2005 provides a unique opportunity to assess the improvement in coastal monitoring due to the increased resolution of this multisatellite configuration. This is particularly helpful in preparing for forthcoming new altimeter concepts that will be better suited for coastal region monitoring, such as wide-swath altimeters (e.g., SWOT), Ka-band altimeters (e.g., AltiKa) or constellations of altimeters (e.g., GANDER); for more details, see *Cotton et al.* [2004] and *Mourre et al.* [2006]. With the present generation of altimeters, we can still investigate certain unexploited possibilities, such as the high along-track data rate and the merging of existing data sets.

[6] New processing software dedicated to coastal ocean applications has been developed, based on the GDR (Geophysical Data Record) data streams provided by operational centres at a rate of 10 Hz (T/P and GFO) and 20 Hz (Jason 1 and Envisat). Details about the processing strategy are reported in section 2 and 3 of the auxiliary material.[1] In addition to standard procedures for large-scale error reduction and editing, some innovations are introduced in the estimation of Sea Level Anomalies (hereafter SLA). Firstly

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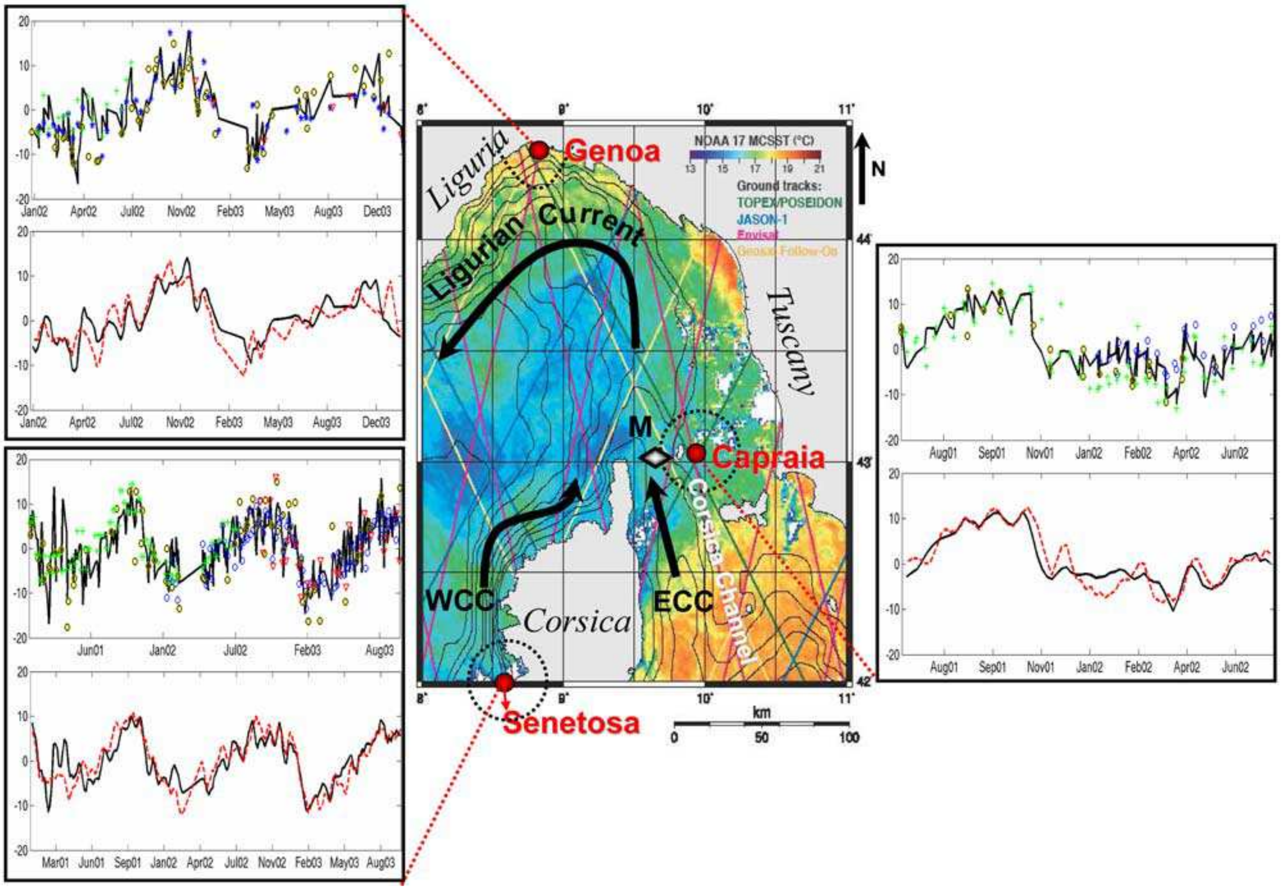

Figure 1. (middle) Map of the study area showing a satellite snapshot of the sea surface temperature (AVHRR, NOAA) overlaid by altimeters ground tracks. M indicates the location of the mooring in the Corsica Channel. Outset boxes show comparisons between in situ and altimeter-derived SLA time series at three locations: (top) instantaneous tide gauge (black line) and altimetric values at the r_{max} positions (T/P: green; GFO: yellow; Jason 1: blue; Envisat: red) and (bottom) shows the 20 days- LPF in situ SLA (black line) against the merged altimetric ones (red line).

a regional barotropic model has been adopted in place of a global model to remove high frequency signals. This reduces the residual alias over the continental shelves of about 18% at multisatellite crossovers. Secondly, quality-control procedures are applied to the 10/20 Hz fully-corrected along-track data allowing an increase in the statistical confidence. The processing does not account for the wet tropospheric correction, which can be contaminated by land within 50 km from the coast. The methodology is that, when at a given location all the corrections are within the editing criteria limits, the SLA is computed, otherwise the point is flagged as bad. The alongtrack SLAs are then spatially Low-Pass Filtered (LPF) with a 50 km cut-off Loess filter [*Cleveland and Devlin*, 1988] to reduce remained noise.

[7] Our processing strategy approach is to avoid systematic rejections and recover all SLAs that exhibit a physical significance. The obvious benefits of this high resolution multi-satellite data set (called MAP, Margin Altimetry Project) are therefore to improve both the spatial and temporal sampling.

3. Study Area

[8] The performance of the new high resolution multi-mission data set in the coastal region is highlighted through a case study example located in the NWM. This region is limited to the north and east by Liguria and Tuscany and to the south by the French island of Corsica. A large-scale cyclonic circulation dominates this region, isolating the deepest central area from coastal influences (see Figure 1).

[9] Two main currents flow northwards on either side of Corsica, with the Eastern Corsica Current (ECC) warmer than the Western Corsica Current (WCC). Both vary seasonally and interannually [e.g., *Vignudelli et al.*, 2000]. These currents mix north of Corsica, forming the Ligurian Current (LC) that flows cyclonically along the coast of Italy extending 30 to 50 km offshore and then continues along the French and Spanish coastline [*Conan and Millot*, 1995]. The LC exhibits a quite variable behaviour throughout the year being more energetic, narrower and deeper in winter; it also develops marked mesoscale meanders [*Millot and Taupier-Letage*, 2005]. This current is of particular environmental and economical interest as it affects one of the NWM's most human-impacted coastal regions [*European Environment Agency*, 2006].

4. Validation

[10] Altimeter-derived sea level data from MAP and a regional AVISO product [*Segment Sol Multimissions*

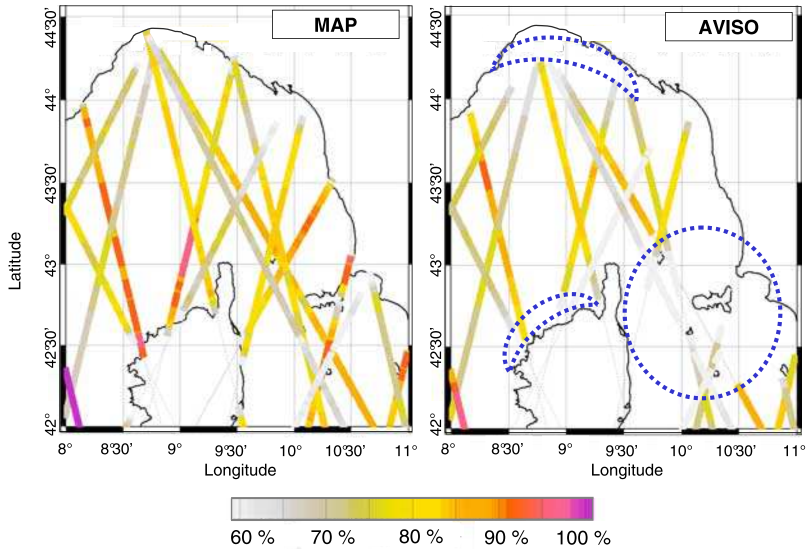

Figure 2. Percentage of data availability for along-track data from the Jason 1, GFO and Envisat satellite missions. (left) The improved multimission altimetry data set and (right) the regional alongtrack AVISO product. The blue dashed lines highlight regions where AVISO data are greatly reduced in number.

d'Altimétrie and d'Orbitographie et de Localisation Précise/ Data Unification Altimeter Combination System, 2006] are intercompared with concurrent in situ measurements at three Sea Level Stations (hereafter SLS) within the study area. (Refer to section 1 of the auxiliary material for in situ data details.)

[11] For each track, the location of maximum correlation with the SLS (called "r_{max} position") varies depending on the relative position between the altimetric measurement, the SLS location and the physical processes which occur in between. (Refer to section 5 of the auxiliary material for AVISO/MAP/in situ intercomparisons at single tracks.) Another key aspect concerns the relative importance of the noise due to land contamination in the altimetric data. When the MAP data processing is applied, the remaining noise is, in some cases, of lower amplitude than the dynamical local oceanic signature. For example, the r_{max} position for the MAP T/P track 44 at the Capraia SLS is at a distance of 19 km and exhibits a correlation of 0.90. The r_{max} position for the AVISO data, whilst outside the 50 km contaminated zone, shows a correlation of 0.81 and a shorter time series. Indeed, for the MAP tracks, the r_{max} positions are located within the 50 km neighbourhood of the coast (33% closer than the corresponding AVISO ones) where the radiometric footprint is still disturbed by the presence of land. Even when the AVISO altimetric tracks are not systematically eliminated within the 50 km neighbourhood of the SLS (5 tracks out of 16) the time series are 24% shorter compared to the MAP ones.

[12] For each SLS, multisatellite time series have been computed from altimetric data located within a 60 km neighbourhood. For each altimetric track, the point selected is located at the r_{max} position. Figure 1 shows that both the sea level time series from SLS and the merged multimission MAP exhibit variability from seasonal to shorter timescales. (Also refer to section 7 of the auxiliary material for the temporal spectrum.) The seasonal signals are well reproduced at 180 and 360 days, but sub-seasonal harmonics associated with mesoscale variability are also observed in both the SLS and the altimetric time series. For example, significant power spectra signals at 35, 42 and 59 days, respectively at Capraia, Genoa and Senetosa are observed. When the signals are smoothed (Figure 1 (bottom)), the consistency between the improved altimetry and the SLS signal increases. The mean rms difference between the improved altimetry and the three SLS is 2.9 cm, whereas it is more than 3.7 cm when using the altimetric product from AVISO. (Refer to section 6 of the auxiliary material for a summary of multimission AVISO/MAP/in situ intercomparisons.)

[13] The mean multimission time-sampling around a tide gauge depends on the number of satellite tracks within a 60 km radius of it. In the case of the MAP data, the mean time difference between measurements is 4.6, 4.1 and 7.3 days at the Senetosa, Capraia and Genoa SLS respectively. This allows us to efficiently sample mesoscale dynamics: for the regional AVISO product, the mean sampling interval is more than doubled, due to the relatively poor data availability along the different altimetric tracks close to the SLS.

[14] Figure 2 shows that the quantity of valid data increases in the whole domain compared to the regional AVISO product. Indeed, large sections of along-track data that are automatically eliminated in the along-track AVISO product become available after our customized processing. Information is recovered that would otherwise be lost by the standard open-ocean processing.

[15] Thus, the improved altimetric product shows greater consistency with the tide gauge measurements located in the coastal zone in addition to a better spatial coverage due to the multisatellite configuration.

5. Application to Coastal Circulation

[16] The multimission altimetric data set can be used to highlight interesting aspects of the ocean circulation in the

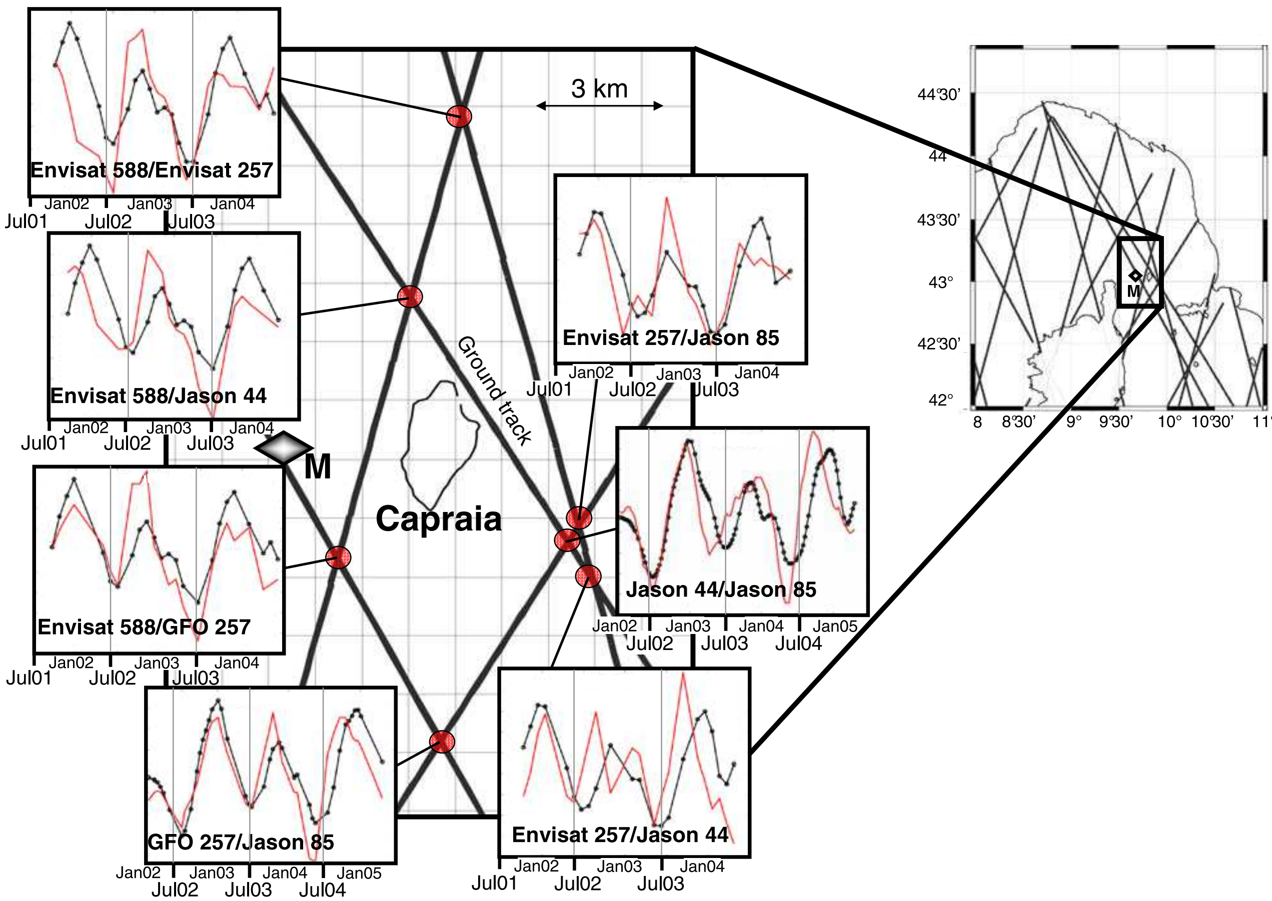

Figure 3. Comparison of multimission meridional GVA at selected crossovers (red line) versus water volume transport through the Corsica Channel from measurements gathered at the mooring site (black line). M indicates the location of the mooring.

test area where altimetric data are often flagged as spurious. The circulation in the area of the Corsica Channel (hereafter CC) is essentially geostrophic and meridional [see *Vignudelli et al.*, 2005]. Figure 3 shows comparisons at multi-satellite crossovers between altimeter-derived meridional Geostrophic Velocity Anomalies (hereafter GVA) and the water volume transport measured through the CC from 2002 to 2005. (Refer to section 4 of the auxiliary material for details on the multisatellite crossover GVA calculation.) Although the geostrophic calculations from altimetry represent only surface GVA, observations in the CC reveal high correlations between the surface velocities and deeper velocities [*Vignudelli et al.*, 2000]. The mean of both data sets is computed over the same period as the altimeter data and removed; the data are also normalized by their rms. The time series of meridional GVA are generally coherent with the concurrent in situ transport. The seasonal signals are well represented, with a maximum in February/March and minimum in July/August, however, short time-lags due to the different locations of mooring and crossovers are observed.

[17] The averaged time lagged-correlation between the raw altimetric and mooring GVA signals are 0.68 and 0.57 for the meridional and the zonal component, respectively (crossover inside the dashed box of Figure 4). (Refer to section 8 of the auxiliary material.) If the currents are LPF to retain only the annual and inter-annual signals (cut-off: 182.5 days) we have an averaged meridional correlation of about 0.78. The averaged meridional rms difference is about 7 cm/s for a mooring signal of about 10 cm/s. The zonal signal is of minor amplitude with rms differences close to 1.5 cm/s (values of the same order of errors). For most of crossover points southeast of the mooring location, the meridional lags are about 20–30 days (mooring lags cross-over point). When the annual signals are removed, both zonal and meridional significant correlations are about 0.5 with equivalent time de-phasing lower than ±1 month.

[18] Ellipses of GVA computed at multisatellite crossover locations (Figure 4) provide a directional measure of the current variability. Their orientation parallel to the isobaths near Capraia and the N-W area of Corsica in both winter and summer seasons suggests that most of the variability is strongly steered by the bathymetry. The largest ellipses are at crossovers inside the ECC, where observations at the mooring site indicate an energetic seasonal flow. Both the altimetry and current meter data show a significant eccentricity at the eastern part of the CC. This agrees with the fact that the mean flow is constrained along the coast of Corsica by the steep bathymetry with lower cross-shelf meandering.

[19] Figure 4 also shows that the oceanic circulation is strongly marked by a seasonal variability of the current intensity. As stated previously, the mean circulation over

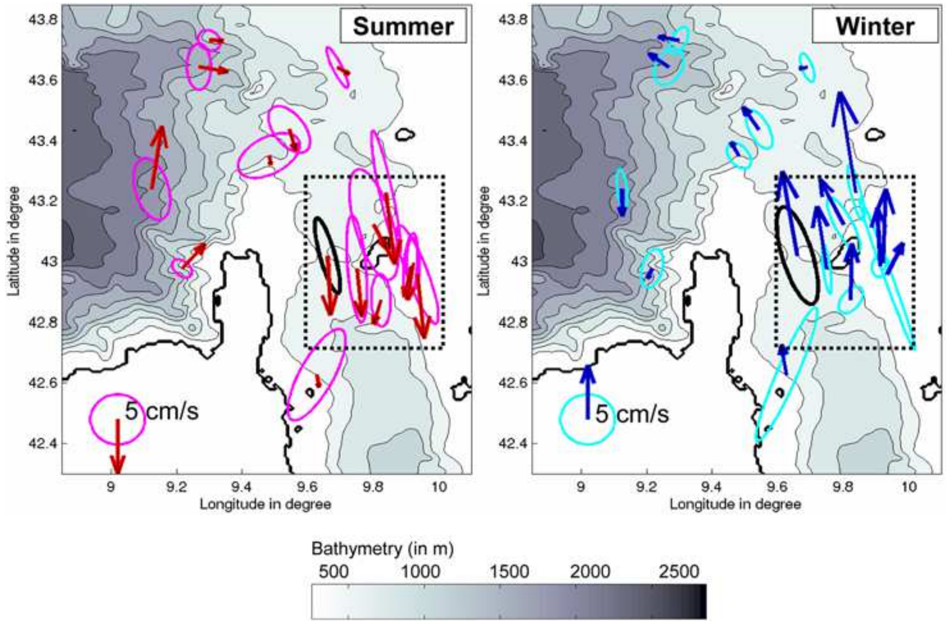

Figure 4. Ellipses of GVA computed at satellite crossovers: the summer season and the winter season are defined during the 3-year multimission time period. Bathymetry (m) is indicated by contour lines. A velocity scale is in the bottom left corner. The arrows indicate the mean polarization of the GVA. The black ellipse corresponds to the in situ current measurements.

our study area is essentially cyclonic. In winter (summer) the mean velocity anomaly field is essentially oriented in a cyclonic (anticyclonic) way. This means that the current intensity increases in winter (between November and March) whereas it slows down in summer (between June and October). This variability is especially clear in the CC area, at the crossovers located close to Capraia. The ellipses and mean seasonal GVA vectors are oriented in a quasi-meridional direction: in summer, both the altimetric and the current meter ellipses indicate southward anomalies inside the CC whereas in winter, the mean vector anomalies point to the N-NW. The variability ellipses of the current meter data closely resemble those observed by altimetry, even though the measurements are not located exactly at the same place.

6. Concluding Remarks and Perspectives

[20] Exploiting the information from multiple altimeter missions is particularly challenging over the *coastal ocean*. Over our study area, we show that it is possible to build an improved multimission data set compared to AVISO in terms of (1) distance to the coast (33% closer), (2) time series length (24% longer) and (3) accuracy when compared to SLS (decrease of 22% of the rms difference). These multimission results, confirm and extend previous studies based on a single mission [*Vignudelli et al.*, 2005].

[21] Even though the r_{max} position of the multimission altimetric data are all less than 50 km of the coast (between 10 and 49 km), our method still cannot provide optimized SLAs right up to the coastline since the altimeter waveforms and radiometer signals remain contaminated by land reflections here. Further re-processing of the radar echo and decontamination of the radiometric signal are necessary to improve the raw altimetric range in the 50 km coastal band.

[22] Over the Corsica Channel, we show that our multimission crossovers can be used as virtual current meter, allowing us to monitor the two components of GVA at high spatial resolution, from seasonal to sub-seasonal time scales.

[23] In general, coastal operational oceanography is limited by the lack of real-time measurements to assimilate into the models with the result that the coastal domain is unconstrained leading the large errors in this key region. With an adapted processing strategy, high-resolution altimetry may compensate for this gap and may also be used to control, and optimize the boundary conditions of coastal models.

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