**Biogeosciences
Discussions**

Quantitative reconstruction of sea-surface conditions over the last ~150 yr in the Beaufort Sea based on dinoflagellate cyst assemblages: the role of large-scale atmospheric circulation patterns

L. Durantou[1], A. Rochon[1], D. Ledu[2], and G. Massé[2]

[1]Institut des sciences de la mer (ISMER), Université du Québec à Rimouski,
310 allée des Ursulines, Rimouski, G5L 3A1, Canada
[2]UMR 7159 LOCEAN Institut Pierre-Simon Laplace, 4 Place Jussieu, BP100,
75252 Paris Cedex 05, France

Correspondence to: L. Durantou (lise.durantou@uqar.qc.ca)

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper

BGD

9, 7257–7289, 2012

**Paleoceanography
on the Beaufort Sea**

L. Durantou et al.

Title Page

Abstract	Introduction
Conclusions	References
Tables	Figures

◄ | ►
◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Abstract

Dinoflagellate cyst (dinocyst) assemblages have been widely used over the Arctic Ocean to reconstruct sea-surface parameters on a quantitative basis. Such reconstructions provide insights into the role of anthropogenic vs natural forcings in the actual climatic trend. Here, we present the palynological analysis of a 36 cm-long core collected from the Mackenzie Through in the Canadian Beaufort Sea. Dinocyst assemblages were used to quantitatively reconstruct the evolution of sea surface conditions (temperature, salinity, sea ice) and freshwater palynomorphs influxes were used as local paleo-river discharge indicators over the last ∼ 150 yr. Dinocyst assemblages are dominated by autotrophic taxa (68 to 96 %). *Pentapharsodinium dalei* is the dominant specie throughout most of the core, except at the top where the assemblages are dominated by *Operculodinium centrocarpum*. Quantitative reconstructions of sea surface parameters display a serie of relatively warm, lower sea ice and saline episodes in surface waters, alternately with relatively cool and low salinity episodes. The warm episodes are characterized with high dinocyst productivity. Variations of dinocyst influxes and reconstructed sea surface conditions are closely linked to large scale atmospheric circulation patterns such as the Pacific Decadal Oscillation (PDO) and to a lesser degree, the Arctic Oscillation (AO). Positive phases of the PDO correspond to increases of dinocyst influxes, warmer and saltier surface waters, which we associate with upwelling events of warm and relatively saline water from Pacific origin. Freshwater palynomorph influxes increased in three phases from AD 1857 until reaching maximum values in AD 1991, suggesting that the Mackenzie River discharge followed the same trend when its discharge peaked between AD 1989 and AD 1992. The PDO mode seems to dominate the climatic variations at multi-annual to decadal timescales in the Western Canadian Arctic and Beaufort Sea areas.

1 Introduction

Recent observations revealed that the Arctic is experiencing a climatic warming at a rate nearly twice of the global average during the past decades (e.g., IPCC, 2001, 2007; McBean, 2005; Hassol, 2004). Most of the climate variability over the Arctic has
5 been associated with change in the phase of large scale atmospheric patterns such as the Arctic Oscillation (AO) or the Pacific Decadal Oscillation (PDO) (Niebauer and Day 1989; Macdonald et al., 2005; Overland et al., 1999; Thompson and Wallace, 1998), which are both important natural patterns in global climate variability. Unfortunately, the lack of long-term observations in the Arctic makes it impossible to reach any definitive
10 conclusion concerning the impacts climatic oscillations in Arctic regions (e.g., Polyakov et al., 2002). In this context, paleoceanographic studies at high temporal resolution (i.e. multi-annual to decadal scales) were recently solicited in order to acquire a better knowledge about past and actual climate affecting high latitudes. Previous paleoceanographic studies have actually shown a relative importance of the Arctic Oscillation in
15 the Southern Beaufort Sea during the Holocene (e.g., Bringué et al., 2012; Ledu et al., 2010). The Arctic Oscillation is a multi-year run of positive and negative values index reflecting anomalies in the strength of the circumpolar vortex, which is well-correlated with the interannual and decadal time scale variability in the Arctic (Thompson and Wallace, 1998). However, the actual understanding of natural variability versus the an-
20 thropogenic warming contribution, essentially based on past observations with both proxy and instrumental records still needs to be better documented at accurate temporal scales. In this paper, we present quantitative multi-year resolution (3–5 yr) reconstructions of sea-surface conditions based on dinocyst assemblages preserved in the Beaufort Sea sediments. The sediment core was collected as part of the Malina
25 Program (http://www.obs-vlfr.fr/Malina) in an attempt to provide a paleoenvironmental perspective on the recent climatic evolution in the Beaufort Sea coastal region, which has experienced a drastic reduction of both area and thickness of sea-ice cover (SIC) over the last few decades (Baber and Hanesiak, 2004).

Dinoflagellate cyst (dinocyst) assemblages were used as proxy indicators to document the quantitative evolution of sea-surface conditions. Dinoflagellates are unicellular protists, some of which will produce a cyst as part of their life cycle to avoid adverse conditions (e.g. winter), and will return to their planktonic form the following season. They can be found in most marine sediments because of the composition of their highly resistant organic membrane, and despite extremely cold conditions (e.g., Harland and Pudsey, 1999; de Vernal et al., 2001). Dinocysts are particularly useful microfossils in high latitudes because they are especially sensitive to sea-surface conditions in Arctic and sub-Arctic areas (e.g., Kunz-Pirrung, 2001; Matthiessen et al., 2005; Mudie and Rochon 2001; Radi et al., 2001; de Vernal et al., 2001, 2005). Furthermore, dinocysts are well preserved, especially in environments like the Mackenzie Trough where sediment accumulation rates are high, which prevent oxidation.

2   Study area

The Mackenzie Shelf is a 120 km wide and 530 km length area, representing approximately 6.0×10^4 km^2 (Carmack et al., 2004). It is located between the Mackenzie Trough to the west and the Amundsen Gulf to the East (Fig. 1), and the water column is characterized by local water masses, as well as from Pacific origin. Atlantic water is also present at depth below 200 m. Sea-ice is generally present between mid-October and the end of May (Wang et al., 2005; O'Brien et al., 2006). Among others, the Beaufort Shelf surface circulation is strongly influenced by ice, winds and freshwater input resulting from river discharge and sea-ice melt.The water column at the core location is composed of 3 layers: the upper polar mixed layer (salinity < 28), the relatively cold lower Polar Mixed Layer (20–50 m, salinity of 28 to 30.7) (Matsuoka et al., 2011) and the nutrient-rich relatively warm and salty Bering Summer Water below 50 m (with a salinity of $\sim$ 31) (Carmack et al., 1989; Carmack and Macdonald, 2002; Macdonald et al., 1987) composed in part by the Alaskan Coastal Water (Steele et al., 2004). The upper polar mixed layer is a combination of surrounding sea ice melt, Mackenzie

River discharge, but also other processed waters (from Pacific and/or Atlantic). In this layer, primary production usually responds to nutrient inputs. ~~Intense~~ turbidity due to the Mackenzie plume between May and September and the absence of nutrients limit primary production, but a chlorophyll *a* maximum is found near 20–60 m depth (Martin et al., 2010). Offshore, the Beaufort Gyre flows clockwise while, closer to shore, the relatively warm Alaskan Coastal Current (Fig. 1) (Aagaard, 1984; Coachman et al., 1975) flows eastward throughout the year (Nickolopoulos et al., 2009) transporting the Alaskan Coastal Waters, which composed a part of the halocline of the water column in the study area (Aaagard, 1984; Melling, 1998).

The Mackenzie River is the fourth largest Arctic river in term of freshwater discharge but the first in term of sediment discharge, which represents annually 127 Mt of sediments, and largely influenced by an ice cover, winds and currents (Macdonald et al., 1998). Closer to shore, the Mackenzie River freshwater inputs form a large plume (Fig. 1), dominant at the surface during summer time, which distributes water properties of the river over the Beaufort Sea surface layer (Macdonnald et al., 2002). The Mackenzie River plume is typically 2–3 m thick and there is a strong vertical structure and horizontal currents in surface waters. It follows westward coastal winds toward the Mackenzie Trough and eastward surface current to the Canadian Archipelago (Carmack and Macdonald, 2002). The Mackenzie shelf receives 249–333 km^3 of freshwater annually (Dittmar and Kattner, 2003), usually during May–September period (Macdonald et al., 1998). It is generally accompanied by an important terrigenous sediment discharge (O'Brien et al., 2006), but reduced in winter near the coast, underneath the land fast ice (Macdonald et al.,1995). Coastal erosion represents around 7 Mt yr^{-1} over the shelf (Macdonald et al., 2002.) depending on Mackenzie River flow intensity and storms.

The Mackenzie River drainage basin covers a large part of Western Canada, around 1.8×10^6 km^2 (Abdul Aziz and Burn, 2006; Hill et al., 2001; Wang et al., 2005), delimited by the west flank of the Rocky and Mackenzie Mountains. Highest sediment accumulation rates are found in the Mackenzie Trough and the nearby continental slope (Hill

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

et al., 1991; Macdonald et al., 1998). The main part of the Mackenzie Trough is composed of silty sediments, while the nearby shelf is mostly characterized by silt and sand (Blasco et al., 1990; Hill 1996). The morphology of the Mackenzie Trough, together with strong winds and ice dynamics, can cause upwelling of the warmer and saltier Pacific halocline (Aagaard, 1984). These conditions occur over the trough, shelf areas, along the slope, and many were observed over the last 4 decades (Carmack et al., 1989, 2004; Iseki et al., 1987; Kulikov et al., 1998; Macdonnald et al., 1987; Williams et al., 2006). Periods with no upwelling conditions are characterized by relatively lower sea-surface primary production (Macdonald et al., 2002). Both ice-motion and ice-free conditions allow the development of upwelling events, which are observed in both winter and summer seasons.

3 Material and methods

3.1 Sampling and preparations

The 36 cm-long core MA680BC (69°36′15″ N, 138°13′34″ W) studied here was collected during the 2009 Malina sampling campaign onboard the *CCGS Amundsen* with a Box Corer at 56 m water depth (Fig. 1). The core was sub-sampled at 1 cm intervals and treated using standardized palynological procedures (e.g., Rochon et al., 1999) involving chemical treatments. To that end, 5 cm^3 of sediments were collected by water displacement and a tablet of makers grains (*Lycopodium clavatum*, University of Lund, Sweden) with known concentration (12 100 spores ± 1892 spores/tablet, Batch no. 414831) were added to the sediments, allowing calculation of palynomorphs concentrations (Matthews, 1969). Sieving at 10 and 100 μm was performed in order to eliminate fine and coarse particles (< 10 μm and > 100 μm). This was followed by warm acid treatments using hydrochloric acid (HCl-10 %, 4 treatments) to dissolve the carbonated fraction alternating with hydrofluoric acid to dissolve the silicate fraction (HF-49 %, 3 treatments). A final sieving was realized (10 μm) to eliminate fine particles and

fluorosilicates formed during the chemical treatments. Finally, a drop of the remaining fraction was mounted on slides using glycerin gel.

3.2 Dinocysts counts

Slides were observed in transmitted-light microscopy (Leika, DM5500B) at 40× magnification. All palynomorphs (pollen, spores, dinoflagellate cysts, freshwater palynomorphs, organic foraminifera linings, acritarchs and pre-Quaternary palynomorphs) were counted systematically in each sample. A minimum of 300 dinocysts were counted to obtain a useful statistical representation of the dinoflagellate cyst populations. Relative abundances, calculated from the total dinocysts sum, were used to present dinocyst assemblages, and influxes were calculated using concentrations (cysts cm^{-3}) and the calculated sediment accumulation rates (specimens cm^{-2} yr^{-1}). High sediment accumulation rates (0.23 to 0.32 cm yr^{-1}; Richerol et al., 2008) in the study area prevented oxidation of organic material within the core, including dinoflagellate cyst assemblages. The low oxidation level was evidenced by the excellent preservation of the most oxidation-sensitive taxa, such as those of the genus *Brigantedinium*.

3.3 MAT method – estimation of past sea surface conditions and taxonomy considerations

The reconstruction of past sea-surface conditions was done using the Modern Analogue Technique (MAT) (Guiot et al., 1990; Prell, 1985; de Vernal et al., 2001, 2005) with the statistical software R version 2.13.0 MAT is routinely used and particularly well-suited for the reconstruction of past sea-surface conditions in high-latitude environments (Guiot and de Vernal, 2007, 2011; Bonnet et al., 2010; Ledu et al., 2010). The MAT method is based on similarity between fossil dinocyst spectra and modern analogs from a large reference database (1429 sites). Modern sea-surface temperature (SST) and salinity (SSS) (at 10 m depth) are respectively from the World Ocean Atlas (NODC, 2001) and Arctinet 2009 data. Sea ice cover (SIC) data (number of months per year

with > 50 % of sea-ice coverage) are from the National Snow and Ice Data Center. Data of Mackenzie River discharge are from the Environment Canada website, and viewed with HYDAT software (ftp://arccf10.tor.ec.gc.ca/wsc/software/HYDAT/). Data of the AO and the PDO are from the National Oceanic and Atmospheric Administration (NOAA).

Dinocyst nomenclature follows that of Rochon et al. (1999), de Vernal et al. (2001), Head et al. (2001), Radi et al. (2001), Fensome and Williams (2004) and Radi et al. (2012). The following taxa are grouped together with *Islandinium minutum* because they often co-occur in samples and their individual ecologies are still unknown: *Islandinium brevispinosum* (Fig. 5i), *Echinidinium karaense* (Fig. 5k), *Echinidinium zonneveldiae*, *Echinidinium granulatum* and *Echinidinium*? sp. Z.*Spiniferites elongatus*, *S. frigidus* and intergraded morphotypes are also grouped together (cf. Rochon et al., 1999).

3.4 Palynomorphs counts

Other palynomorphs include pollen and spores, freshwater palynomorphs, which include *Pediastrum* (Fig. 5a), *Halodinium* (Fig. 5b) and spores of *Zygnema* (Fig. 5c), acritarchs and pre-Quaternary palynomorphs. All these palynomorphs were expressed with influxes (specimens $cm^{-2} yr^{-1}$). Freshwater palynomorphs are identified at the genus level and are used as indicators of freshwater input from the Mackenzie River. Acritarchs and pre-Quaternary palynomorphs, which include dinocysts, pollens grains and spores, are used as sediment reworking indicators.

3.5 Chronology

The chronological framework of core MA680BC was determined by ^{210}Pb and ^{226}Ra activities. The measurements of ^{210}Pb excess were made in the UMR5805 EPOC-OASU laboratory using the constant rate supply model (Appleby and Oldfield, 1978) in order to obtain sediment accumulation rates. The activity of ^{137}Cs was also used to validate the ^{210}Pb-based chronology, based on two markers (the Chernobyl accident

of 1986 and the maximum of thermonuclear weapon testing in 1963) showed by two peaks of ^{137}Cs activity.

4 Results

4.1 Chronology

The 36-cm long core encompasses the last 154 yr and the age-depth model is based on a second order polynomial regression (Ledu et al., 2012). The calculated sediment accumulation rates range from 0.22 cm yr^{-1} at the base of the core to 0.32 cm yr^{-1} in the upper part of the sequence allowing for a multi-annual resolution of 3–4 yr throughout the record.

4.2 Palynomorphs influxes

Dinocysts concentrations varied between 700 and 2400 cysts cm^{-3} (average 1500 cysts cm^{-3}) and are similar to those previously found in surface sediments from the Beaufort Shelf area (200–3100 cysts cm^{-3}) (Geotop dinocysts database, http://www.geotop.ca/). In the present study we are presenting dinocyst results as influx to better reflect changes in dinoflagellate primary productivity throughout the time period covered by our core. Dinocyst fluxes (Fig. 2a) vary between 200 and 1400 cysts cm^{-2} yr^{-1} (average 500 cysts cm^{-2} yr^{-1}). From ~AD 1865–1930, fluxes increase gradually from 300 to 1000 cysts cm^{-2} yr^{-1}). Between ~AD 1930–1970, dinocysts influxes are decreasing, with a minimum value reached around AD 1950 (200 cysts cm^{-2} yr^{-1} at 14 cm downcore) and increase again from AD 1970–1980 to reach a maximum value of 1400 cysts cm^{-2} yr^{-1} at 8 cm downcore. Dinocyst influxes then steadily decrease from ~AD 1980 to their modern value of 500 cysts cm^{-2} yr^{-1} at the top of the core.

Freshwater palynomorphs, pollen grains and spores, and pre-Quaternary paly-nomorphs influxes are all characterized by an increase from minimum values around ∼AD 1885 to maximum values during ∼AD 1992–1997 (Fig. 2f–h, respectively).

Pollen and spores influxes (Fig. 2g) remain relatively stable during ∼AD 1855–1950 with a mean value of 267 grains cm^{-2} yr^{-1}, despite a peak centered ∼AD 1900. From AD 1950, influxes progressively increase to reach a maximum value of 660 grains cm^{-2} yr^{-1} during ∼AD 1980–2000, with a mean value of 580 grains cm^{-2} yr^{-1}. Only 5 genus composed the pollen assemblages: *Picea*, *Pinus, Betula, Alnus* and *Salix. Pinus* dominated the assemblages and it is generally over-represented in ocean basins due to its morphology and density, which allow transport over long distances (e.g., Heusser, 1983; Mudie, 1982; Rochon and de Vernal, 1994). Influxes of pollen and spores and pre-Quaternary palynomorphs (pollen grains, spores, acritarchs and dinocysts) present similar distribution patterns. Influxes are minimum ∼AD 1880 (210 and 190 cm^{-2} yr^{-1}, respectively) and gradually increase until ∼AD 1980. They are then characterized by an important increase between ∼AD 1980–2000 and reach maximum values of 660 and 915 specimens cm^{-2} yr^{-1}, respectively (Fig. 2h).

Freshwater palynomorphs were used as tracers for the variations of the Mackenzie River discharge (Fig. 2f). Their influxes gradually increase from minimum values of ∼30 specimens cm^{-2} yr^{-1} around AD 1880 to maximum values of 200 specimens cm^{-2} yr^{-1} in the period ∼AD 1980–2000.

4.3 Dinocyst assemblages

A total of 24 dinocyst taxa were observed in all the samples, but 7 taxa comprised more than 95 % of the assemblages (Fig. 3). The assemblages are dominated by the autotrophic taxa *Pentapharsodinium dalei* (Fig. 5e) and *Operculodinium centrocarpum sensu lato*, which includes the arctic and short spines morphotypes (Fig. 3). Both taxa are common in Arctic and sub-Arctic regions (Mudie and Rochon, 2001; Kunz-Pirrung et al., 2001) and were recorded in estuarine environments (Dale, 1976; Persson et al., 2000). *Pentapharsodinium dalei*, which represents 68 to 96 % of the assemblages, is

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

|◄ | ►|

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

generally associated with low salinity environments and stratified waters in summer. The second most abundant taxa, *O. centrocarpum sensu lato*, represents 9–66 % of the assemblages (average 31 %). The accompanying taxa include *Spiniferites elongatus/frigidus* and a series of heterotrophic taxa: *Islandinium minutum* sensu lato (2–18 %), *Brigantedinium simplex* (1–30 %), the cyst of *Protoperidinium americanum* (≤ 2 %) and the cyst of *Polykrikos* var. Arctic (≤ 3 %).

The software zone allowed to differentiate three dinocyst assemblage zones, which can also be distinguished on the basis of the relative abundance of all taxa: Dinocyst assemblage 1 encompasses the period ∼AD 1855–1880 (Fig. 3), and is characterized by the co-dominance of *P. Dalei* (34–56 %) and *O. centrocarpum sensu lato* (28–46 %), accompanied by *S. elongatus/frigidus* (2–4 %) (Fig. 5h), *I. minutum* sensu lato (5–17 %) and *B. simplex* (3–10 %). Dinocyst assemblage 2 encompasses the period ∼AD 1880–1987 and is dominated by the autotrophic taxa *P. dalei* (24–73 %), *O. centrocarpum* sensu lato (9–46 %), while *S. elongatus/S. frigidus* (0.3–3 %) show their minimum relative abundances in this zone. Conversely, the assemblage is characterized by the maximum abundance of heterotrophic taxa, such as *I. minutum* sensu lato (up to 24 %) and *B. simplex* (up to 20 %), and by the appearance of cysts of *P. americanum* (0.3–2 %) and cysts of *Polykrikos* var. Arctic (0.3–3 %); Dinocyst assemblage 3, from AD 1987–2009, is characterized by a marked decrease of *P. dalei* abundance (from 46 to 11 %) and dominance of *O. centrocarpum* sensu lato (up to 65 %). This assemblage is also marked by the maximum abundance of *S. elongatus/frigidus* (up to 5 %), the minimum abundance of all heterotrophic taxa and the disappearance of the cysts of *P. americanum*.

4.4 Reconstruction of sea-surface conditions

Summer temperature reconstructions are characterized by a decreasing trend between ∼AD 1855–1960. Indeed, reconstructed SST values between ∼AD 1885–1935 are warmer by up to 3 °C with respect to the average modern temperature at the coring site (4.1 °C). During ∼AD 1935–1975 reconstructed SSTs are ∼1 °C below the modern

value. Within the next 10 yr, the temperature increases up to 5.4 °C (∼AD 1987) and gradually decreases towards the modern value of 4.1 °C.

The reconstructed SIC trend mirrors that of reconstructed SSTs (Fig. 4b). Between ∼AD 1887–1945, reconstructed SIC values are as low as 3.9 months yr^{-1}, which is nearly 6 months yr^{-1} below the modern value (9.8 months yr^{-1}). The period AD 1945–1975 is marked by reconstructed SIC values similar to the modern conditions. A sudden decrease in SIC characterizes the period AD 1975–1995, with values as low as 4.6 months yr^{-1}, which is 5 months below the modern value. Sea-ice cover duration then gradually increases towards the modern value.

Reconstructions of SSS depict a series of oscillations between minimum and maximum values varying between −7 and +5 salinity units around the modern salinity conditions at the coring site (27) measured at 17 stations in 2009 all located within 30 km of the coring site. The periods AD 1860–1905, 1935–1980 and 1990–2009 are characterized by reconstructed SSSs lower than the modern value, while SSS is similar to modern conditions between AD 1905–1935. The most salient feature of the reconstructions is the sharp peak recorded by all parameters during ∼AD 1980–1990.

5 Discussion

Instrumental data for the Mackenzie River discharge are only available since 1938, which allow for short time scale observations on the fluctuations of the freshwater discharge. In an attempt to trace the temporal variability of freshwater inputs to the Beaufort Sea area prior to 1938, Richerol et al. (2008) previously showed the similarities between concentrations of the freshwater palynomorph *Halodinium*, a thecamoeban-like palynomorph, and the Mackenzie River discharge in the Beaufort Sea area. Here, we have used the influxes of several freshwater palynomorphs, including *Halodinium*, as well as remains of the freshwater algae *Pediastrum* (Chlorophyceae) and *Zygnema* (Zygnematophyceae). Figure 2d illustrates the influxes of these palynomorphs next to the Mackenzie River discharge (Fig. 2e) data from 1938 to 2005. Because of the

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

|◄ | ►|

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

similarity between both profiles, we suggest that the influx of these freshwater paly-
nomorphs can be used as tracers of the river discharge prior to instrumental data,
which is directly related to precipitations within its catchment area.

The freshwater palynomorph influxes curve (Fig. 4f) displays 3 major phases: from
AD 1858–1902 where freshwater palynomorph influxes are minimum (∼ 50 specimens
cm^{-2} yr^{-1}); an intermediate phase from AD 1900–1976 (∼100 specimens cm^{-2} yr^{-1});
and the most recent phase, from AD 1976–2004, where their influxes reach maximum
values (∼130 specimens cm^{-2} yr^{-1}). Previous studies of tree ring records from Central
Canada (Case and Macdonald 1995; Sauchyn and Beaudoin, 1998; Sauchyn and Skin-
ner, 2001), Yellowknife and the Mackenzie delta area (Pisaric et al. 2007, 2009; Porter
et al., 2009) going as far back as AD 1505 can be used to infer precipitations and
assess the variability of freshwater inputs from the Mackenzie River. Reconstructions
of August–July annual precipitations in two regions of the Western Canadian Prairies
(Western Saskatchewan) indicate that the period AD 1850–1900 was characterized
by drought or low-precipitation episodes lasting several years, the most severe occur-
ring between ∼AD 1860–1875 (Case and Macdonald, 1995), AD 1880–1900 (Sauchyn
and Beaudoin, 1998, Sauchyn and Skinner 2001), and AD 1942–1877 in the Eastern
Rocky Mountains (Saint Georges et al., 2009). For the Yellowknife area, June precipita-
tion reconstructions indicate a negative anomaly (low precipitations) during AD 1850–
1890, which coincides with a particularly low level stand of lake Athabasca (Stockton
and Fritts, 1973) and low river levels in Northern Saskatchewan (Case and Macdon-
ald, 1995). For the Mackenzie delta region, the tree-ring width index for the period AD
1850–1900 displays relatively low values (Pisaric et al., 2007), and it also corresponds
with the AD 1855–1880 positive Northern Hemisphere summer temperature anomaly
(Brohan et al., 2006). The minimum values of freshwater palynomorph influxes in our
record during AD 1855–1900 (∼30 specimens cm^{-2} yr^{-1}), coupled with the relatively
high sea surface temperature reconstructions during AD 1855–1890 (up to 3°C above
the modern value) correlate very well with these records and strongly suggest that the
Mackenzie River discharge was at a minimum level during the 150 yr of our record.

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◄ | ►

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

The intermediate phase of our freshwater palynomorph record (AD 1902–1976; ∼ 100 specimens $cm^{-2} yr^{-1}$) corresponds to a relatively wet period, during which the population census divisions in the Prairies doubled (Government of Canada, 1938), and which was also marked by more favorable climatic conditions for crop production until the 1970s. Indeed, the 20th century began with a wet period (AD 1900–1920) (Sauchyn and Beaudoin, 1998; Watson and Luckman, 2006), as indicated by the Palmer Drought Severity Index (drought index), which was often positive during that period (Sauchyn and Skinner, 2001). The most recent phase during AD 1976–2004 (∼130 specimens $cm^{-2} yr^{-1}$) is marked by maximum influxes of freshwater palynomorphs (Fig. 4f). This period is well documented with instrumental data and displays the highest annual Mackenzie River discharge values on record (between 700 and 11900 $m^3 s^{-1}$), with a maximum reached in 1990. The Mackenzie Trough area is thus clearly affected by freshwater inputs from the Mackenzie River (Rawlins et al., 2009), which are probably controlled by regional and global oceanic and atmospheric (precipitations) circulation patterns, such as the PDO.

The PDO is a major mode of North Pacific climate variability and is reflected in the evolution of North Pacific monthly surface temperatures (Mantua et al., 1997; Mantua and Hare, 2002; Minobe, 1997). During positive phases, it manifests itself by low sea-level pressure anomalies over the North Pacific and high sea-level pressure anomalies over Western North America. At the same time, the surface air temperatures tend to be anomalously cool in the Central North Pacific and anomalously warm along the west coast of North America. The PDO also affects low pressure centers like the Aleutian Low system, which controls most of the daily precipitations in the Mackenzie and Yukon River basin (Cassano and Cassano, 2010) and the Bering Sea oceanic advection (Danielson et al., 2010). Moreover, the most recent variations of the position and intensity of the Aleutian Low centered above the Gulf of Alaska are linked with the PDO pattern (Moore et al., 2003; Schneider and Cornuelle, 2005). The Aleutian Low has been shown to deepen during positive phases of the PDO (Bjerknes, 1966, 1969, 1972; Overland et al., 1999). These regime shifts have many environmental impacts,

like sea-ice coverage anomaly in the Bering Sea during PDO positive phases (Niebauer 1989, 1998). On the other hand, Aleutian Pacific-born storms (and especially northward tending trajectories storms) have many impacts in oceanic environment along the Beaufort Shelf. They generally induce upwelling events and intrusions of warmer waters through the Alaskan Coastal Current onto the Beaufort Shelf (Okkonen et al., 2009; Pickart et al., 2009). Reconstructions of sea surface parameters for the entire time-period covered by the core indicate SSTs and SSSs above modern values during positive phases of the PDO (Fig. 4). Estimations of SIC indicate a lower duration of sea ice, with respect to modern values, during warm episodes and are consistent with upwelling events of saltier and warmer Pacific water recorded during positives phases of the PDO between AD 1925–1946 and 1979–1996 (e.g., Macdonnald et al., 1987). These events have many impacts in local productivity (e.g., Tremblay et al., 2011), such as the enhancement of local zooplankton density (Suzuki et al., personal communication) affecting the carbon cycle (Mucci et al., 2010). Our data indicate peaks of dinocyst influxes during these two periods, synchronous with higher than normal SST and SSS estimates, decreased SIC duration, which are consistent with an increase of primary productivity caused by upwellings of Pacific-water in the Mackenzie Trough area. Conversely, dinocysts fluxes are minimum during negative phases of the PDO, which are usually characterized by cooler than normal conditions (e.g., Schneider and Cornuelle, 2005). Our temperature and salinity estimates also agree with the sea-surface conditions expected during negative phases of the PDO (cooler temperatures, lower salinities and normal or slightly increased SIC values). A study by Ledu et al. (2012) on the same core based on lipid compounds production (IP_{25}) by sea-ice algae indicated a close relationship between PDO index and sea ice productivity. They attributed the enhancement of sea ice primary productivity to the increased frequency of upwelling events of warm and salty Pacific waters along the Beaufort slope events during positive phases of the PDO.

Most authors attributed interannual variability of the Arctic Ocean with fluctuations of the North Atlantic (NAO) and Arctic (AO) Oscillations (e.g., Deser et al., 2000; Morison

et al., 2012). The AO is generally difficult to distinguish from the NAO, which is a major source of low-frequency variability. The AO switched to a positive mode around AD 1970, but showed a maximum around AD 1991 (Dickson et al., 2000; Hurell, 1995; Hurrel and Van Loon, 1997). Our results indicate that freshwater palynomorph influxes increased > fivefold between AD 1972 and 1991, from 37 specimens cm^{-2} yr^{-1} to 202 specimens cm^{-2} yr^{-1}. Also, the maximum positive phase of the AO around AD 1991 coincides with a shift from a *P. dalei*-dominated dinocyst assemblage to one dominated by *O. centrocarpum*, which is also marked in our reconstructions by a decrease of SIC duration (from 9 to 5 months yr^{-1}) and an increase of $\sim$ 1.5 °C in SST (Fig. 4b, c), that are consistent with satellite data reported by National Snow and Ice Data Center in the same period. In the same way, Radi et al. (2001) noticed a decrease in the relative abundance of *P. dalei* when sea ice cover duration is reduced in the Chukchi Sea and Bering Strait areas. They also noted that this taxa is generally replaced by *O. centrocarpum* and *S. elongatus/frigidus* when ice conditions become important again, which is also depicted by our dinocyst assemblages (Fig. 3).

The positive reconstructed temperature and salinity values and associated decline of reconstructed sea-ice in our results occurred quasi-synchronously with: (1) a positive phase of the PDO during AD 1979–1996; (2) a major shift in the Arctic atmospheric and oceanic circulation associated with a positive phase of the AO that began in the 1970s (Thompson and Wallace, 1998, 2000; Walsh et al., 1996). This atmospheric configuration generated an anomalously low sea level pressure in the Arctic. In the same time, satellite imagery and physico-chemical data (Macdonald et al., 1999; Parkinson et al., 1999) suggest that a strong seasonality prevailed in the marginal seas surrounding Canada Basin during the 1990s with respect to sea ice coverage, with large areas of open water during the summer season and intensification of Pacific water intrusions in the Arctic during positive AO phases (McLaughin et al., 2002). However, the observed seasonality and associated reduction of sea ice extent in summer coincides with the maximum values of the Mackenzie River discharge and the maximum influxes of freshwater palynomorphs (Fig. 4b–f). The similarity between the freshwater palynomorphs

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◄ | ►

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

record (Fig. 4f) and the AO index (Fig. 4g) during the most recent phase of our fresh-water palynomorph record (1976–2004) would suggest a relationship between the AO and the Mackenzie freshwater discharge, but not appears during the previous phase (1902–1976). Déry and Wood (2004) have highlighted such teleconnection between the AO with the recent decline of Hudson Bay river discharge, therefore linking the AO with the regulation of terrestrial hydrology budgets. However, Burn (2008) compared the trends in the timing of runoff of three sub-watersheds of the Mackenzie River Basin with a series of 6 climatic indices. The results showed that the AO had no effect on the timing of river runoff, suggesting that the AO has little to no effect on the hydrologic cycle in the Mackenzie Basin. His analysis clearly showed a link between the timing of runoff within these watersheds and the PDO index. Moreover, the oscillation that has the greatest impact on the zones located around the AO Core Region is probably the PDO (Zhao et al., 2006). At a global scale, the PDO pattern seems to show a covari-ability with AO (Hetzinger et al., 2011). Thus, the series of climatic oscillations affecting the Northern Hemisphere are linked through a teleconnection sequence between the oceans and the atmosphere called "stade wave" (Wyatt et al., 2012). This teleconnec-tion plays a crucial role in climatic changes, notably in exchanges of heat fluxes within the Arctic thought the Bering Strait (Woodgate et al., 2004). According to our results, the PDO pattern is closely linked with most of the sea-surface condition variability in the study area through upwelling events of Pacific origin. However, the effect of the AO cannot be totally excluded, especially with respect to freshwater inputs.

6 Conclusions

The Mackenzie Trough is characterized by a high sedimentation rate suitable for high resolution studies of paleo-sea surface conditions. The excellent preservation of pa-lynomorphs allowed the reconstructions of sea-surface parameters. We also demon-strated that the evolution of temperature, salinity, sea ice cover and dinoflagellate pro-ductivity of the Mackenzie Trough area are closely linked with the phases of the PDO at

a decadal timescale. Positive phases of the PDO are associated with warm, high salinity, low sea ice and high primary productivity conditions in surface waters. Conversely, negative phases are associated with cool and low salinity conditions. Freshwater palynomorphs were used to infer the evolution of local freshwater inputs, which showed three distinct phases, a dry phase in the late 19th century, and intermediate phase from AD 1900 to ~ 1976 and the maximum Mackenzie River discharge phase which peaked around 1990. The AO does not seem to correlate with any of the parameters considered in the present study, which suggests that the Mackenzie Trough primary productivity and Mackenzie River freshwater discharge may be controlled by other parameters. The PDO may be the dominant climate oscillation mode leading oceanic circulation pattern, sea-surface parameters and productivity in the Western Canadian Arctic, at least at decadal timescales.

References

Aagaard, K.: The Beaufort Undercurrent, The Alaskan Beaufort Sea: Ecosystems and Environments, Academic Press, New York, 47–71, 1984.

Abdul Aziz, O. I. and Burn, D. H.: Trends and variability in the hydrological regime of the Mackenzie River Basin, J. Hydrol., 319, 282–294, 2006.

Appleby, P. G. and Olfield, F.: The calculation of lead-210 dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment, Catena, 5, 1–8, 1978.

Bjerknes, J.: A possible response of the atmospheric Hadley Circulation to equatorial anomalies of ocean temperature, Tellus, 18, 820–829, 1966.

Bjerknes, J.: Atmospheric teleconnections from the equatorial Pacific, Mon. Weather Rev., 97, 162–172, 1969.

Bjerknes, J.: Large-scale atmospheric response to the 1964–65 Pacific equatorial warming, J. Phys. Oceanogr., 2, 212–217, 1972.

Blasco, S. M., Fortin, G., Hill, P. R., O'Connor, M. J., and Brigham-Grette, J. K.: The Late Neogene and Quaternary stratigraphy of the Canadian Beaufort continental shelf, in: The Arctic Ocean Region, Vol. L, edited by: Grantz, A., Johnson, L., and Sweeney, J. F., Geological Society of America, The Geology of North America, 491–502, 1990.

Bonnet, S., de Vernal, A., Hillaire-Marcel, C., Radi, T., and Husum, K.: Variability of sea-surface temperature and sea-ice cover in the Fram Strait over the last two millennia, Mar. Micropaleontol., 74, 59–74, 2010.

Brohan, P., Kennedy, J., Harris, I., Tett, S. F. B., and Jones, P. D.: Uncertainty estimates in regional and global observed temperature changes: a new data set from 1850, J. Geophys. Res., 111, D12106, 2006.

Burn, D. H.: Climatic influences on streamflow timing in the headwaters of the Mackenzie River Basin, J. Hydrol., 352, 225–238, 2008.

Carmack, E. C. and Macdonald, R. W.: Oceanography of the Canadian Shelf of the Beaufort Sea; a setting for marine life, Arctic, 55, 29–45, 2002.

Carmack, E. C., Macdonald, R. W., and Papadakis, J. E.: Water mass structure and boundaries in the Mackenzie Shelf estuary, J. Geophys. Res., 94, 18043–18055, 1989.

Carmack, E. C., Macdonald, R. W., and Jasper, S.: Phytoplankton productivity on the Canadian Shelf of the Beaufort Sea, Mar. Ecol. Prog. Ser., 277, 37–50, 2004.

Case, R. A. and MacDonald, G. M.: A dendroclimatic reconstruction of annual precipitation on the Western Canadian prairies since AD 1505 from Pinus flexulus James, Quaternary Res., 44, 267–275, 1995.

Cassano, E. N. and Cassano, J. J.: Synoptic forcing of precipitation in the Mackenzie and Yukon River basins, Int. J. Climate, 30, 658–674, 2010.

Coachman, L. K., Aagaard, K., and Tripp, R. B.: Bering Strait: the Regional Physical Oceanography, University of Washington Press, Seattle, 1975.

Dale, B.: Cyst formation, sedimentation, and preservation: factors affecting dinoflagellate assemblages in recent sediments from Trondheimsfjord, Norway, Rev. Palaeobot. Palynol., 22, 39–60, 1976.

Danielson, S., Eisner, L., Weingartner, T., and Aagaard, K.:Thermal and haline variability over the Central Bering Sea shelf: seasonal and interannual perspectives, Cont. Shelf Res., 31, 539–554, 2011.

Déry, S. J. and Wood, E. F.: Teleconnection between the Arctic Oscillation and Hudson Bay river discharge, Geophys. Res. Let., 31, L18205, 2004.

Deser, C.: On the teleconnectivity of the Arctic Oscillation, Geophys. Res. Lett., 27, 779–782, 2000.

Dittmar, T. and Kattner, G.: The biogeochemistry of the river and shelf ecosystem of the Arctic Ocean: a review, Marine Chem., 83, 103–120, 2003.

Fensome, R. A. and Williams, G. L. (Eds.): The Lentin and Williams Index of fossil dinoflagellates, American Association of Stratigraphic Palynologists Foundation, Contr. Ser. 42, 1–909, 2004.

Government of Canada: Census of the Prairie Prooinces, 1936, King's Printer, Ottawa, 1938.

Guiot, J.: Methods and programs of statistics for paleoclimatology and paleoecology, in: Quantifications des Changements Climatiques: Methode et Programmes, edited by: Guiot, J. and Labeyrie, L., Institut National des sciences de l'Univers, INSU, France, Paris, Monographie 1, 1990.

Guiot, J. and de Vernal, A.: Transfer functions: methods for quantitative paleo- ceanography based on microfossils, in: Proxies in Late Cenozoic Paleoceanography, edited by: Hillaire-Marcel, C. and de Vernal, A., Elsevier, Amsterdam, 523–563, 2007.

Harland, R. and Pudsey, C. J.: Dinofagellate cysts from sediment traps deployed in the Bellingshausen, Weddell and Scotia seas, Antarctica, Mar. Micropaleontol., 37, 77–99, 1999.

Hassol, S. J.: Impacts of a warming Arctic, in: Arctic Climate Impact Assessment, Cambridge University Press, New York, 2004.

Head, M. J., Harland, R., and Matthiessen, J.: Cold marine indicators of the late Quaternary: the new dinoflagellate cyst genus Islandinium and related morphotypes, J. Quatenary. Sci., 16, 621–636, 2001.

Hetzinger, S., Halfar, J., Mecking, J. V., Keenlyside, N. S., Kronz, A., Steneck, R. S., Adey, W. H., and Lebednik, P. A.: Marine proxy evidence linking decadal North Pacific and Atlantic climate, Clim. Dynam., doi:10.1007/s00382-011-1229-4, 2011.

Heusser, L. E.: Pollen distribution in the bottom sediments of the Western North Atlantic Ocean, Mar. Micropaleontol., 8, 77–88, 1983.

Hill, P. R.: Late Quaternary sequence stratigraphy of the Mackenzie Delta, Can. J. Earth Sci., 33, 1064–1074, 1996.

Hill, P. R., Blasco, S. M., Harper, J. R., and Fissel, D. B.: Sedimentation on the Canadian Beaufort Shelf, Cont. Shelf Res., 11, 821–842, 1991.

Hill, P. R., Lewis, C. P., Desmarais, S., Kauppaymuthoo, V., and Rais, H: The Mackenzie Delta: sedimentary processes and facies of a high-latitude, fine-grained delta, Sedimentology, 48, 1047–1078, 2001.

Hurrell, J. W.: Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation, Science, 269, 676–679, 1995.

Hurrell, J. W. and van Loon, H.: Decadal variations in climate associated with the North Atlantic oscillation, Clim. Change, 36, 301–326, 1997.

IPCC (Intergovernmental Panel on Climate Change): Third Assessment Report: Climate Change 2001, edited by: Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Xiaosu, D., McCarthy, J., Canziani, O. F., Leary, N. A., Dokken, D. J., White, K. S., Metz, B., Davidson, O., Swart, R., Pan, J., and Watson, R. T., Cambridge University Press, Cambridge, UK, 2001.

IPCC (Intergovernmental Panel on Climate Change): Climate Change 2007: Synthesis Report: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm, 2007.

Iseki, K., Macdonald, R. W., and Carmack, E.: Distribution of particulate matter in the Southeastern Beaufort Sea in late summer, Polar Biol., 1, 35–46, 1987.

Kulikov, E. A., Carmack, E. C., and Macdonald, R. W.: Flow variability at the continental shelf break of the Mackenzie Shelf in the Beaufort Sea, J. Geophys. Res., 103, 12725–12741, 1998.

Kunz-Pirrung, M.: Dinoflagellate cyst assemblages in surface sediments of the Laptev Sea region (Arctic OCean) and their relationship to hydrographic conditions, J. Quaternary Sci., 16, 637–649, 2001.

Ledu, D., Rochon, A., de Vernal, A., and St-Onge, G.: Holocene paleoceanography of the Northwest Passage, Canadian Arctic Archipelago, Quat. Sci. Rev., 29, 3468–3488, 2010.

Paleoceanography on the Beaufort Sea

L. Durantou et al.

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◄ | ►|

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Ledu, D., Kaiser, J., Massé, G., Bouloubassi, I., Scmidt, S., Rochon, A., and Babin, M.: The use of IP$_{25}$ lipid biomarker as a potential proxy of upwelling events along the Canadian Beaufort shelf, submitted to J. Geophys. Res., 2012.

Macdonald, R. W., Wong, C. S., and Erickson, P. E.: The distribution of nutrients in the South-eastern Beaufort Sea: implications for water circulation and primary production, J. Geophysical Res. C Oceans, 92, 2939–2952, 1987.

Macdonald, R. W., Paton, D. W., Carmack, E. C., and Omstedt, A.: The freshwater budget and under-ice spreading of Mackenzie River water in the Canadian Beaufort Sea based on salinity and ^{18}O/^{16}O measurements in water and ice, J. Geophys. Res., 100, 895–919, 1995.

Macdonald, R. W., Solomon, S. M., Cranston, R. E., Welch, H. E., Yunker, M. B., and Gobeil, C.: A sediment and organic carbon budget for the Canadian Beaufort Shelf, Mar. Geol., 144, 255–273, 1998.

Macdonald, R. W., Carmack, E. C., McLaughlin, F. A., Falkner, K. K., and Swift, J. H.: Connections among ice, runoff and atmospheric forcing in the Beaufort Gyre, Geophys. Res. Lett., 26, 2223–2226, 1999.

Macdonald, R. W., McLaughlin, F. A., and Carmack, E. C.: Freshwater and its sources during the SHEBA drift in the Canada Basin of the Arctic Ocean, Deep-Sea Res. Pt. I, 49, 1769–1785, 2002.

Macdonald, R. W., Harner, T., and Fyfe, J.: Recent climate change in the Arctic and its impact on contaminant pathways and interpretation of temporal trend data, Sci. Total Environ., 342, 5–86, 2005.

Mantua, N. J. and Hare, S. R.: The Pacific decadal oscillation, J. Oceanogr., 58, 35–44, 2002.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J., and Francis, R.: A Pacific interdecadal climate oscillation with impact on salmon production, B. Am. Meteor. Soc., 78, 1069–1079, 1997.

Martin, J., Tremblay, J.-É., Gagnon, J., Tremblay, G., Lapoussière, A., Jose, C., Poulin, M., Gosselin, M., Gratton, Y., and Michel, C.: Prevalence, structure and properties of subsurface chlorophyll maxima in Canadian Arctic waters, Mar. Ecol. Prog. Ser., 412, 69–84, 2010.

Maslanik, J. A., Serreze, M. C., and Barry, R. G.: Recent decreases in Arctic summer ice cover and linkages to atmospheric circulation anomalies, Geophys. Res. Lett., 23, 1677–1680, 1996.

Matthews, J.: The assessement of a method for the determination of absolute pollen frequencies, New Phytol., 68, 161–166, 1969.

Matthiessen, J., de Vernal, A., Head, M., Okolodkov, Y., Zonneveld, K., and Harland, R.: Modern organic-walled dinoflagellate cysts in Arctic marine environments and their (paleo-) environmental significance, Palaontol. Z., 79, 3–51, 2005.

McBean, G., Alekseev, G., Chen, D., Førland, E., Fyfe, J., Groisman, P. Y., King, R., Melling, H., Vose, R., and Whitfield, P. H.: Arctic climate: past and present, Arctic Climate Impact Assessment, Scientific Report, Cambridge University Press, Cambridge, 2005.

Melling, H.: Hydrographic changes in the Canada Basin of the Arctic Ocean, 1979–1996, J. Geophys. Res., 103, 7637–7645, 1998.

Minobe, S.: A 50–70 year climatic oscillation over the North Pacific and North America, Geophys. Res. Lett., 24, 683–686, 1997.

Moore, G. W. K., Holdsworth, G., and Alverson, K.: The impact that elevation has on the ENSO signal in precipitation records from the Gulf of Alaska Region, Clim. Change, 59, 101–121, 2003.

Morison, J., Kwok, R., Peralta-Ferriz, C., Alkire, M., Rigor, I., Andersen, R., and Steele, M.: Changing Arctic Ocean freshwater pathways, Nature, 481, 7379, 66–70, 2012.

Mudie, P. J.: Pollen distribution in recent marine sediments, Eastern Canada, Can. J. Earth Sci., 19, 729–747, 1982.

Mudie, P. J.: Circum-Arctic Quaternary and Neogene marine palynofloras: paleoecology and statistical analysis, in: Head, M. J. and Wrenn, J. H. (Eds), Neogene and Quaternary Dinoflagellate Cysts and Acritarchs, American Association of Stratigraphic Palynologists Foundation, Dallas, 347–390, 1992.

Mudie, P. J. and Rochon, A.: Distribution of dinoflagellate cysts in the Canadian Arctic marine region, J. Quaternary Sci., 16, 603–620, 2001.

Niebauer, H. J.: Variability in Bering Sea ice cover as affected by a regime shift in the North Pacific in the period 1947–1996, J. Geophys. Res. C. Oceans, 103, 717–727, 1998.

Niebauer, H. J. and Day, R. H.: Causes of interannual variability in the sea ice cover of the Eastern Bering Sea, Geol. J., 18, 45–59, 1989.

Nikolopoulos, A., Pickart, R. S., Fratantoni, P. S., Shimada, K., Torres, D. J., and Jones, E. P.: The Western Arctic boundary current at 152° W: structure, variability, and transport, Deep-Sea Res. Pt. II, 56, 1164–1181, 2009.

NODC: World Ocean Atlas, National Oceanographie Center, CD-Rom data Sets, National Oceanic and Atmospheric Administration, Boulder, CO, 2001.

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper

O'Brien, M. C., Macdonald, R. W., Melling, H., and Iseki, K.: Particle fluxes and geochemistry on the Canadian Beaufort Shelf: implications for sediment transport and deposition, Cont. Shelf Res., 26, 41–81, 2006.

Okkonen, S., Ashjian, C. A., Campbell, R. G., Maslowski, W., Clement-Kinney, J., and Potter, R.: Intrusion of warm Bering/Chukchi waters onto the shelf in the Western Beaufort Sea, J. Geophys. Res., 114, C00A11, 2009.

Overland, J., Adams, J., and Bond, N.: Decadal variability of the Aleutian Low and its relation to high-latitude circulation, J. Climate, 12, 1542–1548, 1999.

Parkinson, C. L., Cavalieri, D. J., Gloersen, P., Zwally, H. J., and Comiso, J. C.: Arctic sea ice extents, areas, and trends, 1978–1996, J. Geophys. Res., 104, 20837–20856, 1999.

Persson, A., Godhe, A., and Karlson, B.: Dinoflagellate cysts in recent sediments from the west coast of Sweden, Bot. Marina, 43, 69–79, 2000.

Pickart, R. S., Moore, G. W. K., Torres, D. J., Fratantoni, P. S., Goldsmith, R. A., and Yang, J.: Upwelling on the continental slope of the Alaskan Beaufort Sea: storms, ice, and oceanographic response, J. Geophys. Res., 114, C00A13, 2009.

Pisaric, M. F. J., Sean, K. C., Kokeli, S. V., and Youngblut, D.: Anomalous 20th century tree growth, Mackenzie Delta, Northwest Territories, Canada, Geophys. Res. Lett., 34, 105714, 2007.

Pisaric, M. F. J., St-Onge, S. M., and Kokelj, S. V.: Tree-ring reconstruction of early-growing season precipitation from Yellowknife, Northwest Territories, Canada, Arct. Antarct. Alpine Res., 41, 4, 486–496, 2009.

Polyakov, I. D., Alekseev, G. V., Bekryaev, R. V., Bhatt, U., Colony, R., Johnson, M. A., Karklin, V. P., Makshtas, A. P., Walsh, D., and Yulin, A. V.: Observationally based assessment of polar amplification of global warming, Geophys. Res. Lett., 29, 1878, 2002.

Porter, T. J., Pisaric, M. F. J., Kokelj, S. V., and Edwards, T. W. D.: Climatic signals in δ^{13}C and δ^{18}O of tree-rings from white spruce in the Mackenzie Delta Region, Northern Canada. Arct. Antarct. Alpine Res., 41, 497–505, 2009.

Prell, W. L.: The stability of low-latitude sea-surface temperatures, an evaluation of the CLIMAP reconstruction with emphasis on the positive SST anomalies, Report no. TR025, US Dep. of Energy, Washington, D. C., 1985.

Radi, T., de Vernal, A., and Peyron, O.: Relationships beetween dinoflagellate cyst assemblages in surface sediment and hydrographic conditions in the Bering and Chukchi seas, J. Quaternary Sci., 16, 667–680, 2001.

Radi, T., Bonnet, S., Cormier, M. A., de Vernal, A., Durantou, L., Faubert, E., Head, M. J., Henry, M., Pospelova, V., Rochon, A., and van Nieuwenhove, N.: Operational taxonomy for round, brown, spiny dinocysts from high latitudes of the Northern Hemisphere, submitted to Palaeogeogr. Palaeoclimatol., Palaeoec., 2012.

Rawlins, M. A., Steele, M., Serreze, M. C., Vorosmarty, C. J., Ermold, W., Lammers, R. B., McDonald, K. C., Pavelsky, T. M., Shilomanov, A., and Zhang, J.: Tracing freshwater anomalies through the air-land-ocean system: a case study from the Mackenzie River Basin and the Beaufort Gyre, Atmos. Ocean., 47, 1, 79–97, 2009.

Richerol, T., Rochon, A., Blasco, S., Scott, D. B., Schell, T. M., and Bennett, R. J.: Distribution of dinoflagellate cysts in surface sediments of the Mackenzie Shelf and Amundsen Gulf, Beauford Sea (Canada), J. Marine Syst., 74, 825–839, 2008.

Rochon, A. and de Vernal, A.: Palynomorph distribution in Recent sediments from the Labrador Sea, Can. J. Earth Sci., 31, 115–127, 1994.

Rochon, A., de Vernal, A., Turon, J. L., Matthiessen, J., and Head, M. J.: Distribution of recent dinoflagellate cysts in surface sediments from the North Atlantic Ocean and adjacent seas in relation to sea-surface parameters, American Association of Stratigraphic Palynologists Foundation, Dallas, Texas, Contr. Ser. 35, 152 pp., 1999.

Sauchyn, D. J. and Beaudoin, A. B.: Recent environmental change in the Southwestern Canadian plains, Can. Geogr., 42, 337–353, 1998.

Sauchyn, D. J. and Skinner, W. R.: A proxy record of drought severity for the Southwestern Canadian plains, Can. Water Resour. J., 26, 253–272, 2001.

Schneider, N. and Cornuelle, B. D.: The forcing of the PDO, J. Climate, 18, 4355–4373, 2005.

Steele, M. and Ermold, W.: Salinity trends on the Siberain shelves, Geophys. Res. Lett., 31, L24308, 2004.

Stockton, C. W. and Fritts, H. C.: Long-term reconstruction of water level changes for Lake Athabasca by analysis of tree-rings, Water Resour. Bull., 9, 1006–1027, 1973.

Suzuki, K., Robert, D., Sampei, M., Darnis, G., Bélanger, S., Fortier, L.: Small copepods thrive under the recent upwelling-favorable conditions in the southeastern Beaufort Sea, Canadian Arctic, submitted to Deep-Sea Res., 2011.

Thompson, D. W. J. and Wallace, J. M.: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields, Geophys. Res. Lett., 25, 1297–1300, 1998.

Thompson, D. W. J. and Wallace, J. W.: Annual modes in the extratropical circulation, Part I: Month to month variability, J. Climate, 13, 1000–1016, 2000.

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◄ | ►

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Tucker, W. B., Weatherly, J. M., Eppler, D. T., and Farmer, L. D.: Evidence for rapid thinning of sea ice in the Western Arctic Ocean at the end of the 1980s, Geophys. Res. Lett., 28, 2851–2854, 2001.

de Vernal, A. and Guiot, J.: Is spatial autocorrelation introducing biases in the apparent accuracy of paleoclimatic reconstructions?, Quaternary Sci. Rev., 30, 2011.

de Vernal A., Henry, M., Matthiessen, J., Mudie, P. J., Rochon, A., Boessenkool, K., Eynaud, F., Grøsfjeld, K., Guiot, J., Hamel, D., Harland, R., Head, M. J., Kunz-Pirrung, M., Levac, E., Loucheur, V., Peyron, O., Pospelova, V., Radi, T., Turon, J. L., and Voronina, E.: Dinoflagellate cyst assemblages as tracers of sea-surface conditions in the Northern North Atlantic, Arctic and sub-Arctic seas: the new "$n = 677$" database and application for quantitative paleoceanographical reconstruction, J. Quaternary Sci., 16, 681–698, 2001.

de Vernal, A., Eynaud, F., Henry, M., Hillaire-Marcel, C., Londeix, L., Mangin, S., Matthiessen, J., Marret, F., Radi, T., Rochon, A., Solignac, S., and Turon, J. L.: Reconstruction of sea-surface conditions at middle to high latitudes of the Northern Hemisphere during the Last Glacial Maximum (LGM) based on dinoflagellate cyst assemblages, Quaternary Sci. Rev., 24, 897–924, 2005.

Walsh, J. E., Tanaka, H. L., and Weller, G.: Wadati Conference on Global Change and the Polar Climate, 7–10 November 1995, Tsukuba, Japan, Bull. Am. Met. Soc., 77, 1268–1273, 1996.

Wang, J., Cota, G. F., and Comiso, J. C.: Phytoplankton in the Beaufort and Chukchi seas; distribution, dynamics, and environmental forcing, Deep-Sea Res. Pt. II, 52, 3355–3368, 2005.

Watson, E. and Luckman, B. H.: Long hydroclimate records from tree-rings in Western Canada: potential, problems and prospects, Can. Water Resour. J., 31, 205–228, 2006.

Wendler, G., Shulski, M., and Moore, B.: Changes in the climate of the Alaskan North Slope and the ice concentration of the adjacent Beaufort Sea, Theor. Appl. Climatol., 99, 67–74, 2010.

Williams, W. J., Carmack, E. C., Shimada, K., Melling, H., Aagaard, K., Macdonald, R. W., and Ingram, R. G.: Joint effects of wind and ice motion in forcing upwelling in Mackenzie Trough, Beaufort Sea, Cont. Shelf Res., 26, 2352–2366, 2006.

Woodgate, R. A. and Aagaard, K.: Revising the Bering Strait freshwater flux into the Arctic Ocean, Geophys. Res. Lett., 32, L02602, 2005.

Wyatt, M., Kravtsov, S., and Tsonis, A. A.: Atlantic Multidecadal Oscillation and Northern Hemisphere's climate variability, Clim. Dynam., 38, 929–949, doi:10.1007/s00382-011-1071-8, 2012.

Zhao, J. P., Cao, Y., and Shi, J. X.: Core region of Arctic Oscillation and the main atmospheric events impact on the Arctic, Geophys. Res. Lett., 33, L22708, 2006.

**Paleoceanography
on the Beaufort Sea**

L. Durantou et al.

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◀ | ▶

◀ | ▶

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

**Paleoceanography
on the Beaufort Sea**

L. Durantou et al.
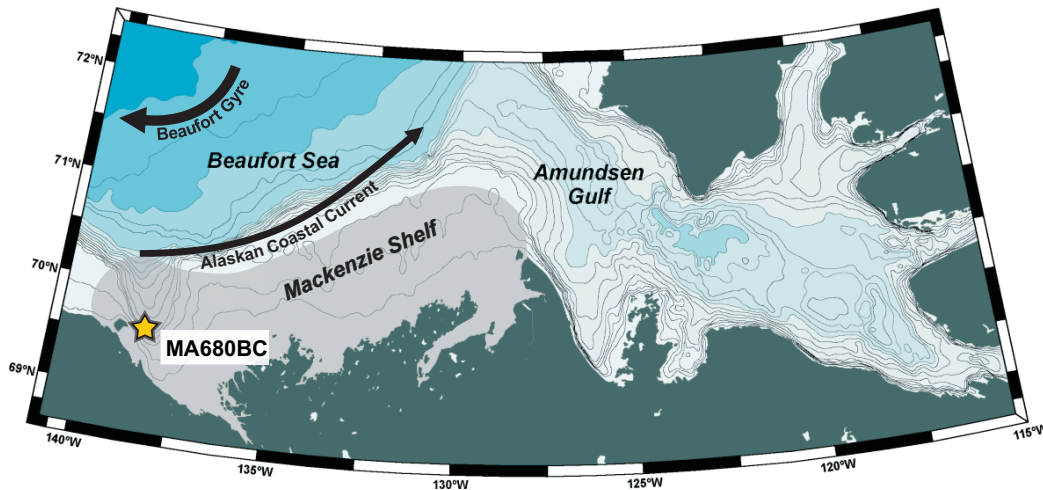
Fig. 1. Location map of core MA680BC and oceanic circulation in the study area. The thick arrow represents the clockwise Beaufort Gyre, the thin arrow indicates the Alaska Coastal Current and the grey area represents the Mackenzie River plume.
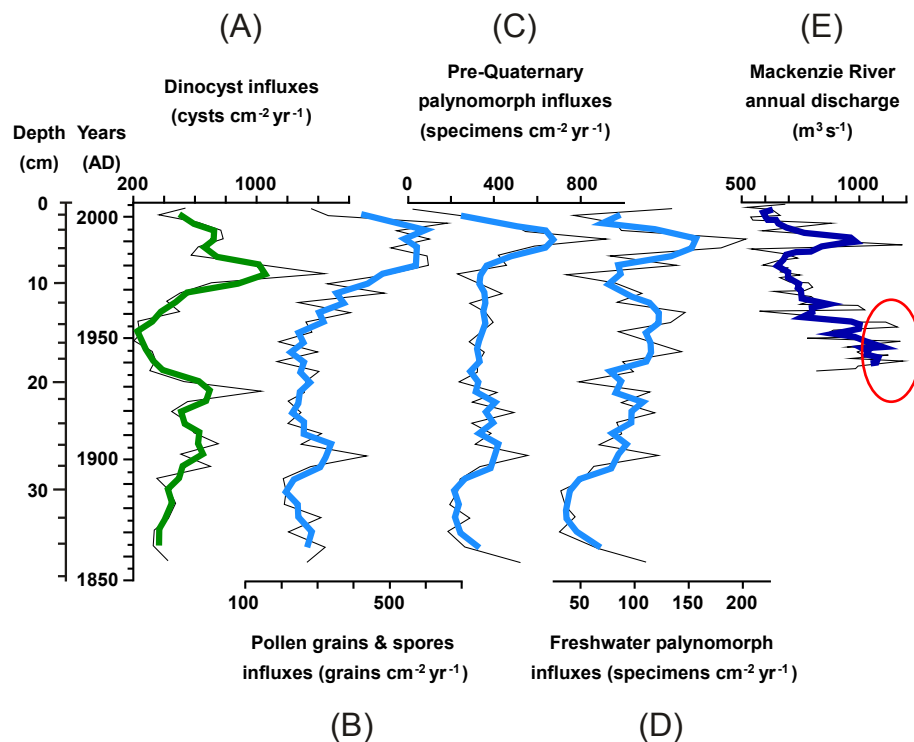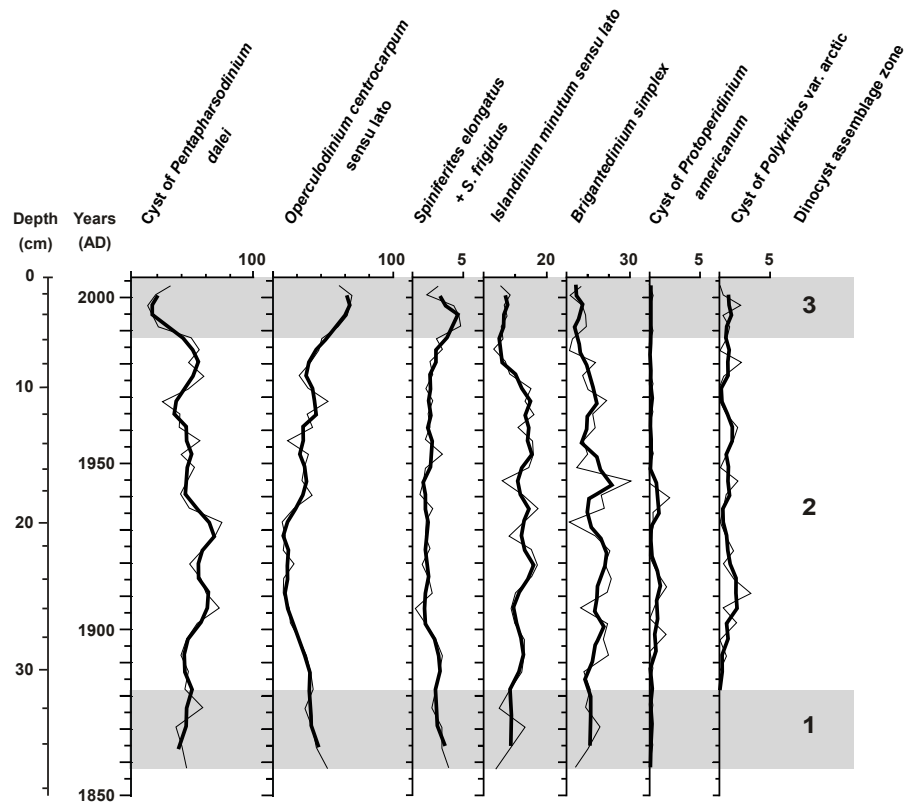
Fig. 2. Palynomorph influxes in core MA680BC plotted against depth and age AD. Dinocyst influxes **(A)**; Pollen and spores influxes **(B)**; pre-Quaternary palynomorph influxes **(C)**; freshwater palynomorph influxes **(D)**; Mackenzie River annual discharge from 1938 to 2006 (HYDAT) **(E)**. The thick curves represent a smooth over 3 data points.

Fig. 3. Relative abundances of the major dinoflagellate cyst taxa in core MA680BC and dinocyst assemblage zones plotted against depth and age AD. The thick curves represent a smooth over 3 data points.
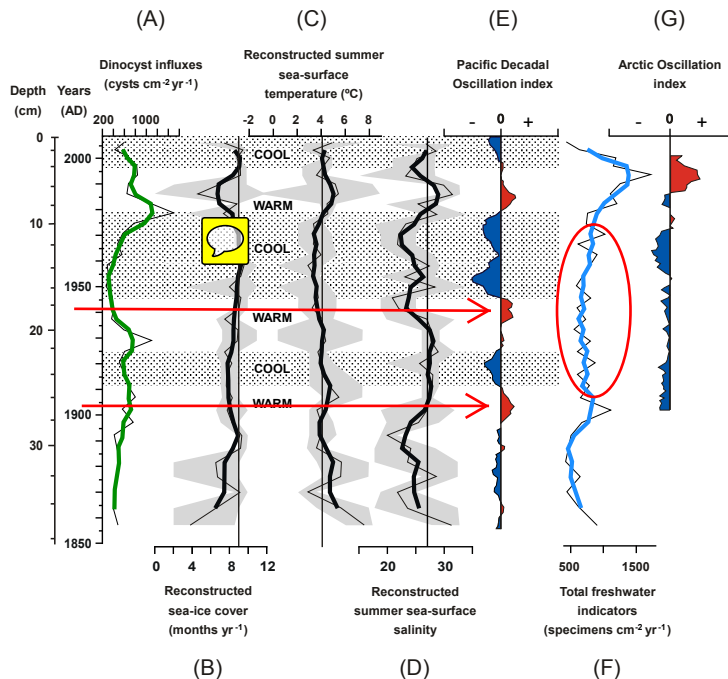
Fig. 4. Dinocyst influxes and reconstructed sea surface parameters in core MA680 BC, and climate indexes plotted against depth and age AD. Dinocysts influxes **(A)**; reconstructed sea-ice cover **(B)**; reconstructed temperature **(C)**; reconstructed salinity **(D)**; Pacific Decadal Oscillation (PDO) normalized index **(E)**; freshwater palynomorph influxes **(F)**; Arctic Oscillation (AO) normalized index **(G)**. The modern values of sea-surface parameters are represented by the vertical line. The grey areas represent the confidence interval (minimum and maximum possible values) for each reconstructed parameter. The horizontal dotted areas represent warm and cool intervals asociated with positive and negative phases respectively for the PDO index (Mantua and Hare, 2002). The thick curves represent a smooth over 3 data points. Both PDO and AO indexes are smoothed over 5 data points.
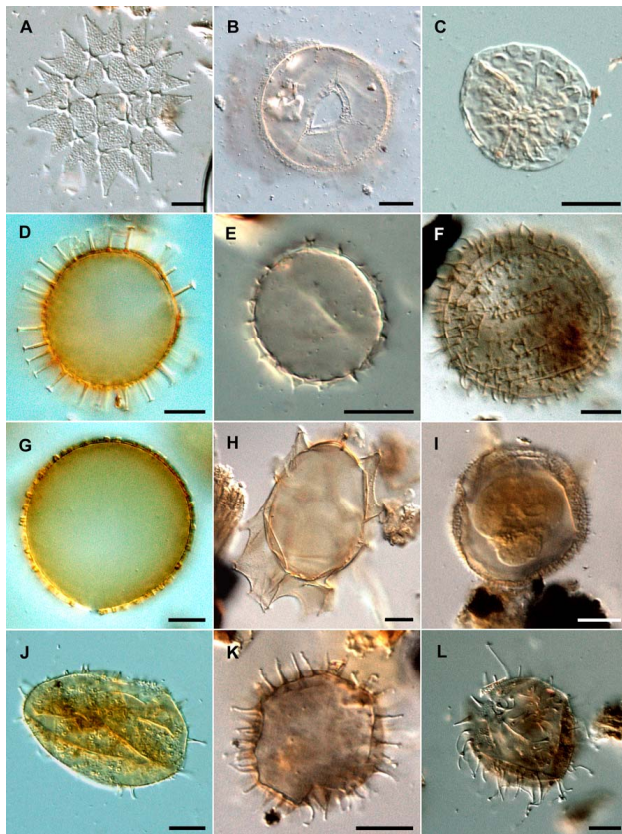
Fig. 5. (A) *Pediastrum* sp. **(B)** *Halodinium* sp. **(C)** *Zygnema* sp. **(D)** *Operculodinium centrocarpum* **(E)** Cyst of *Pentapharsodinium dalei* **(F)** *Islandinium minutum* **(G)** *Operculodinium centrocarpum* short spines **(H)** *Spiniferites frigidus* **(I)** *Islandinium brevispinosum* **(J)** *Operculodinium centrocarpum* var. Arctic **(K)** *Echinidinium karaense* **(L)** *Islandinium minutum* var. Cezare.

Specimens data: MA680BC

- **(A)** *Pediastrum* sp.: 19–20 cm, K14, 3
- **(B)** *Halodinium* sp.: 19–20 cm, K26; 4
- **(C)** *Zygnema* sp.: 20–21 cm; U15
- **(D)** *Operculodinium centrocarpum*: 21–22 cm, O28; 4
- **(E)** Cyst of *Pentapharsodinium dalei*: 21–22 cm; E15; 3
- **(F)** *Islandinium minutum*: 19–20 cm, M23; 4
- **(G)** *Operculodinium centrocarpum* short spines: 25–26 cm; R10; 2
- **(H)** *Spiniferites frigidus*: 21–22 cm; E11; 1
- **(I)** *Islandinium brevispinosum*: 29–30 cm, V23; 1
- **(J)** *Operculodinium centrocarpum* var. Arctic : 19–20 cm; 535; 3
- **(K)** *Echinidinium karaense*: 21–22 cm, G4; 3
- **(L)** *Islandinium minutum* var. Cezare: 21–22 cm: E38