**Notes**

1. The list of authors will be alphabetical except for the first and last authors.
2. **Everyone should pay explicit attention to the text regarding their data to verify/confirm what I wrote.**
3. Please let me know if you think of more interesting figures to add to the paper. Keep in mind that this is not a traditional research paper, we shall not interpret the data, just present it.
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**Figures**

<https://github.com/PMassicotte/malina_data_paper/raw/master/manuscript/essd/latex/pmassicotte_et_al_2020.pdf>

**The Malina oceanographic expedition: understanding the impact of climate change on the fate of terrestrial carbon exported to the Arctic Ocean**

Philippe Massicotte, yyy, zzz and Marcel Babin

**Abstract**

TODO

**1. Introduction**

The Mackenzie River is the largest single source of terrestrial particles entering the Arctic Ocean (Doxaran2015 and references therein). For the past decades, temperature rise, permafrost thawing, coastal erosion and increasing river runoff have contributed to intensifying the export of terrestrial carbon by the Mackenzie River to the Arctic Ocean. The environmental changes currently happening in the Arctic have profound impacts on the biogeochemical cycling of this exported carbon. On one hand, reduction in sea-ice extent and thickness expose a larger fraction of the ocean surface to higher solar radiations and increase the mineralization of this carbon in atmospheric CO2 through photo-degradation (refs). On the other hand, the increase in nutrients brought by Arctic rivers contributes to higher autotrophic production and sequestration of organic carbon (Tremblay2014, more refs). Given that these production and removal processes are operating simultaneously, the fate of arctic river carbon transiting toward the Arctic Ocean is not entirely clear. Hence, detailed studies about these processes are needed to determine if the Arctic Ocean will become a source or a sink of atmospheric CO2. With regard to these questions, the MALINA oceanographic expedition was designed to document and get insights on the stocks and the processes controlling carbon fluxes in the Mackenzie River and the Beaufort Sea. Specifically, the main objective of the MALINA oceanographic expedition was to determine how primary production, bacterial activity and organic matter photo-oxidation influence carbon fluxes and cycling in the Arctic. In this article, we present an overview of an extensive and comprehensive data set acquired from a coordinated international sampling effort conducted in the Mackenzie River and in the Beaufort Sea in August 2009.

**2. Study area, environmental conditions and sampling strategy**

**2.1 Study area and environmental conditions**

The MALINA oceanographic expedition was conducted between 2009-07-30 and 2009-08-25 in the Mackenzie River/Beaufort Sea system (Fig. 1). The Mackenzie River Basin is the largest basin in northern Canada and covers an area of approximately 1 805 000 km2 which represents around 20% of the total land area of Canada (AbdulAziz2006). Between 1972 and 2016, the average monthly discharge (recorded at the Arctic Red River station) varied between 3296 and 23241 m3 s-1 (shaded area in Fig. 2A). The period of maximum discharge usually occurs at the end of May whereas the period of low and stable discharge extends between December and May. During the MALINA oceanographic cruise, the daily discharge varied between 12600 and 15100 m3 s-1 (coloured segment in Fig. 2A). Draining a large watershed, the Mackenzie River delivers on average 2100 Gg C yr−1 and 1400 Gg C yr−1 of particulate organic carbon (POC) and dissolved organic carbon (DOC) annually into the Arctic Ocean (Stein2004, Raymond2007). During the expedition conducted onboard the CCGS Amundsen, the air temperature recorded by the foredeck meteorological tower varied between -2 and 11 °C (Fig. 2B). The average air temperature was 3 °C and usually remained above 0 °C.

**2.2 Sampling strategy**

**For the following sections, please be concise. Write few lines to explain how the sampling was done. You can cite your published papers for the details.**

The sampling was conducted over a network of sampling stations illustrated in Fig. 1A. A total of 64 stations were sampled across seven shelf–basin transects (south-north) to capture the latitudinal gradient between the estuary and the open ocean. Within each transect, station numbers were listed in descending order from south to north. At these stations, the bathymetry varies between 2 and 1847 m (394 ± 512 m, mean ± standard deviation). The stations in the Beaufort Sea were sampled onboard the Canadian research ice-breaker CCGS Amundsen. Two transects (600 and 300) were extended to very shallow waters on the shelf and sampled using either a zodiac or a barge (the bathymetry profiles are shown in Fig. 1B). In the context of this data paper, these two transects were chosen to present an overview of the principal variables measured during the MALINA campaign. A summary of the various sampling strategies used to sample water is presented below.

**2.2.1 CTD and rosette deployments**

* Claudie Marec
* Pascal Guillot
* Louis Prieur, (L)ADCP was attached to the rosette?

Onboard the CCGS Amundsen, a rosette equipped with a CTD (Seabird SBE-911+) was deployed at each sampling station (Fig. 1). The CTD data were verified and calibrated following the UNESCO technical papers (Crease, 1988).

Water samples for measurements of dissolved and particulate carbon (both concentration and absorption), nutrients, chlorophyll-a, phytoplankton absorption, total suspended matter and genetic analysis such as DNA and RNA were collected from 24 12L Niskin bottles attached to the rosette.

**2.2.2 Net deployments**

* Alexandre Forest

**2.2.3 Coring sampling (casq core, box core)**

* Guillaume Massé
* André Rochon
* Heike Link
* Philippe Archambault

**2.2.4 Optical measurements from the deck (Amundsen) and the Barge**

* Stan Hooker

Vertical profiles of radiometric quantities were collected during MALINA Leg2b using a Compact-Optical Profiling System (C-OPS) manufactured by Biospherical Instruments Inc. (San Diego, California) and built with micro-radiometers (Morrow et al. 2010). The rationale for the development of this in-water profiling system is provided in Hooker et al. (2013) along with a detailed description of its design and operation, and further demonstration of its capability in deriving high-accuracy radiometric data close to the surface. This profiler provides high resolution vertical profiles of the downward irradiance, Ed, and the upwelling radiance at nadir, Lu, in 19 spectral bands, as follows: 320, 340, 380, 395, 412, 443, 465, 490, 510, 532, 555, 560, 625, 665, 670, 683, 710, 780 nm and PAR. The high dynamic range of the micro-radiometers provides 10 decades of dynamic range. The C-OPS was deployed from a 12-m barge in parallel to, but distant from, the *Amundsen* icebreaker main operations. This protocol avoided any ship perturbation, either due to shadowing from the hull and superstructures or due to mixing of the upper layers from propulsion. It also allowed an easy and unobstructed deployment of a reference radiometer using a telescoping mast (Hooker 2010) for collection of the global solar irradiance, Ed(0+) or Es, and getting close to ice fields for specific casts.

The processing of these data is based here on a well-established methodology (Smith and Baker 1984) that was evaluated in an international round robin (Hooker et al. 2001) and shown to be capable of agreement at the 1% level when the processing options were as similar as possible. Hooker et al. (2001) provide sufficient details that only a brief overview for obtaining data products from a vertical profile of Lu and Ed, is presented here. In-water radiometric quantities in physical units are normalized with respect to simultaneous and slowly varying Ed(0+,λ,t0)/Ed(0+,λ,t) observations (e.g., due to the solar transit), with t explicitly expressing the time dependence and t0 is generally chosen to coincide with the start of data acquisition. For simplicity, the variable t is omitted in the following text. In addition, any data collected when the vertical tilt of the profiler exceeds 5° are excluded from the ensuing analysis.

After normalization and tilt filtering, a near-surface portion of Ed(z,λ) centred at z0 and having homogeneous optical properties (verified with temperature and attenuation parameters) extending from z1=z0+Δz and z2=z0-Δz is established separately for the blue-green and red wavelengths; the ultraviolet (UV) is included in the interval most similar to the UV attenuation scales. Both intervals begin at the same shallowest depth, but the blue-green interval is allowed to extend deeper if the linearity in ln[Lu(z,λ)] within the interval, as determined statistically, is thereby improved. The negative value of the slope of the regression yields the diffuse attenuation coefficient, Kd, which is used to extrapolate the fitted portion of the Ed profile through the near-surface layer to null depth, z=0-.

Fluctuations caused by surface waves and so-called *lens effects* prevent accurate measurements of Ed(λ) close to the surface (Zaneveld et al., 2001). A value just below the surface (at null depth z=0-) can be compared to that measured contemporaneously above the surface (at z=0+) with a separate solar reference using

Ed(0-,λ) = 0.97 Ed(0+,λ), (1)

where the constant 0.97 represents the applicable air-sea transmittance and reflectance terms. The distribution of Ed measurements at any depth z influenced by wave focusing effects do not follow a Gaussian distribution, so linear fitting of Ed in a near-surface layer is poorly constrained, especially if the number of samples is small. The application of (1) to the fitting process establishes a *boundary condition* or *constraint* for the fit (Hooker et al. 2013).

The appropriateness of the extrapolation interval, initially established by z1 and z z2, is evaluated by determining if (1) is satisfied to within approximately the uncertainty of the calibrations (a few percent); if not, z1 and z2 are redetermined—while keeping the selected depths within the shallowest homogeneous layer possible—until the disagreement is minimized (usually to within 5%). The linear decay of all log-transformed light parameters in the chosen near-surface layer are then evaluated, and if linearity is acceptable, the entire process is repeated on a cast-by-cast basis. Subsurface primary quantities at null depth are obtained from the slope and intercept given by the least-squares linear regression of the extrapolation interval specified by z1 and z2.

The water-leaving radiance is obtained directly from

Lw(λ) = 0.54 Lu(0-,λ), (2)

where the constant 0.54 accurately accounts for the partial reflection and transmission of the upwelled radiance through the sea surface, as confirmed by Mobley (1999). To account for the dependence of Lw on the solar flux, which is a function of atmospheric conditions and time of day, Lw is normalized by the (average) global solar irradiance measured during the time interval corresponding to z1 and z2:

 (3)

where Rrs is the remote sensing reflectance.

An additional refinement includes the bidirectional nature of the upwelled radiance field, which is to a first approximation dependent on the solar zenith angle. An early attempt to account for the bidirectionality of Lw by Gordon and Clark (1981), following Austin (1974), defined a normalized water-leaving radiance, [Lw (λ)]N, as the hypothetical water-leaving radiance that would be measured in the absence of any atmospheric loss with a zenith Sun at the mean Earth--Sun distance. The latter is accomplished by adjusting Rrs(λ) with the time-dependent mean extraterrestrial solar irradiance, F0 (ignoring all dependencies except wavelength for brevity):

[Lw (λ)]N = F0(λ) Rrs (λ), (4)

where F0(λ) is usually formulated to depend on the day of the year and is derived from look-up tables (Thuillier et al. 2003).

The solar zenith angle for the MALINA data set ranged from 53-79° and had an average value of 62°, which is within or close to the 75° threshold for some of the data processing corrections, e.g., computing the bidirectional correction for the exact form of the normalized water-leaving radiance. The vast majority of the MALINA data were collected under overcast (i.e., diffuse) conditions, wherein the Fresnel reflectance does not vary appreciably (i.e., literature values are to within 2% of the value used in the data processing scheme). In addition, the majority of the data were collected in quiescent waters from a small vessel, so wave-focusing effects were minimized. Under these conditions the convergence between the extrapolated in-water Ed(0-) values taken through the air-sea interface for comparison with Ed(0+) (per the bounding condition used in the processor) is easily satisfied with minimum manipulation of the extrapolation interval (assuming the interval is defined in a homogenous layer, which is required).

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Mobley, C.D.: Estimation of the remote-sensing reflectance from above-surface measurements. *Appl. Opt*., **38,** 7,442–7,455, 1999.

Thuillier, G., Hersé, M., Simon, P. C., Labs, D., Mandel, H., Gillotay, D., and Foujols, T.: The solar spectral irradiance from 200 to 2400nm as measured by the SOLSPEC spectrometer from the Atlas 1-2-3 and EURECA missions, *Solar Phys.,* **214,** 1–22, 2003.

Zaneveld, J. R. V., Boss, E., and Barnard, A.: Influence of surface waves on measured and modeled irradiance profiles, Appl. Opt., 40, 1442-1449, 2001.

* Simon Bélanger
* David Doxaran
* David Antoine
* Edouard Leymarie

An array of various optical radiometers were attached to the cage rosette. These include a transmissometer (Wetlabs C-Star, path 25 cm) for beam attenuation measurement, a nitrate sensor (ISUS V2, Satlantic) and a chlorophyll fluorometer (SeaPoint).

**2.2.5 In situ pumps (vertical fluxes)**

* Juan-Carlos Miquel
* Beat Gasser

**2.2.6 Sediment traps**

* Alexandre Forest

**2.2.7 Chemistry of DOM**

* Ron Benner
* Jean-François Rontani
* Cedric Fichot
* Richard Sempere

**2.2.8 UVP**

**3. Data quality control and data processing**

Section to be written by Flavienne?

**4. Data description: an overview**

***4. 1 Water masses distribution (Fig. 3)***

* Bruno

***4.2 Physical variables (temperature and salinity) (Fig. 4)***

* Yves Gratton
* Louis Prieur

The latitudinal cross-sections of water temperature and salinity measured by the CTD between 0-100 meters in transects 600 and 300 are presented in Fig. 4.

* Water temperature warmer at the surface (Fig. 4A).
* Clearly see the influence of the freshwater input from the Mackenzie River at the surface at transect 600 compared to transect 300 because of the lower salinity (Fig. 4B).

***4.3 Nutrients (Fig. 5)***

* Patrick Rimbault
* Jean-Éric Tremblay

Nitrate, nitrite, phosphate and silicate concentrations were measured from water filtered through…

***4.4 Optical measurements (Fig. 6)***

* Annick Bricaud
* Simon Bélanger
* Atsushi Matsuoka
* Jens Ehn

The vertical distribution of a wide range of inherent and apparent optical properties measurements was characterized during the campaign. These include the absorption of dissolved (*a*CDOM) and particulate (*a*P) organic matter, the absorption coefficient of non-algal particles (*a*NAP) and phytoplankton (*a*phy), backscattering coefficients of particulate material (*b*p), light transmittance (*T*), photosynthetically available radiation (PAR), downward irradiance (*E*d) and the vertical diffuse attenuation coefficient for downward plane irradiance (*K*d). The spectral absorption, attenuation and the backscattering coefficients of particulate and dissolved material were characterized using in situ optical profilers (AC9 and BB9, Wetlabs) attached to the CTD-Rosette profiler frame onboard the CCGS Amundsen (details can be found in XXX). Chromophoric dissolved organic matter absorption (*a*CDOM) was measured from water samples filtered using 0.2 µm GHP filters (Acrodisc Inc.) using an UltraPath (World Precision Instruments Inc.) between 200 and 735 nm. In most cases, a 2 meters optical path length was used for the measurement, except for coastal waters near the Mackenzie River mouth (Fig. 1) where a 0.1 meters optical path length was used. Details about particulate and dissolved absorption measurements can be found in Belanger2013b.

Examples of *a*CDOM spectra measured at the surface for the northern and southern stations in transects 600 and 300 and are presented in Fig. 6A. The marked influence of the organic matter of terrestrial origin can be observed for the stations located at the mouth of the Mackenzie River (697 and 398). Because the organic matter delivered by the river is highly humic and coloured, the absorption at 254 nm of the southern shelf stations for both transects was approximately 15 times higher compared to the northern stations (620 and 320). Likewise, the specific UV absorbance of dissolved organic carbon at 254 nm (SUVA254), a metric commonly used as a proxy for assessing both chemical (weishaar2003; westerhoff2004) and biological reactivity (berggren2009, asmala2013) of the DOM pool in natural aquatic ecosystems, decreased rapidly along the south-north gradient in both transects 600 and 300 (Fig. 6B). This observation is in accordance with a previous study that showed that SUVA254 was higher in inland ecosystems due to elevated lateral connectivity with surrounding terrestrial landscape and organic matter inputs from the tributaries (Massicotte2017). The decrease in SUVA254 toward north stations (Fig. 6B) suggests that terrestrially-derived DOM transiting toward the ocean is gradually degraded into smaller and more refractory molecules.

***4.5 Pigments (Fig. 7)***

Who should write this part?

* Josephine Ras

***4.6 Bacteria (Fig. 8)***

Who should write this part?

* Fabien Joux

***4.7 Carbon fluxes (Figs. 9-11)***

In the context of climate change, the main objective of the MALINA oceanographic expedition was to determine how (1) primary production, (2) bacterial activity and (3) photo-degradation influence carbon fluxes and cycling of organic matter in the Arctic. In the following sections, we present an overview of these ...

***4.7.1 Phytoplankton primary production (Fig. 9)***

* Patrick Rimbault

***4.7.2 Photo-degradation (Fig. 10)***

* Huixiang Xie

***4.7.3 Bacterial production (Fig. 11)***

Who should write this part?

* Eva Ortega
* Fabien Joux

# **5. Conclusions**

# **6. Code and data availability**

The raw data provided by all the researchers, as well as metadata, are available on the LEFE-CYBER repository ([PROOF / LEFE CYBER CRUISE](http://www.obs-vlfr.fr/proof/php/malina/x_datalist_1.php?xxop=malina&xxcamp=malina)). The data presented in this paper and in Table 2 are hosted at SEANOE (SEA scieNtific Open data Edition) under the CC-BY license (link to the SEANOE database once it is uploaded). Detailed metadata are associated with each file including the principal investigator’s contact information. For specific questions, please contact the principal investigator associated with the data (see Table xxx).