

The Arctic Ocean in the Cenozoic climate system

C. Hillaire-Marcel, GEOTOP, *Université du Québec à Montréal*, Canada,

The history of the Arctic Ocean remained poorly known until the 2004 IODP coring of Lomonosov Ridge sediments which revealed the existence of an Eocene 'lake-stage' prior to the marine submergence (e.g., Moran et al., *Nature* 441, 2004). As a consequence of high latitude plate tectonics movements, the opening of Fram Strait (cf. Jakobsson et al., *Nature* 447, 2007) allowed input of North Atlantic marine water into the Arctic basin leading to a shift from lacustrine to marine environmental conditions. Osmium isotope stratigraphy and Re-Os isochrons concur to assign a Late Eocene age (~36 Ma) to this lake drainage/marine submergence event (Poirier & Hillaire-Marcel, *GRL* 36, 2009; *GRL* 28, 2011). This late Eocene opening of Fram Strait confers a potential role to the Arctic basin into the inception of the Atlantic Meridional Overturning Circulation (AMOC) during the Early Oligocene (Davies et al., *Nature* 410, 2001). Coring expeditions of the last decade yielded complementary records spanning the last few climatic cycles, although stratigraphies, in the central Arctic Ocean notably, remain open to debate beyond a few tens of thousand years. Nonetheless, the late deglaciation is sufficiently well documented to illustrate the potential role of export of Arctic Ocean sea-ice and freshwater into instabilities of the AMOC.

Prof. Claude HILLAIRE-MARCEL

Degrees: 1966 Licence ès Sciences (Sci. naturelles), Sorbonne, Paris
1967 Diplôme d'Etudes supérieures, Sorbonne, Paris
1979 Doctorat d'État (Sci. naturelles), Paris VI, France

Positions: since 1969 Professor Dept. Earth Sci., Université du Québec
2000 - 2005 UNESCO Chair for Global Change Study (UQAM)
1990 - 2000 Industrial Chair of the *Natural Science & Engineering Research Council of Canada* (Environment)
1984 - 1989 *Directeur de Recherche*, CNRS France
1981 - 2009 Invited-professor during sabbatical leaves (Univ. Paris XI, IPG-Paris, Salamanca, Aix-Marseille III, etc.)

Research Work: "Isotopes & Earth surface processes " are the unifying thread of my research and tutorial activities. The use of stable, radioactive and radiogenic isotopes to unravel mechanisms driving climate and ocean changes at geological time scales requires parallel efforts towards understanding the behaviour of isotopic tracers and chronometers in modern environments. Thus, my major contributions concern both paleo- and modern environmental issues, with focus on the Arctic Ocean and North Atlantic paleoceanography, Quaternary sea-level changes, and isotope hydrology & paleohydrology.. Major research projects in course include i) studies of fresh-water fluxes and paleo-sea ice conditions in the Arctic within the frame of the European project Past4Future, ii) investigations on sea-level changes in islands of archipelagos of the Atlantic Ocean and Mediterranean Sea (in collaboration with Spanish & Portuguese scientists) and iii) investigations on the use of U-series isotopes for dating purposes.

Professional: 2011 – 2012 Geoscience committee of the Natural Science and Engineering Council of Canada
2010 - present AIEA committee (Isotopic standards and reference materials)
2009 - present Organizing Committee of the 2012 Goldschmidt Conference (GEOTOP-Montreal)
2000 - 2004 Vice-president of the Quebec Funds for Research (Nature & Technologie)
Since 1976 Membership and/or chair of a large array of Canadian and foreign/international bodies (INQUA commissions, IAEA, French ANR & AERES, UNESCO-IUGS projects, etc .)

Editorial tasks: Editor *Quaternary Science Reviews* (Elsevier)
Associate-editor *Canadian Journal of Earth Sciences* (NRC)

Distinctions: 2008 Medal of the *Université du Québec à Montréal*
2006 Killam Scholar (Canadian Council of Arts)
2006 Logan Medal (Geological Association of Canada)
2006 Fellow, American Association for the Advancement of Science (AAAS)
2003 Johnston Medal of the Canadian Association for Quaternary Studies (CANQUA)
2002 Scientific Prize (Prix Marie-Victorin) of the Québec Government

(APGGQ)	2000 Medal for Scientific Merit in Environmental Studies, <i>Association professionnelle des géologues et géophysiciens du</i>	Québec
	1992 Prize Michel-Jurdant, <i>Association canadienne-française pour l'Avancement des Sciences (ACFAS)</i>	
	1991 Fellow of the Royal Society of Canada (Academy of Sciences)	

Peer-reviewed publications (last five years; * relevant public. for this proposal)

2012

- Rosa, E., Gaillardet, J., Hillaire-Marcel, C.: Chemical weathering rates over shield vs sedimentary platform basements in eastern Canada: Environmental and carbon cycling aspects. *Canadian Journal of Earth Sciences* (accepted for publication).
- Rosa, E., Hillaire-Marcel, C., Ghaleb, B., Terry, D.A.: Hydroclimatic and anthropic controls on riverine dissolved uranium in the Hudson, James and Ungava Bays region, Canada. *Canadian Journal of Earth Sciences* (accepted for publication).
- Ruiz-Fernández, A.C et al. (incl. Hillaire-Marcel, C.): Effects of land-use change and sediment mobilization on coastal contamination (Coatzacoalcos River, Mexico). *Continental Shelf Research*, in press .
- Not, C., Brown, K., Ghaleb, B., Hillaire-Marcel, C., 2012: Conservative behavior of Uranium with respect to Salinity in Arctic Sea Ice and Brines. *Marine Chemistry* 130-131, 33–39.
- *Channell, J.E.T., Hodel, D.A., Romer, O., Hillaire-Marcel, C., de Vernal, A., Stoner, J.S., Mazaud, A., Röhl, U., 2012: A 750-kyr detrital-layer stratigraphy for the North Atlantic (IODP Sites U1302–U1303, Orphan Knoll, Labrador Sea). *Earth and Planetary Science Letters* 317–318, 218-230.
- *Not, C., Hillaire-Marcel, C., 2012: Enhanced sea-ice export from the Arctic during the Younger Dryas. *Nature Communications*, doi: 10.1038/ncomms1658.
- *Maccali, J., Hillaire-Marcel, C., Carignan, J., Reisberg, L.C., 2012: Pb isotopes and geochemical monitoring of Arctic sedimentary supplies and water-mass export through Fram Strait since the Last Glacial Maximum. *Paleoceanography* 26, doi:10.1029/2011PA002152.
- Refsnider, K.A., Miller, G.H., Hillaire-Marcel, C., Fogel, M., Ghaleb, B., Bowden, R., 2012: Subglacial carbonates constrain basal conditions and oxygen isotopic composition of the Laurentide Ice Sheet over Arctic Canada. *Geology* 40, 135-138.

2011

- Ruiz-Fernández, A.C., Páez-Osuna, F., Soto-Jimenez, M., Hillaire-Marcel, C., Ghaleb, B., 2011. The loading history of trace metals and nutrients in Altada-Ensenada del Pabellon lagoon complex, northwestern Mexico. *Journal of Environmental Radioactivity* 69, 129-143.
- *Hoogakker, B.A.A., Chapman, I.M.R., McCave, N. Hillaire-Marcel, C., Ellison, C.W.R., Hall, I.R., Telford, R., 2011. Dynamics of North Atlantic Deep Water Masses during the Holocene. *Paleoceanography*, 26, doi:10.1029/2011PA002155.
- *Poirier, A., Hillaire-Marcel, C., 2011. Improved O₃ isotope stratigraphy of the Arctic Ocean. *Geophysical Research Letters* 38, doi:10.1029/2011GL047953.
- *Genovesi, L., de Vernal, A., Thibodeau, B., Hillaire-Marcel, C., Mucci, A., Gilbert, D., 2011. Recent changes in bottom water oxygenation and temperature in the Gulf of St. Lawrence; geochemical and micropaleontological evidence. *Limnology and Oceanography* 56(4), 1319-1329.
- *Hillaire-Marcel, C. de Vernal, A., McKay, J., 2011. Foraminifer isotope study of the Pleistocene Labrador Sea, northwest North Atlantic (IODP Sites 1302/03 and 1305), with emphasis on paleoceanographical differences between its "inner" and "outer" basins. *Marine Geology* 279, 188-198.
- *Dabrio, C.J. Zazo, C. Cabero, A., Goy, J.L., Bardají, T., Hillaire-Marcel, C., González-Delgado, J.A. Lario, J., Silva, P.G. , Borja, F., García-Blázquez, A.M. , 2010. Millennial/submillennial-scale sea-level fluctuations in western Mediterranean during the second highstand of MIS 5e. *Quaternary Science Reviews* 30: 345-356.
- *Thibodeau, B., de Vernal, A., Hillaire-Marcel, C., Mucci, A., 2010. 20th Century warming in deep waters of the Gulf of St. Lawrence: a unique feature of the last millennium. *Geophysical Research Letters* 37, L17604, doi:10.1029/2010GL044771.

- *Not, C. & Hillaire-Marcel, C., 2010. Time constraints from ^{230}Th and ^{231}Pa data in late Quaternary, low sedimentation rate sequences from the Arctic Ocean: An example from the northern Mendeleev Ridge. *Quaternary Science Review* 25-26: 3665-3675.
- *Ruiz-Fernández, A.C., Hillaire-Marcel, C., 2010. ^{210}Pb -derived ages for the reconstruction of terrestrial contaminant history into the Mexican Pacific coast: Potential and limitations. *Marine Pollution Bulletin* 59: 134-145.
- *Bonnet, S., de Vernal, A., Hillaire-Marcel, C., Radi, T., Husum, K., 2010. Variability of sea-surface temperature and sea-ice cover in the Fram Strait over the last two millennia. *Marine Micropaleontology* 74(3-4), 59-74.
- 2009
- *Bardají, T., Goy, J.L., Zazo, C., Hillaire-Marcel, C. et al., 2009. Reply to the comments by Mauz, B., Antonioli, F. and Jedoui, J. on "Sea level and climate changes during OIS 5e in the Western Mediterranean". *Geomorphology* 110 (3-4), 231-235. pdf
- *Ruiz-Fernández, A.C., Hillaire-Marcel, C., 2009. ^{210}Pb -derived ages for the reconstruction of terrestrial contaminant history into the Mexican Pacific coast: Potential and limitations. *Marine Pollution Bulletin* 59: 134-145.
- *Ruiz-Fernández, A.C., Hillaire-Marcel, C., Ghaleb, B., Frignani, M. et al., 2009. Trace metals (Cd, Cu, Hg and Pb) accumulation recorded in the intertidal mudflat sediments of three coastal lagoons in the Gulf of California, Mexico, *Estuaries and Coasts*, 32, 551-564. DOI 10.1007/s12237-009-9150-3. pdf
- *Zazo, C., Goy, J.L., Hillaire-Marcel, C., Dabrio, C.J. et al., 2010. Sea level changes during the last and present interglacials in Sal Island (Cape Verde archipelago). *Global and Planetary Change*, doi:10.1016/j.gloplacha.2010.01.006.
- *Bardají, T., Goy, J.L., Zazo, C., Hillaire-Marcel, C. et al., 2009. Reply to the comments by Mauz, B., Antonioli, F. and Jedoui, J. on "Sea level and climate changes during OIS 5e in the Western Mediterranean". *Geomorphology* 110(3-4), 231-235.
- *Poirier, A., Hillaire-Marcel, C., 2009. Os-isotope insights into major environmental changes of the Arctic Ocean during the Cenozoic, *Geophysical Research Letters*, 36, L11602, doi:10.1029/2009GL037422.
- *Bardají, T., Goy, J.L., Zazo, C., Hillaire-Marcel, C. et al., 2009. Sea level and climate changes during OIS 5e in the Western Mediterranean. *Geomorphology* 104, 22-37.
- *Ruiz-Fernández, A.C., Hillaire-Marcel, C., de Vernal, A., Machain-Castillo, M.L. et al., 2009. Changes of coastal sedimentation in the Gulf of Tehuantepec, South Pacific Mexico, over the last 100 years from short-lived radionuclide measurements, *Estuarine, Coastal and Shelf Science* 82, 525-536.
- *Waelbroeck, C., et al. (incl. Hillaire-Marcel, C.), 2009. Constraints on the magnitude and patterns of ocean cooling at the Last Glacial Maximum. *Nature Geoscience*, DOI: 10.1038/NGEO411.
- 2008
- Ávila, S.P. et al. (incl. Hillaire-Marcel, C.), 2008. Mass extinctions in the Azores during the last glaciation: Fact or myth? *Journal of Biogeography* 35 (6), 1123-1129.
- *Carignan, J., Hillaire-Marcel, C., de Vernal, A., 2008. Arctic vs North Atlantic water mass exchanges in Fram Strait from Pb isotopes in sediments. *Canadian Journal of Earth Sciences* 45, 1253-1263. pdf
- *Carlson, A., Stoner, J., Donnelly, J., Hillaire-Marcel, C., 2008. Response of the southern Greenland Ice Sheet during the last two deglaciations. *Geology* 36, 359-362.
- *de Vernal, A., Hillaire-Marcel, C., Solignac, S., Radi, T., Rochon, A., 2008. Reconstructing Sea Ice Conditions in the Arctic and Sub-Arctic Prior to Human Observations, in Eric T. DeWeaver, Cecilia M. Bitz, L-Bruno Tremblay (Eds): Arctic Sea Ice Decline: Observations, Projections, Mechanisms, and Implications, *Geophysical Monograph Series* 180, Doi: 10.1029/180GM04.
- *de Vernal, A., Hillaire-Marcel, C., 2008. Natural Variability of Greenland Climate, Vegetation and Ice Volume during the Last Million Years. *Science* 320, 1622-1625.
- *Hillaire-Marcel, C. 2008. Decadal- to millennial-scale variability of Arctic-subArctic oceans and adjacent lands: a contribution of the Polar Climate Stability Network of Canada to the International Polar Year. *Canadian Journal of Earth Sciences* 45, 1199-1201.
- *Hillaire-Marcel, C., de Vernal, A., 2008. Stable isotope clue to episodic sea ice formation in the glacial North Atlantic. *Earth and Planetary Science Letters* 268 (1-2), 43-150.
- *Hillaire-Marcel, C., Hélie, J.-F., McKay, J., de Vernal, A., 2008. Elusive isotopic properties of deglacial meltwater spikes into the North Atlantic: Example of the final drainage of Lake Agassiz. *Canadian Journal of Earth Science* 45, 1235-1242.
- *McKay, J.L., de Vernal, A., Hillaire-Marcel, C., Not, C., Polyak, L., Darby, D., 2008. Holocene fluctuations in Arctic sea-ice cover: Dinocyst-based reconstructions for the eastern Chukchi Sea. *Canadian Journal of Earth Sciences* 45, 1377-1397.

- *Not, C., Hillaire-Marcel, C., Ghaleb, B., Polyak, L., Darby, D., 2008. ^{210}Pb - ^{226}Ra - ^{230}Th systematics in very low sedimentation rate sediments from the Mendeleev Ridge (Arctic Ocean). *Canadian Journal of Earth Science* 45, 1207-1219 (best paper award GSC-CJES 2008).
- *Peltier, W.R., de Vernal, A., Hillaire-Marcel, C., 2008. Rapid climate change and Arctic Ocean freshening-Reply. *Geology*, doi: 10.1130/G24971Y.1
- *Stevenson, R., Meng, X.W., Hillaire-Marcel, C., 2008. Impact of melting of the Laurentide Ice Sheet on sediments from the upper continental slope off southeastern Canada: Evidence from Sm-Nd isotopes. *Canadian Journal of Earth Sciences* 45, 1243-1252 .
- *Vásquez-Bedoya, L.F. et al. (incl. Hillaire-Marcel, C.), 2008. Centennial record of organic-walled dinoflagellate cysts and benthic foraminifera in coastal sediments from the Gulf of Tehuantepec, eastern equatorial Pacific. *Marine Micropaleontology* 68, 49-65.
- *Hillaire-Marcel, C. and de Vernal, A., 2008. Technical comment on " Mixed-Layer Deepening During Heinrich Events: A Multi-Planktonic Foraminiferal $\delta^{18}\text{O}$ Approach". *Science* 320: 1161-1162.
- *Carlson, A., Stoner, J., Donnelly, J. and Hillaire-Marcel, C., 2008. Response of the southern Greenland Ice Sheet during the last two deglaciations. *Geology* 36: 359-362.
- *Hillaire-Marcel, C. and de Vernal, A., 2008. Stable isotope clue to episodic sea-ice formation in the glacial North Atlantic. *Earth and Planetary Science Letters* 268: 143-150.

2007

- *Evans, H.F., Channell, J.E.T, Stoner, J.S., Hillaire-Marcel, C. et al., 2007: Paleointensity-assisted chronostratigraphy of detrital layers on the Eirik Drift (North Atlantic) since marine isotope stage 11. *Geochem. Geophys. Geosystems* 8, Q11007, doi:10.1029/2007GC001720
- *Kim, S.-T., O'Neil, J.R., Hillaire-Marcel, C. and Mucci, A. 2007. Oxygen isotope fractionation between synthetic aragonite and water: Influence of temperature and Mg^{2+} concentration. *Geochimica et Cosmochimica Acta* 71, 4704-4715..
- *Zazo, C., Goy, J.L., Dabrio, C.J., Soler, V., Hillaire-Marcel C., et al., 2007. Quaternary marine terraces on Sal Island (Cape Verde archipelago). *Quaternary Science Reviews* 26: 876-893.
- *Ruiz-Fernández, A.C., Hillaire-Marcel, C., Páez-Osuna, F. et al., 2007. ^{210}Pb chronology and trace metal geochemistry at Los Tuxtlas, Mexico, as evidenced by a sedimentary record from the Lago Verde crater lake. *Quaternary Research* 67: 181-192.
- *Hillaire-Marcel, C., de Vernal, A. and Piper, D. J W., 2007. Lake Agassiz Final drainage event in the northwest North Atlantic. *Geophysical Research Letters* 34, L15601, doi:10.1029/2007GL030396.

2006

- *Goy, J.-L., Hillaire-Marcel, C., Zazo, C., Ghaleb, B. et al. 2006. Further evidence for a relatively high sea level during the penultimate interglacial: open-system U-series ages from La Marina (Alicante, East Spain). *Geodynamica Acta* 19: 409-426.
- *de Vernal, A., Rosell-Mele, A., Kucera, M., Hillaire-Marcel, C. et al., 2006. Comparing proxies for the reconstruction of LGM sea-surface conditions in the northern North Atlantic. *Quaternary Science Reviews* 25: 2820–2834
- *de Vernal, A. and Hillaire-Marcel, C. 2006. Provincialism in trends and high frequency changes in the northwest North Atlantic during the Holocene. *Global and Planetary Cycles* 54: 263-290.
- *Fisher, D. et al (incl. Hillaire-Marcel C.), 2006. Natural Variability of Arctic Sea Ice over the Holocene. EOS (American Geophysical Union) 87: 273 & 275.
- Kim, S.-T., Hillaire-Marcel C. and Mucci A. 2006. Mechanisms of equilibrium and kinetic oxygen isotope effects in synthetic aragonite at 25°C. *Geochimica et Cosmochimica Acta* 70: 5790-5801.
- *Fagel, N. and Hillaire-Marcel, C., 2006. Glacial/interglacial instabilities of the Western Boundary Undercurrent during the last 360 kyr from Sm/Nd ratios of the sedimentary clay-size fractions at ODP Site 646 (Labrador Sea), *Marine Geology* 232: 87-99.

Reviewed conference proceedings (last 5 years)

- *Hillaire-Marcel, C., 2011. Foraminifera isotopic records, with special attention to high northern latitudes and the impact of sea-ice distillation processes. *Integrated Ocean drilling Program, Summer School, IOP Conf. Series: Earth and Environmental Science* 14 (2011) 012009 doi:10.1088/1755-1315
- *Hillaire-Marcel, C., 2009. The U-series dating of (biogenic) carbonates. *From Deep-Sea to Coastal Zones: Methods – Techniques for Studying Paleoenvironments*, IOP Conference Series: Earth and Environmental Science, 5, 012008, doi:10.1088/1755-1307/5/1/012008.

Book chapters & monographs (last 5 years)

- *de Vernal, A., Hillaire-Marcel, C., Solignac, S. and Radi, Taoufik, 2008. Reconstructing Sea Ice Conditions in the Arctic and Sub-Arctic Prior to Human Observations. *Geophysical Monographs* 180, 10.1029/180GM04.
- *Hillaire-Marcel, C. and de Vernal, A., 2007: Introduction and definitions. In *Methods in Late Cenozoic Paleoceanography*. Elsevier, Hillaire-Marcel and de Vernal, eds., Elsevier, Amsterdam (NL).
- *Ravelo, C. and Hillaire-Marcel, C., 2007: The Use of Oxygen and Carbon Isotopes of Foraminifera in Paleoceanography. In *Methods in Late Cenozoic Paleoceanography*. Elsevier, Hillaire-Marcel and de Vernal, eds., Elsevier, Amsterdam (NL).

Post-doctoral fellow supervised (last 5 years; * co-supervised)

- | | | |
|-------------------|------|--|
| *Bianca Fréchette | 2011 | <i>Paleoclimatology of the Arctic</i> |
| André Poirier | 2007 | <i>Isotope geochemistry of Osmium on Lomonosov Ridge</i> |
| Jennifer McKay | 2007 | <i>Paleoceanography of the Western Arctic</i> |

Doctorate theses supervised (last 5 years; * co-supervised)

- | | | | |
|------------------|------|--|--------|
| *Jenny Maccali | 2012 | <i>Arctic-North Atlantic linkages through Fram Strait</i> | |
| *Eric Rosa | 2011 | <i>Isotope tracers of large river basin systems of Eastern</i> | Canada |
| Christelle Not | 2010 | <i>Geochemistry of actinides and daughter isotopes in Arctic Sediments</i> | |
| *Matthieu Moingt | 2007 | <i>Residence time of organic carbon in aquatic systems</i> | |
| *Kim, Sang-Tae | 2006 | <i>Isotopic fractionation in carbonates</i> | |

Ongoing Theses (expected year of completion and working titles; * co-supervised):

- | | | | |
|---------------------|------|---|--|
| *Matthieu Dellinger | 2012 | <i>Traceurs élémentaires et isotopiques des flux particulaires et dissous du fleuve Mackenzie</i> | |
| Laurence Nuttin | 2013 | <i>Les actinides dans les sédiments quaternaires (mer du Labrador et Baie de Baffin)</i> | |
| *Olivia Gibb | 2012 | <i>Micropaléontologie, géochimie isotopique et paléocéanographie (Baie de Baffin & Mer du Labrador)</i> | |
| *Quentin Simon | 2012 | <i>Géochronologie & paléomagnétisme sédiments quaternaires Baie de Baffin</i> | |