Report from SAGES Theme 2 PECRE Exchange

Visit by Dr. Exbrayat (University of Edinburgh) to Justus Liebig University, Giessen, and Karlsruhe Institute of Technology, Garmisch-Partenkirchen, September – October 2016

1. Overview & Objectives

The SAGES Postdoctoral & Early Career Researcher Exchange supported a 5-week trip in autumn 2016 to ignite collaboration with two German research groups. The aim of my visit was to plan improvements to the CARDAMOM model-data fusion framework (Bloom et al., 2016) that lies at the centre of my research. CARDAMOM applies state-of-the-art data-assimilation methods to a simple ecosystem carbon model to estimate the global terrestrial carbon cycle in agreement with climate data and satellite observations of the biosphere (see Figure 1).

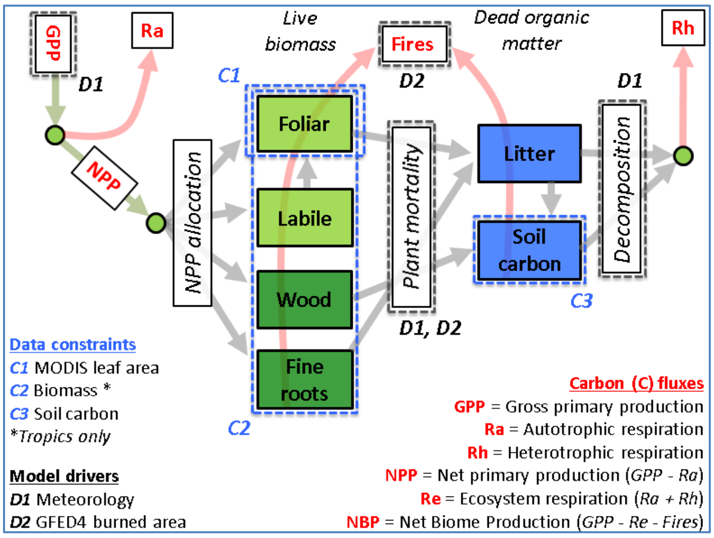

Figure 1. Summary of the CARDAMOM model-data fusion framework. Within each pixel, a Bayesian model-data fusion algorithm is used to retrieve carbon states and fluxes in agreement with leaf area, biomass and soil carbon stocks as a function of climate and disturbance drivers. At each time-step the Bayesian approach produces explicit confidence intervals of each parameter, flux and stocks. Figure adapted from Bloom et al. (2016).

However, CARDAMOM currently lacks an explicit representation of the water cycle. It may therefore misrepresent the impact of droughts on ecosystem carbon cycle. Indeed, Gross Primary Productivity (GPP) is currently calculated as a function of leaf area index (LAI), solar radiation and air temperature, implicitly assuming no water limitations. Furthermore, CARDAMOM relies on a simple fire module that could be refined by using simulations of the water balance to adjust the flammability of fuels for example. These current limitations may result in a biased estimation of the global terrestrial carbon cycle in regions prone to droughts and/or fire.

To start addressing these problems, I visited hydrological modellers at the Institute for Landscape Ecology and Resources Management at the Justus-Liebig-University (JLU) in Giessen, and fire modelling specialists at the Institute of Meteorology and Climate Research at the Karlsruhe Institute of Technology (KIT) in Garmisch-Partenkirchen.

2. Implementation of a bucket model

2.1 Model description

A main requirement of CARDAMOM is to remain simple to allow exploring the parametric uncertainty through a model-data fusion procedure. Therefore, we designed a parsimonious bucket model to limit GPP as a function soil moisture content *V* (in mm) with the water balance calculate for each time step *t* such as

$$V_{t+1} = V_t + P_t - E_t - Q_t \qquad (1)$$

where P_t is precipitation (in mm/day), E_t is evapotranspiration (in mm/day) and Q_t (in mm/day) is an outflow term that combines runoff and deep percolation that occur if *V* is greater than field capacity *fc* (in mm). The actual evapotranspiration E_t is calculated as a function of potential evaporation PE_t, the theoretical evapotranspiration in well-watered conditions, and moisture availability V_t with respect to soil physical properties: field capacity *fc* (in mm) and wilting point *wp* (in mm).

There exist multiple formulations of various complexity to estimate *PE*. Here, for simplicity we used the Hargreaves and Samani (1985) method that only requires latitude and diurnal temperature range. Finally, the ratio of E_t / PE_t is used to currently non-water limited GPP_{pot} (in g C m-2 day-1) calculated by CARDAMOM such as

$$GPP_{act,t} = GPP_{pot,t} \times \frac{E_t}{PE_t} \qquad (3)$$

where $GPP_{act,t}$ (in g C m-2 day-1) is the actual amount of carbon that enters the ecosystem at time step *t* (Figure 1). Overall, the new soil moisture module requires two new drivers: *P* and *PE* as well as the calibration of three additional parameters: *fc*, *wp* and V_0, the initial soil moisture content.

2.2 Validation of the bucket model

An initial validation of the bucket model was performed using data from the Howard Springs eddy-covariance flux tower near Darwin (Northern Territory, Australia). This ecosystem experiences very contrasted wet and dry seasons that constitute a good test bench to validate the soil moisture module. Data assimilated at Howard Springs include daily land-atmosphere carbon fluxes (GPP, Net Ecosystem Exchange and Ecosystem Respiration), snapshots of LAI from the MODIS sensor and estimates of woody biomass stocks in 2008 and 2014. To assess the improvement generated by the addition of the soil water module, two experiments were performed: one with the current CARDAMOM (i.e. without explicit water cycle), and another one with the new CARDAMOM that includes the soil water module.

The new version of the model that includes feedback of soil moisture on GPP outperforms the current version of the model (Figure 2). Indeed, the current version of CARDAMOM systematically underestimates annual maximum LAI values (Figure 2a) while the new version of CARDAMOM simulates an inter-annual variability in LAI that is more in agreement with observations (Figure 2b). Furthermore, the current version of CARDAMOM is not able to match measured woody carbon stocks and growth through time (Figure 2c) while the new version provides estimates of woody carbon stocks and their evolution through time much closer to the observations (Figure 2d).

Overall, the new version of CARDAMOM is more skilled at representing the ecosystem carbon cycle in agreement with all observational data streams, while missing processes led the former model version to some trade-offs in the representation of LAI and woody carbon stocks.

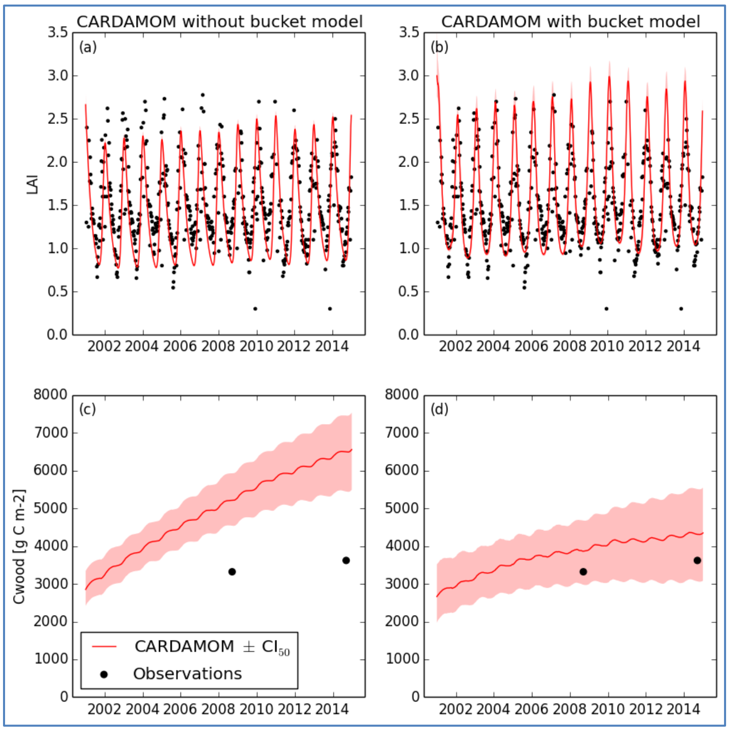

Figure 2. Comparison of observed and simulated LAI and woody carbon stocks at Howard Springs (NT, Australia) with the current CARDAMOM version and the new version with soil moisture feedback. Simulations with the water module capture the amplitude in LAI, and especially extreme values, better than simulations with the current version of CARDAMOM. This is accompanied with a better long-term representation woody carbon pool stocks and growth through time.

3. Outlook

A soil moisture module was successfully implemented in the CARDAMOM framework, leading to improvements in the simulation of ecosystem carbon dynamics in a northern Australian ecosystem. This module provides the foundation to improve the fire module currently used in CARDAMOM by using moisture to limit fire completion rates (like in Glob-FIRM, Thonicke et al. 2001). Overall, the work initiated during this trip will lead to improvements in the global terrestrial carbon cycle simulated by CARDAMOM. It is already planned that these new findings will be reported in joint publications.

References

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