BIOCLIMATIC CONCEPT FOR ASSESSMENT OF ATMOSPHERE AND FOREST LAND-COVER COUPLING AT A REGIONAL SCALE

Julia S. Stoyanova

National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences, Sofia, Bulgaria
E-mail : *julia.stoyanova@meteo.bg*

Abstract: A biophysical model for quantitative description of mountain forest cover in relation to environmental features (climate, relief, growing season) is developed. It is based on the climatoligical approach of Budyko and accounts for the long-term coupling between the forest functioning and atmosphere. Approximations of heat- and water-balances of mountain natural vegetation environment are framed in a bi-dimensional biosphere-atmosphere equilibrium scheme that defines forest-cover classes as Forest Functional Types (FFTs). The index of dryness of Budyko and potential evapotranspiration (net radiation estimates) during the growing season are used as bioclimatic indicators of the bi-dimensional framework to define the limits of FFTs stable equilibrium. Forest-vegetated land cover of South and South-eastern Bulgaria is considered. Modelling is run for the present-day climate by using meteorological data, which cover space- and altitudinal- environmental differences of the region. Human-induced land cover change is simulated and the potential impacts due to the 'albedo effects' through forest-atmosphere feedbacks are evaluated.

Keywords: *atmosphere-land surface interaction, regional space-scale, long-term time-scale, bioclimaic equilibrium indicators, FFTs differentiation, land-cover change scenario*

1. INTRODUCTION

Interactions between the atmosphere and the land surface have considerable influence on regional and global climate variability. Vegetation impacts climate directly through moisture, energy and momentum exchanges with the atmosphere, and indirectly through biogeochemical processes that alter atmospheric CO_2 concentration (Pielke et al., 1998) as well as by changes in global-scale atmospheric circulation that can result from changes in these fluxes (Bonan et al., 1992; Zhang et al., 1996).

The long-term biogeophysical/biogeochemical (physiological) elements of atmospheric and terrestrial ecosystem dynamics influence atmospheric processes and shape the pattern of landscape heterogeneity. Feedbacks on climate depend on the properties of local vegetation and soil, which in turn respond to climate. An adequate description of land cover is needed to determine the global fluxes of Greenhouse Gases between the terrestrial biosphere and the atmosphere. Understanding climate impact on the biosphere and feedbacks to climate is critical processes for describing and analyses of climate change-related mechanisms, provoked by both anthropogenic and natural causes. Most of the current knowledge of these feedbacks resulted from studies using coupled vegetation climate models (e.g. Foley et al., 1998).

This study is focused on quantitative description of long-term coupling between atmosphere and land cover on a regional scale. Generally, it aims to develop a model of biophysical equilibrium mechanisms and bioclimatic driving forces that establish functional heterogeneity of forest land cover. Specific problems to be addressed are: (i) To define the biophysical driving mechanisms responsible for the long-term coupling between climate and natural vegetation land cover; (ii) To elaborate a conceptual scheme for differentiation of natural forest cover into functional classes; (iii) To define the limits of stable equilibrium of these functional units at different climate environment; (iv) To evaluate the consequences of a simulated human induced land cover change and accompanying albedo effects.

2. DATA AND METHODS

2.1 Region of study and data set

The studied region is located in the south and south-eastern parts of Bulgaria (ca. 41° 33' - 42°42' N, 23° 58' - 28° 02' E), spanning about 300 km from west to east, between the high mountain parts of the Rodophes mountains and the eastern hilly and hilly/plain regions along the Black Sea. Large environmental changes occur in the region over short distances, including difference in annual rainfall of > 400 mm, and a difference in altitude of > 1500 m between the extreme points.

The data set covers parameters necessary to force a simple land surface model, as follows: Physical canopy properties, topography and clear sky solar irradiance; Meteorological data for the present-day climate (1961-1990); Phenology. As land cover characteristics we accept the dominant for the region vegetation types, determined via experimental survey at the province level by Gerasimov et al. (1960): native coniferous (highest and wettest extreme), xerophytic broadleaved species (driest extreme in intermediate points), mesophytic broadleaved (intermediate points) and coastal forests. The physical canopy properties are described (Rudnev, 1984) corresponding to the dominant vegetation cover range. Meteorological and phenological data from 14 representative for the region stations of the National Meteorological and Forest Network that cover space- and altitudinal- environmental differences of studied region are used.

2.2 Theoretical assumptions

The key consideration in this study is the multiple bi-directional functional relation between the potential vegetation (forest) at mountain environment and the climate system. To quantify this coupling at a regional scale, some basic assumptions and well-known statements from the literature are accepted and used in guiding development of the model, as follows:

Natural forest ecosystem functioning. Ecosystem structure and its functioning, via exchanging matter and energy between the biota and the environment are strongly determined on timescales of decades to centuries by climate influences, primarily through temperature ranges and water availability as well as by surface albedo and biogeochemical cycling (e.g. Neilson, 1995).

The principle of natural zonality in climate-vegetation processes. The idea that zonality is caused not only by the heat- and water- amounts but by their relative proportions have been fully developed by Budyko (1974). It is framed in a bioclimatological theory, which links climate to major global vegetation zones (biomes) within a bi-dimensional framework . The two indicators of this scheme are: the net radiation R_n of moist surface and the radiative aridity index of Budyko $\beta = R_n/LP$, i.e. the ratio of the yearly sums of net radiation to those of the latent heat, L and precipitation, P. The parameters R_n and β approximate the main components of heat- and water-balances, and their relation may serve for global biome classification and thus to describe the various climatic regimes.

Biogeophysical and biogeochemical terrestrial ecosystems processes of influence on climate. Being functionally related, the biogeophysical processes, i.e. the mass- and energy- exchange at the boundary layer between leaf system and environment, determine the efficiency of biogeochemical processes. This mechanism was approved through laboratory experiments at molecular level for single plants (Stoyanova, 1985; 1996) and we can transfer this knowledge as valid at an ecosystem level.

The concept of plant functional types (PFTs). The PFTs concept has received new attention in response to human-induced global changes. The biomes consist of individual species of measurable leaf physiology and carbon allocation. PFTs reduces the complexity of species diversity in ecological function to a few key plant types and are advocated to predict the composition and functioning of ecosystems in a changing environment (Bonan et al., 2002). Valentini et al. (1999) pointed out the importance of defining functional units in terrestrial ecosystems based on exchange of matter and energy that has the clear advantage of defining the exchange of trace gases and energy between land surface–atmosphere. Based on this, another functional units type classification is introduced (Section 3.2) as a standpoint of our regional model.

3. RESULTS

3.1 Model development

Based on theoretical considerations in Section 2.2, a biophysical model aiming to quantify the major processes in the long-term land-atmosphere interactions is developed. The model simulates some aspects of matter/energy flows on a regional scale and includes the following adjustment steps: (i) Assessing evaporation efficiency as a function of air aridity (or humidity) and type of active surface; (ii) Budyko energy balance estimates of potential evapotranspiration during the growing season as a measure of energy loading; (iii) The vegetated active surface (coniferous/broadleaved canopy) is specified by corresponding radiative properties of the dominant land cover type; (iv) The growing environmental gradients are specified by both: the length of the growing season (limited by 10 °C temperature thresholds) and the solar irradiance as modified by the relief of studied region.

The model consists of separate units for parameterisation of solar irradiance transfer, net radiation partition and soil water content. It operates on a 10-days time step to adopt the method of Budyko (1974) for regional 'process-based' long-term climate-vegetation coupling estimates. Climatological approximations of heat- and water- balances of natural vegetation in mountain environment are performed through radiative index of dryness of Budyko β, and potential evapotranspiration of forested-land surface (net radiation estimates: $E_o(veg) \approx R_n/L$) during the growing season. The index β and $E_o(veg)$ are the main model outputs derived in an ideal variant of land surface water status as the following limitations are applied: (i) Mountain terrains with a sky view of more than 90 percent up to a nearly unobstructed view; (ii) Full vegetation coverage of soils with one vegetation layer; (iii) Homogeneity of land cover assuming moist conditions over a forest canopy; (iv) Moisture flux is not soil controlled but atmosphere controlled; (v) Soil moisture regime is accounted qualitatively (i.e. soil hydrophysical properties are not considered).

3.2 Model results: Bioclimatic concept for natural vegetation differentiation

The model is used to describe functional heterogeneity due to the regional-scale environmental gradient (climate, relief, soil, growing season). On this basis, a boiclimatic concept for differentiation of potential natural forest cover is proposed. This concept is framed in a bi-dimensional biosphere-atmosphere equilibrium scheme that aggregates the parameterised forest-cover into functional units. In conformity to the Budyko's climatic classification (Budyko, 1974), we propose a static equilibrium scheme, where a direct correspondence between vegetation and climate is assuming without considering the transient response over time. In achieving this, we develop the concept of forest functional types (FFTs), which are defined independently of vegetation structure and focus on the exchange of the energy and matter of ecosystems. The FFTs are conceptually related to PFTs (see Section 2.2) but FFTs group similarly functioning ecosystems independent of structure. In other words, biogeophysical long-term coupled processes of water- and energy-exchange are used as criteria to define the bioclimatic limits of FFTs in their capacity of biogeochemical cycling units in a stable equilibrium. A similar approach has been applied by Paruelo et al. (2001) who introduce Ecosystem Functional Type EFTs on functional principle.

Figure 1a presents a classification of the land surface (i.e. forest cover type and soils) derived by using a plot method in terms of our bi-dimensional static equilibrium scheme of climatic energetic and hydrological resources. The FFTs are delimited by their *x,y* plot position (β on the *x*-axis, $E_o(veg)$ on the *y*-axis). Using this technique, the natural land cover in the region of south and southeastern Bulgaria is differentiated on Figure 1a in three functional units: Native coniferous (▲); Xerophytic broadleaved species (♦); Mesophytic broadleaved and coastal forests (●).

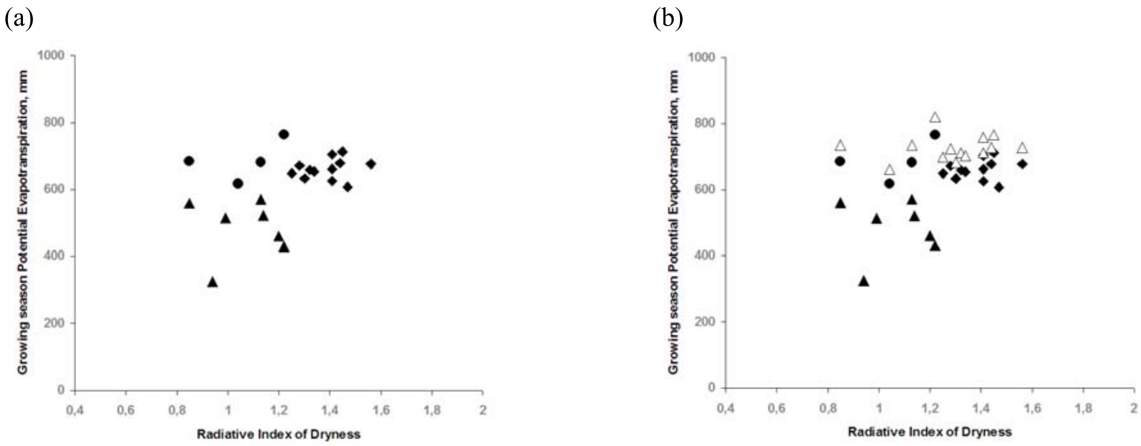

Figure 1: Land-surface classification plot of forest functional types in south and south-eastern Bulgaria. (a) Native forests: coniferous (▲); xerophytic broadleaved (♦); mesophytic broadleaved and coastal (●). (b) The same as (a) along with the artificial coniferous established in the lower forest belt (Δ).

3.3 Simulating human induced land-use/cover change

Changes in vegetation, which can affect the physical properties of the land surface and its interaction with the atmosphere, have occurred (file:///E:/M-vo%20Zem&Gor/NUG/Forest_Policy/Forest_BG.html) in arid and semiarid regions of Bulgaria. The drought stress and high temperature in this region in relation to the Mediterranean influence put some uncertainties in artificial forest system functioning. The feedback of these change to hydrological characteristics (potential evapotranspiration and climate-caused moistening) are largely related to land cover impacts on albedo and the subsequent impacts on the energy balance. Changing natural broadleaved to coniferous land cover tends to result in warmer surface temperatures and typically affects the energy balance by altering the water cycle and the disposition of energy from the surface. The model is applied to simulate any shifts in potential impacts on forest-atmosphere feedbacks at changing environment. Figure 1b shows the land-surface classification plot of Figure 1a along with the position of artificial coniferous (Δ). The model shows that plantations at the low elevated areas, would shift energetic and water cycles in respect to native broadleaved deciduous habitats, resulting in a new FFTs distribution pattern. The decreased albedo effect would increase the amount of water vapour on average by around 49 % and the heat released into the atmosphere that fuel weather systems during vegetation compared to native coniferous stands, and the trees would pump up amounts of water vapour from underground on average by 8 % more compated to native oaks.

4. CONCLUSIONS

A simple regional biophysical model that quantifies the link between land cover and atmosphere on a regional space scale is developed. On this basis an integrating concept for coupling climate and forest ecosystems is developed to serve for classification of the land surface in functional units, FFTs, delimited by the threshold levels of water-limited equilibrium conditions. Above these threshold limits, environmental pressure is directed towards disturbance of the site water balance optimality. This conceptual model is not developed with the aim to give a precise description of the land surface processes and their interaction with the atmosphere, but to describe the processes important for long-term climate variation and hence study the role of and surface processes in climate variability. This is a first-step of delineation FFTs as indicators of climate environment that helps to solve the following problems: (i) To derive the physical principles of forest-atmosphere coupling and to elaborate a background for further developments, which will focus climate, climate change and land surface analyses/processes; (ii) Provides a universal tool to define the functional forest units at different environmental gradients (climate, soil, landscape units), i.e. for regional climate-vegetation classifications should be applied; (iii) Would facilitate land-cover classification through the possibility to match both, the 'bottom-up' model analyses and 'top-down' remote sensing.

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