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Temporal variability of sulphur plumes in the northern Benguela upwelling system and forcing processes

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The Benguela upwelling system is one of the four eastern boundary upwelling systems of the global ocean. This system sustains a very high primary production associated with the upwelling of nutriment rich waters forced by the trade winds. Due to the subsequent export production and the intense remineralisation, an oxygen minimum zone is present in the northern Benguela upwelling system where the trade winds are permanent all the year. In the northern Benguela upwelling system off Namibia, hydrogen sulphide outbreaks and their sulphur plumes are unique events not found anywhere else in the global ocean with such intensity. These events influence the marine ecosystem due to their toxic effects, have direct impacts on the biogeochemical cycles and are able to affect the Namibian fish industry. At the moment, there are large gaps in the knowledge about these sporadic events. Up to now their temporal variability as well as their forcing by local and remote-driven processes are not well-known.
The objective was to investigate the seasonal and annual variability of coastal sulphur plumes in relation to their forcing using different remote sensing data sets. We quantified their spatial extension and intensity from 2002 to 2012 with a specific algorithm based on the water-leaving reflectance measured with the medium resolution imaging spectrometer (MERIS) on board the ENVISAT satellite of the European Space Agency (ESA). Overall, our study illustrates that the sulphur events have a strong seasonal cycle with pronounced main and off-seasons forced by local and remote-driven processes. The main peak season is in late austral summer and early austral autumn at the beginning of the annual upwelling cycle. The sulphur plume activity is high between February and April during the seasonal oxygen minimum. The annual variability of coastal surface plumes was never investigated before, especially not with the long-term satellite data of MERIS. The annual variability of sulphur events is characterized by very high activities in years 2004, 2005 and 2010 interrupted by periods of lower activity in years 2002-2003, 2006-2009 and 2011-2012. This result can be explained by the relative contributions of local and remote-driven forces. The probability for the occurrence of sulphur plumes is enhanced in years with a lower annual mean of upwelling intensity, decreased oxygen supply associated with decreased lateral ventilation of bottom waters, more southern position of the Angola Benguela Frontal Zone and stronger downwelling coastal trapped waves.