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Improvement of Terrestrial Ecosystem Model in terms of High CO_2 Response

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Comprehensive studies of plant responses to high CO_2 world by an innovative consortium of ecologists and molecular biologists

Photograph. Members of the project: Comprehensive studies of plant responses to high CO_2 world by an innovative consortium of ecologists and molecular biologists.

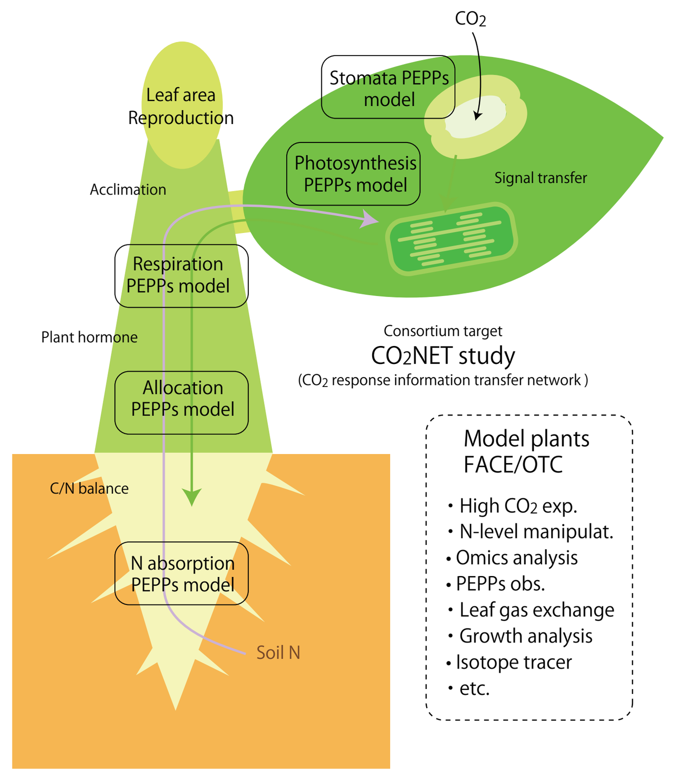

Figure 1. Phenotypic ecophysiological parameters [PEPPs] in relation to plant CO_2 response investigated by the project.

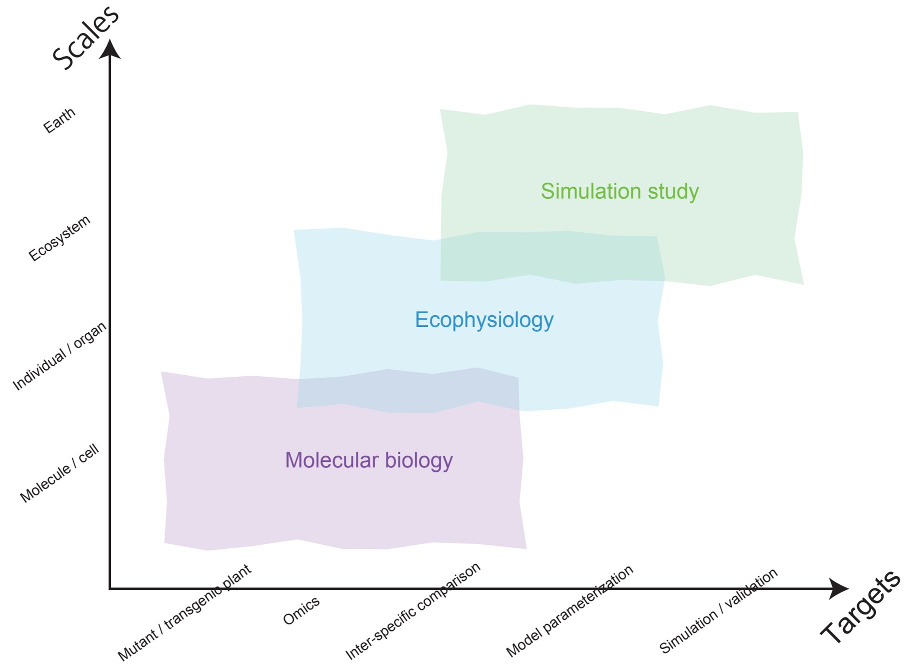

Figure 2. Scales and research targets of the project, in which consortium of molecular biology, ecophysiology, and simulation study will be formed.

This project explores “inclusive elucidation of plant response to elevated atmospheric CO_2 concentration”, i.e., an urgent issue to establish a basis to make prediction of the plant CO_2 fixation in response to global environmental change, through the formation of a consortium of ecologists and molecular physiologists. First, we raise plants under high CO_2 conditions and analyze the dynamics of information network concerning environmental response by means of targeted omics, allowing us to grasp the whole features of plant CO_2 response. Then, we specify analytical factors and apply them to representative species of natural ecosystems including tree species, in order to clarify the plant high CO_2 response with respect to environmental dependence and inter-species differences in a quantitative and inclusive manner. Based on these findings, we develop a molecular physiological model of individual plant CO_2 response, which will be provided to ecosystem model researchers. Finally, we break a new direction of molecular physiology to make effective contribution to plant individual-level studies and to make substantial progress in botanical science.

To achieve these purposes, we analyze phenotypic ecophysiological parameters (PEPPs) such as stomatal conductance, photosynthetic rate, respiration rate, C/N balance, allocation (aboveground / belowground, leaf / stem and branching), and growth, which are usually used in ecophysiological studies, by means of indoor remote sensing, high-definition gas exchange measurement, stable isotopic tracer experiment, and other methods, utilizing previously-identified mutant plants that have functional loss and gain in CO_2 response factors. In parallel with the PEPPs responses, we elucidate the whole features of plant CO_2 response by understanding the dynamics of CO_2 response information-transfer network (CO_2NET) through targeted omics for plant metabolites and hormones. We establish and maintain a platform to search the group of marker factors such as genes, enzymes, metabolites, and hormones, which play key roles in the CO_2NET.

Model development : VISIT

This study used the process-based terrestrial model: Vegetation Integrated SImulator for Trace gases (VISIT: Inatomi et al 2010; Ito 2010). The model consists of sub-modules simulating radiation budget, hydrology, phenology, and carbon and nitrogen cycles. The ecosystem structure is simplified into four sectors of carbon stock: canopy trees, floor plants, dead biomass (litter), and mineral soil (humus). Each carbon stock sector is then divided into several carbon pools; for example, the tree sector is composed of leaf, stem, and root pools (see Ito et al [2005] for a schematic diagram). Photosynthetic CO_2 assimilation, which is gross primary production (GPP) at the ecosystem scale, is estimated as a function of leaf area index (LAI; estimated from the leaf carbon pool and specific leaf area), canopy light absorption coefficient, and leaf-level photosynthetic parameters (Ito and Oikawa 2002). Plant and soil respiration rates are estimated from the pool-specific respiration rate, pool size, and response to temperature. Total respiration is called ecosystem respiration (RE). Net ecosystem production (NEP; equivalent to net CO_2 exchange with the atmosphere) is calculated as the difference between GPP and RE.

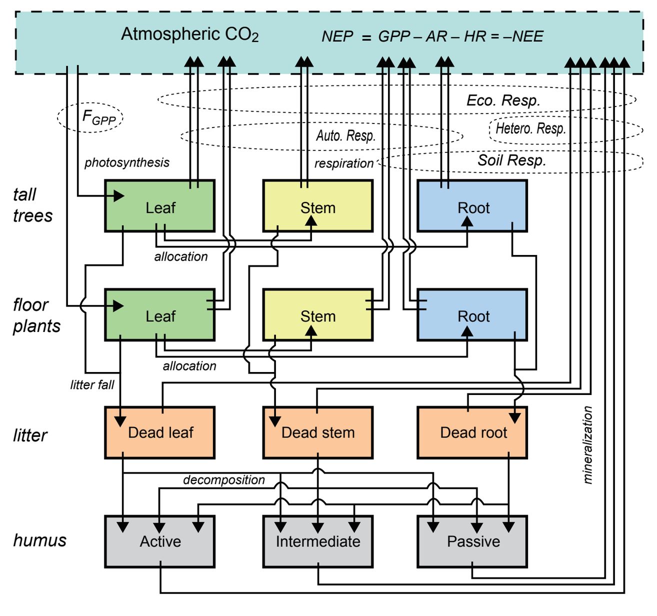

Figure 3. Schematic diagram of carbon cycle in the VISIT model.

Study 1:Detection and attribution of global change and disturbance impacts on a tower-observed ecosystem carbon budget: a critical appraisal

Observations worldwide are providing an increasing amount of atmosphere–ecosystem flux data. Thus, establishing a data-mining methodology to detect significant trends and attribute changes to specific factors is important. This study examined the possibility of detecting significant trends in observed data at a test site with one of the longest records of flux measurements (Takayama, Japan). Statistical tests using non-parametric methods showed a ‘likely’ trend (i.e., detected at 66–90% confidence levels) of increasing carbon sequestration. To investigate the change in carbon sequestration in relation to biological and environmental factors (ambient CO_2, temperature, radiation, precipitation, and disturbance), mechanistic and numerical methods were applied. A process-based model was used for the mechanistic attribution of change, and an optimal fingerprinting method in combination with model-based sensitivity simulations for numerical attribution. At the study site, local disturbances appeared to exert an impact on the observed carbon sequestration, whereas climatic factors made moderate contributions. These results indicate the feasibility of detection and attribution using current flux measurement data, although more evidence is needed to confirm global coherence.

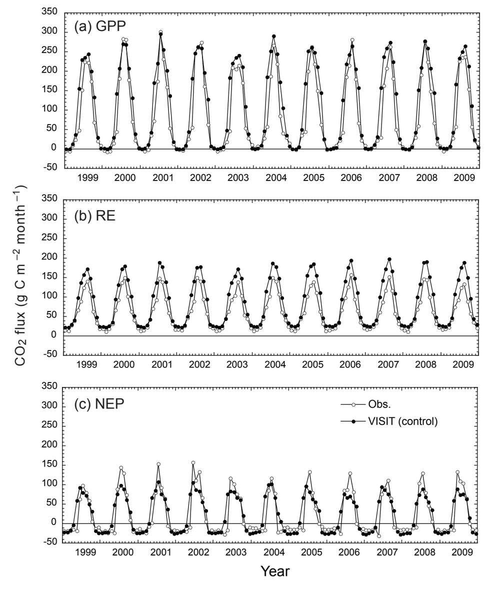

Figure 4. Comparison between the observed and model-estimates CO_2 fluxes.

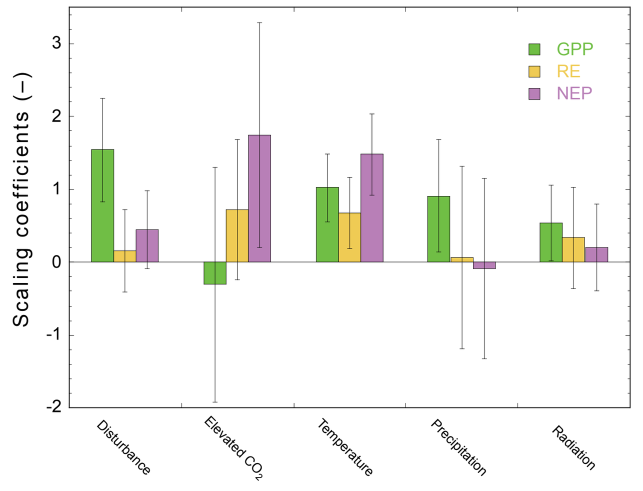

Figure 5. Scaling coefficients estimated by the optimal fingerprinting method for the carbon budget change at the Takayama site.

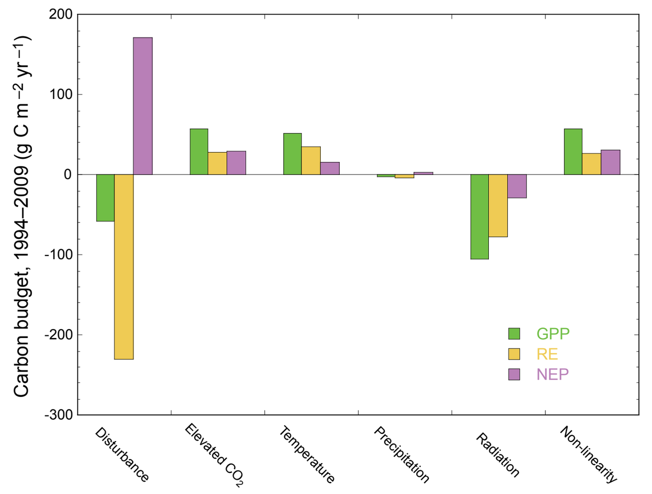

Figure 6 Contributions of different factors to net carbon sequestration observed at the Takayama site. Results of the mechanistic attribution on the basis of process-based model (VISIT) simulations.

Study 2 : Water-use efficiency of the terrestrial biosphere: a model analysis focusing on interactions between the global carbon and water cycles

Carbon and water cycles are intimately coupled in terrestrial ecosystems, and water-use efficiency (WUE, carbon gain at the expense of unit water loss) is one of the key parameters of ecohydrology and ecosystem management. In this study, the carbon cycle and water budget of terrestrial ecosystems were simulated using a process-based ecosystem model, called Vegetation Integrated SImulator for Trace gases (VISIT), and WUE was evaluated: WUEC defined as gross primary production (GPP) divided by transpiration, and WUES defined as net primary production (NPP) divided by actual evapotranspiration. Total annual WUEC and WUES of the terrestrial biosphere were estimated as 8.0 and 0.92 g C kg–1 H2O, respectively, for the period 1995–2004. Spatially, WUEC and WUES were only weakly correlated. WUES ranged from <0.2 g C kg–1 H2O in arid ecosystems to >1.5 g C kg–1 H2O in boreal and alpine ecosystems. The historical simulation implied that biospheric WUE increased from 1901 to 2005 (WUEC, +7% and WUES, +12%) mainly as a result of the augmentation of productivity in parallel with the atmospheric carbon dioxide increase. Country-based analyses indicated that total NPP is largely determined by water availability, and human appropriation of NPP is also related to water resources to a considerable extent. These results have implications for (1) responses of the carbon cycle to the anticipated global hydrological changes; (2) responses of the water budget to changes in the terrestrial carbon cycle; and (3) ecosystem management based on optimized resource use.

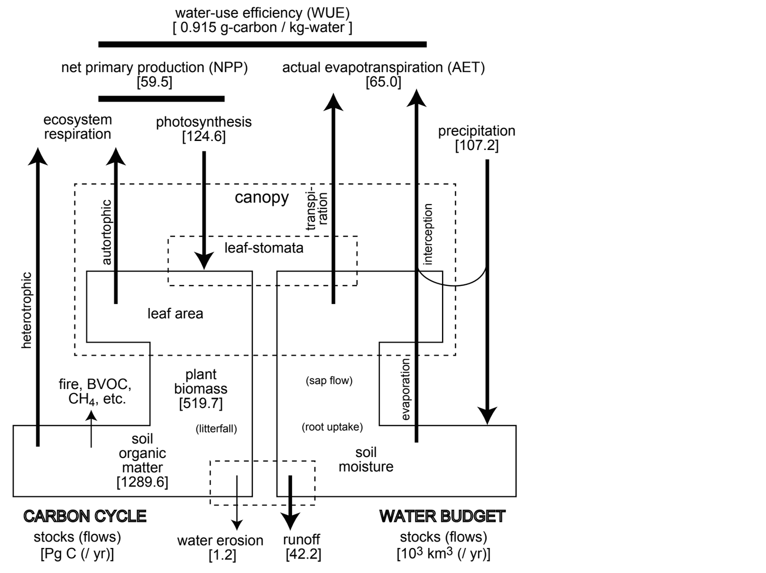

Figure 6. Summary schematic diagram of the carbon cycle and water budget of terrestrial ecosystems estimated by the VISIT model for 1995–2004.

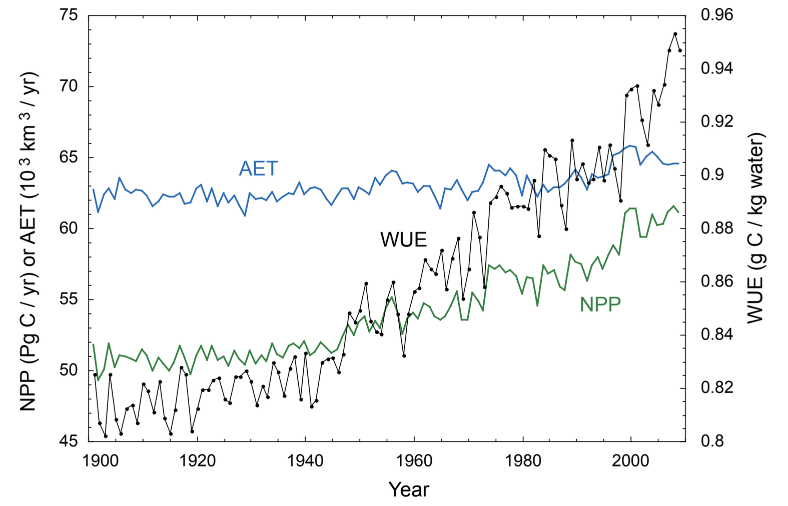

Figure 7. Interannual variability in the global net primary production (NPP), actual evapotranspiration (AET), and water-use efficiency (WUE) simulated by the VISIT model for 1901–2005.

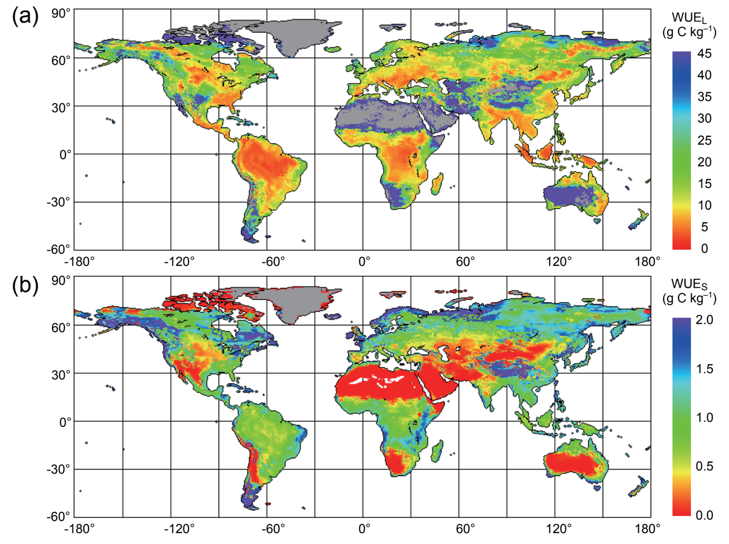

Figure 8. Global distribution of (a) canopy-level water-use efficiency (WUE_C, defined as NPP/AET) and (b) stand-level water-use efficiency (WUE_S, defined as GPP/TR), simulated by the VISIT model for 1995–2004.

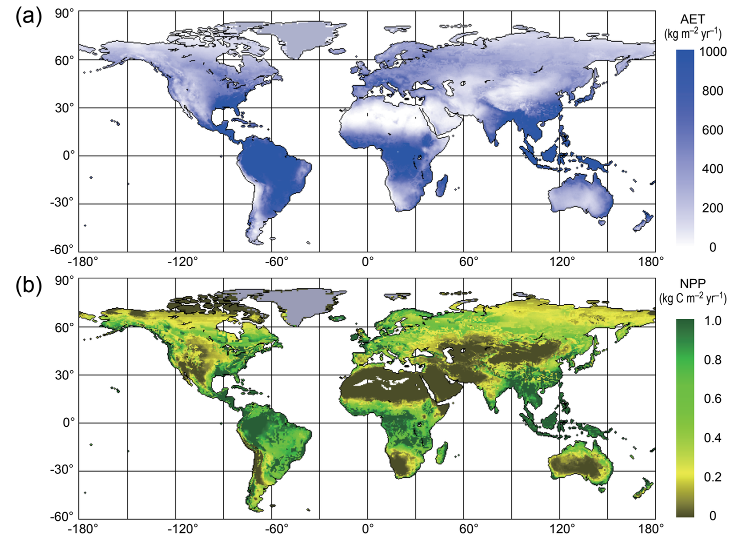

Figure 9. Global distribution of (a) annual actual evapotranspiration (AET) and (b) annual net primary production (NPP), simulated by the VISIT model for 1995–2004.

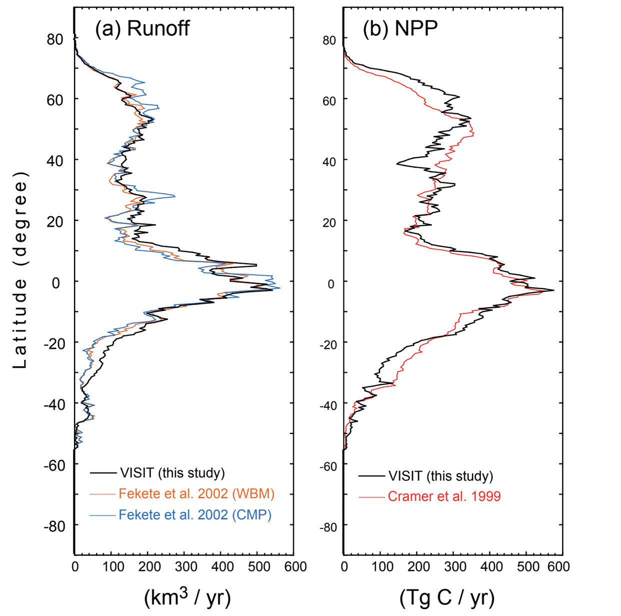

Figure 10. Latitudinal distribution of (a) runoff discharge and (b) net primary production (NPP) of terrestrial ecosystems around 2000, as simulated by the Vegetation Integrated SImulator for Trace gases (VISIT) model. The model estimations are compared with those of Fekete et al. (2002) for runoff, who used a water-balance model (WBM) and reported a composite result based on observational data (CMP), and Cramer et al. (1999) for NPP, who used 17 terrestrial ecosystem models.

References

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Ito A, Inatomi M (2012) Water-use efficiency of the terrestrial biosphere: a model analysis on interactions between the global carbon and water cycles. Journal of Hydrometeorology, 13, 681–694.