Land cover coupling to the climate system; implementing an interactive carbon cycle in ACCESS

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About half of the anthropogenic carbon added to the atmosphere over recent decades has been taken up by the biosphere and the ocean. The rates of carbon uptake by the biosphere are likely to change due to increasing concentration of carbon dioxide in the atmosphere. It is likely that climate change and climate variability will enforce changes to precipitation and temperature which will further affect the functioning of the biosphere. Carbon uptake by plants is also limited by the availability of nutrients, particularly nitrogen.

Diagnosing and understanding biosphere feedbacks in the complex climate system will require both observations as well as carefully designed coupled carbon-climate experiments. To address these questions, carbon cycle dynamics including vegetation and soil carbon cycling is being included into global climate models.

The Australian Community Climate and Earth System Simulator (ACCESS) initiative is in the process of building a fully coupled global climate model which includes a fully interactive carbon cycle. One of the key priorities is to build a model able to perform IPCC 5th Assessment Report (AR5) experiments. The strategy for ACCESS in terms of land-biosphere modelling for the AR5 is to couple the CSIRO Atmosphere Biosphere Land Exchange (CABLE), CASA-CNP and LPJ DGVM models. The coupled system has to be calibrated against available observations and stable under present climate conditions when coupled to ACCESS atmospheric model by mid 2009.

CABLE is a model of biosphere-atmosphere exchange which includes the aerodynamic and radiative interaction of a canopy with the bare ground below and atmosphere above and the treatment of turbulence inside the canopy. CABLE is a one layer two-leaf canopy model as described in Wang and Leuning (1998) and it was formulated on the basis of a multilayer model of Leuning et al. (1995). CABLE was coupled to the CSIRO global circulation model but it is available to be used as an offline model by the Australian research community.

The main features of CABLE are:

- a coupled model of stomatal conductance, photosynthesis and the partitioning of absorbed net radiation into latent and sensible heat fluxes

- the model differentiates between sunlit and shaded leaves i.e. two-big-leaf submodels for calculation of photosynthesis, stomatal conductance and leaf temperature

- the radiation submodel calculates the absorption of beam and diffuse radiation in visible and near infrared wavebands, and thermal radiation

- the vegetation is placed above the ground allowing for full aerodynamic and radiative interaction between vegetation and the ground Raupach et al. (1997)

- the plant turbulence model by Raupach et al. (1997) is used to calculate the within canopy air temperature and humidity

- a multilayer soil model is used; Richards equations are solved for soil moisture and heat conduction equation for soil temperature

- the snow model computes temperature, density and thickness of three snowpack layers.

For full description of the model see Kowalczyk at al.(2006).

CABLE was coupled with the CSIRO global Conformal-Cubic atmospheric model to perform the first phase of the Coupled Climate Carbon Cycle Model Intercomparison Project (C4MIP).

The C4MIP experiment was designed to test the functioning of the biosphere and required simulation of the twentieth century climate change using prescribed sea surface temperatures and global CO2. The simulations were assessed using observed CO2 concentrations at a number of sites. The model was able to reproduce many key features of the XX century carbon cycle, including interannual variability of CO2 growth rate at Mauna Loa, Northern hemisphere seasonal and diurnal cycles of CO2. However the Southern hemisphere seasonal cycles were out of phase due to inadequate description of savannah photosynthesis and soil respiration in the tropics (see Law at al., 2006).

At present we are developing a global terrestrial biogeochemical model for carbon, nitrogen and phosphorus (CASACNP) including symbiotic nitrogen fixation (see Wang, Houlton and Field, 2007). Our model is similar to CENTURY, but includes biochemical phosphorus mineralization and symbiotic nitrogen fixation, both processes are important to the soil nutrient cycling in the tropical forest and savannah. An offline version of the model is being calibrated. Coupling of the LPJ (Lund-Potsdam-Jena) dynamic vegetation model to CABLE and CASACNP will be led by the Australian universities.

E.A. Kowalczyk, Y.P. Wang, R.M. Law, H.L. Davies, J.L. McGregor and G. Abramowitz, 'CSIRO Atmosphere Biosphere Land Exchange (CABLE) model for use in climate models and as an offline model', CMAR Research Paper 013, 2006.

Law, R.M., Kowalczyk, E.A. and Wang, Y.P. (2006). Validation of a simplified carbon-climate simulation for the 20th century using atmospheric CO2 data. Tellus, 58B:427-437.

Wang, Y.P. and Leuning, R. (1998) A two-leaf model for canopy conductance, photosynthesis and partitioning of available energyI. model description and comparison with a multi-layered model. Agricultural and Forest Meteorology, 91:89-111.

Wang, YP, Houlton, B. and Field, CB. 2007. A model of biogeochemical cycles of carbon, nitrogen and phosphorus including symbiotic nitrogen fixation and phosphatase production. Global Biogeochemical Cycles, 21, GB1018, doi:10.1029/2006GB002797.