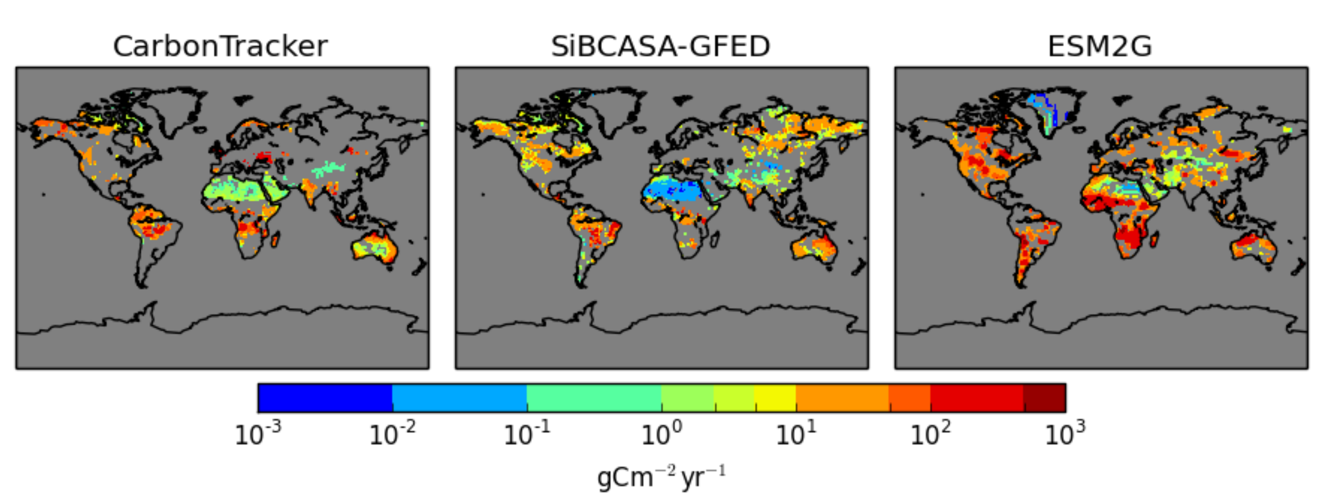
EVALUATION OF THE CARBON CYCLE IN THE CMIP5 EARTH SYSTEM MODEL ESM2G

M. LEONARD[1,2], L. BRUHWILER[1], J. DUNNE[3], E. SHEVLIAKOVA[3]

[1] *NOAA BOULDER, ESRL/GMD, BOULDER, CO, UNITED STATES,* [2] *SCIENCE AND TECHNOLOGY CORPORATION, BOULDER, CO, UNITED STATES,*
[3] *PRINCETON UNIVERSITY, PROGRAM IN ATMOSPHERIC AND OCEANIC SCIENCES, PRINCETON, NJ, UNITED STATES*

Abstract

Understanding potential carbon cycle climate feedbacks is essential, however future simulations are extremely uncertain. Coupled climate-carbon cycle models project an additional rise in CO_2 by year 2100 of between 20 to 200 parts per million (ppm) due to carbon cycle feedbacks. The higher end of this range could have significant additional impacts on global climate. We demonstrate methods to improve these models by evaluating based on an indispensible and multi-decadal data record. We will focus on the model Geophysical Fluid Dynamics Laboratory (GFDL) ESM2G that is a possible prior flux model for the future coupled climate-carbon models that can diagnostically quantify the carbon budget over decades covered by the National Oceanic and Atmospheric Administration (NOAA) observational record. Such models will help improve coupled climate-carbon models by improving their ability to simulate the recent past. We investigate global to regional scaled comparisons of the coupled climate-carbon model GFDL ESM2G using two types of data-constrained models: CarbonTracker and SiBCASA-GFED. The former is constrained by atmospheric observations, while the latter is constrained by space-based estimates of photosynthesis unlike the GFDL ESM2G, which is purely predictive. We identify and discuss in detail global to region scaled fire, terrestrial and oceanic carbon flux comparisons between models. We determine that ESM2G is capable of representing carbon fluxes in a global scale with annual resolution, however regional scales and shorter temporal resolution engenders bias and other amalgamated problems. This includes an early growth seasons in the northern boreal regions, an inverse annual cycle around the Indian and Southern Ocean, and an overestimation of gross primary production (GPP) in regions near the Inter Tropical Convergence Zone. We present ideas for improving future versions of GFDL ESM2G applicable for other coupled climate-carbon models.



CarbonTracker

CarbonTracker is a state-of-the-art data assimilation system constrained by multiple diverse observational network data and capable of forecasting atmospheric CO_2 mole fractions across the globe. It is developed using a combination of CO_2 surface exchange models and an atmospheric transport model (TM5) driven by meteorological fields. Observations include a record of net CO_2 exchange from the multiple processes, geographic areas, and time collected by NOAA's ESRL. In addition, carbon exchange is monitored by a worldwide collection of surface flux measurements in diverse ecosystems. Efforts to monitor biomass burning, land-use changes, and other surface environmental stress factors are targeted by direct satellite observations. Simulated distribution of CO_2 is resampled with observations to minimize surface flux differences using a set of linear scaling factors. CarbonTracker's net CO_2 surface fluxes are weighed by prescribed (fixed) fossil fuel and Global Fire Emissions Database (GFED) fire estimates and adjustable biospheric and oceanic fluxes.

SiBCASA-GFED

Simple Biosphere Model, Version 2.5, (SiB2.5) is a biophysical model capable of estimating land-surface carbon fluxes, latent and sensible heat, radiant energy and momentum at 10-20 minute resolution. It uses photosynthesis and biophysical processes scaled up using absorbed fraction of Photosynthetically Active Radiation (*fpar*) derived from Normalized Difference Vegetation Index (NDVI). SiB2.5 can predict total respiration, but cannot produce biomass and assumes long-term carbon balance (*NEE=0*). Consequently, it cannot predict long-term carbon sinks or sources. SiB2.5 is combined with the **Carnegie-Ames-Stanford Approach (CASA)** model, which uses a simple light efficiency model to estimate NPP and carbon interaction between biogeochemical pools. [Potter et al., 1993]. These two models combined create **SiBCASA**; the terrestrial biosphere model extended with biomass burning emissions from 13 distinctly modified carbon pool configurations using remotely sensed burned areas from the GFED project. This biogeochemical model meets the broad variety of biological and physical processes needed to understand the terrestrial carbon cycle and predict ecosystem biomass and carbon fluxes. It includes prescribed environmental stress factors influence CO_2 uptake and is driven by meteorological driver data.

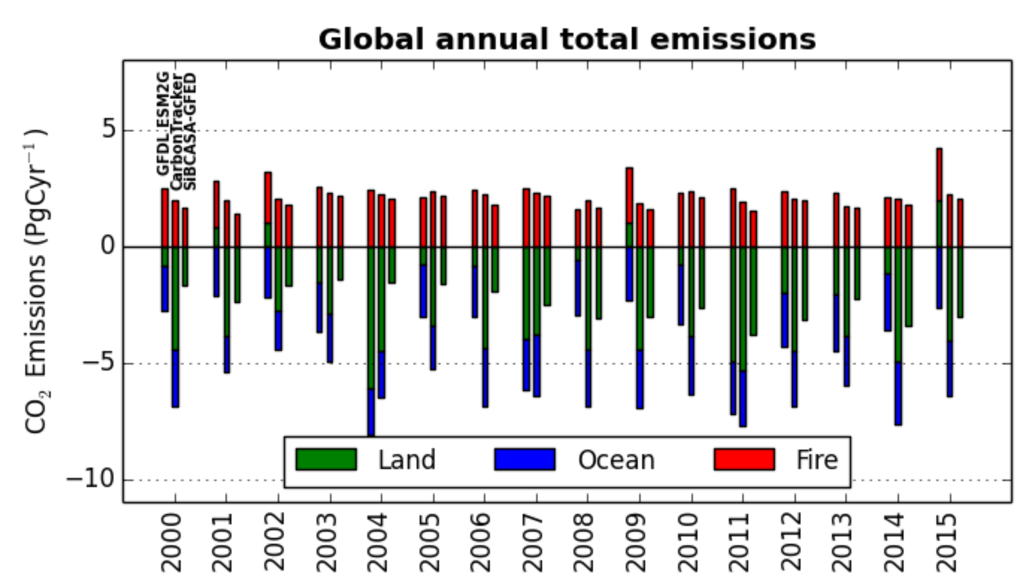
ESM2G

NOAA's first Earth System Model **ESM2G** is designed to study the impact of climate change on ecosystems, ecosystem changes on climate and human activities on ecosystems. ESM2G is constructed by NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) with collaborative efforts by Princeton University, Department of Interior, and other institutes. It is a physical climate model designed to advance our understanding of the how the Earth's biogeochemical cycles, including human actions, interact with the climate system. ESM2G is coupled with both atmospheric and oceanic circulation using simulation tools derived to represent land, sea ice and iceberg dynamics. In addition, this model incorporates biogeochemistry and a closed carbon cycle that represents climate and ecosystem interactions and their potential natural and anthropogenic changes. There is an abundance list of physical features and variables included in the atmospheric and oceanic components mentioned in *Dunne et al. 2012, 2013.* ESM2G allows us to understand the sensitivity of a coupled climate-carbon system over time to our improving knowledge of our land and ocean carbon exchanges.

van der Velde, I. R., Miller, J. B., Schaefer, K., van der Werf, G. R., Krol, M. C., and Peters, W.: Terrestrial cycling of 13CO2 by photosynthesis, 25 respiration, and biomass burning in SiBCASA , Biogeosciences, 11, 6553–6571, doi:10.5194/bg-11-6553-2014, 2014.

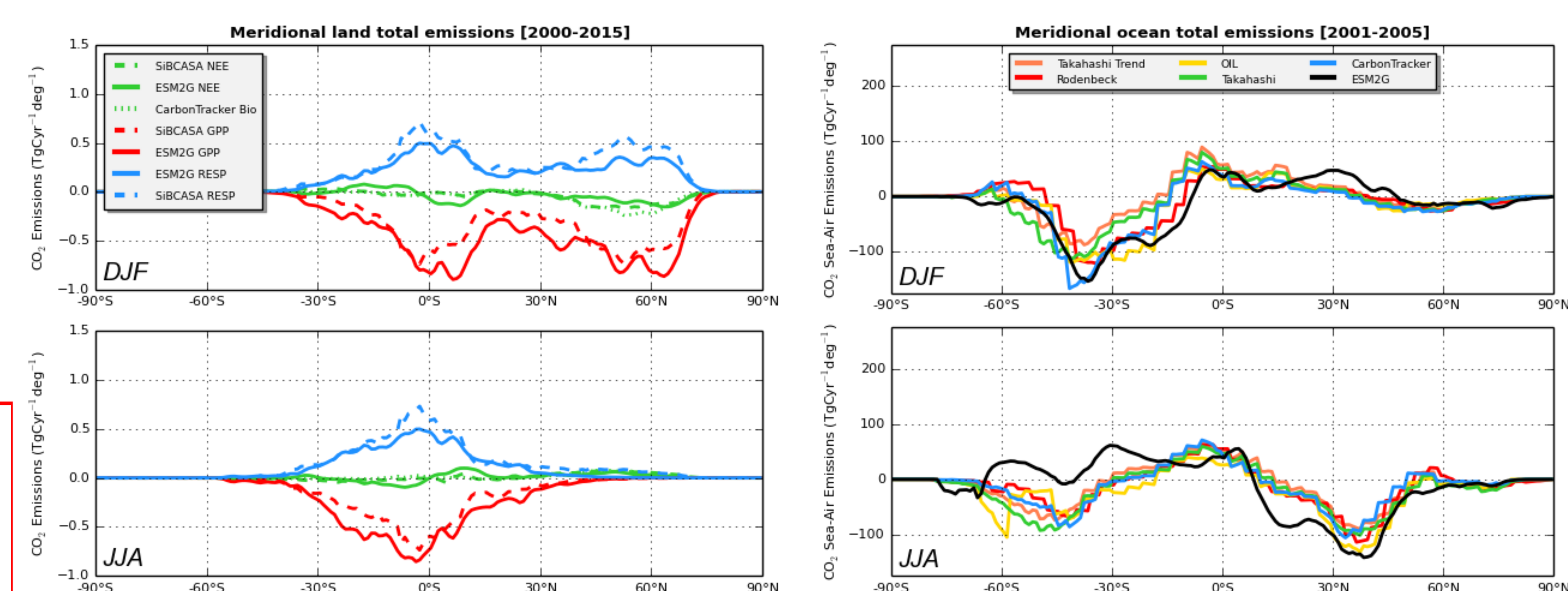
Dunne, et al, 2012: GFDL's ESM2 global coupled climate–carbon Earth System Models. Part I: Physical formulation and baseline simulation characteristics. *J. Climate*, **25**, 6646–6665.

Peters, W. *et al.* (2007), An atmospheric perspective on North American carbon dioxide exchange: CarbonTracker, *PNAS*, November 27, 2007 , vol. 104, no. 48, 18925-18930



Global Totals

Comparison between global land, ocean and fire emissions are shown between 2000 and 2015. Land fluxes represent the net mass flux of carbon between land and atmosphere calculated as photosynthesis minus the sum of plant and soil respiration, carbonfluxes from fire, harvest, grazing and land use change. Ocean Fluxes modules include partial pressure of CO_2, inversion methods and included biogeochemical processes.

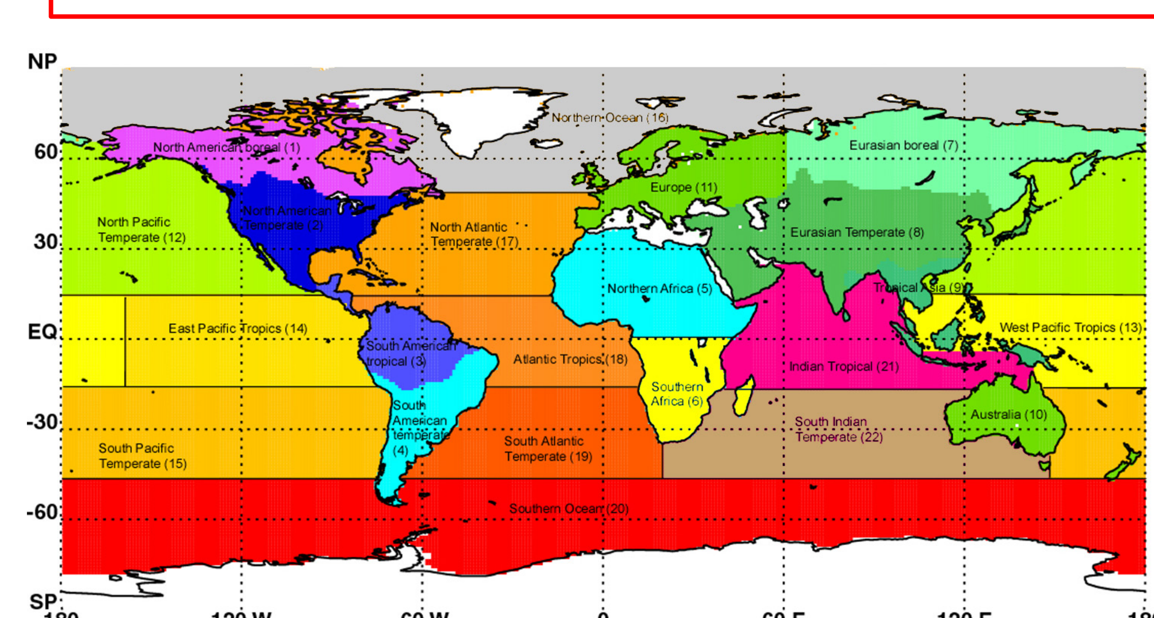


Meridional Distribution

Knowing each model's global total CO_2 emissions from 2000 to 2015, we categorizes meridional gradients of land and ocean flux totals of CO_2 within seasonal extremas—summer (JJA) and winter (JFM). ESM2G, compared to CarbonTracker and SiBCASA, estimates 1 PgCyr^{-1} more carbon into the atmosphere in the warm months of the Northern and Southern Hemisphere Tropics and a net sink of 1 PgCyr^{-1} in the Tropical winters. In the mid- and higher latitudes, Net Ecosystem Production (NEP) comparisons are similar, particularly in the North Hemisphere winter. CarbonTracker and SiBCASA are comparable to *40±10* TgCyr^{-1} in summer and *7±6* TgCyr^{-1} in winter. Ocean fluxes are comparable within 5 TgCyr^{-1} for all models. There are no significant irregularities for different seasons at different latitudinal regions.

Transcom Regions.

The terrestrial biosphere is divided into 19 ecosystem types as well as geographical locations. Using these regions can further allocate the source of variances between model fluxes at across different latitudinal regions. ESM2G has an earlier terrestrial growing season in northern boreal and temperate regions and an unrealistically large seasonal cycle across the entire southern hemisphere, compared to other models. This may be attributed to an error of transparency in shortwave radiation during precipitable cloud events and greater Inter Tropical Convergence Zone (ITCZ). ESM2G has a reversed seasonal cycle in the tropical Indian and Southern ocean. In addition, it's ocean flux produces slightly larger seasonal cycle in the South and North Pacific than data-interpolated ocean models.



The terrestrial and oceanic biosphere is divided into 22 distinctive regions as well as geographical locations as shown from the TransCom inversion study (e.g. Gurney et al., [2002]).

Summary

Tropics
Contains largest flux discrepancy with ESM2G, particularly with tropical NEP due to location of ITCZ.

Higher Northern Latitudes
Models have a small phase shift difference in both GPP and Respiration. ESM2G overestimated forests to compensate for sea-ice melting.

Southern Hemisphere
ESM2G contains annual cycles in GPP and contains large bias in Amazonian Respiration.

Oceans
ESM2G has slight bias of 0.5 Pg Yr-1 in southern hemisphere oceans. In addition, Southern Ocean has a half phase shifted annual cycle with respect to Takahashi and OIF.