in Massachusetts via Service Argos. The data are purposefully withheld from assimilation by the operational numerical weather prediction models so that model performance can be examined under the stratus deck. Following post-calibration of the buoy sensors, surface meteorological and air-sea flux data will be made available at the raw 1-min sampling rate of the IMET sensors. (For further information, contact Robert A. Weller at Woods Hole Oceanographic Institution; E-mail: rweller@whoi.edu).

At 20°S, 85°W, incoming solar radiation (Figure 3b) has a large annual cycle with a range of over 150 Wm^{-2}, nearly twice that found at 10°N, 95°W. Although the seasonal minimum was lower at 20°S, 85°W than at 10°N, 95°W, very dark days were not observed. The minimum 24-hour averaged Q_{sol} for the entire record was 65 Wm^{-2}.

During the austral autumn from March through June 2000, there was little variability in Q_{sol}. In contrast, cloud forcing was largest and most variable from October 2000 through January 2001, when top of the atmosphere solar radiation was high and the surface temperatures were cold. However, no rainfall was observed throughout the entire record. Incoming solar radiation at 20°S, 85°W was on average 18 Wm^{-2} higher than climatology (Figure 3b). In fact, except for October and November 2000, every month averaged higher than climatology by nearly 10–40 Wm^{-2}. Analyses of the upper ocean heat budget will show where this excess heat goes and its climatic implications.

Potential for Data

EPIC-enhanced monitoring provides an invaluable data set for climate studies of the eastern tropical Pacific. A wide range of variability is observed, providing context for the EPIC2001 intensive process study analyses and insight into the structure and temporal variability of the coupled ocean-atmosphere system. While some of the EPIC-enhanced monitoring data are available through the GTS and ingested into numerical weather prediction models and climate analyses, some are specifically withheld to provide a benchmark in model performance analyses. Further, the cloud statistics derived from the enhanced monitoring will help improve cloud model parameterizations and satellite retrieval methods. With moorings near both the Central American and South American coasts, it is expected that this data set will be valuable for a host of coupled land-ocean-atmosphere climate studies, such as the North American Monsoon Experiment (NAME) and the Variability of the American Monsoon Systems (VAMOS) program.

Acknowledgment

Enhanced monitoring for EPIC is supported by the NOAA Office of Global Programs and the NOAA Office of Oceanic and Atmospheric Research. The efforts of the officers and crew of the NOAA ships *Ka'imimoana* and *Ron Brown* and of the R/V *Revelle* are gratefully acknowledged.

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References

Chelton, D. B., et al., Observations of coupling between surface wind stress and sea surface temperature in the eastern tropical Pacific, *J. Climate, 14*, 1479–1498, 2001.

Johnson, G. C., M. J. McPhaden, G. D. Rowe, and K. E. McTaggart, Upper equatorial Pacific Ocean current and salinity variability during the 1996–1998 El Niño-La Niña cycle, *J. Geophys. Res., 105*, 1037–1053, 2000.

McPhaden, M. J., et al., The Tropical Ocean Global Atmosphere (TOGA) observing system: A decade of progress, *J. Geophys. Res., 103*, 14,169–14,240, 1998.

Mechoso, C. R., et al., The seasonal cycle over the tropical Pacific in coupled ocean-atmosphere general circulation models, *Mon. Weather Rev., 123*, 2825–2838, 1995.

Philander, S. G. H, D. Gu, D. Halpern, G. Lambert, N. C. Lau, T. Li, and R. C. Pacanowski, Why the ITCZ is mostly north of the equator, *J. Climate, 9*, 2958–2972, 1996.

Eco-hydrology's Past and Future in Focus

PAGES 205, 211–212

Lately, something called eco-hydrology has blazed forth as the next big thing in hydrologic science. A series of four papers on the topic appeared in *Advances in Water Research* last year [*Rodríguez-Iturbe et al.*, 2001]. Before that, in 1996, the International Hydrology Programme (IHP) initiated a new project under the title of eco-hydrology [*Zalewski et al.*, 1997]; and the AGU Spring Meeting, also in 1996, included a special session on eco-hydrology. Since then, a book of edited contributions has appeared [*Baird and Wilby*, 1999], and eco-hydrology was the topic of both a "vision for the future" in *Water Resources Research* [*Rodríguez-Iturbe*, 2000] and the Langbein Lecture at AGU's 2000 Spring Meeting. Another session on the topic will be featured at this year's AGU Spring Meeting, and a Chapman Conference on Eco-hydrology of Semiarid Landscapes will be held in September 2002.

What is this all about? Perusing the Web will confirm all of the above, but it will also raise some questions. Is eco-hydrology an entirely new field of study? What topics fall under this heading? We can answer these questions through a survey of recent usage of the term and a brief exploration of its historical roots. Eco-hydrology emerges as an engaging topic of study with multiple facets and deep roots in the history of hydrologic science.

A plausible definition would describe eco-hydrology as the sub-discipline shared by the ecological and hydrologic sciences that is concerned with the effects of hydrological processes on the distribution, structure, and function of ecosystems, and on the effects of biotic processes on elements of the water cycle.

This combines Rodríguez-Iturbe's [2000] definition of eco-hydrology as "the science which seeks to describe the hydrologic mechanisms that underlie ecologic pattern and processes" with his subsequent observation that "the connection between the role of plants in the water balance... is central to eco-hydrology" [*Rodríguez-Iturbe et al.*, 2001]. The offered definition also emphasizes the focus on ecosystems implied by Rodríguez-Iturbe's definition and the research that he describes. Baird and Wilby [1999] define eco-hydrology more narrowly as the study of plant-water relations and the hydrological processes related to plant growth. This is not as restrictive as it might seem. Plant communities influence the structure and function of many ecosystems, so the shift to an ecosystem focus is only a small step from the study of plant-water relations.

Eco-hydrology occupies the interface between the disciplines of ecology and hydrology. It falls clearly within the scope established for hydrologic science by the National Research Council [1991]. Hydrologic science encompasses "those biological processes that interact significantly with the water cycle... [including] those that are an active part of the water cycle, such as vegetal transpiration and many human activities, but [excluding] those that merely respond to water, such as the life cycle of aquatic organisms." Baird and Wilby [1999] review eco-hydrology's connection to ecology. Possibly the first published instance of the term "eco-hydrology" appeared in reference to bogs and mires [*Ingram*, 1987].

Why is this field called eco-hydrology rather than hydro-ecology? Is it that eco-hydrology is concerned more with the ecologically-related aspects of hydrologic science, and hydro-ecology with the hydrologic aspects of ecology? These two terms are sometimes used interchangeably. In both disciplines, eco-hydrology is used generally to refer to topics at their interface. Hydro-ecology is used in a more restrictive fashion, in reference either to the study of hydrologic and hydraulic characteristics of river and stream ecosystems, or sometimes, to the area known as aquatic ecology in the United States.

Scope of Eco-hydrology

Until recently, the term eco-hydrology had been applied to a few distinct areas of interdisciplinary study. No one has yet attempted a comprehensive description of the sub-discipline, which potentially encompasses the entire biosphere. The IHP identifies eco-hydrology with a new paradigm for sustainable management of water resources [*Zalewski et al.*, 1997]. Even so, it seems unlikely that a single unifying paradigm could cover the range of water-mediated interactions between biotic components of all ecosystems and their abiotic environments. It is more likely that eco-hydrology, the science, will embrace the formulation, testing, and application of conceptual models to describe these interactions within specific constraints of scale and geomorphic setting. Some of these are described below.

Readers of *Eos* may be familiar with Peter Eagleson's work on the eco-hydrology of water-limited ecosystems [*Eagleson*, 1978, 1982], which Rodríguez-Iturbe et al. [2001] have recently taken up and extended. Eagleson's approach represents dynamics of the terrestrial water balance at a point in terms of a spatially aggregated reservoir of soil moisture responding to a stochastic climate. Soil properties and the varying moisture content of the soil control the partitioning of rainfall between infiltration and runoff. Vegetation controls the loss of soil moisture by evapotranspiration, but evaporation and drainage by percolation also occur. Eagleson's model explicitly excluded the effects of lateral flows and interactions between soil moisture and a shallow water table. In spite of this underlying simplicity, Eagleson's investigations generated fundamental insights into the relationship among the dynamic and interdependent properties of soil, vegetation, and climate [*Hatton et al.*, 1997].

Research on wetlands has played a central role in the development of eco-hydrology in Europe and the United Kingdom [*Baird and Wilby*, 1999]. Hydrologic and ecological processes are intimately connected in wetlands, and their interaction has consequences not only for these ecosystems, but also for the functions they serve on larger scales. For example, water, ice, and permafrost constitute an important component of the organic soil formed in the extensive wetland regions found at high latitudes in the Northern Hemisphere. The interaction of hydrology and ecological processes involved in soil diagenesis influences stream flow, water quality, and geomorphology in the local drainage basin and the carbon cycle and climate on a global scale. Under a warming climate, these soils will thaw, dry, and oxidize, releasing stored carbon back into the atmosphere [*Gorham*, 1991].

Groundwater, surface water, and sediment transport interact to influence the structure and functioning of river and stream ecosystems. These ecosystems comprise distinctive channel and flood plain geomorphic components that are physically shaped by stream flow and sediment transport [*Petts and Bradley*, 1997]. Cycles of flood and recession modulate ecological interactions between the channel and the adjacent margin, as well as maintain their characteristic morphology. Groundwater exchange with the channel establishes base flow and influences temperature of the surface water. As well, groundwater mediates the exchanges of solutes laterally between channel and flood plain and vertical exchanges between water flowing in the channel and subsurface water in the hyporheichyporetic zone. At the scale of the entire basin, the equilibrium structure of river and stream ecosystems varies predictably from headwaters to mouth, as described by the river continuum concept of Vannote et al. [1980]. This hypothesis and its corollaries have proven useful in understanding the natural, undisturbed state of river ecosystems and the response of these systems to human activities that affect stream flow and sediment movement.

As a final example, consider the influence that river flow and its variation exert on estuarine and near shore ecosystems. Although the mechanisms involved are not yet fully known, empirical evidence links the rate of fresh water discharge to the productivity of estuarine and coastal fisheries. Certainly, the supply of nutrients carried in the discharge is part of the story [*National Research Council*, 2000]. But, just as flow and sediment discharge interact to determine the geomorphology of river and stream ecosystems, freshwater discharge and internal mixing processes interact to determine the salinity regime, stratification of the water column, and circulation characteristic of each estuary. Changes in hydrology derived from climate and human activities on the watershed have both long- and short-term effects on coastal ecosystems. Long-term effects include changes to the rate of sediment accretion that is necessary to maintain the stability of the coastline in low-lying areas [*Working Group on Sea Level Rise and Wetland Systems*, 1997]. Short-term effects include changes in fishery yields [*Loneragan and Bunn*, 1999] and overall structure and productivity of the food web [*Livingston et al.*, 1997].

Eco-Hydrology's Past

The recent flurry of interest in eco-hydrology signals its emergence as an area of focused study, but eco-hydrology is rooted firmly in the history of the hydrologic and ecological sciences. Eagleson's work on the equilibrium relationship among climate, vegetation, soil properties, and the water balance builds on concepts established in much earlier investigations of water flow in soil and plants [*Honert*, 1948] and the relationship between climate and soil moisture [*Thornthwaite*, 1948]. Petts and Bradley [1997] and Gurnell et al. [2000] trace the roots for eco-hydrology of river and stream ecosystems to work on the form and evolution of channels, stream networks, and catchments performed in the 1950s and 1960s. Investigations into hydrologic constraints on ecosystem structure in wetlands date back at least 50 years to Wickman's [1951] work on the equilibrium morphology of raised bogs. The pervasive influence of hydrology on estuarine and coastal ecosystems perhaps first came to light through studies in the 1960s that demonstrated a correlation between fish abundance and river runoff (that is, papers cited in Skreslet [1985]).

Along each of these roots, the integration of concepts and measurements from different disciplines has served a valuable synthetic function that has advanced the disciplines of hydrology and ecology. Some mechanism for synthesis is required in the study of complex, natural systems as a counterweight to the reductionist approach predominant in the hydrologic and ecological sciences [*Hatton et al.*, 1997; *Dunne*, 1998]. The ecological optimality hypothesis, for which Eagleson was recognized with the award of the Stockholm Water Prize in 1997, serves this function by providing testable theory for the interdependence of soil properties, vegetation, and partitioning of water budget components. Similarly, river continuum concept provides a testable theory for the spatial variation in the structure and functioning of river ecosystems. Eagleson achieved synthesis directly through the formal analytical framework of statistical mechanics. The river continuum concept provides a hypothesis around which synthesis has occurred through observations and analysis across a number of systems. In both cases, an intuitive insight into the behavior of the whole system has been tested and validated through the integration and analysis of concepts and observations from both hydrology and ecology.

Eco-hydrology's Future

Finding solutions to practical problems has driven the development of hydrological science throughout its history. Most of these problems have been related to the management of water, agriculture, or related natural resources. The relatively recent recognition of hydrology as a distinct geoscience acknowledges a more question-driven, scientific approach to hydrologic research that has taken hold in the last 30 years or so [*National Research Council*, 1991]. This is a significant milestone in the maturation of the discipline. Understandably, recent assessments of hydrological science emphasize progress that has been made in "scientific" hydrology and the challenges still ahead [*National Research Council*, 1991; *Dunne*, 1998]. However, recent years have also seen dramatic changes in the goals set for water management and the type of information that managers need to achieve these goals. These changes create new demands on hydrologic science and new opportunities, albeit in the traditional area of "engineering" hydrology [*Nuttle*, 1999].

For example, the Water Resources Development Act (WRDA) adopted by the U.S. government in 2000 approves a 40-year public works program that directs water managers to first "restore, preserve and protect the south Florida ecosystem" before pursuing other traditional goals for water management in the region. This continues a trend in resource management toward adopting broad ecosystem or watershed goals that began with passage of the U.S. National Environmental Policy Act (NEPA) in 1969. Whereas NEPA only committed government agencies to harmonizing their activities with environmental protections, WRDA 2000 sets goals that are more specific and demanding. Water managers in south Florida are now accountable for improving and preserving ecological functions in a natural system that is as yet imperfectly understood and only partly in their control.

Eco-hydrology addresses both the practical needs related to these new expanded goals for water management and the natural drive of scientists to better understand the water cycle as a component of the biosphere. Thirty years ago, the goal of conserving nature motivated a few ecologists to begin studying the interaction of hydrologic and ecological processes in wetlands, streams, and rivers. This work continues today under the heading of eco-hydrology [*Baird and Wilby*, 1999]. Given the stakes, it seems certain that the need to sustain natural resources will continue to drive the development of the applied aspects of eco-hydrology. At the same time, eco-hydrology has come to be recognized as a fruitful topic of study within "scientific" hydrology [*Hatton et al.*, 1997; *Rodríguez-Iturbe*, 2000]. For these and other reasons, it appears that previously unrelated areas of scientific inquiry are now coming together. This heralds a promising future for eco-hydrology!

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References

Baird, A. J., and R. L. Wilby, *Eco-hydrology: Plants and Water in Terrestrial and Aquatic Environments*, 402 pp., Routledge, London, 1999.

Dunne, T., Wolman Lecture: Hydrologic science...in landscapes...on a planet...in the future, in *Hydrological Sciences: Taking Stock and Looking Ahead*, pp. 10–43, National Research Council, Washington, D.C., 1998.

Eagleson, P. S., Climate, soil, and vegetation. 1. Introduction to water balance dynamics, *Water Resour. Res., 14*, 705–712, 1978.

Eagleson, P. S., Ecological optimality in water-limited natural soil-vegetation systems. 1. Theory and hypothesis, *Water Resour. Res., 18*, 325–340, 1982.

Gorham, E., Northern peatlands: Role in the carbon cycle and probable responses to climatic warming, *Ecol. Appl., 1*, 182–195, 1991.

Gurnell, A. M., C. R. Hupp, and S. V. Gregory, Linking hydrology and ecology, *Hydrol. Proc., 14*, 2813–2815, 2000.

Hatton, T. J., G. D. Salvucci, and H. I. Wu, Eagleson's optimality theory of an ecohydrological equilibrium: quo vadis? *Functional Ecol., 11*, 665–674, 1997.

Honert, T. H. van den, Water transport in plants as a catenary process, *Disc. Faraday Soc., 3*, 146–153, 1948.

Ingram, H. A. P., Ecohydrology of Scottish peatlands, *Trans. Royal Soc. Edinburgh Earth Sci., 78*, 287–296, 1987.

Livingston, R. J., G. C. Woodsum, N. Xufeng, and F. G. Lewis, Freshwater input to a gulf estuary: Long-term control of trophic organization, *Ecol. Appl., 7*, 277–299, 1997.

Loneragan N. R., and S. E. Bunn, River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland, *Austral. J. Ecol., 24*, 431–440, 1999.

National Research Council, *Opportunities in the Hydrologic Sciences*, 347pp., National Academy of Sciences, Washington, D.C., 1991.

National Research Council, *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*, 405 pp., National Academy Press, Washington, D.C., 2000.

Nuttle, W. K., Ecosystem restoration a challenge for unified hydrologic science, *Eos, Trans. AGU, 80*, 469, 1999.

Petts, G. E., and C. Bradley, Hydrological and ecological interactions within river corridors, in *Contemporary Hydrology*, edited by R. L. Wilby, pp. 241–271, John Wiley and Sons, Chichester, 1997.

Rodríguez-Iturbe, I., Ecohydrology: A hydrologic perspective of climate-soil-vegetation dynamics, *Water Resour. Res., 36*, 3–9, 2000.

Rodríguez-Iturbe, I., A. Porporato, F. Laio, and L. Ridolfi, Plants in water-controlled ecosystems: Active role in hydrologic processes and response to water stress I. Scope and general outline, *Adv. Water Resour., 24*, 695–705, 2001.

Skreslet, S., The role of freshwater outflow in coastal marine ecosystems, *Proc. NATO Advanced Research Workshop*, Bodo, Norway, 21–25 May, 1985.

Thornthwaite, C. W., An approach toward a rational classification of climate, *Geogr. Rev., 38*, 55–94, 1948.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing, The river continuum concept, *Can. J. Fish. Aquat. Sci., 37*, 130–137, 1980.

Wickman, F. E., The maximum height of raised bogs and a note on the motion of water in soligenous mires, *Geol. Foren. Stockh. Forh., 73*, 413–422, 1951.

Working Group on Sea Level Rise and Wetland Systems, Conserving coastal wetlands despite sea level rise, *Eos, Trans. AGU, 78*, 257–262, 1997.

Zalewski, M., G. A. Janauer, and G. Jolankai, *Ecohydrology: A New Paradigm for the Sustainable Use of Aquatic Resources*, 58 pp, International Hydrological Programme, UNESCO, Paris, 1997.

New Chairman Takes Helm at Climate Change Panel

PAGES 205–206

An Indian industrial engineer and economist who supports the Kyoto Protocol, and who has sharply criticized the administration of George W. Bush on the climate change issue for not doing enough to curb greenhouse gas emissions, won the first-ever contested election for chairman of the Intergovernmental Panel on Climate Change (IPCC) during a meeting on 19 April.

Rajendra Pachauri is the first representative from a developing country to chair the IPCC, a panel of about 2,500 experts on a wide range of areas related to climate change. The IPCC was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme. In total, the IPCC currently includes 192 member states. Although the bulk of the IPCC's work is conducted by three technical working groups, the chairman plays a key role in facilitating the overall process of the IPCC, organizing the scientific debate within the IPCC, and serving as chief spokesman.

A former IPCC vice-chair, Pachauri already is looking to heal any rifts within the organization that may have been caused by a highly-publicized, divisive election; and he is proceeding with plans to begin to map out the process for pulling together the fourth IPCC assessment. This is scheduled to be completed in 2007 (see accompanying article on next page).

Pachauri defeated standing chairperson Robert Watson of the United States, an atmospheric scientist and chief scientist for the World Bank who had also served in the Clinton-Gore administration.

Pachauri, who is director general of the Tata Energy Research Institute in India, won by a vote of 76 to 49. He also turned back an effort to establish a joint co-chair arrangement.

The United States and a number of developing countries supported Pachauri's candidacy in the secret ballot.

Many scientists lauded Pachauri as a good choice for the position. They said that although the new chair is not an atmospheric scientist, others in the IPCC will provide expertise in that area, and that his managerial abilities and understanding of economics and technology will prove very useful.

Others, though, said Pachauri will need to develop strong consensus-building skills necessary for producing complex climate change assessments and other inter-governmental documents. Pachauri's election also raised concerns among some scientists about the lobbying by sectors of the energy industry in opposition to Watson, and about the politicization of the IPCC. A memo sent to the White House on 6 February 2001 by the Exxon-Mobil Corporation, and made public in April 2002, recommended removing Watson from any IPCC decision-making activities.

"The incredible politicization of this decision [to vote Watson out] and the fact that it came at the behest of one of the major fossil fuel companies is pretty troubling," said William Moomaw, professor of international environmental policy at Tufts University in Medford, Massachusetts.

But other scientists, including University of Alabama-Huntsville atmospheric scientist John Christy, accused Watson of crossing the line from being policy-relevant to policy-making.

Charles Kennel, president of the Scripps Institution of Oceanography in La Jolla, California, and others, including Bert Bolin, the first IPCC chair, praised Watson's efforts at the IPCC. Watson has "an abiding faith in the correctness of the science," Kennel said.

Criticism of Bush Administration's Stance

Some scientists have wondered why the United States supported a candidate who does not share the Bush administration's perspective on climate change.

In a 14 June 2001 column in *The Newspaper Today* of India, Pachauri called for India, China,