References

Cowan, I. (1986), Economics of carbon fixation in higher plants, in *On the* Eco*nomy of Plant Form and Function*, edited by T. J. Givnish, Cambridge Univ. Press, Cambridge, U.K., pp. 133–170.

Evans, S. E., and M. D. Wallenstein (2013), Climate change alters ecological strategies of soil bacteria, *Ecol. Lett.*, *17*, 155–164.

Hunt, A. G., and R. P. Ewing (2003), On the vanishing of solute diffusion in porous media at a threshold moisture content, *Soil Sci. Soc. Am. J.*, *67*, 1701–1702.

Jarvis, P. G., and K. G. McNaughton (1986), Stomatal control of transpiration - Scaling up from leaf to region, *Adv. Ecol. Res.*, *15*, 1–49.

Lennon, J. T., Z. T. Aanderud, B. K. Lehmkuhl, and D. R. Schoolmaster (2012), Mapping the niche space of soil microorganisms using taxonomy and traits, *Ecology*, *93*, 1867–1879.

Manzoni, S., and G. Katul (2014), Invariant soil water potential at zero microbial respiration explained by hydrological discontinuity in dry soils, *Geophys. Res. Lett.*, *41*(20), 7151–7158.

Manzoni, S., G. Vico, S. Palmroth, A. Porporato, and G. Katul (2013), Optimization of stomatal conductance for maximum carbon gain under dynamic soil moisture, *Adv. Water Resour.*, *62*, 90–105.

Manzoni, S., G. Katul, and A. Porporato (2014a), A dynamical system perspective on plant hydraulic failure, W*ater Resour. Res.*, *50*(6), 5170–5183.

Manzoni, S., S. M. Schaeffer, G. Katul, A. Porporato, and J. P. Schimel (2014b), A theoretical analysis of microbial eco-physiological and diffusion limitations to carbon cycling in drying soils, *Soil Biol. Biochem.*, *73*, 69–83.

Manzoni, S., G. Vico, G. Katul, S. Palmroth, and A. Porporato (2014c), Optimal plant water-use strategies under stochastic rainfall, *Water Resour. Res.*, *50*(7), 5379–5394.

Roberts, J. (1983), Forest transpiration - A conservative hydrological process, J*. Hydrol.*, *66*, 133–141.

Schimel, J. P., T. C. Balser, and M. Wallenstein (2007), Microbial stress-response physiology and its implications for ecosystem function, *Ecology*, *88*, 1386–1394.

Todd-Brown, K. E. O., F. M. Hopkins, S. N. Kivlin, J. M. Talbot, and S. D. Allison (2012), A framework for representing microbial decomposition in coupled climate models, *Biogeochemistry*, *109*, 19–33.

A Fellow Speaks: Opportunities and Fortunes in Global Hydrology

Taikan Oki
The University of Tokyo

Even though I have been a member of AGU for more than two decades, I paid no attention to the honor of becoming an AGU Fellow because I thought it was none of my business. After I was notified that I was elected a Fellow, I was both humbled and honored to realize the prestige this recognition carries and to know that I am the first Japanese AGU Fellow in the Hydrology Section. I would like to extend my sincere gratitude to the colleagues who spent special efforts to nominate me.

In 1987, when I entered the Graduate School at The University of Tokyo, I came across the article of *Bras et al.* [1987], which termed Hydrology in the late 20th century as "The forgotten Earth science." At that time, hydrological sciences supported human well-being by reducing risks associated with extremes (scarcities and excess of water) through management. However, the work was largely isolated from other tightly coupled Earth sciences, such as meteorology, oceanography, and geology. As *Bras et al.* [1987] pointed out, there was an impending need to build a more coherent understanding of the global water cycle in its full complexity.

As a master's student, I chose to work on research related to orographic rainfall, because I thought rainfall is the major driver of floods and droughts and fundamental to the advancement of hydrology. I tried to develop a simple atmospheric model, which could relate upwind areas with orographic rainfall distribution estimated from rain gauge network data. I was very lucky that I had the opportunity to present the results of my master's thesis in the Pacific International Seminar on Water Resources Systems in Tomamu, Hokkaido, Japan, in summer in 1989. Prof. Soroosh Sorooshian coorganized the meeting, and strongly encouraged me to submit the results I presented to *WRR*, of which he was the editor at that time. I knew nothing about submitting a journal paper, but Soroosh helped me a lot, and finally I could publish my result as an article in *WRR* [*Oki et al.*, 1991].

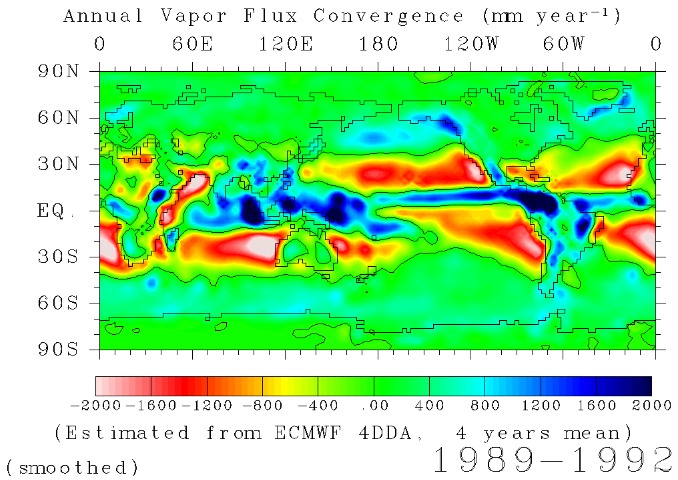

Figure 1. Vertically integrated annual water vapor convergence (mm year^{-1}) mean from 1989 to 1992, updated from *Oki et al.* [1995]. Positive value corresponds to annual excess of precipitation over evapotranspiration. Slight negative values over land are mostly due to the limitation of the accuracy of the methodology and data, but partially regarded as the impacts of irrigation, with which evapotranspiration from cropland can be larger than local precipitation.

Being a member of the research group of Prof. Katumi Musiake at IIS/UT, whose research was dedicated to urban hydrology, I felt at that time isolated in pursuing my interests in atmospheric modeling. However, I had an opportunity to study physical climatology from Dr. Kooiti Mauda using a text by Prof. Oort (published later as a book [*Peixöto and Oort*, 1992]). I was extremely fascinated with the concept of atmospheric water balance [e.g., *Peixöto*, 1970; *Peixöto and Oort*, 1983] and eager to update the estimates.

Fortunately, the 1980s were the dawn of four-dimensional data assimilation (4DDA) of global atmosphere. I was really excited to calculate the vertically integrated water vapor convergence (Figure 1) utilizing operational analyses by ECMWF and JMA, even though I had to handle several dozen magnetic tapes at the computer center. Another fortune was that Prof. Murugesu Sivapalan participated in IAHS in Yokohama, Japan, in 1993; he also gave a seminar at IIS/UT, and he found my research on atmospheric water balance interesting. He invited me to a workshop in Robertson in 1994, and I could publish the results [*Oki et al.,* 1995] in the special issue of *Hydrological Processes*, for which Siva was the guest editor. I'll never forget how enthusiastically Siva helped me revise and improve the paper. I believe *Oki et al.* [1995] was one of the first papers to demonstrate the potential capability of 4DDA data to estimate terrestrial water balances through the combined use of global precipitation observations and large basin river discharge based on the atmospheric water balance (AWB) method. *Oki et al.* [1995] opened the door to global water balance studies by AWB in the modern era. Our approach, using 4DDA data, is now commonly applied to estimate global water balances, even though reanalysis data, the postprocessed version of 4DDA data, is more popular than operational analysis data.

Afterward, I had an opportunity to spend 2 years at NASA/GSFC as a visiting scientist, and had some free time to work on time-consuming research such as manual correction of a global river channel network, named "TRIP" [*Oki and Sud*, 1998]. I was also fortunate to have an opportunity to participate to the 2nd phase of the global soil wetness project (GSWP2), and validated the accuracy of the global water balance estimated by 11 land surface models (LSMs), that are a part of GCMs and provide lower boundary conditions to the atmosphere, with a simple river routing scheme [*Oki et al.*, 1999]. TRIP and the river routing scheme were widely adopted by several GCMs in the world, for example, six out of 23 future projections employed in the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) utilized TRIP. Even now, TRIP is coupled within a latest Earth System Model and a GCM. In summary, *Oki and Sud* [1998] filled a missing link in the water cycle of GCMs and expanded their utility into river flood events.

I'm quite happy to see that *Oki et al.* [1999] established a framework for evaluating global water cycles via off-line (uncoupled with atmosphere) simulation of LSMs combined with river routing schemes. At present, the framework is commonly used to assess LSM accuracy and improve them by thorough validation, and calibration to observed river discharge. The framework is also useful for translating climate change–driven changes to hydrological cycles (projected by GCMs) into socially relevant information, such as changes in the frequency of floods and droughts [e.g., *Nohara et al.*, 2006; *Hirabayashi et al.*, 2008]. The 2nd phase of the Global Soil Wetness Project (GSWP2) also utilized this framework [*Dirmeyer et al.*, 2006], and a comprehensive review of the global hydrologic cycle and world water resources based on the estimates from GSWP2 were published in Science [*Oki and Kanae*, 2006]. Establishing a scientific illustration of the global hydrological cycle (Figure 2) has been one of my

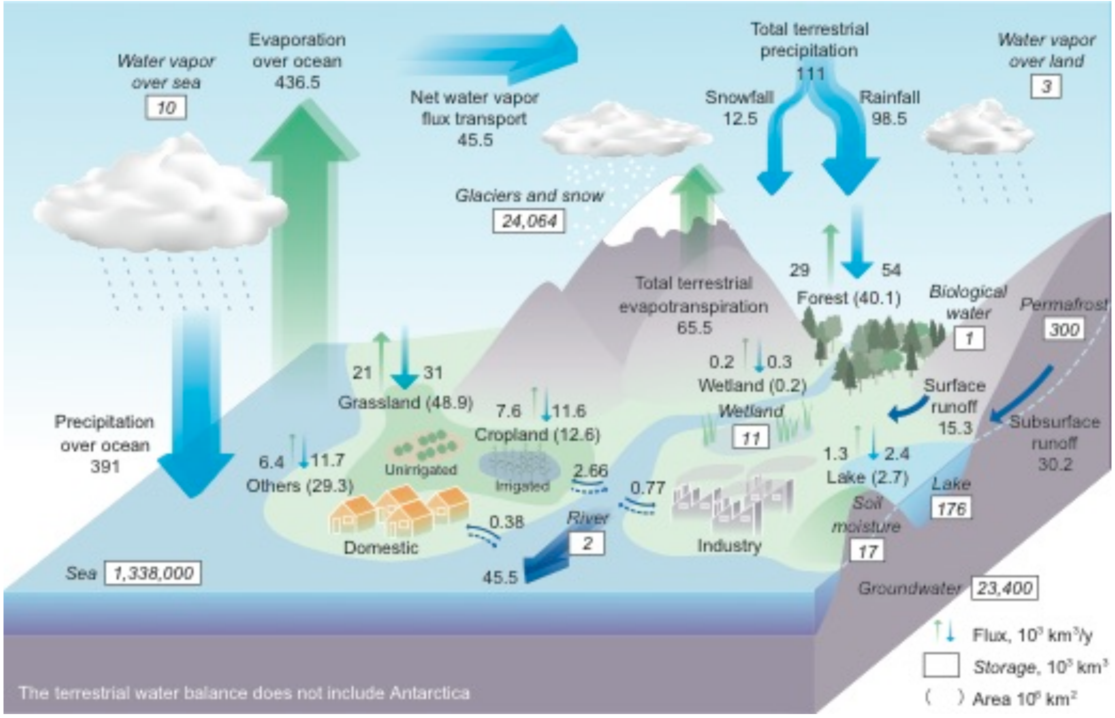

Figure 2. Global hydrological fluxes (1000 km^3 yr^{-1}) and storages (1000 km^3) with natural and anthropogenic cycles are synthesized from various sources. Big vertical arrows show total annual precipitation and evapotranspiration over land and ocean (1000 km^3 yr^{-1}), which include annual precipitation and evapotranspiration in major landscapes (1000 km^3 yr^{-1}) presented by small vertical arrows; parentheses indicate area (million km^2). The direct groundwater discharge, which is estimated to be about 10% of the total river discharge globally, is included in river discharge. The values of area sizes for cropland and others are corrected from original ones. From *Oki and Kanae* [2006].

dreams and goals, and I felt really accomplished with the publication.

However, real hydrological cycles are often influenced by anthropogenic activities, such as reservoir operations and water withdrawals for human needs, and differ substantially from natural hydrological cycles. Even though human withdrawals are indicated, Figure 2 critically lacks the artificial reservoirs. The first integrated water balance and water resources model considering major human interventions on a global scale was developed by *Hanasaki et al*. [2008], named as H08. H08 is coupled with submodels of reservoir operation, human water withdrawal, environmental flow, and crop growth, in addition to a natural water balance sub-model. Recently, the human intervention components were transplanted into an LSM, which was then applied to assess the impacts of changes in the terrestrial water storage on trends in the global mean sea level [*Pokhrel et al*., 2012].

The field of global hydrology today has certainly evolved and established itself nearly 3 decades after *Bras et al.* [1987] led the call for greater prominence. Current hydrology has a capability to monitor, understand, and predict global hydrological cycles of social-ecological systems, combining both human and natural systems. I am gratified to see that global hydrology has a prominent place among other Earth sciences now. I cannot list the names of all my colleagues who contributed to the development of the field, either as a student, as a postdoctoral fellow, or as a collaborator, but I appreciate very much their untiring dedication and significant contributions. I feel I have been just lucky in my research life, but I'm very proud to have witnessed the evolution of global hydrology as one of Earth system sciences.

References

Bras, R., P. S. Eagleson, E. K. Turner, and R. M. Parsons (1987), Hydrology, the forgotten Earth science, *Eos Trans*. AGU, *68*, 227.

Dirmeyer, P. A., X. Gao, M. Zhao, Z. Guo, T. Oki, and N. Hanasaki (2006), GSWP-2 - Multimodel analysis and implications for our perception of the land surface, *Bull. Am. Meteorol. Soc.*, *87*, 1381–1397.

Hanasaki, N., S. Kanae, T. Oki, K. Masuda, K. Motoya, N. Shirakawa, Y. Shen, and K. Tanaka (2008), An integrated model for the assessment of global water resources - Part 1: Model description and input meteorological forcing, *Hydrol. Earth Syst. Sci.*, *12*, 1007–1025.

Hirabayashi, Y., S. Kanae, S. Emori, T. Oki, and M. Kimoto (2008), Global projections of changing risks of floods and droughts in a changing climate, *Hydrol. Sci. J.*, *53*(4), 754–772.

Nohara, D., A. Kitoh, M. Hosaka, and T. Oki (2006), Impact of climate change on river discharge projected by multimodel ensemble, *J. Hydrometeorol.*, *7*(5), 1076–1089.

Oki, T., and S. Kanae (2006), Global hydrological cycles and world water resources, *Science*, *313*(5790), 1068–1072.

Oki, T., K. Musiake, and T. Koike (1991), Spatial rainfall distribution at a storm event in mountainous regions estimated by orography and wind direction, *Water Resour. Res.*, *27*, 359–369.

Oki, T., K. Musiake, H. Matsuyama, and K. Masuda (1995), Global atmospheric water balance and runoff from large river basins, *Hydrol. Proc.*, *9*, 655–678.

Oki, T., T. Nishimura, and P. Dirmeyer (1999), Assessment of annual runoff from land surface models using Total Runoff Integrating Pathways (TRIP), *J. Meteorol. Soc. Jpn.*, *77*, 235–255.

Oki, T., and Y. C. Sud (1998), Design of Total Runoff Integrating Pathways (TRIP) – A Global River Channel Network. *Earth Interact.*, *2*, 1–37.

Peixöto, J. P. (1970), Pole to pole divergence of water vapor, *Tellus*. *22*, 17–25.

Peixöto, J. P., and A. H. Oort (1983), The atmospheric branch of the hydrological cycle and climate, in *Variations in the Global Water Budget*, D. Reidel, Dordrecht, Netherlands, pp. 5–55.

Peixöto, P., and A. H. Oort (1992), *Physics of Climate*, Am. Inst. of Phys., Washington, D. C., 520 pp.

Pokhrel, Y. N., N. Hanasaki, P. J.-F. Yeh, T. J. Yamada, S. Kanae, and T. Oki (2012), Model estimates of sea-level change due to anthropogenic impacts on terrestrial water storage, *Nat. Geosci.*, *5*, 389–392.

A Fellow Speaks: A "TOGA COARE" Program for Continental Hydrology and Hydrometeorology

Ana P. Barros
Duke University

It's been roughly 25 years of unexpected privilege since my early days as a graduate student at the University of Washington, for which I am deeply grateful. Born in Angola in the headwaters of the Congo River Basin, one of my earliest memories is that of watching Neil Armstrong step on the moon in 1969, a grainy movie on an odd screen, a momentous event played again and again on an improbable shop window in downtown Luanda on the day of my birthday. Twenty-something years later, NASA's EOS (Earth Observing System) program was in many ways the "stepping on the moon" for Earth Sciences. For us in Hydrology and Hydrometeorology, it was a "watershed" moment, with the global planet as study domain and unprecedented observations available over unprecedented ranges of spatial and temporal scales.

EOS observations of the Dynamic Earth and the increasing data analysis, synthesis, and modeling capacity afforded by High-Performance Computing prompted new research directions and the development of interdisciplinary "many – a – hyphen" science (hydro-eco-geo-met-…..) and scientists. Global observations highlighted the importance of climate and orography in the organization of the Earth's water transfers and moisture transport from remote to local scales. New satellite observations brought the Water Cycle to the forefront of Earth Sciences.

From seasonal albedo changes of 30% at spatial scales of 10s to 100s of km^2, to the diurnal cycle of subdaily precipitation variability and soil water storage, water and energy budget closures are within reach at mesoscales. We find that, in the context of the coupled land-atmosphere system, it is the spatial range of water cycle teleconnections that determines the effective boundaries of the River Basin including an airshed that spans the regional moisture source regions, and a landshed that partitions rainfall, distributes groundwater between basins below mountain ranges, and delivers runoff to the canonical terrestrial outlet. Upstream and downstream are space-time varying concepts: earlier studies showed that cutting trees in the Amazon changed rainfall there and downwind in the Andes; recent studies show that cutting trees in the Andes changes the rainfall there and over the Amazon Basin. "Everybody lives downstream" as the world