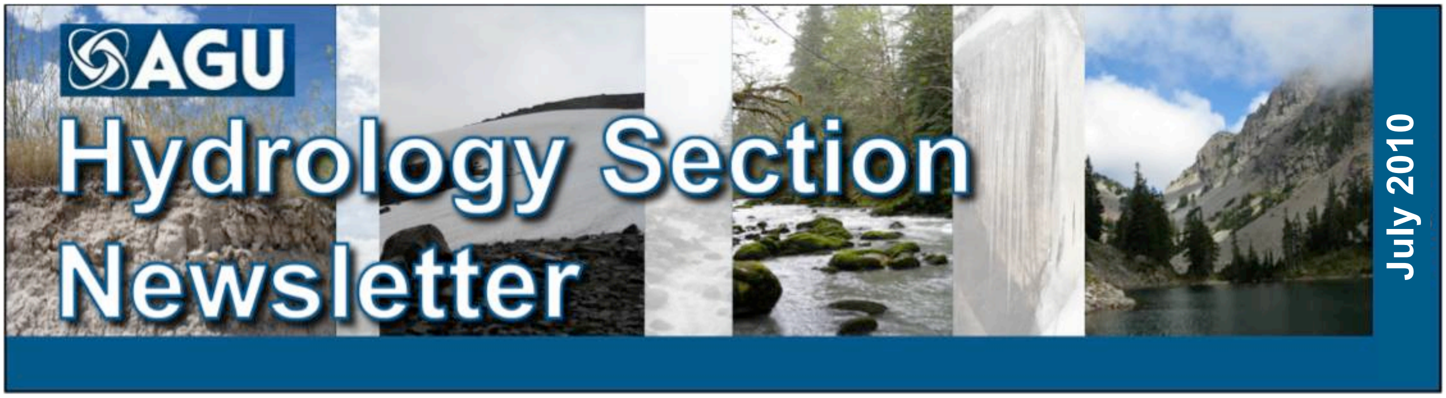

From the President

Dennis P. Lettenmaier (University of Washington)

Welcome to the first edition of the Hydrology Section newsletter. My intention is to produce newsletters twice a year – one on (about) July 1, and the other about December 1, before the Fall Meeting. They will be all electronic, although in PDF format so you can print them if you so desire. The intent of the newsletter is to provide a means for promoting the objectives of the Section, which according to our bylaws (slightly abstracted) are *To promote the scientific study of hydrology and water resources ... by scientific discussion, publication, and other dissemination ... and by sponsorship of scientific and technical symposia, colloquia, and meetings; To initiate and participate in hydrologic and water resource research programs including ... international cooperation; To promote cooperation among ... scientific organizations ... in the hydrologic and water resource disciplines.*

I will serve as the newsletter editor. I am happy to print anything that is relevant to the Section's objectives; about the only restriction is that it not be inflammatory. Much of the content of the first two issues will come from two sources. The first are short articles by our new Fellows, of which there were a total of ten this year. Roughly half have prepared articles for this edition; the remainder will appear in the December issue. I have asked them to say what they would like to say – whether it be technical in flavor, or otherwise (I view these articles as a written version of the very successful

In This Issue

Imminent Deadlines

July 15 – Hydrological Sciences Award Applications (see hydrology.agu.org)
July 15 – Langbein Lecture nominations (see hydrology.agu.org)
July 15 – Early Career Hydrological Sciences Award nominations (see hydrology.agu.org)
July 18 – Young U.S. scientist travel grants for 2nd Pan-GEWEX Meeting, Seattle, 23-27 August 2010 (see www.gewex.org/2010pangewex/funding.html)

"The Fellows Speak" talks at the Toronto Joint Assembly a year ago). The second source are summaries by the Technical Committees of their view of evolving science issues and priorities in their areas (more on this below). As the newsletter evolves, I expect that the content will become somewhat more spontaneous, and I encourage any section member to submit an article for the next issue. Articles could, for instance, highlight evolving science issues, they could state opinions as to the functioning of the Section, or as to our interactions with the public at large, or summarize key activities of interest to the Section at large.

I'm sure that all of you are aware that AGU has undergone large changes over the last two years. I thank John Wilson, our immediate past President, for guiding the Section through this somewhat turbulent period. I won't go into details here, as the changes have been widely publicized in *EOS* articles, and many of you participated in the election of a new Board of Directors (of which past-Section President Rafael Bras is one). The Union also has a new Executive Director, Christine McEntee, effective late this summer. All of this has consumed much of the attention of the Union's guiding body, the Council, over the last 18 months. A positive effect of these changes is that AGU staff has become much more open, accessible, and accommodating of members' interests under the guidance of interim Executive Director Bob Van Hook, who in my opinion, has done an excellent job of managing the Union over the last 18 months. I have certainly seen this in my interactions with staff, and I expect that many of you have as well.

When I was asked to run for Section President 2-1/2 years ago, I identified two major issues facing the Section. First, the number of Section members has remained more or less static (most recently around 7000; see Figure 1), and I didn't feel that we had a good idea of what motivated AGU members to affiliate with the Section (and in particular, relative to focus groups that in the past were home to disciplines closely related to Hydrology). That remains that case. Second, I was concerned with the issues facing *WRR* (as with other AGU journals) in transitioning to the all-electronic era. These issues were also colored by internal AGU staff issues in the publications area, many of which have since been resolved, or at least appear to be on a path towards resolution. Furthermore, former Chief Editor Marc Parlange and his team, and current Chief Editor Praveen Kumar, have done an excellent job with the journal, and I view my role here as primarily to assist where I can in facilitating interactions with AGU. Please see the accompanying article by Praveen in which he comments recent changes in the management of *WRR*.

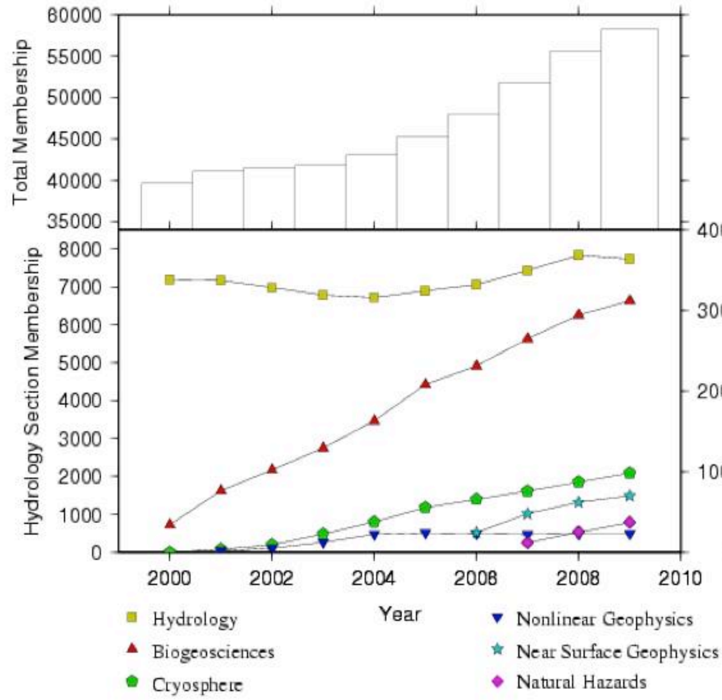

Figure 1: Hydrology Section membership, compared with selected focus groups and Biogeosciences Section (lower panel) and Union total membership (upper panel). Visual courtesy Elizabeth Clark, University of Washington.

Back to the first issue: The accompanying plot may be informative. Section membership has been more or less static at around 7000 (although one has to take these numbers with a grain of salt, as it turns out that the primary section/focus group identification of long-standing members may be different than for newer ones). The important point is that ten years ago, there were no focus groups, and no Biogeosciences Section. What this suggests to me is that we need to interpret Hydrology in the AGU context somewhat more broadly than just those members who identify the Section as their primary affiliation, and we need to find creative ways to work with the focus groups and sections that are "close to" hydrology in a disciplinary sense. At the Union level, there remain governance issues connected with focus groups in particular, and how they can most effectively function. This issue is especially important for the Hydrology Section, given the number of closely related focus groups.

From the standpoint of the Union as it is "seen" by most of our members, the picture is encouraging. *WRR* remains the premier journal in the field, and as I've noted above, Chief Editor Praveen Kumar as well as the AGU Editorial Board are pursuing various options that will increase the visibility of *WRR* as well as other AGU journals (incidentally, we owe great thanks to Jay Famiglietti for his service as GRL Chief Editor, which I believe had a lot to do with an increase in the number of high profile hydrology articles being published in that journal). Attendance at the fall meeting continues to grow, as do the number of Hydrology submissions. The Fall Meeting Program has their hands full, with over 115 session abstracts submitted for this year's meeting. Increasingly, the challenge of the Committee (presently Roseanna Neupauer, Matt Roddell, and Mike Cosh – Roseanna is the lead for this year's meeting) has been to combine sessions. Our target is 60, which I can tell you is difficult to meet. Still, it is a problem many societies would love to have – the reason people want to have sessions, and come to, San Francisco is the quality of the meeting.

I look forward to leading the section over the next two years, and to working with Section Secretary Martha Conklin, and President-Elect Eric Wood. Feel free to contact me if you have any thoughts as to directions for the section. I especially encourage younger members to become involved. One way to do so is via the Technical Committees (see the Section web site (hydrology.agu.org) for descriptions). The meetings of the Technical Committees (normally held at the Fall Meeting) are open, and are an excellent entry point to the activities of the Section.

From the President-Elect

Eric F. Wood (Princeton University)

I look forward to serving the Section in my capacity as President-Elect and helping Section President Dennis Lettenmaier and Secretary Martha Conklin guide the section so you, the section members, find the Hydrology Section an exciting and productive home for your AGU activities. As President-Elect my specific duties under the section by-laws are to sit on the Union Council with our Section President, chair the Section Fellows Committee and the Section awards committee. Dennis has also asked me to coordinate with the Liaison Subcommittee, a committee that helps with coordination between the Hydrology Section and relevant government agencies and professional organizations. Currently the committee includes representatives from AWRA, CUAHSI, IAHS, NASA, NOAA, NRC, NSF, and USGS.

I believe that AGU is the world's leading society for scientific hydrology, with members world-wide and has usually contributed more presentations at AGU meetings than any other section. The activities and health of the Section are therefore extraordinarily important to the community. We have been lucky to have had exceptionally qualified and dedicated colleagues who have served the section on our Technical Committees, program committees; and as editors, reviewers and authors for *WRR* and related AGU journals.

Dennis Lettenmaier in his newsletter article briefly mentions recent changes in governance at the Union level. In early June, Dennis and I (along with Rafael Bras in his capacity as a Union Board of Director member) attended an AGU Leadership Conference at AGU Headquarters. The Union leadership has initiated a long term strategic planning activity for the Union through a number of Task Forces. It is expected that the outcome from the strategic planning will identify medium term (3 – 5 years) and long-term (~25 years) goals for AGU scientific leadership and collaboration; AGU's scientific contribution to societal needs; the fostering and development of a global talent pool in Earth and space science; and, through its new governance structure, being responsive to AGU members and our stakeholders.

Over the next year you'll hear more about these activities through *EOS* and from colleagues. Dennis, Martha and I will keep you informed through the Section newsletter. It is clear from member surveys that more integrative science within AGU is desired. Historically, the Section has represented a diversity of research and applications across the hydrologic sciences and water resources disciplines, and their various subdisciplines. I believe that the Section can help AGU in framing the strategic plan and its goals – both individually and through our Technical Committees – and further enhance activities within the Section and through collaborations with the focus groups. Furthermore, discontinuation of the Spring Meeting offers the opportunity to develop more focused meetings, like Chapman Conferences, that may incorporate a number of Technical Committees, other AGU sections and focus groups, or even other societies.

If you have thoughts or questions regarding the Union's new governance structure or strategic plans and/or the Section's role or response, please communicate with Dennis, Martha or me. Over the next year we will be communicating with you regarding these and other issues related to the Section. Again, I look forward to helping to guide the section in this period of change with the goal of strengthening the Section and its activities within the Union.

From the Water Resources Research Editor-in-Chief

Praveen Kumar (University of Illinois)

I am honored for the opportunity to serve as the Editor-in-Chief for Water Resources Research. We have a committed team on the editorial board including Ron Griffin, Hoshin Gupta, Tissa Illangasekare, Graham Sander, and John Selker.

Hoshin and Ron joined in January 2010. Ron brings a much-needed expertise to the board in water resources economics, a rapidly growing area for the journal. Thomas Torgersen, after five years on the editorial board, joined the National Science Foundation in January as the Hydrological Sciences Program Director. Thank you Tom for your guidance during the past year. We owe deep appreciation to Marc Parlange, Brian Berkowitz, Amilcare Porporato, and Scott Tyler for continuing to serve as editors during the past year to ensure a smooth transition. Thanks are also due to the Associate Editors and the reviewer community for their invaluable contributions in ensuring the quality of the journal.

We are committed to improving our service to authors in a variety of ways. We have put in place a plan to improve the turn-around time for the authors. We especially encourage the community to support our efforts through timely reviews. We have recently initiated "Featured Articles" which are intended to highlight some of the best papers, as judged at the time of publication. These papers will be available as open access articles for a limited period of time and they will also be included in "Research Highlights" published in *EOS*. While we recognize that not all of these may bear out the test of time as leading edge contributions, we hope that the timely communication of the leading science, and understanding and awareness achieved from its broad dissemination will help to develop wide appreciation and support for addressing today's pressing problems related to water resources. We welcome the support of the reviewing community in this effort by identifying and promoting the work of our colleagues that appear appropriate for this designation. We are also inviting Review Articles that present a synthetic assessment of the state of the art in a given subject area, provide a benchmark for scientists within the field, and can serve as a point of entry for students and scientists new to the subject. We are exploring the option of implementing an "Educational Online Supplement" to make it easier for authors to facilitate faster diffusion of the research. This option will allow authors to upload presentations, data, programs, movies, etc. directly related to the paper so that the research outcomes may be readily adopted in the classroom or other educational settings.

The journal remains strong with about 500 articles published in 2009 and submission numbers this year tracking those of last year. The large volume demands a significant review load so we urge the community to support this effort by generously accepting this responsibility. We recognize that the journal will grow and remain contemporary by embracing the interdisciplinary research themes emerging at the periphery. We, therefore, interpret the scope of the journal broadly (see editorial article Kumar et al., 2009). We welcome suggestions so that the journal may better support the needs of the *WRR* community.

References:

Kumar, P., T. Illangasekare, G. Sander, J. Selker, and T. Torgersen (2009), Editorial: Building on the legacy of Water Resources Research, Water Resour. Res., 45, W06101, doi:10.1029/2009WR008174.

The Fellows Speak: Changes in intense precipitation over the central U.S. – Manifestation of global climate change, regional land use, or both?

Pavel Ya. Groisman (UCAR Project Scientist, NOAA National Climatic Data Center, Asheville, NC)

I do not yet have the answer to the question I pose in the title of this note. Instead I show what has happened with intense precipitation over the central United States during the past 60 years. I believe that the observed changes are too large to be ignored, and deserves more thorough investigation.

On average over the conterminous United States, two thirds of annual precipitation falls during ~20% of rain days with totals above 12.7 mm (0.5", intense precipitation). I focus only on these precipitation days and multi-day events constructed from consequent intense precipitation days. Other definitions of precipitation intensity that I use throughout this note are: "moderately heavy" precipitation (within 13 mm to 25 mm per day or in the 0.5" to 1" range), "very heavy" precipitation (the daily rain events above 75 mm that for the Central U.S. correspond approximately to the upper 0.3% of the rain days with 3 to 4 years return period, (Groisman et al. 2004). I also define extreme daily and multi-day rain events that may be loosely attributed to floods, property damage, or worse and in the following discussion are associated with rare events with return periods that are more than 10 years or above 155 mm (6 in.).

Past research into changes in precipitation (and in particular, intense precipitation) over the U.S. has found that total precipitation over the conterminous U.S. (CONUS) increased during the 20th century by ~6% (Karl et al. 2009). These changes were not monotonic, nor were they spatially or seasonally homogeneous. During most of the 20th century,

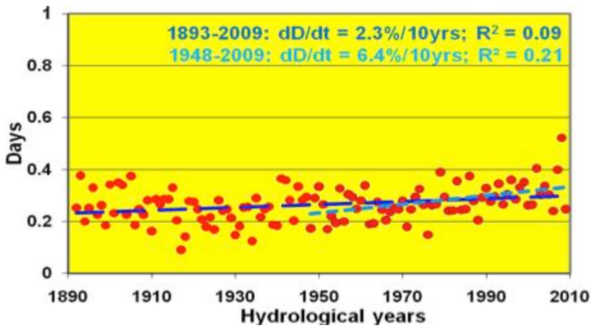

Figure 1. Annual number of days with very heavy precipitation (defined as an upper 0.3% of daily precipitation events) over regions of the central U.S. (Upper Mississippi, Midwest, and South) and inferred linear trends. Linear trends for the 1893–2009 and 1948–2009 periods are statistically significant at the 0.01 level or higher (CCSP 2008, updated to 2009).

moderately heavy and very heavy precipitation varied widely without apparent long-term trends, but in the past several decades the frequency of very heavy precipitation events began to increase over much of the CONUS east of the Rockies (cf., Figure 1) and their contribution to the annual totals also increased (CCSP 2008).

More recently, my colleagues and I have assessed the climatology of intense precipitation over the CONUS at hourly, daily, and multi-day time scales, and have tracked changes during the past 60 years. Our intent has been to better understand the nature of changes in the frequency of extreme rainfall with totals above 155 mm. The Hourly Precipitation Data (HPD) network (~3000 long-term rain gauges across the CONUS) was used as the main data source, augmented by data from the cooperative observer (daily) network (COOP; ~6000 long-term stations). At all stations within each sub-region of the CONUS that we studied, we selected only days with intense precipitation (as defined above). We sorted these events and grouped them within seven intensity ranges. Thereafter for each region and for the entire CONUS, we summed all intense precipitation data within each daily or multi-day intensity range, along with the correspondent peak hour intensity, number of days, and number of hours with non-zero precipitation during these days. From these tallies we calculated mean precipitation duration, mean daily and maximum hourly intensity for the days with precipitation for each intensity category. The same approach was applied to subsets of our data for (a) the first 30 years and the last 30 years of our sample, (b) the warmest 30 years and the coolest 30 years during the 1948-2007 period using the mean annual surface air temperature of the Northern Hemisphere (TNH) and of the CONUS as guidance, (c) intense precipitation derived from tropical cyclones (TC) in the hurricane season (June through November) and intense precipitation that originated without direct TC impact, and (d) various other combinations and complements (e.g., warmest years versus coolest years for TC-originated precipitation; warmest years versus coolest years for the hurricane-free season, and others. Our analyses show that:

- Over the Central U.S. (and CONUS), a statistically significant redistribution in the spectra of intense precipitation days/events during the past decades has occurred. Moderately heavy events (that account for more that 70% of days and about half of intense precipitation totals) became less frequent compared to days and events with precipitation totals above 25.4 mm.
- During the past 30 years (compared to the previous 3 decades), significant increases occurred in the frequency of "very heavy" (above 76.2 mm) and extreme precipitation events in the central region of the CONUS, with up to 40% increases in the frequency of days and multi-day rain events with precipitation totals above 155 mm day^{-1} (Figure 2).
- The average probability of extreme rain days (above 6 inches) at a single COOP (HPD) station in the post WW-II period was 0.027 (0.018). The COOP network is denser than the HPD network and this explains the differences in empirical probabilities. The same probability of observing a multi-day extreme rain event with precipitation totals above 155 mm day^{-1} was 0.105 (COOP) and 0.073 (HPD), respectively. The changes shown in Figure 2 imply a dramatic reduction of the return periods of these extremes (e.g., for extreme rain days, from 44 to 32 years at the COOP network and from 68 to 48 years at the HPD network respectively).

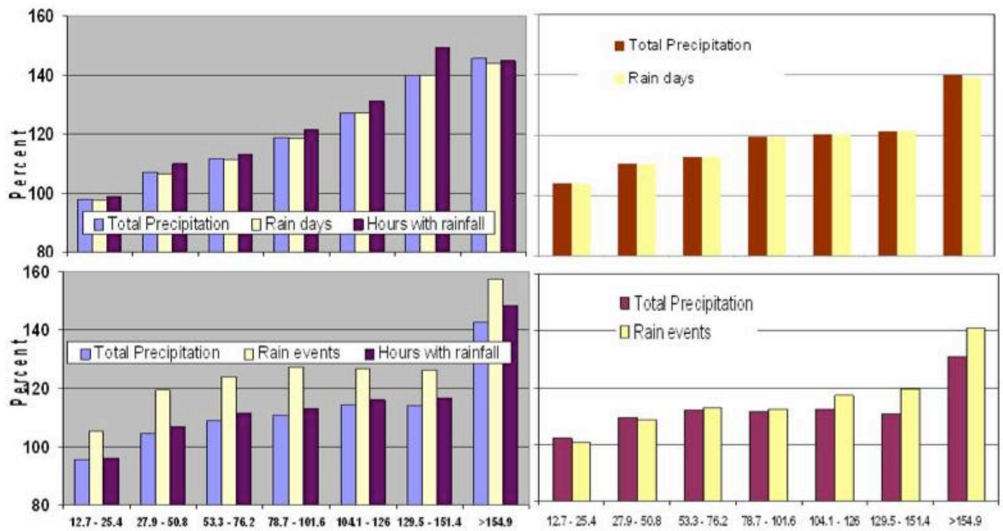

Figure 2. Comparison of intense precipitation days (upper plots) and multi-day intense precipitation events (lower plots) over the central U.S. for 1978-2007 and 1948-1977 sorted by day/event intensities (in mm). Estimates of precipitation characteristics for these 30-yr periods were averaged and their ratios (in percent per station) are shown for HPD (left) and COOP (right) networks.

- The "usual suspects" associated with extreme precipitation (tropical cyclones) do not significantly contribute to the changes shown in Figures 1 and 2.
- With time as well as in a "global warming experiment" (for which we specifically selected the 30 warmest TNH years and compared them with the coldest TNH years), the internal precipitation structure (for example, mean and maximum hourly precipitation rates within each preselected range of daily or event totals) did not noticeably change.

Figures 1 and 2 show that *substantial changes in intense precipitation have occurred over the central U.S. during the past several decades. But why do they occur?* The 1978-2007 period is characterized by approximately 0.5°C warmer TNH, than the previous decades. It would be tempting therefore to attribute the observed changes in intense precipitation over the central U.S. to the global climate change. If true, this would have disastrous implications. If a 0.5°C increase "caused" a 40% increase in intense precipitation, what can we expect from global temperature increases projected for the next few decades? How to mitigate this unfortunate scenario? We believe that this would be a hasty conclusion though. In the central U.S., the water cycle changes observed over the past 70 years have occurred simultaneously with changes in land use and water management. Changing crop patterns and water use over large areas may feed back to the water cycle through changes in transpiration and evaporation from additional open water surfaces, thus supplying the atmosphere with additional water vapor. It may well be that changing land use and water management has interacted with global climate change to yield more intense precipitation.

Studies using modeling and observations demonstrate that the added atmospheric moisture due to irrigation and reservoir construction or major land cover modifications can significantly change regional rainfall and alter extreme precipitation patterns (cf., Feddema et al., 2005). The regional changes in intensity of the water cycle are usually quantified through the precipitation recycling ratio that describes the contribution of local evaporation to local precipitation. Estimates made under the GEWEX Continental-scale Experiment in the Mississippi River Basin showed that recycled precipitation plays here a significant role during the warm season (Brubaker et al. 2003), varies significantly between dry and wet summers (Bosilovich and Schubert 2001), and correlates with agriculture production (Zangvil et al. 2004). All the above indicate a potential for strong feedbacks of the land use and water management changes to the hydro-meteorological conditions over the central U.S.

Over the next several decades, society may be able to project, but cannot realistically impact the "global climate" component of Earth System changes. However, the impacts of regional land use change arguably can be projected and even reversed if its negative impact is proven and overweighs its benefits. We have observed large changes in extreme rainfall over the central U.S. More comprehensive studies will be required to separate climatic and local anthropogenic factors in any attribution of causality. A combination of global and regional climate and hydrological modeling driven by well documented external anthropogenic forcing (that includes, in addition to global factors, regional land use and water management changes) can be a way to perform this attribution study. Only thereafter, can the acquired knowledge be used for realistic regional projections of extreme precipitation changes in the future.

Acknowledgements:
This note was prepared in close collaboration with my NCDC colleagues, Richard W. Knight and Thomas R. Karl.

References:

Bosilovich, M.G. and S. D. Schubert, 2001: Precipitation Recycling over the Central United States Diagnosed from the GEOS-1 Data Assimilation System. *J. Hydrometeorol*., **2,** 26-35.

Brubaker, K. L., D. Entekhabi, and P. S. Eagleson, 1993: Estimation of continental precipitation recycling. *J. Climate,* **6,** 1077–1089.

CCSP, 2008: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S.Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Thomas R. Karl, Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.)]. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 164 pp.

Feddema, J. J., K. W. Oleson, B. Bonan, L. O. Mearns, L. E. Buja, G. A. Meehl, and W. M. Washington, 2005: The importance of land cover change in simulating future climates, *Science,* **310***,* 1674–1678

Groisman,P.Ya., R.W. Knight, T.R. Karl, D.R. Easterling, B.Sun, and J.M.Lawrimore, 2004: Contemporary Changes of the Hydrological Cycle over the Contiguous United States: Trends Derived From In-Situ Observations, *J. Hydrometeorol*., **5**, 64-85.

Karl, T.R., J.M. Melilo and T.C. Peterson, eds., 2009: *Global Climate Change Impacts in the United States*. Cambridge University Press, New York, 188 pages. Also available from www.globalchange.gov/usimpacts.

Zangvil, A., D.H. Portis, and P.J. Lamb, 2004: Investigation of the Large-Scale Atmospheric Moisture Field over the Midwestern United States in Relation to Summer Precipitation. Part II: Recycling of Local Evapotranspiration and Association with Soil Moisture and Crop Yields. *J. Climate*, **17**, 3283–3301.

The Fellows Speak: Hydroclimatology – A Growth Field

Randal Koster (Global Modeling and Assimilation Office, NASA/Goddard Space Flight Center)

My daughter, a college freshman, is deciding on a major, and one of the fields she's considering is environmental science. Naturally I offer advice, with no expectation that she'll heed it; I point out to her that, unfortunately for the world, environmental science is a "growth field" – humans are putting more and more stress on the environment, and the containment of our impacts will accordingly require more expertise in the decades to come.

For similar reasons, and somewhat unfortunately for the world, hydrology is arguably also a "growth field". I won't pretend here to be well-versed in the factors that shape society and its responses to stress, and I'm sure the joint analysis of hydroclimatic and world population data presented here will appear overly simplistic. Even so, the analysis, such as it is, suggests that certain populations will be especially vulnerable in the coming decades to inevitable increases in water demand.

The hydroclimatic data examined here were extracted from the ISLSCP-2 data set (Hall et al., 2006; online access at http://islscp2.sesda.com/ISLSCP2_1/html_pages/islscp2_home.html), with precipitation data originally from GPCP [Adler et al. 2003] and radiation data from the SRB project [Stackhouse et al. 2004]. These data allow the computation of the global distribution of Budyko's "dryness index", or DI: the ratio of mean annual net radiation to mean annual precipitation, with the precipitation scaled by the latent heat of vaporization to make the ratio dimensionless (Budyko, 1974; see Koster et al. [2006] for more details on the ISLSCP-2-based calculation.) A DI of 1.0 implies that the energy available to evaporate water, as measured by net radiation, is matched by water supply, as measured by precipitation. Water is still available, of course, for vegetation and society when DI lies above 1.0 – certainly not all of the net radiative energy has to be used to evaporate water – but a larger value of DI nevertheless implies a more limited water availability.

The global DI distribution is shown in the top panel of Figure 1. All of the Earth's deserts show up, as expected, with very high DI, upwards of 4 or 5. Notice, though, that most land areas on Earth show a DI greater than 1 – over most land, the energy available to evaporate water exceeds the water itself. Only a few locations (e.g., the Amazon and Indonesia) have abundant water relative to net radiation. The potential water limitations suggested by higher DI are further exacerbated by the fact that the coefficient of variation (the ratio of the standard deviation to the mean) of annual precipitation tends to increase with increasing DI, so that regions that are already dry on average are hit even further with larger year-to-year percent variations in water supply.

A comparison of the DI map to known population distributions suggests that much of the world's population lives in water-limited areas. This is confirmed by the histogram in the middle panel of the figure, produced by merging the DI data with population density data (Gridded Population of the World, Version 2; investigators: Balk, Yetman, and Deichmann), also available on the ISLSCP-2 data set. The logarithm of DI was separated into bins of equal size, and the fraction of the globe's population residing in a given dryness index bin was computed and plotted. The data show that roughly two-thirds of the world's population live where DI exceeds 1, and about a quarter live where DI exceeds 2. The average DI for an individual on Earth is 2.1, and the median DI is 1.3. Of course, vulnerability to water shortage is determined by far more than local dryness index; it can be mitigated in large part by lateral water transport (e.g., rivers) between the $1^o x 1^o$ cells examined here and by the importing of water-intensive products into water-scarce areas (e.g., selling oil for food). Nevertheless, the map and histogram provide a first-order indication of where, from a hydroclimatic perspective, people live; they provide a cursory picture of the degree to which the Earth's present population is vulnerable to limitations in water availability. It's worth noting that even regions with modest DI can experience periods of water shortage; consider, for example, the recent costly drought in Georgia, which has a DI below 1.2.

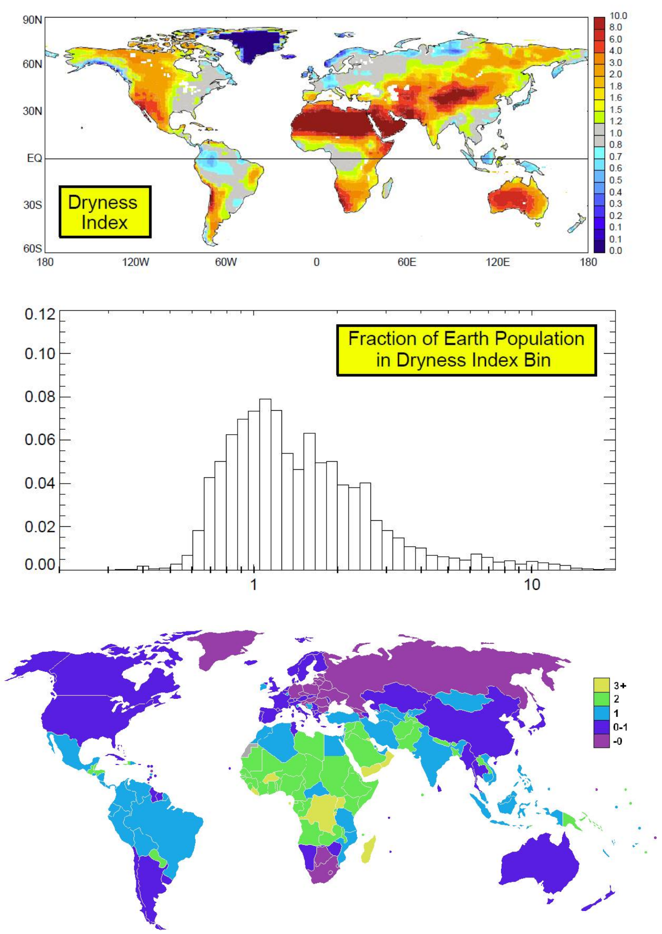

Figure 1: Global distribution of Budyko's dryness index, DI (upper panel), histogram of fraction of Earth's population by DI (middle panel), and population growth rates in percent per year (lower panel).

There are several reasons to expect an increase in water demand in the coming decades, an increase that can put further stress on already vulnerable areas. One reason is population growth. The lowest panel in the figure shows the current population growth rate as provided by the CIA World Factbook (http://en.wikipedia.org/wiki/File:Population_growth_rate_world.PNG). Growth is taking place – and, according to projections, is expected to keep taking place – in many areas of high dryness index, such as sub-Saharan Africa and the Middle East. As these populations grow, demands on the already limited water there will also grow. Another, and in some areas a more important, reason to expect increased demand is the continuing drive for economic development, for bringing the standard of life for much of the world to the level enjoyed by many western nations; economic development entails increased water use. Still other reasons include diminishing water quality (e.g., pollution), which can reduce the availability of useful water, and global climate change (the big wild card), which may change the global distribution of DI and thereby reduce water availability to many already in high DI areas.

Responding to increased demands for water will require expertise in many fields: socio-economics, agriculture, water chemistry, desalinization technology, water conservation, and so on. Hydrologists, however, have a logical and important role to play. Key to the management of a region's limited water resources – to avoiding, for example, the negative impacts of water supply shortfalls during particularly dry periods – is a proper quantification of the statistical moments of water cycle components. Even more helpful would be an ability to predict temporal variations in those components, an ability that requires a fundamental understanding of the physical mechanisms underlying hydrological variability and of how these mechanisms may change with changing climate. Hydrologists, working in conjunction with meteorologists and climatologists, can work to provide this understanding of the global water cycle. Hydrologists are also highly relevant, of course, for other critical tasks, including the optimization of water resource management, the development of new sources (or enhancement of existing sources) of water, and the provision of guidance for the development of new infrastructure to address growing water demand.

Increased demand can certainly be expected, and the above hydroclimatic picture of where people live suggests that much of the Earth's population is already, from a dryness index standpoint, potentially vulnerable. From this perspective, hydrology is indeed a growth field.

References:

Adler, R. F., et al., 2003: The version 2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (1979-present), *J. Hydromet*. 4, 1147– 1167.

Budyko, M. I., 1974: *Climate and Life*, 508 pp., Elsevier, New York.

Hall, F. G., E. B. de Colstoun, G. J. Collatz, D. Landis, P. Dirmeyer, A. Betts, G. J. Huffman, L. Bounoua, M. Bosilovich, and B. Meeson, 2006: The ISLSCP Initiative II global data sets: Surface boundary conditions and atmospheric forcings for land-atmosphere studies, *J. Geophys. Res.* 111, doi:10.1029/2006JD007366.

Koster, R. D., B. M. Fedete, G. J. Huffman, and P. W. Stackhouse, 2006: Revisiting a hydrological analysis framework with International Satellite Land Surface Climatology Project Initiative 2 rainfall, net radiation, and runoff fields, *J. Geophys. Res.* 111, D22S05, doi:10.1029/2006JD007182.

Stackhouse, P. W., Jr., S. K. Gupta, S. J. Cox, J. C. Mikovitz, T. Zhang, and M. Chiacchio, 2004: 12-year surface radiation budget data set, *GEWEX News* 14(4), 10–12.

The Fellows Speak: Some challenges for hydrological science in addressing UK water needs – a personal reflection

Howard Wheater (Department of Civil and Environmental Engineering, Imperial College, London, UK)

The award of an AGU Fellowship is a major honour, and a career landmark. I am deeply grateful to the friends and colleagues who made the award possible. It is recognition of a team effort over more than 30 years, and tribute is due to the many colleagues, post-docs and students with whom I have had the very great pleasure of working to achieve this. They are too many to name here, but my close colleagues at Imperial College cannot escape recognition – Adrian Butler, Neil McIntyre and Christian Onof. And of course there has been the stimulation of interactions with many brilliant friends around the world, who have always been free to share their ideas and insights.

As it happens, this award coincides with a time of great personal change for me. After 32 years at Imperial I am moving to Canada in October to take up the unique opportunity of a Canada Excellence Research Chair at the University of Saskatchewan, which comes with $30 million support from the Federal and Provincial Governments and the University. It is not coincidental that this comes at a time when the water environment globally is facing huge challenges. Unsustainable development has been the rule, not the exception, and at the same time the water environment is facing unprecedented threats – not just from over abstraction, but from pollution and environmental change. These are world-wide issues, but also of fundamental strategic importance for Canada. In the prairies, the Saskatchewan River is reaching limits for abstraction, pollution is creating eutrophication, and climate change is changing Canada's land and its water. Glaciers are retreating, permafrost is melting. And one of the largest land use changes Canada has seen has been associated with warmer winters - forest death due to beetle infestation.

It is impressive to see Canada being prepared to invest in the science needed to meet the challenges faced by the water environment. I look forward to working at large scales and high latitudes, very much at the forefront of global warming (which I'm relying on for the winters). I also look forward greatly to working with my new colleagues in the University (John Pomeroy et al.) and at Environment Canada, as well as closer contact with those of you elsewhere in Canada and south of the border. There are, remarkably, 67 academic staff at U of S (including 5 research chairs) in water and closely-related disciplines. A major challenge for water science is to achieve the integration of disciplines needed to address current management issues, and to understand societal, policy and management interactions. In Saskatoon we have identified a set of thematic challenges: climate change and water security; land-water management and environmental change; sustainable development of natural resources. Our ambition is to develop the integrated science and tools needed to address these, within a new Institute for Water Security.

So, what am I leaving behind in the UK, and what's new? Too much to discuss in detail, including work in Africa, Asia, the Middle East and South America, but a key theme at Imperial has been the development of the science needed to inform policy and management, and two high profile UK issues have recently challenged our scientific understanding and capability.

Firstly, due to several major floods in the last decade, flood hydrology has been high on the UK's political agenda, and this has led to some difficult hydrological questions. One issue has been the effect of rural land use and land management change on flood risk. The UK is a heavily managed environment, and major changes to agriculture have taken place since the second World War, with significant intensification between the 1970s and 1990s in particular. For example, in Wales, extensive land 'improvement' has taken place and sheep numbers increased by a factor of 6, with individual animal weights doubled. The management and policy question is: Has changing land management contributed to an increase in flood risk, and if so, can agricultural practices be modified to provide an element of flood risk mitigation? A review led by Enda O'Connell showed that data and tools to address this were lacking. Keith Beven led a project focussed on catchment-scale data analysis, which showed that if effects had occurred, they could not be distinguished from the effects of climate variability, data limitations and data and model error (land use is well characterised, land management is not, and most catchments have a complex mosaic of both). At Imperial, with the Centre for Ecology and Hydrology, we have been working with Welsh farmers to provide multi-scale observational data (from plot to catchment-scale) and new modelling methods.

We (Beth Jackson) developed detailed physics-based models, conditioned on our experimental data, to represent local scale effects, for example, of soil compaction and the planting of tree shelter belts. With 1 cm vertical resolution of the soil and 1 m in the horizontal, these are too detailed for catchment-scale application, so we developed a 'meta-modelling' strategy in which parsimonious conceptual models were trained using the detailed model results, and then applied in a semi-distributed catchment-scale model. Results are providing the quantification badly needed for agricultural and flood management policy – land management interventions can have large effects on frequent floods, but more minor impacts on extreme events. There are important generic research issues embodied in this problem concerning the role and utility of physics-based models with different levels of data support, their relationship to conceptual approaches to model and parameter identification, and the needs of regionalisation for data sparse environments. Working with Enda O'Connell, we (Caroline Ballard) have developed physics-based models of upland peat to explore management impacts, and in the absence of local data have used surrogate data to parameterise these. In parallel, we (Natasha Bulygina) have been addressing the issue of regionalisation of effects for data limited sites, using Bayesian constraints on hydrograph characteristics. This provides a set of hybrid modelling tools that can represent local detail and catchment scale impacts.

Secondly, there are critical issues of water management under current and future climates in the densely populated but low rainfall South and East of England, where we have the Chalk geology that provides the UK's most important aquifer, locally providing up to 80% of water resources, and characteristic groundwater-dominated chalk streams, in many cases designated as sites of special scientific interest. There are obvious management pressures in balancing the demands for abstraction for water users and the needs for effluent dilution and ecosystem protection. In addition, water quality pressures arise, due to nutrient pollution. And the extreme winter of 2000/2001 highlighted the risk of long duration groundwater flooding in these systems (inundation for weeks and months), with high associated damage and disruption. Superimposed on these are the issues of climate change impacts assessment and adaptation, which challenges London's water supply.

A typical Chalk stream has a seasonal hydrograph, reflecting the water table dynamics of the aquifer which it drains (winter recharge and a progressive water table decline through summer and autumn); the stormflow component of streamflow may represent as little as 2% of the incident rainfall, appearing as noise superimposed on the seasonal hydrograph. The streamflow source migrates seasonally, moving up the catchment in winter and retreating during summer; under drought conditions (or due to over-abstraction), flow may cease over significant lengths of channel.

Under conditions of extreme long duration rainfall, streams may expand further than normal, and springs break out in dry valleys, giving rise to local flooding; given the typically low runoff and associated small river channels, floods are associated with highly non-linear responses and relatively large out-of-bank flows. Flood risk assessment in these systems is a major challenge; conventional event-based methods of design flood estimation are inappropriate, and the spatial extent of inundation is difficult to predict. In addition, historical data on flood occurrence and extent are limited.

A further complication is the fact that the groundwater catchment may not be the same as the surface water catchment, and that groundwater divides vary seasonally. One of our study catchments, the river Pang, has additional complexity; groundwater connection to the stream is seasonal and intermittent, so that effective rainfall falling on the Pang topographic catchment may contribute to Pang streamflow, or alternatively may flow under the Pang to the Thames. Conventional rainfall-runoff models, which aim to preserve mass balance based on topographic catchment areas, are inappropriate and will fail to reproduce observed stream response.

The unsaturated zone is important for groundwater recharge and diffuse pollution transport, but Chalk is a fractured porous medium, and hence flow and transport processes in the unsaturated zone are complex, and difficult to observe. The fine pore matrix retains saturation at high negative pressures, and there has been much debate over the relative role of fracture flow, focussed on a perceived duality of observed response; water table rise from winter effective rainfall can occur within days, whereas solute profiles have been observed to move down the profile, with little dispersion, at a rate of less than 1 m/year. Combining detailed field measurements and the development of dual permeability and lately, dual continuum models, we (Simon Mathias and Andrew Ireson) have shown that flow predominantly occurs in the matrix, with very limited occurrence of significant fracture flow. Two effects have importance for management. Under extreme conditions, recharge can reach the water table in hours, rather than (the more usual) weeks. Under drought conditions, slow drainage of the large unsaturated pore storage can maintain river flows when conventional analysis would indicate they should be dry.

Groundwater flow has its own challenges – in related work Adrian Butler has shown that drilling conventional wells changes the inter-connection of fractures; pumping tests create yet further changes to fracture flow paths. Pumping tests are therefore of very limited value in aquifer characterisation. And stream aquifer interactions are complex, with connectivity that is spatially limited and temporally variable.

In short, the Chalk provides an important and scientifically very challenging environment, for which current modelling tools have major limitations. We are working with the British Geological Survey and CEH to develop the new modelling tools needed to capture flood and drought response, as well as pollutant transport, and with Imperial's Grantham Institute to develop improved tools for climate change analysis and assessment.

In conclusion, I would like to thank our incoming Section President, Dennis, for the opportunity of contributing this article, and look forward with great enthusiasm to a new chapter in my career, as I add some of the challenges of North American hydrology to my portfolio of hydrological interests.

For further information see:

http://www3.imperial.ac.uk/ewre/research/currentresearch/hydrology

http://www.usask.ca/water/

The Fellows Speak: The hidden frontier – Hydrological exploration of physical and ecological origins of microbial diversity in the vadose zone

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Notwithstanding extreme fluctuations in hydration, temperature, nutrients and restrictions imposed by numerous environmental constraints, the shallow vadose zone (=soil) is the most biologically active compartment of the biosphere hosting unparalleled microbial diversity at all scales. Microbial density in the vadose zone exceeds values found in oceans by more than 4 orders of magnitude (Whitman et al., 1998). Estimates of soil microbial diversity are even more impressive, in one ton of fertile soil there are more species than in all oceans combined. Even at very small scale, many thousands to millions of distinct genotypes may inhabit one gram of soil. Recent results show that fungal, archaeal, and viral communities are as diverse as soil bacteria (Schloss and Handelsman, 2006). By some accounts exploring microbial diversity found in the vadose zone represents a scientific frontier at the scope similar to that of space exploration – Curtis and Sloan (2005) state "*...there are 10^9 times more bacteria on Earth than there are stars in the Universe… an immense and unexplored frontier in science of astronomical dimensions and of astonishing complexity*".

The high degree of microbial diversity found in the vadose zone is attributed to complex pore surfaces and spaces in which dynamic aqueous and chemical microenvironments delineate unique spheres of influence that may separate bacteria spatially, physiologically, or genetically. As aquatic organisms, the dynamics and spatial arrangement of water is particularly important for soil bacteria. Temporal and spatial variations in amount and configuration of water in soil pores result in a flickering aqueous network that shapes diffusional pathways for nutrients and promotes or suppresses mobility and connections between soil microbial communities even over very short distances (Mills, 2003). Although heterogeneity and microhabitat fragmentation are often cited as factors promoting the immense soil microbial diversity, mechanistic description and interplay among key factors sustaining diversity remain sketchy.

Modeling pore-scale abiotic microbial interactions in the vadose zone

Understanding the origins and mechanisms promoting soil microbial diversity require quantitative models for integrating key hydro-geochemical processes with biological interactions at appropriate spatial and temporal scales. Prominent among these quantitative tools are organism-based models that explicitly account for micro-scale aqueous and diffusional heterogeneity that define nutrient fluxes and control bacterial motility (Wang and Or, 2010). A modified *Reaction-Diffusion Model* links nutrient diffusion-consumption fields with individual-based modeling of bacterial growth and dispersion,

$$\begin{cases} \dfrac{\partial b}{\partial t} = D_b \nabla^2 b + \dfrac{\mu_{Max} S}{K_S + S} b \\ \dfrac{\partial S}{\partial t} = D_S \nabla^2 S - \dfrac{Y \mu_{Max} S}{K_S + S} b \end{cases}, \qquad (1)$$

where b is bacteria number, S (mg/L) is nutrient concentration, D_b and D_S (mm^2/hr) are effective

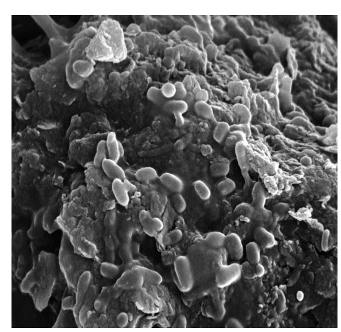

Figure 1. Bacterial colonies (some embedded in extracellular polymeric substances - EPS) on soil surfaces. (Tippkoetter and Eickhorst, 2009 - http://www.microped.uni-bremen.de)

diffusion coefficients of bacteria motion and of nutrients, respectively, t (hr) is elapsed time, K_S (mg/L) is half-saturation constant, μ_{Max} (hr^{-1}) is maximum specific growth rate, and Y is the yield term (linking bacterial growth with consumed nutrient). We replace the continuum solution for bacteria numbers with an *Individual-Based model (IBM)* (Kreft et al., 1998),

$$X(t+1) = X(t) + X(t)\mu_B \Delta t\,, \qquad (2)$$

where X (mg) is bacterial cell (dry) mass, t and Δt (hr) are time sequence and time interval, and μ_B (hr^{-1}) is specific growth rate, which can be described as,

$$\mu_B = \frac{\mu_{Max} S}{K_S + S} - mY\,, \qquad (3)$$

with m (mg substrate/[mg dry mass × hr]) maintenance rate. The IBM approach allows individual cells to adjust own growth rates and motility to local conditions where at each time step an individual bacterium intercepts nutrients by diffusion, consumes stored inner energy and carries out activities such as motion and reproduction. The physiological parameters used in the model were similar to those of representative of *E. coli* (Kreft et al., 1998).

An important impact of hydration status is on bacterial motility and dispersion rates (Dechesne et al., 2008). These effects are incorporated in models by considering hydrodynamic cell-surface interactions and onset of capillary pinning forces in liquid films. The effects are succinctly lumped into analytical functions λ and F_C, respectively, linking cell size, water film thickness, and cell velocity (Fig. 2a) according to (Wang and Or, 2010),

$$V = V_0 \frac{F_M - F_\lambda - F_C}{F_M}\,, \qquad (4)$$

with $V = 0$ for $F_M - F_\lambda - F_C < 0$, where V_0 (mm/hr) is cell velocity in bulk liquid, V (mm/hr) is constrained cell velocity, F_M is propulsion force for a bacterium swimming at maximum velocity (V_0) in bulk liquid, and F_λ and F_C are viscous resistive force associated with cell-surface hydrodynamic interactions and capillary pinning force, respectively. Wang and Or (2010) have used the model to demonstrate how capillarity and water films constrain bacterial motility and colony growth on partially hydrated rough surfaces (Fig. 2). Simulations confirmed by experimental results define a surprisingly narrow range of hydration conditions where motility confers ecological advantage; for matric potential values lower than -5 kPa there is no difference in expansion rates of motile and non motile bacteria, in agreement with experiments of Dechesne et al. (2008). Subsequent studies focusing on the roles of hydration and surface roughness heterogeneity on coexistence of two competing species illustrated that dryer and more heterogeneous rough surfaces promote and

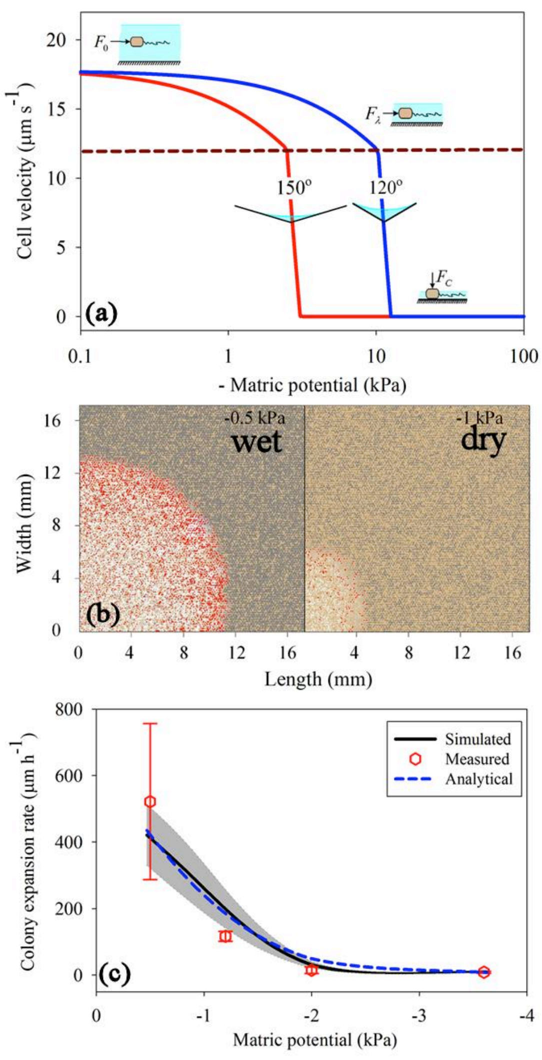

Figure 2. Effects of hydration status (matric potential) on bacteria motility and colony expansion on rough surface: (a) model of cell velocity as a function of matric potential for rough surface v-shaped elements with two spanning angles; (b) simulated patterns of microbial colony 25 hrs after inoculation on "wet" and "dry" rough surfaces; and (c) comparison of numerical and analytical models with measurements (Dechesne et al., 2008) of colony expansion rates as a function of matric potential (Wang and Or, 2010).

prolong extent of coexistence. These basic modeling tools provide means for systematic evaluation of micro-hydrologic factors (amount and arrangement of water) that promote or suppress coexistence of competing soil microbial species.

Microhydrology and bacterial survival strategies

Even mild temporal fluctuations in hydration conditions that are common in many soils of temperate regions may exert significant influence on microhabitats and microbial function in unsaturated soils. The narrow range of hydration conditions sustaining bacterial motility in soil pores and on natural surfaces suggests that colonization of new surfaces and dispersion of microbial populations in the vadose zone soils is limited to short time windows when soil water content is near saturation. It also highlights limitations to standard modeling of passive bacterial transport under unsaturated conditions and the need to reevaluate the underlying biophysical processes involved.

The range of water potentials (and relative humidity - RH) supporting growth and activity of microbial life is also relatively narrow; at 99% RH microbial growth becomes limited, and at water potential of -5 MPa (RH~96%) bacterial respiration ceases (Potts, 1994). Desiccation extremes require significant physiological adjustments, where under extreme desiccation conditions the best survival strategy is for microorganisms to completely abolish their metabolism and switch into a dormant state until conditions improve, consequently, many microorganisms developed resting stages or spores (Torsvik and Ovreas, 2008). The links between spatial and temporal aspects of micro-hydrology dynamics with functionality of species having different survival and reactivation strategies is presently unexplored yet essential for understanding diversity maintenance, i.e., what part of diversity is shaped by recent ecological conditions and what results from long term population interactions (in resting form). Such quantitative links would elucidate effects of dynamic hydration conditions across many time scales on microbial life and composition, nutrient cycles and other bio-geo processes in soils of different regions.

An important and ubiquitous microbial response to local hydration fluctuations is formation of biosynthesized extracellular polymeric substances (EPS) in which cells are embedded forming aggregates or sessile colonies attached to solid surfaces. Soil bacterial aggregation and pooling of resources offer a successful adaptation to variations in hydration status and in nutrient availability, and enhances cooperative genetic and metabolic exchanges. The ubiquity of such microbially excreted exopolymeric substances across many different environmental conditions and habitats is attributed to its key role in environmental adaptation in particular anchoring, nutrient entrapment, and maintenance of favorable hydration conditions (Roberson and Firestone, 1992). EPS supports higher water retention and consequently higher nutrient diffusion rates within EPS-rich microenvironments relative to surrounding soil under dry conditions. Notwithstanding its importance for microbial (and plant) life in unsaturated soils, most studies on EPS function in natural systems focused on water replete environments such as aquifers, sludge, and aquatic environments. Advancing understanding of microbial life and function in the unsaturated zone is linked with quantitative description of the role and function of EPS and its interactions with soil water and transport processes (Or et al., 2007).

Concluding thoughts on linking hydrology and microbial life in the vadose zone

The need for quantitative links between hydrological processes and microbial life in the vadose zone is motivated by both fundamental ecological questions related to diversity and its maintenance, as well as, by practical environmental and engineering issues. For example issues related to introduction and stimulation of bacteria for remediation activities in the vadose zone, or prediction of bacterial mediated gaseous fluxes at all scales. The environmental impact of the ongoing molecular revolution with rapid advances in identification and unraveling of complex functions of microbial populations would be significantly enhanced when placed in the proper hydrological and porous media context. The traditional “bio” component of hydrology focused primarily on macroscopic plant-atmosphere interactions and their potential impact on components of the hydrologic cycle and nutrient fluxes. Contemporary environmental concerns and growing appreciation for a broad range of bio-hydrological agents (from bacteria to stomata) necessitate re-evaluation of our approach to the numerous biological transport and transformations processes taking place in the vadose zone and their impact on life at scales ranging from a single grain to continents.

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References:
Curtis TP and Sloan WT. 2005. Exploring microbial diversity - a vast below. *Science* 309: 1331-1333.
Dechesne A, Or D, Gülez G and Smets BF. 2008. The porous surface model: a novel experimental system for online quantitative observation of bacterial processes under unsaturated conditions. *Appl Environ Microbiol* 74: 5195-5200.
Kreft JU, Booth G and Wimpenny JWT. 1998. BacSim, a simulator for individual-based modelling of bacterial colony growth. *Microbiology-UK* 144: 3275-3287.
Mills AL. 2003. Keeping in touch: Microbial life on soil particle surfaces. *Adv Agron* 78: 1-43.
Or D, Smets BF, Wraith JM, Dechesne A and Friedman SP. 2007. Physical constraints affecting bacterial habitats and activity in unsaturated porous media: a review. *Adv Water Res* 30: 1505-1527.
Potts M. 1994. Desiccation tolerance of prokaryotes. *Microbiol Rev* 58: 755-805.
Roberson EB and Firestone MK. 1992. Relationship between desiccation and exopolysaccharide production in a soil Pseudomonas. *Appl Environ Microb* 58: 1284-1291.
Schloss PD and Handelsman J. 2006. Toward a census of bacteria in soil. *PLoS Comp Biol* 2: 786-793.
Torsvik V and Ovreas L 2008. Microbial diversity, life strategies, and adaptation to life in extreme soils, in: P. Dion and C.S. Nautiyal (eds.), *Microbiology of Extreme Soils*, Springer Berlin Heidelberg, pp. 15-43.
Wang G and Or D. 2010. Aqueous films limit bacterial cell motility and colony expansion on partially saturated rough surfaces. *Environ Microbiol* 12: 1363-1373.
Whitman W, Coleman D and Wiebe W. 1998. Prokaryotes: the unseen majority. *Proc Natl Acad Sci USA* 95: 6578-6583.

New missions, datasets, and applications for remote sensing in hydrology[1]

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Recent wildfires in California, the 'Snowpocolypse' on the US east coast, the Texas agricultural drought, and floods in the southeastern US have reminded us of the importance of accurately monitoring and predicting environmental changes, not only at the local and regional scales but also at global scales to assess climate trends and forecasts. These not so subtle reminders are being addressed by the remote sensing community with advances in remote sensing technology and hydrologic applications. The advances include developments and datasets from recently launched missions, new algorithms and applications for the upcoming satellite missions, refinements of existing datasets, and new applications of datasets from the current missions. Out of these efforts several novel methods have been generated for monitoring, predicting, and assessing many aspects of the hydrologic cycle.

A major move toward improved understanding of the global hydrologic cycle through remote sensing was achieved with the launch of the Soil Moisture and Ocean Salinity (SMOS) mission on November 2, 2009, by the European Space Agency (ESA). The SMOS satellite consists of a passive microwave sensor designed to provide global maps of soil moisture every three days and ocean salinity averaged over 30 days (Kerr et al., 2010). The sensor is a 2D interferometric radiometer, operating at 1.4 GHz (wavelength of 20 cm) with a spatial resolution of 30-50 km. The mission entered its operational life in the last week of May 2010 after six months of extensive testing during the commissioning phase. Initial observations indicate that Radio Frequency Interference (RFI) is a major challenge, particularly across Europe, and the scientists are investigating various mitigation techniques. The microwave brightness temperature data is expected to be released in June 2010 and the soil moisture and ocean salinity data will be available in September 2010. An early result of SMOS soil moisture retrievals over West Africa is shown in Figure 1. SMOS is now one of the two L-band satellite-based sensors, along with the Japanese Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar (PALSAR) that was launched in 2006. As demonstrated by recent aircraft and field campaigns with L-band sensors, the regional estimates of soil moisture such as those to be provided by the SMOS will be of great benefit to the community in characterizing land-atmosphere interactions for improved hydrologic fluxes and states, and reducing uncertainties in agricultural and ecological applications.

The SMOS mission will be complimented by another mission dedicated to soil moisture, the Soil Moisture Active Passive (SMAP) mission that is planned for launch in 2014 by NASA. The long-awaited SMAP mission is the first of the missions recommended by the Decadal Survey that was conducted by the Committee on Earth Science and Applications from Space, National Research Council in 2007. The SMAP mission is expected to provide global maps of soil moisture and freeze/thaw state every three days using combined active (radar) and passive (radiometer) sensors at 1.26 and 1.41 GHz, respectively (Entekhabi et al., 2010). The spatial resolutions of the radar and the radiometer are 3 and 36 km, respectively. Even though the mission is still four years away, prelaunch activities are well underway with the formation of four working groups aimed to prepare for near real-time applications of the SMAP data soon after launch. These working groups are charged with developing integrated active and passive retrieval algorithms for soil moisture and freeze/thaw state, developing calibration and validation plans for both pre- and post-launch science requirements, identifying sources of RFI and developing hardware and software-based mitigation techniques for RFI, and investigating various applications of the SMAP datasets and products.

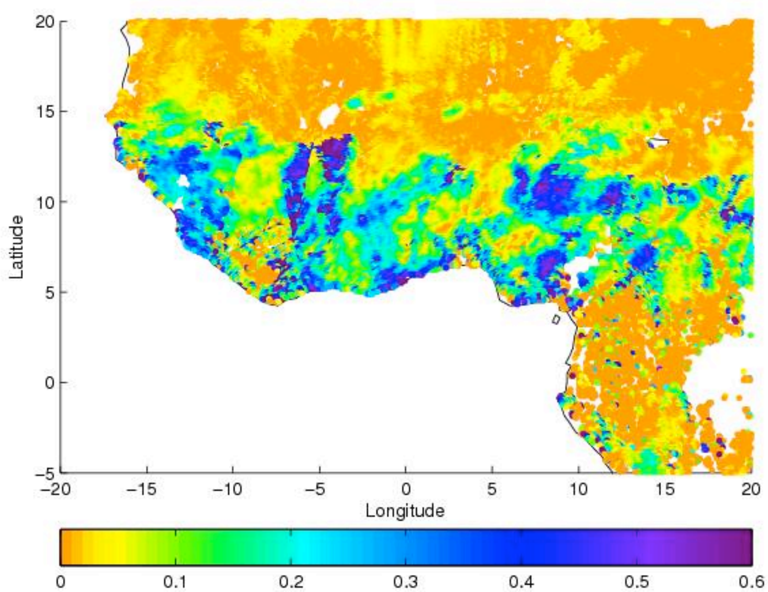


Figure 1: Soil moisture over western Africa obtained from 11 acquisitions of SMOS data collected during the beginning of the rainy season from June 19 – 21, 2010 (courtesy C. Gruhier and Y.H. Kerr, CESBIO).

While the SMOS and the SMAP missions are addressing the challenges in estimation of soil moisture, the challenges in estimation of snow and ice in the Polar Regions, where the most of world's fresh water is stored, is being addressed by the Cold Regions Hydrology High-resolution Observatory (CoReH2O). The CoReH2O is one of the three Earth Explorer mission concepts currently being considered by the ESA, and is envisioned to improve global snow and ice estimation (Kern et al, 2010). The mission is designed to provide detailed observations of key snow, ice and water cycle characteristics, to improve the modeling of snow and ice processes, and to advance the prediction of stream flow in regions where snow and glacier melt are important components of the water balance. The CoReH2O will utilize a dual frequency radar operating at 9.6 and 17.2 GHz to provide snow and ice information over two temporal scales of 3 and 12-15 days.

Precipitation is another key component of the hydrologic cycle as the primary source of fresh water over the globe and an important variable for weather prediction. The Global Precipitation Measurement (GPM) mission builds upon the success of the current Tropical Rainfall Measuring

Mission (TRMM) to provide more frequent measurements of global precipitation from space. The GPM will use an international constellation of up to eight satellites that are contributed by various US and international organizations to study global rain, snow, and ice to better understand the hydrometeorological processes. The mission is planned for launch in 2013 and will consist of a central precipitation-measuring observatory with a dual-frequency precipitation radar and a multi-channel GPM microwave imager, developed by NASA and the Japanese Aerospace Exploration Agency (JAXA). From this effort, GPM will extend our ability to measure precipitation to higher latitudes. Many pre-launch activities are underway internationally that are focused on evaluating and updating our current rainfall products, and improving methods for quantifying uncertainties in precipitation retrievals from satellite- and ground-based observations.

Global distribution of surface water storage and river discharge is important for understanding the terrestrial branch of the water cycle, but is still not known. For example, the Congo River is the second largest in the world yet the 3M km^3 basin remains essentially ungauged. Along with the SMAP and the GPM missions, the Surface Water and Ocean Topography (SWOT) mission has also been recommended by the Decadal Survey. This mission concept aims to monitor ocean, lake, and river water levels for ocean and inland water dynamics. It combines hydrology with the expertise in ocean surface topography using Ka-band radiometry and altimetry to measure storage changes globally in lakes and reservoirs that are larger than a hectare and provide an estimate of discharge in river reaches with channels that are wider than 100m (Durand et al., 2010).

The launch of every new mission increases the efforts required to calibrate and validate the products. Recent advances in cyber-infrastructure have allowed development of databases or observation networks that enable validation of satellite products and new interdisciplinary research activities. For example, the NASA's Making Earth System data records for Use in Research Environments (MEaSUREs) program was developed to produce consistent, long-term, calibrated datasets and products from multiple missions and satellite sensors. The Program is in its third year with 29 funded projects in 10 Earth science disciplines including hydrology. Some of the Program's innovative projects in the hydrology domain are creating earth system data records for land surface freeze-thaw state, inundated wetlands, northern hemisphere snow, surface turbulent fluxes, and consistent global terrestrial water cycle parameters. A similar program by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) has established seven Satellite Applications Facilities (SAFs) to provide weather and climate related satellite-based products and validate new products for hydrological applications. A SAF to support operational hydrology and water management is under development. Some of the products under development include snow water equivalent, precipitation rate, soil moisture from radar, and soil moisture assimilation in the European Centre for Medium-Range Weather Forecasts (ECMWF) model. Another program, the International Soil Moisture Network (ISMN), is an international collaboration as a part of ESA, the Land Product Validation subgroup established by the Committee of the Earth Observation Satellites and GEWEX to foster quantitative validation of global land products from the satellites. The goal of ISMN is to develop a global database of in situ soil moisture for validating satellite products and hydrologic models. Scientists from across the globe voluntarily contribute datasets to the Network.

Applications of datasets from current missions, such as the Gravity Recovery and Climate Experiment (GRACE), are continually improving. GRACE is sensitive to variations in water stored at all levels on and below Earth's surface, including groundwater, root zone soil moisture, and deep snow and ice sheets, though at coarse spatial and temporal resolutions of > 150,000 km^2 and monthly, respectively. With the aid of other observations and/or land surface models, GRACE-derived terrestrial water storage anomalies can be spatially, temporally, and vertically downscaled (Zaitchick et al., 2008). Such downscaled results are now being applied for regional to global drought and flood monitoring (Reager and Famiglietti, 2009), groundwater depletion studies in northern India (Rodell et al., 2009) and in California's central valley, and water availability assessments in the Middle East North Africa region.

While applications of current missions are being continually refined, novel applications of existing data that are traditionally not used for hydrological purposes are being developed. For example, radar altimetry, which has been used extensively for oceanography, has been recently extended in terrestrial hydrology. For example, a multi-satellite study analyzed data from TOPEX/POSEIDON, Jason-1, ERS-2, and Envisat sensors, with temporal samplings ranging from every 10 to 35 days, and found lake and river levels with high correlations when compared with Gauge data. These studies focus on those lakes that opportunistically lie beneath the orbital tracks, a limitation that misses millions of the world's lakes and associated storage changes.

Another effort has demonstrated added utility of using thermal band imagery from geostationary platforms, such as the Geostationary Operatial Environmental Satellites (GOES) and Meteosat Second Generation (MSG) for real-time monitoring of Evapotranspiration (ET) (Anderson et al., 2007). ET is an important variable for calculating cumulative water loss and a critical component of the energy and water balance. By utilizing the time-differential land surface temperature measurements provided by geostationary satellites, evaporative fluxes are directly estimated at resolutions of 5 to 10 km over continental scales (Hain et al., 2009). Higher resolution thermal imagery from polar orbiting satellites like Landsat can be used to spatially disaggregate geostationary ET flux maps down to the 100 m scale for local applications. Unlike the traditional water balance approach to ET estimation, this novel remote sensing method does not require *a priori* information about precipitation and subsurface soil properties and can be applied to regions with sparse rainfall data or substantial delays in meteorological reporting. Recent work successfully demonstrated this methodology for near real-time ET and moisture stress across the US and the Nile Basin. Thermal-based surface moisture assessments have proven to be a valuable complement to microwave soil moisture retrievals, providing improved spatial resolution and sensitivity under moderate to dense vegetation cover.

It is clear that improved hydrologic prediction and monitoring is critical to the well being of many people around the globe. This is likely to be become more evident in the near future, as the value of fresh water resources continues to grow due to increasing demand from population growth and the improper use of fresh water resources. Just over the past decade, significant advances have been made in monitoring and prediction of our environment and different components of the hydrologic cycle using remote sensing. These advances have altered our understanding of our environment and as a result, our role in the environment. We now expect to have immediate access to real-time images of extreme hydrometeorological events, forest fires, and even ash clouds from volcanic eruptions around the globe. The way we approach hydrological problems is changing too. Hydrological assessments have shifted from point evaluations using a motley of rain and stream gauges to near real-time global images from satellite-based platforms and improved model-based predictions providing regionally meaningful information. As a consequence, it is now difficult to imagine hydrologic predictions without remote sensing. For instance, much of the prediction skill of numerical weather and climate forecasts is obtained from estimates of sea surface dynamics - where regular observations from gauge data cannot be obtained. We have seen examples of estimated ground water, ET, and lake and stream levels from space, and efforts to calibrate, validate, and apply remote sensing data and products for improved hydrological estimates. Advances such as these are only likely to persist as new opportunities in remote sensing for observing the hydrologic cycle continue to evolve and be re-invented. We can rest assured that the future of remote sensing in hydrology will be even more fascinating in the years to come.

[1]This article was prepared by the authors on behalf of the Remote Sensing Technical Committee.

References:

Anderson, M. C., J. M. Norman, J. R. Mecikalski, 2007. J. A. Otkin, and W. P. Kustas. A climatological study of evapotranspiration and moisture stress across the continental U.S. based on thermal remote sensing: 2. Surface moisture climatology, *J. Geophys. Res.* 112, D11112, doi:11110.11029/12006JD007507.

Durand, M., L. L. Fu, D. P. Lettenmaier, D. Alsdorf, E. Rodriguez and D. Esteban-Fernandez. 2010. The Surface Water and Ocean Topography mission: Observing terrestrial surface water and oceanic submesoscale eddies, *Proceedings IEEE* 98, 766-779.

Entekhabi, D., E.G. Njoku, P.E O'Neill, K.H. Kellogg, W.T Crow, W.N. Edelstein, J.K. Entin, S.D. Goodman, T,J. Jackson, J. Johnson, J. Kimball, J.R. Peipmeier, R,D, Koster, K.C McDonald, M. Moghaddam, M.S. Moran, R. Reichle, J.C. Shi, M.W. Spencer, S.W. Thurman, 2010. The Soil Moisture Active and Passive (SMAP) Mission, *Proceedings IEEE* 98, 704-716.

Hain, C.R., J.R Mecikalski, and M.C. Anderson, 2009. Retrieval of an available water-based soil moisture proxy from thermal infrared remote sensing. Part I: Methodology and validation, *J. Hydromet*. 10, 665-683.

Kerr Y H., P. Waldteufel, J.P. Wigneron, S, Delwart, F, Cabot, J. Boutin, M.J. Escorihuela, J., Font, N. Reul C. Gruhier, S. Juglea, M.R. Drinkwater, A. Hahne, M. Martin-Neira, S. Mecklenburg, 2010. The SMOS Mission: New tool for monitoring key elements of the global water cycle, *Proceedings IEEE* 98, 666-687.

Kern, M., H. Rott, D. Cline, C. Duguay, R. Essery, P. Etchevers, I. Hajnsek, F. Heliere, M. Macelloni, E. Malnes, A. Lecuyot, J. Pulliainen, and S. Yueh, 2010. ESA's candidate core explorer mission CoReH2O: A satellite mission dedicated to snow and ice research, *Geophysical Research Abstracts* 12, EGU2010-8557, EGU General Assembly.

Reager, J.T., and J.S. Famiglietti, 2009. Global terrestrial water storage capacity and flood potential using GRACE, *Geophys. Res. Lett.* 36, L23402, doi:10.1029/2009GL040826.

Rodell, M., I. Velicogna, and J.S. Famiglietti, 2009. Satellite-based estimates of groundwater depletion in India, *Nature* 460, 999-1002, doi:10.1038/460789a.

Zaitchik, B.F., M. Rodell, and R.H. Reichle, 2008. Assimilation of GRACE terrestrial water storage data into a land surface model: results for the Mississippi River Basin, *J. Hydromet.* 9, 535-548, doi:10.1175/2007JHM951.1.

Surface water issues and opportunities in the 21st century[1]

Terri S. Hogue (UCLA) and
Kristie J. Franz (Iowa State University)

Local, regional and global water resources are under escalating stress for many reasons, including increasing climate variability and related impacts to snow, soil moisture, and precipitation fluxes; acute and chronic land cover change related to urbanization, fire, deforestation, woody encroachment and other ecosystem transitions; degradation in water quality from atmospheric pollutants and land use practices; and growing demands on water supplies from increasing global populations. As noted in several publications (e.g. Milly et al., 2008; Olson et al., 2010) individual stressors, or combinations of stressors, over the last century have resulted in nonstationarity, challenging both the research and operational communities to advance current approaches to water resource management and improve prediction capabilities. Participants at the recent Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management held at Colorado State University concluded that the scientific and planning communities need to move forward quickly to provide useful information and tools that address nonstationary in order to design robust and resilient water management systems for the future (proceedings available at: http://www.cwi.colostate.edu/publications/is/109.pdf). As noted in the proceedings, scientists should "focus their efforts on using nontraditional data for hydrologic predictions, understanding the nature of ongoing hydrologic change, and rethinking the methods currently used for flood risk estimation."

Corresponding with the intense interest in climate variability and nonstationarity among the science community at large, there has been a significant body of literature on the analysis of historical trends in hydrologic fluxes. Studies have been widely published in both the scientific literature as well as in state and national agency reports. Much of the work, particularly in the western U.S., notes that warmer temperatures will result in reduced snowpack, earlier melt, and reduced runoff (e.g. Cayan et al., 2001; Mote, 2003; Dettinger, 2005). However, other studies show contrasting trends towards wetter conditions (primarily based on streamflow) over large parts of the country (Lins et al., 2010; McCabe and Wolock, 2002), including parts of the western U.S. Investigation of individual watersheds used in the California 8-river index (including the American, Sacramento, Merced, San Joaquin, Tuolumne, Stanislaus, Feather, and Yuba Rivers) indicates that for many of these river systems there are periods with increasing flows (at a significant level) (Figure 1). It is apparent that trend analysis and interpretation varies widely and results are highly dependent on the spatial and temporal scales utilized.

In the Midwest U.S., trends towards more precipitation and warmer conditions are being observed and are anticipated to benefit agricultural in the area by producing a longer growing season. However, increasing precipitation is leading to increased soil moisture, particularly in the spring (Conrad and Franz, 2010, unpublished), and studies have found an increase in the number of high flow days for the upper Midwest. As a result, there is concern over the potential for more frequent flooding in the future. Low flows (or baseflow conditions) are also increasing, and have been attributed to both conservation practices and climate change (Tomer and Schilling, 2009). The impact of climate on the hydrology of regions experiencing intense land use change and management, and the related issues of land use sustainability and water quality, is difficult to identify and predict, and presents significant challenges for the surface water community.

The wide array of results related to climate change and hydrologic signals highlights the need for continued valuation and analysis of surface water observations and improved community dialogue on assessment tools and relevant scales of study. Additionally, collaboration among groundwater and surface water researchers will be critical to parse out the relative impacts of climate versus land cover change on water resources. Given the increasing importance of observational systems to trend interpretations, process understanding, model synthesis and model development, the continuity of quality observations is also crucial and remains a central study area of surface water studies.

Improved data management and sharing are being promoted through CUAHSI's (Consortium of Universities for Advancement of Hydrologic Sciences, Inc.) Hydrologic Information System (HIS)

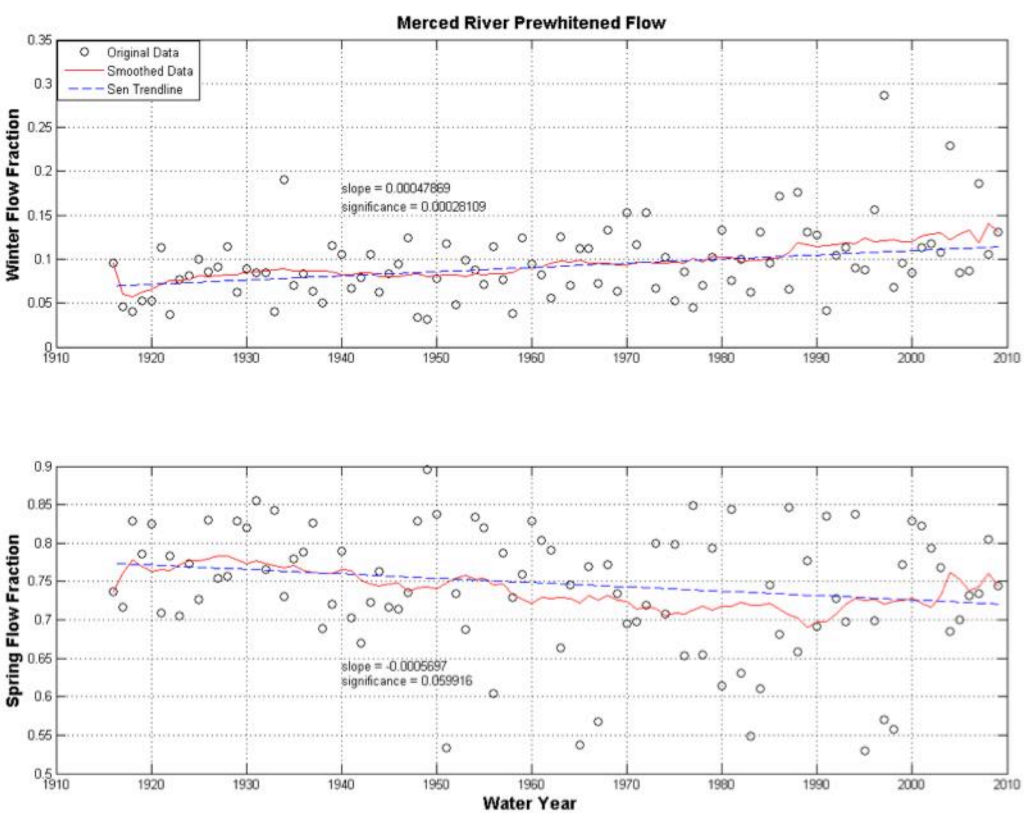


Fig. 1. Seasonal flow fractions (winter and spring) for the Merced River, CA 1916-2009. Data have been pre-whitened (to eliminate the influence of serial correlation), smoothed with a 9-year moving average (red line) and fitted with a Sen's technique (trendline with blue dashed line). The winter season (January-March) shows a statistically significant increasing trend (Mann-Kendall test) while the spring season (April-June) shows a decreasing, but non-significant, trend after pre-whitening. From Barco and Hogue, 2010; (unpublished).

and recent policies at NSF that require researchers to submit plans for making data available post-publication, among other activities. Increasing efforts in this arena will improve data use efficiency by providing researchers expanded and timely data access, which is particularly important given the growing competition for limited research funds. Improving the rate at which research is transitioned to applications is also a key issue for the surface water community. Efforts to build community hydrologic modeling systems (e.g. the CUAHSI Community Hydrologic Modeling Platform (CHyMP) and the U.S. National Weather Service Community Hydrologic Prediction System (CHPS)) are aimed at facilitating the linkage and testing of multiple or alternative models through use of a common computing platform. Finally, water resources managers are under increasing pressure to utilize research community results to inform decisions on delivery and supply of surface (and groundwater) systems (Roe et al., 2010). Integrated observing systems, improved data sharing and access, community modeling platforms, and direct interaction and collaboration with local, state and regional planners and forecasters will facilitate efforts in this direction.

Although there are extensive topics of interest within the AGU surface water community, we have chosen to highlight a few key areas that have been persistent in meeting sessions and committee discussions. Our discourse is not meant to be exhaustive or complete. Given the complexity of global water issues, successful collaboration among hydrologists, engineers, biologists, ecologists, geographers, social scientists and urban planners is vital. The AGU Surface Water committee is committed to facilitating sessions relevant to its members as well as fostering cross-committee collaboration in order to address critical issues in surface hydrology.

[1]This article was prepared by the authors on behalf of the Surface Water Technical Committee.

References:

Dettinger, M.D., 2005. Changes in streamflow timing in the western United States in recent decades, USGS Fact Sheet FS2005-3018.

Cayan D. R., Kammerdiener S. A., Dettinger M. D., Caprio J. M., and D.H. Peterson, 2001. Changes in the onset of spring in the western United States, *Bull. Am. Met. Soc.* 82, 399-415.

Lins, H.F., Hirsch, R. M., and J. Kiang, 2010: Water-the nation's fundamental climate issue: A white paper on the U.S. Geological Survey Role and Capabilities, U.S. Geological Survey Circular 1347, 9 p., available at http://pubs.usgs.gov/circ/1347.

McCabe G.J. and D.M. Wolock, 2002. A step increase in streamflow in the conterminous United States, *Geophys. Res. Lett.* 29, doi:10.1029/2002GL015999.

Mote, P.W., 2003. Trends in snow water equivalent in the Pacific Northwest and their climatic causes, *Geophys. Res. Lett.* 30, doi:10.1029/2003GL0172588.

Olsen, J. R., J. Kiang and R.Waskom, (editors), 2010. Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management. Colorado Water Institute Information Series No. 109. www.cwi.colostate.edu.

Roe, J., Dietz, C., Restrepo, P., Halquist, J. Hartman, R., Horwood, R., Olsen, B., Opitz, H., Shedd, R., and E. Welles, 2010. Introduction of NOAA's Community Hydrologic Prediction System, presented at 26th IIPS, AMS Meeting, Atlanta, GA, Jan., 2010.

Tomer, M.D. and K.E. Schilling, 2009. A simple approach to distinguish land-use and climate-change effects on watershed hydrology, *J. Hydrology* 376, 24-36.

Ecohydrology: Towards a fully transient and spatially explicit ecohydrology in natural and human-dominated landscapes[1]

Enrique R. Vivoni (Arizona State University), Kelly Caylor (Princeton University) and Paolo D'Odorico (University of Virginia)

The development of ecohydrology as an interdisciplinary field has progressed rapidly in the last decade, as evidenced by two Chapman conferences, popular topical sessions at recent meetings and a growing body of literature dedicated to the subject. It is certainly tempting to itemize and celebrate these past successes in this and future newsletters. However, we have chosen instead to focus attention on current challenges that present new opportunities for interesting research by individuals and collaborative groups.

Certainly one of the major contributions of ecohydrology in the past decade has been the progress achieved in describing the effects of vegetation on the dynamics of key hydrologic states, such as soil moisture [*Rodriguez-Iturbe and Porporato*, 2005]. This progress, however, has been made under the assumption that vegetation states and functional relations are invariant at seasonal to interannual time scales. In our view, this simplification constrains our ability to address critical issues related to how ecosystems respond to hydrologic change. Recent research has begun to incorporate the dynamic, two-way interactions between plant communities and hydrologic processes [*Ivanov et al.,* 2008]. Further, transient approaches to handling coupled ecologic and hydrologic variability are necessary to address societally-relevant questions regarding climate change. For example, while plant phenology is one of the most recognizable features of ecosystems [*Schwartz et al*., 2003], few studies account for the transient responses of plants to varying abiotic conditions and their subsequent hydrologic impact. Progress on representing phenology can be made by utilizing quantitative observations from satellite remote sensing, ground-based phenological imagery and manipulative ecosystem experiments aimed at identifying changes in vegetation states or functional relations.

Recent studies have also shed light on how vegetation spatial patterns are a recognizable outcome of underlying ecohydrologic interactions that impact plant stress [*Rodriguez-Iturbe and Porporato*, 2005]. Progress in understanding ecosystem patterns, however, has generally simplified the role played by plant physiological adaptations over short and long-term periods. In our view, attention is warranted on incorporating how plants alter carbon allocation and biomass structure in response to abiotic stresses, their hydrologic impact and the subsequent effects on observed patterns. Recent research has started to address the role of above-ground and below-ground plant architecture on community patterns [*Caylor et al*., 2006]. Further research is required on quantifying the interactions between dynamic root allocation and hydrologic states, including soil moisture and groundwater. Similarly, the spatial heterogeneity and adaptations in plant canopies and their role in structuring spatial vegetation patterns requires additional attention. Increasing the use of plant physiology in ecohydrological studies will require new observational approaches in the rhizosphere and canopy environment that resolve biomass adaptations and functional shifts in response to hydrologic changes.

An important omission in the development of ecohydrology to date has been the treatment of anthropogenic impacts. Engineered human systems alter the distribution of water, nutrients, light, and species that can redefine or entirely replace ecosystems. Given the scale of anthropogenic effects on natural areas, significant resources should be invested on identifying the ecohydrology alterations occurring in agricultural settings and urban centers and the ecohydrological services provided by these systems. Recent research has begun to address ecohydrological impacts in human-dominated systems, including agricultural [*Scanlon et al.*, 2007] and urban settings [*Grimm et al*., 2008]. Additional studies are required to quantify how engineered systems release or add abiotic stressors that ultimately affect ecosystem structure and function. For example, understanding how urban irrigation releases plant stress, alters phenology and influences biomass adaptations is largely unexplored. A promising approach to address this is via comparative studies of natural and human-dominated landscapes within similar climate settings.

Within the last decade, ecohydrology has emerged as an interdisciplinary field attracting attention from the earth, environmental and biological sciences. To capitalize on this momentum, it is imperative to continually pose new research questions that have a greater relevance to society. In this newsletter, we discussed three examples of unfulfilled challenges –phenology, physiological patterns, and human-impacts – that we believe can catalyze a closer study of biotic and abiotic interactions over a range of ecosystem settings.

[1]This article was prepared by the authors on behalf of the Ecohydrology Technical Committee.

References:

Caylor, K.K., D'Odorico, P. and Rodriguez-Iturbe, I., 2006. On the ecohydrology of structurally heterogeneous semiarid landscapes, *Water Resources Research*, 42: W07424.

Grimm, N.B and co-authors, 2008. Global change and the ecology of cities, *Science* 319(5864), 756-760.

Ivanov, V.Y., Bras, R.L. and Vivoni, E.R., 2008. Vegetation-hydrology dynamics in complex terrain of semiarid Areas. II. Energy-water controls of vegetation spatiotemporal dynamics and topographic niches of favorability, *Water Resources Research* 44, W03430.

Rodriguez-Iturbe, I. and Porporato A., 2005. *Ecohydrology of water-controlled ecosystems,* Cambridge Univ. Press, Cambridge, U.K., 460 pp.

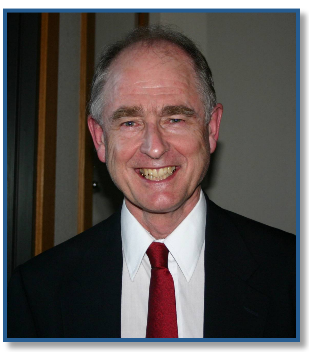
Scanlon, B.R., Jolly, I., Sophocleous, M. and Zhang L., 2007. Global impacts of conversions from natural to agricultural ecosystems on water resources: Quantity versus quality, *Water Resources Research* 43, W03437.

Schwartz, M.D., 2003. *Phenology: An Integrative Environmental Science*, Kluwer Academic Publishers, Dordrecht, The Netherlands, 592 pp.

Steve Burges Retirement Symposium

Nicoleta Cristea (University of Washington)

In a career that has spanned four decades, Steve Burges has made significant contributions to the fields of hydrology and water management. As important as his own work has been, the advice that he has provided to generations of hydrologists arguably has influenced the field just as much. Steve is a past Editor of *Water Resources Research* (1980-1985) and served as President of the AGU Hydrology Section from 1994-1996. He was the 2001 Langbein Lecturer; the recipient of the Ray K. Linsley Award of the American Institute of Hydrology in 2003 *for major contributions to engineering hydrology*; and received the American Society of Civil Engineers' Ven Te Chow Award in 2008.



In honor of Steve's career, the University of Washington hosted symposium in Seattle March 24-26, 2010, titled *Hydrology in the 21st Century: Links to the past and a vision for the future*. Colleagues, former students, and collaborators assembled from around the world to honor Steve's diverse and distinguished career. Meeting participants were invited to present and discuss ongoing research, identify how it is linked to the past and will project into the future, and to share personal thoughts on how Steve Burges influenced their professional paths and lives.

The symposium consisted of five half-day sessions, each of which began with a keynote talk assessing the evolution of selected sub-disciplines and future directions. Rafael Bras, (College of Engineering, UC Irvine) opened the meeting with a review *Thirty years of complexity in hydrology (and thirty years of fun with Steve Burges)*. The second keynote speaker, John Wilson (New Mexico Tech) continued with reflections on *Groundwater science in an evolving interdisciplinary world*. The remaining keynote presentations addressed some of the challenges and opportunities of the current trends in hydrologic research: *The changing carpet of hydrology: Shifts in magnitude-frequency-duration require new thinking* (Efi Foufoula-Georgiou, University of Minnesota); *A testbed for integrated water cycle observations :A grand challenge for the community* (Eric Wood, Princeton University) and *Will restoring wet meadows solve California's water problems?: A curmudgeon's tale* (Gordon Grant, USDA Forest Sciences Laboratory, Corvallis).

Keynote speakers were followed by oral and poster presentations covering topics related to surface and subsurface hydrology, water management, remote sensing and large scale hydrology, among many others. The event concluded with a talk by Steve *Why I am an optimist* that reflected on developments in hydrology in the context of the broader socio-political setting during his professional life.

The complete symposium program and more details about the event are available online at: www.hydro.washington.edu/burges_symposium;

Steve's talk is available at www.hydro.washington.edu/burges_symposium/video. Many of the presentations are expected to be contributed as papers for a special section of *Water Resources Research* that is now in review.

NRC Challenges and opportunities study

George Hornberger (Vanderbilt University) and Laura Helsabeck (National Research Council)

The National Research Council's Water Science and Technology Board has launched a new study of current and emerging challenges and opportunities in the hydrologic sciences, which effectively will be an update of the so-called NRC Eagleson Report ("blue book*") Opportunities in the Hydrological Sciences* (NAS Press, 1991). The current study will review the current status of Hydrology and its subfields and of their coupling with related geosciences and biosciences. The committee is also charged with identifying promising new opportunities to advance hydrologic sciences for better understanding of the water cycle that can be used to improve human welfare and the health of the environment. In particular, the study is intended to:

- Identify important and emerging issues in hydrology and related sciences,
- Assess how current research modalities impact the ability of hydrologic sciences to address important and emerging issues,
- Identify needs and research and education opportunities for making significant advances in hydrologic sciences, and
- Assess current capabilities in and identify opportunities to strengthen observational systems, data management, modeling capacity, and collaborations needed to support continued advancement of hydrologic sciences, and also their relationships to and value for mission-related agencies and, reciprocally, how observational systems of mission-related agencies relate to and contribute to hydrologic sciences.

The study sponsored is the National Science Foundation. George M. Hornberger of Vanderbilt University is the committee chair; the study director is WSTB staff officer Laura J. Helsabeck (lhelsabeck@nas.edu). The committee intends to meet five times over a 24-month period; its report is expected to be released late in 2011. For more information, including committee membership see: http://www8.nationalacademies.org/cp/projectview.aspx?key=49153. Updates on the activities of the committee including meeting information can be obtained by requesting addition to the committee listserv, contact Stephen Russell (srussell@nas.edu).

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