論文の内容の要旨

論文題目　　植生の構造および生理が蒸発散に果たす役割に関する研究
Title of Dissertation　　A study on structural and physiological roles of vegetation for evapotranspiration

氏　名　　趙　在一（CHO, Jaeil）

(Abstract)

The Intergovernmental Panel on Climate Change (IPCC) published their fourth report, which described how and why climate systems are changing, the impact assessment on mankind and ecosystems, and many of its possible future impacts. However, the simulation of future climate change by global climate models has included many of the generic uncertainties. The difficulty of estimating the impact of the change on the hydrological cycle should be one of problems because the transport of moisture is associated with the energy transport. The water cycles have significant impacts on the regional and global climate systems, respectively. The hydrological cycle is a highly non-linear portion in Earth’s climate system. It is the critical result of climate change and plays a key role in regulating the climate, such as positive and negative feedbacks.

The vegetation influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrological cycle, and atmospheric composition, and this action has the different effect on many time scales, for example on a sub-daily scale (e.g. stomatal closure, solar elevation angle), on a seasonal time scale (e.g. vegetation phenology) and on multi-year scales (e.g. changes in land cover, extreme climate change). These complex and nonlinear atmosphere-biosphere interactions can dampen or amplify anthropogenic climate change. Therefore understanding how energy and water are exchanged between the atmosphere and terrestrial biosphere becomes an important component in understanding and predicting climate change which includes global water cycle. However, the influence of vegetated land surface on large-scale climate is still poorly understood in the real world. This theme is able to approach the system of land-atmosphere interactions on a range of space and time scales using observation experiment products to develop hypotheses, prepare parameters and validate models.

In nature, soil-vegetation-soil transfer system explicitly considers the role of vegetation in affecting water and energy balance by taking into account its 1) physiological (stomatal conductance) and 2) structural (canopy aerodynamics) properties. These two vegetation functions are also the basis of evapotranspiration parameterizations in physically-based hydrological and climate models. However, most current SVAT schemes and hydrological models do not parameterize the characteristics of vegetation as a dynamic component. The aim of this study is to understand the role of vegetation for evapotranspiration which is critical factor on the partitioning of land surface energy and water cycling, regionally and is linking factor for both microclimate and hydrometeorology, globally.

In chapter 2, Land surface energy partitioning in various vegetated surfaces is controlled by climatological and biophysical factors. The “big leaf” model represents these conditions by three resistance parameters: bulk surface resistance, aerodynamic resistance, and climatological resistance.

Author tries to understand land surface energy partitioning in various vegetated surfaces with the flux and meteorological data from 27 FLUXNET sites, and using the big leaf model of bulk surface, aerodynamic, and climatological resistance in Penman-Monteith approach. Here, author introduces a new method to estimate the total resistance and normalized surface resistance and shows that the Priestley-Taylor coefficient can be related to the total resistance, and the Bowen ratio can be described by air temperature and normalized surface resistance. The proposed empirical method in this chapter is useful for estimating evapotranspiration using remotely-sensed data and for understanding the energy balance partitioning in land surface models.

In chapter 3, the author introduces MATSIRO (Minimal Advanced Treatments of Surface Interaction and RunOff), the well-known one of 3rd generation land surface model, as main three sub-schemes related with canopy structural and plant physiological effects on land surface energy partitioning: radiation transfer, aerodynamic surface roughness, and plant physiological process schemes in MATSIRO. Atmospheric general circulation models used for climate simulation and weather forecasting require the fluxes of radiation, heat, water vapor, and momentum across the land-atmosphere interface to be specified. These fluxes are calculated by sub-models called land surface parameterization scheme (LSPs). Recent LSPs represent globally the system of soil-vegetation-atmosphere transfer as advances in plant physiological and hydrological research. It incorporates biogeochemical and ecological knowledge. The author applied four modifications based on sensitivity tests in order to improve the simulation accuracy:

1) The role of tree stems on radiation energy balance and aerodynamic transfer is considered. In early LSPs, leaf area index and canopy height are used as manner of describing the above-canopy structure. However, only both canopy structure components are not sufficient parameters to represent land properties in the surface boundary layer because of passing over the impact of stem morphologies as the permeable obstacles for the rain falling, the light penetrating, and the wind going through. Therefore, in recent LSPs, stem area index (SAI) is added with leaf area index (LAI) which is one of main key phonological parameters in LSPs. In order to consider SAI, LAI is replaced by plant area index to estimate interception loss and roughness length. The simple weighted factor with the ratio of SAI and LAI on PAI is used. Nevertheless, the simple application of PAI in previous studies is not available to represent the effects of stem because the whole skins of leaves and stem are not exposed to outside and the reflection and drag coefficient for leaf and stem object are different. Therefore, the author applies the exposed weighted factor using Monsi-Saeki's light extinction in MATSIRO.

2) The hydrological impact of the vertical distribution of plant root is critical on land water cycle. In nature, roots define the biologically and chemically most active zone of the soil profile. The depth of the rooting zone of the vegetation cover, or rooting depth, determines the extent to which soil moisture can be extracted by vegetation for transpiration. In LSPs, root vertical distribution is treated as a static component. The parameter of vertical root distribution in MATISRO is determined by look-up table of vegetation types. In other word, most of LSPs assume that root distribution profile in one vegetation type is not changed. However, the changes in leaf and stem biomass are reflected in not only leaf area index and vegetation height but also rooting depth, as following plant allometric relationships. In most grassland and cultivation area, transpiration is increased and runoff is decreased. In fact, the root fractions in first soil layer of grassland and cultivation type are relatively larger different than other vegetation types. In Africa region, decreased runoff might be caused increased transpiration. This area is dry, and thus first layer soil moisture is quite variable through the amount of rainfall.

3) Photosynthetically active radiation (PAR) energy reaching on the vegetated surface is a key determinant of physiological processes. In order to procure PAR variable in the model, the ratio of

PAR to R_s (PAR/R_s) is commonly used to convert R_s into PAR. PAR estimated from incoming solar radiation (R_s) reduces the weather data requirements. It will reduce the weather date requirements for the model. Several models simply use 0.5 for PAR/R_s as the constant ratio. However, previous field experiments have been represented the variations of PAR/R_s, not constant ratio. The previous empirical equations for estimating PAR/R_s are derived from the data of relatively long time-scale (e.g., daily and monthly) and limited measurement sites. It is not suitable for current biosphere model having with several hourly and global scale simulation. Here, we represent the exponential correlation between hourly PAR/R_s and sky clearness index (0~1) using data set of 54 measurement sites in Ameriflux. PAR/R_s is increased until 0.6 by cloudy conditions of below about 0.2 clearness index. To the contrast, PAR/R_s of over 0.2 clearness index is retained 0.42 as the constant value. When our empirical equation is replaced with previous one in biosphere model, it will be possible to bring -4~2 percent different on stomatal conductance, which is most critical parameter for plant transpiration.

4) The scale-up method from leaf to canopy considering diffuse radiation is important on climate change. Scaling processes from a single leaf to an entire canopy is necessary when considering the role of stomatal response to environmental variables on interaction between biosphere and atmosphere because of complex environmental and physiological gradients within the canopy. Several studies have shown that diffuse light, which enters a complex canopy from all directions, reaches leaves more evenly than light in the direct solar beam. Consequently, canopy light use efficiency increase with fraction of diffuse radiation and canopy photosynthesis has less tendency to saturate. Beer's law, which is the assumption theory of Monsi and Saeki theory does not account for the loss of scattered radiation if the extinction coefficient is calculated as $G/\cos(\theta)$, where G is the mean area projected onto a surface normal to the sun's ray per unit leaf area, and θ is the zenith angle of incident radiation. Because of its simplicity, Beer's law has been used in most models. One previous study found that the absorption of intercepted and scattered radiation could be accounted for by reducing the canopy extinction coefficient. The absorptions of direct beam and diffuse radiation are not calculated separately. It is necessary for the canopy scaling-up considering with diffuse radiation in global climate simulation.

In chapter 4 and 5, canopy structural and plant physiological effects are investigated, respectively. In chapter 4, the author hypothesizes that a functional relation between albedo and roughness length can be sought for a vegetated surface since both land surface parameters are conceptually related to vegetation structure parameters such as leaf area index, canopy height, canopy density and crown area. The author investigated this relationship between α and z_0 by using vegetation structure parameters collected from observed data from 48 measurement sites worldwide covering various vegetated surfaces. Based on these data, an inverse nonlinear relationship between roughness length and albedo is found. It is shown that this observed relationship can be empirically related to canopy structure parameters such as leaf area index and canopy height. Our results demonstrate that plant canopy structure formed by the pattern of biomass partitioning with the accumulated carbon assimilation determines the key land properties for surface energy budget: albedo and roughness length.

In chapter 5, recent simulation results by land surface parameterization schemes (LSPs) used for climate modeling represent the change of global water balance through stomatal regulation. The author investigates the stomatal response to humidity and CO_2 concentration. Real stomatal behavior which is summarized in previous literatures is compared with the calculated stomatal conductance, and the method of stomatal conductance is modified considering both influences of humidity and CO_2 concentration. The author modified two parts of stomatal conductance model; 1) leaf temperature calculation and 2) performance of the Ball-Berry model under the elevated CO_2. Those two model modifications are very important to represent plants' physiological effects realistically in any similar stomata models. Transpiration decreasing by “CO_2-induced stomatal closure” is under-estimated in original MATSIRO (Ball-Berry model) because of relatively high VPD in tropical regions. However, it is equivalent to “runoff increase” because the increased surface soil moisture by reduced transpiration results in less water stress on soil evaporation. Therefore, “runoff increase” by the CO_2-induced stomata closure will possibly occur, but the magnitude of increase may vary from region to region, because of the differences in humidity and soil moisture conditions. These results highlight certain important impacts of plant physiological changes on the global hydrological cycle. However, it is critically important to understand the real physical processes at work; 1) validate the modified Ball-Berry model using observed data and 2) conduct on-line simulations considering precipitation change.