A Land Surface Model (IAP94) for Climate Studies
Part I: Formulation and Validation in Off-line Experiments

Dai Yongju (戴永久) and Zeng Qingcun (曾庆存)
Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100080
Received May 14, 1997

ABSTRACT

The IAP (Institute of Atmospheric Physics) land-surface model (IAP94) is described. This model is a comprehensive one with detailed description for the processes of vegetation, snow and soil. Particular attention has been paid to the cases with three water phases in the surface media.

On the basis of the mixture theory and the theory of fluid dynamics of porous media, the system of universal conservational equations for water and heat of soil, snow and vegetation canopy has been constructed. On this background, all important factors that may affect the water and heat balance in media can be considered naturally, and each factor and term possess distinct physical meaning. In the computation of water content and temperature, the water phase change and the heat transportation by water flow are taken into account. Moreover, particular attention has been given to the water vapor diffusion in soil for arid or semi-arid cases, and snow compaction. In the treatment of surface turbulent fluxes, the difference between aerodynamic and thermal roughness is taken into account. The aerodynamic roughness of vegetation is calculated as a function of canopy density, height and zero-plane displacement. An extrapolation of log-linear and exponential relationship is used when calculating the wind profile within canopy.

The model has been validated against field measurements in off-line simulations. The desirable model's performance leads to the conclusion that the IAP94 is able to reproduce the main physical mechanisms governing the energy and water balances in the global land surface. Part II of the present study will concern the validation in a 3-D experiment coupled with the IAP Two-Level AGCM.

Key words: Land Surface Model, Off-line Experiment, Validation

I. INTRODUCTION

In recent years, parallel to the proliferation of climate change studies using AGCMs, many land-surface parameterization schemes (LSPs) have been proposed, which range from rather simple to complex representations of soil and vegetation. Most of them have been applied to AGCM following limited off-line calibrating and testing, and have shown the improvement of the representation of surface climates. Simulations of surface climate by AGCM are not only sensitive to the changes of the surface albedo, roughness, soil moisture, and evapotranspiration, but also very much dependent on the formulation of their LSPs (see the review of Garratt, 1993; Sellers et al., 1996). Increased realism in the climate modelling has been shown that the improvement of the land surface component of coupled climate models is still a challenging task (Gates et al., 1996).

This work was funded by the National Key Project of Fundamental Research “Climate Dynamics and Climate Prediction Theory” of China.
The global landscape can be simply classified into three major types: vegetation cover, desert and the permanent or seasonal snow. There exist great differences in energy and water partitioning at the surface of these media due to the differences of their thermal and hydrological characteristics. Current schemes are concentrated mainly on soil and vegetation processes incorporating with only some rudimentary considerations on snow, desert and frozen soil (Dickinson et al., 1993; Sellers et al., 1996, etc.). One of the challenges in developing LSP using in AGCMs is how to comprise a comprehensive and accurate description for all these different surface types without overwhelming the parent model with its computational requirements.

One of the difficulties in establishing a comprehensive LSP may be the presentation of universal control equations of temperature and water for all kinds of surface media. In dealing with this problem, it is unavoidable to have variable coefficients in diffusive equations. A series of experimental studies have shown that the specific heat capacity of frozen soil is about half of that of unfrozen soil at the same water content (including ice), which undergoes a sudden change about 0°C, and is largely dependent on the water content; while the heat conductivity is less dependent on the temperature change, but largely dependent on the water content (Haynes et al., 1980). Thus, if we study the mixture cases in which snow, frozen soil or unfrozen soil coexist, we must treat the variable coefficient diffusive problems. Regarding the calculation of ground temperature, generally, two main types are used in the present LSPs: one is the force–restore method, and the other is the direct spatial discretization of the thermal diffusive equation. The former, which is derived from the assumptions of periodic heating and uniform thermal properties (Bhumralkar, 1975), requires considerable modification if inhomogeneous or snow covered soils are concerned (Dickinson, 1988). As for the latter, if explicit method is adopted, in order to avoid the computational error and instability, a harsh relationship between the time interval and spatial thickness must be satisfied; while, if implicit method is adopted, it is generally CPU consumption. Since its physical meaning is clear in comparison with force–restore method, it is still used in some of LSPs (Verseghy, 1991; Viterbo and Beljaars, 1995, etc.). In the direct discretization method case, in order to apply a large thickness of ground surface layer, a zero heat capacity skin layer for surface is usually introduced. Nevertheless it can not evade the embarrassment of the nonconservation and the overestimated evaporation in drying period. The same criticisms can be made also for the moisture calculations.

A new LSP, suitable for various land surface media, has been developed in order to tackle the problems referred above. Special attention has been devoted to an accurate representation of the control equations for energy and moisture. In the natural environment, soil, snowpack or vegetation canopy are a complex assembly of solid matrix, three phases of water and dry air. Morland et al. (1990) had laid down a rigorous theoretical framework for a four constituents phase-changing snowpack, which were derived from the principles of mixture theory. A simplified one-dimensional approach has been successfully used for snow cover by Jordan (1991). In addition, there are many works on fluid dynamics for porous media in engineering and water resource (Bear, 1972). In the viewpoint of the mixture theory and the fluid dynamics in porous media, we try to develop a set of universal control equations of energy and water for the global land surface media. In the model development, we also attempt to improve the calculation of the surface radiation fluxes and turbulent fluxes between surface and the atmosphere. In the numerical solution, the control–volume approach of Patankar...