New Coupled Vegetation-Carbon Model Used Inversely for Reconstructing Past Terrestrial Carbon Storage from Pollen Data: Validation of Model Using Modern Data

Haibin Wu [1-4] Changhui Peng [2*] Joel Guiot [3] Zhengtang Guo [4]

[1]SKLLQ, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710075, China.
[2]Institut des sciences de l´environnement, Université du Québec à Montréal, Montréal H3C 3P8, Canada.
[3] CEREGE, UMR 6635, CNRS/ Université Paul Cézanne, BP 80, 13545, Aix-en-Provence cedex 4, France.
[4]Institute of Geology and Geophysics, Chinese Academy of Sciences, P.O. Box 9825, Beijing 100029, China.
* Corresponding authors: E-mail: peng.changhui@uqam.ca

Introduction

Ice core measurements reveal that CO_2 concentrations of earth's atmosphere exhibit large variations over glacial-interglacial cycles. A key challenge for understanding long-term global carbon cycling is to identify the potential impacts of climate change on terrestrial vegetation and carbon storage capacity within ecosystems. In this respect, Quaternary itself offers the key in understanding what occurred under large atmospheric CO_2 variations in the past. A long-standing issue exists between data concerning the discrepancy of paleocarbon storage reconstructions since the Last Glacial Maximum by means of pollen, carbon isotope, and general circulation model (GCM) analysis. In this study, a new estimate of past biospheric carbon stocks is reported using a new paleocarbon model (PCM), which is defined as a physiological process vegetation model (BIOME4) coupled to a process-based biospheric carbon model (DEMETER). The PCM was constrained to fit pollen data to obtain realistic estimates.

Objectives

- To validate the inversion scheme with observable global vegetation types, biomass and soil carbon.
- To estimate long-term global terrestrial vegetation and carbon dynamics during glacial-interglacial periods, and improve understanding of the processes contributing to global carbon cycle .

Method and Data

Data

Pollen data compiled by the BIOME6000 project concerns three key periods: 0 k, 6 k and 21 k cal ^{14}C BP. For this test, the modern dataset containing 1491 sample sites from Africa and Eurasia were used only, covering most of the biome types throughout the world. The vegetation biomass and soil carbon density data were from global observational datasets .

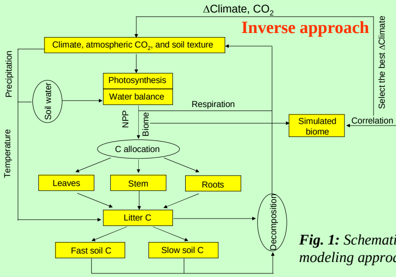


Fig. 1: *Schematic diagram of the inverse vegetation modeling approach to the paleocarbon reconstruction.*

Model structure

Figure 1 provides a scheme of the method used. It is based upon vegetation, carbon models, and an inversion algorithm. The first model, BIOME4, is a physiological process-based global model that is particularly useful when working with palaeovegetation since it operates with a limited monthly climates that are easily available. However, its equilibrium design makes it impossible to directly simulate terrestrial carbon stocks. The second model, DEMETER, provides a better simulation of the global biospheric carbon storage within vegetation, litter and soil, but provides only a simple potential vegetation sub-model derived from the BIOME1 model. To overcome the shortcomings of both approaches, these models are coupled with biome types and NPP that are calculated by BIOME4 and then used as inputs in the DEMETER model. The pollen data reveals the biome types of sites, but not the corresponding climate, a major model input. To work around this, each model output was matched with the pollen data and the model inputs were deduced. Typically, this is an inversion problem.

Inverse procedure

The inversion process consists of finding all combinations of climatic factors that could support a biome similar to the one observed at a given site. The main input parameters driving vegetation are temperature and precipitation. To limit the number of parameters, we fitted the model outputs to the observed data by changing January and July temperature and precipitation, and deduced the other monthly parameters. For a given pollen site, we selected a four-dimensional vector of climate deviations (i.e., differences between past and modern values). The calculation procedure was as follows: (1) We deduced the other monthly components of the climate using empirical equations; (2) we added the deviations to the values for the modern climate and applied the BIOME4 model; and (3) we use a transfer matrix to convert the BIOME4 biome to biome scores, and compare the simulated biome scores with the observed ones using a Euclidian distance between observed and simulated biome scores, then calculate the likelihoods (LH) function. (4) The acceptance-rejection rule is based on the criteria C. If the LH satisfies the rule, we decide to keep the climate anomalies; if not, we reject it. (5) We then randomly selected another climate deviation vector and return back to procedure (1) . This iterative process stopped when we obtained a sufficient number of valid scenarios to calculate the *a posteriori* probability distributions, normally 200-300 scenarios in 5000 iterations or less. In the last step, we deduced the most probable climate with its confidence percentage using the *a posteriori* probabilities.

Validation using Measured Data

To evaluate the reliability of the method: ***firstly,*** the reconstructed biomes had to be compared (*Fig. 2a-b*). There are no systematically regional errors between pollen and predicted biomes. In total, 61% of the biomes were correctly predicted. The method worked particularly well for arboreal biomes, which correctly predicted 57% to 100% of the sites. If climatically contiguous biomes are acceptable (e.g., STEP/DESE or SAVA/STEP), it increases to 91%, considered an acceptable fit. For the other 9% of sites, disagreement can be explained (1) partly by human impact on modern vegetation (e.g., deforestation), so that pollen biomes do not reflect potential vegetation; (2) partly by an incorrect estimation of the modern climate in mountainous regions where there are fewer weather stations; or (3) partly by the uncertainties in pollen-based biomization itself.

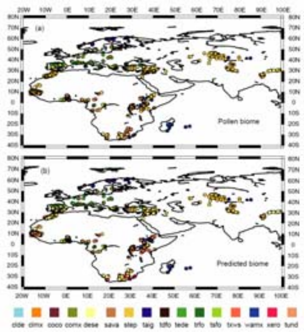
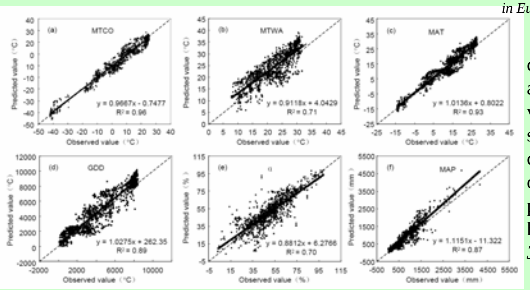


Fig. 2: *Comparison of each site between simulated biomes (a) and pollen-based (b) in Eurasia and Africa at 0 ka BP.*



Secondly, statistical correlations between actual and reconstructed climate variables at pollen sample sites were examined. The correlations (R^2) between the observed and estimated parameters were significantly high, from 0.70 to 0.96 (*Fig. 3a-f*).

Fig. 3: *Correlation between observed climates and predicted values by the model in Eurasia and Africa at 0 ka BP. (a) Mean temperature of the coldest month (MTCO), (b) Mean temperature of the warmest month (MTWA), (c) Growing degree-days above 5° C (GDD), (d) Ratio of actual to potential evapotranspiration (α), (e) Mean annual temperature (MAT), and (f) Mean annual precipitation (MAP). Solid line is the least-squares linear regression, and dashed line is the 1:1 line.*

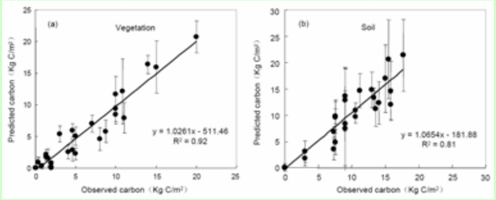


Fig. 4: *Correlation between averaged PCM carbon simulations and averaged biome observations: (a) Vegetation carbon density, and (b) Soil carbon density. The error bars are the 95% confidence intervals.*

Thirdly, terrestrial carbon between model reconstructions and measurements was compared. These averages by biome were compared to the data available. The coefficient of determination was 0.92 for vegetation C (*Fig. 4a*) and 0.81 for soil C (*Fig. 4b*). The simulated biome-average carbon densities are therefore in good agreement with the measured vegetation and soil carbon data.

Summary and Future Improvements

The validation of PCM with modern data shows that the method can successfully simulate most pollen biomes, modern climates, and biome-averaged terrestrial carbon variables. It can be applied to past pollen data for palaeocarbon estimate. However, the PCM approach is not a panacea. Since it is a model-based approach, it is highly dependent upon the quality of the vegetation model itself. Additional verification should be used when using other vegetation models.

Acknowledgement

This research was supported by funding from the National Basic Research Program of China, the National Natural Science Foundation of China, the PICC project funded by the French National Agency for Research (ANR), a grant from the French Ministry of Research to H.B. Wu as well as from the Canada Research Chair Program.

References

- Foley JA (1995) An equilibrium model of the terrestrial carbon budget. *Tellus*, 47B, 310-319.
- Guiot J, *et al.* (2000) Inverse vegetation modeling by Monte Carlo sampling to reconstruct palaeoclimate under changed precipitation seasonality and CO_2 conditions: application to glacial climate in Mediterranean region. *Ecology Modelling*, 127, 119-140.
- Kaplan JO (2001) *Geophysical applications of vegetation modeling*. Lund University, Sweden.
- Olson JS, Watts JA, Allison LJ (1985) *Major world ecosystem complexes ranked by carbon in live vegetation*. A Database. NPD-017. Carbon Dioxide Information Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.
- Peng CH, Guiot J, Campo EV (1998) Estimating changes in terrestrial vegetation and carbon storage: using palaeoecological data and models. *Quaternary Science Reviews*, 17, 719-735.
- Prentice IC, Jolly D, BIOME 6000 P (2000) Mid-Holocene and glacial-maximum vegetation geography of the northern continents and Africa. *Journal of Biogeography*, 27, 507-519.
- Wu HB, *et al*. (2007a) Climatic changes in Eurasia and Africa at the Last Glacial Maximum and mid-Holocene: reconstruction from pollen data using inverse vegetation modelling, *Climate Dynamics*, 29, 211-229, doi: 10.1007/s00382-007-0231-3.
- Zinke PJ, *et al.* (1984) *Worldwide organic soil carbon and nitrogen data* (No. ORNL/TM-8857). Oak Ridge National Laboratory, Oak Ridge, Tennessee.