American Geophysical Union | Hydrology Section | December 2018 Newsletter

December 2018

Newsletter

Hydrology Section

FALL MEETING
Washington, D.C. | 10–14 Dec 2018

AGU100 ADVANCING EARTH AND SPACE SCIENCE

In this Issue

AGU100 ADVANCING EARTH AND SPACE SCIENCE | Hydrology

From the Section President

Jeffrey J. McDonnell, University of Saskatchewan

It's a pleasure to welcome everyone to the Hydrology Section (HS) Fall Newsletter. AGU is less than a month away and the HS is a hub of activity! As always, I want to celebrate a few things with you in this newsletter and then update you on developments within the section and the DC Fall Meeting. The newsletter then follows with reports from our Executive with contributions from the President-Elect, Secretary, Water Resources Research (WRR) Editor-in-Chief, Student Sub-Committee Chair and then write-ups from some of our recent AGU HS Fellows and Union award winners. I want to thank Jaivime Evaristo for doing such a great job assembling all this material in the newsletter and maintaining the HS web page.

Passing the baton: My term as President ends following the DC meeting. This will be bitter sweet as I have enjoyed serving as section President these past two years. As I have said before, being President of the AGU HS requires a light touch, but I think that together, we have made some small improvements over the past two years:

"I have enjoyed serving as Section President these past two years"

Nominations: We now have a new nomination process for section awards that is simple, straightforward and resulted in considerable increases in nominations this past cycle. As such, we will continue with the new process in this next year.

Technical Committees: The quarterly WebEx meetings with the HS Executive and the Technical Committees (TC) Chairs has proved to be a useful model for attending to HS business. The Rodell report (see the July 2018 newsletter) will be a roadmap for future changes to our TC operations.

Award Committee Best Practices: After consultation with HS Award Chairs and the HS Executive, I have crafted some Best Practices to help guide our HS award practices (https://hydrology.agu.org/awards).

Early Career Award: Additional recognition for the HS Early Career Award has now been approved by AGU. Going forward, we will have "up to 3" awardees for the Early Career Award.

MOU with IAHS: We have a signed MOU with the International Association of Hydrological Sciences (IAHS) to pursue exchanges of information, conferences and workshops. This will begin in earnest at the July 2019 IUGG/IAHS meeting in Montreal.

Nominations Committee (starting next year): Beginning January 2019 when I take over as Chair of the HS Nominations Committee, the committee will evolve from a 'drumming-up nominations' committee to also a 'nominations-writing' committee. Using excellence as our principal goal and priority for award nominations, we will seek to supplement the much larger number of nominations from HS members with nominations focused on further improving our diversity and equity.

Despite all this, there is still much to do. We need to 'up our game' in the way of communications, and implement some of the recommendations in the Famiglietti Ad Hoc Report (see December 2017 newsletter). We need to do more with international engagement and representativeness on committees and awards. And, engaging better with our Chinese colleagues who are now second to our American colleagues in HS membership and Fall Meeting attendance. I too would like to see ways to further recognize excellence in our Early Career members: a post-doctoral excellence award perhaps; recognition for outstanding achievement in field investigations, etc.

I leave the Section in terrific hands. Scott Tyler and I have worked closely together these past two years (including a few days together in Reno last month to orchestrate the leadership transition). Scott is ready to take on the leadership mantle and has spent the last two years on the Council Leadership Team where he learned much of AGU's internal machinations. He leaves the AGU Fellows Selection Committee (that he chaired as President-Elect) in great shape and I know he will be a hardworking and dedicated leader starting January 1st. Thank-you Scott! We all look forward to your leadership in 2019! To our absolute delight, Charlie Luce is continuing for a second term as HS Secretary. Charlie is the unsung hero of the HS: juggling the Student Travel Grant Committee, the Outstanding Student Presentation Committee and so many other things. Thank-you Charlie! Efi Foufoula-Georgiou will end shortly her term as Past-President and Nominations Committee Chair. This concludes 6 years of dedicated service to our section, including leading the assembly of names for the new President-Elect position. Thank-you Efi for your service! As you all know, our incoming President-Elect is Ana Barros, who will begin her term on January 1, 2019. Congratulations Ana and best of luck as you begin your six-year leadership term, as President-Elect, President and Past-President.

Congratulations: I want to congratulate our Union Fellows from the HS: Andrew T. Fisher, University of California, Santa Cruz (co-sponsored with Ocean Sciences); Hayley J. Fowler, Newcastle University; Charles Harvey, Massachusetts Institute of Technology; Heidi Nepf, Massachusetts Institute of Technology (co-sponsored with Ocean Sciences); Christa D. Peters-Lidard, NASA Goddard Space Flight Center; Balaji Rajagopalan, University of Colorado, Boulder; Lee Slater, Rutgers University (co-sponsored with Near Surface Geophysics); David Tarboton, Utah State University (co-sponsored with Informatics) and Doerthe Tetzlaff, IGB Leibniz Institute of Freshwater Ecology and Inland Fisheries and Humboldt University. Such Fellowship recognition is rare as no more than 0.01 percent of the total AGU membership is recognized annually. Well done, class of 2018! We look forward to celebrating with you in DC.

“Going forward, we will have ‘up to 3’ awardees for the Early Career Award”

We also have a number of members of our HS who have received Union honors, and these will be celebrated at the DC meeting. Congratulations to Dennis Lettenmaier (UCLA), recipient of this year's Robert Horton Medal; Esteban Jobbagy (Universidad Nacional de San Luis) for the Ambassador Award; Walter Immerzeel (Utrecht University) for the Macelwane Award; Rick Hooper (CUASHI) for the Flinn Award; and Alberto Montanari (University of Bologna) for the William Kaula Award.

Fall Meeting: The DC Fall Meeting is set to break all attendance records. Megan Smith (our Program Committee Chair) and her committee have done outstanding work in assembling the many HS sessions. This is very hard work and we owe Megan and her committee a huge debt of gratitude. Megan Brown (Student Chair) and her committee have also been hard at work in preparation for DC and we commend their efforts. Both of their reports in this newsletter outline what you can expect at the Fall meeting. Here I wish to highlight but a few things:

“We need to ‘up our game’ in the way of communications”

(1) Centennial Session: 100 Years of Progress in Hydrologic Science (Tues, Dec 2018, 08:00 - 10:00am)

This session is led by Adam Ward and will kick-off the HS's year of centennial celebrations by reflecting on the evolution of our discipline. The session features a slate of invited speakers highlighting key advances and changing paradigms in hydrologic science, and the role of our evolving scientific methods and techniques (measurement, modeling, conceptualization, and experimentation) in advancing hydrologic science.

(2) Langbein Award Lectures and Section Award Celebrations (Tues, Dec 11, 4-6pm)

From the Section President (continued)

I hope that every member of the HS can attend this celebratory event. The program will be as follows:

4-4:30pm
Introduction
Citationist for the Hydrological Sciences Award (Lu Zhang)
Hydrological Sciences Award response (Bridget Scanlon)
Citationist for the Early Career Award (Günter Blöschl)
Early Career Award response (Yoshihide Wada)
Celebration of Union Awardees and Fellows

~4:30-6pm
Citationist for the Langbein Lecture (John Selker)
Langbein (response and) Lecture, Dani Or

(3) Hydrology Section and CUAHSI Business Meeting (Tues, Dec 11, 6:30-8pm, Grand Hyatt)

The HS Business Meeting is again co-sponsored by CUAHSI. The meeting will start following the end of the Langbein Lecture festivities. We have sold a record number (750) tickets. We'll have a short <30 min program that will begin at 7pm sharp. This will include:

Welcome, Jeff McDonnell, President, Hydrology Section
Welcome, Gordon Grant, Incoming Chair of the CUAHSI Board of Directors
Small announcement from NSF, Holly Barnard
Presentation of the Horton Research Grants
WRR Editors report from Martyn Clark, Editor-in-Chief
Concluding remarks by Jeff McDonnell and Scott Tyler

(4) Catchment Science Symposium (Wed, Dec 12, 8:20am-5pm; note that this will be held in the nearby Washington Grand Hyatt hotel)

We will again have this special symposium within AGU week. The day is meant to be a refuge from the main meeting and to serve as community building exercise across our section. It is led by Jim Kirchner and includes invited talks from topical areas across our broad section.

(5) The Paul A. Witherspoon Lecture (Thurs, Dec 13, 1:40-2:40pm)

This special lecture will begin with a citation by Jud Harvey and then response and lecture by this year's awardee, Beth Boyer. Congratulations Beth!

6. Annual WRR Synthesis Session (Thurs, Dec 13, 10:20am-12:20pm)

In this session, editors and authors from Water Resources Research will discuss areas of fundamental growth, summarizing the key scientific messages and highlighting emergent research challenges. Overview presentations will offer context and framing relative to the broader field from both reflective and visioning perspectives.

Best wishes for a spectacular Fall Meeting! It has been an honor and pleasure to serve as your President these past two years. I look forward to seeing all of you in DC and socializing with you at the Business Meeting.

Hydrology Section Business Meeting and Awards Reception
(jointly sponsored with CUAHSI)

6:30-8:30 pm
Grand Hyatt Independence East and Corridor B

Note: This is a ticketed event
Cost to attend: $15

Catchment Science Symposium 2018

8:20am-5:00 pm
Grand Hyatt Washington

From the Section President-Elect

Scott Tyler, University of Nevada Reno

As my term as President-Elect winds down, I am looking forward to the opportunities and challenges of serving as your president for the next two years. I am very pleased to join an incredible team of Hydrology Section volunteers who daily make sacrifices of their time to move the Section forward. Starting in 2019, I look forward to working closely with our dedicated Executive Committee. It is a pleasure to welcome to the Executive Committee Ana Barros as our new Section President-Elect. Charlie Luce will be returning as Section Secretary; a role that requires a significant commitment of time and energy; a role that he has done with tremendous grace and efficiency over the past two years. Jeff McDonnell will be moving into the role of Past-President, where he will continue his efforts in recruiting Section leadership and awards. I also want to personally thank outgoing Past-President Efi Foufoula-Georgiou for her efforts in many areas of the Section and Union. I also want to shout out to Jaivime Evaristo who will be staying on in 2019 as our tremendous Newsletter Editor and website guru!

Over the past two years, we have implemented significant changes in our awards procedures and in our technical committee participation, and I will continue to give these my full attention. These changes have resulted in significant advances in the efficiency, transparency and diversity of our awards and committee participation. You will be seeing some minor changes based on feedback we have had over the past year, and I look forward to continuous improvement and transparency in all of the operations of the Section.

In addition to keeping the Section "running along on the rails", I look forward to working on several new initiatives with your help. When I first considered running for Section leadership, I believed that the Section could expand its communication efforts, both to reach our own membership, but also to be more effective in reaching policy makers and the public. Working off last year's report from our Task Force on Strategic Communication (December 2017 Section Newsletter), we are already on the way to this goal. Thanks to the energy of our Water and Policy Technical Committee the Section is sponsoring the first "Science and Water Policy Panel" on Thursday afternoon of the Annual Meeting in partnership with the National Academies of Science, Engineering and Medicine. I encourage you to register for this opportunity to engage with federal and state policy leaders, as well as legislative staff. Seating is very limited and registration is required (Free registration **here**).

Our newsletter and website will continue to be the flagship of member communication, but as I stated two years ago, I hope to engage our members in new and creative ways. Several of our Technical Committees are already experimenting with new forms of rapid communication and social media, and I am looking forward to working with these innovators to bring our Section communication to the forefront. As this is an area somewhat new to me also, I will be looking to all of our membership for input, advice and ideas.

Beginning early last year, we have also been informally discussing the logic and logistics of spinning off an independent Hydrology Section meeting, similar in concept to the long running, alternate year Ocean Sciences Section meeting. The concept was initially motivated by both opportunities within AGU and also from many of our Section membership's concerns over the enormity of the Annual Meeting. Such a meeting

"These changes have resulted in significant advances in the efficiency, transparency and diversity of our awards and committee participation."

would not replace the Annual Meeting, but could give our community an opportunity to focus on such areas as emerging topics in hydrology. Based on informal discussions with many of you, there is general support but also expected questions. Most importantly, I am not seeking to “add yet another meeting” to your busy schedules, or dilute our presence at existing meetings but rather see if we can leverage the Section’s strength to increase our communication and impact to society. This is very much a “work under consideration” and I will be convening a Section Task Force in early 2019 to formally gather input and assess the pros and cons of such an off year meeting. The Task Force will be comprised of both our membership, and members from our partner organizations and consortia, many of whom are also looking for ways to expand their communication within our discipline. I believe there is an opportunity here for the Section to add to its visibility and collaboration, but not without a thorough and transparent assessment of the benefits and costs. I am looking forward to hearing from you to hear your opinions, interests and ideas and I hope that you will respond to requests for input from the Task Force in 2019.

And finally, I want to personally thank outgoing President Jeff McDonnell for his leadership, inspiration and friendship. It has really been a pleasure to work with and learn from him, and I hope that I can continue the tradition of leadership and motivation that he and past section presidents have shown.

From the Section Secretary

Charlie Luce, United States Forest Service Boise

Meetings are an important part of the scientific process. They are, at the simplest level, a place where scientists share their results and ideas. More than that, though, meetings are a place where many conversations happen, where a breadth of ideas on related topics for a project can be explored to find context and to relate recent efforts to work that many others have been doing. It’s also a place for honing messages and practicing ways to present and frame ideas. It’s all about communication.

Annually, many students come to AGU to listen and present, to engage in this particular component of the scientific process. And, annually, many established scientists volunteer their time to engage these students to learn about what they are working on and to help them improve their presentation skills. Under the aegis of the Outstanding Student Paper Award (OSPA), anonymous “judges” view student presentations and visit their posters to learn about their work and offer some written impressions and feedback.

Like many review tasks, presentation judging can seem thankless, and it is difficult to know if the comments and thoughts made much difference. So, in this brief period of the year where we take a moment to focus on gratitude, it seems worthwhile to share some thanks from some of the 25 OSPA awardees from the 2017 Fall Meeting:

“Thank you so much for this great honor! To the coordinators, thank you for giving me the opportunity to give a talk. The session was great; I learned a lot and got great feedback on my project. To the judges, thank you for taking the time to come to my talk and for the helpful comments! I really appreciate it. I hope to be a part of this session again next year!”

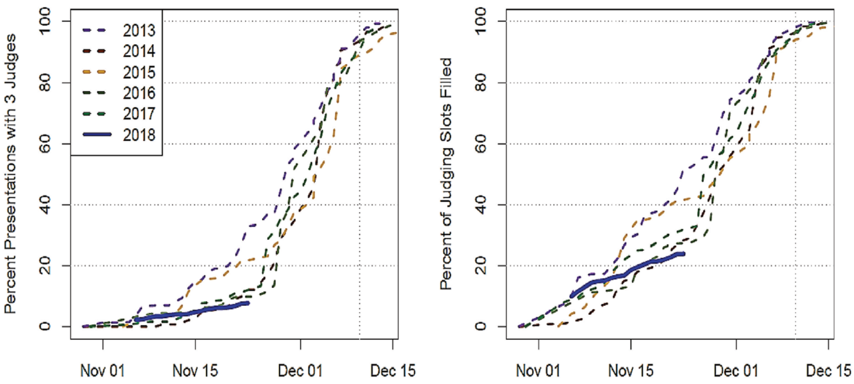
“Thank you for your time and effort! I know this is voluntary service and it is really helpful, especially the specific feedback. I appreciate your comments and will work on addressing them in future presentations. I often don't get specific feedback like this at other presentations, so yours is important for my improvement. Thanks!"

“Thank you so much for the feedback on my presentation, I know from speaking to other judges at the meeting that it was a significant commitment to volunteer. I actually felt quite disappointed and disheartened after my presentation, I felt it was nervy and

rushed. So it's great to get positive responses back, and I know I can improve on the timing. I'll definitely be less nervous going into my next conference talk thanks to this!"

"Thank you very much for your feedback, the positive comments surely encourage me as a student and I also thank you for the constructive criticism that will help me improve for future presentations."

"Thank you to the coordinators and judges who took time out of their busy schedules to organize this event! I had a great time at AGU and am honored to receive such an award."



Progress on judge recruitment for the 2018 meeting. The vertical grey line on Dec. 10 denotes the start of the meeting, against which the timing of signups for previous meetings are normalized.

"Thank you for your time and effort in judging my presentation, particularly at 5:15 on Friday afternoon. I feel honored to have received an award."
"Thank you for all your work and for making AGU such an enjoyable experience. The feedback I got on my research, the connections made within and across fields, and the motivation to keep moving forward are benefits that will carry me through my graduate education and beyond. I am truly grateful to the AGU community."

"Dear Judges, Thank you for your time and valuable feedback. I am honoured to receive this award and it provides great motivation to continue my research, attend future conferences and improve my presentation!"

"Dear Coordinators and Jugdes, I thank you very much for the time and effort you spend on coordinating and judging all the student posters. I appreciate the valuable work you are doing."

"Coordinators and Judges, Thank you for your time and interest. It makes me hopeful as a student that there are people who will volunteer their time and efforts to help develop young scientists and provide them with valuable feedback. I enjoyed talking to you and sharing my research with you."

"Thank you to the judges and individuals who came to my poster and provided feedback and support for my work. It has been a long and difficult road but it is great to hear such positive reactions. I had no idea who were my judges, so good job on being anonymous but at the same time inquisitive enough to glean sufficient information from my poster for judging purposes. Thank you all!"

"Thank you so much for the wonderful organization and the efforts of judges. I really appreciate it! Also thank you for the positive feedback on my work and this honor. I am really grateful to have it."

From these comments, I hope it is easy to see the value that student presentation judges bring to the meeting for this emergent generation of scientists. Certainly, I've appreciated the value from the other side, both in learning some of their cutting edge work and further in reflecting on how to better communicate ideas to those who may be unfamiliar with the field of work I am in. To the many judges from previous years, I add my thanks to your support for our community, and hope you can help again this year.

Participation of students in OSPA at the 2018 Fall Meeting nearly matches the record set by OSPA participation in 2017. In 2017, 510 presentations were judged and this year, 508 students have signed up to be judged. The 2018 OSPA committee, Rolf Hut (Delft University), Alicia Kinoshita (San Diego State University), Matthew Weingarten (Stanford University), Heidi Asbjornsen (University of New Hampshire), and I have been working with Liaisons trying to encourage judges to sign up. So far judge sign-ups are lagging previous years, and we could use some help!

Fall Meeting Updates

Megan Smith (Hydrology Section Fall Meeting Committee Chair)

Hydrology Section Events

Date	Time	Title	Location
Tuesday, 11 December	8:00-10:00	H21B – Centennial Session: 100 Years of Progress in Hydrologic Science I	Walter E. Washington Convention Center – 146B
Tuesday, 11 December	10:20-12:20	H21B – Centennial Session: 100 Years of Progress in Hydrologic Science II	Walter E. Washington Convention Center – 146B
Tuesday, 11 December	16:00-18:00	Walter B. Langbein Lecture	Marriot Marquis – Marquis 5
Tuesday, 11 December	18:30-20:00	Hydrology Section Business Meeting	Grand Hyatt – Independence East and Corridor B
Wednesday, 12 December	8:20-17:00	Catchment Science Symposium	-
Wednesday, 12 December	18:00	Honors Ceremony	Walter E. Washington Convention Center – Ballroom A-C
Wednesday, 12 December	20:00	Honors Banquet	Grand Hyatt – Independence
Thursday, 13 December	10:20-12:20	H42F – Recent Advances in the Hydrologic Sciences (Talks & Panel)	Walter E. Washington Convention Center – 146B
Thursday, 13 December	13:40-14:40	Paul A. Witherspoon Lecture	Marriot Marquis – Marquis 5
Thursday, 13 December	18:00-19:30	Biogeosciences, Geohealth, Global Environmental Change, Hydrology, and Societal Impacts and Policy Sciences Joint Sections Early Career Student Event	Grand Hyatt – Independence F-I

Union Lectures of Interest

Date	Time	Title	Location
Monday, 10 December	12:30-13:30	2018 AGU Presidential Forum Lecture: Lisa Jackson	Walter E. Washington Convention Center – Ballroom A-C
Monday, 10 December	16:00-18:00	U14A – Can We Manage Earth's Future?	Walter E. Washington Convention Center – 202A
Tuesday, 11 December	8:00-10:00	U21B – Toward a More Resilient Global Society	Walter E. Washington Convention Center – 202A
Tuesday, 11 December	16:00-18:00	U24A – Highlights from the 4th National Climate Assessment	Walter E. Washington Convention Center – 202A
Wednesday, 12 December	8:00-10:00	U31A – How Science Influences Action: Responding to Climate Change in Developing Countries	Walter E. Washington Convention Center – 202A
Wednesday, 12 December	12:30-13:30	U33C – Sexual Harassment of Women: Climate Culture and Consequences – with Special Emphasis on Earth and Space Science Work Environments	Walter E. Washington Convention Center – Ballroom A-C
Thursday, 13 December	12:30-13:30	U43B – Agency Lecture: Jim Reilly	Walter E. Washington Convention Center – Ballroom A-C
Thursday, 13 December	13:40-15:40	U44A – The New Generation of Scientists	Walter E. Washington Convention Center – 202A
Friday, 14 December	13:40-15:40	U53B – AGU Literature Review Panel	Marriott Marquis – Marquis 12-13

Town Hall Meetings and Tutorial Talks

Date	Time	Title	Location
Monday, 10 December	12:30-13:30	TH13A – Alternative Careers: I Can Do Research There?	Marriott Marquis – Marquis 12-13
Monday, 10 December	18:15-19:15	TH15B – Diversity and Inclusion Town Hall: Action Recommendations from AGU and NAS	Walter E. Washington Convention Center – 204A-C
Tuesday, 11 December	12:30-13:30	TH23E – NASA Earth Science Division Town Hall Session	Marriot Marquis – Capitol/Congress
Tuesday, 11 December	12:30-13:30	TH23F – NSF Geosciences Town Hall	Marriott Marquis – Independence D
Tuesday, 11 December	12:30-13:30	TH23K – Using Observationally Based Metrics to Evaluate and Improve Precipitation	Marriott Marquis – Independence F-H

Town Hall Meetings and Tutorial Talks (continued)

Date	Time	Title	Location
Wednesday, 12 December	12:30-13:30	TH33A – Carbon, Climate, and Everything Else: More than 20 Years of Research Coordination, Advancing, and Assessing Science	Marriott Marquis – Independence A-C
Thursday, 13 December	10:50-11:20	TT42B – Ecological Drought: An Emerging Threat Across the U.S.	Marriott Marquis – University of DC/Catholic University
Thursday, 13 December	12:30-13:30	TH43A – Critical Zone Observatories: Platforms for Collaborative Science	Marriott Marquis – Independence A-C
Thursday, 13 December	12:30-13:30	TH43J – The U.S. Global Change Research Program's Interagency Integrated Water Cycle Group	Marriott Marquis – Liberty N-P
Thursday, 13 December	12:30-13:30	TH43K – WHONDRS: A Community Resource for Studying Dynamic River Corridors	Marriott Marquis - Archives
Thursday, 13 December	18:15-19:15	TH45B – DOE's Climate and Environmental Sciences Division Strategic Plan	Marriot Marquis – Liberty I-K
Thursday, 13 December	18:15-19:15	TH45E – Next-Generation Measurements of Changes in Vegetation and Ice Cover	Marriott Marquis – Independence D
Friday, 14 December	12:30-13:30	TH53J – Water Security in China and Southeast Asia	Marriott Marquis – Independence A-C
Friday, 14 December	12:30-13:30	TH53L – The New, the Underutilized, and the Upcoming: Applications of Remote-Sensing Data to Decision-Making	Marriott Marquis – Marquis 9-10

From the Section Student Subcommittee Chair

Megan Brown, University of Colorado Boulder

The members of H3S have been busy putting together events and activities for this year's Fall Meeting. H3S Members look forward to seeing you at the Student and Early Career Scientist Conference on Sunday, December 9 (registration required). We also hope you'll join us at our two Town Hall Meetings that focus on alternative careers to academia. On Monday, December 10 and Tuesday, December 11 from 12:30 – 1:30 PM join us for a free buffet lunch and discussion on alternative careers in science. Monday will have a panel of researchers that work at places other than the more traditional university setting (TH13A: Alternative Careers: I Can Do Research There? Research in Places You May Not Expect, Marriott Marquis, Room: Marquis 12-13), and Tuesday will have a panel of scientists whose work deals directly with policy, defense, and international aid (TH23A: Alternative Careers: Research in Action in Washington, DC, Marriott Marquis, Room: Liberty N-P).

"At the Fall Meeting, H3S will be wearing buttons indicating they are members; we hope you will say hello and ask us any questions you have."

We also have two workshops planned: one that focuses on tip and tricks for using technology to increase your efficiency (Tuesday, December 11, 2:00 – 4:00 PM, Outsmart Your Research with Contemporary Technology) and one on scaling relationships in hydrologic modeling featuring an expert panel (Thursday, December 13, 10:00 – 11:30 AM, Identifying Representative Spatial Scales in Hydrologic Modeling). Come join us in the Convention Center's Career Workshop Room Tuesday and Thursday to learn more about these topics. Find more information: https://fallmeeting.agu.org/2018/students/events/.

H3S is also hosting five Pop-Up Sessions in their original format. Join us Monday, Dec. 10; Tuesday, Dec. 11; and Thursday, Dec. 13 from 4:00 – 6:00 PM in the Convention Center Hall E: Career Center and Student Lounge for short format talks on a variety of topics. Monday we will have pop-ups on *The role of a scientist in the 21st century: Big Ideas for the next 100 years and how to get there.* On Tuesday, we will focus on Hydrology with two sessions: *Frontiers in Hydrology: Paths Toward the Next Century in Water Research and Hydrology for Public Good: Best Practices and Lessons Learned from Community Engagement*. On Thursday, we will have pop-up talks from two sessions focused on the social and policy side of science: *Building Communities Through Shared Experiences: Social Dimensions in AGU and Bridging Science and Policy for Change: Best Practices.* The Pop-Up schedule with individual talk information will be posted on our website (https://hydrology.agu.org/student/hydrology-student-subcommittee) soon.

Friends of H3S, Sam Zipper and Sheila Saia, have organized a Hydrology Coding Help Desk that will be available for walk-in help and short 10-15 minute tutorials on specific topics each day (e.g. version control, spatial data analysis, streamflow depletion models, etc.), which will be announced the week before the meeting. The Coding Help Desk will be open Monday – Thursday (Dec. 10 – 13) 10:00 AM – 12:00 PM in the Career Center and Student Lounge.

We also hope you will come meet with H3S members during the Hydrology Section Business Meeting and Reception (Tuesday, December 11, 6:30 PM – 8:00 PM, Grand Hyatt Washington, Independence East & Corridor B) and at the Biogeosciences, Geohealth, Global Environmental Change, Hydrology, & Societal Impacts and Policy Sciences Joint Sections Early Career and Student Event (Thursday, December 13, 6:00 – 7:30 PM, Grand Hyatt Washington - Independence Level, Rooms F, G, H & I). We will be available in the Convention Center Hall E: Career Center and Student Lounge Wednesday, December 12, from 4:00 – 6:00 PM to answer any questions about H3S and to hear your suggestions on future activities and events. We also have a poster on Wednesday (Dec. 12) afternoon: ED33E-1124: Beyond the Water Cooler: Networking Lessons Learned by the Hydrology Section Student Subcommittee (H3S).

As always, follow us on Twitter (@AGU_H3S) for updates. We were thrilled with the response to our "Haiku Your Research" contest on Twitter, and we will be announcing the winners soon. At the Fall Meeting, H3S will be wearing buttons indicating they are members; we hope you will say hello and ask us any questions you have. Watch for our call for new members just after the Fall Meeting with an application deadline in early January. See you in DC!

From Water Resources Research Editorial Board

Martyn Clark (Editor-in-Chief), Jean Bahr, Marc Bierkens, Jim Hall, Charles Luce, Jessica Lundquist, Scott Mackay, Ilja van Meerveld, Harihar Rajaram, Xavier Sanchez-Vila, Peter Troch, and Ellen Wohl (Editors)

We're very happy to report that 2018 has been an excellent year for WRR. We're continuing to see high-quality innovative contributions across a broad range of topics. In addition to regular WRR submissions, the WRR special sections are helping to catalyze advances across many sub-fields of hydrologic science. Noteworthy special sections in 2018 include (1) the dynamics of intensively managed landscapes; (2) advances in remote sensing, measurement, and simulation of seasonal snow; and (3) big data and machine learning in water sciences. Key growth areas for WRR include advances in interdisciplinary models of coupled human-hydrology interactions as well as advances in integrated hydrologic simulations across continental and global domains.

Water Resources Research
AN AGU JOURNAL

The WRR special section on socio-hydrology deserves special mention. Early socio-hydrology research was based on rather simplistic models of coupled human-hydrology interactions for individual basins, but is now maturing as a rigorous sub-field in the hydrologic sciences. The 30+ papers published in the WRR special section exemplify how the field of socio-hydrology is broadening its disciplinary base, strengthening its theoretical underpinnings, expanding in scope to regional and global scales, and increasing in value for debates on threats/responses to water security. Please see the excellent paper, "*Expanding the scope and foundation of socio-hydrology as the science of coupled human-water systems*" (WRR 2018), where Megan Konar and her colleagues summarize the key contributions of the papers in the socio-hydrology special section and articulate outstanding research needs.

As we move towards the Fall Meeting and the start of the AGU Centennial celebrations, we see an important role for WRR to help the community brag about its accomplishments. We will kick-off the Hydrology Section's year of centennial celebrations by reflecting on the evolution of our discipline and defining a bold path forward for the future of hydrology (Centennial Session: 100 years of progress in hydrologic science, on Tuesday morning, led by Adam Ward). This Centennial session features a slate of invited speakers to highlight key advances and changing paradigms in hydrologic science, and the role of our evolving scientific methods and techniques in advancing hydrologic science. We're inviting the speakers in the session – as well as others in the community – to submit papers to a new special section on "Game changers in hydrology", to discuss the difficulties/surprises/controversies encountered as the research developed, how science questions were refined, how discoveries/capabilities were used in unexpected ways, and how the research benefited society.

"Key growth areas for WRR include advances in interdisciplinary models of coupled human-hydrology interactions as well as advances in integrated hydrologic simulations across continental and global domains."

Also at the AGU Fall Meeting, on Thursday morning, we will hold our second annual "WRR Session" on recent advances in the hydrologic sciences. In this session a past WRR editor provides a broad perspective on the evolution of hydrologic science, and editor-author pairs provide a synthesis of innovations published in WRR across different sub-fields of hydrology. For 2018, the past WRR Editor is Steve Burges, and the editor-author pairs are Jessica Lundquist and Laurie Huning (snow science), Jim Hall and David Yu (socio-hydrology), and Marc Bierkens and Luis Samaniego (global hydrology). We held our inaugural WRR Session at the 2017 Fall Meeting in New Orleans, to an overflowing room, where we had a vigorous interdisciplinary discussion of research challenges across different sub-fields in the hydrologic sciences.

Last, but certainly not least, it is our pleasure to announce the 2017 recipients of the WRR Editors' Choice Award. These papers represent an excellent cross-section of the major advances across different sub-fields in hydrology:

(1) Apurv, T., Sivapalan, M. and Cai, X., 2017. Understanding the role of climate characteristics in drought propagation. Water Resources Research, 53(11), pp.9304-9329.

(2) Bonnafous, L., Lall, U. and Siegel, J., 2017. An index for drought induced financial risk in the mining industry. Water Resources Research, 53(2), pp.1509-1524.

(3) Cheng, F.Y. and Basu, N.B., 2017. Biogeochemical hotspots: Role of small water bodies in landscape nutrient processing. Water Resources Research, 53(6), pp.5038-5056.

(4) De Simone, S. and Carrera, J., 2017. Analytical solutions to coupled HM problems to highlight the nonlocal nature of aquifer storage. Water Resources Research, 53(11), pp.9580-9599.

(5) Huang, Y., Liu, H., Hinkel, K., Yu, B., Beck, R. and Wu, J., 2017. Analysis of Thermal Structure of Arctic Lakes at Local and Regional Scales Using in Situ and Multidate Landsat-8 Data. Water Resources Research, 53(11), pp.9642-9658.

(6) Kim, H., Dietrich, W.E., Thurnhoffer, B.M., Bishop, J.K. and Fung, I.Y., 2017. Controls on solute concentration-discharge relationships revealed by simultaneous hydrochemistry observations of hillslope runoff and stream flow: The importance of critical zone structure. Water Resources Research, 53(2), pp.1424-1443.

(7) Suzuki, A., Watanabe, N., Li, K. and Horne, R.N., 2017. Fracture network created by 3-D print-

From Water Resources Research Editorial Board (continued)

er and its validation using CT images. Water Resources Research, 53(7), pp.6330-6339.

(8) Tennant, C.J., Harpold, A.A., Lohse, K.A., Godsey, S.E., Crosby, B.T., Larsen, L.G., Brooks, P.D., Van Kirk, R.W. and Glenn, N.F., 2017. Regional sensitivities of seasonal snowpack to elevation, aspect, and vegetation cover in western North America. Water Resources Research, 53(8), pp.6908-6926.

(9) Wing, O.E., Bates, P.D., Sampson, C.C., Smith, A.M., Johnson, K.A. and Erickson, T.A., 2017. Validation of a 30 m resolution flood hazard model of the conterminous United States. Water Resources Research, 53(9), pp.7968-7986.

(10) Yang, S., Paik, K., McGrath, G.S., Urich, C., Krueger, E., Kumar, P. and Rao, P.S.C., 2017. Functional topology of evolving urban drainage networks. Water Resources Research, 53(11), pp.8966-8979.

(11) Yu, D.J., Sangwan, N., Sung, K., Chen, X. and Merwade, V., 2017. Incorporating institutions and collective action into a sociohydrological model of flood resilience. Water Resources Research, 53(2), pp.1336-1353.

(12) Zimmer, M.A. and McGlynn, B.L., 2017. Ephemeral and intermittent runoff generation processes in a low relief, highly weathered catchment. Water Resources Research, 53(8), pp.7055-7077.

In addition to a number of well-established researchers, authors of the "Editors' Choice" papers include a number of early career scientists and engineers, and this bodes well for the future of hydrologic sciences. Please seek out these authors at the AGU Fall meeting and congratulate them for their outstanding work.

We're all very much looking forward to seeing you throughout the AGU Fall Meeting and learning more about your recent science discoveries. As always, please feel free to share your ideas, your opinions, your concerns, and your experiences, so that we can improve the extent that WRR advances hydrologic science.

"...authors of the "Editors' Choice" papers include a number of early career scientists and engineers, and this bodes well for the future of hydrologic sciences."

A Fellow Speaks: Collaborating Across Disciplines, Generations, and Communities

Andrew T. Fisher, University of California, Santa Cruz

I am grateful and humbled by this recognition, and appreciate AGU's Ocean Sciences and Hydrology sections for jointly supporting my nomination. I value being part of multiple research communities, and have many colleagues to acknowledge and thank.

As an undergraduate, I was inspired and encouraged by James Ingle, who told fascinating stories of marine geology, and John Harbaugh who introduced me to computing in Earth Science, including a brief unit on groundwater modeling. I am especially grateful to Keir Becker, my graduate advisor at the Rosenstiel School, University of Miami, where I went to study seafloor hydrothermal systems. Keir was part of the "second wave" of researchers who established the discipline of marine hydrogeology, and he has been an inspiring, thoughtful, and generous collaborator for 30+ years. Keir took me to sea during my first year as a graduate student on Ocean Drilling Program (ODP) Leg 102 to the North Atlantic Ocean, and shared expertise in geothermics, computational methods, crustal geophysics, and hydrogeology. He also served as a mentor by example, demonstrating resolve, tireless problem solving, and grace under difficult conditions.

Through Keir and the ODP, I learned about interdisciplinary research and met innovative leaders in geology, geophysics, geochemistry, and hydrogeology who influenced my thinking and became role models (and sometimes collaborators), including: Mark Langseth, Miriam Kastner, Joris Gieskes, Dick Von Herzen, Earl Davis, Susan Humphris, and Nari Narisimhan. Through ODP and other programs, I also met and collaborated with Geoff Wheat, Mike Underwood, Rob Harris, Paul Baker, Rob Zierenberg, Heiner Villinger, Volkard Spiess, Katrina Edwards, Dave Chapman, and Beth Orcutt, leading to decades of exploration and discovery. Mark, Dick, Nari, and Katrina are gone now; I miss them, and wish I could thank them directly.

As a graduate student, I worked on several seafloor geothermal projects, including a field study on the southern flank of Costa Rica Rift. This region had become one of several "endmember" examples of coupled fluid and heat flow in the volcanic crust beneath thick sediments, leading to systematic, regional deviations in seafloor heat flux. After returning from this expedition (and two others that year), I wished to learn about computer modeling of seafloor hydrothermal systems. Keir encouraged me to contact other researchers to find a collaborator with expertise in numerical methods that could be applied to fluid flow in the ocean crust. Keir introduced me to Nari Narasimhan, who offered to host an extended visit so that we could collaborate. The results of that work [(1) and later studies] helped to understand key characteristics of ridge-flank hydrothermal circulation, including: relations between bathymetric and basement relief and hydrothermal flow, isothermality at the sediment-basement interface, lateral flow in overlying sediments, and upper crustal permeability. The initial models demonstrated some basic features, and over the years, colleagues, students and I improved representation of these systems, eventually leading to the first three-dimensional, transient simulations of an outcrop-to-outcrop hydrothermal siphon, driving flow laterally through the crust across >50 km (2-4). It has been gratifying to advance these projects over time, with new observational and modeling studies building from earlier achievements and understanding.

After graduate school, my first job was as a staff scientist with ODP (which eventually became the Integrated Ocean Drilling Program, and later the International Ocean Discovery Program), focusing on downhole measurements and physical properties. This job offered many opportunities to learn and apply techniques, develop tools and software, write tutorials, edit site reports and other documents, and manage complex research projects. I also benefitted from working with people from many different backgrounds, including Tom Pettigrew, a Special Tools Engineer who designed and developed multiple generations of borehole observatory systems (with scientific leadership from Keir, Earl Davis, Bobb Carson, Geoff Wheat and others), and ODP/IODP Coring Technicians such as Joe "Bubba" Attryde. Core techs, drillers, operations superintendents and many other at-sea, technical heroes dedicate long, difficult days to fixing problems and achieving ambitious scientific goals.

Photo: A. Fisher, D. Winslow, J. Attryde, K. Becker on the deck of the DR/V Resolution, standing next to a long-term borehole observatory, on IODP Expedition 327 in 2010.

While I was a graduate student, I also sailed with ODP to the Barbados accretionary complex with J. Casey Moore, who exemplified creative thinking and grace; I never imagining that I would be his department colleague at UCSC 19 years later. I have also benefitted while at UCSC from collaboration with Eli Silver, Justin Revenaugh, Slawek Tulaczyk, and many outstanding students and postdocs. I worked with Eli and others on a series of hydrothermal and crustal studies offshore of Costa Rica, helping to identify a large region of chilled seafloor where there are massive flows of cool, hydrothermal fluid (5-7). Observational studies in that region lead to recent simulations showing that crustal permeability must be very high (10-10 to 10-9 m2), much greater than inferred or measured in other ridge-flank settings, to allow ridge-flank fluids to extract so much lithospheric heat between widely-spaced volcanic outcrops (8). Slawek introduced me to the polar research community and got me involved in an exciting drilling project to explore conditions below the West Antarctic Ice Sheet. My group and I also benefitted from working with Phil Stauffer, a graduate student at UCSC when I arrived, who introduced us to FEHM, LaGrit and related numerical tools for simulation of coupled flows. Phil connected us to his brilliant, thoughtful colleagues at LANL, including Carl Gable, George Zyvoloski, and Bryan Travis.

As I retooled for research in freshwater, I was encouraged and challenged by constructive interactions with Steve Ingebritsen, Graham Fogg, Ken Bencala, Paul Hsieh, Carol Kendall, and Roger Bales. Their advice and examples have led to productive studies in catchment hydrology, groundwater mechanics, surface water-groundwater interactions, and managed recharge. One impactful collaboration was with Christine Hatch and others, developing a new analytical method for interpretation of shallow thermal data to quantify surface water – groundwater interactions (9). Our main contributions were in (a) recognizing that time-series temperature signals at depth were more readily interpreted by filtering for a single frequency band (because different frequency signals travel at different rates), and (b) deriving an analytical solution that allowed rapid processing of long datasets to resolve changes in fluid flow rates and/or directions with time and as a function in sensor spacing (and not absolute depth). This work contributed to a renaissance in using heat as a tracer in hydrologic systems, including streams, wetlands, and groundwater infiltration basins. My group at UCSC later applied this method to understanding relations between infiltration during recharge and impacts on water quality and soil microbiology (e.g., 10, 11). Regional colleagues and I recently launched a program in Recharge Net Metering, incorporating lessons learned from many kinds of field, lab, and modeling studies, and incorporating social, legal, and economic considerations, as an incentive to encourage improved groundwater management, benefitting the quantity and quality of resources (12).

There are additional people who have collaborated and been influential as I've wandered between topics and disciplines, on land and at sea, but space is limited, so I'll close with this summary: I am indebted to numerous generous, patient, and smart colleagues, and grateful to work at a time and in a place where curiosity-driven research is possible. Finally, I have to thank my wife and daughter, Carrie Pomeroy and Cora Fisher, who have put up with frequent long absences, dad jokes, and mental lacunas. To all of the those listed above and many others: thank you for your support, trust, encouragement, and friendship.

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A Fellow Speaks: The Need To Combine Cutting-edge Science With Societal Needs

Hayley Fowler, Newcastle University

I am deeply honoured to be elected as a Fellow of the AGU, and excited to join the thousands of other scientists in celebrating this special year: the launch of the AGU's Centennial. I have been very lucky in my career to have been surrounded by many great hydrologists and climate scientists and would like to thank them for generously donating their time with wise mentorship and also to my committee who dedicated such effort to my nomination. I am indebted in particular to my mentors and advisors, Stuart Lane, Chris Kilsby, Enda O'Connell, Phil Jones, Rob Wilby, Dennis Lettenmaier and Linda Mearns to name but a few. I consider myself privileged to collaborate and be intellectually stimulated by so many colleagues and friends who have helped to shape my research and the academic I am today, and whose passion for hydroclimatology I now pass on to my students and post-docs.

My passion for hydrology, and mountains, was first shaped by a Geography fieldtrip to North Wales at the age of 16. Learning how ice had shaped and then water reshaped the landscape was both fascinating and startling, stimulating me to learn more. My intellectual approach to research was really cemented during my time as a Geography undergraduate at Cambridge in the mid-1990s. My mentor, Stuart Lane, was (and is) terrifyingly smart but also extremely generous with his time and extensive knowledge. I was privileged to spend two field-seasons on the Arolla Glacier investigating the connectivity of sub- and intra-glacial streams which further ignited my passion for understanding natural processes and for mountaineering. I then changed tack a little and moved to Newcastle University to study for a Masters in Water Resource Systems Engineering: I wanted to do research that mattered to society and this is a theme that has transcended my work ever since. I stayed on to do a PhD at Newcastle, to follow my two passions: of climbing and science; spending two happy summers hitching to and mountaineering in the Alps. By day doing data analysis and computer modelling researching climate change impacts on drought in Yorkshire, and then spending afternoons, evenings and weekends out in the great 'County' of Northumberland and elsewhere in the UK. It was a peaceful time of reflection and intellectual stimulus: the time before email got popular and there were no smart phones to distract us.

Since my PhD, for nearly two decades now, I have worked at the interface between hydrology and climatology, making significant contributions to three areas of climate change impacts research: the changing risks of extreme rainfall, floods and droughts, developing climate change scenario methodologies for local and regional scale studies, and examining the impacts of climate change on water resource systems in the developed and developing world. I have pioneered new downscaling techniques to bridge the gap between climate modellers and users of climate scenarios (e.g. UKCP09 Weather Generator) and to improve climate resilience by providing better projections of impacts for climate adaptation. My research has yielded important, and often fascinating, insights into the way our changing climate is affecting and will affect the way we manage water resources to minimise the potential impacts of floods and droughts and has demonstrated how sensitive hydrological systems are to relatively small changes in climate variability.

One of my key publications (Fowler et al. 2007) demonstrated the need for more impact-specific downscaling methods in hydrology and moreover, laid out recommendations to better link climate modelling to the needs of water resource management with the final objective of robust decision making. I see the need to combine cutting-edge science with societal needs, to provide solutions, or at least the path towards solutions, in a decision-focussed approach. This requires us, as scientists, to co-develop research which will deliver the bespoke tools and results that are needed for adaptation. Over the years I have followed my passions and interests in research and tried to get funding to address what I perceive as real societal needs. For example, my recent focus on blue skies research into intense short-duration rainfall extremes resulted from my identification of a real gap in the ability of standard resolution climate models to deliver such information for future projections (e.g. Fowler and Ekström, 2009). Over the last eight years, together with my close collaborators at the UK Met Office, we have developed new high-resolution convection-permitting climate models (based on the UKV weather forecast model) to produce the first climate-length runs. These projected a 5-fold increase in flash-flooding by the end of the century in the UK under RCP8.5 compared with no change projected by a 12-km standard-resolution convection-parameterised RCM (Kendon et al. 2014: Figure 1).
This is a robust result from different CPM simulations across different regions (Kendon et al. 2017) and means that all current regional and national climate

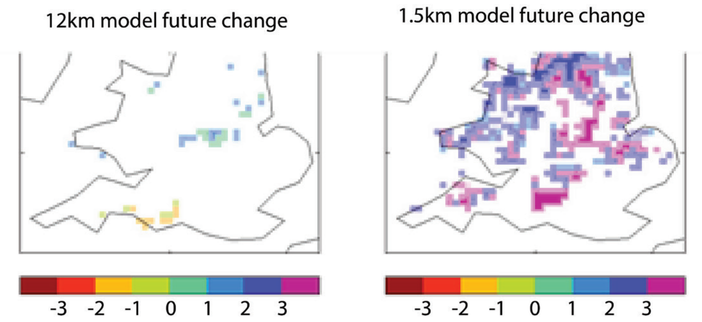

Figure 1: Adapted from Kendon et al. (2014). Heavy rainfall on hourly timescales (mm h^{-1}) in summer (June–July–August; JJA). Difference between 2100 and present-day for 12 km and 1.5 km models, left and right panels respectively. Heavy rainfall is defined as the mean of the upper 5% of wet values (>0.1mm h^{-1}). White indicates differences or future changes not significant at the 1% level compared to year-to-year variability.

scenarios provide inadequate information on changes to convective precipitation extremes. The UK Met Office are incorporating these high-resolution simulations into the next set of climate projections for the UK – UKCP18 - to be available next summer but how do we include this information in other national scenarios? We are now improving projections of other storm-related weather extremes and working with various stakeholders to co-develop and deliver new tools and climate change allowances for practitioners in the UK and Europe to be used alongside UKCP18 and contribute to the wider work by the European Environment Agency on climate change impacts and adaptation. My work will hopefully enable Europe to better deal with the impacts of climate change. Analysis of hourly rainfall extremes in other regions suggests that these are changing much faster than expected with warming (Guerreiro et al. 2018). It is through understanding the processes that drive these changes that we can understand how they will change in the future and how we need to adapt (Lenderink and Fowler, 2017; Lenderink et at. 2018).

To limit the impacts of climate change we need to act fast with mitigation – we've got 12 years according to the IPCC SR15 – but we will still need to adapt to increased climate variability and extremes. I really believe therefore in the need for both sustained engagement with the public and the need for training and mentoring of young people in interdisciplinary or transdisciplinary approaches to address the climate change Grand Challenge. With inspiration and strong leadership and vision from Linda Mearns, we (myself, Chris Forest and Rob Wilby) organised a couple of summer schools at NCAR in 2012 and 2014, turning the uncertainty cascade on its head (Figure 2) and examining climate change uncertainties from the perspective of decision-making in an integrated approach. These more than 70 young people (decision-makers, scientists, economists, behavioural psychologists, infrastructure engineers, political scientists, and so on…) have now finished their PhDs/post-docs and gone out into the world. Hopefully they will now use their new understanding to start to change the way we approach the climate change problem – becoming more collaborative, integrated and decision-focused.

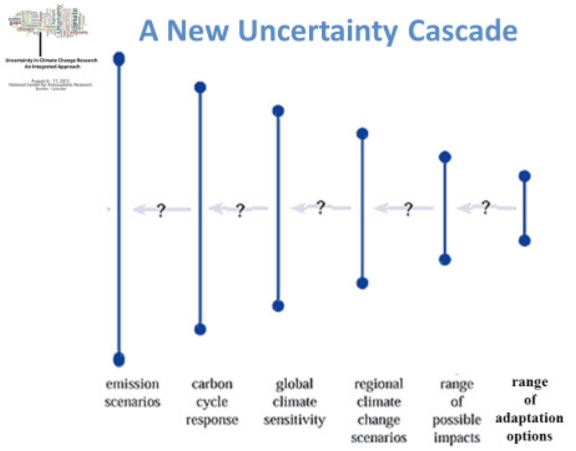

Figure 2: A new uncertainty cascade putting decision-making first.

I am a hydrologist and climate scientist but I think like an engineer. To be effective we need to work in teams. I have never published a single author paper. Someone always influences your ideas, let's be honest, and these get better by talking about them. My philosophy is one of openness with ideas and perseverance with getting those new ideas out there. Convincing people of the need for new approaches is difficult and sometimes publishing ideas or results that are contradictory and challenging can be demanding. Some of my best papers are on climate denier lists (e.g. Fowler and Archer, 2006) and have been used to suggest global warming is not happening. However, if we are honest about our science we can eventually come up with process explanations for these anomalies; whether it is summer cooling in the western Himalaya (Forsythe et al., 2017) or the 'pause' in warming since 1998. I am inspired by my post-docs and students: please go out there and challenge society, challenge the way we currently do things. Let your research move in unexpected ways, the best and most challenging questions are at the edges of the disciplines.

Finally, I must thank a close friend and colleague, David Archer, who made my research move in unexpected ways by stimulating my interest into working on climate change in the Himalaya. We first met sitting at the same table at the British Hydrological Society Symposium dinner in 2002 and David convinced me to look at some data with him. David has been 'retired' for years but is an inspiration; still challenging the way we do things, still convincing people of the need for new approaches. I dedicate this fellowship to all the people like him who have intellectually challenged me over the years, and continue to do so in pushing back the frontiers of science to build a better society for all our futures.

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A Fellow Speaks: A Grateful, if Cranky, Appreciation of Opportunities in Hydrology

Charles F. Harvey, Massachusetts Institute of Technology

Thank you. I greatly appreciate the effort and kindness extended by my nominators. I am humbled, thrilled, and surprised to be recognized by the AGU with this honor.

I have always been grateful for the freedom to spend time thinking about the natural world. In high-school I spent a lot of time looking at the natural world, finding and exploring caves in West Virginia, floating on rivers and climbing rocks. At Oberlin College, I developed better skills in critical and quantitative thinking, and in kvetching, arguing, and discussing. I could have applied my quantitative skills to a career thinking about money flowing through financial systems; instead, I am truly thankful for the opportunity to think about water flowing slowly through dirt.

My career as a hydrologist began in 1988 at the Richmond Virginia branch of the USGS. I was paid to back-up the office's computer on reel-to-reel tape at night and survey well elevations in swamps (and speak with otters) during the day. At the USGS, I had the transformative experience of seeing my field measurements inform numerical groundwater models that were then used to assess regional recharge and discharge budgets. I liked how measurements of physical reality, extracted from swamps, combined with mathematics to create understanding of hydrologic processes. I am very fortunate to have worked with a great public-service organization like the USGS.

From the Richmond USGS office, I moved to graduate school in Steve Gorelick's group at Stanford. One strength of this program was that we employed new engineering methods in a scientific context. The nineties were an exciting time for new tools in hydrogeology, stochastic differential equations and fast computers. In the School of Earth Science, there was also a strong appreciation for questions about the natural world, empiricism, and the scientific method. There was little patience for complex methods for their own sake. This combination of curiosity-driven science, familiarity with trendy new tools, and skepticism of trendy new tools, continues to sustain my enthusiasm for research.

Discovering new things is the greatest joy in research. It always happens with students; I've never discovered anything really good alone. Here are some examples, from the work of Mason Stahl, Toby Kessler, Kurt House, Alex Cobb, Neha Mehta, that make me smile: Who knew that terrestrial crabs perforate surface clay layers with burrows every meter in their need to replenish their shells with groundwater, making the vertical conductivity of "aquitards" greater than that of sandy aquifers? Did you know that the flux of dissolved inorganic carbon carried deep underground by groundwater flux is at least as great as the flux of carbon setting on the deep ocean floor? Did you know that the energy expense of separating CO2 from N2 in flue gas for geologic carbon sequestration (which will never really happen!) is about the same as simply injecting all the flue gas? Who knew that tropical peatlands, when they reach an equilibrium where carbon accumulation is balanced by decomposition, are shaped such that the Laplacian of the land surface is the same everywhere? That the ratio of Radium-224 to Radium-228 activities in groundwater will always be greater than one at equilibrium, even though Radium-224 is down the same decay chain from Radium-228?

I did not plan to spend most of my career working in South and Southeast Asia, but I'm tremendously grateful to have spent so much time working in this part of the world. I've been exceptionally fortunate to work with a fantastic group of students and collaborators, both from Bangladesh and US, on our study of arsenic-contaminated groundwater. Our primary goal has been to explain the patterns of very high dissolved arsenic in aquifers, although we have also taken on a variety of more tractable side questions. To be honest, we still don't really understand the arsenic patterns. So, why haven't we solved the problem? First, it is complicated. But, second, there has never been the kind of field program necessary to answer the question fully. In the US, aquifers at Superfund sites are riddled with sampling wells to characterize groundwater flow patterns and chemical transformations over decades. In Bangladesh, nearly everyone drinks untreated groundwater, yet there is no place where we monitor 3D paths of groundwater flow from an array of carefully placed multilevel samplers and determine where the arsenic is mobilized. The Borden, Cape Cod, and Mississippi groundwater study sites were all established where no one drinks contaminated groundwater — perhaps we could find a way to fund such a field endeavor in Bangladesh, where 5% of mortality is attributed to arsenic in groundwater?

For the last eight years, I've been immersed in a tropical peat swamp forest in Borneo and thoroughly enjoying it. These forests of gigantic trees exist because of a subtle coupling of ecological and hydrologic processes that maintain a thin layer of water on the forest floor. Almost all of these peat forests have been cut down over the last twenty years and the underlying peat drained, allowing oxygen into the soil and reversing the land-atmosphere carbon flux: the peat is degrading, emitting immense fluxes of CO2 to the air, subsiding towards sea level, catching fire and spewing huge plumes of toxic haze that blanket the region. We found a forest in Brunei, possibly the last undisturbed peat forest in Southeast Asia, to set-up a field site, funded largely from Singapore. I am thrilled and humbled to imagine that our work might be used someday in the future to restore peatlands — but this will happen only if policy shifts to reverse the ongoing devastation.

Lastly, I want to take this opportunity to voice a wish that the AGU find some courage to deal with the fossil fuel industry. The AGU decided to continue taking money from Exxon because, as the AGU states, "There was not unequivocal evidence that ExxonMobil continues to participate in climate misinformation." What a ridiculously low bar for accepting sponsorship! The issue is moot now because Exxon backed out. But, come on AGU, have some courage — we can afford to stand-up for straightforward principles of honest scientific dialogue, let alone responsible stewardship of the planet.

A Fellow Speaks: Still Searching for Land Information

Christa D. Peters-Lidard, NASA

It is a great honor to be elected an AGU Fellow, and I am deeply grateful to my nominator and letter writers, in addition to all of my mentors and supporters that have encouraged me along the way. From my undergraduate days at Virginia Tech in the Geosciences Department through graduate school in Princeton's Water Resources program, to teaching and advising at Georgia Tech and finally at NASA's Goddard Space Flight Center (GSFC), I have been surrounded by outstanding and intellectually stimulating professsors, students, post-docs, and colleagues—most notably the Hydrological Sciences Laboratory at GSFC. All of this has rested on the foundation of support from my parents, husband, friends, and family. Thank you all.

There have been numerous guideposts along my path starting as a geophysics undergraduate at Virginia Tech using MODFLOW and learning FORTRAN. The USGS gave me my first exposure to field hydrology and GIS as an undergraduate hydrologic technician, as we visited well drilling sites to determine layer depths for the Regional Aquifer System Analysis. This experience, combined with another summer at USGS working on surface water modelling for the Potomac and Pearl Rivers helped solidify my desire to pursue a Ph.D. in Hydrology. Mentors at USGS pointed me to NASA/GSFC's Hydrological Sciences Branch head for graduate school recommendations, and my Ph.D. research with Eric Wood at Princeton University focused on soil moisture measurement and modelling using airborne data from a NASA hydrology field program that was a precursor to the Soil Moisture Active/Passive mission launched in 2015. A huge impact on my personal research and education was the so-called Eagleson "Blue Book" (NRC, 1991) that helped define hydrology as a distinct geoscience, hence the "Geosciences Era" from 1990-2010 (Sivapalan and Blöschl, 2017).

As my research focus evolved to hydrometeorology, I began to appreciate the role of the land surface in modulating land-atmosphere interactions. From the role of soil thermal conductivity in energy partitioning (Peters-Lidard et al., 1998), to the multiscaling of soil moisture moving from drainage-dominated to evaporation-dominated regimes (Peters-Lidard et al., 2001), it became clear that land information was required to accurately predict land-atmosphere exchanges. This recognition, combined with an interest in applying high performance computing and communications to this problem, culminated in the development of the community Land Information System (LIS; http://lis.gsfc.nasa.gov; Kumar et al., 2006; 2008) framework, which is widely used software that supports Land Data Assimilation Systems (LDAS) at NASA's Goddard and Marshall Space Flight Centers, US Air Force, NOAA's National Centers for Environmental Prediction, and USAID's Famine Early Earning Systems Network (e.g., McNally et al., 2017) . In addition to customizing LIS for these partners, we have had many attempts to increase the information content of this system, e.g, inverting pedotransfer functions to retrieve soil hydraulic properties (e.g., Santanello et al., 2007, Peters-Lidard et al., 2008); assimilating soil moisture to improve evapotranspiration (Peters-Lidard et al., 2011); assimilating soil moisture and snowpack to improve drought (Kumar et al., 2014); assimilating snowpack to improve streamflow (Liu et al., 2015); assimilating soil moisture to improve coupled land-atmosphere prediction (Santanello et al., 2016); and more recently, multivariate assimilation to constrain water and energy budgets for climate assessment (Kumar et al., 2018a). Yet, despite our ability to exploit LIS capabilities and NASA's computational resources, we have found that land data assimilation is not the solution to our lack of adequate information constraining land-atmosphere interactions. While some of this can be attributed to the lack of information in the remotely sensed data (e.g., Kumar et al., 2018b) or inefficiencies in the data assimilation methods (e.g., Nearing et al., 2018), the reality is that our land surface models are missing information. The information missing in land surface models can be quantified through benchmarking, as in Nearing et al., (2016, Figure 1). As shown in that work, for soil moisture, uncertainty in model parameters dominates the information loss, while for evapotranspiration, uncertainty in boundary conditions (e.g., radiation, winds, temperature, humidity) dominates. This work, and subsequent extensions, suggest that we must move towards a data-driven modelling paradigm in order to make progress in hydrometeorological science.

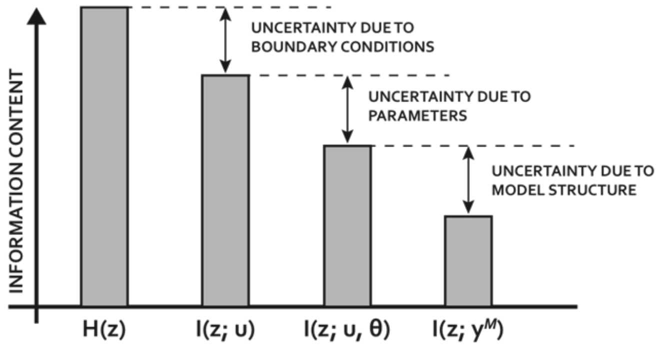

Figure 1: A conceptual diagram of uncertainty decomposition using Shannon information following Nearing et al., (2016). The term H(z) represents the total uncertainty (entropy) in the benchmark observations, and I(z; u) represents the amount of information about the benchmark observations that is available from the forcing data. Uncertainty due to forcing data is the difference between the total entropy and the information available in the forcing data. The information in the parameters plus forcing data is I(z; u), and I(z; u, θ)<I(z; u) because of errors in the parameters. The term I(z; yM) is the total information available from the model, and I(z; yM)<I(z; u, θ) because of model structural error.

The growth of hydrometeorological science, from empiricism (1st paradigm), via theory (2nd paradigm), to computational simulation (3rd paradigm) has yielded important advances in understanding and predictive capabilities. The bulk of my career I have focused on this 3rd paradigm, and there have been tremendous advances in our abilities, despite the persistence of known issues (e.g., Clark et al., 2017). The 4th paradigm (Hey et al., 2009) is a concept that focuses on how science can be advanced by enabling full exploitation of data via new computational methods. The concept is based on the idea that computational science constitutes a new set of methods beyond empiricism, theory, and simulation, and is concerned with data discovery in the sense that researchers and scientists require tools, technologies, and platforms that seamlessly integrate into standard scientific methodologies and processes. By integrating these tools and technologies for research, we provide new opportunities for researchers and scientists to share and analyze data and thereby encourage new scientific discovery. Advances in data science now allow the 4th paradigm to inject "big data" into the scientific method using rigorous information theoretic methods without eliminating the other parts of the scientific method. In Peters-Lidard et al., (2017) we argued that accelerating advances in hydrologic science will require us to embrace the 4th paradigm of data-intensive science, to use emerging datasets (e.g., McCabe et al., 2017) to synthesize/scrutinize theories and models, and to improve the data support for the mechanisms of Earth System change. A move to the 4th paradigm means that we seek modelling-driven monitoring, and simultaneously, monitoring-driven modelling. This is what will make hyper-resolution land surface modelling defensible (Wood et al., 2011; 2012; Beven et al., 2012; Beven et al., 2015), and this is how we will continue our search for land information.

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A Fellow Speaks: Reflections On My Journey

Balaji Rajagopalan, Univ. of Colorado Boulder

I am honored and thankful for being elected Fellow of the AGU, to join the ranks of so many illustrious scientists who I now regard. I wish to thank my nominators Martyn Clark and Amir Aghakouchak and, supporters who thought highly of my research contributions and made my case with perseverance. I have been very fortunate to have great mentors, collaborators and students over the years since my time in graduate school. They continue to inspire and lead me to new frontiers to explore. They share in this recognition as much as I do.

I was asked to provide this piece as a way for the section members to 'know me'. This request and the moment provoke me to reflect on my rather improbable journey - especially starting from modest beginnings in India and being the first in my family to attend college. I offer this collection of reflections and thoughts about the field to serve as renewed motivation for me and potentially for others, younger colleagues, in particular, to break new grounds.

Formative

My admission to the PhD program at Utah State University, Logan, UT in the Fall of 1991, was a result of an application sent on a whim and serendipitously reaching Upmanu Lall, who was a Professor there at that time, two years later. When I went to Manu's office for the first time after arriving from India, before knocking on the door, I vividly remember the newspaper article pasted on Manu's office door that described the El Nino and its impacts on climate. Not knowing what El Nino was at that time, I knew I would be on an exciting journey of discovery with Manu. The journey continues.

Before I arrived in Logan for the Fall quarter late September, Manu had submitted an abstract titled Probabilistic Structure of Mountain Precipitation (Rajagopalan et al., 1991), to the Fall AGU for me to give an oral presentation. Thus, started my introduction to hydroclimate research, AGU and, the long association ever since.

The hydrology and water resources graduate program at Utah provided me the exposure to wide range of topics – physical hydrology, hydrologic modeling, climatology, Nonparametric function estimation, nonlinear dynamics, Fractals, water resources systems and stochastic hydrology. Furthermore, intellectual environment fostered by the faculty and the student cohort, be it working late night coding the Vogel-Stedinger disaggregation method for David Tarboton's stochastic hydrology course or, engaging in exciting discussions on the latest variety of topics, developed my research repertoire. My first journal publication was with David Tarboton (Rajagopalan and Tarboton, 1993), a result of class project from his course on Fractals, which attests to the vibrant research ecosystem. It is indeed a special honor for me to be elected Fellow of AGU along with David Tarboton.

In addition to the rigor and breadth of the program, working with Manu and David instilled in me a robust research philosophy that I still follow. Which is to - maintain a healthy dose of skepticism; think outside the box; keep high intellectual standards by asking insightful questions; write well; be intellectually restless and curious all the time and keep learning; not develop parental affection to any particular idea or model; pursue ideas for the pure joy of discovery and; above all be generous. The rest – funding, recognition, etc. will follow in due course. In the current research climate, unfortunately, these qualities are becoming scarce. Working with Manu on Nonparametric function estimation in the context of rainfall modeling for my PhD, was not only a pioneering effort that made significant contributions to stochastic hydrology but also developed a good research ethos in me that continues.

After my PhD in 1995, I was offered a Postdoc by Mark Cane at Lamont-Doherty Earth Observatory of Columbia University. This was towards end of the

TOGA program and El Nino forecasts that he pioneered, were becoming skillful. Also, serendipitously, for, he was not looking for a hydrologist, but he envisioned good utility of El Nino forecasts on water resources management and, decided to add a hydrologist to his large group. Working with Mark and excellent researchers in the group, I learned climatology, paleoclimate, ocean-atmosphere interaction, uncovering physical mechanism from analyzing large data sets and much more. Interestingly, I learned about the Indian Monsoon and its space-time variability while there. I never did much of hydrology with Mark but worked on a variety of climatological topics with new perspectives including Monsoon-ENSO connections. Mark did not mind, as he too had the same research philosophy and encouraged pursuit of ideas for the pure joy of learning.

Academic

My research continues to evolve with three simple interconnected questions in mind – (i) What drives year-to-year, multidecadal and multi-century scale variability of regional hydroclimatology and extremes?; (ii) How can this understanding be used in skillful forecasting and simulation? And; (iii) How to incorporate these in efficient management and planning of natural resources? Pursuing these questions led me into other fascinating areas with complementary research questions – such as, drinking water and wastewater quality; construction safety; building energy and public health.

Joining the faculty at University of Colorado, Boulder (CU) in 2000 provided me with the best opportunities and the collaborators to explore the research questions. Working with colleagues at CU, pursuing these questions has proven to be of immense value in the operations, management and planning of water resources in the semi-arid river basins of the western U.S., especially the Colorado River system. This system, with all its history, culture, legal and climate constraints, offers a fascinating and multi-disciplinary research problem, one that is highly relevant to our water sustainability. Understanding the variability of flow in the river over several centuries and the development of novel stochastic streamflow simulation methods in collaboration with a long list of exceptional colleagues and students in particular, working with Prof. Edie Zagona, we continue to provide crucial inputs to developing innovative operation guidelines for managing the Colorado River during drought years.

Alongside, I kept alive my passion for uncovering the variability of the Indian monsoon at contemporary and paleo time scales. This included identifying the flavors of El Nino, the role of Tibetan plateau and Indian Ocean. Variability of monsoon during the Holocene has had significant impact in the rise and fall of civilizations in the Indian subcontinent, which offers unique lessons for modern societies experiencing warming climate variability due to climate. Collaborating with renowned paleoclimate experts at CU, in particular, Prof. Peter Molnar, on this topic has been highly rewarding and fulfilling. This understanding will potentially have a positive impact on the socio-economic health of more than a billion denizens of the Indian subcontinent. Having grown up in India with water shortages due to the vagaries of the monsoon rainfall, this research has a special personal meaning. In many ways Indian monsoon variability and the water resources has more in common with the Colorado River hydroclimatology and water supply.

The monsoon research has been fascinating to me. It is a labor of love, with no formal grant funding, yet, some of my work on the Indian monsoon has garnered the most scientific recognition. A lesson here is that sometimes not having funding liberates one to pursue creative ideas purely for the joy of discovery.

The Indian Monsoon and Colorado River are close to my heart and, recognized for my research in both areas in my citation for Fellow of AGU is of great personal and professional satisfaction.

In Parting

Competition for freshwater resources, the necessities of life, is intense as global populations increase given the spatial and temporal variability of the resource. This is exacerbated by climate change. Ensuring that we have a safe and reliable water supply for the burgeoning global population is the defining challenge of our times. For hydroclimatologists and water resources engineers, this is the best period for research with challenging and interesting problems.

Maps fascinated me from a young age and do so to this day – for, they exhort us to think and raise above our parochial and petty minutia of daily lives and provide a humbling space-time perspective on life and the physical, climatological and cultural diversity of the world's denizens. Growing up in a small railroad town with chronic water shortages, to now studying hydrology and water resources on a global scale, with maps, to address such shortages with maps is a happy fulfillment of my fascination. To this, I am enormously thankful to the exceptional mentors, collaborators and students – from whom I learn big and small in making me a better researcher and better person.

In general, in this era, research problems that are intellectually challenging, exciting and have contemporary relevance reside at the intersection of disciplines. Intellectual restlessness, curiosity and willingness to learn new topics are imperative for pushing the boundaries of knowledge and have societal impact. The water problem offers all of this and thus we have an instinct and training to be interdisciplinary researchers and, our professional history bears this out.

There are excellent young researchers in our midst who are continuing this tradition and make us all proud. I have the good fortune to work with some of them. However, what concerns me are – the diminishing breadth in our graduate curriculum and too often strong parochial attachment to ideas, models and methods. It behooves us to ensure that we produce well-rounded, open-minded researchers, who can deftly combine physics with statistical function estimation to spawn creative ideas and solutions - for, our problems demand this.

One of history's creative genius and curious minds, Leonardo DaVinci said it best "Learning never exhausts the mind". My advice for us is to Be Curious. Be Intellectually Flexible and above all to Be Generous.

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A Fellow Speaks: Some Unexpected Discoveries Using Near-surface Geophysics

Lee Slater, Rutgers University Newark

As is the case for many personal stories, it was an outstanding mentor/teacher that lit the spark of curiosity that grew into my lifelong interest and passion for learning. During my time as an undergraduate student at University of East Anglia (UK), I was extremely fortunate to take classes, including an intensive applied geophysics field course, with Frederick Vine. His explanation of the geophysical measurements of magnetic anomalies around mid-ocean ridges, and the Vine-Matthews-Morley hypothesis supporting sea floor spreading, left me fascinated with the power of applied geophysics for understanding processes occurring in the Earth. Rather than pursuing solid earth geophysics, I was keen to couple my curiosity for applied geophysics with my interests in environmental issues. Andrew Binley (Lancaster University, UK) gave me a golden opportunity to apply emerging geophysical imaging techniques to studies of hydrogeological processes, where we made some contributions to the growth of the Hydrology sub-discipline known as Hydrogeophysics (Binley et al., 2015). In these early days of Hydrogeophysics in the mid 1990s, Andrew opened my eyes to the fact that geophysical imaging techniques could go far beyond resolving geological structures; rather, they provided a unique opportunity to improve understanding of hydrogeology by non-invasive monitoring of fluid transport through soils and rocks across multiple scales. During this period, it felt like a new application for geophysical imaging was being identified every week, such was the need for new non-invasive technologies for illuminating subsurface processes.

Indeed, discoveries from basic and applied research in near-surface geophysics over the last two decades have highlighted that geophysical measurements can monitor not just hydrogeological processes, but also a wide variety of biogeochemical and microbial processes. We have learned that geophysical measurements are not just proxies of flow and transport parameters: under the right circumstances they can also be proxies of geochemical transformations, including dissolution and precipitation processes, as well as microbial-driven transformations, for example the microbial degradation of contaminants. These discoveries have fueled another sub-discipline, known as Biogeophysics, which is concerned with the geophysical signatures resulting from microbial interactions with geologic media (Atekwana and Slater, 2009).

Exploiting the untapped potential of geophysical measurements as forensic tools for investigating geochemical and microbial processes in the Earth required innovators to step out of their comfort zone and engage in interdisciplinary research. Geophysicists had to learn some basics in geochemistry and microbiology. A pioneer in this field is Estella Atewkana (University of Delaware), who was full of vision and passion for the value of geophysical measurements in sensing microbial processes. I consider it my great fortune have spent three years at the University of Missouri, where I benefitted immensely from Estella's vision. In truth, it is perhaps not surprising that geophysical methods can detect certain microbial processes that modify the physical properties of porous materials long known to control geophysical properties. For example, induced polarization geophysical measurements can be used to track the production of FeS biominerals formed by sulfate reducing bacteria (Figure 1): the thick FeS biofilms that result are analogous to a microbially produced FeS ore body and, indeed, the induced polarization method was originally developed as a prospecting technique in mineral exploration. Similarly, the electrical signature of long-term degradation of hydrocarbon contaminants is an increase in the electrical conductivity driven by contaminant mineralization, the production of organic acids and resulting mineral dissolution, all of which increase the specific conductance of the pore fluids. The fact that increasing pore fluid specific conductance increases the electrical conductivity of the Earth was by no means a novel discovery, it being the premise of Archie's famous empirical law (Archie, 1942). However, it was again the lucrative product of interdisciplinary research that led to the recognition that a simple electrical geophysical measurement could provide a non-invasive proxy of the progress of hydrocarbon contaminant degradation.

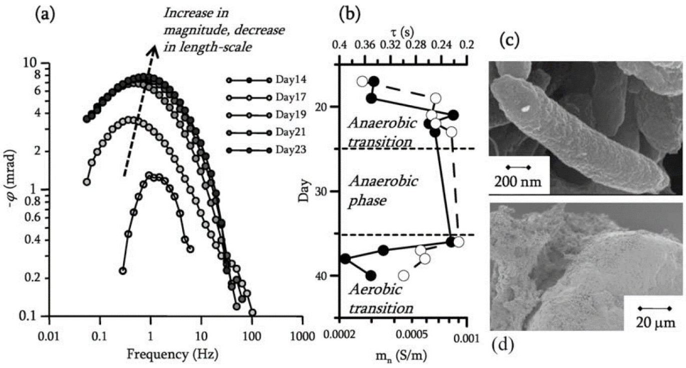

Figure 1: (a) Induced polarization signal as a function of time during FeS biomineralization associated with sulfate reducing bacteria induced by an anaerobic transition. (b) This biomineralization response is largely reversible during subsequent dissolution (aerobic transition) as apparent from the behavior of modeled Cole-Cole parameters (normalized chargeability, mn, and time constant, τ). (c) SEM images for samples extracted from the column on termination of experiment showing (c) tube-like, elongate biominerals and (d) quartz sand particle encrusted with biomineralization, equivalent to the production of an FeS mineral (after Atekwana and Slater, 2009).

I have long been fascinated by peatlands, a landscape I encountered first in Ireland as a geophysics student tasked with estimating the volume of carbon in a peat basin and subsequently discovering more peatlands upon my arrival in the United States in central Maine. Through a wonderful long-term collaboration with Andrew Reeve (University of Maine), I learned that peatland studies were foremost the domain of ecologists, and that questions about peatland formation and hydrology lacked conclusive answers. The application of applied geophysical techniques in these systems led to discoveries about the role of the post-glacial depositional setting of these systems in controlling bog hydrology and regulating the patterning of the characteristic ponds that are found in ombrotrophic raised bogs. However, it was again the possibility of indirectly observing microbial processes with geophysical measurements that provided opportunities for scientific advances. In peatlands, methanogenic archaea (microbes that lack a cell nucleus) produce methane as a metabolic byproduct under anaerobic conditions. This process is so active in peatlands that free phase production is extensive, with total gas contents readily exceeding 20%. Peatlands have long been recognized as contributing 5-10% of the global methane flux to the atmosphere, but ebullition of gaseous phase methane has resulted in much uncertainty about this number and how it is affected by the pathways for methane transport and the distribution of the delivery to the atmosphere. The production (and transport) of free phase gas is a remarkably strong geophysical signal that has been exploited to yield new understanding of where in the peat profile methane is produced and also how releases are regulated by environmental forcing (Comas et al., 2008). The role of non-invasive geophysical monitoring in understanding such processes cannot be understated. All invasive methods of gas sampling in peatlands dramatically disrupt the natural system (e.g. by breaching confining layers and allowing extensive outgassing). Geophysical methods provide access to these processes in situ, without disturbance and over multiple scales that can often avoid the bias inherent in localized point measurements.

In parallel with the growing recognition that geophysical measurements might sense multiple biogeochemical processes, this explosion of activity in geophysical monitoring has highlighted some of the intractable limitations and pitfalls of these technologies. Whilst it sometimes seems that there is no end to the new applications of applied geophysics in subsurface monitoring, it is also increasingly obvious that these measurements are only proxies of the information that is truly needed to understanding hydrological processes and biogeochemical transformations. Despite efforts to develop elaborate mechanistic models linking geophysical signatures to specific processes (e.g. the growth of microbial cells, or precipitation of mineral phases), quantitative predictions from such models will likely be futile when applied to the complexity of subsurface media/processes and the unescapable fact that geophysical properties depend on multiple factors. Indeed, I am guilty of previously expecting too much of these non-invasive proxies of subsurface processes given the inherent and long known ambiguity in the information and the danger of misinterpretation. The situation is made worse when the limitations of inverse methods and geophysical image uncertainty are not respected and false structures are interpreted as true subsurface variability relating to processes. However, there is a great opportunity to better harness the information content inherent in geophysical sensing of biogeochemical processes through the development of new geophysical monitoring platforms. Advances in open source hardware platforms are drastically reducing the costs involved in establishing long-term geophysical monitoring systems. Fully harnessing these opportunities will require more near surface geophysicists stepping outside of the comfort zone provided by their disciplinary silo and engaging with hydrologists, geochemists and microbiologists. Once achieved, these proxy measurements will likely provide invaluable information that can guide more diagnostic sampling techniques to focus on biogeochemical hot spots and hot moments.

This AGU fellowship is the greatest honor of my career. It is especially meaningful as AGU is the organization that I consider my academic home. I am indebted to those that considered me worthy of this honor and who put in the hard work involved in creating a competitive nomination package. Over the last 16 years, I have gained much of my motivation and inspiration from working collaboratively with a remarkably talented, hard-working and collegial group of undergraduate, graduate and postdoctoral students that have come through Rutgers University-Newark. Many of them are now some of my closest friends. I take great pride in being a member of the faculty at Rutgers University-Newark. Since 1997, the first year that U.S. News & World Report began ranking colleges on the diversity of their student bodies, U.S. News has rated Rutgers University-Newark the most diverse national university in the United States; no other school has been so recognized. I have experienced the benefits of this diversity first hand, working with students from all walks of life, students from a wide variety of cultures and traditions. The benefits of this diversity have been reflected in a broad range of viewpoints, ways of looking at problems and philosophies that have broadened my thinking about not just my scientific endeavors but life in general. I owe my passion for a career in the geosciences to three outstanding mentors, Andrew Binley, Angela Davis (University of North Wales) and Frederick Vine. I dedicate this passage to the late Aubrey Horace Green, a wonderfully energetic headmaster and family friend, who recognized that my potential for learning exceeded my own early intentions and expectations.

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A Fellow Speaks: Let the Data Speak

David Tarboton, Utah State University

As an imperfect idealist let me say to those who read this looking for inspiration, guidance or advice, "Do as I say, not necessarily as I have done." Let the data speak. Make decisions based on quantifiable information. Pursue a hydrology where decisions, all decisions, are based on data to the maximal extent possible. Address questions and research problems where the data, or lack of it, suggests an opportunity, and develop methods and practices to gather and record data about everything in a way that it can be analyzed and used.

The emphasis over the last several years of my career has been on hydrologic information systems. I learned from David Maidment that **it is as important to represent hydrologic environments with data as it is to represent hydrologic processes with equations**. This statement made crisp in my mind the previously foggy intuition I had that there was something important in hydrologic information systems and their pursuit as a direction of research. I learned that **the**

way that data is organized can enhance or inhibit the analyses that can be done. Just as we encapsulate physical laws and principles in simulation models in what we might call **hydrologic process science** to provide predictions about hydrologic conditions, we need to encapsulate increasingly detailed representations of the hydrologic environment in the data models of **hydrologic information science** to also inform predictions of hydrologic conditions. While hydrologic processes are often well understood, characterizing the properties that describe the environment where they occur is often the largest challenge or source of uncertainty. We know the equations of motion for water in a river, but we do not know the shape of the surfaces bounding the channel to practically solve these equations (e.g., see Figure 1). In the subsurface we know Darcy's equation, or at a smaller scale the equations of flow through pores, yet it is impossible to characterize the shape of the pores or the actual values and variability of hydraulic conductivity over the areas we need to make predictions. This is one reason why there is so much calibration of hydrologic models, which may be viewed as "measuring" the place specific parameters. As measurements become more detailed and prolific, we need new ways to bring these into our models. This is where information systems and hydrologic information science meet hydrologic process science, and where there is, in my opinion, a fertile area for new advances.

Figure 1: Debbie Tarboton investigates the waterfall in Spring Creek, a mere 5 mile run from our home in Logan, Utah. Precise representation of channel shapes like this to provide boundary conditions for the solution of flow equations is a challenge in hydrologic modeling.

I am profusely appreciative of this recognition as a Fellow. Thank you to David Maidment for nominating me and to those who wrote letters. Thank you to Upmanu Lall for being a close colleague and friend in my early days as a faculty member, and for starting me on the path of nonparametric and exploratory examination of data. There are seeds for "let the data speak" in characterizing probability distributions and stochastic models based on data alone, free from assumptions of normality or the distortions of normalizing transformations (Tarboton et al., 1998; Sharma et al., 1998). Thank you Rafael Bras for nurturing me through MIT and for letting me explore **digital elevation models (DEMs) as a thing** in hydrology (Tarboton et al., 1991; 1992). DEM data for land surface topography is available at increasingly high resolution and provides the opportunity to let the data speak in understanding and modeling the hydrology on and near the surface of the earth. My work with DEMs started with looking to understand fractal and scaling properties of river networks (Tarboton et al., 1988; 1989), and persists today in investigations of the height above the nearest drainage for flood modeling at continental scale (Zheng et al., 2018; Liu et al., 2018). Thank you to all my students who have joined me on this path of **data and models** (Tarboton et al., 1995; Sharma et al., 1997; Williams and Tarboton, 1999; Prasad et al., 2001; Luce and Tarboton, 2004; Istanbulluoglu et al., 2004; Prasad et al., 2006; You et al., 2014; Chinnayakanahalli et al., 2011; Loscher, 2006; Mohammed and Tarboton, 2012; Tesfa et al., 2011; Bandaragoda et al., 2004; Mahat and Tarboton, 2012; Byrd, 2013; Dhungel et al., 2016; Sen Gupta et al., 2015; Yıldırım et al., 2015; Sazib, 2016), not to be confused with **data models** (Horsburgh et al., 2008; Horsburgh et al., 2016a), and who put up with my demands that too often went beyond not letting the perfect be the enemy of the good enough.

Thank you to Geoff Pegram who inspired me to a career in hydrology. Sorry that I did not stay in South Africa, my country of birth, to study with you. When I think about some of the foundational ideas I hold core, and that I express in "let the data speak" they go back to a story you told, that I have probably embellished over time. As I recall you spoke of a farmer whose land had a flooding problem, and who was searching for a solution. He finally asked an individual who I will refer to as an inspired hydrologist. The inspired hydrologist started exploring the problem and asked, "How big is the area drained?" Answer, "Oh an average area." Question, "How much does it rain?" Answer, "Oh, you know, the typical storm for around here. It rains quite hard." Question, "What is the condition of the land?" Answer, "Oh you know, some sand, some rock, typical of what you get around here." You get the picture. No real, actionable, quantifiable information was available. The inspired hydrologist assessed the situation, then said, "I have a solution for you." The farmer responded, "Wonderful, you don't know how many experts I have asked who could not help. They all said I did not have enough information." The inspired hydrologist said, "Dig a ditch 2 m wide and 1 m deep to drain your land". He had specified an average ditch. "Great!" said the farmer. "You have been very helpful." "But wait," said the inspired hydrologist. "Next time it rains, go out into the field and check the ditch. If it is overflowing, dig it 1 m wider." **Close the feedback loop**. Manage the problem adaptively and do it based on observations, or data. Make a data-based decision.

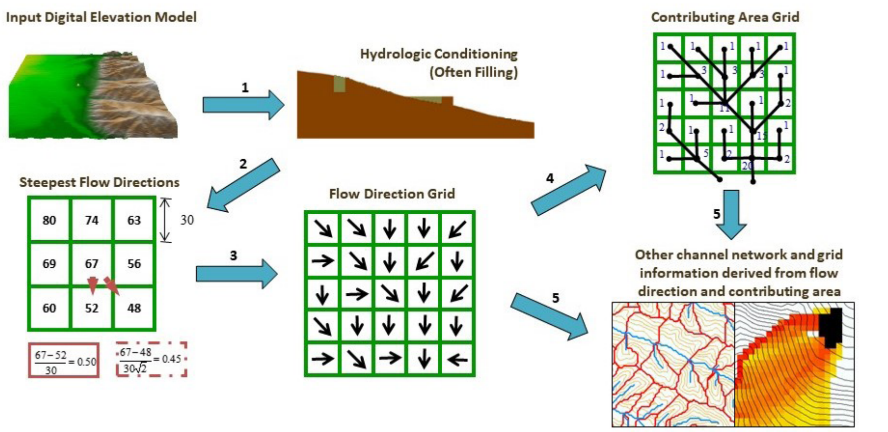

Figure 2: Terrain Flow Data Model used to enrich the information content of a digital elevation model (DEM). Starting from a simple grid DEM, a rich set of data structures and information useful for hydrologic analysis is derived.

AGU has a motto "Unselfish cooperation in research." Perhaps I stumbled into following this when early in my career I just put the code I had developed to delineate river networks from digital elevation models online, on an ftp site, for anyone to use, and I answered a lot of emails about it. This ultimately led to the open source TauDEM software package (http://hydrology.usu.edu/taudem) and a high number of citations for the paper describing some of the methods (Tarboton, 1997). Work on hydrologic terrain analysis was driven by a desire to **let topography data speak for itself**, namely use digital elevation model (DEM) data, available at increasingly high resolution to enrich the content available from simply a grid data structure into information that represents the terrain flow field and supports quantification of a host of derived quantities useful for hydrologic analysis (Figure 2). Watersheds are fundamentally the most basic hydrologic landscape elements. Topography dictates the flow of water across the landscape. Flowing water sculpts the landscape. This synergy is at the heart of much hydrologic modeling relating to questions of runoff generation important for flooding and water resources. Representing hydrologic processes at high resolution is important to help solve these problems. There are also important questions to be answered in interpreting the signature of hydrologic processes on the terrain and using this information to quantify hydrologic parameters such as soil depth and retention, related to residence time (e.g., Nicótina et al., 2011).

Another manifestation of unselfish cooperation in research is AGU's promotion of the FAIR data principles, the concept that data should be findable, accessible, interoperable and reusable (Stall et al., 2017). It has gratified me over the last several years to work with the Consortium of Universities for the Advancement of Universities for Hydrologic Science (CUAHSI) on hydrologic information system development that has culminated in HydroShare (http://www.hydroshare.org) the CUAHSI data sharing and collaboration platform that supports the FAIR data principles. HydroShare includes a repository for users to share and publish data and models in a variety of flexible formats, and to make this information available in a citable, shareable and discoverable manner that meets the data management publication and collaboration needs of the Hydrology research community. Hydroshare also includes tools in the form of web applications that can act on content in HydroShare providing users with a gateway to web based collaborative analysis and computing. Data and models saved as online resources in HydroShare become social objects because they are the things we share and use in collaboration (Horsburgh et al., 2016b). By being online, it is easier to share and manage how others can access the data. It is also easier to document and make workflows reproducible, thus enhancing transparency and trust. Web application tools may be built by anyone and loosely coupled to the HydroShare repository through its REST application programming interface (e.g., Rajib et al., 2016; Crawley et al., 2017). This is a powerful extensibility mode. Ultimately, we can enable the community to more easily and freely share products resulting from their research, not just the scientific publication summarizing a study, but also the data and models used to create the scientific publication, thus doing our part in the mandate for data to be open, machine readable and accessible (Obama, 2013). Development of HydroShare has been a collaborative team effort. I am profusely grateful for the work of the HydroShare team. The open development process (Idaszak et al., 2017) has enabled hydrology graduate students to contribute code and build functionality that they directly want (Sadler et al., 2015; Morsy et al., 2017). I think that this makes it more responsive to user needs than a system specified by hydrologists, but built by computer scientists would be.

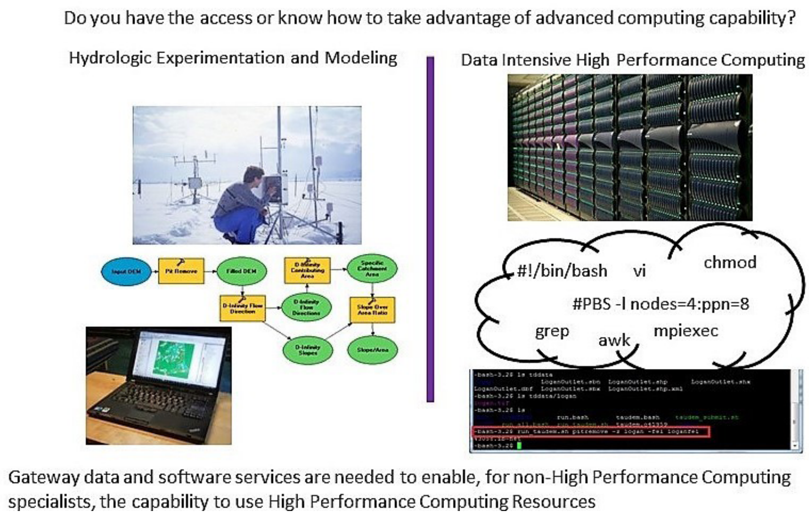

Figure 3: A digital divide between hydrologic experimentation and modeling and the expertise needed to take advantage of advanced computing.

An important motivation for HydroShare is collaboration. It is rare, or impossible, for a single investigator working alone to gather the measurements that can advance understanding. Rather, nowadays, it requires a team, or a community. Advances will come from diverse data, from different lines of investigation, and different disciplines being integrated and brought to bear on a problem. The vision for HydroShare is to provide a platform to enable the integration of information from multiple sources, the data and computationally intensive analysis and modeling, and the collaboration and teamwork that I think are what are needed to transform hydrologic research. How do we collaborate when the datasets are too large to exchange? How do we interactively explore datasets that are too big for desktop computers? How do we conduct research requiring the use of big datasets in different places? These are some of the cyberinfrastructure questions that the HydroShare team is pursuing in the context of hydrology.

Too often computational complexity inhibits modeling and data exploration. Researchers get bogged down in issues of data format, computer code and library compatibility. This is one form of a digital divide (Figure 3). The ultimate vision for where I think we can go with hydrologic information systems is a platform for collaboration and computation that integrates data storage, organization, discovery, analysis and modeling through web applications that allow researchers to employ services beyond their desktop to make data storage and manipulation more reliable and scalable, while improving ability to collaborate and reproduce results. This would, I think, be a cyberinfrastructure ecosystem of many interfaces to shared services (Chaudhary and Ramnath, 2017). It would be web based and support the ability to work with large datasets and integrate data from different sources. It needs to hold data public and private so that researchers can work with data in the system, before it is ready for publication. It needs to integrate data and computation to "let the data speak" for itself in new ways. It needs to support the complete data life-cycle and provide easy to use tools that implement best of practice methods in a user-friendly coding environment.

What has been called harnessing the data revolution, the US National Science Foundation big idea that is motivating funding in this area, for me means using the proliferation of data to understand, through models that represent physical processes, how hydrologic systems work, and through these models to be able to predict the consequences of change. I am a fan of physically based modeling at scales that capture the important processes and integrate them up to the scales at which decisions need to be made, and questions answered. This requires sensitivity to the variability of processes and parameters, and integration across scales. For me, a strength of physically based models is their amenability to incorporating directly physical input changes. I think that there are opportunities for the community to better pursue structured model and hypothesis testing (e.g., Clark et al., 2015) and for cyberinfrastructure to enable and facilitate this approach for a broader spectrum of hydrologic researchers.

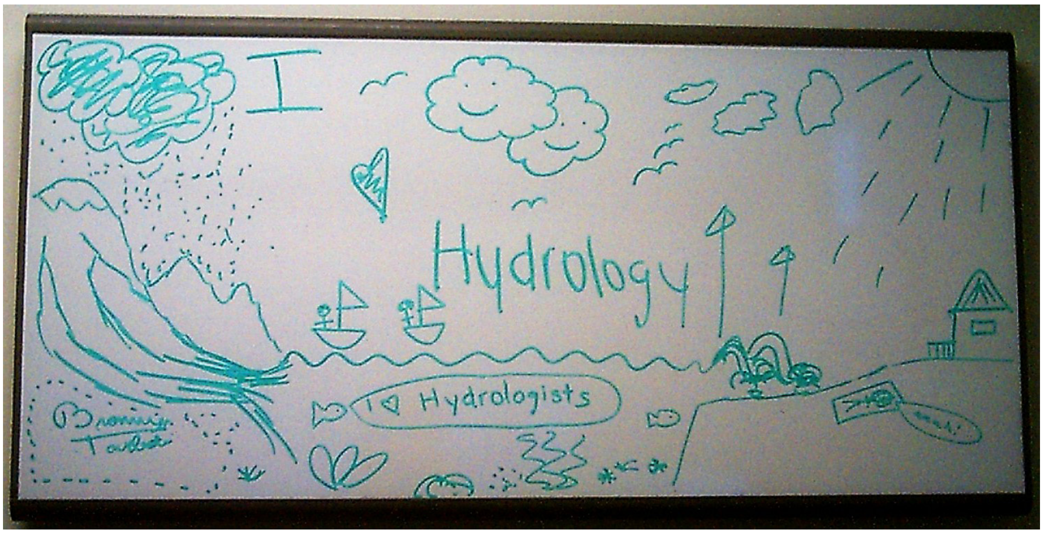

Figure 4: The Hydrologic Cycle through the lens of 14 year old Bronwyn Tarboton.

Fortunately, there is rapid progress in the areas of cyberinfrastructure and hydrologic information systems, going down the pathways to develop some of the capability outlined above. However, for this capability to serve the hydrology community, it cannot only be developed by computer scientists and software engineers. It has to be developed with considerable input from the hydrology research community. If you have read this far, my appeal to you is to get involved in building hydrology's bridge across the digital divide and advancing information systems and cyberinfrastructure to where we can easily and collaboratively conduct research using data and models. Imagine what we can learn when we can better hear the data speak!

And lastly in closing let me end thanking and expressing appreciation for the support of my wife Debbie (pictured in Figure 1 above), and daughters Bronwyn and Paisley. I owe them a lot and would not be who I am without their love and understanding. A perspective on the hydrologic cycle drawn in my office by Bronwyn (Figure 4) served for several weeks as a reminder of the importance of family. It speaks for itself.

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A Fellow Speaks: The Joys and Responsibilities of Becoming a Hydrologist

Doerthe Tetzlaff, IGB Leibniz Institute and Humboldt University

The Stream: Pouring of water through the night, through the year
The last sound before sleep, the first on waking;
Transparent pat, almost overgrown beside
The trodden path's embankment of earth and stone;
Clear-bodied wholeness at the field's edge, logic
Finding out the lowest place, the easiest way;
An elemental beside the human sense,
Where he kneels to drink, to paint his skin with cold.
[Robert Wells]

I am delighted and very proud to be elected a Fellow of AGU. It is an incredible honour, and I sincerely thank my colleagues for their efforts to nominate and support me. I am very grateful to all my colleagues - who became friends - I collaborated with over the years; for them sharing and discussing scientific ideas, their ever uplifting spirit, their enthusiasm for their science and simply the fun they brought to our and my work and projects! Thank you!

After my early studies in Landscape Ecology and Physical Geography, I received my PhD in Hydrology at the University of Freiburg, Germany. However, I feel that I truly became a hydrologist when a postdoctoral fellowship allowed me to work at the University of Aberdeen in Scotland. Scotland: in my view a dream for all hydrologists and environmental scientists with its breath-taking landscape, its streams and lakes, mountains and wide valleys, its very (!) wet climate, the blue sky (when the sun is shining!), the clear air, the light green beech trees in spring, the purple flowering heather in summer and the orange-yellow birches in autumn – and the emptiness of the landscape. One can SEE hydrology happening wherever you look. Coming from Germany and seeing my first Atlantic salmon (Salmo salar) jumping up large rocky barriers back to its spawning ground was simply amazing. I soon became a lecturer and then later full professor at the University of Aberdeen, and I stayed in Scotland for 15 years of my career!

The focus of my work is understanding the physical processes that generate stream flow, and the way these processes influence the hydrochemistry and hydroecology of streams. Speaking of jumping salmon: first work in Scotland resulted in collaborative projects with the Scottish Government's Freshwater Laboratory, examining hydraulic and hydrological influences on the ecology of different life stages of Atlantic salmon. Thus, initial research involved exploration of the inter-linkages between catchment hydrology and instream hydraulics which provided a strong inter-disciplinary focus for understanding influences on feeding habitats of juvenile salmon and the migratory movement of adult salmon into spawning tributaries (e.g. Tetzlaff et al., 2005). This work was then extended to explore the utility of the concept of connectivity between landscapes and riverscapes, showing the effects of catchment-scale hydrological processes on the migratory movement of adult salmon (Tetzlaff et al., 2007).

A further fundamental part of my work has been to gain an understanding of how the variability in catchment hydrological behaviour underpins flow variations and hydroecological responses. Thus, in parallel with my aquatic ecology research, I became increasingly involved in stable isotope hydrology that has sought to understand the influence of landscape controls on hydrological flow paths and the transit times of water in different catchments. Stable isotope records from precipitation, stream flow and various geographical runoff sources have provided invaluable insights into catchment-scale runoff responses and the timing of dominant flowpaths (e.g. Tetzlaff et al., 2015). In addition to providing information on water provenance, flow paths and transit times, insights from tracer studies supply a valuable means of calibrating or testing more detailed conceptual or numerical models across scales.

Much of my work has focussed on the comparative examination of experimental catchments, first at small scales in Scotland, but then upscaling insights to larger mesoscale catchments and importantly, to other geographic regions. In recent years, I was extremely fortunate to lead international intersite-comparison projects with partners from Canada, Sweden and the USA; using insights from different geographical environments to synthesise more holistic understanding of hydrological and ecological function, particularly with respect to climatic change (Tetzlaff et al., 2013). Having the opportunity to work closely with international colleagues at "their" sites was amazing; clearly opening my eyes to the "uniqueness of place" [quoting one of my scientific heroes Keith Beven]. For example, quantitative, process-relevant analyses of mesoscale catchments highlighted the potential of quantitative landscape analysis in catchment comparison and the need for caution in extrapolating relationships between landscape controls and metrics of hydrological function beyond specific geomorphic provinces (Tetzlaff et al., 2009). Recently, my work centred on contextualising these findings more broadly into the relationship between structure and function of northern temperate catchments; their response to climate change and how the ecohydrological implications differ. The overall aim of all these studies is to facilitate an inter-catchment comparison yielding a comprehensive, interdisciplinary, and regional understanding of the recent effects of climatic change to provide a stronger scientific basis for predicting what further changes are likely.

And of course, catchment studies usually start with a specific question and a group of scientists committing to place-based research and acquiring the resources to initiate empirical observations to understand hydrological processes and other biophysical phenomena. But it is the observations and data from long-term experimental watersheds are the foundation of hydrology as a geoscience (Tetzlaff et al., 2017). They allow us to benchmark process understanding, observe trends and natural cycles, and are pre-requisites for testing predictive models. Long-term experimental watersheds also are places where new measurement technologies are developed offering a crucial evidence base for understanding and managing the provision of clean water supplies; predicting and mitigating the effects of floods, and protecting ecosystem services provided by rivers and wetlands.

Long-term experimental studies are the basis to assess how to manage land and water in an integrated, sustainable way that reduces environmental and economic costs. Hence, the long-term work I could conduct in Scotland was so important (Fig1). However, after years working in cold, wet environments such as Scotland, coming back to Germany propelled me into the exceptional drought year of 2018. Now,

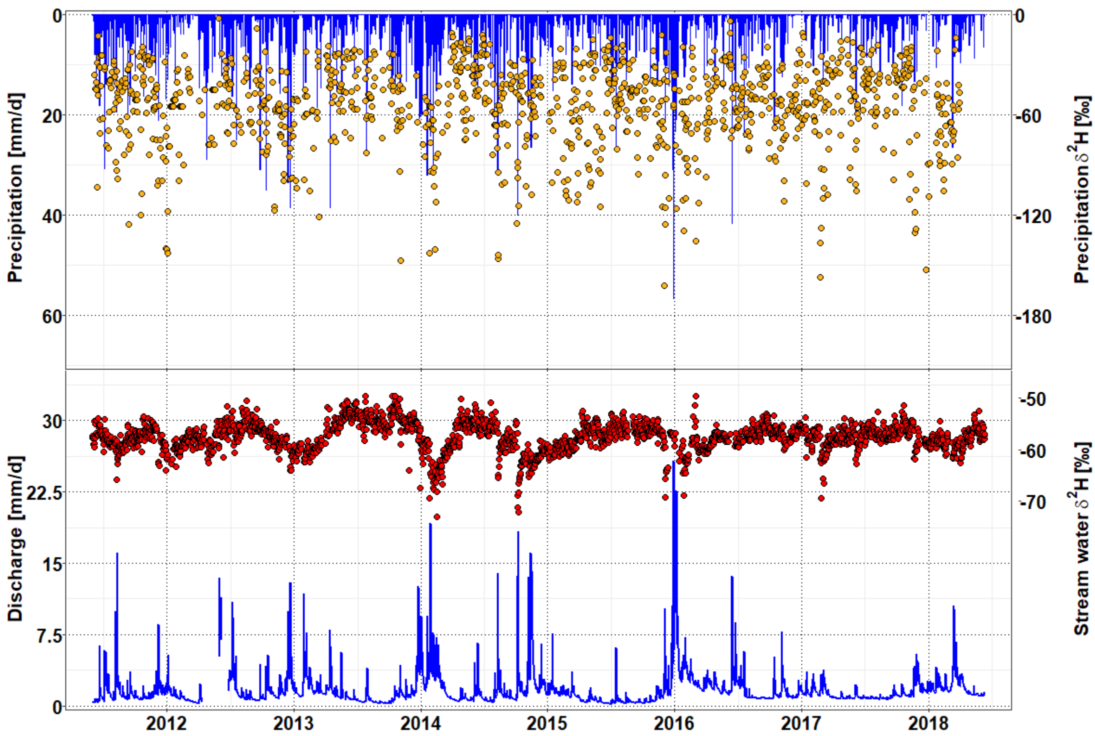

Figure 1: Long-term daily stable isotope data measured in precipitation and streamwater at the Bruntland Burn experimental site in Scotland, UK.

again I have the opportunity to show how monitoring evolving from curiosity driven research is vital to policy makers and society, providing a fundamental basis for rational decision making (Lovett et al., 2007). Policy makers and other stakeholders typically have very specific questions, and the short time scales of annual financial budgets or electoral cycles might limit long-term studies. I have been in the fortunate position to be introduced to extremely open and visionary stakeholders in Germany already and I am looking forward to the future to integrate my science and data into land management decisions. I see the role of scientists should be to understand of unexplained phenomena, which may often seem obscure and removed from the needs of policy makers. However, it is clear that scientific knowledge yields long-term dividends, such as the understanding the effects of climate and land use change and the processes governing the vulnerability and resilience to floods and droughts. There is a need for the hydrological community to be more effective at promoting their work to stakeholders and wider society and to enhance the non-scientific impact and build "hydroliteracy" amongst the general public. Recent research shows the benefits of encouraging "citizen science" and involving the public in hydrological data collection (Seibert and McDonnell, 2015). There remains an urgent social responsibility for us as hydrologists. We need to continue to do high quality science and effectively communicate the findings, but we also need to promote our work and its value to stakeholders and the wider public.

I would like to end this piece with a hopefully uplifting note to all my fellow female colleagues: It IS possible to strike a balance between career and family! Be aware that you can have both, if you want to. Pursuing a career does NOT exclude leading a normal family life. However, it is essential to possess creativity and flexibility, and to be able to set priorities so as to strike a balance between them. Do what you want to do. It goes without saying that it helps enormously when you have a family who supports you. So – thank you to my wonderful husband and best daughter in the world for helping make this all possible!

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Yoshihide Wada: 2018 Early Career Award

The Hydrologic Sciences Early Career Award recognizes outstanding contributions to the Science of Hydrology, education, or societal impacts by a scientist at his or her early career stage. This prestigious award acknowledges early career prominence and promise of continued contributions to hydrologic science.

I am truly honored and thrilled to have been selected as the recipient of the 2018 Hydrologic Sciences Early Career Award. I would sincerely like to thank my mentors and colleagues who generously dedicated their time to nominate me for this award.

Learning hydrology coming from social science was a unique career path, and it was challenging to bridge the interface between the social and natural sciences. However, I have truly enjoyed the experience, owing to our great hydrologic community with numerous forerunners, to whom I would like to dedicate this award for making my work possible and for accepting my new ideas and encouraging me to explore them further. The AGU hydrologic community is very open and accessible, and I am indebted to those who are continuously working to make our community better and to the honors committee for their voluntary service and strong devotion.

"The AGU hydrologic community is very open and accessible..."

In this article, I would like to draw your attention to the development of water future scenarios. At the International Institute for Applied Systems Analysis (IIASA), we work a lot with stakeholders such as local policy makers for various purposes.

Water scenario building process, when structured and shared globally, provides a unique platform to foster action and learning.

Water scenario development for global or regional hydrological models is still in its infancy. The World Water Vision- the first global effort of envisioning water futures - was released by the World Water Council in 2000. The vision report built on a foresight process similar to that pioneered by Royal Dutch Shell in the 1960s. The 18 months consultation brought together approximately 15,000 individuals to participate at various scales, evaluated three alternative water futures of i) business-as-usual, ii) technology, economics, and private sector and iii) values and lifestyles. In the recent years, other global initiatives such as the UN-WWAP World Water Scenarios Projects and IIASA's Water Futures and Solutions (WFaS) initiative have followed suit, with the latter providing the first set of global water scenarios consistent with the Shared Socioeconomic Pathways (SSPs) and the Representative Concentration Pathways (RCPs), elaborating water relevant narratives across five dimensions of i) nature, ii) economy, iii) society, iv) freshwater systems and v) well-being.

The knowledge accumulated through these water scenario efforts, along with similar work by IPCC global emissions scenario communities, however attest common shortcomings of the existing global scenario approach. While scenario process is aimed at development of storylines and parameters as end-products, as a wider group of modelers and practitioners adopt them for sensitivity analysis, scenarios will have 'a life of their own', far removed from the original intent or discourses surrounding them. Global scenario researchers increasingly recognize that scenario exercises instead be perceived as a process of social learning in which processes are more firmly embedded in specific local contexts and policy issues. Also called for are opportunities for scenario developers, modellers and decision makers to engage continuously in dialogue and learning.

Water sector provides a unique opportunity to co-develop global water scenarios at different spatial scales. Water is inherently heterogeneous resources across the globe, and scale is one of the most vexing challenges of water modelling. For global hydrologists, water cycle is a global phenomenon; it is hard to separate a specific water flow in space and time from glob-

"Water sector provides a unique opportunity to co-develop global water scenarios at different spatial scales."

al feedbacks that underpin it, such as weather systems, nutrient and carbon cycles or other human influences including virtual water trade. With pervasive human footprints significantly altering global water cycles, there is no surprise, then, how global hydrological modelling as a discipline has flourished over the past decades.

At the same time, water management decisions are, for the most part, made regionally at the scale of water basin or country. What matters to public and water managers are issues such as water quality and stability of water access that makes their livelihoods possible. How individual and collective decisions to make our lives better today, when aggregated, may cause regional and global ramifications in a far distant future is therefore not a matter of urgent concern. Tailor-made models, better calibrated and capturing local granularities, are suited to answer specific water management questions. Yet, systematic assessment and learning are difficult to achieve from these individually implemented local models.

Instead of performing straightforward downscaling of global scenario concepts such as the SSPs, regional water scenario processes are seen as a way of convening committed local actors for collective envisioning and learning, where storylines and narratives provide ways to contextualising scientific knowledge of hydrological modelling. The scenario process is designed as a policy exercise where stakeholders first learned and built – using data provided by modelers - baseline conditions of biophysical and socioeconomic system interactions including current water balance, land and energy use, infrastructure access in their local sub-basins. While stakeholders collectively debate desired futures and alternative pathways, hydrological models serve as a mental aid, stretching their analytical time horizons and helping them perceive trade-offs, connectivity and feedbacks.

"... hydrological models serve as a mental aid, stretching their analytical time horizons and helping them perceive trade-offs, connectivity and feedbacks."

Improving water scenario building process is important so that stakeholders are empowered to make use of science, act on it and to learn from it, which is a grand challenge of next generation hydrological models.

Bridget Scanlon: 2018 Hydrologic Science Award

The Hydrologic Sciences Award, known as the Robert E. Horton Award from 1956 to 1998, was established in 1956 and is granted by the Section for outstanding contributions to the Science of Hydrology over a career, with an emphasis on the past five years.

I am honored to be selected to receive this year's Hydrologic Science Award and humbled when considering past awardees. I would like to thank Lu Zhang for the nomination and the Awards Committee members for selecting me.

Because the award represents my contributions to hydrology over time, I thought I would take this opportunity to reflect on how my career has evolved, and to thank those who have allowed me to grow in my field. I have worked at the Bureau of Economic Geology, which is now part of the Jackson School of Geosciences within The University of Texas at Austin, for the past

31 years. The Bureau is a research organization that mostly relies on external support, requiring that we conduct applied research with societal relevance and encouraging collaboration. In this setting I have been given the opportunity to experiment and expand my knowledge and science.

> "We found that many of the tools and techniques used to characterize unsaturated systems could also be used to estimate groundwater recharge in various settings."

One of my first projects at the Bureau involved characterizing sites for low-level radioactive waste disposal in the Chihuahuan Desert of West Texas. Figuring out potential pathways of the waste to rivers or deep aquifers was challenging, particularly because I had no formal background in unsaturated zone hydrology, and those were the days before Wikipedia. I relied on long phone conversations with leaders such as Peter Wierenga, the late Glendon Gee, Gaylon Campbell, Fred Phillips, Bryan Travis, and Chris Milly for guidance on field instrumentation, lab measurement techniques, and vadose-zone modeling analysis. I am extremely grateful for the time and effort these individuals spent in educating me, and for their patience with my ignorance. Without the burden of formal education in unsaturated systems and what was considered feasible, we went into the field and applied many techniques to characterize what a colleague later described as "nothing happening." Applying soil physics and soil chemistry techniques through sampling and monitoring the thick unsaturated zone, we learned that water was moving very slowly upward, building up salts from rain over millennia.

> "This work demonstrated the importance of vegetation in controlling subsurface flow, and it contributed to the burgeoning field of ecohydrology."

I would like to thank my Bureau colleagues during this time for their support, particularly Bill Mullican, Fred Wang, Bernd Richter, and several others. Although the proposed radioactive waste disposal site was not permitted, we were able to develop a field laboratory at the proposed site, funded by EPA, to assess various types of engineered covers for waste disposal, and to test our understanding of flow systems using state-of-the-art monitoring techniques (surface geophysics, TDR, neutron probes, pressure sensors, and applied tracers). This work also provided an opportunity to assess the reliability of unsaturated zone fluid-flow codes. My Bureau colleague, Bob Reedy, almost literally lived in the field during this time and greatly enhanced our research.

We found that many of the tools and techniques used to characterize unsaturated systems could also be used to estimate groundwater recharge in various settings, allowing us to quantify recharge in different regions. I have benefited greatly from collaborating with Rick Healy (USGS) on recharge estimation, and I think that his book on this topic is an extremely valuable resource.

During the late 1990s and 2000s I began to realize that we were using most of our water resources to support food production, and decided to focus on this topic. Starting in the High Plains aquifer in Texas we drilled hundreds of boreholes, and analyzed thousands of soil samples to characterize the flow direction and water residence time using pressure sensors and chloride profiles under irrigated and rainfed cropland, with native vegetation providing a baseline. Results of this work highlighted large-scale groundwater depletion to support irrigation. We expanded across the southwestern U.S. showing similar results in many regions. This work demonstrated the importance of vegetation in controlling subsurface flow, and it contributed to the burgeoning field of ecohydrology. Bob Reedy, John Gates, Dani Kurtzman, and others

> "At first I was skeptical, but then realized that satellites provide another set of eyes, just eyes with cataracts."

spent long hours in the field. I benefited greatly from discussions with David Stonestrom (USGS) and comparison with other sites in the southwestern U.S. and Australia.

During the Jackson School's early years in the 2000s, we had a funded post-doctoral program, and I learned much from our incoming postdocs. We started to examine the use of GRACE satellites for monitoring changes in land use and water storage, carrying on from the early work that Matt Rodell and Jay Famiglietti began while at UT-Austin. At first I was skeptical, but then realized that satellites provide another set of eyes, just eyes with cataracts. The postdocs during this time, including Laurent Longuevergne and Gil Strassberg and collaborator, Dr. Clark Wilson, advanced applications of GRACE satellite data to the U.S. High Plains and Central Valley. Di Long, another postdoc, showed the value of the data for monitoring storage changes during the most extreme one-year drought on record in Texas, in 2011. I have continued to collaborate with many people, particularly Zizhan Zhang at the Chinese Academy of Sciences (Wuhan) and Himanshu Save (Univ. Texas Center for Space Research), comparing global models and GRACE satellite data to better understand trends and seasonal signals in water storage in river basins globally. I very much enjoyed visiting universities during my 2006 Birdsall Dreiss lecture tour, discussing impacts of food production on water resources and applications of GRACE satellite data. However, I doubt the degree of impact I had because I was trying to convince people of the importance of a vegetarian diet to reduce their water footprint, while not even convincing my own family. I have backed off this soapbox because what matters is not just the water footprint but where the food is grown. For example, is it better to eat almonds from California when they are in a drought or to eat beef from Nebraska during non-drought conditions?

> "Is it better to eat almonds from California when they are in a drought or to eat beef from Nebraska during non-drought conditions?"

Because the Bureau is an externally funded research organization, our research foci continually change, and we must morph to adapt to new challenges. My latest forays have been into water energy linkages, including unconventional oil and gas extraction and electricity. I have learned much from Bureau colleague, J-P Nicot, who pioneered this work in the mid-2000s; we enjoy trying to put the numbers in context. I commend the National Science Foundation for emphasizing the food, energy, and water nexus to provide broader perspectives on these pertinent issues.

Throughout my career, my underlying modus operandi has been to constrain large uncertainties, which my research group and I have addressed by simultaneously applying multiple investigative techniques. I am very grateful for all the opportunities arising during my career, particularly support from the Jackson Endowment and Fisher Foundation, and I look forward to continuing much of this work in the future. And, as stated earlier, I greatly appreciate having been given this most prestigious award.

> "Throughout my career, my underlying *modus operandi* has been to constrain large uncertainties..."

Dani Or: 2018 Walter B. Langbein Lecture

The Walter B. Langbein Lecture is given for lifetime contributions to the science of hydrology and/or for unselfish cooperation in hydrologic research. Additional considerations may be the candidate's renown as a lecturer and/or as an educator.

The tyranny of small scales – *on representing soil processes in global land surface models*

I am deeply honored by the recognition of being selected to deliver the 2018 Walter B. Langbein lecture. It is both humbling and thrilling to join the ranks of previous distinguished Langbein lecturers; the significance of this opportunity clearly resonates from their insightful and inspiring lectures filled with wisdom and universal messages (I urge you to view some of these lectures posted on the AGU website). To my embarrassment I did not know much about Walter Langbein's many contributions and I had only a vague notion of his career; the more I read the more I became fascinated and impressed by his prolific and multifaceted career, personality and lifelong service to building a modern and scientifically-oriented hydrology community. This has been a gratifying journey of discovery into the life and contributions of this humble giant of hydrology.

The primary goal of this presentation is to discuss the challenges of transitioning from the study of soil hydrologic processes at the sample and pedon scales to assessing potential impacts at regional and global scales relevant to climate. I begin by reviewing historical aspects of land-surface representation for weather prediction dating back to the seminal work of Richardson (1922). Before focusing on global scales, we need to visit aspects of a long-standing challenge of small-scale representation in watershed hydrology. The gap in scales and the frustration with lack of parameterization and proper physics for bridging these scales illustrates the tyranny of small scales. In transitioning to global scales we skip so many scales that detailed process representation seems to lose importance (especially for pixels of many km in size). We use soil maps and derived pedotransfer functions (PTFs) to parameterize surface hydraulic properties for contemporary hydrological and Earth System Models (ESM). This critical link between small and global scales goes beyond just parameterization; many assumptions regarding physical processes carry over with this link (e.g., surface resistance to evaporation). Considering the magnitude of the challenge and the impasse presented by the small scale, a practical mode of progress focuses on incremental improvements for example, by fixing the PTF parametrization via injection of additional physical constraints, incorporating vegetation and soil structure, and using small-scale information in global flux partitioning (evaporation-infiltration) models within available physical frameworks. The availability of spatially resolved and continuous data opens new possibilities for making inferences based on observed large-scale system responses to constrain parameters and improve model structure.

"The availability of spatially resolved and continuous data opens new possibilities for making inferences based on observed large-scale system responses to constrain parameters and improve model structure."

Soil representation and numerical weather prediction: The journey takes us 100 years ago (about the foundation of AGU in 1919) right after the First World War. Lewis Frey Richardson (Fig. 1a) was 37 years old when he came back from the war where he served with Friends' Ambulance Unit transferring wounded from the battle lines (he was a Quaker and an ardent pacifist, and as a contentious objector, he was exempt from regular military service).

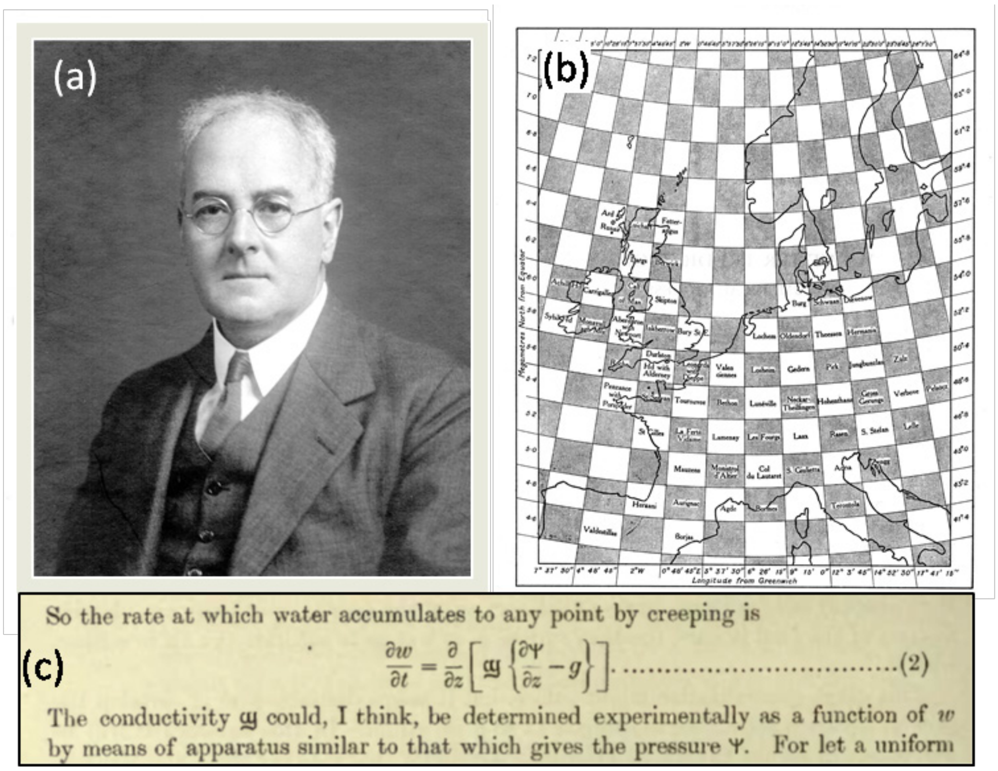

Figure 1: (a) Lewis Frey Richardson (1881-1953), (b) Richardson's map of weather stations and landscape grid for pressure (dark) and velocity (white) calculations: frontispiece of *Weather Prediction by Numerical Process* (Cambridge University, 1922), (c) The Richardson-Richards equation for unsaturated capillary flow in soil.

During the war he managed to complete a manuscript on *"Weather Prediction by Numerical Process"* and send it back from the front lines to be lost and then accidently found and subsequently published in 1922. Among the numerous theoretical and practical topics that Richardson was required to solve, was the challenge of land surface representation and water fluxes at the soil surface. This recognition of the importance of soil surface fluxes, led Richardson to deriving what is now known as the *Richards equation* in 1917, more than a decade before L.A Richards published his work in 1931 (see Fig. 1c). Richardson's work is inspiring by the foresight that paved the way for the systematic numerical modeling of weather and climate, as we know today. Equally important are Richardson's insights into the links between near surface hydrologic processes and climate modeling, and his pioneering efforts to couple them from the very beginning of numerical weather modeling.

Small-scale processes in watershed hydrology: Before moving up the scale to soil surface representation in contemporary global Earth System models, it is instructive to revisit an important and long-standing challenge of small-scale representation in the intermediate scale of catchment hydrology. The challenge of small-scale representation has dominated the hydrological discussion for the past few decades – from an initial enthusiasm and adoption of concepts of distributed hydrological models (Freeze and Harlan, 1969) to highlighting limitations and inadequacies of such endeavors (Dooge, 1986; Klemes 1983; Beven 2001, Wood 1995, McDonnell et al. 2007, Sivapalan 2018 and others). Combined with recent analyses of the opportunities presented by large data with the need for rigorous model selection and hypotheses testing (Clark et al. 2017), it seems that modeling under the "business as usual" mode is no longer viable, and a paradigm shift is required. Nevertheless, a realistic assessment of the available options for such paradigm change must also include the key question of whether efforts should remain focused on resolving the watershed scale representation. Central to this long-standing challenge are three core issues:

(1) the prohibitive task of small scale parameterization of large and heterogeneous hydrologic systems (common to scales ranging from watershed hydrologic models to ESM);

(2) small scale physics may not represent processes at large scales;

(3) over-parameterization and complex model structure preclude credible testing (especially with heterogeneity).

The tyranny of small scale seems to have created an impasse.

"The tyranny of small scale seems to have created an impasse."

Beven in his 2001 Dalton lecture "How far can we go in distributed hydrological modelling?" made the following observation: "*It is clear that we have kept the Richards equation approach as a subgrid scale parameterisation for so long because it is consistent with measurement scales of soil physical measurements… we have not developed the equivalent, scale consistent, process descriptions that would then take account implicitly of the effects of subgrid scale heterogeneity and nonlinearity*". Beven (2001) further listed a range of critical issues (uncertainty, equifinality, heterogeneity) that echo Klemes (1983) and Dooge (1986) quest for unifying laws and ways for addressing the challenge of scales in hydrology (see also a review by Bloeschl and Sivapalan, 1995). A young hydrologist reflecting on these learned discussions may feel frustration by the lack of a clear path and the apparent conceptual stagnation (related to small-scale representation). However, while key issues of uncertainty, equifinality, heterogeneity, systematic hypothesis testing, model structure and scale appropriate parameters remain largely unresolved, progress seems to be occurring everywhere in unexpected ways. This is evident in the advent of global scale Earth system models supported by unprecedented observations, the stronger integration with ecological and climate models, continental scale surface and groundwater models and more. These developments seem to fulfill the prophetic lines of Klemes (1983) regarding leap of scales: "*hydrology will jump ahead after its links with processes at the planetary level are better established, in a similar way as advances in chemistry were made possible by developments in atomic physics. This belief stems from an observation that a successful solution of a problem is more likely if it is approached from two opposite directions. In hydrology, the "other" direction is "downwards" from global concepts*". In other words, the hydrology community gradually embraces pragmatic approaches that skip many scales (inspired by global climate models) to circumvent the impasse of the watershed scale challenge – in the following we discuss ingredients of this pragmatism.

"...the hydrology community gradually embraces pragmatic approaches that skip many scales (inspired by global climate models) to circumvent the impasse of the watershed scale challenge"

From Richardson to Dokuchaev – soil surveys and pedotransfer functions: An important ingredient for large-scale hydro-climatic modeling is land surface parameterization (Richardson 1922), in particular soil attributes and hydraulic properties. The general practice is to use maps of soil types based primarily on soil texture (with supplemental information on soil organic matter, density, horizons, etc.) and correlate these properties that were derived from soil surveys with hydraulic, thermal and other properties of the soil required for climatic or hydrologic models. The information used for soil property mapping accumulated primarily from systematic soil surveys dating back to the late 19th century to Dukochaev in Russia (1883) and the inception of soil survey in the US by an act of Congress in 1896 (Div. of agricultural soils at USDA headed by Milton Whitney 1894). The primary motivation was to assist farmers with understanding their soils and improve land-use practices, and for taxation purposes in Europe (Brevik et al. 2016). Scientifically based national surveys of agricultural lands became common in the early 20th century following the rapid expansion of agriculture and improved understanding of soil properties and their classification (national soil surveys in Canada, India, China, Australia and other countries). Some of the national soil survey databases were merged to create present day global soil maps (e.g., Harmonized World Soil Database - HWSD and SoilGrids) by reconciling profile information, using supplemental remote sensing information and advanced machine learning methods such as in the creation of the SoilGrids250m that uses 150000 soil profiles for training and interpolation (Hengl et al., 2017). Despite the remarkable progress in providing detailed soil maps for modeling, we should keep in mind their origins in soil surveys of agricultural/arable lands that represent only 10% of the land surface.

The dominance of arable soils at the core of global soil maps may introduce bias in the distribution of soil textural classes, for example, by the apparent dominance of loamy soil textures (favored for agriculture) as recent analyses of available databases show (results not shown). A bias is also manifested by the lack of soil structure representation known to alter hydrologic response and surface flux partitioning due to biopores, aggregate and decaying plant material not accounted for by soil texture information (e.g., consider for example a forest soil). These two aspects are likely to propagate into the inferences of soil hydraulic properties based on PTFs due to their reliance primarily on soil texture information (van Looy et al. 2017). Pedotransfer functions are used to correlate easy-to-measure soil properties (i.e., texture) with the more difficult to measure soil hydraulic functions (and other properties). The PTFs are derived by various methods ranging from statistical regression, to neural networks and lookup tables. In the core of these correlations are relatively few (probably <5000), often laboratory measured, soil hydraulic properties obtained from soil samples (many from agricultural lands), this information is used for training the neural networks or for establishing the relations for the soil hydraulic properties (SHPs) used in over the entire Earth's land surface.

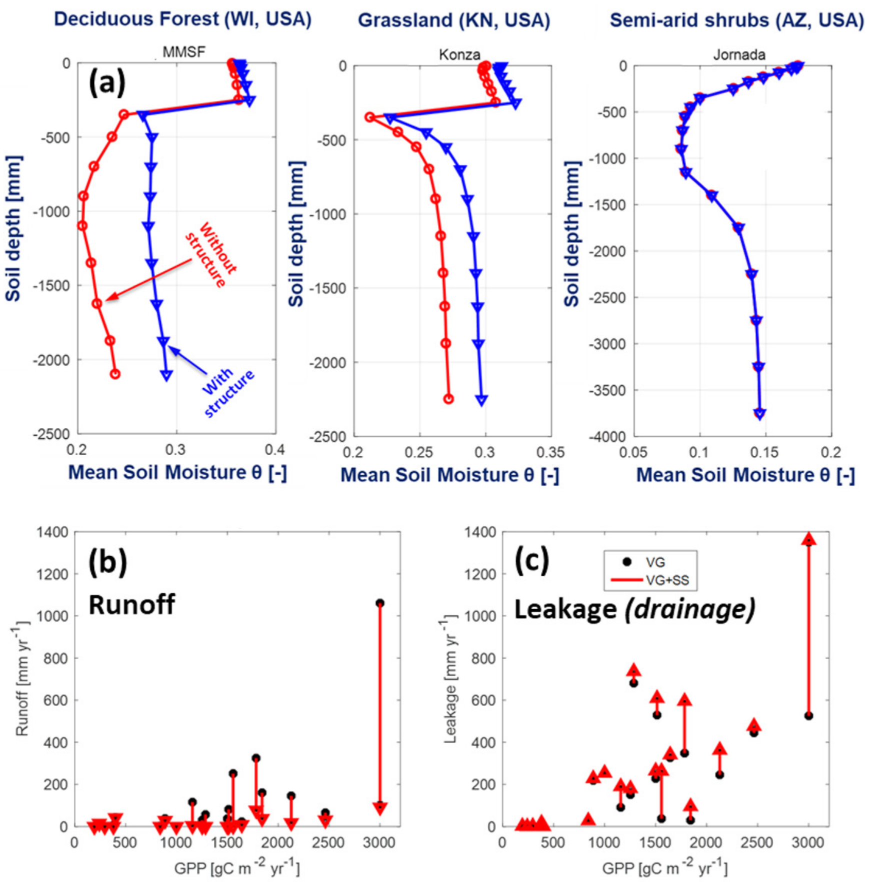

Figure 2: Modeling potential effects of soil structure inclusion in soil hydraulic parameterization on near-surface fluxes for different biomes and climates (***Fatichi et al. in preparation***). (a) A comparison of mean water content profiles with and without soil structure considerations for three study sites with different climatic conditions and biomes; (b) effects on annual surface runoff for 20 locations studied (decreasing); (c) effects of mean annual leakage/drainage from soil profiles for 20 locations studied (increasing). Soil structure is linked with vegetation cover expressed as annual GPP, with the original hydraulic properties marked by VG (black circle) and with soil structure VG+SS (red triangles).

Limitations of pedotransfer functions and practical solutions: The omission of soil structure in PTFs could be responsible for observed scatter in SHPs reported by Gutmann and Small (2007). Their findings suggest that across a range of vegetation covers and climates, soil textural classes explain only 5% of the variance expected from the real distribution of SHPs. In other words, parameter variations exceed expected differences due to soil texture classification. Aware of these challenges, land surface modelers and hydrologists opted for practical solutions such as ad-hoc tuning the values of SHPs to improve model performance (e.g., with respect to runoff or evaporation). While such empirical tuning may offer a practical relief in the short term, it creates a liability in the long term due to reluctance of modelers to embrace new soil information updates due to effects on model performance with new data not considered in the tuning process. This dilemma is not limited to SHPs only, highlights the advantages (in the long term) of a systematic and physically based approaches to determining SHPs with as little empiricism and tuning as feasible.

To address the omission of soil structure in PTF-SHPs with potential impacts of biopores and macroporosity on surface fluxes, Fatichi et al. (in preparation) performed a systematic study of soil structure effects using data from 20 representative locations and modeling the eco-hydrologic responses using an ecosystem model (T&C, Fatichi et al. 2012). Soil structure elements were injected into SHPs by adjusting the saturated hydraulic conductivity to reflect activation of soil macropores during certain conditions. The adjustment reflects soil matrix modification due to biological activity at a location related to vegetation cover (using Gross Primary Production GPP or Leaf Area Index LAI as surrogates) tacitly linking biological generation of soil structure to vegetation cover/productivity. Such approach enable for simple corrections that provide a proof of concept for the importance of such soil attribute using present soil data. Preliminary results of Fatichi et al. (*in preparation*) depicted in Fig. 2 confirm a putative role for soil structure in some conditions on runoff generation, infiltration and drainage (leakage for shallow profiles considered) and average water content in the profile. The results also highlight that in several locations due to rainfall characteristics, vegetation cover, and soil type, soil structure plays a limited role in modifying surface fluxes. For example, it has been shown that hydrologic effects of soil structure in sandy soils was relatively small relative to loamy and clayey soils, and large precipitation events would accentuate effects of soil structure relative to low intensity and long duration events. A more complex question of how the inclusion of soil structure could affect global climate (via potential effects on surface fluxes) has not yet been resolved and is currently under study using a global atmospheric circulation model (OLAM, Walko and Avissar, 2008).

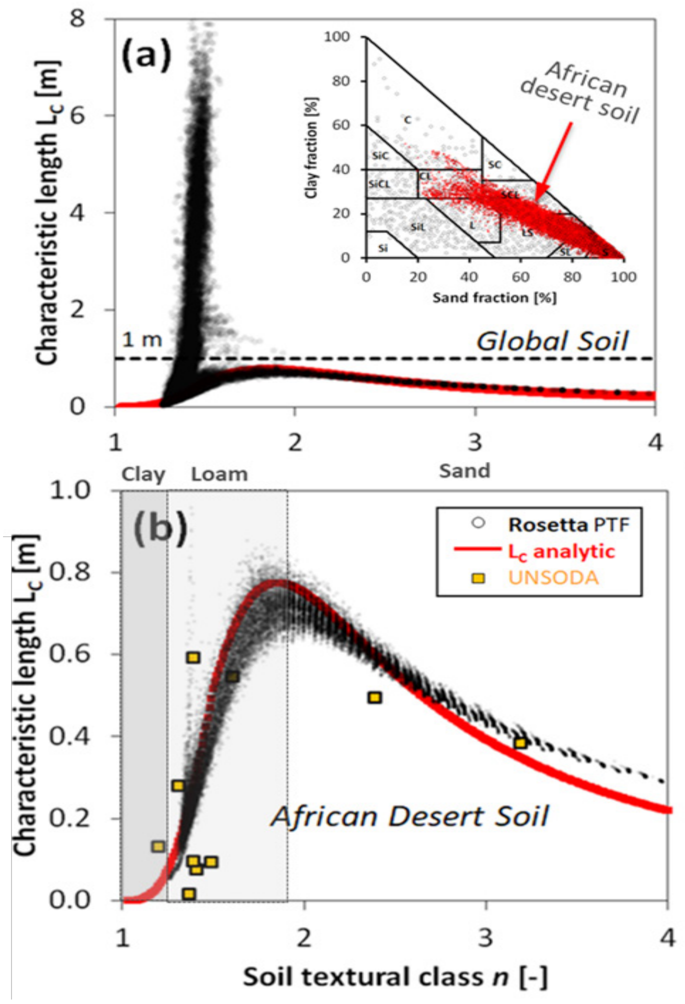

Figure 3: (a) distribution of calculated soil evaporation characteristic lengths L_C based parameters from the Rosetta database with unrealistic values for 1.6>*n*>1.2 (corresponding largely to loam or clay-loam soil); (b) distribution of L_C based on Rosetta parameters and mean values form UNSODA for African desert soils. The theoretical value of L_C for the soil texture (represented by *n* of van Genuchten) is given by the red line. Note the soil texture distributions in the inset of (a).

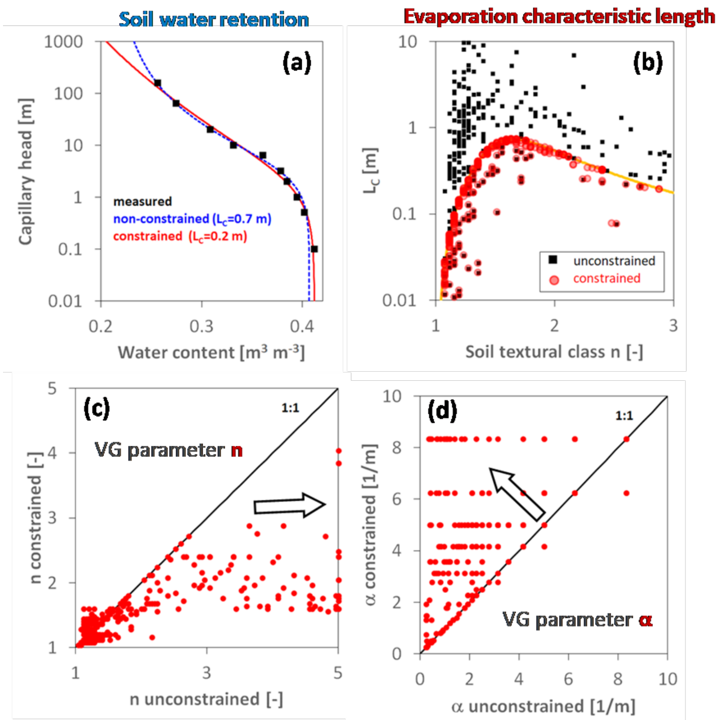

Figure 4: Constraining van Genuchten α and n parameters by requiring simoultaneous fit to (a) soil water retention curve data (a single example), and to (b) evaporation characteristic length L_C (red symbols constrained, black unconstrained). The resulting changes in the values for (c) the *n* parameter and (d) the parameter *α*. Note that the constrained fitting had little effect on the quality of fit to the soil water retention.

The criticism and perceived limitations of present PTFs stem from unrealistic expectations from these products of correlations. Above, we illustrated how vegetation, a prominent ingredient of most land surfaces, could affect surface hydrology beyond what a soil texture would predict through its effect on soil structure formation. In the following example, we focus on ways to systematically constrain SHPs derived from PTFs. This requires imposing physical constraints on estimated sets of parameters, with the aim of weeding out unphysical parameter combinations (hoping to improve process representation). How to identify and remove unphysical combinations of soil hydraulic parameters is not simple. One may limit their potential influence by using simple model structures towards reducing self-compensating errors as discussed by Klemes (1983), or attempting to tame equifinality as discussed by Beven (2001). Taking a pragmatic approach to the PTF-SHP estimation, we require parameter sets to satisfy multiple and potentially different physical criteria simultaneously. The two criteria illustrated next, require the parameters to fit the observed soil water retention curve and simultaneously satisfy a soil evaporation characteristic length (L_C) theoretically predicted for the specific soil type (see Lehmann et al. 2008). Before we illustrate how such a procedure could be implemented, we present in Fig. 3 a distribution of evaporation characteristic lengths (L_C) calculated from the van Genuchten α and n parameters taken from the popular Rosetta PTF-SHPs database (Schaap et al., 2001), and mean parameter values from the UNSODA SHPs database (Nemes et al., 2001) relative to theoretical characteristic length for the soil textural class represented via the n parameter (red line). The results in Fig. 3a show potential effects of "unphysical" parameter combinations (α and n) for the global dataset. We identify these as combinations that produce values of L_C much higher than physically possible (L_C marks the limiting length of capillary continuity to evaporating soil surface during stage-1 evaporation). In Fig. 3b we show that for African desert soils (little vegetation and structure) the "unphysical" deviations are less pronounced, highlighting an additional fingerprint of soil structure on unphysical SHP parameters as seen in Fig. 3a (very high L_C values) for clay-loam soils with 1.4>n>1.2 where soil structure is important and preserved even in arable lands). To constrain the estimation of parameters giving rise to spurious values of L_C we impose the constraints matching the retention curve and theoretical L_C values in the optimization as depicted in Fig. 4. The resulting parameters α and n with the additional constraint are different as seen in Fig. 4 c and d. The preliminary nature of results preclude generalization regarding potential improvements in model performance gained from using these constrained parameters, hence, these serve as an illustration and proof of concept. The practice of using long term observations and system scale response to optimize or tune the parameters used in land surface models is rich with examples such as Gutmann and Small (2007) or Zhang et al. (2010) this practice will undoubtedly expand and guide future parameterization at large scales.

Lessons from going global: Most of my own research is identified with solving small-scale puzzles (pores to samples). However, in recent years our group endeavored to apply principles that we derived from small-scale physics to large and global scale phenomena, for example, the application of soil surface evaporation resistance to estimate global soil evaporation (Or and Lehmann, under review). The journey became possible only through interactions with global scale climate and ecological modelers, especially, interactions via the GEWEX-SoilWat initiative that brought together soil, hydrology and climate people. I recall that a better part of the first day of our GEWEX-SoilWat planning workshop in Leipzig (June, 2016) was devoted to a debate about scale – soil physicists refused to accept representation exceeding several meters and climate modelers would not contemplate anything less than a few km. A compromise of 1 km scale finally paved the way for more productive discussions. As we engage in the journey of "soil processes going global", we learn the value of pragmatism and setting aside universal solutions for sets of small steps, the value of interdisciplinary exchange and learning the language and basis for compromises made at different scales. It is useful to reflect on the state of hydrology that despite certain dissatisfaction with conceptual and theoretical shortcomings; the hydrology community is maturing and becoming well connected and more sophisticated. We have learned to embrace the challenges of large data, to deal with multiple scales, systematic model evaluation and parameter estimation. We are making progress in areas considered insurmountable only a few years back:

Incrementally taming equifinality – studies have expanded the requirements for estimation of consistent sets of parameters by applying physically based constraints that reduce unwarranted degrees of freedom. The need for ad-hoc parameter tuning is reduced where possible by replacing empirical coefficients with physically-based (paving the way for updates as data become available); assembling simple and testable models; and harnessing data availability to improve system representation.

Applying the test of time – it is now the rule rather than the exception to use model "predictions" over extended periods under different conditions to improve parameter and model tuning. Progress in this respect reflects the increase in data availability and the prominence of "climatic" perspectives that are built on long-term observations and averaging.

Capitalizing on large-scale emergent behavior – What was once a challenge of explaining and predicting the intrinsic nonlinearities of emergent system-scale behavior, is now used to evaluate model predictions (i.e., large-scale runoff models to test evaporation estimated). The Budyko framework, the Bouchet complementary relations have not been yet integrated to serve as routine long term and large scale milestones for model evaluation (primarily due to incompatibility with spatial and temporal scales of GCM, ESM or distributed models). Nevertheless, more studies apply these concepts for model evaluation (primarily in the climatic context).

We are not "there" yet; however, hydrology is on the right track and progressing rapidly. I believe Klemes (1986) question "*Dilettantism in hydrology: Transition or destiny?*" has been settled; hydrology was never destined to amateurism.

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Elizabeth Boyer: 2018 Paul Witherspoon Lecture

The Paul Witherspoon Lecture award is given in recognition of outstanding achievements by a mid-career scientist (within 10 to 20 years since PhD) in advancing the field of hydrologic sciences — considering the awardee's research impact, innovative interdisciplinary work, application of research to socially important problems, and inspired mentoring of young scientists. The award also acknowledges that the awardee shows exceptional promise for continued leadership in the hydrologic sciences.

Hydrology as a Central Science

I'm deeply honored to have been selected as this year's Witherspoon Lecturer. The lecture honors the life and work of hydrologist Paul A. Witherspoon, who was a dynamic and influential leader in hydrologic sciences throughout his career. Among many achievements, Witherspoon initiated the Earth Sciences Division of the Lawrence Berkeley National Laboratory and served as its first Director. I got my start in hydrologic sciences as an undergraduate intern at Pacific Northwest National Laboratory. I was interested in pursuing a career in remote sensing at the time, but some great mentors there sparked my interest in surface and ground water hydrology and got me excited about quantifying processes in nature. My undergraduate background in geography (B.S., Penn State University, focusing on remote sensing and geographic information systems), graduate work in environmental sciences (MS & PhD, University of Virginia, focusing on hydrology), and post-doctoral work in biogeochemistry (Cornell University) all encouraged interdisciplinary views of environmental problems. Prior to coming to Penn State, I served on the faculty at the State University of New York at Syracuse, followed by the University of California at Berkeley, I am currently a tenured Associate Professor of water resources in the Department of Ecosystem Science and Management at Penn State University.

> "Interdisciplinary, multi-scale research in the hydrologic sciences provides an important basis for policies and management strategies..."

My research explores natural and anthropogenic processes affecting the water cycle and water quality. I am interested in status and trends of chemical constituents in surface and ground waters, as influenced by landscape characteristics, climatic variability, atmospheric deposition, and watershed management. Much of my work addresses water quality of biogeochemical elements, exploring the fate of carbon, nitrogen, phosphorous, and mercury in watersheds. Despite decades of research, quantifying biogeochemical cycles of nutrients and their fluxes remains challenging, given the need to deal with spatial and temporal variability, to characterize heterogeneous landscapes, and to consider explicit linkages among multiple disciplines. I'm also interested in how changes to eco-hydrologic systems will impact water quality and water scarcity. Many parts of the world already lack clean water, many landscapes are being degraded, and many surface and ground waters are being polluted. Water scarcity will be an even greater problem in the coming years as demand for water increases with population and economic growth, and as global change affects water resources in new ways. Interdisciplinary, multi-scale research in the hydrologic sciences provides an important basis for policies and management strategies to mitigate the effects of water pollution, and to protect, conserve, and restore surface waters.

Horton Research Grants are in support of research projects in hydrology and water resources by Ph.D. candidates in institutions of higher education.

Reactive Interfaces in Agroecosystems: Quantifying the Role of Wetlands and Capillary Fringes in Modulating Landscape Scale Biogeochemical Fluxes

Frederick Cheng, University of Waterloo

Advisor: Nandita Basu

Excess nutrients from agricultural landscapes continue to be a persistent and widespread environmental issue, leading to algal blooms in receiving water bodies and the degradation of aquatic ecosystems (Anderson et al., 2002; Gruber & Galloway, 2008). A certain fraction of the nutrients applied on the landscape are retained in soils, groundwater, wetlands, etc., while the remaining flows to our streams and lakes. Minimizing nutrient pollution thus relies on enhanced retention in various landscape elements. It has been noted that certain areas of the landscape act as "biogeochemical hotspots" such that a disproportionately larger fraction of nutrients are removed here, and help protect downstream waters (McClain et al., 2003). These biogeochemical hotspots or *reactive interfaces* are effective at nutrient removal due to the confluence of favorable environmental conditions and the necessary reactants for intense biogeochemical processes (Figure 1; Krause et al., 2017). Examples of reactive interfaces include the capillary fringe, wetlands, riparian zones, and the hyporheic zone.

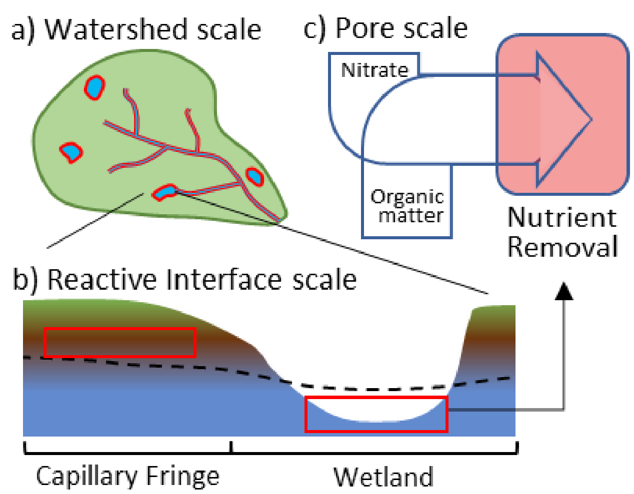

Fig 1. Watershed nutrient removal driven by reactive interfaces which has ideal conditions for removal processes

Over the years, there has been a large body of research from field- and site-scale studies showing the extreme variability in reactive interface function (Bernhardt et al., 2017) and that environmental controls can suppress processing rates, or even flip reactive interfaces from a sink to a source of nutrients (Fisher & Acreman, 2004). For example, wetlands that are often thought of as nutrient sinks can become a nutrient source after sudden flood events (Raisin & Mitchell, 1995). This notion that 'hotspots are not always hot' has not necessarily been translated to watershed management plans due to the lack of predictive frameworks that can capture the transient behaviour of reactive interfaces at the landscape scale. My Horton proposal seeks to address this gap by better characterizing the temporal behaviour of reactive interfaces across a gradient of landscape features and explore the dominant drivers of their biogeochemical functioning. Specifically, I will: 1) quantify how the interaction of water level fluctuations, soil type, and climate modulate the delivery and retention of nutrients in reactive interfaces, and 2) quantify the relative role of reactive interface sub-classes (e.g. small vs large wetlands, upland vs riparian water tables, etc.) and how they contribute to watershed biogeochemical fluxes.

To quantify the interactions between hydrological fluctuations and the nutrient dynamics at a reactive interface, I will be combining the fluctuating water table model by Laio et al. (2009) and the stochastic carbon-nitrogen model by Porporato et al. (2003). This modelling approach would allow me to quantify the probabilistic behaviour of nutrient fluxes and pools as

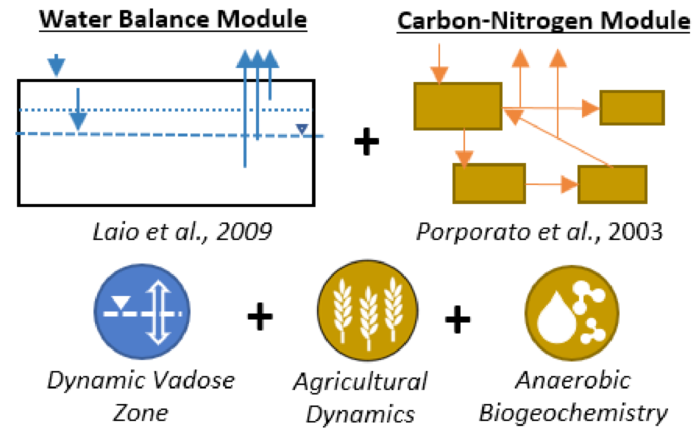

Fig 1: Proposed integration of modelling frameworks to quantify reactive interfaces.

a function of stochastic forcings and characteristics of individual reactive interfaces. With modifications to incorporate agricultural dynamics as well as lateral connections to water bodies such as wetlands, the model will be tested in various iconic ecoregions and used to tease out the relative controls of reactive interface function and their relative role on landscape nutrient processing. The Horton research grant will be critical in supporting collaborations with Prof. Amilcare Porporato at Princeton University. With the development of these modelling frameworks, we will be able to better understand which reactive interfaces to restore, and where to dedicate resources to minimize nutrient export to receiving water bodies.

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Does Groundwater Access Regulate Plant Functional Traits?

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Advisor: Ying Fan Reinfelder

Why is a specific plant found in a specific place? This question has been the subject of many studies for centuries, cutting across disciplines. While general consensus exists that natural vegetation patterns reflect the complex interplay of multiple factors such as water, light and nutrient availability, predation, competition, as well as evolution and past biogeographical controls, much is still unanswered. More recently, under the threat of climate change, it has become imperative to understand how vegetation distribution is governed by the environment to predict ecosystem changes and the complex feedbacks between vegetation and the future climate system.

The goal of my doctoral research is to better understand how the access to groundwater acts as an environmental driver of plant functional traits and plant distribution. While the role of precipitation as a driver

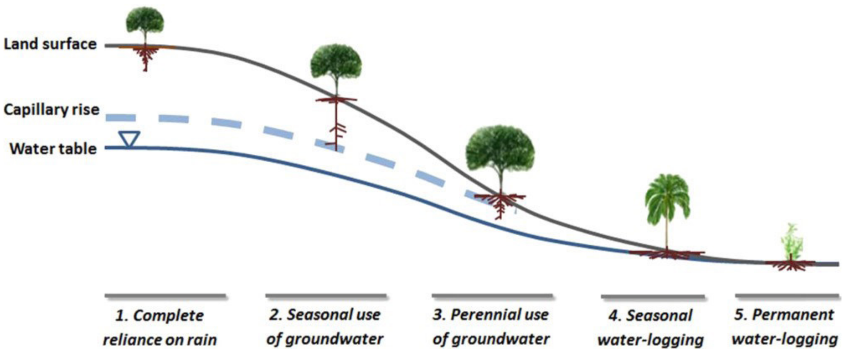

Figure 1: Schematic representation of the groundwater gradient along a hillslope and its influence on plant water availability. Source: Fan (2015)

of large-scale biome distribution has been long recognized (Woodward & Williams, 1987), our understanding of how groundwater governs plant distribution in the local to regional scales is still limited. The reorganization of water by topography generates a heterogeneous pattern of water availability (Fig. 1), one that can subject plants under the same climate to completely different water regimes (Fan, 2015). This was already shown to govern plant rooting depth in a global study (Fan et al., 2017), as well as changes in species composition along topographical gradients in the Amazon (Schietti et al., 2014). Recent studies have also shown that hydraulic traits – physiological characteristics which control how plants respond to drought – might be one of the underlying plant mechanisms to this segregation (Cosme et al., 2017; Oliveira et al., 2018).

To address this question, I will integrate hydrologic modeling, plant hydraulics models, and field observations of plant hydraulic traits. With the help of the Horton Research Grant, I will be able to travel to Brazil and join Dr. Rafael Silveira at UNICAMP (Brazil) for a field campaign in the Amazon and surrounding biome transitions to collect plant hydraulic traits data along groundwater gradients in different topography-climate combinations (Fig. 2). We expect that such integrated model-observation studies will allow us to better understand the mechanisms of groundwater-vegetation interactions, and to gain further insight into forest response to future climate change, a critical step towards a more sustainable management of our natural resources.

Figure 2: The undulating topography in central Amazon (image source: https://factslegend.org/30-amazon-rainforest-characteristics-facts-homework/).

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Solar-induced Fluorescence to Improve Terrestrial Evaporation Representation and Drought Monitoring

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Evaporation is the primary nexus between global water, carbon and energy cycles (Hetherington and Woodward, 2003). Plant transpiration dominates the global flux of terrestrial evaporation (Jasechko et al., 2014). As such, biophysical and biochemical feedbacks on climate are highly dependent on vegetation phenology and plant response to stress conditions. These responses vary among plant species and make the modeling of photosynthesis and transpiration processes particularly challenging. Despite its vital and complex role in climate, most Land Surface Models (LSMs) compute the vegetation response (specifically stomatal conductance) to stress conditions semi-empirically. These variations in terrestrial water and energy cycle processes in models have proven to be responsible for a large uncertainty in projecting climate change impacts on droughts (Prudhomme et al., 2014). Furthermore, there is a lack of global continuous observations of photosynthesis and transpiration to validate these semi-empirical algorithms, which may inhibit real-time drought monitoring.

Given (a) the importance of transpiration for global hydrology and climate, (b) the dependency of transpiration on the response of stomatal conductance to environmental stress, and (c) the difficulties to represent this response in models, there is a need to investigate the impact of environmental stress on transpiration at the global scale from an observational perspective. Due to the scarcity and limited coverage of in situ observations, satellite retrievals are an attractive means to monitor transpiration stress, unravel the implications in terms of land feedbacks on climate, and improve the representation of evaporation in hydrologic and climate models.

Solar-induced chlorophyll fluorescence (SIF) is a by-product of photosynthesis: a small fraction of light, initially absorbed by chlorophyll pigments, that is re-emitted as a subtle glow of energy in the spectral range of 650–800 nm (Papageorgiou 1975). Therefore, the intensity of the SIF signal is indicative of the functioning of the photosynthetic machinery (Porcar-Castell et al., 2014). As water lost through transpiration and carbon uptake through photosynthesis is regulated by stomatal opening, negative anomalies in SIF should integrate the effects of different environmental stressors on transpiration (Figure 1). Conveniently, spaceborne datasets of SIF have become available in recent years and are already used to monitor crop photosynthetic activity and gross primary production (i.e. Joiner et al., 2014).

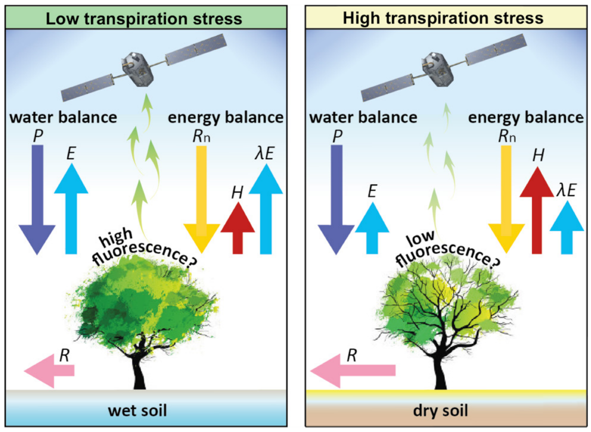

Figure 1: Conceptual diagram of the expected satellite SIF signal, water and heat fluxes under conditions of stress. The diagram includes precipitation (P), evaporation (E), runoff (R), net radiation (Rn), sensible heat (H) and latent heat (λE).

Preliminary results successfully show the ability of using SIF to estimate transpiration stress globally. Our next steps are to utilize satellite observation of SIF to improve global evaporation retrievals and drought monitoring efforts.

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Obituary: Al Rango

Dr. Al Rango, Research Hydrologist, passed away on April 26, 2018 in Las Cruces NM after nearly a 50-year career with Penn State, NASA, and USDA, Agricultural Research Service (ARS). Al was an active participant in AGU Hydrology and Cryosphere Section activities especially those related to applications of satellite technology to monitor snow cover depletion and use of the SRM-Snowmelt Runoff Model. Through Al's efforts SRM was ultimately applied to streamflow prediction on over 125 basins and in 20 countries including his home basin of the Rio Grande in NM. In more recent years his work expanded to use of new technology for monitoring ecological status of range lands and providing leadership for the USDA Southwest Climate Hub. During his career, Al received the Exceptional Service Award from NASA in 1974 and with ARS he was named Senior Scientist of the Year in 1999 and received the prestigious Presidential Rank Award of Meritorious Service from the White House in 2005. It was only fitting that on June 15, 2018 Al's family, friends and colleagues held the Rango Jamboree to celebrate his life and accomplishments at the Jornada Experimental Range near Las Cruces.

-David R. DeWalle, Penn State Emeritus Professor

Hydrology

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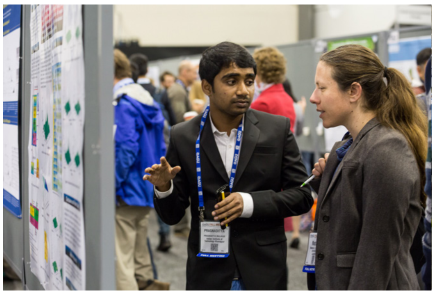

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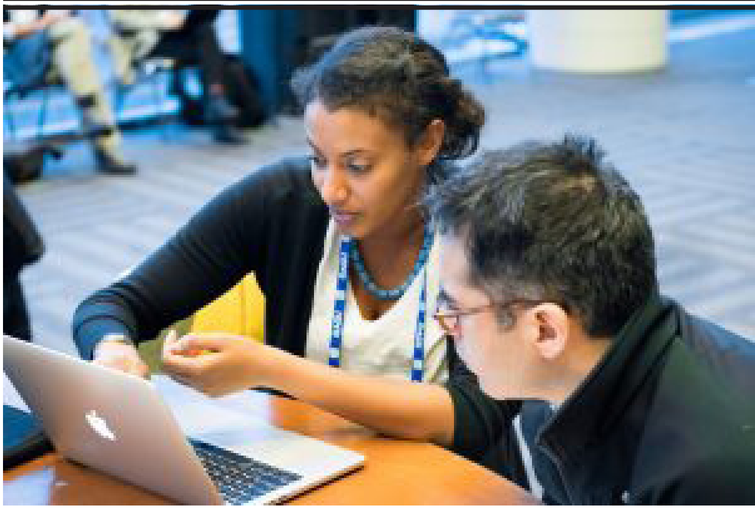

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