Changes in carbon uptake and emissions by oceans in a changing climate

EU FP7 Collaborative Project, Large-Scale Integrating Project, March 2011 – February 2015

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University of Bergen, Geophysical Institute and Bjerknes Centre for Climate Research,Norway (Project Coordination)

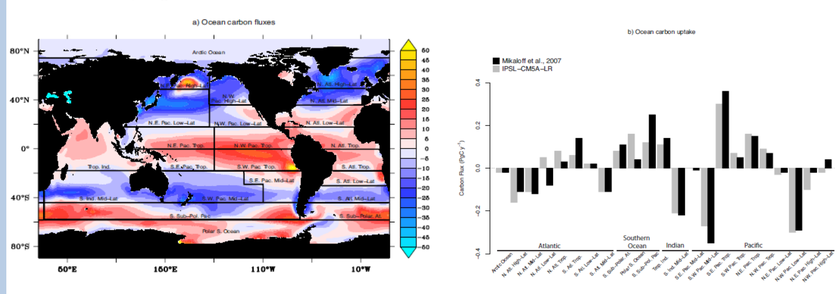
CARBOCHANGE aims at quantifying the ocean's role in the uptake of human-produced carbon dioxide, and at investigating how large this uptake rate has been in the past, how it is changing at present, and how it will evolve in the future.

Highlight 1

Dynamical and biogeochemical control on the decadal variability of ocean carbon fluxes

R. Séférian, L. Bopp, D. Swingedouw, and J. Servonnat

Several recent observation-based studies suggest that ocean anthropogenic carbon uptake has slowed down due to the impact of anthropogenic forced climate change. However, it remains unclear whether detected changes over the recent time period can be attributed to anthropogenic climate change or rather to natural climate variability (internal plus naturally forced variability) alone. One large uncertainty arises from the lack of knowledge on ocean carbon flux natural variability at the decadal time scales. To gain more insights into decadal time scales, we have examined the internal variability of ocean carbon fluxes in a 1000 yr long preindustrial simulation performed with the Earth System Model IPSL-CM5A-LR. Our analysis shows that ocean carbon fluxes exhibit low-frequency oscillations that emerge from their year-to-year variability in the North Atlantic, the North Pacific, and the Southern Ocean. In our model, a 20 yr mode of variability in the North Atlantic air-sea carbon flux is driven by sea surface temperature variability and accounts for 40% of the interannual regional variance. The North Pacific and the Southern Ocean carbon fluxes are also characterised by decadal to multi-decadal modes of variability (10 to 50 yr) that account for 20–40% of the interannual regional variance. These modes are driven by the vertical supply of dissolved inorganic carbon through the variability of Ekmaninducedupwelling and deep-mixing events. Differences in drivers of regional modes of variability stem from the coupling between ocean dynamics variability and the ocean carbon distribution, which is set by large-scale secular ocean circulation.



Long-term mean of **(a)** simulated ocean carbon fluxes (in g Cm−2 yr−1) and **(b)** simulated regional carbon fluxes (in Pg C yr−1) compared to inversion-based estimates published in Mikaloff Fletcher et al. (2007). Black and grey bars indicate model and inversion-based estimates, respectively

Séférian, R., Bopp, L., Swingedouw, D., and Servonnat, J. (2013)
Dynamical and biogeochemical control on the decadal variability of ocean carbon fluxes,
Earth Syst. Dynam., 4, 109–127, doi :10.5194/esd-4-109-2013,

Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis

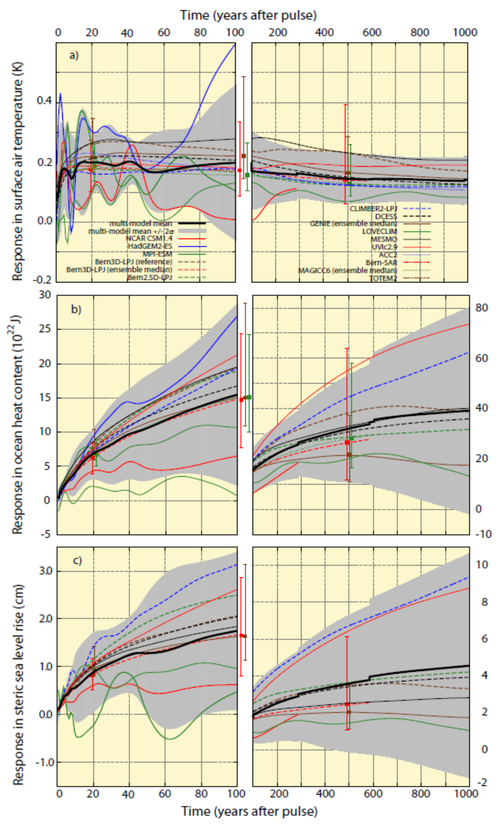
F. Joos, R. Roth, J. S. Fuglestvedt, G. P. Peters, I. G. Enting, W. von Bloh, V. Brovkin, E. J. Burke, M. Eby, N. R. Edwards, T. Friedrich, T. L. Frölicher, P. R. Halloran, P. B. Holden, C. Jone[7], T. Kleinen, F. T. Mackenzie, K. Matsumoto, M. Meinshausen, G.-K. Plattner, A. Reisinger, J. Segschneider, G. Shaffer, M. Steinacher, K. Strassmann, K. Tanaka, A. Timmermann, and A. J. Weaver

The responses of carbon dioxide (CO_2) and other climate variables to an emission pulse of CO_2 into the atmosphere are often used to compute the Global Warming Potential (GWP) and Global Temperature change Potential (GTP), to characterize the response timescales of Earth System models, and to build reduced-form models. In this carbon cycle-climate model intercomparison project, which spans the full model hierarchy, we quantify responses to emission pulses of different magnitudes injected under different conditions. The CO_2 response shows the known rapid decline in the first few decades followed by a millennium-scale tail. For a 100 Gt-C emission pulse added to a constant CO_2 concentration of 389 ppm, 25 ± 9% is still found in the atmosphere after 1000 yr; the ocean has absorbed 59 ± 12% and the land the remainder (16 ± 14%). The response in global mean surface air temperature is an increase by 0.20 ± 0.12 °C within the first twenty years; thereafter and until year 1000, temperature decreases only slightly, whereas ocean heat content and sea level continue to rise. Our best estimate for the Absolute Global Warming Potential, given by the time-integrated response in CO_2 at year 100 multiplied by its radiative efficiency, is 92.5×10^{-15} yr W m^{-2} per kg-CO_2. This value very likely (5 to 95% confidence) lies within the range of (68 to 117) $\times 10^{-15}$ yr W m^{-2} per kg-CO_2. Estimates for time-integrated response in CO_2 published in the IPCC First, Second, and Fourth Assessment and our multi-model best estimate all agree within 15% during the first 100 yr. The integrated CO_2 response, normalized by the pulse size, is lower for pre-industrial conditions, compared to present day, and lower for smaller pulses than larger pulses. In contrast, the response in temperature, sea level and ocean heat content is less sensitive to these choices. Although, choices in pulse size, background concentration, and model lead to uncertainties, the most important and subjective choice to determine AGWP of CO_2 and GWP is the time horizon.

Response to the 100Gt C pulse as perturbation in global mean surface air temperature **(a)**, in ocean heat content **(b)**, and in steric sea level rise **(c)**. Results are for a CO2 emission pulse of 100 GtC added to a current CO2 concentration of 389 ppm (PD100).We note that the signal-to-noise ratio is small for the models that feature a dynamic atmosphere (HadGEM2-ES, MPI-ESM, NCAR-CSM1.4, and LOVECLIM) and the plotted evolutions for these models represent both the forced response and a contribution from the models' internal (unforced) climate variability. Small abrupt changes in the multi-model mean and confidence range arise from a change in the number of model simulations; different groups run their model over different periods, pending on CPU availability.

Joos, F., Roth, R., Fuglestvedt, J. S., Peters, G. P., Enting, I. G., von Bloh, W., Brovkin, V., Burke, E. J., Eby, M., Edwards, N. R., Friedrich, T., Frölicher, T. L., Halloran, P. R., Holden, P. B., Jones, C., Kleinen, T., Mackenzie, F. T., Matsumoto, K., Meinshausen, M., Plattner, G.-K., Reisinger, A., Segschneider, J., Shaffer, G., Steinacher, M., Strassmann, K., Tanaka, K., Timmermann, A., and Weaver, A. J. (2013)
Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis
Atmos. Chem. Phys., 13, 2793-2825, doi:10.5194/acp-13-2793-2013

Highlight 3



The EU FP7 project CARBOCHANGE brings together over 100 scientists from 29 partner institutions in 15 countries.

UiB	UiB	Coordinator: University of Bergen	Norway
VitusLab	VitusLab	VitusLab Copenhagen, Denmark	Denmark
IFREMER	IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer	France
CEA	CEA	Commissariat à l'Energie Atomique/ Laboratoire des Sciences du Climat	France
UPMC	UPMC	Université Pierre et Marie Curie, Paris	France
AWI	AWI	Alfred Wegener Institute for Polar and Marine Research	Germany
CLIMMOD	CLIMMOD	CLIMMOD Engineering SARL	France
GEOMAR	GEOMAR	Helmholtz Centre for Ocean Research Kiel	Germany
MPG	MPG	Max-Planck-Society, Institute for Meteorology	Germany
UniHB	UniHB	University of Bremen	Germany
MRI-UI	MRI-UI	Hafrannsóknastofnunin - Marine Research Institute and University of Iceland	Iceland
NUIG	NUIG	National University of Ireland, Galway	Ireland
INRH	INRH	Institut National de Recherche Halieutique, Casablanca	Morocco
NIOZ	NIOZ	Netherlands Institute for Sea Research	Netherlands
NERSC	NERSC	Nansen Environmental and Remote Sensing Center	Norway
UNIRESEARCH	UNIRESEARCH	Bjerknes Centre for Climate Research, UniResearch AS	Norway
CSIC	CSIC	Agencia Estatal Consejo Superior de Investigaciones Científicas	Spain
ULPGC	ULPGC	University of Las Palmas de Gran Canaria, QUIMA group	Spain
UGOT	UGOT	University of Gothenburg	Sweden
ETH Zürich	ETH Zürich	Eidgenössische Technische Hochschule, Zürich	Switzerland
UBERN	UBERN	University of Bern	Switzerland
MetO	MetO	The Met Office, Hadley Centre for Climate Prediction and Research	United Kingdom
NERC	NERC	National Oceanography Centre Southampton, Natural Environment Research Council	United Kingdom
PML	PML	Plymouth Marine Laboratory	United Kingdom
UNIVBRIS	UNIVBRIS	University of Bristol	United Kingdom
UEA	UEA	University of East Anglia	United Kingdom
CSIR	CSIR	Council for Scientific and Industrial Research	South Africa
PU-AOS	PU-AOS	Princeton University	USA
DU	DU	Dalhousie University	Canada

Carbon dioxide in the surface ocean has to pass through the bottleneck of oceanic mixing on its way to the deep ocean. Climate change feedbacks and biogeochemical processes further modify the oceanic absorption of carbon dioxide. CARBOCHANGE employs **cutting-edge measurement and modelling techniques** to observe the on-going carbon dioxide uptake by the oceans, to understand the underlying processes, and to predict future changes in uptake.

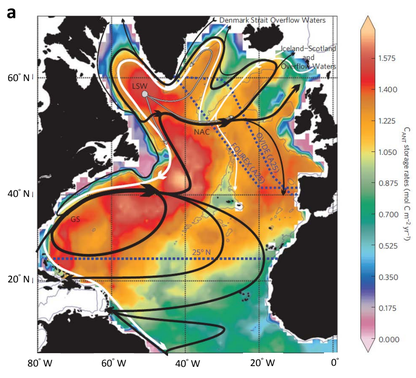
The project places special emphasis on a **systematic combination of ocean carbon observations and ocean models** through advanced model performance assessments and data assimilation methods.

Highlight 2

Atlantic Ocean CO_2 uptake reduced by weakening of the meridional overturning circulation

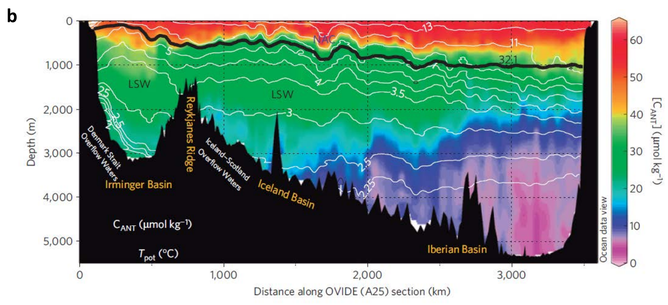
Fiz F. Pérez, Herlé Mercier, Marcos Vázquez-Rodríguez, Pascale Lherminier, Anton Velo, Paula C. Pardo, Gabriel Rosón , Aida F. Ríos

Uptake of atmospheric carbon dioxide in the subpolar North Atlantic Ocean declined rapidly between 1990 and 2006. This reduction in carbon dioxide uptake was related to warming at the sea surface, which—according to model simulations—coincided with a reduction in the Atlantic meridional overturning circulation. The extent to which the slowdown of this circulation system—which transports warm surface waters to the northern high latitudes, and cool deep waters south—contributed to the reduction in carbon uptake has remained uncertain. Here, we use data on the oceanic transport of volume, heat and carbon dioxide to track carbon dioxide uptake in the subtropical and subpolar regions of the North Atlantic Ocean over the past two decades. We separate anthropogenic carbon from natural carbon by assuming that the latter corresponds to a pre-industrial atmosphere, whereas the remaining is anthropogenic. We find that the uptake of anthropogenic carbon dioxide—released by human activities—occurred almost exclusively in the subtropical gyre. In contrast, natural carbon dioxide uptake—which results from natural Earth system processes—dominated in the subpolar gyre. We attribute the weakening of contemporary carbon dioxide uptake in the subpolar North Atlantic to a reduction in the natural component. We show that the slowdown of the meridional overturning circulation was largely responsible for the reduction in carbon uptake, through a reduction of oceanic heat loss to the atmosphere, and for the concomitant decline in anthropogenic CO_2 storage in subpolar waters.



Figures following Perez et al 2013

Circulation and C_{ANT} in the North Atlantic:
(a) C_{ANT} storage rates (mol C m^{-2} yr^{-1}) and the main currents and water masses participating in the MOC (black line: NAC, Gulf Stream; grey line: LSW; white lines: Denmark Strait and Iceland–Scotland Overflow Waters). The 25ºN, FOUREX and OVIDE section tracks are indicated (blue dotted lines).



(b) Vertical distribution of [C_{ANT}] (μmol kg^{-1}) during the OVIDE 2004 cruise. Potential temperature (ºC; white lines) and the isopycnal σ_1 = 32:10 (solid black line) separating the upper and lower limbs of MOC are also shown.

Perez FF, Mercier H, Vazquez-Rodriguez M, Lherminier P, Velo A, Pardo PC, Roson G, Rios AF (2013)
Atlantic Ocean CO_2 uptake reduced by weakening of the meridional overturning circulation
Nature Geosciences DOI: 10.1038/NGEO1680

CARBOCHANGE results contribute to **international synthesis publications** such as the Global Carbon Budget 2011 and 2012, and the IPPC 5th Assessment Report. CARBOCHANGE thus provides science-based **guardrails for political decisions on mitigation actions** in order to control and alleviate the impact of carbon dioxide emissions and climate change.

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