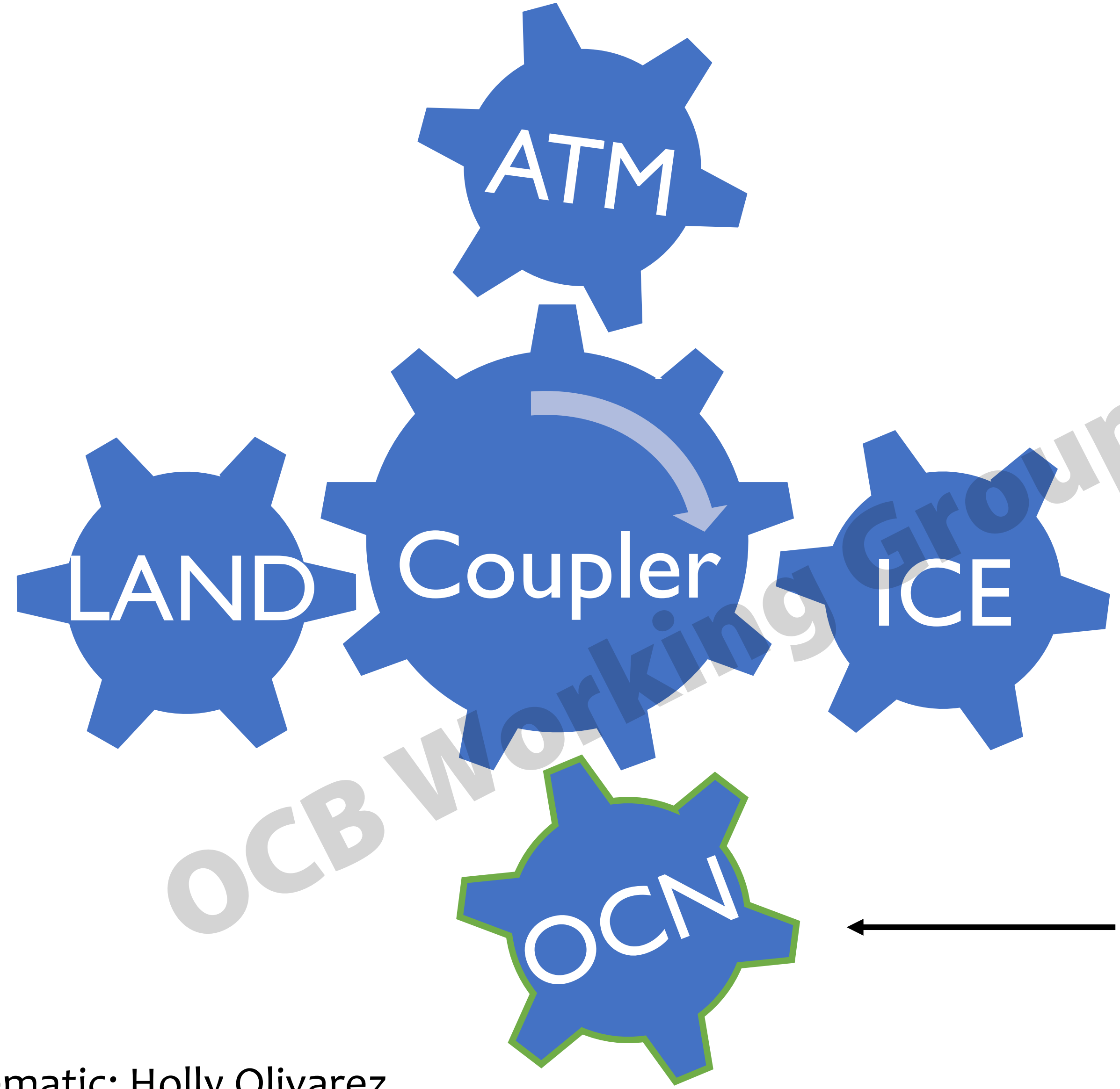
# Decadal Prediction and the WCRP Grand Challenge

Nikki Lovenduski

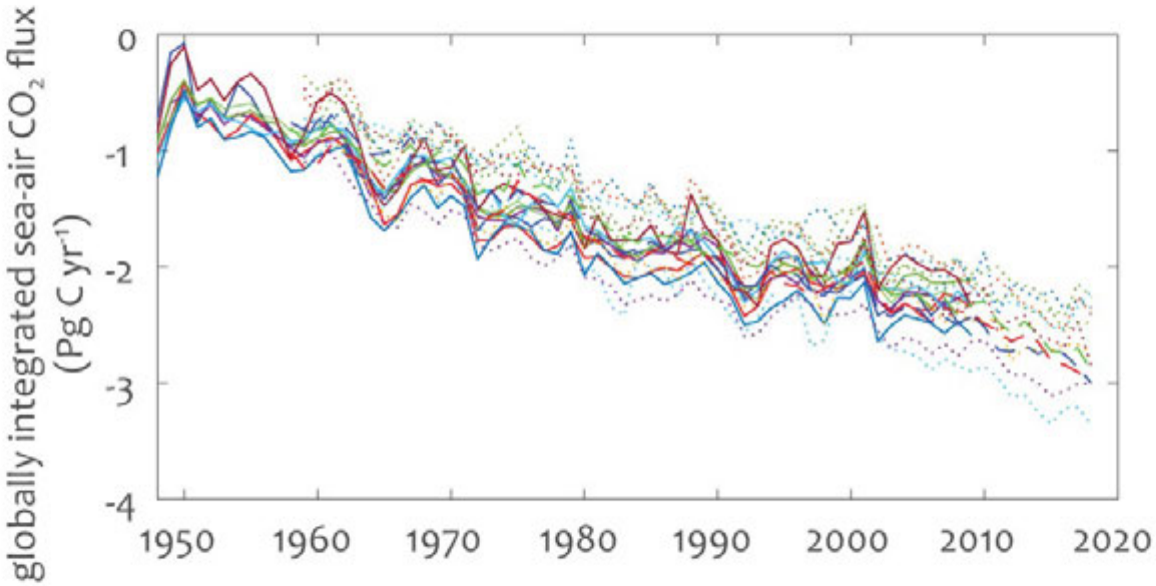
University of Colorado Boulder

# Decadal prediction

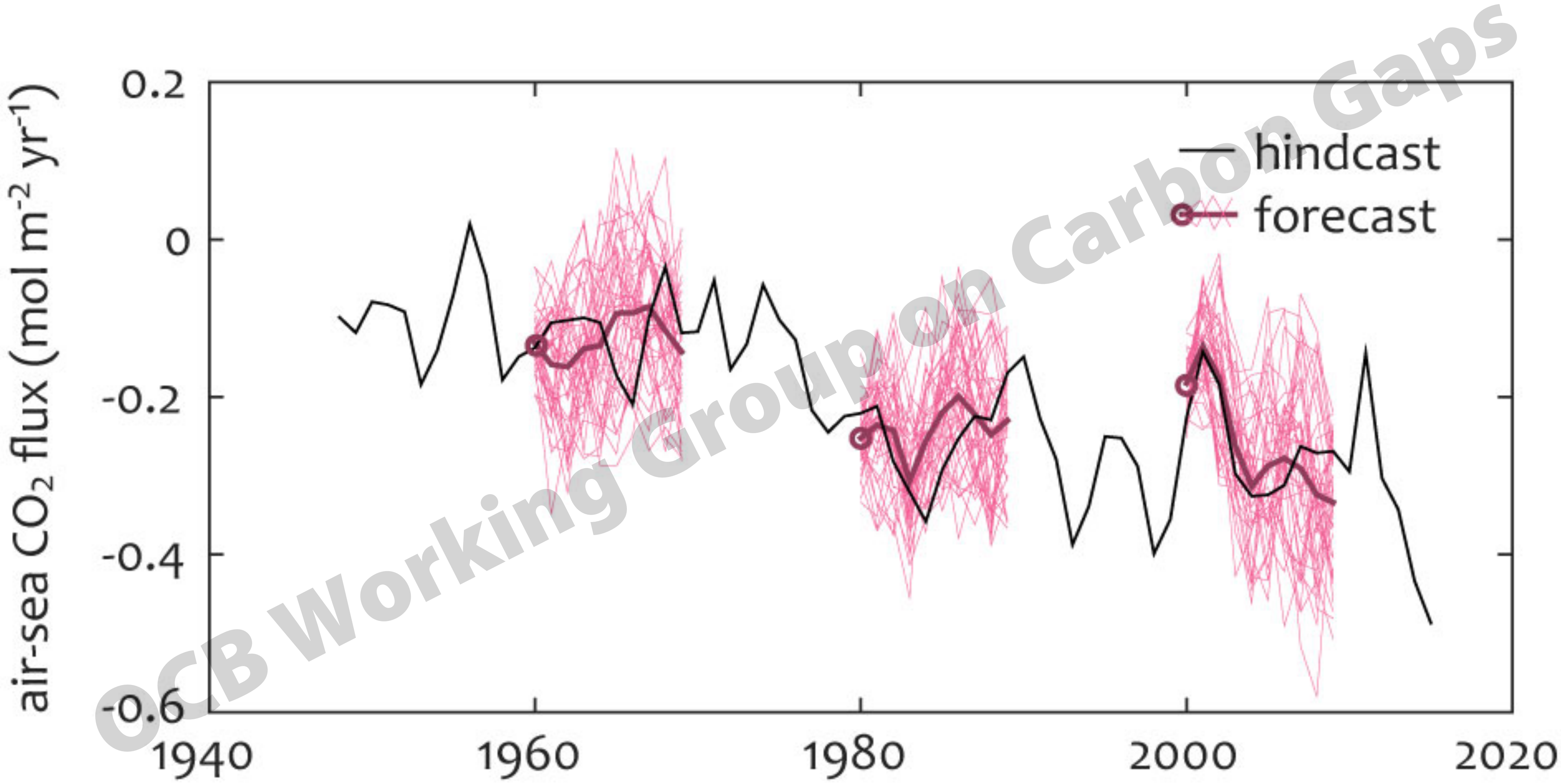



schematic: Holly Olivarez

Ocean initial conditions for predictions provided by a hindcast simulation

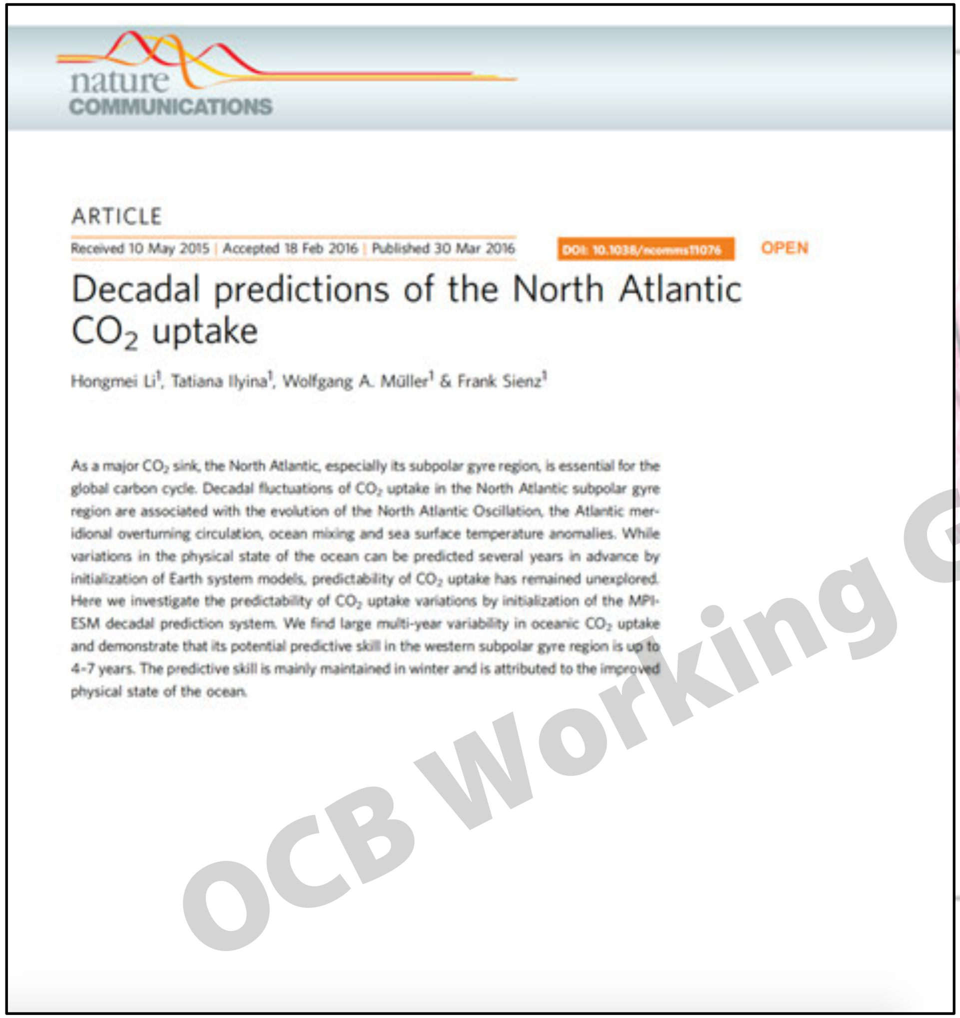


# $CO_2$ flux forecasts




Lovenduski et al. (2019)

# $CO_2$ flux forecasts



nature COMMUNICATIONS

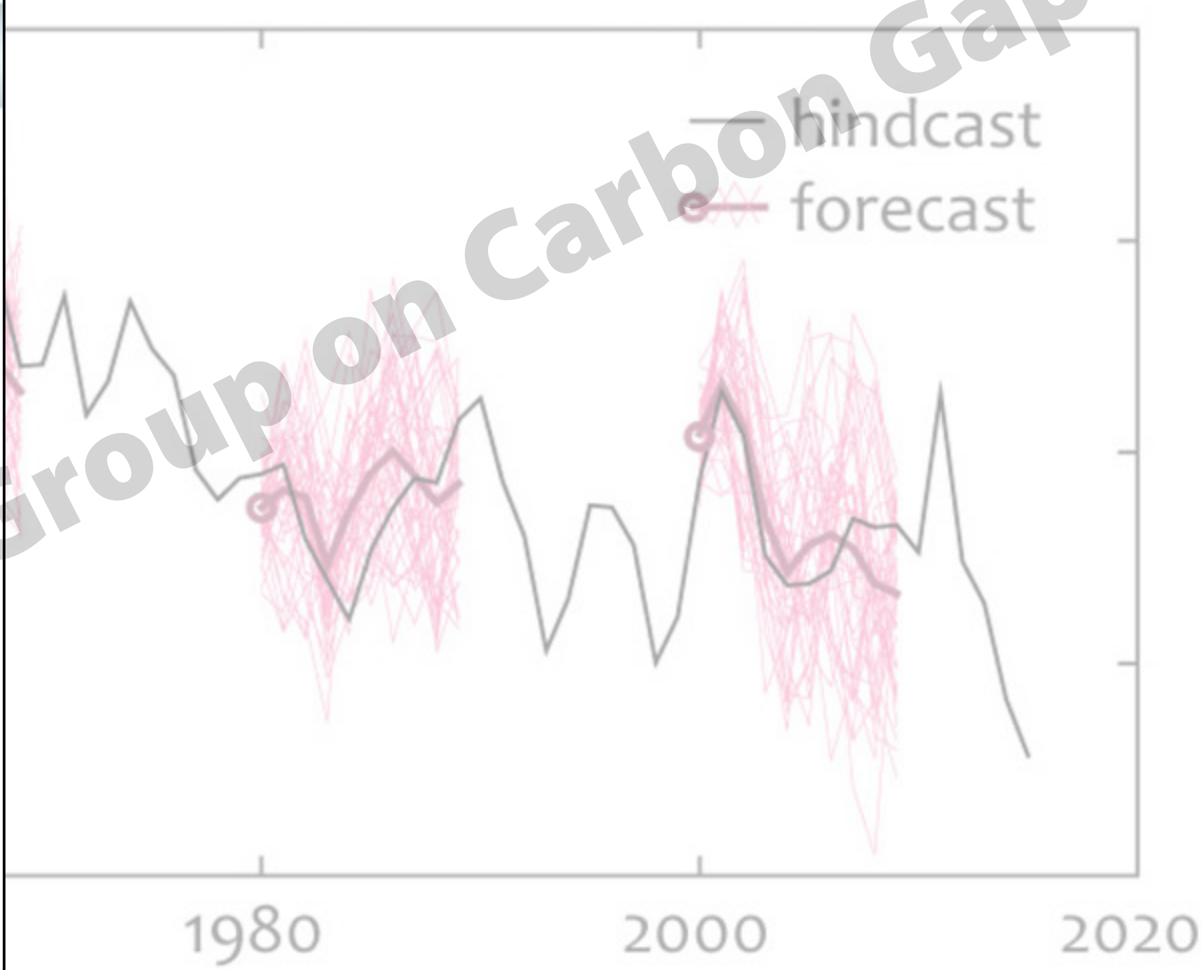
ARTICLE

Received 10 May 2015 | Accepted 18 Feb 2016 | Published 30 Mar 2016 DOI: 10.1038/ncomms11076 OPEN

Decadal predictions of the North Atlantic $CO_2$ uptake

Hongmei Li[1], Tatiana Ilyina[1], Wolfgang A. Müller[1] & Frank Sienz[1]

As a major $CO_2$ sink, the North Atlantic, especially its subpolar gyre region, is essential for the global carbon cycle. Decadal fluctuations of $CO_2$ uptake in the North Atlantic subpolar gyre region are associated with the evolution of the North Atlantic Oscillation, the Atlantic meridional overturning circulation, ocean mixing and sea surface temperature anomalies. While variations in the physical state of the ocean can be predicted several years in advance by initialization of Earth system models, predictability of $CO_2$ uptake has remained unexplored. Here we investigate the predictability of $CO_2$ uptake variations by initialization of the MPI-ESM decadal prediction system. We find large multi-year variability in oceanic $CO_2$ uptake and demonstrate that its potential predictive skill in the western subpolar gyre region is up to 4–7 years. The predictive skill is mainly maintained in winter and is attributed to the improved physical state of the ocean.



# $CO_2$ flux forecasts

nature COMMUNICATIONS

ARTICLE

Received 10 May 2015 | Accepted 18 Feb 2016 | Published 30 Mar 2016

## Decadal predictions of the $CO_2$ uptake

Hongmei Li[1], Tatiana Ilyina[1], Wolfgang A. Müller[1] & Frank S

As a major $CO_2$ sink, the North Atlantic, especially its subpolar gyre re
global carbon cycle. Decadal fluctuations of $CO_2$ uptake in the North
region are associated with the evolution of the North Atlantic Oscilla
idional overturning circulation, ocean mixing and sea surface temper
variations in the physical state of the ocean can be predicted sever
initialization of Earth system models, predictability of $CO_2$ uptake ha
Here we investigate the predictability of $CO_2$ uptake variations by in
ESM decadal prediction system. We find large multi-year variability
and demonstrate that its potential predictive skill in the western subp
4-7 years. The predictive skill is mainly maintained in winter and is att
physical state of the ocean.

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL076092

## Assessing the Decadal Predictability of Land and Ocean Carbon Uptake

Roland Séférian[1], Sarah Berthet[1], and Matthieu Chevallier[1]

[1]Centre National de Recherches Météorologiques, Météo-France/CNRS, Toulouse, France

**Key Points:**
- Global carbon fluxes can be predicted up to six years in advance
- Predictability of global carbon flux is driven by ocean, not by land
- The Southern Ocean supports most of the global carbon flux predictability

**Supporting Information:**
- Supporting Information S1

**Correspondence to:**
R. Séférian,
rseferian.cnrm@gmail.com

**Citation:**
Séférian, R., Berthet, S., & Chevallier, M. (2018). Assessing the decadal predictability of land and ocean carbon uptake. *Geophysical Research Letters*, 45, 2455–2466. https://doi.org/10.1002/2017GL076092

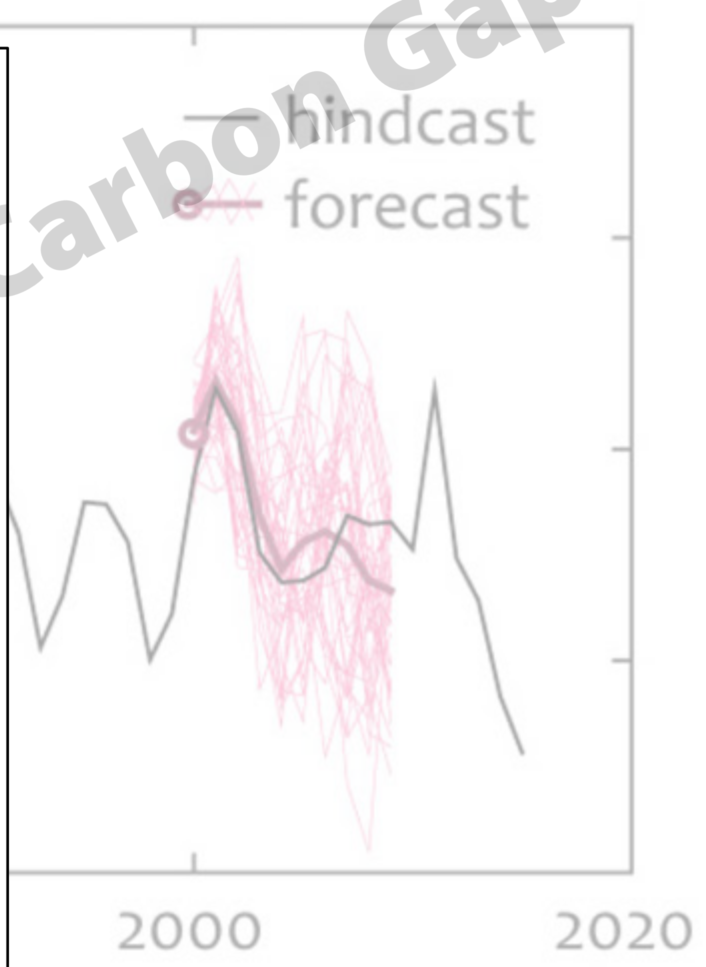
Received 17 OCT 2017
Accepted 21 FEB 2018
Accepted article online 28 FEB 2018
Published online 15 MAR 2018

**Abstract** The decadal predictability of carbon fluxes has been examined over continents and oceans using a "perfect model" approach based on a 400 year preindustrial simulation and five 10-member ensembles from the Centre National de Recherches Météorologiques-Earth System Model version 1. From these experiments, we find that the global land uptake and ocean carbon uptake are potentially predictable by up to six years, with a median predictability horizon of four years. Predictability of global carbon uptake is prominently driven by the ocean's predictability. The difference in predictability between ocean and land carbon fluxes stems from the relative capability of ocean or land to generate low-frequency fluctuations in carbon flux. Indeed, ocean carbon fluxes display low-frequency variability that emerges from the year-to-year variability in the North Atlantic, the North Pacific, and the Southern Ocean. The Southern Ocean carbon uptake can be predicted up to six years in advance and explains most of the global carbon uptake predictability.

### 1. Introduction

Anticipating the growth of atmospheric $CO_2$, several years in advance may facilitate efforts for reducing anthropogenic fossil fuel emissions over the next decades, hence mitigating global warming (Hallegatte et al., 2016; Rogelj, den Elzen, et al., 2016). Alongside continuous observations of carbon fluxes at a global scale, Earth system models are a powerful tool to predict the evolution of the global carbon cycle over the next few decades. However, their predictive ability remains largely underexplored.

Several attempts have been conducted to assess carbon flux predictability or its related fields and components (Canal et al., 2017; Li et al., 2016; Séférian, Bopp, et al., 2014; Zeng et al., 2008). Most attempts were made at a seasonal scale using a land surface model (LSM) forced by an atmospheric seasonal forecast. With Vegetation-Global-Atmosphere-Soil LSM forced with National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction coupled climate forecasting system over the period 1981–2005, Zeng et al. (2008) show that the predictability horizon for land carbon flux is approximately nine months. This predictability is predominantly driven by El Niño Southern Oscillation (ENSO) variability in the tropics. Recently, Canal et al. (2017) assessed seasonal predictions of crop harvested biomass with Interactions between Soil, Biosphere and Atmosphere (ISBA) LSM over France using a multimodel ensemble seasonal forecast from the ENSEMBLE project (Weisheimer et al., 2009). While ISBA LSM has shown a predictive ability to reproduce harvested biomass, Canal et al. (2017) explain that model skill is prominently driven by subsurface soil moisture. Attempts using Earth system models were performed during phase 5 of the Coupled Model Intercomparison Project (Taylor et al., 2007) mimicking efforts of the physical oceanography community to quantify predictability of key climate fields such as the Atlantic meridional overturning circulation (Msadek et al., 2010; Persechino et al., 2013) or climate modes of variability (Chikamoto et al., 2013; Kim et al., 2012; Mochizuki et al., 2010). Using the decadal forecast system MPI-ESM1-LR, Li et al. (2016) estimated that ocean carbon flux can be predicted seven years in advance in the North Atlantic. A large part of the predictability is due to the low-frequency mode of variability occurring



# $CO_2$ flux forecasts


nature COMMUNICATIONS

ARTICLE

Received 10 May 2015 | Accepted 18 Feb 2016 | Published 30 Mar 2016

Decadal predictions of the
$CO_2$ uptake

Hongmei Li[1], Tatiana Ilyina[1], Wolfgang A. Müller[1] & Frank S

As a major $CO_2$ sink, the North Atlantic, especially its subpolar gyre re
global carbon cycle. Decadal fluctuations of $CO_2$ uptake in the North
region are associated with the evolution of the North Atlantic Oscilla
idional overturning circulation, ocean mixing and sea surface temper
variations in the physical state of the ocean can be predicted sever
initialization of Earth system models, predictability of $CO_2$ uptake ha
Here we investigate the predictability of $CO_2$ uptake variations by in
ESM decadal prediction system. We find large multi-year variability
and demonstrate that its potential predictive skill in the western subp
4-7 years. The predictive skill is mainly maintained in winter and is att
physical state of the ocean.

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2017GL076092

Assessing the Decadal Predictability of Land and Ocean Carbon Uptake

Roland Séférian[1], Sarah Berthet[1], and Matthieu Chevallier[1]

[1]Centre National de Recherches Météorologiques, Météo-France/CNRS, Toulouse, France

Key Points:
- Global carbon fluxes can be predicted up to six years in advance
- Predictability of global carbon flux is driven by ocean, not by land
- The Southern Ocean supports most of the global carbon flux predictability

Supporting Information:
- Supporting Information S1

Correspondence to:
R. Séférian,
rseferian.cnrm@gmail.com

Citation:
Séférian, R., Berthet, S., & Chevallier, M. (2018). Assessing the decadal predictability of land and ocean carbon uptake. Geophysical Research Letters, 45, 2455–2466. https://doi.org/10.1002/2017GL076092

Received 17 OCT 2017
Accepted 21 FEB 2018
Accepted article online 28 FEB 2018
Published online 15 MAR 2018

Abstract The decadal predictability of carbon fluxes has been examined over continen
using a "perfect model" approach based on a 400 year preindustrial simulation and five 10-m
ensembles from the Centre National de Recherches Météorologiques-Earth System Model ve
these experiments, we find that the global land uptake and ocean carbon uptake are potentia
by up to six years, with a median predictability horizon of four years. Predictability of global ca
prominently driven by the ocean's predictability. The difference in predictability between oce
carbon fluxes stems from the relative capability of ocean or land to generate low-frequency f
carbon flux. Indeed, ocean carbon fluxes display low-frequency variability that emerges from th
variability in the North Atlantic, the North Pacific, and the Southern Ocean. The Southern Oce
uptake can be predicted up to six years in advance and explains most of the global carbon
uptake predictability.

1. Introduction

Anticipating the growth of atmospheric $CO_2$, several years in advance may facilitate effort
anthropogenic fossil fuel emissions over the next decades, hence mitigating glo
(Hallegatte et al., 2016; Rogelj, den Elzen, et al., 2016). Alongside continuous observations of
at a global scale, Earth system models are a powerful tool to predict the evolution of the globa
over the next few decades. However, their predictive ability remains largely underexplored.

Several attempts have been conducted to assess carbon flux predictability or its relat
components (Canal et al., 2017; Li et al., 2016; Séférian, Bopp, et al., 2014; Zeng et al., 2008).
were made at a seasonal scale using a land surface model (LSM) forced by an atmospheric sea
With Vegetation-Global-Atmosphere-Soil LSM forced with National Oceanic and
Administration/National Centers for Environmental Prediction coupled climate forecasting sy
period 1981–2005, Zeng et al. (2008) show that the predictability horizon for land c
approximately nine months. This predictability is predominantly driven by El Niño Southe
(ENSO) variability in the tropics. Recently, Canal et al. (2017) assessed seasonal predictions of c
biomass with Interactions between Soil, Biosphere and Atmosphere (ISBA) LSM over Fr
multimodel ensemble seasonal forecast from the ENSEMBLE project (Weisheimer et al., 200
LSM has shown a predictive ability to reproduce harvested biomass, Canal et al. (2017) explain t
is prominently driven by subsurface soil moisture. Attempts using Earth system models we
during phase 5 of the Coupled Model Intercomparison Project (Taylor et al., 2007) mimicking
physical oceanography community to quantify predictability of key climate fields such a
meridional overturning circulation (Msadek et al., 2010; Persechino et al., 2013) or climate mode
(Chikamoto et al., 2013; Kim et al., 2012; Mochizuki et al., 2010). Using the decadal fo
MPI-ESM1-LR, Li et al. (2016) estimated that ocean carbon flux can be predicted seven years
the North Atlantic. A large part of the predictability is due to the low-frequency mode of varia



Earth Syst. Dynam., 10, 45–57, 2019
https://doi.org/10.5194/esd-10-45-2019
© Author(s) 2019. This work is distributed under
the Creative Commons Attribution 4.0 License.

Earth System Dynamics

Open Access

EGU

Predicting near-term variability in ocean carbon uptake

Nicole S. Lovenduski[1], Stephen G. Yeager[2], Keith Lindsay[2], and Matthew C. Long[2]

[1]Department of Atmospheric and Oceanic Sciences and Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado, USA
[2]Climate and Global Dynamics Laboratory, National Center for Atmospheric Research, Boulder, Colorado, USA

Correspondence: Nicole S. Lovenduski (nicole.lovenduski@colorado.edu)

Received: 27 September 2018 – Discussion started: 5 October 2018
Revised: 23 December 2018 – Accepted: 14 January 2019 – Published: 24 January 2019

Abstract. Interannual variations in air–sea fluxes of carbon dioxide ($CO_2$) impact the global carbon cycle and climate system, and previous studies suggest that these variations may be predictable in the near term (from a year to a decade in advance). Here, we quantify and understand the sources of near-term predictability and predictive skill in air–sea $CO_2$ flux on global and regional scales by analyzing output from a novel set of retrospective decadal forecasts of an Earth system model. These forecasts exhibit the potential to predict year-to-year variations in the globally integrated air–sea $CO_2$ flux several years in advance, as indicated by the high correlation of the forecasts with a model reconstruction of past $CO_2$ flux evolution. This potential predictability exceeds that obtained solely from foreknowledge of variations in external forcing or a simple persistence forecast, with the longest-lasting forecast enhancement in the subantarctic Southern Ocean and the northern North Atlantic. Potential predictability in $CO_2$ flux variations is largely driven by predictability in the surface ocean partial pressure of $CO_2$, which itself is a function of predictability in surface ocean dissolved inorganic carbon and alkalinity. The potential predictability, however, is not realized as predictive skill, as indicated by the moderate to low correlation of the forecasts with an observationally based $CO_2$ flux product. Nevertheless, our results suggest that year-to-year variations in ocean carbon uptake have the potential to be predicted well in advance and establish a precedent for forecasting air–sea $CO_2$ flux in the near future.

# WCRP Grand Challenge

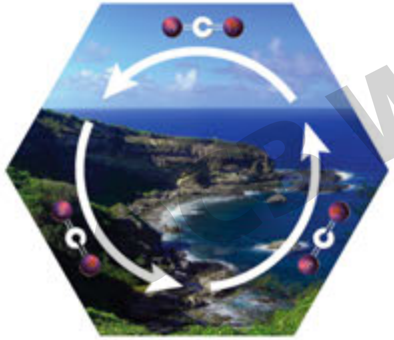
WCRP
World Climate Research Programme

International Science Council

Search Ok
Advanced search

About WCRP | Core Projects | Unifying Themes | Grand Challenges | Initiatives & Activities | Events | News | Resources

## Carbon Feedbacks in the Climate System



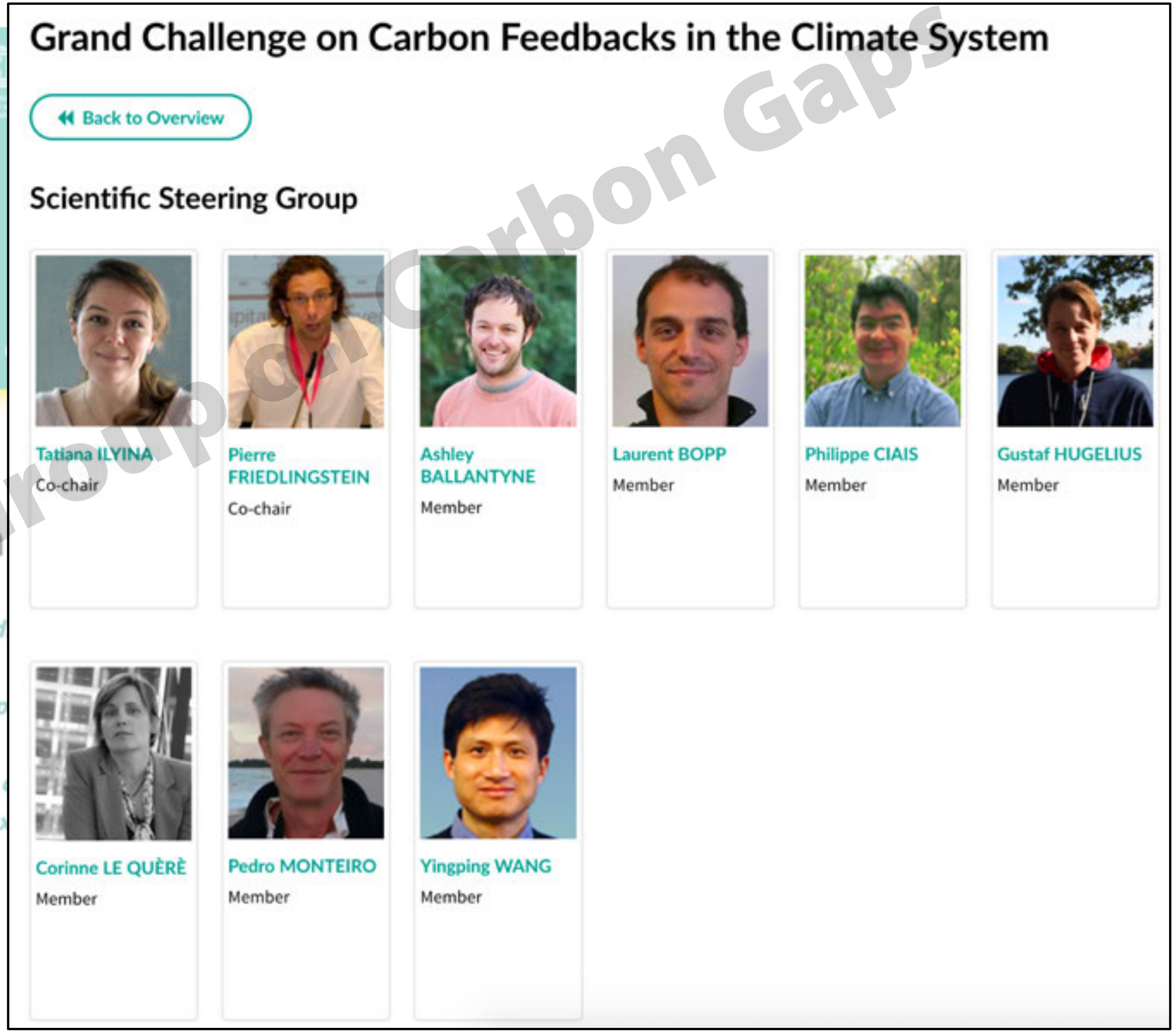
*What biological and abiological processes drive and control land and ocean carbon sinks?*
*Can and will climate-carbon feedbacks amplify climate changes over the 21st century?*
*How will highly-vulnerable land and ocean carbon reservoirs respond to a warming climate, to climate extremes, and to abrupt changes?*

### Carbon Feedbacks in the Climate System

- **Overview**
- Leadership
- Research Objectives
- Meetings and Activities
- Documents

Grand Challenges Overview

# WCRP Grand Challenge

# WCRP Grand Challenge


## Research Objectives

The Grand Challenge on Carbon Feedbacks in the Climate System will pursue the following objectives:

**I. Process understanding on land:**

- quantification of the strength of the $CO_2$ fertilization, photosynthesis and limitations from nitrogen cycle
- quantification of gross carbon fluxes sensitivity to warming and variability (and changes in hydrology)
- understanding of ecosystems vulnerability and risk of carbon loss

**II. Process understanding in the ocean:**

- quantification of the strength of the Southern Ocean $CO_2$ uptake
- the relative role of physical vs. biological processes in determining ocean carbon sink
- understanding the origins of variability (from seasonal to decadal) of the ocean carbon sink
- relationship between anthropogenic carbon and heat uptake

**III. Learning from the existing record:**

- observational frameworks
- model evaluation/benchmarking
- developing new emerging constraints
- from paleorecord to satellite data

**IV. Towards improved projections:**

- improved feedback framework (water cycle, regional focus)
- improved Earth System models
- ESM re-analysis (physics and biogeochemistry)