Modelling the interactions between biospheric and weathering processes: towards a mechanistic description of the land environment

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Recently, some tentative attempts to calculate the distribution of the rock chemical weathering rate over the continents and its variation from the last glacial maximum to the present have been published in the literature (e.g. Gibbs and Kump, 1994). These investigators used empirical relationships between the weathering rate of most important rock types and water runoff. The reconstruction of past weathering can then be performed from the water budget predicted by general circulation models. Although runoff is one of the most important environmental factors contolling chemical weathering at large spatial scales, many complex processes may influence weathering and its response to climatic forcings. For instance, temperature, orogeny or mechanical weathering (and the associated exposure of fresh mineral surface), and vegetation may exert non negligible controls on weathering, as widely discussed in recent years. In particular the effect of vegetation and soil microbial activity is recognized as important in promoting mineral dissolution (e.g. Schwartzman and Volk, 1989), through enhancement of the soil CO_2 pressure and through organic secretion from plant roots and fungi. It is unlikely that simple statistical relationships calibrated on the present-day system can be successful in predicting chemical weathering rates under past climatic conditions when the atmospheric CO_2 level and the vegetation distribution were very different from today. For this reason, it is necessary to build more mechanistic models of the coupled vegetation-soil-rock system, which should describe in some detail the various processes involved in rock weathering, plant growth and soil microbial activity. However, the drawback of such a process-oriented approach is that it must involve an upscaling methodology from small (site, catchment) to large (river basin, continent) spatial units and from short (day, season) to long (10^3-10^6 years) time periods, including a validation at each level. Such an initiative has been pursued over the last few years in the biospheric community and global process-oriented models of the land biosphere are currently available. A similar effort may be conducted within the scientific community studying soil formation and weathering.

Here we present a preliminary attempt towards a mechanistic description of rock weathering and its interactions with vegetation and soil biogeochemistry. Our approach is based on the chemical weathering model developed by Gwiazda and Broecker (1994) coupled to the CARAIB (CARbon Assimilation In the Biosphere; Warnant *et al.*, 1994) model of the land biosphere.

The CARAIB model couples various modules associated with the budget of soil water, photosynthesis, plant growth and respiration, and soil microbial oxidation of organic matter. The most important outputs are the soil water amount, evapotranspiration, surface runoff, drainage at the bottom of the root zone, net primary productivity (NPP) of vegetation, autotrophic and heterotrophic respirations, and the contents of vegetation, litter and soil carbon reservoirs. The model is designed to be used at the global scale and, in such applications, a resolution of 1°1° in longitude-latitude is usually adopted. Nevertheless, in the case of local applications, the spatial resolution may easily be modified or eventually the calculation may only be performed for one single grid cell (test site). The temporal resolution is 1 day for the calculation of every water and carbon reservoirs. If input climatic data are provided monthly, a weather generator can be used to transform these data into daily inputs. This allows to take into account the high degree of non-linearity of soil hydrology and leaf photosynthesis. The soil water module calculates the water balance in the root zone. It considers precipitation and its interception by the canopy, snow melt, evapotranspiration, drainage at the bottom of the root zone and surface runoff. The photosynthesis module calculates the net carbon assimilation by the leaves every 2 hours. It is based on the mechanistic schemes by Farquhar *et al.* (1980) for C_3 and Collatz *et al.* (1992) for C_4 plants. The heterotrophic respiration rate depends on temperature (Q_{10} relationship) and soil water.

Monthly outputs of the CARAIB model are used to force the weathering model of Gwiazda and Broecker (1994). This latter model is designed for warm temperate climates. Soil (heterotrophic+root) respiration fluxes are used to calculate the CO_2 pressure in and below the root zone. The amount of organic matter in the soil is used to evaluate the dissolved organic content (DOC) of soil water. The water and cations budgets of the soil layer below the root zone is calculated on a monthly basis by using the water drainage at the bottom of the root zone calculated by the hydrological module of CARAIB. As in the original Gwiazda and Broecker's (1994) model, weathering is assumed to occur below the root zone, only silicate (feldspar) weathering is considered and the composition of the soil water solution is calculated from a total of 15 chemical equilibrium equations.

As an illustration of its capabilities, this biosphere-weathering model is applied on a geographical transect with a precipitation gradient. Several sensitivity tests are performed. In particular, the response of the system to atmospheric CO_2 changes is analysed. At this stage, no validation on site data is attempted. However, this is an important task for the future, as well as the extention of this model to other rock types or weathering regimes. Another important improvement would be the extention of the weathering model to the root zone in order to consider potential feedbacks on the vegetation associated with the release of nutrients from weathering processes. Such developments would lead to a mechanistic and dynamic quantitative description of the land environment.

References

Collatz, G.J., Ribas-Carbo, M. and Berry, J.A. (1992) *Aust. J. Plant Physiol.*, **19**, 519–38.

Farquhar, G.D., von Caemmerer, S. and Berry, J.A. (1980) *Planta,* **149**, 78–90.

Gibbs, M.T. and Kump, L.R. (1994) *Paleoceanography,* **9**, 529–43.

Gwiazda, R.H. and Broecker, W.S. (1994) *Global Biogeochem. Cycles,* **8**, 141–55.

Schwartzman, D.W. and Volk, T. (1989) *Nature,* **340**, 457–60.

Warnant, P., François, L., Strivay, D. and Gérard, J.-C. (1994) *Global Biogeochem. Cycles*, **8**, 255–70.