

Greenhouse gas emission and climate impacts of the Enbridge Northern Gateway pipeline

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Introduction

The Northern Gateway Pipeline Project proposes a 1,170 km long dual pipeline connecting Alberta's oil sands to the Pacific Coast at Kitimat (1). The westward line would export 525,000 barrels per day of diluted bitumen or synthetic crude oil and eastward line would import 193,000 barrels per day of condensate, which is used to dilute raw bitumen for pipeline transport. The pipeline is deemed important in order to provide an avenue for increasing Alberta heavy crude exports to new or expanding markets in the U.S. and Asia. Also, the pipeline would facilitate export of growing volumes of both upgraded and non-upgraded bitumen from Alberta oil sands (2).

The Canadian oil sands industry currently contributes 40 megatonnes (Mt) of carbon dioxide equivalent (CO₂eq) emissions annually, or 5% of Canada's total greenhouse gas emissions¹ (3). This number is forecast to increase to 92 MtCO₂eq by 2020 (13% of Canada's total emissions), making oil sands Canada's fastest growing source of greenhouse gases. If all currently economically viable oil sand reserves were to be utilized, total emissions would amount to 82,000 MtCO₂ (4).

Continued growth of greenhouse gas (GHG) emissions is of concern because it contributes to the worsening of the anthropogenic greenhouse effect, which is altering climate patterns around the world. In 2009, the international community agreed to limit global warming to 2°C above the pre-industrial temperature (1.2°C above the current level), which is considered a level beyond which the impacts from climate change will likely become "dangerous"². Scientific evidence suggests that to keep within the 2°C ceiling, global emissions of greenhouse gases will have to peak by 2020 at the latest, be cut by at 50-80% percent of their 1990 levels by 2050, and then continue to decline to zero.

The purpose of this report is to:

- Quantify the emissions of greenhouse gases (GHGs) associated with the Northern Gateway Pipeline
- Examine the implications of these emissions for Canada's greenhouse gas emission targets
- Quantify the climatic effects resulting from these emissions

Greenhouse gas emissions associated with the Northern Gateway Pipeline

Using lifecycle analysis estimates of GHG emissions from oil-sands derived fuels (5, 6), we calculate that the Northern Gateway Pipeline Project would facilitate "well-to-wheels" GHG emissions of 100 MtCO₂eq/yr (best estimate), with a range of 84 to 102 MtCO₂eq/yr (see Appendix for details on the calculations).

Emissions of 100 MtCO₂eq/yr are equivalent to 150% of British Columbia's 2009 GHG emissions of 67 MtCO₂eq (7). They also correspond to 14% of Canada's 2008 emissions, and are almost equivalent to Canada's entire 2008 electricity sector (120 MtCO₂eq) (3).

¹ Based on 2008 greenhouse gas emissions, which are the latest comprehensive figures available.

² Recent research suggests that "dangerous" impacts may occur well below a global warming of 2°C, and the threshold should be more appropriately set between 1°C and 1.5°C (12).

Emitted over a period of 40 years, which we here assume as the lifetime of the Northern Gateway pipeline (see Appendix), cumulative GHG emissions associated with the pipeline would amount to 4,000 MtCO₂eq (3,370-4,060 MtCO₂eq).

The reason for considering the full lifecycle (well-to-wheel) GHG emissions associated with the pipeline is that the climate impacts will be independent of where the oil-sands derived fuel will be combusted (greenhouse gases mix quickly throughout the Earth's atmosphere). In order to assess the significance of these emissions for Canada's emission reduction target, however, we also calculate the GHG emissions that will arise in Canada. These are the emissions associated with the extraction, upgrading, and transportation of oil-sands derived products. Based on the same lifecycle analyses as above (5, 6) we calculate "well-to-refinery" GHG emissions of 17 MtCO₂eq/yr (see Appendix for details), or 16% of the well-to-wheels emissions associated with the pipeline.

Significance for Canada's emission target

Under the Copenhagen Accord, Canada pledged to reduce its GHG emissions in 2020 by 17% relative to 2005. This corresponds to an emission target of 607 MtCO₂ by 2020 or a reduction in GHG emissions of 127 MtCO₂ from the 2008 value (3). Over the same period (2008 to 2020), emissions associated with oil sands are forecast to rise by 52 MtCO₂ (3). In order to comply with its emission target, Canada will have to reduce emissions in other sectors by 180 MtCO₂ if oil sands expansion proceeds as expected.

The annual "well-to-wheels" GHG emissions associated with the Northern Gateway pipeline correspond to 16% of Canada's 2020 emission target. If the segment of emissions due to fuel combustion in vehicles (which will occur abroad) is subtracted, "well-to-tank" emissions associated with the pipeline are still equivalent to 5% of Canada's allowable emissions. Acknowledging that emission arising from refinery will also be exported abroad, pipeline emissions will amount to about 3% of Canada's emission target.

Climate impacts

Recent research (8, 9) has shown that the increase in global mean temperature the Earth will experience depends only on the total amount of carbon dioxide (CO₂) emitted, independently of how quickly the CO₂ is released. In a report by the US National Academy of Science (10), the best estimate for the temperature increase per unit CO₂ emitted (termed the "climate carbon response") is given as 0.5°C per trillion ton (Tt) of CO₂, with a very likely range of 0.3-0.7 °C/TtCO₂³.

Using this estimate and the cumulative GHG emissions associated with the pipeline of 4,000 MtCO₂eq we calculate the potential global mean warming from the GHG emissions associated with the pipeline as 0.002°C⁴. This is only a skirmish, but if we

³ In the National Academy of Science report, the estimate is given in °C per trillion ton of carbon. We convert their estimates to °C/TtCO₂ by multiplying the values by 0.27 (12/44) i.e. the ratio in molecular mass of elemental carbon versus that of CO₂.

⁴ Strictly speaking the climate carbon response is valid only for greenhouse gases with a long atmospheric lifetime, such as CO₂, as opposed to short-lived gases such as methane. Assuming

consider the warming potential from the currently economically viable oil sand reserves (170 billion barrels), this value rises to 0.04°C (4). And if the entire Alberta oil sands reserve (1.8 trillion barrels) were to be consumed, global mean temperature would rise by 0.42°C (4), or less than a third of the remaining warming that will bring us past the 2°C threshold⁵.

The linear relationship between global mean temperature change and total CO₂ emissions can also be used to derive the total emissions that are compatible with climate targets. To restrict the odds of exceeding the 2°C target to 1 in 3, Zickfeld et al. (9) derive an allowable emission “budget” of 1,800 gigatons (Gt; 1Gt = 1,000 Mt) of CO₂⁶. While emissions from the pipeline would use up only a small fraction of this budget, exploitation of the entire Alberta oil sands reserve (oil in place) would consume as much as 50% of the global emission budget compatible with limiting global mean temperature to 2°C.

In their latest World Energy Outlook (11), the International Energy Agency calculates that 80% of the cumulative energy-related CO₂ emissions permissible by 2035 under the 2°C target are already locked-in by existing energy infrastructure. If the world proceeds on a business-as-usual trajectory, infrastructure put in place by 2017 will use up the entire budget allowed up to 2035, leaving no room for additional power plants, factories and other infrastructure unless they are zero-carbon.

Conclusions

If approved, the Northern Gateway pipeline will facilitate substantial annual GHG emissions, comparable to those from Canada’s electricity sector in 2008.

GHG emissions associated with the pipeline in particular, and with expansion of oil sands operations in general, will make it increasingly difficult, if not impossible for Canada to meet its emission targets pledged under the Copenhagen Accord.

Due to the GHG emissions commitment from existing and future energy-related infrastructure, keeping within the 2°C ceiling requires that we turn away immediately from the construction of infrastructure that will lock the world into the consumption of fossil fuels for decades. Construction of the Northern Gateway pipeline is clearly counter this requirement.

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that non-CO₂ gases contribute only a small fraction, we apply this measure to the total emissions from the pipeline.

⁵ The global mean temperature has warmed by about 0.8°C since the pre-industrial era.

⁶ The estimate given in Zickfeld et al. (9) is 2200 GtCO₂ (590 GtC) emitted over the period 2001-2500. About 400 GtCO₂ have been emitted over the 2001-2011 decade, giving a remaining budget of 1800 GtCO₂ (490 GtC).

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Appendix

GHG emissions of oil-sands derived products

The greenhouse gas (GHG) emissions associated with the Northern Gateway pipeline were calculated based on lifecycle analysis (LCA) estimates of GHG emissions from oil sands operations.

Here we consider two studies (1, 2) which are meta-analysis summarizing the results of a range of different analyses. The Charpentier et al. (1) review (henceforth referred to as Ch09) considers 13 studies whereas the Brandt (2) review (henceforth referred to as Br11) includes 6 studies published in 2009 and 2010 (not included in the Ch09 review).

Lifecycle studies usually consider different pathways of bitumen extraction and upgrading. Depending on the depth of the reserve, oil sands deposits can either be surface mined, or heated underground with injected steam, so the bitumen can flow to a well and be pumped to the surface (*in situ* recovery). The majority of the extracted bitumen is upgraded into a higher quality synthetic crude oil (SCO) and then refined into gasoline or diesel fuels. The remaining bitumen (from *in situ* production) is sent directly to refineries. Since raw bitumen has a high viscosity and cannot flow, the raw bitumen is diluted with lighter hydrocarbons (diluted bitumen or *dilbit*).

Lifecycle studies of oil sands GHG emissions can be divided in different groups, depending on the lifecycle stages they include:

- **Well-to-wheel** (WTW) analyses include contributions from bitumen extraction, upgrading, refining, and combustion in vehicles.
- **Well-to-tank** (WTT) analysis is the same as WTW, but without the combustion stage.
- **Well-to-refinery** (WTR) analyses include emissions from bitumen extraction and upgrading.
- **Tank-to-wheels** (TTW) analyses consider only the emissions from combustion in the vehicle.

Ch09 report well-to-wheel emissions of 436 to 533 kgCO₂eq per barrel (bbl) of refined product for surface mining and upgrading (“SM&Up”) and 525-585 kgCO₂eq/bbl for in situ and upgrading (“IS&Up”) respectively⁷. For in situ without upgrading (“in situ”) they report emissions of 446-558 kgCO₂eq/bbl. Ch09 also report well-to-refinery emissions of 62-164 and 99-176 kgCO₂eq per barrel SCO for SM&Up and IS&Up, respectively. For in situ, they report 37-105 kgCO₂eq per barrel bitumen⁸.

Br11 reports well-to-tank GHG emissions. We calculated the corresponding well-to-wheel estimates using the tank-to-wheel emissions of Ch09 (352 kgCO₂eq/bbl). The

⁷ Well-to-wheel emission estimates in Ch09 are given in gCO₂eq/km and have been converted to kgCO₂eq/bbl using a fuel efficiency of 9.6 l/100 km, the same value used in Ch09.

⁸ Note that well-to-wheel emissions are given per barrel refined product, whereas well-to-refinery emissions are given per barrel SCO or bitumen.

resulting estimates are 473-529, 521-613 and 505-53 kgCO₂eq/bbl for surface mining and upgrading, in situ and upgrading and in situ without upgrading, respectively⁹.

We also calculated the well-to-refinery emissions from the studies included in the Br11 review by summing up the emissions arising from extraction, upgrading (for SM&Up and IS&Up), transport and venting and flaring (Br11 Table 8). Since the resulting emission estimates are per barrel of refined product, we convert those to emissions per barrel SCO and bitumen by assuming a SCO/gasoline volumetric ratio of 1.1, and a bitumen/gasoline volumetric ratio of 1.3 (derived based on numbers provided in Ch09). We derive ranges of 65-118 kgCO₂eq/bbl SCO for surface mining and upgrading, 106-232 kgCO₂eq/bbl SCO for in situ and upgrading, and 73-103 kgCO₂eq/bbl bitumen for in situ without upgrading.

The ranges in GHG emissions arise because of different pathways, life-cycle stages, assumptions and boundaries (i.e. which activities are included in the analysis) of the studies considered in the Ch09 and Br11 reviews. For instance, the GHGenius study (3) in Br11 includes GHG emissions from venting and flaring as well as land use change associated with mining operations, whereas most other studies do not.

	Best estimate kgCO₂eq/bbl	Reference	Low estimate kgCO₂eq/bbl	Reference	High estimate kgCO₂eq/bbl	Reference
SM&Up	529	GHGenius in Br11	468	McCann in Flint in Ch09	529	GHGenius in Br11
IS&Up	579	GHGenius in Br11	521	GREET in Br11	613	TIAX (resid. fuel) in Br11
In situ	558	GHGenius in Ch09	446	McCann in Flint in Ch09	558	GHGenius in Ch09

Table 1: Best, low and high estimates of well-to-wheel GHG emissions for SM&Up, IS&Up and in situ pathways. References are to studies examined in the Ch09 and Br11 reviews.

Best, low and high GHG emissions estimates

Based on the Ch09 and Br11 reviews, we defined a best, low and high estimate of GHG emissions for each pathway (SM&Up, IS&Up, in situ). Following the recommendation of Br11 we use the emissions estimates based on the GHGenius model (3) as our best (most-likely) estimates. For the low and high estimates we use the lowest and highest values from the range of studies examined in Ch09¹⁰ and Br11 for each pathway. Table 1 summarizes the best, low and high well-to-wheel emission estimates used in our analysis.

⁹ Tank-to-wheel estimates in Br11 are given on an energy basis (gCO₂eq/MJ). The values were converted to gCO₂eq/bbl using the low heating value (LHV) from GHGenius (3) of 44 MJ/kg and assuming a density of refined product (gasoline) of 719.7 kg/m³.

¹⁰ We disregard the lowest estimate from Furimsky included in the Ch09 review since it based on future scenarios with very low emissions (2).

For well-to-refinery emissions we use best estimates of 118, 167 and 83 kgCO₂eq/bbl SCO or bitumen for SM&Up, IS&Up and in situ pathways, respectively.

The Alberta Energy Research Conservation Board (4) forecasts that in 2020 45% of bitumen will be recovered by surface mining and 55% from in situ (compared to 55% mining and 45% in situ extraction in 2010). They also report that in 2010 all Alberta surface mined bitumen and 11% of in situ production was upgraded to SCO, with the latter proportion forecast to increase to 13% in 2020. Based on these numbers we assume a 50:50 split between SM&Up and IS&Up pathways for SCO production for all our estimates.

GHG emissions facilitated by Northern Gateway pipeline

If approved, the Northern Gateway Pipeline Project will consist of 1,170 km of dual pipeline connecting Alberta's oil sands to that Pacific Coast at Kitimat (5). The 36-inch westward line could export 525,000 barrels per day of diluted bitumen or SCO and the 20-inch eastward line could import 193,000 barrels per day of condensate.

In this report, we only consider the GHG emissions facilitated by the westward export pipeline.

In our calculations we make the following assumptions:

- The average operating capacity of the export pipeline is 500,000 barrels per day (6). This capacity will not be ramped up over the lifetime of the project.
- The pipeline will transport 60% diluted bitumen (300,000 bbl/day) and 40% synthetic crude oil (200,000 bbl/day) (6).
- In order to apply the well-to-wheel GHG emissions estimates from Ch09 and Br11 (which are per barrel of refined product) to the unrefined products flowing through the pipeline (SCO and dilbit), we assume a SCO/gasoline volumetric ratio of 1.1, and a bitumen/gasoline volumetric ratio of 1.3 (1).
- The mixing ratio of the diluted bitumen transported by the pipeline will be 70% bitumen and 30% condensate (6). We neglect the GHG emissions associated with the condensate, which is equivalent to assuming that the condensate will not enter the refinery stream with the bitumen, but will be recycled.
- The lifetime of the pipeline will be 40 years (7). This assumption is based on the lifetime of oil sands projects, rather than pipeline lifetime.

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Education

- Apr 1999 - Mar 2004 Doctoral studies in Climate Physics, Potsdam University and Potsdam Institute for Climate Impact Research, Germany.
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Professional history

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 - Climate-carbon cycle interactions
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 Collaborator in the NSERC-funded *Training Program in Interdisciplinary Climate Science*, University of Victoria, BC, Canada
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 - Earth system modelling

- Climate sensitivity and transient climate response
- Ocean and land carbon cycle feedbacks on climate
- Emissions pathways avoiding “dangerous” climate change
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Collaborator on the NSF-funded *Climate Change Decision Making Centre*, Carnegie Mellon University, Pittsburgh, PA, USA.

Apr 2004 - Dec 2005 **Postdoctoral research associate**, Potsdam Institute for Climate Impact Research, Potsdam, Germany (parental leave Nov 2004 – June 2005).

Collaborator on the project *Integrated Assessment of Changes in the Thermohaline Circulation (INTEGRATION)* (April 2004 – Dec 2005).

- Risk assessment of changes in the thermohaline circulation

Jan 1999 – Mar 2004 **Research associate**, Potsdam Institute for Climate Impact Research, Department of Integrated Systems Analysis, Potsdam, Germany.

Collaborator on the project *Integrated Assessment of Changes in the Thermohaline Circulation (INTEGRATION)* (April 2001 – Mar 2004).

Collaborator on the project *Integrated Assessment of Climate protection strategies (ICLIPS)* (Jan 1999 – Dec 2000).

- Conceptual climate models
- Stability of the Indian monsoon
- Stability of the Atlantic thermohaline circulation
- Integrated assessment modelling of climate change
- Contributing author to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)

Jan 1996 - June 98 **Research assistant**, Free University of Berlin, Department of Physics, Berlin, Germany.

Awards

Prize “Elf der Wissenschaft” (elected among the top eleven young scientists in Germany across all disciplines) of the sponsor association for German science and the science magazine “Bild der Wissenschaft” (2006).

Shortlisted for the Young Scientist Award of the Leibniz Association of Science (2005).

Michelson Prize of the Faculty of Mathematics and Science of Potsdam University for the best Ph.D. dissertation of the academic year 2003/2004 (2004).

Prize of the Society of Friends and Promoters of the Potsdam Institute for Climate Impact Research for the outstanding Ph.D. thesis (2004).

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Contributing author to Smith, J.B., H.-J. Schellnhuber, M.Q. Mirza, S. Fankhauser, R. Leemans, L. Erda, L. Ogallo, B. Pittock, R. Richels, C. Rosenzweig, U. Safriel, R.S.J. Tol, J. Weyant, G. Yohe, 2001, Vulnerability to Climate Change and Reasons for Concern: A Synthesis, in: J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, K.S. White (Eds.): *Climate Change 2001: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 913-967.

Articles in conference proceedings

Bruckner, T., and **K. Zickfeld**, 2008, Inverse integrated assessment of climate change: the guardrail approach, *International conference on policy modelling*, July 2-4 2008, Berlin, Germany.

Bruckner, T., and **K. Zickfeld**, 2004, Low risk emissions corridors for safeguarding the Atlantic thermohaline circulation, *Expert Workshop on "Greenhouse gas emissions and abrupt climate change: positive options and robust policy"*, October 30 – October 1, 2004, Paris, France.

Zickfeld, K., and T. Bruckner, 2002, Emissions corridors preserving the Atlantic Ocean thermohaline circulation, In: A. E. Rizzoli, A.J. Jakeman (Eds.), *Integrated assessment and decision support - Proceedings of the 1st biennial meeting of the International Environmental Modelling and Software Society*, 24-27 June 2002, Lugano, Switzerland, 145-150.

Selected presentations and seminars

Invited presentations and seminars

Modelling Marine Climate-Carbon Cycle Feedbacks, Keynote lecture, *Greencycles II Summer School*, May 22 2011, Peyresq, France.

Climate response to carbon emissions: Characteristics and policy implications, *Faculty of Environment Seminar Series*, January 25 2011, Simon Fraser University, Vancouver, BC, Canada.

The role of oceans in anthropogenic CO₂ uptake, Plenary talk, *National Council for Science and the Environment Conference*, January 19-21 2011, Washington DC, USA.

Setting cumulative emissions targets to reduce the risk of dangerous climate change, *Resource and Environmental Management Seminar Series*, November 19 2010, Simon Fraser University, Vancouver, BC, Canada.

Irreversibility of anthropogenic climate change on centennial timescales, *Canadian Institute for Advanced Research Workshop*, May 5-6, 2010, Vancouver, BC, Canada.

Setting cumulative emissions targets to reduce the risk of dangerous climate change, January 22, 2010, Department of Geography, Simon Fraser University, Vancouver, BC, Canada.

Climate response to carbon emissions: characteristics and policy implications, *ESRL/CSD Seminar Series*, February 10, 2010, National Oceanographic and Atmospheric Administration, Boulder, CO, USA.

Setting cumulative emissions targets to reduce the risk of dangerous climate change, *School of Earth and Ocean Seminar Series*, September 29, 2009, University of Victoria, Canada.

Quantifying uncertainty in allowable emissions consistent with temperature targets, *MOCA-09: IAMAS-IAPSO-IACS 2009 Joint Assembly*, July 19-29, 2009, Montréal, Canada.

Climate response to carbon emissions, *PIK seminar series*, May 18, 2009, Potsdam Institute for Climate Impact Research, Potsdam, Germany.

Greenhouse gas emissions targets to reduce the risk of dangerous climate change, *Department of Environmental Earth System Science Seminar Series*, October 22, 2008, Stanford University, Palo Alto, USA.

Modelling the effects of future ocean circulation changes on the global carbon cycle, *School of Earth and Ocean Sciences Seminar Series*, September 30, 2008, University of Victoria, Canada.

Emissions pathways reducing the risk of dangerous climate change, *Pacific Institute of Mathematical Sciences Workshop*, July 21-23, 2008, University of Victoria, Canada.

The University of Victoria Earth System Climate Model – Description and Applications. School of Resource and Environmental Management, Simon Fraser University, Vancouver, Canada, June 10, 2008.

Modelling the effects of future ocean circulation changes on the global carbon cycle, *Earth, Atmospheric and Planetary Sciences Department Lecture Series*, May 21, 2008, Massachusetts Institute of Technology, Boston, USA.

Impacts of future ocean circulation changes on the global carbon cycle, *Department of Atmospheric and Oceanic Sciences Seminar*, McGill University, Montreal, Canada. February 18, 2008.

Carbon cycle feedbacks of changes in the Atlantic meridional overturning circulation. *Topics in the Atmosphere and Ocean Seminar Series*, University of Victoria and Canadian Centre for Climate Modelling and Analysis, November 21, 2006, Victoria, Canada.

Contributed presentations and seminars

Is the climate response to CO₂ emissions path dependent? *Congress of the Canadian Meteorological and Oceanographic Society*, June 5-9 2011, Victoria, Canada. Oral presentation.

Nonlinearity of carbon cycle feedbacks, *Congress of the Canadian Meteorological and Oceanographic Society*, May 31-June 4 2011, Ottawa, Canada. Oral presentation.

Expert judgments about transient climate response to radiative forcing, *AGU Fall Meeting*, December 14-18 2009, San Francisco, USA. Poster presentation.

Setting cumulative emissions targets to reduce the risk of dangerous climate change, *IARU Climate Change Congress*, 10-12 March 2009, Copenhagen, Denmark. Oral presentation.

Setting cumulative emissions targets to reduce the risk of dangerous climate change, *AGU Fall Meeting*, December 15-19, 2008, San Francisco, USA. Oral presentation.

Setting cumulative emissions targets to reduce the risk of 'dangerous' climate change, *ESF-FMSH Entre-Sciences Conference "New Methodologies and Interdisciplinary Approaches in Global Change Research"*, November 5-10, 2008, Porquerolles, France. Oral presentation.

Negative feedback of poleward intensifying Southern Hemisphere winds on atmospheric CO₂, *Congress of the Canadian Meteorological and Oceanographic Society*, May 25-29, Kelowna, Canada. Oral presentation.

Expert judgments about transient climate response and climate sensitivity, *AGU Fall Meeting*, December 10-14, 2007, San Francisco, USA. Poster presentation.

Impacts of changes in the Atlantic meridional overturning circulation on the global carbon cycle, *CMOS-CGU-AMS Congress*, May 28 – June 1, 2007, St John's, Canada. Oral presentation.

Emissions corridors reducing the risk of reorganizations of the Atlantic meridional overturning circulation, *European Geosciences Union (EGU) General Assembly*, April 15-20, 2007, Vienna, Austria. Oral presentation.

Sensitivity of the Indian monsoon to human activities. *Global Environmental Change Open Science Conference*, November 9-12, 2006, Beijing, China. Poster presentation.

Sensitivity of the Indian monsoon to changes in boundary conditions. *International Young Scientists' Global Change Conference*, November 5-8, 2006, Beijing, China. Oral presentation.

Emissions corridors reducing the risk of abrupt climate change. *Rapid Climate Change International Science Conference*, October 24-27, 2006, Birmingham, UK. Poster presentation.

Effects of potential changes in the Atlantic thermohaline circulation on the global carbon cycle. *Rapid Climate Change International Science Conference*, October 24-27, 2006, Birmingham, UK. Oral presentation.

Safeguarding the Atlantic thermohaline circulation: cost-effective emissions paths and emissions corridors. *1st General Assembly of the European Geophysical Union (EGU)*, Acropolis, April 25-30, 2004, Nice, France. Oral presentation.

Bifurcations in a reduced-form model of the Indian monsoon. *1st General Assembly of the European Geophysical Union (EGU)*, Acropolis, April 25-30, 2004, Nice, France. Poster presentation.

Safeguarding the Atlantic thermohaline circulation: Sensitivity analysis of emission corridors. *International Conference on Earth System Modelling*, Sept 15-19, 2003, Hamburg, Germany. Poster presentation.

Safeguarding the Atlantic thermohaline circulation: a sensitivity analysis of emission corridors. *EGS-AGU-EUG Joint Assembly*, Acropolis, April 6-11, 2003, Nice, France. Oral presentation.

Reducing the risk of dangerous climate change. *NCCR-Climate Summer School*, Sept 7-14, 2002, Grindelwald, Switzerland. Poster presentation.

Reducing the risk of abrupt climate change: emissions corridors preserving the Atlantic thermohaline circulation. *1st biennial meeting of the International Environmental Modelling and Software Society (IEMSS)*, June 24-27, 2002, Lugano, Switzerland. Oral presentation.

Reducing the risk of abrupt climate change: emission corridors preserving the thermohaline circulation. *Annual Meeting of the Center for the Integrated Study of Human Dimensions of Global Change*, May 28-31, 2002, Pittsburgh, USA. Oral presentation.

Expert elicitation on the Atlantic thermohaline circulation. *Annual Meeting of the Center for the Integrated Study of Human Dimensions of Global Change*, Carnegie Mellon University, May 28-31, 2002, Pittsburgh, USA. Oral presentation.

Reducing the risk of abrupt climate change: emission corridors preserving the thermohaline circulation. *27th General Assembly of the European Geophysical Society (EGS)*, Acropolis, April 21-26, 2002, Nice, France. Oral presentation.

Emissions corridors preserving the Atlantic ocean thermohaline circulation. *Fall Meeting of the American Geophysical Union (AGU)*, Dec 10-14, 2001, San Francisco, USA. Poster presentation.

A reduced-form model for the transient response of the thermohaline circulation to global warming. *Fünfte Deutsche Klimatagung*, Oct 2-6, 2000, Hamburg, Germany. Poster presentation.

A reduced-form model for the transient response of the thermohaline circulation to global warming. *23rd International conference on mathematical geophysics*, La Citadelle, June 18-23, 2000, Villefranche sur Mer, France. Poster presentation.

Professional activities

Committees

Program committee of NSERC-funded *Training program in Interdisciplinary Climate Science* (since October 2009).

Reviewer contributions

Journals: Atmosphere-Ocean, Climatic Change, Climatic Change Letters, Climate Dynamics, Energy Policy, Geophysical Research Letters, Journal of Climate, Nature Climate Change, Nature Education, Plos One, Proceedings of the National Academy of Science, Tellus.

Project proposals: National Science and Engineering Research Council (Canada), National Science Foundation (USA), National Oceanographic and Atmospheric Administration (USA), National Environmental Research Council (UK).

Conference sessions

Session co-convenor *Climate change and the carbon cycle*, Congress of the Canadian Meteorological and Oceanographic Society, June 5-9, Victoria, Canada.

Session co-convenor *Climate change and the carbon cycle*, Congress of the Canadian Meteorological and Oceanographic Society, May 31-June 4, Ottawa, Canada.

Session chair *Climate Sensitivity, Climate Feedbacks and Regional Responses to Global Forcing*, MOCA-09: IAMAS-IAPSO-IACS 2009 Joint Assembly, July 19-29, 2009, Montréal, Canada.

Session co-convenor and chair *Climate Stabilization: Prospects, Trajectories, Uncertainties*, AGU Fall Meeting, December 15-19, 2008, San Francisco, USA.

Membership in professional societies

American Geophysical Union (since 2001), Canadian Meteorological and Oceanographic Society (since 2011).

Teaching experience

Courses taught

The Atmosphere-Ocean System, graduate course (EOS 550), co-taught with Dr. R. Wania, School of Earth and Ocean Sciences, University of Victoria, B.C., Canada, spring term 2010.

The Atmosphere-Ocean System, undergraduate/graduate course (EOS 433/550), co-taught with Dr. K.J. Meissner, School of Earth and Ocean Sciences, University of Victoria, B.C., Canada, spring term 2009.

The Atmosphere-Ocean System, undergraduate/graduate course (EOS 433/550), co-taught with Dr. C. Curry, University of Victoria, B.C., Canada, spring term 2008.

Guest lectures

Research Frontiers in Earth and Ocean Science, graduate course (EOS 525), instructors: Dr. C. Garrett and Dr. D. Canil, University of Victoria, B.C., Canada, fall term 2009.

The Ocean-Atmosphere System, undergraduate/graduate course (EOS 433/550), instructor: Dr. K. Meissner, University of Victoria, B.C., Canada, spring term 2007.

Climate Change 2001: The third assessment report of the IPCC, graduate seminar, instructors: Dr. G. Petschel-Held and Dr. M. K. B. Lüdeke, Potsdam University, Germany, summer term 2002.

Global Climate Change, graduate seminar, instructor: Dr. T. Bruckner, Technical University Berlin, Germany, summer term 2001.

Modelling Seminar, graduate seminar, instructors: Prof. Dr. Fredi Tröltzsch and Dr. T. Slawig, Technical University Berlin, Germany, summer term 2001.

Supervision

Supervisor, Tyler Herrington, M.Sc. candidate, Department of Geography, Simon Fraser University (2011-)

Supervisory Committee Member, Ashwin Kumar, Ph.D. candidate, Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, USA (2009-)

Supervisory Committee Member, Robin Matthews, M.Sc. candidate, School of Earth and Ocean Sciences, University of Victoria (2009-).

Supervisory Committee Member, Chris Avis, Ph.D. candidate, School of Earth and Ocean Sciences, University of Victoria (2007-)

Supervisor, Sylvain Lassonde, Intern, Canadian Centre for Climate Modelling and Analysis (January-June 2010).

Co-supervisor, Karin Kvale, M.Sc. student, School of Earth and Ocean Sciences, University of Victoria (2007-2009).

Co-supervisor, Brigitte Knopf, Ph.D. student, Potsdam Institute for Climate Impact Research. Thesis: On intrinsic uncertainties in Earth system modelling (2001-2006).

Other interests and qualifications

2002 – 2005: Gender representative of the Potsdam Institute for Climate Impact Research.

2004: Investigation about the impacts of the paper industry on peat forests in Indonesia.

2003: Visit to a project of the German development cooperation in Laos.

1998 - 2000: Repeated visits to projects of the German development cooperation in Nicaragua.

1994: Participation in a work-camp in support of an indigenous community project in Peru.

Languages

German (native speaker), Italian (native speaker), English (fluently spoken and written), Spanish (fluently spoken and written), French (good working knowledge), Russian (basic knowledge), qualification in Latin and ancient Greek.

References

Prof. Dr. Andrew J. Weaver

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