The impact of soot deposition on Carbon pumps

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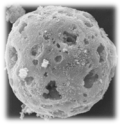
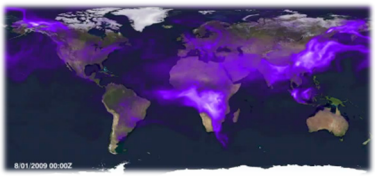


Atmospheric BC (Size = 50 nm; Density = 1.8 g cm^{-3}).

Abstract. Black Carbon (BC) is an aerosol emitted as soot during biomass burning and fossil fuels combustion. A large fraction of atmospheric BC deposits on the surface of the ocean and enters marine ecosystems at a global rate of about 12 Tg C per year. Owing to their high surface-active properties, BC modifies the functioning and the structure of the microbial ecosystem by adsorbing dissolved compounds and microorganisms. We show evidence for the occurrence of various BC-induced processes, such as: the adsorption of dissolved organic matter followed by an enhanced formation of marine aggregates, and the adsorption of viruses and bacteria followed by an increase in the activity of particle-attached bacteria. As for CO_2, BC has intertwined relationships with climate change in the sense that climate change influences BC emission and deposition patterns and rates, and atmospheric BC is a major player (right next to CO_2) in climate change. However, the impact of BC on climate change could be even wider than solely inferred from its effects in the atmosphere due to its impact on both the Biological and the Microbial Carbon pumps.



Regional hotspots of BC emission (Optical Density of BC - GOCART model (NASA/Goddard Space Flight Center Scientific Visualization Studio).

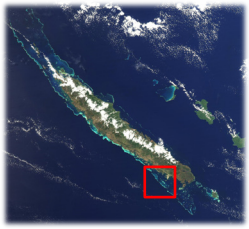
Rationale.

- Atmospheric BC emission is concentrated in regional "hotspots".
- Short lifetime in the atmosphere (< few weeks).
- Can travel long distances, but preferentially deposits near sources.
- Removed from the atmosphere via dry/wet deposition on land and ocean.
- Annual oceanic deposition ~12 Tg C y^{-1}.
- Highly porous structure and surface coverage with oxygen-containing functional groups = highly surface-active and high exchangeable cation sorption and retention capacity. Therefore, may have **high adsorptive properties for dissolved compounds and small particles in seawater**.

Methods.

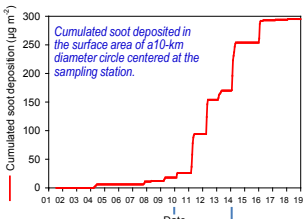
(1) *In situ* study of the BC-induced biogeochemical (particle size distribution in the water column, DOC at 1-m depth) and microbial (bacterial and viral abundances and bacterial production at 1-m depth) changes during a dry deposition event in an ultra-oligotrophic marine system (in New Caledonia).
(2) Laboratory study of DOC adsorption by BC (10 mg L^{-1}).
(3) Laboratory study of BC-induced aggregation mechanisms (10 mg L^{-1}).

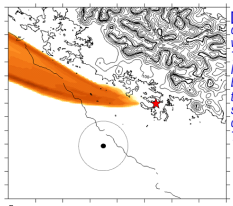
Results of the study in New Caledonia.



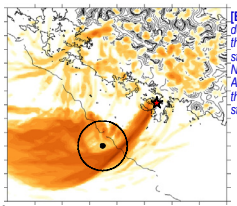
Island in the South Pacific. Dominant and most regular source of atmospheric-BC is a oil-fired power plant. Well-defined wind conditions with trade-winds that are dominant ~70% of the year.

Trade-winds may stop for days, allowing the accumulation of BC in the atmosphere above the local ultra-oligotrophic marine ecosystem, and subsequent deposition. Such an event occurred and was monitored in November 2008.

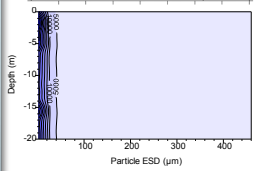




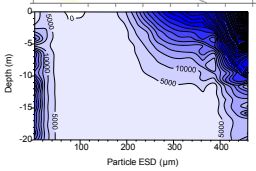
[A] *Area of soot deposition during well-established Trade-winds (10 November). Soot blown away from the sampling station and deposition in the Trade-winds' axe.*



[B] *Area of soot deposition when the Trade-winds stopped (14 November). Accumulation over the sampling station.*



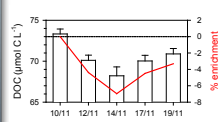
[A] *Particle size spectra along the water column on10 November.*



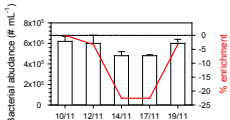
[B] *Particle size spectra along the water column on14 November.*

[A] Before deposition particle volume concentration low and constant (~1.5 µL L^{-1}) and small particles (<20 µm) dominate.

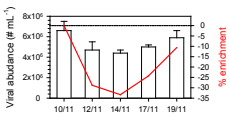
[B] After deposition, volume concentration increases (x30 at 1-m depth) due to the appearance of large particles (>200 µm), diminution (disappearance) of small particles in surface water, and large particles (>200 µm) undetected below 10 m suggesting aggregation during sedimentation generating aggregates larger than upper detection limit of the equipment (i.e. from 2.5 to 500 µm).



Changes in DOC concentration.



Changes in free (i.e. unattached to particles) bacterial abundance.

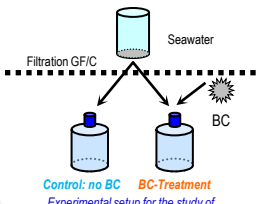


Changes in free (i.e. unattached to particles) viruses abundance.

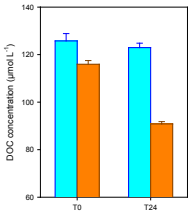
The concentrations of DOC, free bacteria , and free viruses decreased concomitantly with the observed increase of particle volume concentration (i.e. from 10 to 14 November), respectively of 7%, 23% and 33%. In addition, particle-attached bacterial production (>1-µm) doubled during the same period.

BC seem to promote aggregation in the water column, and to "adsorb" DOC and small particles "OVERAGGREGATION"

Results of DOC adsorption experiment.

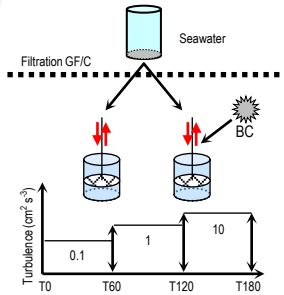


Experimental setup for the study of DOC adsorption by BC.

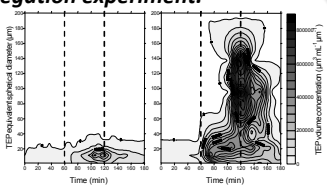


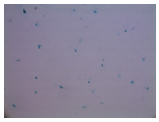
Immediate adsorption of DOC after addition of BC (8%), and removal of 26% after 24 h.
This experiment confirms in situ observation that BC adsorbs DOC.

Results of aggregation experiment.

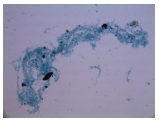


Experimental setup for the study of the impact of BC on Transparent Exopolymer Particles (TEP) formation from DOM.





[A] *Example of TEP formed without BC at T_{120}.*



[B] *Example of TEP formed with BC at T_{120}.*

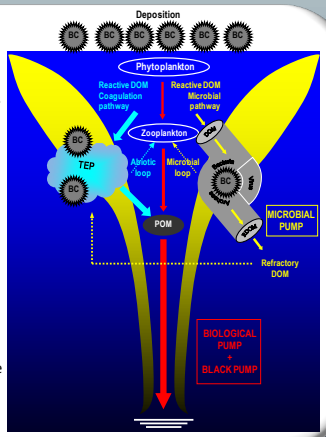
The observed increase of the TEP pool is due to an increase of the concentration of TEP in each size class and to the formation of very large TEP.
This experiment confirms in situ observation that BC promotes aggregation.

Conclusions.

The impact of soot deposition is not limited to an enrichment of the water column by associated nutrients, but also encompasses physical and biological effects potentially altering the biological pumps:

Physical effects
- DOM adsorption and alteration of the MOD/MOP equilibrium.
- Formation of large aggregates by stimulating TEP formation.
- Ballasting of aggregates.

Biological effects
- Adsorption of viruses by BC (reduced pressure on bacteria).
- Adsorption of bacteria by BC and/or active colonization of large aggregates formed because of the introduction of BC.
- Stimulation bacterial activity.



Mari X, Lefèvre J, Torréton J-P, Bettarel Y, Pringault O, Rochelle-Newall E, Marchesiello P, Menkes C, Rodier M, Migon C, Motegi C, Weinbauer MG, Legendre L (2014) Effects of soot deposition on particle dynamics and microbial processes in marine surface waters. *Global Biogeochemical Cycles*, 28: 662-678 .