Interactive comment on "Intra-annual variability of carbon and nitrogen stable isotopes in suspended organic matter in waters of the western continental shelf of India" by M.V.Maya et al.

We thank Dr. Holtvoeth for his thorough review which has helped us improve the manuscript to a substantial extent. Our response to his comments is as follows:

Referee comment: Abstract: *The abstract should present the key research motivation early on (understanding the biogeochemical cycles of C and N on the WCSI, human impact and the recent development of sedimentary* ^{15}N*).*

Reply: We agree.

Referee comment: Chapter 2.1 Study area: *Maybe this section should be part of the 'introduction' instead of the 'methods' chapter since it describes the sampling site rather than any analytical procedure.*

Reply: The introduction will be restructured to bring out more clarity. Section 2.1 which was earlier under methods will be incorporated into the introduction.

Referee comment: **Page *3926, lines 20-26 and Figure 1:*** *I can't quite picture the circulation regime. Although both the SW and the NE monsoon are said to oppose the direction of the WICC this results in upwelling in one case and downwelling in the other. Intuitively, I would have assumed upwelling to occur during the offshore NE monsoon, for example. I suppose the described circulation pattern is either a result of the specific angles between coastline, wind direction and coastal current or controlled by remote re-organisation of the Indian Ocean surface circulation as mentioned in Schott and McCreary (2001)? It would be helpful if the contrasting wind regimes (SW and NE monsoon) and the pathway of the West India Coastal Current/WICC could be included in Figure 1. Since atmospheric forcing appears to play a key role for the upwelling and downwelling regimes on the WCSI is there any wind data available (directions and speed) that could be plotted with the time series?*
Schott and McCreary (2001) mention an undercurrent opposing the surface current between April and September. Is this undercurrent known from the study site? Temporarily opposing surface current and undercurrent might represent an important oceanographic feature because it could mean that, at times, suspended organic matter of different provenance and/or age could be present in the water column due to lateral advection. This would be an important issue when comparing surface and bottom water samples.

Reply: A detailed account of coastal circulation which can answer all the queries raised by the referee including the probable remote forcing of coastal currents and occurrence of an undercurrent is available in Naqvi et al. (2006a, b). We do not wish to repeat that information again, but we will make more clear reference to these articles and also include some specific information here keeping in view the referee's comments. Unfortunately, the wind data are not available. As for the undercurrent, this does not extend to the inner shelf where our time series station is located. The cold, oxygen-depleted bottom

water does, however, originate from offshore and should thus be expected to possess different characteristics from the surface water.

Referee comment: Page 3928, line 8: *What is the precision of the elemental analyzer? How was the C/N ratio calculated (atomic ratio or by weight)?*

Reply: The ratios presented are atomic ratios. We have included details of blanks and instrument precision in methods (section 2) of the revised manuscript

Referee comment: Page 3930, line 11: *How were the concentrations of dissolved oxygen (O_2) and nitrate (NO_3^-) determined? (missing in "methods" chapter)*

Reply: Analytical details for oxygen and nitrate are included in section 2 'methods' of the revised manuscript.

Referee comment: Page 3930, line 23: *I don't think one should calculate averages of the isotope data from both the 2007 and 2008 SW monsoon events. As the authors mention later in their discussion and as apparent from Figure 3 the situation in August and September 2008 is considerably different from September 2007: concentrations of SPOM as reflected by C and N concentrations are much higher and the SPOM in the surface water (0-9m) is a whopping 6-7‰ heavier in August/September '08 than in September '07. This is significant! The differences become even more obvious when comparing the pigment of September '07 and August '08. I wonder if there is meteorological data available for these periods that might help explaining these differences? In any case, the data from the 2007 and 2008 monsoon events should be described and interpreted separately. Accordingly, the cross plots in Figure 5 should be adjusted or, at least, samples from the pre-monsoon and monsoon seasons of different years should be represented by different symbols*.

Reply: The 2007 and 2008 SW monsoon data are indeed quite different but there is no obvious explanation of this variability. We will discuss this briefly in the revision. As advised, the data for the two years will be considered separately. Figure 5 will also be modified.

Referee comment: Page 3930, lines 25-27: *I fail to spot the described difference in surface and bottom water 13C composition for the SW monsoon period in the data in Table 2. On the contrary, ^{13}C values appear to vary very little throughout the water column in August and September 2008. There is no data for the bottom water in September 2007 and the described depth trend probably derives from calculating average values for the surface water across two monsoon seasons - which I think is not feasible regarding the inter-annual variability. Instead, the most pronounced difference in ^{13}C values between surface/subsurface waters and bottom waters appears in the pre-monsoon season, on 24 April '07. A pronounced 3‰ shift in ^{13}C values also appears on 2 April '08 which, furthermore, is the only date when ^{13}C values and C/N ratios show a consistent depth trend and near-perfect correlation ($r^2 = 0.96$).*

Reply: We agree with the observations and will modify our discussion incorporating the suggested comments.

Referee comment: Page 3933, lines 2-4: *The sentence "We carried out… during this season." can be deleted*.

Reply: We agree.

Referee comment: Page 3933, lines 14-15: *The statement that low ^{15}N values "can only be caused by nitrogen fixation" needs references. Reynolds et al. (2007) give an additional/alternative explanation for low ^{15}N values: instead of directly taking up isotopically light N_2 from the atmosphere phytoplankton/cyanobacteria may also use ^{15}N-depleted ammonia (NH_4^+) excreted by zooplankton*.

Reply: Concentrations of ammonium are generally quite low; indeed, the DIN is almost below detection limit when the Trichodesmium blooms appear during the Spring Intermonsoon. Therefore, there has to be a source of new nitrogen, which evidently is nitrogen fixation. However, we will add references and rephrase the statement.

Referee comment: Page 3934, lines 15-22: *The binary end-member model for C/N ratios (1 marine and 1 terrestrial end member) by now is a bit dated. As I have already mentioned in an earlier comment on this manuscript (see BGD online discussion) organic material from terrestrial sources can in fact reveal C/N ratios significantly lower than 12, strongly degraded soil organic matter, in particular. For the pre-monsoon period, however, the authors might actually exclude any contribution of nitrogen-rich soil-derived OM due to the fact that terrestrial run-off is minimal at this time of the year. This aspect will gain importance for the data of the monsoon season. I was wondering, though, if the lightest ^{13}C value and the second highest C/N ratio of the pre-monsoon period determined on 2 April 2008 at the surface could results from dust input. Plant-derived organic compounds are common components of aerosols (see, e.g., Schefuss et al., 2003) and would indeed have a high C/N ratio and light isotopic value provided they derive from C3 plants*.

Reply: We thank the referee for bringing out these possibilities and will incorporate the suggested explanations in the revised manuscript.

Referee comment: Page 3935, lines 10-12*: "It's hard to pin down… although several possibilities have been suggested" such as...?? It would be good to have the options listed.*

Reply: Although we have backed this statement with reference to Naqvi et al. (2006), we will list out the possibilities in the revised manuscript.

Referee comment: Page 3935, lines 22/23: *"The ^{13}C of SPOM generally ranged from −17.6 to −19.7‰, and was thus typically of marine origin." This is the 2008 monsoon, only! The sentence may be deleted altogether since the data should already be described in the results chapter.*

Reply: This sentence will be deleted in the revised manuscript.

Referee comment: Page 3935, lines 24/25*: "The modest enrichment of ^{13}C in SPOM during the 2008 SW monsoon … may be attributed to the dominance of diatoms and dinoflagellates." The statement that diatoms and dinoflagellates are isotopically heavier needs a reference, here*

Reply: We will include appropriate reference in support of the above statement.

Referee comment: Page 3936, lines 3-5: *"While such depletion is characteristic of terrestrial organic matter, the corresponding C/N value (5.7) is not indicative of the terrestrial origin. We are unable to explain this anomaly." As I have mentioned above and in my earlier comment on this manuscript soil OM would be a good candidate to significantly lower the C/N ratio. Additionally, clay minerals associated to soil material supply may introduce ammonium and/or bind some of the ammonium present in the water column during this period (Naqvi et al., 2006) and, thus, reduce the C/N ratios even further. This explanation would be consistent with increased freshwater supply from the nearby Mandovi and Zuari estuaries to the coastal surface waters as indicated by the reduced salinity presented in Figure 4b of Naqvi et al. (2006). Suprit and Shankar (2008) also associate the drop in salinity of the coastal surface waters during the SW monsoon to freshwater supply through the short but numerous rivers along the Indian east coast draining the windward slopes of the Western Ghats. Menon et al. (2011) present satellite data of chromophoric dissolved organic matter (CDOM) and suggest a terrestrial origin of CDOM in the Mandovi estuary during the monsoon season in response to increased river run-off. Furthermore, their satellite data reveals a river plume off the Zuari estuary in September 2005. Unfortunately, such data is not available for the previous months (due to cloud cover, presumably). Nevertheless, these findings illustrate that during the monsoon season river-derived organic material does reach offshore areas where it might be dispersed with the coastal current. In contrast, during the pre- and post-monsoon phases discharge from the Mandovi and Zuari Rivers is negligible (Purnachandra Rao et al., 2011). Thus, introduction of nitrogen-rich and 13C-depleted material may be considered for the late 2007 SW-monsoon data (September 07) only. There is, apparently, discharge data available for the Mandovi River (see Suprit & Shankar, 2008) which could be included in Figure 3 along with meteorological data (rainfall, wind direction).*
Regarding the significant differences observed not only between the 2007 and 2008 monsoon events but also between the pre-monsoon phases (compare, e.g., March '07 and March '08 pigment data) the authors might consider discussing some inter-annual variability of SPOM composition, even though the time series does not cover two full annual cycles, admittedly. They themselves make a case for such an approach by
describing an "early onset of upwelling … on 24 May 2007", assuming that "N_2 fixation … probably varies substantially from year to year" and, eventually, finding that the "data for the two years are somewhat divergent". Could it be that the monsoon season in 2007 was longer and/or more intense than the in

2008? Again, meteorological data could provide the means to pin down the observed differences, thus, resulting in a more convincing data interpretation.

Reply: We thank the referee for the references provided and the possible interpretations of the anomaly observed during the SW monsoon of 2007. The suggestions will be appropriately included in the revised manuscript.

Referee comment: Page 3937, lines 1-7: *Here, an increase in the ^{13}C value of more than 3‰ from -23.8‰ to -19.3‰ associated with constantly low C/N ratios is suggested to indicate predominantly marine OM whereas a similar ^{13}C value of -24.7‰ combined with a (moderately) higher C/N ratio is suggested to indicate terrestrial OM supply. Assuming a constant marine OM origin when one proxy clearly varies while the other remains constant is tricky. What about a mix of nitrogen-rich but ^{13}C-depleted soil OM and nitrogen-rich as well as ^{13}C-enriched marine OM? The impact of soil OM export on common proxies to assess marine and terrestrial OM amounts and the resulting severe underestimation of terrestrial OM sedimentation has been described for tropical river systems elsewhere (Weijers et al., 2009; Holtvoeth et al., 2005). Decreasing proportions of soil OM after the SW monsoon could very well result in the observed pattern of decreasing ^{13}C values and constant C/N ratios from September to December 2007. In January '08, there is indeed evidence for the supply of "conventional" terrestrial input, i.e. of plant matter. This time, the C/N ratios do increase. This could be interpreted as eolian input which would complement the assumption of atmospheric nitrogen supply during the winter made earlier in the discussion.*

Reply: In the revision we will consider the possibility of inputs of soil organic matter as suggested by the referee.

Referee comment: Page 3937, line 21: *The possibility of atmospheric deposition of nitrogen and terrestrial run-off are mentioned in the manuscript but not properly discussed. There is evidence in the data for eolian input of nitrogen and carbon at times (e.g., 31-Jan-08 and 2-Apr-08) that could possibly be backed up with data on wind directions – if available. No data has been presented for the timing and amounts of fluvial run-off.*

Reply: More in-depth discussion on atmospheric deposition and terrestrial run off will be included in the revised manuscript following the referee's comments.

Referee comment: Page 3938, lines 1, 2: *I am not very familiar with the post-sedimentary effect of early OM diagenesis on the nitrogen isotopic composition. Is it not very likely that diagenetic processes in the surface sediments increase the proportion of the heavy isotope? Although the possibility of diagenetic enrichment is mentioned in the abstract there is currently no discussion of this aspect in the manuscript. Please, add a few lines on this matter.*

Reply: In the revision we will discus the diagenetic effects on nitrogen isotopic composition in the sediments.

Referee comment: Page 3938, lines 5-9: *As mentioned above, there is a very good chance of soil OM supply during the monsoon season that would keep C/N ratios low but modifies the carbon isotope signature. Please, consider this aspect for the monsoon/post-monsoon period in the discussion.*
It would be nice to see a scheme or conceptual model illustrating how the composition of SPOM changed over the period of the time series with regard to marine productivity (shifting, e.g., from phytoplankton to cyanobacteria), eolian input and terrestrial run-off. It could display a succession of events such as "upwelling", "trichodesmium bloom", "fluvial soil OM supply", "bottom water oxygen deficit", "eolian plant OM supply" and the like. Although all of this can be filtered out of the data displayed in the figures and the data discussion I think this would help the reader
a great deal in picturing what was going on at the site before, during and after the monsoon seasons of 2007 and 2008. Such a scheme could be presented in the conclusions chapter or combined with Figure 3 and meteorological data (if available).

Reply: We thank the referee for his constructive suggestions. As stated above the effect of soil OM will be considered and the summary will include the effect of various dominant processes at various times of observations.

Technical corrections

Referee comment: *Page 3926, line 18: delete "Indian Ocean"*

Reply: The line will be deleted.

Referee comment: *Page 3933, line 15: correct Trichodesmium*

Reply: 'Tricodesmium' corrected to 'Trichodesmium'

Referee comment: *Page 3935, lines 10, 12 and 18: Please, specify Naqvi et al. (2006) as 2006a or b according to the reference list.*

Reply: Naqvi et al. (2006) has been changed to Naqvi et al. (2006a)

Referee comment: *Table 1: replace "24 May 2007" with "24 April 2007"*

Reply: Table 1 shows the correct days. In figure 3 "24 April 2007" has now been replaced with "24 May 2007".

Referee comment: *Figure 2: Please, add units of contour lines (M) to figure or figure captions.*

Reply: Units will be added to figure captions.

Referee comment: *Figure 3: The figure displays the wrong data for 2-Apr-08!! This appears to be a copy of the data from 31-Jan-08. Correct according to Table 1.*

Reply: We thank the referee for pointing out the error which has been rectified.

Referee comment: *Figure 5: Please, separate the samples from the 2007 and 2008 pre-monsoon and monsoon periods by using different symbols. In fact, it might be worth plotting the data separately. Check how correlations change then.*

Reply: Figure 5 will be modified.