Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-01 Room:511 Time:April 29 09:00-09:15

Interannual variations and its control factors of evapotranspiration in a temperate Japanese cypress forest

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1.Introduction

Evapotranspiration from forests is a major factor affecting water yield and therefore water resources. Understanding the long-term impacts of variations of meteorological factors on variability of evapotranspiration is important, especially in the context of current and future climate change. Long-term continuous measurements of evapotranspiration using the eddy covariance method provide an opportunity to examine the response of forest ecosystem processes to climate change. We quantified the interannual variations of evapotranspiration, and examined its control factors using the multi layer model.

2.Material and methods

Observations were made in the Kiryu Experimental Watershed in the south of Shiga Prefecture, central Japan. The forest around the watershed comprises mainly 50-year-old Japanese cypress forest. A meteorological observation tower is located in the watershed. The fluxes of momentum, sensible heat, latent heat, and CO2 were measured using eddy covariance methods at a tower height of 28.5 m. Precipitation was observed at the open site.

We used the multi layer model to clarify the control factors of interannual variations of evapotranspiration. The model contained sub-models that calculated the gas exchange processes, including H2O and CO2 exchanges of leaves and the ground surface. This multi layer model simulates the above-canopy fluxes based on vertical profiles of meteorological factors. This model requires the above-canopy environmental variables as the input data. The parameters representing leaf gas exchange characteristics are determined by leaf gas exchange measurements. We used 7 years of eddy covariance data (from January 2001 to December 2007) in this study.

3.Results and discussion

Annual evapotranspiration for the seven years ranged between 715 (2001) and 780 mm (2004) with the average of 743 mm. Maximum interannual fluctuation in evapotranspiration was 75 mm.

Diurnal, seasonal, and interannual variations of evapotranspiration for the seven years were reproduced by a model simulation. This indicates that the model structure and parameterization are validated.

We calculated the components of evapotranspiration such as transpiration, evaporation, and soil evaporation. Each component shows interannual variations relating to meteorological factors. Wet years such as 2001 and 2002 had small annual evaporation and large annual transpiration. Dry years such as 2003 and 2006 had large annual evaporation and small annual transpiration. Both annual evaporation and transpiration were relatively large in 2004. Annual soil evaporation was slightly smaller than evaporation and transpiration. Interannual fluctuations in soil evaporation were also small compared with evaporation and transpiration.

We examined seasonal variations of evapotranspiration for the contrasting two years; 2004 and 2003 with maximum and minimum annual evapotranspiration simulated, respectively. The deviations of evapotranspiration for the two years were large in summer from June to August. Transpiration increased with vapor pressure deficit and solar radiation. Transpiration was relatively small in 2003, which had low vapor pressure deficit and solar radiation in the summer. Transpiration was relatively large in 2004, which had high vapor pressure deficit and solar radiation in the summer. Soil evaporation for the two years showed the similar seasonal variations with transpiration. Seasonal variations of evaporation were the similar to those of precipitation.

Each component of evapotranspiration showed different responses to the meteorological factors seasonally and annually. Interannual variations of evapotranspiration were almost explained by those of meteorological factors.

Keywords: Evapotranspiration, Interannual variation, Eddy covariance, Multi layer model, Japanese cypress forest

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-02 Room:511 Time:April 29 09:15-09:30

Evapotranspiration and water use efficiency on a coniferous planted forest watershed in south western Japan

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Japanese cedar (*Cryptmeria japonica* D. Don) and Japanese cypress (*Chamaecyparis obtusa* Endl.) are the most popular planted species in Japan. These species cover about 20% of the land surface of the country. On a mountainous topography which is common in Japan, Japanese cedar was usually planted from valleys to lower hillsides with relatively wet and fertile soils, while Japanese cypress was planted on the drier and more nutrient poor ridge areas. Accordingly, evapotranspiration (ET) and carbon assimilation may be variable in the two species.

We applied multiple methods to estimate ET from a planted forest watershed located in Kyushu Island, south western part of Japan. The watershed existed on mountainous terrain, and the right bank was mainly covered with well-grown Japanese cedar while the larger part of the left bank was covered with relatively less-grown Japanese cypress. We applied the eddy covariance method, using an observation tower built in the center of the watershed. The eddy covariance data were experimentally divided to two sectors by wind direction, right bank side and left bank side of the watershed, and the lack of data for each wind sector were interpolated by the mutual imputation method. The analysis period in this study is 2007-2008. Within the period, the rainfall interception loss (I_c) and sap-flux density were also measured in Japanese cedar plots, and the lower canopy ET was estimated by a model. From the eddy covariance result, ET from the left bank side was estimated as 85% of that from the right bank side in the period. Compared the right bank side ET with the combination of I_c, upper- and lower-canopy ET, the difference in annual total ET was about 1% when global solar radiation (S_d) was greater than 0, which assured the accuracy of the eddy covariance method even over the complex terrain.

As for carbon assimilation, we simultaneously measured CO_2 flux and CO_2 concentration profile by using the observation tower. Based on the measurements, we can estimate the CO_2 exchange between the forest and atmosphere through the similar procedure to ET. Thus in this study, we will estimate the carbon budged and calculate the water use efficiency of the whole ecosystem of the watershed and of the both bank sides. From the tentative result obtained at present, the average NEE of the left bank side was 87% to that of the right bank side, in the daytime (S_d >0) in 2007-2008. From the value and the aforementioned ET ratio (0.85), the water use efficiency of the both bank sides were might be almost the same as each other. In the presentation, we will discuss about the detail, considering the respired CO_2 in the nighttime and the rainfall interception in the Japanese cypress plot.

Keywords: Planted coniferous forest stand, Growth difference, Water vapor flux, Carbon dioxide flux, Water use efficiency

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-03 Room:511 Time:April 29 09:30-09:48

Water budget and the consequent canopy duration period in a teak plantation in a dry tropical region

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A soil-plant-air continuum multilayer model was used to numerically simulate canopy net assimilation (A_n), evapotranspiration (ET), and soil moisture in a deciduous teak plantation in a dry tropical climate of northern Thailand to examine the influence of soil drought on A_n. The timings of leaf flush and the end of the canopy duration period (CDP) were also investigated from the perspective of the temporal positive carbon gain. Two numerical experiments with different seasonal patterns of leaf area index (LAI) were carried out using above-canopy hydrometeorological data as input data. The first experiment involved seasonally varying LAI estimated based on time-series of radiative transmittance through the canopy, and the second experiment applied an annually constant LAI. The first simulation captured the measured seasonal changes in soil surface moisture; the simulated transpiration agreed with seasonal changes in heat pulse velocity, corresponding to the water use of individual trees, and the simulated An became slightly negative. However, in the second simulation, A_n became negative in the dry season because the decline in stomatal conductance due to severe soil drought limited the assimilation, and the simultaneous increase in leaf temperature increased dark respiration. Thus, these experiments revealed that the leaflessness in the dry season is reasonable for carbon gain and emphasized the unfavorable soil water status for carbon gain in the dry season. Examining the duration of positive A_n (DPA) in the second simulation showed that the start of the longest DPA (LDPA) in a year approached the timing of leaf flush in the teak plantation after the spring equinox. On the other hand, the end appeared earlier than that of all CDPs. This result is consistent with the sap flow stopping earlier than the complete leaf fall, implying that the carbon assimilation period ends before the completion of defoliation. The model sensitivity analysis in the second simulation suggests that a smaller LAI and slower maximum rate of carboxylation likely extend the LDPA because soil water from the surface to rooting depth is maintained longer at levels adequate for carbon gain by decreased canopy transpiration. The experiments also suggest that lower soil hydraulic conductivity and deeper rooting depth can postpone the end of the LDPA by increasing soil water retention and the soil water capacity, respectively. These hypotheses will be verified based on observations.

Keywords: canopy dyration period, carbon gain, dry tropical region, soil-plant-air continuum system, teak plantation, water budget

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-04 Room:511 Time:April 29 09:48-10:03

Influence of canopy interception on the recovery in water balance after clear-cutting at a small headwater catchment

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The impact of forest disturbance on stream runoff has been well studied using the paired catchment approach, usually finding increased stream runoff following forest disturbance due to the decline of transpiration and canopy interception. However the recovery processes of transpiration and interception have rarely been directly observed under a recovering forest, therefore mechanisms behind recovery time of stream runoff following forest cutting is still not well understood. The objective of this study is to evaluate the contribution of interception to the change of stream runoff after forest cutting. This study was conducted in a pair of small headwater catchments, where one catchment was clear-cut in 1999 and planted with the same species in 2000. Annual runoff increased 200 to 300 mm/yr after forest cutting and the higher runoff remains 12 years after cutting. Interception ratio in the clear-cut catchment were lower than 10 % of precipitation in 2007, 2011 and 2012, and those in the control catchment were 20 to 24 % of precipitation. The mean annual interception was still around 300 mm/yr smaller in the young forest compared to the mature forest, although canopy cover and LAI were similar. These results suggested that the recovery of interception rate is an important controlling factor for the recovery of stream runoff after forest cutting, and not only canopy structure, but also the microclimate condition above the canopy of young forest could be also important factors affecting interception.

Keywords: forest cutting, water balance, canopy interception, headwater catchment

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-05 Room:511 Time:April 29 10:03-10:18

Changes in interannual variability of runoff in a conifer and deciduous hardwood mixed forested watershed

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The National Forest Management conducts forest management in National Forests for the fulfillment of multi functional roles of forest including long-term wood production management. On the other hand, there are few studies that evaluated the runoff characteristics including a state of the forest for a long term. This study was conducted within the Kamabuchi No1 experimental watershed (3.06ha) in North part of Japan. Hydrological observation has been continued in cold snowy region since 1939. It is the longest record in this region in Japan. The site is covered with Natural hardwood forest (ex. Fagus crenata, Quercus mongolica var. grosseserrata and Quercus serrata) and coniferous plantation forest (Cryptomeria japonica and Chamaecyparis obtuse) which planted around 1912 to 1916. Surficial geology is tuff and shaletic tuff of the Tertiary period and soils are clay loam. Meteorological observation was conducted Yamagata experimental forests located to 800m from the watershed to the northeast. A 71-year record (1939-2010) of the precipitation and runoff was used for an analysis of the flow-duration curve. Tree (DBH ≥ 6cm) census in the watershed was also conducted at 5 times (1942, 1950, 1957, 1979, 2008). The tree volume of Chamaecyparis obtuse is a regular tendency and the tree volume of Cryptomeria japonica linearly increased. Stem volume of oak trees has increased remarkably from 1942 to 1979 but there was a close tendency of an increase in 2008 because mortality of oak trees occurred in the watershed. Based on 5 times tree census, positive linear relationship was found between tree volume and age of stand. While the proportion of plentiful runoff has shown a tendency to decrease over long term, those of ordinary, low and scanty runoffs have tended to increase with increasing the tree volume.

Keywords: duration curve, cold snowy region, long term hydrological observation, runoff characteristics

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-06 Room:511 Time:April 29 10:18-10:33

Is there any general rainfall-runoff response function in mountainous catchments?

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Clarifying rainfall-runoff response function in mountainous catchments is one of key issues for flood and sediment disaster prediction, management of aquatic environment, water supply and so on. So, rainfall-runoff response function in mountainous catchments has been debated in more than several decades. A variety of studies, observation, modeling, theoretical studies etc., has been conducted. Many noble efforts have been conducted for clarifying complex systems in catchment hydrology through intensive observations. These observations were effective for documentation of the idiosyncrasies of each catchment environments. However, it has been difficult to derive general rainfall-runoff response function from these basin-centric approaches. So, several researchers emphasized the importance of intercomparison so as to better see first order controls of hydrologic responses. Except for several exceptions, intercomparisons for rainfall-runoff responses in many catchments are still limited. Thus, still it is very hard to predict rainfall-runoff response function at ungauged basin.

Thus, we compiled rainfall and stream flow data for around 150 catchments in Japan. We focused relatively small catchment (<100 km2) and a variety of geological, topographical and climatic conditions. We removed catchments where strongly affected human activities, such as urbanized catchment etc., from our intercomparison.

In this study, we randomly sampled 10 storms, i.e., total rainfall amounts were large than 50 mm, for each catchment and calculated three indices, peak specific discharge, peak lag time and direct runoff ratio, to characterize rainfall-runoff response. Also, we defined rainfall-runoff responses using three reservoirs model. We parameterized all of catchments using four storms data using SCE-UA method and validated these parameters using other four storms data. Then, we tested the roles of rainfall condition, climate, geology and topography on rainfall-runoff responses. We used multiple regression analysis to define first order controls of rainfall-runoff responses.

We found large variability in rainfall-runoff responses and it is hard to define general response patterns. While, through multiple regression analysis, we found several interesting results, as follow;

-Climatic conditions affected peak specific discharge and direct runoff ratio, suggesting that climate might give impacts on hydrological characteristics soil and bedrock.

-Geology, such as type of rocks and geological age, gave impacts on rainfall-runoff responses, but effects of geology were not so large, although many study focused on rock-controls on hydrology.

-Flowpath length, calculated by DEM, was one of important topographic parameters for describing rainfall-runoff responses.

Keywords: headwater catchment, rainfall-runoff response, database, multiple regression analysis

AHW07-07 Room:511 Time:April 29 11:03-11:18

A method of generating virtual drainage-basin by introducing models of slope/stream evolution

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A method of generating virtual drainage basin to understand relationship among characteristics of geomorphic distribution, rainfall distribution, and runoff distribution was developed. Here the concept of generating virtual drainage-basin is that the drainage-basins are generated at random under some physically based conditions on the basin form. The method is an improvement of Nakakita and Matsuda (2007). They proposed the method of generating virtual drainage-basin based on erosional developing model of channel network by Horton (1945). For the improvement, mathematical models of evolution of slopes and streams were introduced into the methodology. As a result, we achieved to introduce the concept of time into the generating virtual drainage-basin model.

Keywords: drainage basin, landform evolution, channel network, slope evolution, longitudinal profile

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-08 Room:511 Time:April 29 11:18-11:36

Rock control, denuded hillslope and discharge system in warm humid regions

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Under humid and warm regions as Japan, a stable discharge system of seepage water in hillslope is maintained by not only geophysical structures(soil and weathered layer) but also biological system such as forest. From long term point of view, topography, soil, ecosystem and water discharge system play hydro-geomorphological interactions directly or indirectly to one another. In the discharge system, both macro and micro pores of soil layer or weathered bedrock play especially important roll, which controls the permeability and storage capacity under the ground. Among them, natural pipes consisting of continuous macro pores play a roll in the water discharge during a heavy rainfall event. The capillary water stored in micro pore can be used by trees in dry season. These macro pores and micro pores are made by physical and chemical weathering processes. However, biological weathering is the most important for the development of these pores in soil. Forest ecosystems can evolve a matured soil system from soil particles in order to adjust a suitable environment for their own lives. Because the tree root system needs not only water but also enough air, an efficient discharge system may be created as one of the most important environment. This discharge system changes as follows according to the rainfall conditions.

1) In the case of usual storms: The discharge system is stable and it can discharge successfully the seepage water.

2) In the case of unusual heavy storms: The slope failure may occurs due to increasing of water pressure when the water table of throughflow, rises or the pipe-discharge system becomes plugged and partially destroyed. However, this system is recovered with the recovery of forest and soil. This can be called a healty feedback. The humid and warm climate suitable for forest contributes much to these recovery. Therefore, this feedback can contol the expansion of a denuded area made by a slope failure and a wide denuded area may not been naturally developed.

3) In the case of unusual heavy storms in bare lands created by severe human activities: In this case, especially in granite area or the Tertiary area, an unhealty feedback acts because the critical threshold of healty feedback is exceeded. Then, the bare land expands rapidly throughout a mountain area. It is almost impossible for forest and soil to be recovered naturally. Human afforestation work is necessary. Such hillslopes were founded in the wide area of Japan till the second half of 20th century. There is no stable discharge system in such bare hillslopes. Consequently, frequent occurrence of overland flow surface flows caused severe floods and soil hazard.

The discharge system seems to be made as a part of hillslope development. The geological character of the bedrock and the climate (rainfall and temperature) play an important roll in making of the discharge system. This system can be considered as one of the effects of rock control.

Keywords: hillslope hydrogy, discharge system, rock control, bare land, ground structure, hydro-geomorphological interaction

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-09 Room:511 Time:April 29 11:36-11:51

The making method of two dimensional distribution map of the collapse prevention force with tree survey

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The collapse prevention force of the forest root system is a grand total of the pulling out resistance of each root per vertical cross section (1m^2) of soil layer. The pulling out resistance of root (T,N) shows a following equation using root diameter (D,mm) , T=a$D^{1.6}$, varies in the coefficient by a tree class. The quantity of root system is distributed concentrically from the tree center and decreases for distance from tree exponentially.

Here I propose the two dimensional distribution map of the collapse prevention force with only the ground information of tree survey, breast height diameters and distribution of trees.

I performed an investigation that each in 3 Hinoki artificial plantation stand and 1 natural broadleaf forest, and made a two dimensional distribution map of the collapse prevention based on the tree positioning and the diameter of trees at breast-height. And I compared which I got by investigating every tree and compared the outcome of maps and the actual measurement that I dug a trench. As a result, the estimated values and the actual values did not exactly match, however a very meaningful relation was seen in both value within 1% of the risk ratio.

Furthermore, I applied this method and estimated a chronological order change of the collapse prevention force. Because the data required for estimating the ability of collapse prevention are only positioning of the trees and diameter measurement at trees breast-height, I can even estimate a change in the result after thinning, by using it in conjunction with the growth prediction by the density management curve.

Keywords: root system, collapse prevention forse, artificial plantation, natural forest, two dimensional distribution map

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-10 Room:511 Time:April 29 11:51-12:06

The growth-collapse simulation method of soil depth in which the effect of vegetation was taken into consideration

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The impact accompanying the transition of the watershed conditions in a forest appears under the structurally development process of a triplex in which time scales differ; geographical feature is formed by a tubercle and erosion of a mountain, the soil which supports and grows up in the root system of a vegetation repeats a collapse and a renature, the forest grows and withers. Without understanding this process, the runoff impact evaluation of watershed conditions cannot occur. We paid our attention to the collapse process in which a soil grows up again, after the soil was supported by the root of the forest, grew up and collapsed with progress of a temporal. And the development method of the longterm soil growth simulation was considered.

This method is computed for every mesh. The following routines perform the compute process of geomorphic development. First, the amount of growths of the soil stratum in the fixed period in each mesh is computed. The amount of developments of the soil depth used the equation of the following which Heimsath et al. (1999) proposed.

Soil Production(m/million year)=77$\times$exp(-0.024$\times$Soil Depth)

The soil depth after a fixed period is computed by applying to the initial soil depth of each mesh the value calculated by the equation. Slope stability is computed using the soil depth set up newly. It is considered by the equation that the mesh by which the safety factor was computed or less with one is that to which the collapse occurred. After setting the value of the soil depth in the mesh to 0, the altitude data after a collapse and a soil depth are re-calculated. A prolonged soil development simulation is computed by repeating the predetermined number of these processes. The simulation was computed at the place which many shallow landslides caused by heavy rainfall. The initial soil depth in the mesh which the collapse caused by the heavy rain was set to 0, and the mesh which has not collapsed was set to 1 m. And, the soil layer assumed the condition of being completely saturated by the heavy rain. In addition, the effective soil internal angle was 32 degrees, effective soil cohesion was 0.01 kPa, unit weight of the moist soil was 17.64 kN/m^3, and unit weight of water was 9.8 kN/m^3. The effect of the vegetation was included in the simulation as the cohesion.

As results of the simulation, It was confirmed that the soil layer which collapsed with progress of the temporal is recovered. Moreover, when a vegetation does not exist, the probability that a soil layer will repeat a collapse becomes high, but when a vegetation exists, a soil layer does not collapse but is recovered early.

Keywords: soil depth, geographical feature, vegetation, simulation method

AHW07-11 Room:511 Time:April 29 12:06-12:30

Limits of Soil Production and the Couplings with Hillslope Hydrology

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Rocky mountain ranges are broken down to sediment that is ultimately removed to the sea. Tectonic forces continually push mountains up, while physical and chemical processes continually transform bedrock to sediment and move it down. This simple sounding cycle is thought to regulate global climate over long timescales, while also responding to climate forcing itself, although the causal direction remain a mystery despite decades of sleuthing. Similarly mysterious are the connections between mechanisms of sediment production and the responses of watersheds to changes driven by humans, climate, or tectonics.

To address some of the potential connections between sediment production and hillslope hydrology, I focus here on soil mantled and steeply sloped landscapes from around the world, some thought to be at a critical threshold of soil cover. Observations reveal that even in the most rapidly eroding landscape there are significant areas mantled with soil that fit the conceptual framework of a physically mobile layer derived from the underlying parent material with some locally-derived organic content. The extent and persistence of such soils depends on the long-term balance between soil production and erosion despite the perceived discrepancy between high erosion and low soil production rates. I present cosmogenic Be-10-derived soil production and erosion rates that show that soil production increases with catchment-averaged erosion, suggesting a feedback that enhances soil-cover persistence, even in threshold landscapes. I also show that a process transistion to landslide-dominated erosion results in thinner, patchier soils and rockier topography, but find that there is no sudden transition to bedrock landscapes. The landslide modeling is combined with a detailed quantification of bedrock exposure for these steep, mountainous landscapes.

To conclude, I draw an important conclusion connecting the physical processes producing and transporting soil and the chemical processes weathering the parent material by measuring parent material strength across three different field settings. Parent material strength is observed to increase with overlying soil thickness and, therefore, the weathered extent of the saprolite. Soil production rates, thus, decrease with increasing parent material competence. These observation highlight the importance of quantifying hillslope hydrologic processes where such multi-facted measurements are made.

Keywords: Soil erosion, Soil production, Critical Zone, Weathering, Hillslope hydrology, Saprolite

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-12 Room:511 Time:April 29 12:30-12:45

Soil production functions and soil layer mobility in Japanese mountainous catchments underlain by granitoid rocks

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Soil-mantled hillslopes cover a major area of mountainous catchments in humid temperate regions. The soil layer on hillslopes is maintained by a balance between soil production and transport especially at hill noses, while the soil accumulated in hollows is eventually removed by a rainfall-induced shallow landslide. The rates of soil production and soil creep pace the growth of soil thickness at a hollow and thus determine the return period of landsliding. The soil layer buffers rainfall infiltration into hillslopes and hence controls subsurface runoff system in a catchment. Hydro-geomorphological evolution of a catchment results from the interaction between long-term soil layer development and short-term rainfall runoff processes. The quantification of soil dynamics on hillslopes is thus critical in understanding present-day hydrological condition of a catchment and for geomorphological landslide hazard mitigation.

The uppermost part of decomposed bedrock (saprolite) gradually disintegrates to form the mobile soil layer, which achieves to a steady-state thickness reflecting sediment budget at a soil column. The saprolite-to-soil conversion rate beneath a soil column decreases with increasing thickness of the soil layer, which is called as soil production function (SPF). Soil particles apart from the saprolite move downslope by soil creep at a rate controlled by slope gradient, biological activity and soil thickness. Evaluation of SPF as well as the soil layer mobility is essential when we simulate soil dynamics on a hillslope. SPF can be determined from concentration of terrestrial cosmogenic nuclides at uppermost part of saprolite, while soil layer mobility can be estimated by soil thickness survey by digging pits on a nose-hollow pair of hillslopes. We present examples of SPFs in Japanese mountainous catchment underlain by granitic rocks, and demonstrate results of simulation of soil development to map potential sites of shallow landslide and to assess volume of sediment that may yield at a catastrophic landslide event by heavy rainfall.

Keywords: soil production function, terrestrial cosmogenic nuclides, sediment transport, shallow landslide, landscape evolution

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-13 Room:511 Time:April 29 14:15-14:30

Interrelation between hillslope soil moisture and stream flow in a Paleozoic sedimentary rock watershed

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It is well known that geology is one of influential factors on river regime. In the Paleozoic sedimentary rocks area in Japan, hydrographs are characterized by low base flow and spiky peak flow. To clarify the reasons of such characteristics occur, observation focused on hillslope soil moisture condition was conducted in the gauged Tatsunokuchi-yama Minami-tani watershed (34 ^{o} 42' N, 133 ^{o} 58' E, 50-257 m, 23 ha) underlain by Paleozoic sedimentary rocks. The watershed is covered with primarily *Quercus serrata* dominant mixed forest, and partly *Chamaecyparis obtusa* stands planted in 1970s. Annual precipitation is about 1200 mm with little snowfall.

Ground water levels (GWL) and soil moisture were continuously measured in and around boreholes in a concave slope in the middle reach. Deeper than 0.3 m from ground surface, a thick fractured and weathered bed rock layer extends down to about 10 m at upper slope, and about 16 m at mid-slope. Below the weathered bed rock layer, boring core was relatively unweathered. But conspicuous cracks were obviously seemed to perform as water flow pathway because the surface of crack was dyed. Low coefficients of permeability which ranged from 2^{-8} to 1^{-6} m/s were measured by in situ test in the boreholes.

In the mid-slope, GWL appeared about 15 to 17.5 m in depth from ground surface when surface soil layer was more than field moisture capacity. Although GWL greatly respond to about over 40 mm rainfall events, direct flow rate did not simply increased. In a little antecedent rainfall condition, GWL rising was detected only at the lower slope. Depending on increase of antecedent rainfall, fluctuations of GWL at the mid-slope and the upper slope became obvious, and also direct flow rate went up. The greater amount of rainfall including antecedent rainfall was brought, the more GWL rising belated to stream flow peak observed. The greater intensity of rainfall leads quick rising of stream flow, but it was not effective for GWL rising. According to the stream water quality, rain water component increased when intense rain was brought, subsequently ground water component increased for the duration of rainfall event.

It is realized that water movement is having macroscopic interrelation in the space from upper slope to stream channel. Its complexity would be derived from large soil moisture change by rainfall amount and vegetation activity in the thick weathered bed rock layer in the hillslope as water flow pathways. And it is considered that since the permeability of subsoil is low, stream flow respond by spiky peak against intense rainfall.

Keywords: permeability, soil water pF, ground water, Seto inland sea climate, Tatsunokuchi-yama

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-14 Room:511 Time:April 29 14:30-14:45

Variability of the chemistry of streamwater and bedrock groundwater at a weathered granite mountain, Japan

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Introduction

Previous studies have noted that bedrock groundwater is one of the important factors influencing stream discharge and streamwater chemistry. However, most previous studies were conducted not by direct measurement of bedrock groundwater but by using indirect methods, such as solute tracers and water budget analysis. Thus, the movement and chemical characteristics of bedrock groundwater remain incompletely understood based on direct measurements of bedrock groundwater. To better understand the dynamics of bedrock groundwater, we investigated groundwater table movement and water chemistry of bedrock groundwater using dense borehole wells at a small catchment in a mountainous area.

Methods

The study was performed at the Fudoji Experimental Watershed located in the Tanakami Mountains in the southeastern part of Shiga Prefecture, central Japan. Precipitation was monitored using tipping-bucket rain gauges, and discharges were observed at eight small catchments, ranging in area from 0.1 to 2.3 ha. Seven small catchments (subcatchments) were included in the largest catchment (2.3 ha), within which we installed 61 borehole wells. The water table of bedrock groundwater was then observed at these borehole wells. Rainwater, streamwater from the small catchments and bedrock groundwater from the borehole wells were sampled, and the concentrations of major ions and SiO_2 as well as the water stable-isotope ratios $d^{18}O$ and dD were measured in the Graduate School of Agriculture, Kyoto University.

Results and Discussion

The results of the analysis of the groundwater table of bedrock groundwater indicated that there were several fluctuating characteristics and that these characteristics of groundwater table change had locality. At the area having higher altitude in the ridge, the bedrock groundwater-table changes were gradual but the ranges of fluctuation were larger than those of the lower wells. At the lower-altitude points, although the bedrock groundwater table responded rapidly, the ranges of fluctuation of the groundwater table were small relative to those of the higher points. Some areas responded only to peak rainfall over a short time. Based on the groundwater flux analysis, bedrock groundwater moves across the surface divide. A catchment inflowed by a neighboring catchment showed a high specific discharge. Additionally, the direction of groundwater movement changed during rainfall events, and such changes were similar for rainfall events of the same size.

The relationships among chemistries derived from the chemical weathering of bedrock indicated that although the weathering processes were similar in the catchment, the weathering level varied among the borehole wells. The chemistries of bedrock groundwater at each catchment and of streamwater at each catchment showed large variability. The concentrations of Na^{+} and Ca^{2+} had local characteristics, but no clear characteristics were observed among other bedrock groundwater components. The chemical concentrations of bedrock groundwater were higher than those of streamwater. We chose borehole wells that may contribute directly to the stream based on the direction of groundwater movement by an analysis of groundwater flux and distance from the borehole wells, and noticed that there were also large gaps between the chemistries of streamwater and bedrock groundwater. These results indicate that complex processes of chemical dynamics occur in the weathered bedrock and from the weathered bedrock to the stream.

Keywords: weatherd bedrock, densely bore holes, chemical variability, bedrock groundwater

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-15 Room:511 Time:April 29 14:45-15:00

Mean residence time and hydrochemistry of bedrock groundwater aquifer in a Granite mountain

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Bedrock groundwater dynamics is one of the latest frontier of hillslope- and catchment hydrology. Although it relate to water resources as well as sediment disasters, only few studies have accessed directly with boreholes to bedrock groundwater aquifer because of, for example, high costs. In this context, tracer approach is effective to clarify the bedrock groundwater dynamics and water pathways within deeper layers of mountains. We have been keeping on monitoring of the chemical and isotopic compositions of bedrock groundwater and streamwater in Kiryu Experimental Watershed (KEW), Japan since 2003. We set up a nested observation system; a hillslope plot (AP, 0.024ha), a subcatchment (A catchment, 0.086ha), and whole of KEW (K catchment, 5.99ha), and monthly sampled the streamwater of K and A, the outflow from AP, which occurs as saturated throughflow on the soil-bedrock interface during rainstorms, and groundwater in the soil sediment. Moreover, we excavated the bedrock and installed some tension lysimeters at 0.1, 0.2, 0.4, and 0.8 m deep and boreholes at 12, 15, and 20 m deep below bedrock surface, and sampled them. The stream flow from K and A were perennial. The SiO2 and Na+ concentrations increased along with the infiltration process. On the other hand, the NO3- concentration was highest at the surface soil water, and removed along with the infiltration process. The concentrations of both solutes in the streamwater from A and K were intermediate between the concentrations in the surface soil water and bedrock groundwater. These facts mean that the streamwater is the mixture of shallow soil water and deep groundwater. The mean residence times calculated by delta 18O variations were about 4 or 5 months in the groundwater in the soil sediment and in the shallow ($<$0.8m) bedrock groundwaters, about 50 months in 12- and 15 m deep, and about 120 months in 20 m deep, respectively. That in the streamwater in A was estimated as about 30 months. Thus, the MRT in 20 m deep groundwater is quite different from the others. The relationship between the MRTs and the solute concentrations were different in each solute; for SiO2, the concentration increased as a saturation curve, and it increased as linearly for Na+. It exponentially decreased for NO3-. The streamwater chemistries in A were on these curves. Therefore, the solute concentrations can be described as functions of MRTs. These results suggest that a part of the bedrock groundwater can contribute to the stream from the shallower layers. The fact that the stream flow is perennial in this subcatchment A means that plentiful supply of groundwater from the relatively shallow bedrock layers exist. On the other hand, other part of the bedrock groundwater infiltrate deeply and less contribute to the stream in this small subcatchment; we have to consider whether the deeply infiltrated groundwater may contribute at the outlet of K catchment. Moreover, as the deeper bedrock groundwater have especially long residence time, we have to keep long-term monitoring to understand the dynamics and roles of this groundwater to hydrological and hydrochemical processes, because it will be a key of spatio-temporal scaling of these processes, as well as the water yield function of forests.

Keywords: Bedrock groundwater, Tracer, Mean residence time, granite catchment

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-16 Room:511 Time:April 29 15:00-15:24

Hydrological change at the catchment scale: The need to address both velocity and celerity

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Water quantity and quality response to climate- and land use change are difficult to predict. Much of this relates to the complexities of water flow paths and our inability to relate measureable catchment properties to measureable hydrologic response metrics. To date, most work has focused on rainfall-runoff response — that is, the celerity component of change. Here I present new work from 15 headwater catchments, (0.1 to 100 km^2) in the Oregon Cascades and Oregon Coast Range in the USA, aimed at quantifying both celerity and flow velocities (i.e. particle transport through the system). I illustrate this velocity component through stable isotope analysis of runoff components and the mean transit time and residence time analysis of surface water and groundwater, respectively. Results show that despite very similar rainfall-runoff determined celerities, these systems have distinctly different tracer velocities, where transit time of headwater streamflow is 1-3 years in the catchments draining the Western Cascade mountains and 3-11 years in the streams draining the Coast Range mountains. More importantly, the scaling of surface water mean residence time in the Cascades is linked to internal topographic structure of individual sub-catchments whereas Coast Range sites show no evidence of this; and streamwater residence times scale linearly with catchment area. I discuss the implications of these celerity-velocity differences for catchment-scale climate- and landuse change effects in the USA Pacific Northwest and for more general efforts like the IAHS Panta Rhei initiative.

Keywords: Hillslope, Rainfall-runoff, Stable isotope, Climate change, Landuse, Groundwater

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-17 Room:511 Time:April 29 15:24-15:39

Toward understanding causal interrelationships between stormflow and erosion processes in a steep zero-order basin

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Stormflow generation and soil-erosion process on a steep zero-order basin have close interdependencies though their timescales are far different. This study pays attention to a difference in interdependences of stormflow and erosion processes between a near-ridge nose and a concave hollow within a zero-order basin.

Due to strong erosional forces in an active tectonic region, soil moves down by the gravity force throughout the basin. In a convex nose near the ridgeline, soil moves gradually by diffusive processes, and the curvature of bedrock surface controls the soil depth (Heimsath, Geomorphology 27, 1999). On the other hand, in a concave hollow, soil layer suddenly collapses as a landslide and a long-term soil-layer evolution at a timescale of 10^2 - 10^4 years continues unless a landslide occurs (Tsukamoto et al., IAHS Publ. 137, 1982). In the nose, the soil layer may move downslope with vegetation on it without disturbances. The recovery of soil layer after a landslide occurrence in a hollow is supported by the soil supply from the nose by the diffusive movement. The diffusive process near nose and the recovery process near hollow are closely related each other.

In order to ensure these processes, saturation excess overland flow should be suppressed both in a nose and a hollow because it is a trigger of landslide initiation. We can assume that the drainage capacity through pipe-like preferential paths (McDonnell, Water Resour. Res. 26, 1990) plays an important role in the suppression.

One hydrological analysis for addressing the assumption is attempted from estimating the expansion of stormflow contribution areas from rainfall-runoff responses in a small catchment. In the wet conditions when most of all the rainfall contributes to the stormflow, a hydraulic continuum under a quasi steady state is created and a single tank model can well simulate rainfall-runoff responses (Tani: Hydrol. Earth Syst. Sci., 17, 2013). This simple characteristic was utilized to estimate the contribution-area expansion with rainfall increases inversely from the runoff responses.

Results show that except a short dry period at the beginning of a storm, the waveform transmission of rainfall to runoff was simulated well by the same model parameters of our tank model though the contribution area only increased. This result suggests the waveform transmission was originated mainly from the vertical water movement instead of the downslope subsurface flow or the overland flow. As suggested from a conceptualized model (Montgomery and Dietrich, Water Resour. Res. 38, 2002), rainwater may be confined within the soil layer due to a large drainage capacity of the pipe-like preferential paths. This strongly encourages the soil-layer evolution process against strong erosional forces not only in a nose but also in a hollow.

Runoff and erosional processes are certainly linked, and collecting field evidences is expected. In addition, however, reanalyzing the existing hydrological data may also provide a new interesting finding from the linking point of view.

Keywords: erosion, hillslope hydrology, soil-layer evolution, stormflow, variable contribution area, zero-order basin

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AHW07-18 Room:511 Time:April 29 15:39-16:00

Interaction between bedrock groundwater and surface-hydrological and geomorphological processes in mountainous headwater

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Enormous landslides with deep slipping surfaces, which are likely to be triggered by the huge storms expected with climate change, can be one of the major geomorphological processes in the temperate climate zone. This study focuses on groundwater in mountainous headwater regions as a potential cause of such landslides. Recent hydrological studies have revealed that large amounts of rainwater infiltrate into bedrock, suggesting the possibility that steep mountains could contain greater amounts of groundwater than previously thought. The decline in groundwater levels due to water harvesting should be effective for the prevention of landslides. At the same time, the exploitation of groundwater resources in mountainous regions may contribute to establish a sustainable supply of safe water; that is, groundwater in mountainous regions is of better quality and less vulnerable to pollution because human activities are limited in the source areas. Thus, the exploitation of groundwater resources in mountainous regions should produce a win?win situation that achieves both disaster mitigation and a sustainable water supply. This study investigates hydrological methods for observing and analyzing quantitative and qualitative signals in mountain streams that can be used for detecting groundwater dynamics in steep mountains. Such hydrological methods are effectively combined with geophysical surveys.

In the steep Rokko mountain range of central Japan, which consists of granite and has been greatly affected by diastrophic activities, discharge hydrographs are characterized by significant amount of baseflow. In order to elucidate contributions of bedrock groundwater to the hydrograph formation, long-term hydrological observations were conducted by using bedrock wells with depths of 7-78 m drilled at 31 points within a 2.1-ha headwater catchment in the Rokko mountain range. Results indicated a fairly regionalized distribution of bedrock groundwater; that is, upper, middle, and lower aquifers were present. We observed large differences in water level among the aquifers, instead of a gradual and continuous decline in water level. Discharge hydrograph from the catchment was notably characterized by gentle and significant variations in base flow and exhibited triple-peak responses. Flashy first peaks occurred just after rainfall peaks, while the second peaks lagged behind the rainfall peaks by a few days. Broad peaks in the base-flow discharge corresponded to the third peaks, which occurred once or twice in each hydrological year. The triple-peak discharge responses were explained by three types of water pathways: the first peak was caused by the peak in soil mantle groundwater around the outlet of the watershed; the second peak was caused by the first peak in the lower aquifer, which was fed by vertical rainwater infiltration; and the third peak was caused by the second peak in the lower aquifer, resulting from an increased lateral water supply from the middle aquifer. The middle aquifer was recharged by vertical infiltration through weathered bedrock and lateral flow from the upper aquifer. Because of its broad regional expanse and large capacity, the middle aquifer had a dominant effect on formation of the discharge hydrograph. Thus, this study has demonstrated how discharge from the steep headwater catchment is dominated by complex flow systems within bedrock groundwater; the spatial expanse of bedrock aquifers and interaction among aquifers are key factors.

Keywords: enormous landslide, geomorphological processes, headwater catchment, bedrock groundwater, water resources