6.5 GLOBAL WATER BALANCE ESTIMATED BY LAND SURFACE MODELS PARTICIPATED IN THE GSWP2

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1. INTRODUCTION

The one of the objectives of the second phase of the Global Soil Wetness (GSWP-2) was targeted to produce the best estimate of global water cycles for years from 1986 through 1995. Offline simulation of the energy and water balance at land surface was calculated by more than 10 land surface models (LSMs), and sent to the Inter-comparison Center (ICC) of the GSWP2, founded at the Institute of Industrial Science, University of Tokyo. It is expected that simple ensemble mean or some statistical processing of the submitted outputs from the LSMs will provide the state-of-the-art information on the global energy and water balance.

2. ANNUAL MEAN WATER BALANCE AVERAGED OVER THE GLOBE

Firstly, the water balance components of 10 year averaged annual mean value were compared with previous estimates. Global mean, continental mean, and zonal mean values of precipitation, evapotranspiration, and runoff were compared with historical publications, other datasets, and previous estimates. Global annual precipitation increased 17% compared to the forcing data used in the first phase of GSWP (GSWP-1). It is significant in Europe, where the increase is approximately 60%. Corresponding to this, annual runoff estimated by a simple Bucket model in Europe increased from 1,680 km^3/y of GSWP-1 to 5,911 km^3/y by GSWP-2. This value is extremely large relative to the estimates of 2,900 km^3/y by WMO (1997) and 2,770 km^3/y by the University of New Hampshire (1998). The forcing data of precipitation for the GSWP-2 was corrected considering the under catch by wind considering the rain gauge type in each country. It is suspected that this correction algorithm might have some deficiency since national borders can be seen in the precipitation data particularly in Northern Europe. It is possible that the original precipitation data in the corresponding European region had already

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corrected for wind under catch, and the GSWP-2 forcing data in the region was over-corrected. More examination and sensitivity study should be needed on this issue.

3. GLOBAL TERRESTRIAL WATER BUDGETS AND THEIR INTER-ANNUAL AND INTER-MODEL VARIATIONS

The similarity of the global water balance among the outputs by various LSMs are examined for annual mean field of runoff, annual amplitude of soil moisture in the root zone, the maximum soil depth, ratio of interception loss in the total evapotranspiration, and the surface runoff ratio. The misaligned outputs by a few LSMs were excluded from further data analysis, and weighted ensemble mean of outputs from remaining LSMs are estimated considering the similarity of the LSMs. Linear weighting confirms the conservation of mass in the water balance at each grid point. However, it was found, for example, that the annual runoff is reduced due to the skewed probability distribution of runoff among LSMs. Qualitatively, the difference between the average of all the LSM runoff at a grid point and the highest value is larger than the difference between the average and the lowest value, and the excluding extreme values at both ends decreases. Even though it is not clear which is the cause and which is the result, evapotranspiration becomes larger than simple mean of the LSMs.

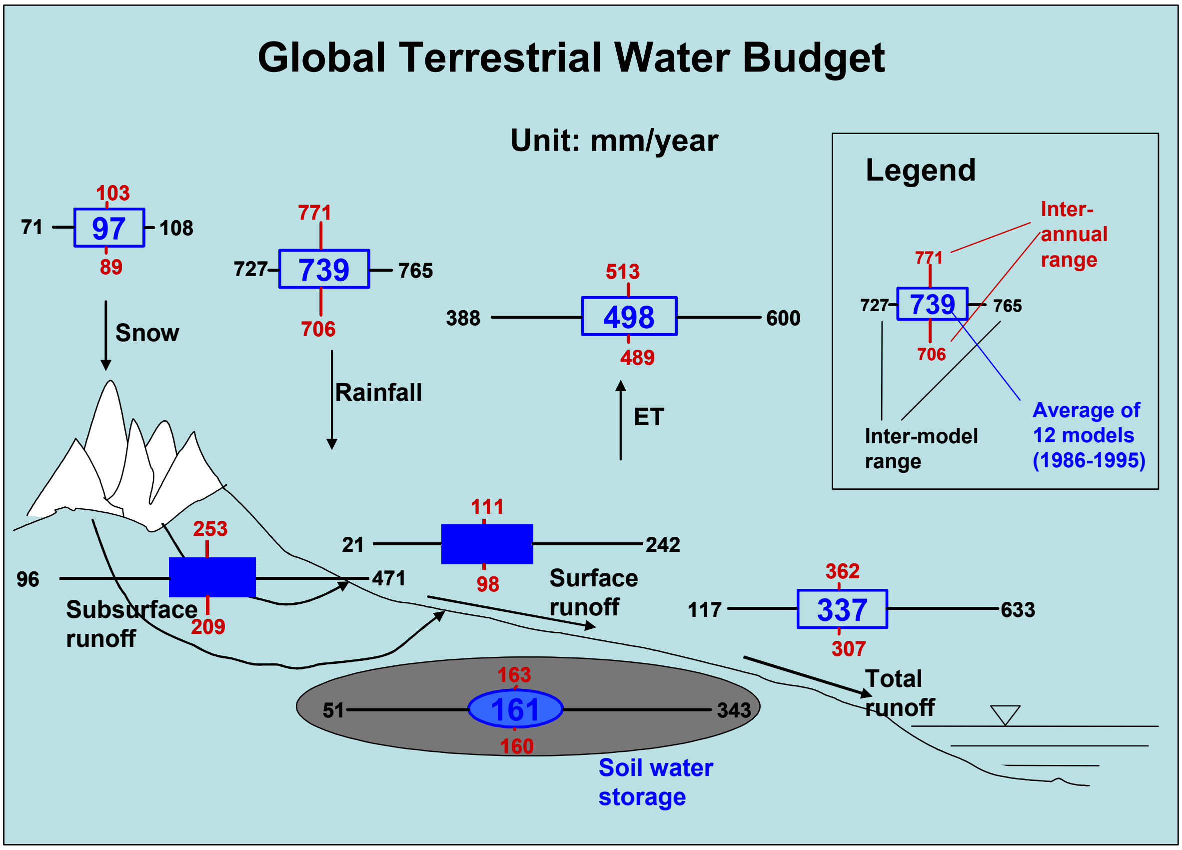

Figure 1: Simple Ensemble Mean of Annual Global Water Balance (mm/y) Averaged for 1986-1995. The inter-annual and inter-model variations are presented.

This "Olympic Style" averaging method was introduced not to exclude whole data of any LSM from the analysis, but more sophisticated algorithm is certainly required. Therefore, simple ensemble mean of all the models are used for calculating global annual water balance over land (Figure 1). Even though the same precipitation forcing data were given for all the LSMs, the differentiation of snow and rain were done by each LSM, and there are discrepancies of the rainfall and snow fall in the final estimates. On average, approximately 12% of annual precipitation (836mm/y) precipitates as snow (97mm/y), and rest precipitates as rainfall over land. Approximately 14% (105mm/y) of rainfall (739mm/y) directly runs off with fast response, and the rest (232mm/y) gradually discharge to the sea. Transiently, the water is stored as soil moisture, and the annual mean value of the stored water in the soil layer of the LSMs is 161 mm. In total, approximately 40% of precipitation becomes runoff (337mm/y) on average, and the rest is the evapotranspiration component (498mm/y). Inter-model variation is dominant particularly runoff and its components. Even though the separation of surface and sub-surface runoff is more philosophical and difficult to observe, regional validation whether these surface and sub-surface runoff separation is realistic should be carried out using daily river discharge data.

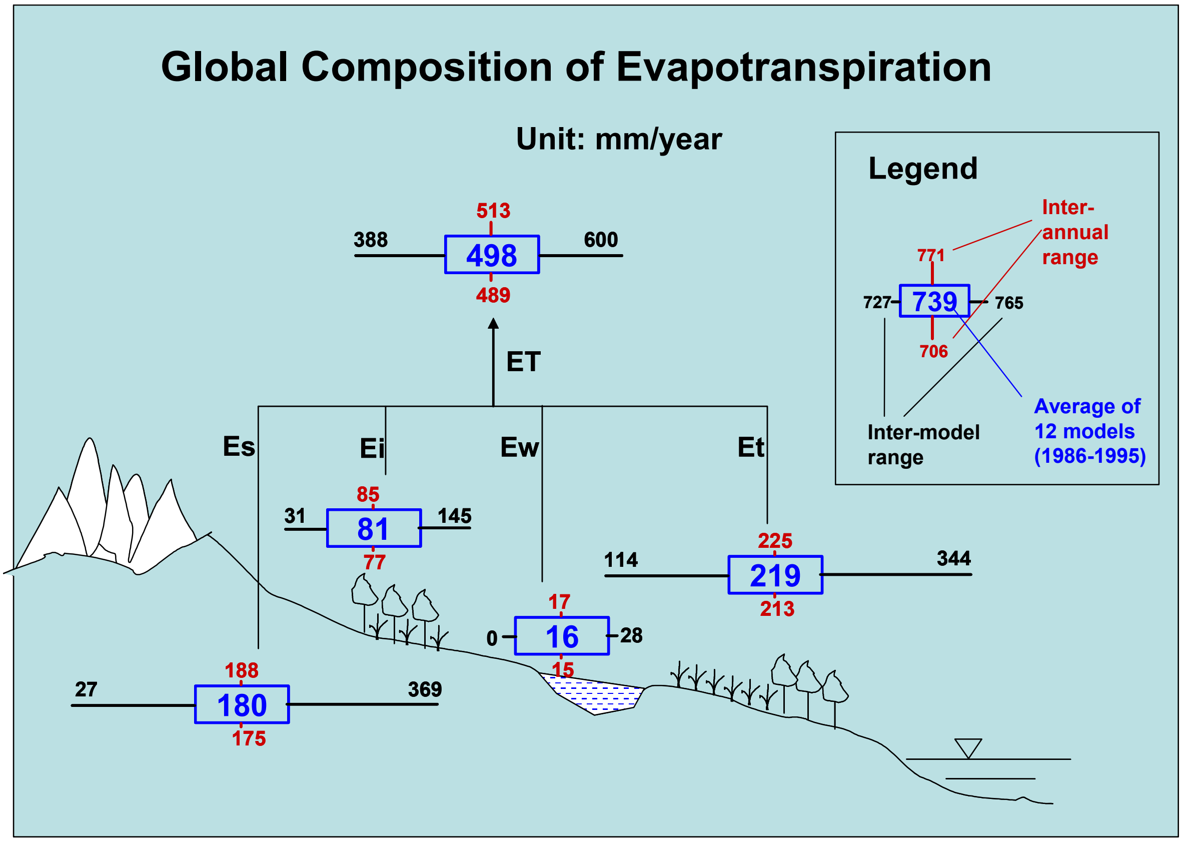

Figure 2: Simple Ensemble Mean of the Components of Annual Evapotranspiration (mm/y) Averaged for 1986-1995. The inter-annual and inter-model variations are presented.

Figure 2 illustrates the components of the evapotranspiration in the annual water balance. On average over land, 16% (81mm/y) of total evapotranspiration (498mm/y) is from intercepted water. Evaporation from water surface is comparatively low as 3% (16mm/y), but it is partially because some LSM does not consider this component, but the maximum estimates by a LSM is still small (28mm/y). Major components of the evapotranspiration are transpiration from vegetation leaves through stomata (44%, 219mm/y) and bare soil evaporation (36%, 180mm/y). The variations among the separation of evapotranspiration into these components among LSMs are very large, and should be presenting the large uncertainties in our current understanding of the processes. Nevertheless, the inter-annual variation of the total evapotranspiration is relatively small compared to that of precipitation and runoff.

Figure 3 illustrates the snow related components averaged over snow possible area of 60.8 million km^2. For snow possible region, annual snow fall is approximately 300 mm/y, and annual mean snow storage is 55 mm on average.

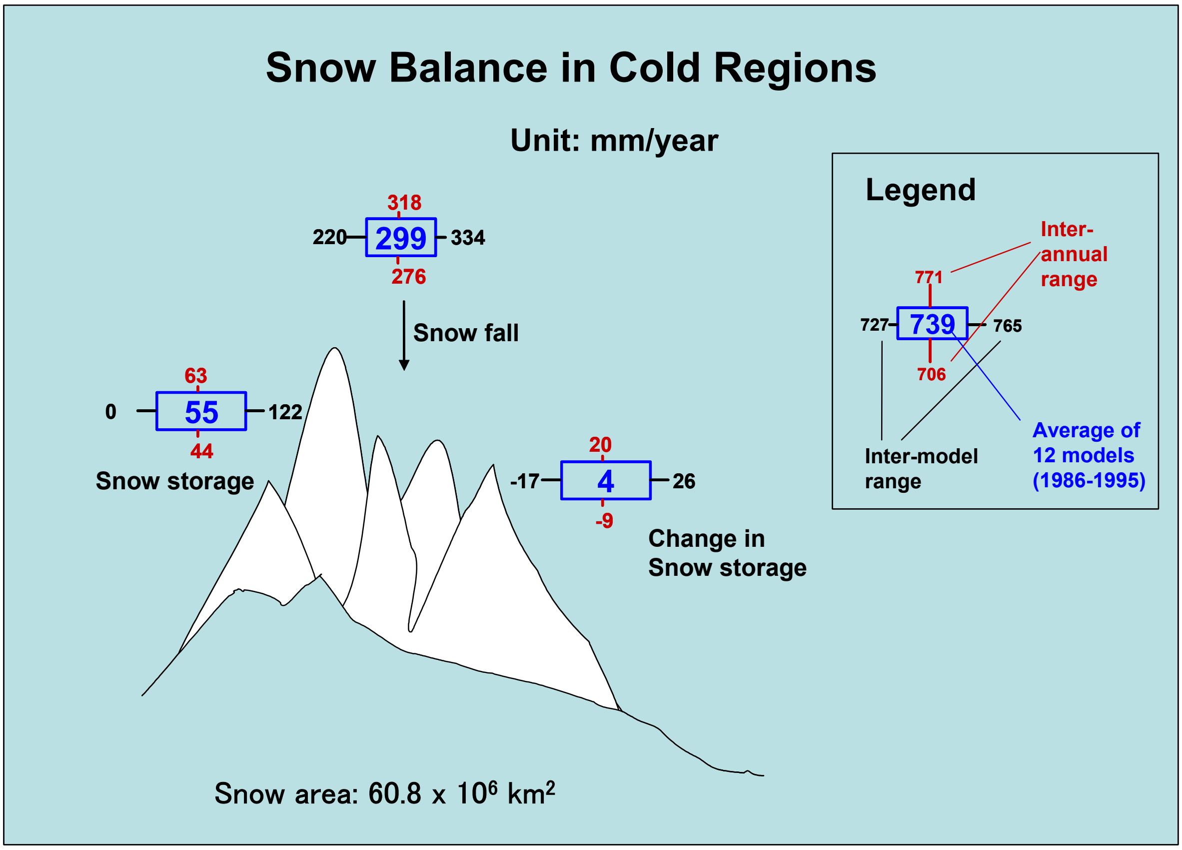

Figure 3: Annual Snow Processes (mm/y) averaged for 1986-1995 mean over snow possible area. The inter-annual and inter-model variations are presented.

Table 1: (A) Renewable water supply (km^3/y), (B) Aggregated water use (km^3/y), consists of (B1) Industrial (km^3/y), (B2) Municipal/domestic (km^3/y), (B3) Agricultural (km^3/y), (C) Mean ratio of use to supply, namely (B) divided by (A), (D) Falkenmark's "crowding index of people in terms of water" namely population per 10^{-3} km^3/y water supply, and (E) number of people (millions) the ratio of use to supply (C) is more than 0.40.

VARIABLE	**ASIA**	**FSU**	**Latin America**	**North Africa**	**OECD**	**Sub-saharan**	**Global**
(A) (km^3/y)	7846	5902	11160	367	12058	4815	42294
(B) (km^3/y)	1516	380	243	271	934	79	3423
(B1)	120	118	22	13	432	3	708
(B2)	99	34	30	20	131	8	321
(B3)	1297	228	192	238	372	68	2394
(C)	0.19	0.064	0.022	0.739	0.077	0.016	0.081
(D) ($c/10^6m^3/y$)	384	48	42	929	115	115	133
(E) (10^6 capita)	712	56	84	91	16	16	1123

4. APPLICATION OF GLOBAL WATER BALANCE ESTIMATES FOR WATER RESOURCES ASSESSMENTS

As an application of the global estimates of annual water balance, the obtained natural water cycle is contrasted with socio economic information such as population and water withdrawals, and analyzed in order to provide basic information for world water resources assessments. Table 1 summarizes the assessment results for various regional aggregations. Values related to anthropogenic activities on water and social statistics are derived from Oki et al.(2001), and regional aggregations follows Vörösmarty et al. (2000). Such an analysis is important not only for current assessment and help promote awareness on water issues, but also for future assessment of world water resources considering both global climate change and societal changes such as population and economic growth that will affect on water usage in the future. Practically, current GCM simulation results are not easy to be used in the world water resources assessment quantitatively because its biases in water cycles. Therefore reliable current estimates are often used as "baseline" of the reliable water cycle on the earth, and changes in the water cycles simulated in the GCMs will be applied to the "baseline" field of water cycles. Consequently, how to estimate reliable current water cycle is of interest, and the frame work of global offline simulation like GSWP should be one of the promising methodologies.

5. Summary

Global offline simulations by more than 10 land surface models were done under the Global Soil

Wetness Project Phase2, and the ensemble mean dataset is analyzed to present new insights in global water cycle. Global mean water balance explicitly including the interception-loss and transpiration, surface and sub-surface runoff, snow ratio in precipitation and snow accumulation, etc., is presented with their inter-annual variations in 10 years and uncertainties inferred from the variance among estimates of various LSMs. Such a process based estimates did not existed in the past. Even though they are derived from numerical models, some of them are well validated, and it is expected that the model bias is somewhat eliminated by the averaging multiple model estimates.

The current results are preliminary, and more detailed analysis and validation should be done. Budyko's diagram, which adopts net-radiation over precipitation and evapotranspiration over precipitation in annual basis as for major variables to explain water and energy balance, will be used in accordance with vegetation cover to classify the global lands into several climatic types. Representative water balance in these land use types is also presented. The global water balance figures shown here will be shown for particular land surface types and climatic zones. Water balance will be validated using river discharge and other observable quantities such as total water storage change derived from atmospheric water balance.

Acknowledgements:

Parts of this study were supported by the Core Research for Evolutional Science and Technology (CREST), the Japan Science and Technology Corporation (JST), Special Coordination Funds for Promoting Science and Technology, rant-in-Aid for Scientific Research (B) from JSPS, and the Research Institute for Humanity and Nature (RIHN).

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