# Above-Belowground Vegetation Carbon Allocation in CMIP5 Earth System Models


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## Background

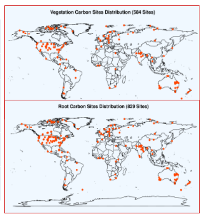
### Introduction

The above-belowground vegetation carbon allocation is an important factor to determine how ecosystem carbon sequestration respond to climate change. Model representation of carbon allocation algorithm significantly influence the simulated terrestrial carbon stock and land-atmosphere interaction within Earth System Models (ESMs). Few previous studies, however, have investigated and evaluated the above-belowground carbon allocation in ESMs. In this study, we analyzed carbon density in belowground (root), total vegetation (above + belowground), and root:total vegetation carbon (R/T) ratios of nine ESMs from the Coupled Model Inter-comparison Project Phase 5 (CMIP5), which were used for the latest IPCC Assessment Report (AR5). Previous datasets ranging form site-level, biome-level, to global scale were compiled to compared with CMIP5 model outputs during 1995-2005 based on historical simulations.

### Data Source

| Dataset | Source | Description | Site Number |
|---|---|---|---|
| 1 | Mokany et al., 2006 | Site level cVeg and cRoot | 276 |
| 2 | Gill et al., 2000 | Site level cRoot | 258 |
| 3 | Iversen et al., 2014 | Site level cVeg and cRoot | 295 |
| 4 | GPG-LULUCF, 2003 | Biome level cVeg and cRoot | 16 biomes |
| 5 | Ruesch et al., 2008 | Global level cVeg and cRoot | Global |

*GPG-LULUCE: Good Practice Guidance for Land Use, Land-Use Change and Forestry.*



### Earth System Models

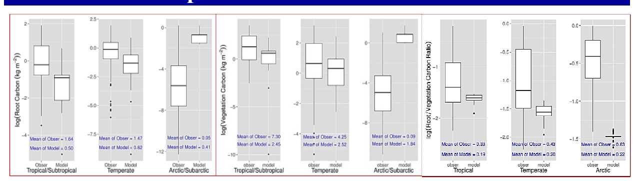
Nine ESMs were used in this study including CCSM4, CESM1-BGC, CESM1-CAM5, GFDL-ESM2M, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, NorESM1-ME, NorESM1-M.

### Definition of Climate Zones and Vegetation Biomes

Three climate zones: 1) Tropical/subtropical zone (30S ~ 30N); 2) Temperate zone (30S ~ 60S, 30N ~ 60N); 3) Arctic/subarctic zone (60N ~ 90N).

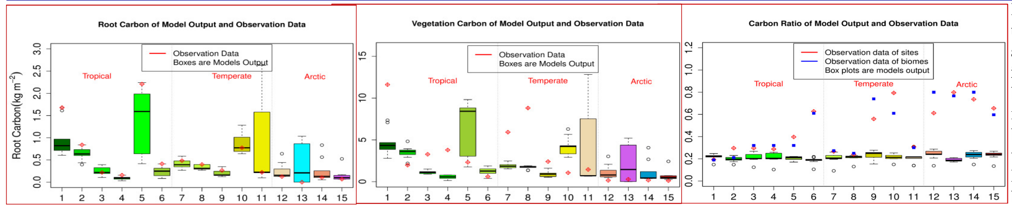
Fifteen biomes: 1) Tropical/Subtropical Moist Forest; 2) Tropical/Subtropical Dry Forest; 3) Tropical/Subtropical Moist Woodland; 4) Tropical/Subtropical Dry Woodland; 5) Tropical Savanna; 6) Tropical/Subtropical Grassland; 7) Temperate Conifer Forest; 8) Temperate Broadleaf Forest; 9) Temperate Shrubland; 10) Temperate Grassland; 11) Boreal Broadleaf Forest; 12) Subarctic Grassland; 13) Subarctic Arid Shrubland/Desert; 14) Tundra; 15) Tidal Marsh.

## Comparisons in Three Climate Zones



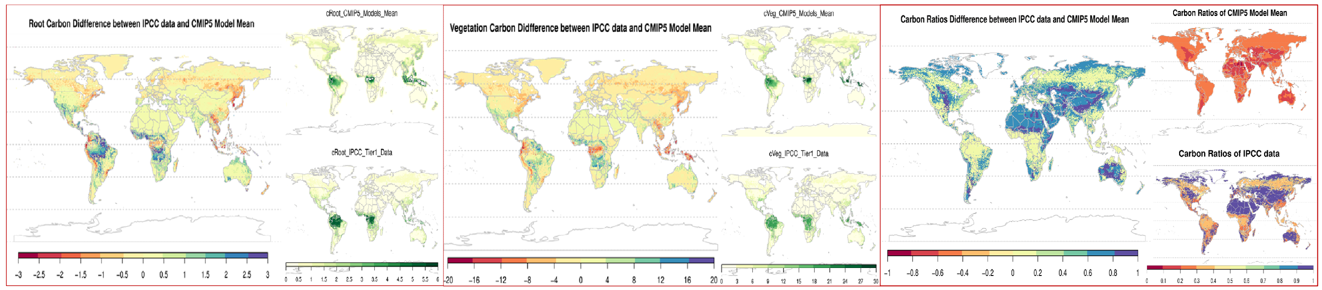
ESMs are not consistent with observational data; both the root and total vegetation carbon density are underestimated in tropical/subtropical and temperate regions, while overestimated in arctic/subarctic regions. The R/T ratios are underestimated in all three climate zones.

## Biome-Level Model Evaluation of CMIP5 Output



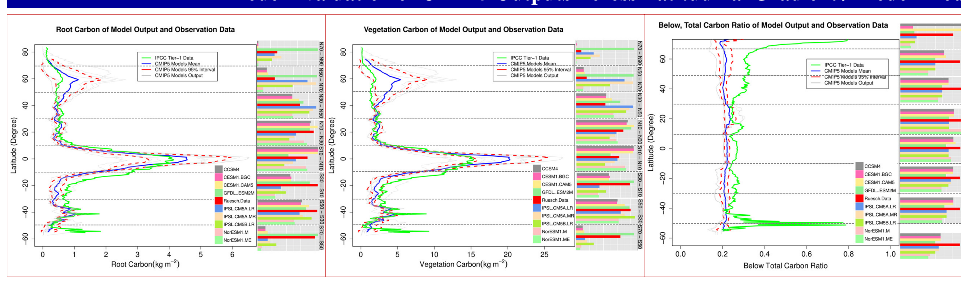

Root carbon in ESMs: 7 biomes underestimated, 7 biomes overestimated and 1 biome consistent. Vegetation carbon in ESMs: 6 biomes underestimated, 7 biomes overestimated. Overestimation of root, vegetation carbon are in moist biomes of tropical and temperate area, while underestimation in dry biomes. R/T ratios: 14 biomes underestimated, 1 biome consistent.

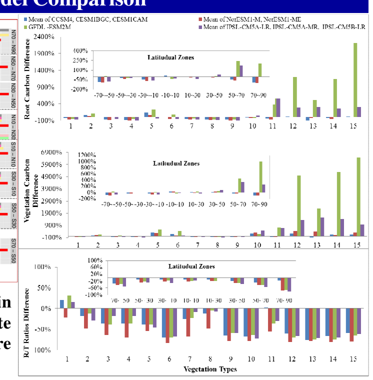
## Spatial Evaluation of CMIP5 Output




ESMs had consistent spatial pattern of belowground and total vegetation carbon with observational data, high carbon density in tropical region, while low in artic and arid ecosystems. ESMs significantly underestimated the R/T ratio across majority of the globe, indicating a need to improve root representation in the earth system models for better simulating carbon processes and terrestrial feedbacks to the climate system.

## Model Evaluation of CMIP5 Outputs Across Latitudinal Gradient / Model-Model Comparison



Basically, ESMs captured the carbon density in root and total vegetation along the latitudinal gradient, while really bad in simulating R/T ratio. Consistent with previous climate zone comparison, ESMs model perform well in tropical and temperate area, while not well in the arctic area. CLM – family has relatively good consistence to observation data; while more improvements are needed for GFDL and IPSL models in simulating root carbon density and R/T ratios.

## Summary

A few conclusions have been reached in this research

1) ESMs underestimated belowground and total vegetation carbon density in tropical/subtropical and temperate regions, while overestimated in arctic /subarctic regions
2) ESMs underestimated the R/T ratio across the majority of the globe
3) Model-model differences are large in simulating carbon density and R/T ratio
4) The carbon allocation algorithms in current ESMs need to be improved, particularly the R/T ratio.