

Anonymous Referee #1

General comments

This manuscript investigates the effects of storms in shelf-slope exchanges of water and particulate matter (PM) through the submarine canyon Cap de Creus in the Gulf of Lion (GoL), NW Mediterranean Sea. Storms, together with dense water formation and cascading, have been recognized earlier as the prevailing forcing mechanisms for PM transport from the shelf to the open sea. This work adds to a number of previous publications on particle transport, and mass fluxes in GoL, focusing on episodes of significant sediment transport during a series of moderate storms. The experimental setup is excellent; a wealth of high-resolution spatial and temporal data obtained by long-term and temporary moorings, as well as meteorological, wave, river, and hydrological data are used, thus providing a solid basis for transport processes identification and their in-depth analysis. This is a well-written manuscript; methodology is presented in detail (except some minor remarks), it is well-organized, the rationale is clear and conclusions are fully supported by the data. In my opinion, minor modifications are required before publication. My comments are as follows:

(1) The term 'flux' is used many times in the manuscript in a variety of combinations with other words: particulate matter fluxes, particle flux dynamics, fluxes of organic and inorganic matter, particle flux, sediment flux, settling flux, apparent settling flux, apparent flux, suspended sediment flux, punctual sediment flux (not correct term), downward particle flux, downward fluxes, downward mass flux, downward sediment flux, horizontal fluxes of suspended sediments. It is obvious that those terms are not all necessary, so please select the most suitable ones and correct throughout the document. However, the commonly used term 'total mass flux' does not appear anywhere in the document. In my opinion, it should be shown at least at the 'Methods' Section, to make clear that all results on fluxes refer to the total mass flux.

We agree with the referee that we may have used too many different word combinations. We tried to uniformize them as much as possible in the revised text. However, the use of some of these different terms is fully justified. In particular, an important distinction must be made between:

a) Horizontal sediment fluxes, calculated from current speed and suspended sediment concentration measurements, and

b) Sediment trap-based downward (also called settling, or in occasions "vertical") particle flux.

The first implies a transport of particles in suspension, the second is a measurement of particles whose density allows them to sink through the water column and hence it is a proxy for sediment deposition, opposed to transport.

Regarding downward mass fluxes estimated by means of sediment traps, the term 'total mass flux' is a widely used term but no less than for example 'bulk mass flux'. Often it is more appropriate to speak of "apparent mass flux" due to the uncertainty usually associated to sediment trap estimations of the downward particle flux. This is of particular concern in near-bottom deployments (where true downward fluxes can be biased by resuspension and material from bottom nepheloid layers) and under strong hydrodynamic regimes (particle collection

might be biased by the formation of vortex in the trap's mouth and by tilting of the trap or the entire mooring line). Since both situations concur in the present study, it is preferable to be cautious and this is the reason why "apparent flux" was indicated several times in the manuscript. However, since the qualitative nature of the downward flux was already highlighted in the methods section, we have removed the word "apparent flux" from the manuscript.

Throughout the revised text, all trap-based flux data is now uniformized to "downward mass flux", replacing other variants such as "settling mass flux", "settling flux", etc.

Also, we have uniformized to "suspended sediment flux" many of the synonyms used such as horizontal flux, downcanyon sediment flux, etc.

(2) Using previous calibrations to transform turbidimeter measurements to suspended sediment concentration is not a good option. Particulate matter variable composition makes such estimates cruise (time) dependable. I would recommend: (a) providing bottle-derived SSC obtained during or shortly before/after CASCADE cruise; or (b) presenting all turbidity plots in FTU units.

During the CASCADE cruise, water samples were collected with Niskin bottles fixed on a rosette associated to the CTD and suspended sediment concentration (SSC) obtained gravimetrically. A linear relation between the SSC thus obtained and simultaneous turbidity measurements was then derived:

$$\text{SSC (mg/l)} = 1.42 \times \text{Turbidity (NTU)} - 0.086 \quad (r^2 = 0.68)$$

However this calibration is only valid for the range 0-5 NTU, while the actual range of turbidity measurements during the study was 0-40 NTU, which could result in underestimation of particle loads during stormy periods (where this work puts its main focus). Hence we have chosen to use the general transformation obtained by Guillén et al. (2000):

$$\text{SSC (mg/l)} = 1.74 \times \text{Turbidity (NTU)} - 1.32 \quad (r^2 = 0.99),$$

which includes the desired turbidity range. Additionally, previous studies in the same area have used the same general transformation, and therefore, it provides a better comparison among them.

(3) In Section 3.3 I could recommend another structure: 3.1) Meteorological, wave and river discharge data; 3.2) Long-term mooring; 3.3) Temporary moorings; 3.4) Hydrological measurements 3.5) Data quality check (all data, not only moorings).

We have modified the order of paragraphs, putting "Meteorological, wave and river discharge data" first, as suggested by the referee.

Presenting first the canyon head line would look as if this *permanent* line at the canyon head is pivotal to this study and the *temporary* lines provide ancillary data, but it is the other way around, as expressed in the text.

The paragraph entitled “data quality check” is not placed accidentally just after the description of the mooring lines. Its purpose is to assess the dynamics of mooring lines. Tilting of mooring lines can compromise the reliability of the data, by shifting instruments from their theoretical depths and in the case of sediment traps by altering the collection efficiency. These biases have nothing to do with the correct operation of the instruments and sensors themselves, and therefore must be assessed separately. To clarify things, we have renamed this paragraph as “Assessment of mooring line dynamics” replacing the too generic title “Data quality check”.

We cannot conduct a quality check on all data. River discharge data for example is provided by the French data bank "Banque Hydro". In this case, data validation is not our competence and we must take it as provided.

Meteoceanic data from the Sète buoy was compared with that measured by the French meteorological service (Météo-France) in meteorological and buoy stations from the Gulf of Lions and the time-series were coherent.

We have inserted some lines in the methods section to address the quality control of the data collected during the cruise:

On ship-based CTD: “Temperature and salinity were corrected using pre- and post-cruise calibrations, yielding a precision of 0.01 °C on temperature and 0.003 on salinity.”

In the subsection on temporary deployments: “Moored CTD sensors (SBE 37 SMP) were calibrated using pre-cruise calibration, yielding an initial accuracy of 0.002°C on temperature and 0.005 on salinity. The standard deviation on ADCP current speed and direction measurements were 1.3 cm s⁻¹ and 2° respectively. All raw time series were checked to remove spurious data points.”

(4) Section 5.2. There is no reference to the work of Pasqual et al., Biogeosciences 2010 'Flux and composition of settling particles across the continental margin of the Gulf of Lion: the role of dense shelf water cascading'. It is an important omission, as the paper reports mass fluxes obtained between 2005 and 2006 at the Cap de Creus Canyon and the neighboring Lacaze-Duthiers Canyon. It is noteworthy that some coauthors of the present contribution were also co-authors in Pasqual et al. paper. A critical comparison highlighting differences in total mass fluxes occurring during dense shelf water cascading and eastern storm events should be included in the revised version of the manuscript.

Such critical comparison is not possible because of the different datasets and orientations of these 2 articles. The work by Pasqual et al. (2010) studies flux and composition of particles collected by means of sediment traps along the axis of the CCC, only the shallowest station in that work overlaps with ours (300 m depth), the rest being deeper than 1000 m along the axis. The current work deals with sediment transport along the southern canyon flank and relatively far from the bottom, while the work of Pasqual et al. (2010) monitors the composition of the flux collected with sediment traps near the bottom along the canyon axis.

There are other works including current-meter and turbidity data at the canyon head station during storms (e.g. Palanques et al., 2008; Ribó et al., 2011) that could be compared with the 2011 records at the same station are much more related with the present dataset than that of Pasqual et al. (2010). However, it is not the goal of this article to conduct an interannual comparison at the canyon head but to characterize the sediment flux along the canyon flank, an aspect that had been omitted in previous works.

A reference to Pasqual et al. (2010) has been added to the updated manuscript where the effects of cascading are summarized.

(5) Several long sentences in the manuscript are confusing and make it difficult for the reader to follow the authors' line of thoughts (e.g. lines 502-505, 561-566, 589-593, 643-647). Consider rephrasing.

-Lines 525-505, the original text was: “*The relative similarity of current speed, SSC and sediment flux at 75 and 115 mab that was patent at SF1 was even more marked at SF2, as it was the response in terms of increasing current speeds inside the canyon to increasing wave heights on the shelf (Fig. 8).*”

It has been rewritten in this way: “As in SF1, SSC was low from the beginning of the deployment to 12 March. Current speeds measured at both depth levels in SF2 were remarkably coherent (i.e. in phase) with the temporal evolution of wave height on the shelf (Fig. 8), implying a fast response to incoming storms.”

-Lines 561-566, the submitted text reads: “*If considered alone, the low temperature of this water mass could lead to interpret it as dense water newly formed by convection over the shelf. But, contrary to our initial expectations, the abrupt decrease in water temperature observed inside the canyon during 13-16 March (Figs. 4, 5, 6) was not related to a tongue of cascading dense water, as evidenced by simultaneous measurements of water temperature and conductivity with CTD probes, that allowed a precise determination of the density anomaly of this water body (Figs. 5, 6 and 9).*”

Rephrased as: “In the absence of complementary data, the abrupt decrease in water temperature observed inside the canyon during 13-16 March (Figs. 4, 5, 6) could be interpreted as a tongue of cascading dense shelf water. But, contrary to our initial expectations, this water mass was actually less dense than the waters occupying the same depth stratum before the storm (Figs. 5, 6 and 9), as evidenced by simultaneous measurements of water temperature and conductivity with CTD probes, that allowed a precise determination of the density anomaly of this water body.”

-Lines 589-593, the submitted text reads: “*This later water mass could have been formed earlier that winter on the shelf, possibly in December when maximum heat losses took place (Rumín-Caparrós et al., 2012) and the most acute temperature drop of the winter was recorded at the canyon head (Fig. 3) or more probably during a prolonged Tramontane period that preceded the CASCADE cruise (21 February to 3 March, see Fig. 3).*”

Rephrased as: “This latter water mass could have been formed earlier that winter on the shelf, possibly in December at the time of maximum heat losses (Rumín-Caparrós et al., 2012) and when the most acute temperature drop of the winter was recorded at the canyon head (Fig. 3). Also, the prolonged period of Tramontane winds that preceded the CASCADE cruise (21 February to 3 March, Fig. 3) is a potential candidate for WIW formed offshore and then advected shoreward following the general circulation (Lacombe and Tchernia, 1972).”

Lines 643-647

Original text: *“Previous studies suggested that during major episodes of offshore transport such as cascading and storm-induced downwelling, the main water flow tends to follow the coastline, affecting to some degree the CCC head but entering the canyon preferentially by the southern flank.”*

Rephrased to:

“Previous studies have suggested that, during major episodes of offshore transport such as cascading and storm-induced downwelling, the main water flow tends to contour the CCC following the isobaths and then enters the canyon preferentially by its southern flank, affecting only partially the canyon head.”

P5L125: dense shelf water cascading was not evidenced during CASCADE cruise, so it should not appear as one of the major goals of the paper

It was one of the major goals of the experimental design and this why it is mentioned in the introduction. Following the referee advice, we have removed it from the last paragraph of the introduction where the main objectives of the present work are outlined.

P6L135: insert reference to Fig. 1a

Figure 1a does not display the spatial area described in this line.

P7L151: "Marin"; remove quotation marks

Done.

P9L218: ... intermediate depths ...

As the referee noticed, we had unwillingly omitted the word “depth”. Corrected, thanks.

P11L255: punctual is not the correct term; consider rephrasing or remove. Also check and correct throughout the document

“Single-point current meter” is the correct term and now replaces the wrong term in the revised manuscript.

P12L284-291: a description of the array behavior at $V=50\text{cm/s}$ is missing, thus there is no reference to Fig. 2a. Either add some text or remove Fig. 2a

We have updated figure 2 to take into account $V=50\text{ cm s}^{-1}$.

P13L311: SeaBird 911Plus is only the deck unit. What about the underwater unit and the types of sensors used?

We have corrected and expanded that paragraph. Now it reads like this:

“CTD casts were carried out using a Seabird 911Plus CTD probe equipped with a SBE 32 Carousel water sampler. 13 data channels (pressure, dual temperature and conductivity with pump, dissolved oxygen, light attenuation, turbidity, fluorescence, dissolved oxygen, Photosynthetically active radiation, Surface photosynthetically active radiation, Colored Dissolved Organic Matter, and altimetry) were measured at a rate of 24 Hz.”

P15L363: Add reference.

Added: Ulses et al. (2008b and references therein)

P15L364: Here the NW wind is named Tramontane, but in P6 it is Mistral; please correct and check throughout the document.

At the study region, Tramontane=NW winds; Mistral = N winds. These were inverted in page 6 of the submitted manuscript as the reviewer has noticed. That mistake is now corrected.

Also Marin is E-SE in P15 and SE-E in P7; I believe E-SE is the correct one

These directions are now uniformized to “E-SE” as suggested by the referee.

P15L372-373: More information would be useful regarding coastal erosion. What was measured and what results point to increased erosion?

We present our apologies, that reference was not accurately quoted. Coastal erosion is not explicitly mentioned in this document that nonetheless reports that highest Hs during the stormy period of 12-15 March 2011 were measured at Sète (central Gulf of Lions) and were lower towards the western Gulf of Lions (our study area). Therefore the sentence has been corrected, changing “in terms of coastal erosion” by “in terms of maximum Hs”.

The link http://www.languedocroussillon.developpement840durable.gouv.fr/IMG/pdf/DREAL_LRrapport_coup_de_mer_12-841%2016_mars_2011_cle5d39f7.pdf returns error:

please check and correct accordingly

The URL has been updated and now it works:

http://www.languedoc-roussillon.developpement-durable.gouv.fr/IMG/pdf/DREAL_LR-rapport_coup_de_mer_12-16_mars_2011_cle5d39f7.pdf

P16L385: Add results for Hs and river discharge rates with reference to Fig. 3

The text has been modified to include the information requested by the referee:

“The highest river discharges of coastal rivers for the entire winter were measured on 16 March ($3950 \text{ m}^3 \text{ s}^{-1}$), when the dominant winds had already changed from E-SE to NW direction and Hs was less than 2 m (Fig. 3).”

P16L388: Briefly describe currents and SSC, and then the fluxes with reference to Fig. 3

That part of text (end of section 4.1) has been modified to accommodate this suggestion of the referee and those of referee #2.

P17L415: What acoustic sensor? Nothing is mentioned in the Methods section
For clarity, we have changed to “turbidity sensor”. In both cases we are talking about the Seapoint turbidimeters described in the methods section.

P18L447: Should read 'dissolved oxygen concentration' throughout the document.
“oxygen” or “oxygen content” have been substituted by “dissolved oxygen concentration” throughout the text.

Also DO units are mg/l but later ml/l (e.g. Fig. 6). Check and correct throughout the document and Figures

The correct units are ml/l. We have amended this error wherever the incorrect units (mg/l) were given in the text or figures.

P23L567: What would be the density value of the water mass in order to cascade down-canyon?

The easiest answer to this question is that, in order to cascade downcanyon, the water mass should have *at least* a density higher than that of ambient waters, and this was not the case. This is the point we tried to convey: the density of this water mass is lower than that of the water mass previously occupying the same depth stratum so this deepening of the isopycnals can only be explained by an external forcing, in this case storm-induced downwelling.

But, to give a more accurate answer to the referee, the density of DSW, although variable depending on meteorological conditions, is higher than 29.1 kg/m³ and up to 29.6 kg/m³ according to Canals et al. (2006).

What is WIW's typical density range? Add references

28.8-29.0 kg/m³ following Vargas-Yañez et al. (2012), quoted in the text; other authors consider a narrower range = 28.9-29.0 kg/m³ (e.g. Puig et al., 2013). In any case its density is higher than the density ~28.75 kg/m³ of the turbid water mass observed in the canyon. References added.

P24L589: Latter, not later

Corrected, thank you

P26L634: Missing references

We have added two: Palanques et al., 2006, 2012. These two works include extensive monitoring on the Gulf of Lions with instrumented moored lines and illustrate well the point expressed in that sentence.

P39L965: Title is 'Sediment transport to the deep canyons and open-slope of the western Gulf of Lions during the 2006 intense cascading and open-sea convection period'

This has been corrected.

Comments on Figures

Fig. 1: Missing a, b

As noticed by the referee, the text invoked “fig. 1a” and “fig. 1b” but these letters were missing from the figure. Now they have been included.

Fig. 2: Missing a, b, c.

There is no need for these subdivisions. Each variable is identified in the figure and caption and the figure is referenced in the text as a whole.

Fig. 2: I suggest combining Figs. 2a and 2b to a single plot, including also the $V=0$ cm/s case (landscape orientation, across page)

Done, figure 2 has been modified following these instructions

Fig. 3: Missing a to h.

Each variable is clearly defined in the figure and/or caption and along the text we have referenced this figure as a whole. No action taken.

Fig. 3: Maintain equal length for all Y-axes.

Done.

Fig. 3: Increase font size wherever possible

Done.

Maintain the same axis titles between different Figures (e.g. in Fig. 3 River discharge ($m^3 s^{-1}$) and in Fig. 4 River water discharge ($m^3 s^{-1}$); in Fig. 3 H_s (m) and in Fig. 4 Significant wave height (m), etc.)

Done.

Fig. 4: Missing a to h.

See similar reply to Fig. 3

Fig. 4: Keep the same order as in the previous Figure, i.e. wind direction, wind speed, H_s , etc.

Figures 3 and 4 are not intended to convey the same information; we have chosen the variables displayed to maximize the useful information given to the reader in the context where they are quoted. The general order of variables from top to bottom (meteorological, oceanographic and mooring data) is maintained in both figures.

Maintain the same X-axis format in Figures 3, 4, 7, 8, 9

Done. Figures have been updated accordingly.

Fig. 5: Missing a to k.

See similar reply to Figs. 3 and 4.

Fig. 5: Remove psu.

It has been removed.

Fig. 5: Oxygen in mg/l or ml/l.

The correct units are ml/l, it is now corrected.

Fig. 5: Also kg/m^3 or $kg m^{-3}$?

We are expressing these units as a ratio in this figure because the software (GS Surfer 10.2.601) used to create it does not support superscript fonts.

Fig. 6: Missing a to h.

This would be confusing to the reader. Only two letters “a” and “b” are given to clearly identify the 14 March (left column) and 21 March (right column) CTD transects. The variables displayed in each column are already clearly defined with labels and further explained in the figure legend.

Fig. 6: Use different colors.

Done, we used different palettes for each variable displayed.

Fig. 6: Increase line weight and font size for all contours.

Done.

Fig. 6: For the 21 March plots, maintain the same axes scales (0-6 km and 0-600 m) and blank the 'no data' area.

The two transect (14 and 21 March) were not the same: the 21 March transect was shorter and shallower too. We are representing the available data and with the actual bathymetry along the transects followed in each case.

Figs. 10-11: Increase font size

Since the font size of Fig. 10 was already quite prominent, we assume the referee means figs. 11 and 12, where certainly font legibility could be improved. We have increased the font size in these 2 figures and wherever it was possible to improve font visibility.

References:

Canals, M., Puig, P., Durrieu de Madron, X., Heussner, S., Palanques, A., and Fabres, J.: Flushing submarine canyons, *Nature*, 444, 354-357, 2006.

Guillén, J., Palanques, A., Puig, P., Durrieu de Madron X., and Nyffeler, F.: Field calibration of optical sensors for measuring suspended sediment concentration in the western Mediterranean, *Sci. Mar.*, 64, 427-435, 2000.

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Puig, P., Durrieu de Madron, X., Salat, J., Schroeder, K., Martín, J., Karageorgis, A., Palanques, A., Roullier, F., López-Jurado, J.L., Emelianov, M., Moutin, T.,

Houpert, L. 2013. Thick bottom nepheloid layers in the western Mediterranean generated by deep dense shelf water cascading events. Progress in Oceanography (in press). DOI: 10.1016/j.pocean.2012.10.003

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