Evaluation of Extratropical Forest Biomass in Earth System Models over the Northern Hemisphere

Cheng-En Yang[1,2], Jiafu Mao[3], Forrest M. Hoffman[2], Daniel M. Ricciuto[3], Joshua S. Fu[1,2], Chris D. Jones[4], and Nuno Carvalhais[5]

[1]Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, TN, USA (cyang10@vols.utk.edu)

[2]Climate Change Science Institute and Computer Science and Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA

[3]Climate Change Science Institute and Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA

[4]Met Office Hadley Centre, Exeter, UK   [5]Max Planck Institute for Biogeochemistry, Jena, Germany

Introduction

❖ Simplified representations of processes driving global forest biomass in Earth system models (ESMs) contribute to large uncertainty and variability among climate predictions, in particular for the simulations of biomass magnitude, carbon allocation, and the responses of biomass to changing climatic conditions

- Utilizing grid-weighted vs. detailed PFT-level carbon mass
- Inconsistencies of the associations between forest biomass and climate
- Uncertainty in the initial vegetation status from ESMs' spin-up procedures

Methodology

Variables	Observations	Models [grid resolution]*
Forest biomass (carbon density, kgC m^{-2}, converted to mass, PgC)	BGI[†] 30ºN–80ºN only [0.01º×0.01º]	(1) BNU-ESM [2.81º×2.81º]
		(2) HadGEM2-CC [1.25º×1.875º]
		(3) HadGEM2-ES[#] [1.25º×1.875º]
Climate precipitation (PR) surface temperature (TAS)	Global Soil Wetness Project phase 3 [0.5º×0.5º]	(4) IPSL-CM5A-LR [1.9º×3.75º]
		(5) IPSL-CM5A-MR [1.25º×2.5º]
		(6) IPSL-CM5B-LR [1.9º×3.75º]
Plant functional type (PFT)	Global Land Cover 2000 22 PFTs [1 km×1 km]	(7) MIROC-ESM [2.81º×2.81º]
		(8) MIROC-ESM-CHEM [2.81º×2.81º]

[†]Thurner, M. et al. (2014), *Global Ecol. & Biogeog.*, **23**, 297–310.
*r1i1p1 ensemble member in the Coupled Model Intercomparison Project Phase 5 (CMIP5).
[#]individual PFT-level carbon density available from Dr. Chris Jones.

❖ Carbon amount for forest components: *total*, *leaves*, *wood*, *roots*, and *wood+roots*

❖ Climate means of CMIP5 outputs: 1982–2005 (t_1) and 1861–1885 (t_2)

❖ Observations are regridded to the same resolutions of each CMIP5 model while retaining PFT distributions

❖ A grid is masked out if either observed or modeled value is unavailable

❖ The association between forest biomass and climate is evaluated for each grid cell by computing local correlations using a 11×11-grids moving window

❖ Relative differences (RE_T, RE_G) of forest carbon and spin-up influence (SR)

Global total carbon

$$RE_T = \frac{\sum_{i=1}^{n} y_i - \sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} x_i}$$

Grid-level mass mean

$$RE_G = \frac{\sum_{i=1}^{n}\left(\frac{y_i - x_i}{x_i}\right)}{n}$$

Spin-up influence

$$SR = \frac{RE_{T,t_1}}{RE_{T,t_2}}$$

$\left(\begin{array}{l} SR \to 1, \text{ highly influenced by} \\ \text{initial spin-up carbon state} \end{array} \right)$

Relative differences in biomass magnitude

Global total carbon (RE_T)   Grid-level average (RE_G)
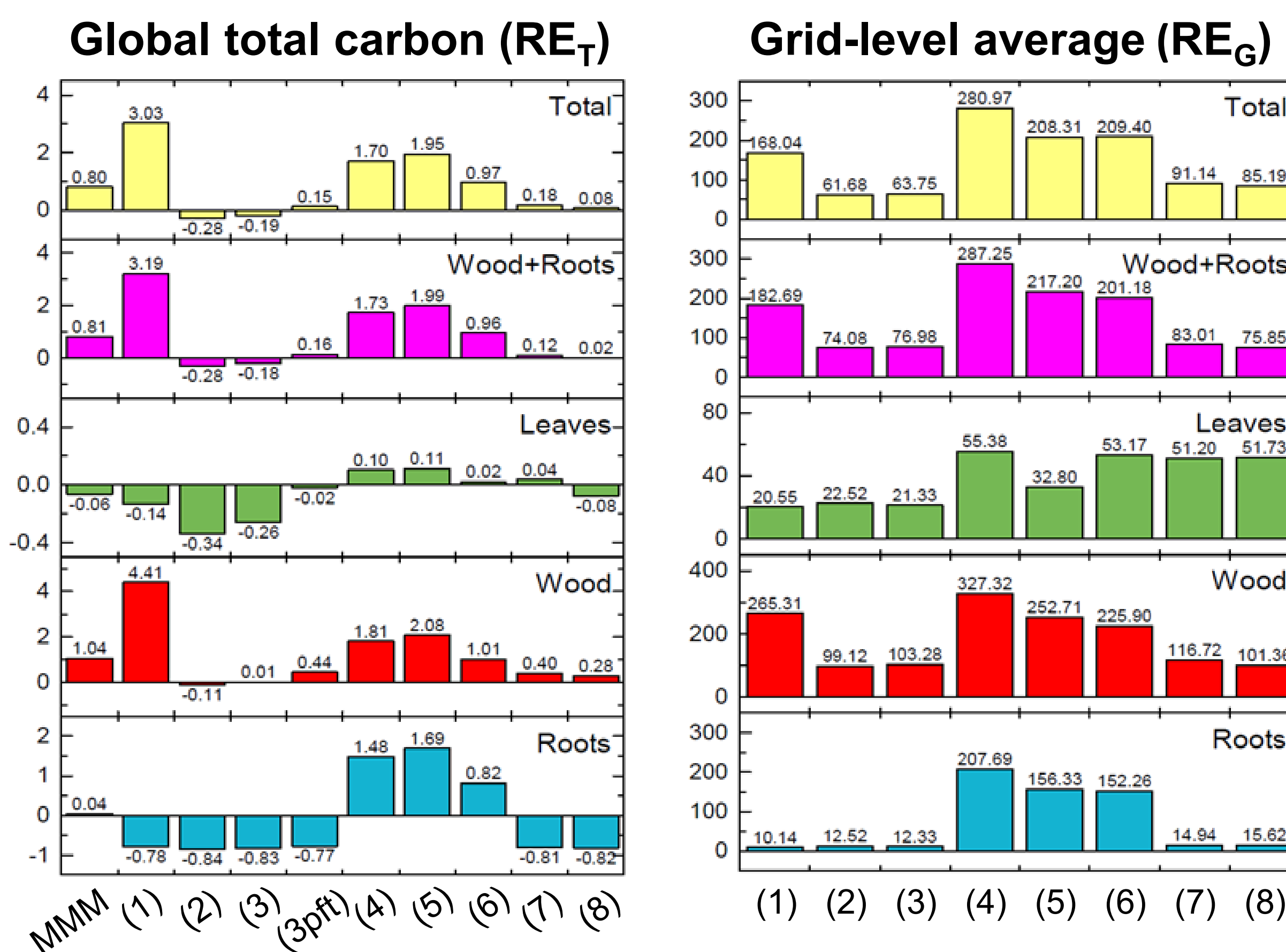
(MMM: multimodel mean; 3pft: HadGEM2-ES with detail PFT-level biomass info)

❖ MMM shows most ESMs overpredict forest biomass in wood+roots component but underestimate that in leaves

❖ Smaller RE_T in detailed PFT-level outputs (3pft) compared to grid-weighted results (3)

❖ Large RE_G values indicate significant spatial biases of forest biomass in ESMs compared to BGI

Spin-up influence
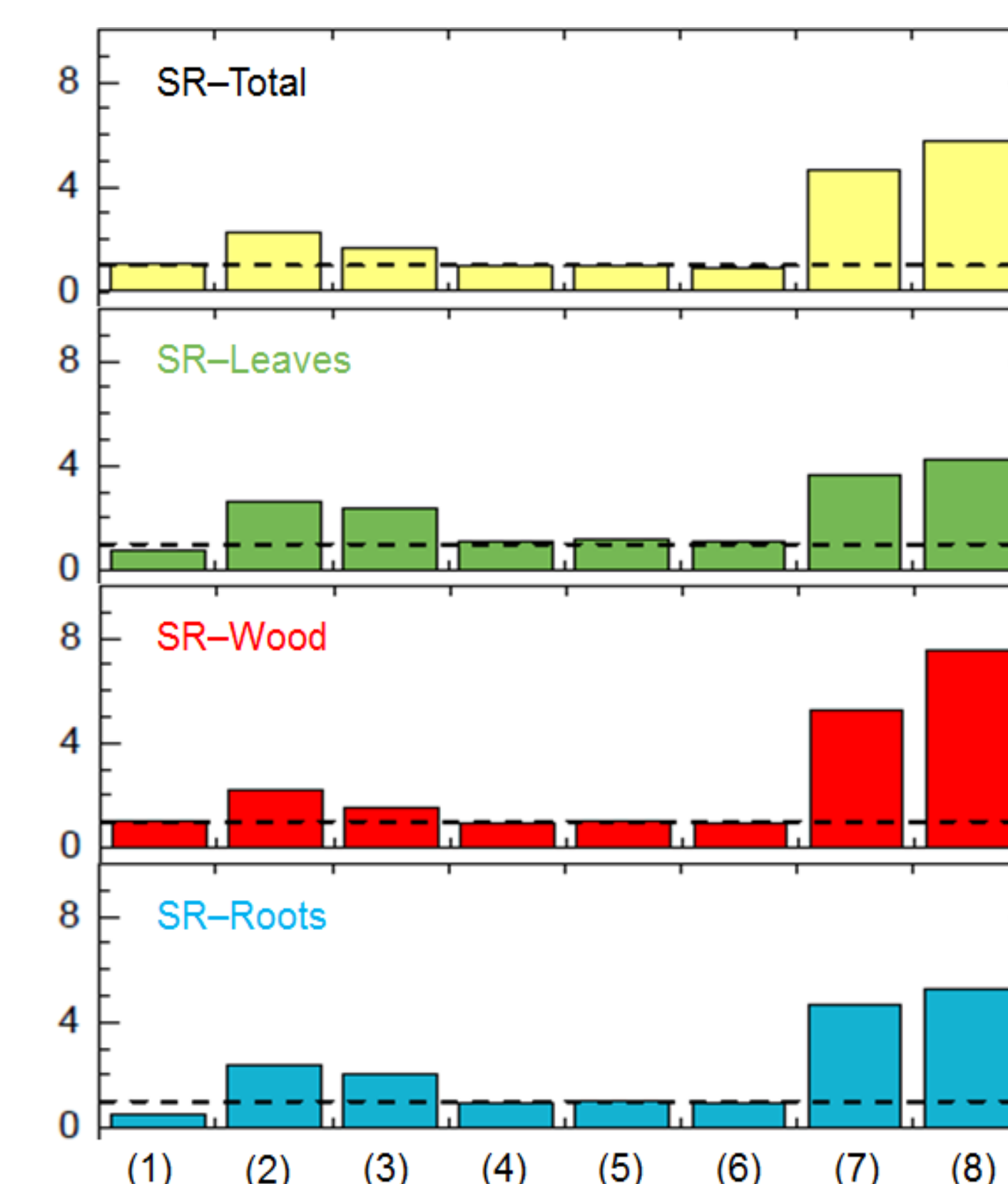
❖ Modeled forest biomass in ESM (1) and ESM (4)–(6) are affected by the initial vegetation status generated from spin-up processes

Carbon allocation in each component
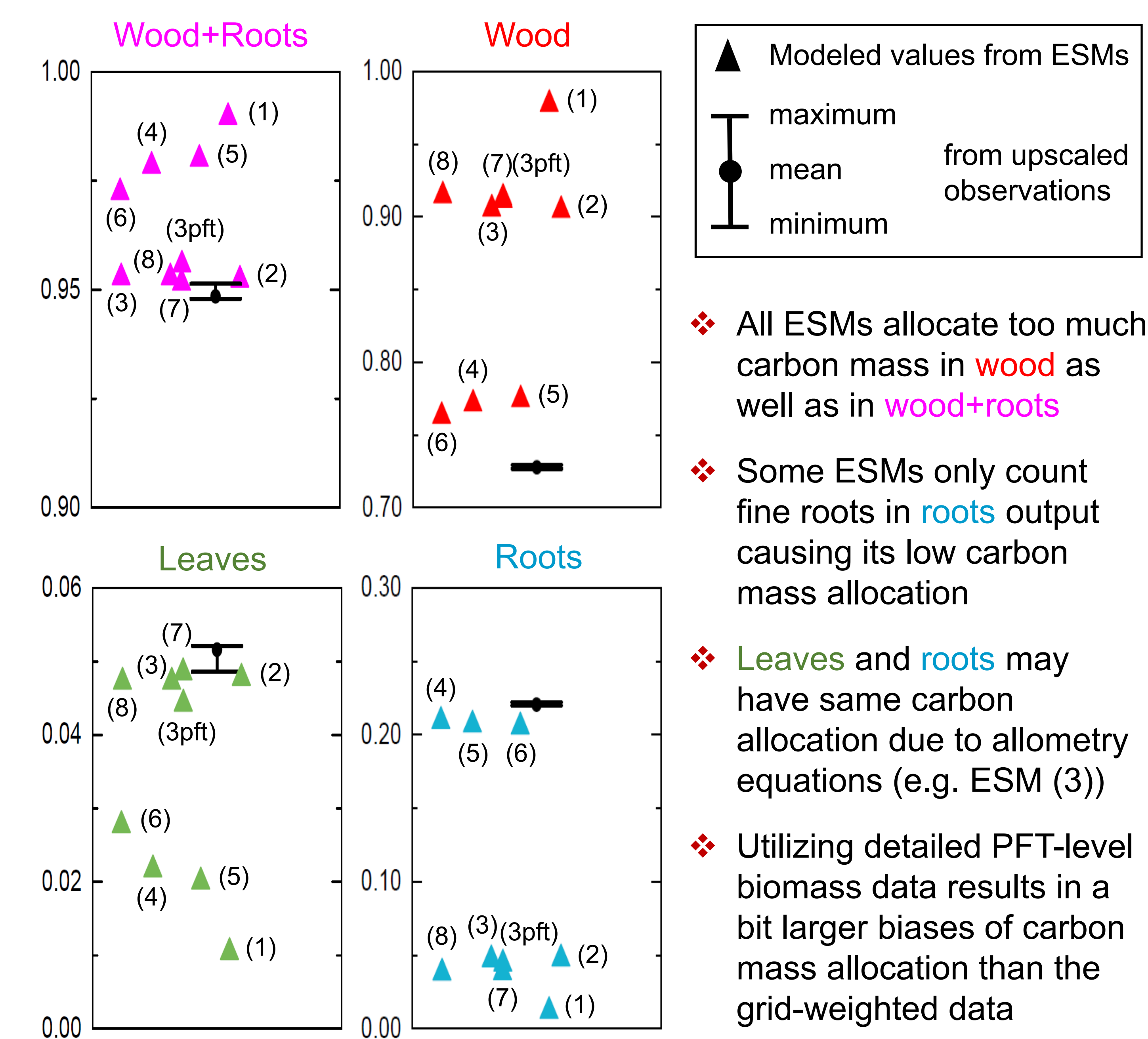
❖ All ESMs allocate too much carbon mass in wood as well as in wood+roots

❖ Some ESMs only count fine roots in roots output causing its low carbon mass allocation

❖ Leaves and roots may have same carbon allocation due to allometry equations (e.g. ESM (3))

❖ Utilizing detailed PFT-level biomass data results in a bit larger biases of carbon mass allocation than the grid-weighted data

Associations between forest biomass and climate
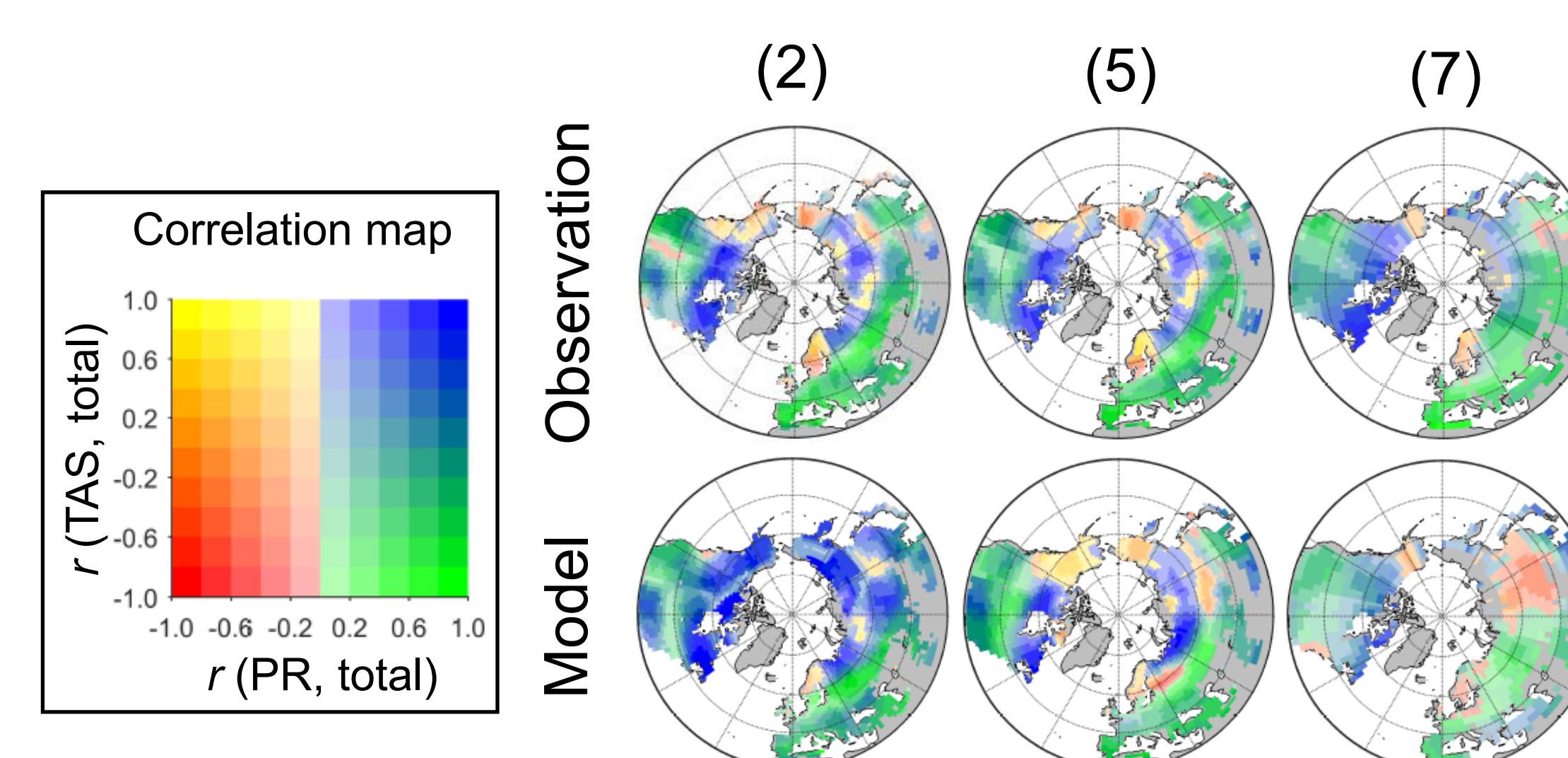
❖ Subtle variations in BGI are averaged out after regridding to coarse grid resolutions (5), (7)

❖ Responses of total carbon mass to climate
- 30ºN–60ºN ∝ (+PR, -TAS)
- > 60ºN ∝ (+PR, +TAS)

❖ Inconsistent biomass responses found in C_3/C_4 grass-dominated regions in ESMs

Summary

❖ All ESMs exhibit large uncertainty of carbon mass in each forest component at grid-level; however, HadGEM2 and MIROC models better capture observed global total carbon biomass.

❖ Modeled carbon mass is allocated excessively to wood+roots but less to leaves (−1.7%∓1.4%).

❖ Detailed PFT-level data provides smaller biases in forest biomass magnitude but causes a bit larger biases in allocating carbon mass in each component for HadGEM2-ES.

❖ Associations between forest biomass and climate in ESMs and in observations are roughly consistent in terms of the high sensitivity of the forest total biomass to PR.

❖ ESM biomass predictions are substantially influenced by the initial vegetation status generated from spin-up procedures.

Acknowledgments