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WEATHER CLIMATE WATER

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Workshop Report

"Innovation in Hydrometry – from ideas to operation"

IAHS-MOXXI and WMO HydroHub joint workshop

MOXXI Measurements & Observations in the 21st Century
Working Group - International Association of Hydrological Sciences

WMO HydroHub

Prepared by: WMO HydroHub Team
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1 The meeting in short

At the beginning of December 2017 around 70 participants from academia, public and private sectors met in the WMO headquarters in Geneva to attend the workshop titled "Innovation in Hydrometry – from ideas to operation". The MOXXI working group of IAHS and the WMO HydroHub jointly organized the two half-day workshop to bring members of the science and operations communities together to learn from each other about new technologies and current research in the area of hydrometry and start a dialog on how to foster uptake of innovative solutions in operational environments.

The workshop was opened by Johannes Cullmann, Director of the Climate and Water Department of the WMO and Christophe Cudennec, Secretary General of IAHS. Dominique Bérod and Flavia Tauro introduced the WMO HydroHub and the MOXXI working group of IAHS to the audience.

The first half day comprised a series of 28 short presentations followed by Q&A with the speakers. The presentations were organized in eight thematic sessions:

Session 1. Gauging Floods
Session 2. Satellite-based monitoring
Session 3. Dealing with networks
Session 4. Monitoring water stress
Session 5. Rainfall monitoring
Session 6. Water quality and soil monitoring
Session 7. Citizen science
Session 8. Round table on drones for hydrology

The second half day was dedicated to motivate collaboration between the communities, discuss experiences and identify possible follow-ups to improve operational uptake of innovative solutions in the field.

Maurizio Mazzoleni[1] presented his work on the "Assimilation of crowdsourced data in hydrological modeling to improve flood prediction" to showcase the possible contribution of crowd-sourcing data to classical models. This new kind of data can be of unknown accuracy, measured at previously unknown locations and times.

In the following interview-style panel discussion, the four panelists, Robert Naudascher (ETH Zürich and hydrosolutions), Paul Kucera (UCAR/NCAR), Cecile Kittel (Technical University of Denmark) and Krunoslav Premec (WMO Secretariat), from academia, public and private sectors shared their experiences in using innovative solutions in operations of national hydromet services and in development projects. They highlighted typical hindrances for uptake of new technologies in operational environments and possible improvements that both sides could consider.

Joël Fisler[2] presented MeteoSwiss' efforts to integrate third-party data into their internal routines. A certification scheme with independent third-party assessments is employed to convey expectations and capabilities between data providers and consumers. Details of this work are available in the following WMO publication: "METEO-Cert: process, certification, thinking capacities and lessons learned".

[1] Maurizio Mazzoleni, IHE Delft Institute for Water Education, m.mazzoleni@un-ihe.org
[2] Joël Fisler, MeteoSwiss, Joel.Fisler@meteoswiss.ch

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The audience then split up into breakout groups to discuss "Innovative technologies in operational environments" and was tasked to 1) perform a SWOT analysis, 2) share best practices and lessons learned and 3) identify key features of a future, more enabling environment for innovation.

In the breakout group discussion, innovators had the opportunity to address their demands directly to representatives of operational and standardizing organizations, while participants from national services were able to describe their challenges with practical use of new technologies.

2 Main points of discussion

The following topics, among others, were highlighted and/or discussed throughout the two days of workshop:

2.1 Communication

There was a general agreement about the need to improve information and knowledge exchange through the whole innovation value chain from the generation of initial ideas, to their conversion into end-user products and eventual application in operational environments. Good communication between the different stakeholders was identified as a crucial prerequisite for successful innovation, and remains a challenge.

2.1.1 Standardizing bodies and hydrological researchers

Participants stressed that communication between standardizing bodies - in particular the WMO's CHy[3] and CIMO[4], ISO's Technical Committee's on Hydrometry - and the hydrological research community needs to be improved.

There was a general understanding among participants that standards are important and useful. All technologies should reference standards to ensure traceability and accuracy of observations. Challenges remain in relation to defining standards in a way which allows for rapid innovation in sensors and methods. There are examples from some countries where standardizing bodies define the required outputs from monitoring technologies but allow some flexibility in how they are achieved - such as the IFS[5] in the U.S. and MCerts[6] in the UK.

Within WMO, there may be benefits from CHy experts and the wider hydrometric research community, working more closely with the CIMO community. This is already common practice for meteorological research and this collaboration has shown good results.

2.1.2 Researchers and end-users

Current research is often not well communicated and too complex for direct application in operational contexts. Additional steps to operationalize solutions are needed. Topics such as user support, maintenance of software and hardware cannot be covered by academia alone. Operationalization in general has to take into account human as well as technical capacities and resources of end-users.

[3] WMO Commission for Hydrology
[4] WMO Commission for Instruments and Methods of Observation (CIMO)
[5] https://www.ifs-certification.com/
[6] https://www.gov.uk/government/collections/monitoring-emissions-to-air-land-and-water-mcerts

The work of UCAR on 3D printed automatic weather stations[7] was highlighted as a good example here. The focus is not only on the technology itself, but covers also coordination with standardizing bodies and knowledge exchange with end-users. UCAR looks at the total cost of ownership of their solutions, provides guidance for a self-manufacturing lab, creates documentation and provides training for trainers.

While self-manufacturing might be a good approach because it allows to understand and develop the tools of daily work (hardware and software), one has to be aware that a specific skillset is required to do so. Indeed, the roles of developers, manufacturers, maintainers are different from those of observers and forecasters. Operational services might not have the needed expertise and might not want to invest the time and resources to develop their own solutions.

2.1.3 Remote sensing and in-situ monitoring communities

The current divide between the remote sensing and the in-situ monitoring communities was highlighted. There is a need for improved communication between these groups to improve the utility of remotely sensed products. For operations, particularly in the developing world, current satellite products are often too complicated.

2.2 Accuracy vs. operational cost

High quality observed data is crucial but cost-efficiency cannot be ignored, as data of limited accuracy can be useful for many applications. Innovative solutions often aim at reducing the cost of equipment and - sometimes compromising on data accuracy. Participants underlined the importance of taking into account the fact that equipment that is low-cost in the initial procurement is not always low-cost when looking at the total cost of ownership over its lifetime. In order to identify adequate solutions, accuracy vs. operational cost in respect to the applications in question needs to be assessed.

The general helpfulness of standards was put forward, as they ensure global comparability and traceability, streamline development, define good quality data among others. Standards however, can also be a hindrance when they exclude low-cost technologies simply because of limited accuracy even though they would perfectly be suitable for the application at hand.

According to some participants, WMO standards currently drive up cost of procurement if tenders are formulated mainly based on standards, ignoring the specific application. Furthermore, objective measures (or classifications) to describe qualities other than ‘high’ are missing. A more elaborate quality scale would allow to formulate quality requirements vs. total cost of ownership to identify adequate and cost-effective technologies depending on the specific application.

While traditional observing networks create a relatively small number of high-cost observations of high-accuracy, crowd-sourcing creates huge quantities of data points that are essentially free to acquire. The resulting data sets require more intricate analytics (big data analysis, correlation with traditional data etc.) but could be a good opportunity to fill some data gaps. Besides of these opportunities there are also threats in crowd-sourcing that arise if possible applications and limitations are not communicated properly. Motivated by reduction of cost, decision-makers could tend to rely more on assumptions instead of objective knowledge. Complicated analysis could be

[7] Paul Kucera, UCAR/NCAR, pkucera@ucar.edu

wrong or wrongly interpreted. It will be of prime importance to robustly define data quality and exchange this information together with the data to make crowd-sourcing data useful for practical application.

2.3 Free and open data sharing

It is a common issue that data is being measured but not freely shared beyond the partners in a project or stakeholders of a specific service. The fact that critical data is not freely available, but has to be bought or comes with restrictions e.g. republication, remains a great obstacle, especially for research and innovation projects.

2.4 Open source software and hardware

Besides of observation data, descriptive instrument meta data and data quality should also be exchanged. Specification of the hardware of instruments and the algorithms utilized to derive the observables from the physical measurement should be fully open. It is for example important to understand exactly how the discharge value is computed by a device to make credible hydrology possible.

Intellectual property and copyrights are a pivotal point in this discussion. WMO and HMEI[8] collaboratively promote open software and hardware to explicitly avoid "black-box" solutions, while getting more cost-effective. Centers of excellence are employed to operationalize newly developed technologies.[9]

Rain radars are a good example for the collaboration of instrument manufacturers and end-users. Specifications of instrumentation are mostly open while implementation is carried out through commercial partners, creating a win-win relationship between public and private sectors.

2.5 Innovation for a reason

It is not easy to identify in what areas innovation is most urgently needed. Good solutions exist for the measurement of discharge and water level but the real challenge might be to see where real benefits could come from for the end-users. In case water is sold by amount in a local community and high quality measurements are not economically viable, an adequate solution might be non-technological e.g. rethinking the business model rather than installing a new gadget.

Especially in the developing world context, "innovation" does not always mean to bring in the newest "toy" but rather to cautiously modernize existing workflows. Technology and innovation must be a means to an end that is adequate and suitable to support and improve work on the ground. Modernization should also be seen as including the acquirement of new skills to adapt to new tools.

Success in hydrometry should always be defined as a long-term output of data and information products and innovation should directly support the provision of end-user services. On this basis, development projects should be designed in a way that users can take ownership in the implementation and deliver. The beneficiaries of project work should receive assistance to execute the main implementation themselves. This approach is more sustainable then short-term teacher-student relationships. Native

[8] The Association of Hydro-Meteorological Equipment Industry (HMEI), http://www.hmei.org/
[9] https://www.wmo.int/pages/prog/www/IMOP/Testbeds-and-LC.html

incentives of the beneficiaries of projects are the best guarantor of long-term sustainability.

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3 Group discussion results

In the following segment, the main results of the break-out group discussions are summarized and brought into context.

3.1 SWOT analysis

Participants highlighted the strengths of using innovation in the production of low-cost equipment, more flexible adaptation of user requirements which is particularly advantageous for local communities. In addition, more data could be collected by observing additional parameters and increasing spatio-temporal resolution.

Weaknesses included the lack of standardization, which can lead to a requirement for additional training and presents risks as fragmentation from use of different technologies might be time consuming to overcome. Direct collaborations are required between researchers and those responsible for operations. Extra efforts are needed to sustain data quality and consistency over time.

Opportunities in the use of new technologies included complementing existing traditional observing networks to fill data gaps and/or add more spatial resolution in observations which could in turn improve services and empower local communities. The community could profit from an increase in competition through entrepreneurs and SMEs in a market that is, in some areas, dominated by a small number of large companies.

While diversifying observations and services provided, there is an inherent threat that users treat complicated innovative sensors as a "black-box", not fully understanding underlying measurement principles and algorithms. As a consequence, the objectivity of measurements could be at risk.. It is important to properly communicate that innovative technologies can only complement traditional observing networks. If low-cost technologies would partially substitute high-accuracy networks, the long-term consistency of data series is at risk, e.g. for climate analyses.

3.2 Key success factors

Key success factors that came out of the discussions include the communication between stakeholders on all levels from the start of a project, and constant feedback throughout a project. Furthermore, the clear communication of the capabilities and limitations of technologies to end-users as well as efforts to increase the understanding of technologies is important. End-users should see the need to adopt a certain technology, based on a customer-focus and good understanding of benefits and drawbacks on the users side, which is pivotal to create ownership for sustainability.

3.3 Lessons learned

Lessons learned focus on communication between all stakeholders: innovators, local agencies, academia and operational staff. Taking good care of proper documentation and training is advised as well as early and continued inclusion of users. A long-term business model for operations after the project has ended supports the ownership in the project and sustainability afterwards. Local conditions, including legal and safety issues, have to be considered. Experiences and challenges of all aspects of technologies and stages of projects should be openly shared and discussed.

3.4 Enabling environments

Projects involving innovative technologies are most successful when they focus on users i.e. striving for early and continuous involvement of end-users and local communities and trying to build confidence in approach and technology. End-users should be involved in research and development at concept level and iteratively assess prototypes. Early adopters should directly contribute, for example, by writing manuals from their own point-of-view.

A certain degree of streamlining of technologies and approaches is needed as well as coordination of different projects with respect to standardization of technologies. Routinely sharing of data and information that comes out of projects under an open data policy would help synergies and avoid duplication of efforts. Technologies employed in the field should be tested in extensive comparison campaigns to prove that they are advantageous for the specific application.

Ownership and participation of governments, and national entities, including financial contributions, should be fostered to also make sure that legal and safety requirements are appropriately recognized.

Systematic publication and sharing of good practices and success stories but also of lessons learned and failures, as well as supporting an open interdisciplinary discussion with all stakeholders would help improve technologies, procedures, projects and eventually operations.

The audience requested WMO to further promote open data policies and develop and publish general guidelines for innovation in hydrometry. For new technologies there is a need for guidelines for certification to classify quality. Incubator funding could be provided to bring innovative ideas to proof-of-concept stage.

4 Conclusions

Harry Dixon, Chair of the WMO HydroHub Innovation Committee and moderator of the second day, concluded that the workshop had demonstrated the need to foster all aspects of innovation in hydrometry, including: identifying areas of monitoring where new sensors or methods are needed; helping to scale up innovative approaches from proof-of-concept to national/international operational use and; ensuring the long-term sustainability of new technologies by promoting a culture of continuous innovation within the WMO community. He noted that the ideas generated at the meeting would be used as input to the HydroHub's deliberations regarding how best to support future innovation and that there was a very clear need for further collaboration between the research community and National Hydrological Services.

Christophe Cudennec and Johannes Cullmann highlighted the long tradition of collaboration of both institutions and the strong overlap of objectives in the hydrology community. The IAHS / WMO collaboration is a good way to bring more science to the hydrology community, discuss new ideas, and bring the provider and consumer communities together. Both sides can profit from more targeted research that is more informed about operational needs and requirements. This collaboration should also be fostered in direct collaboration at working group and project levels.

The new IAHS working group on Citizen Science could be an important contributor to these efforts. Support from sociologists that help transform ideas into services should also be included in future.

5 Participants' feedback

Over half of the 66 workshop participants answered a survey in which the quality and relevance of the two-day workshop and the networking reception in the evening of the first day were assessed.

Half of the responses came from academia, 32% from private sector and 18% from public sector affiliated participants.

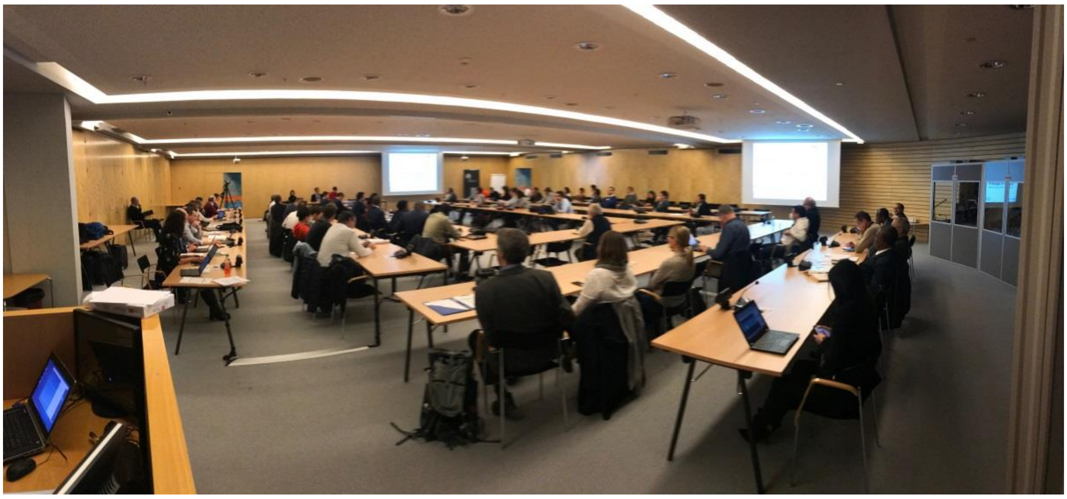
Around 94% of all responses defined both days of the workshop as *good* or *excellent*, while 71% and 75% said that day 1 and day 2, respectively, where *very helpful* or *extremely helpful*. 62% of responses considered the networking reception *very* or *extremely helpful*. No participant qualified the workshop or the reception as *poor* or *not at all helpful*.

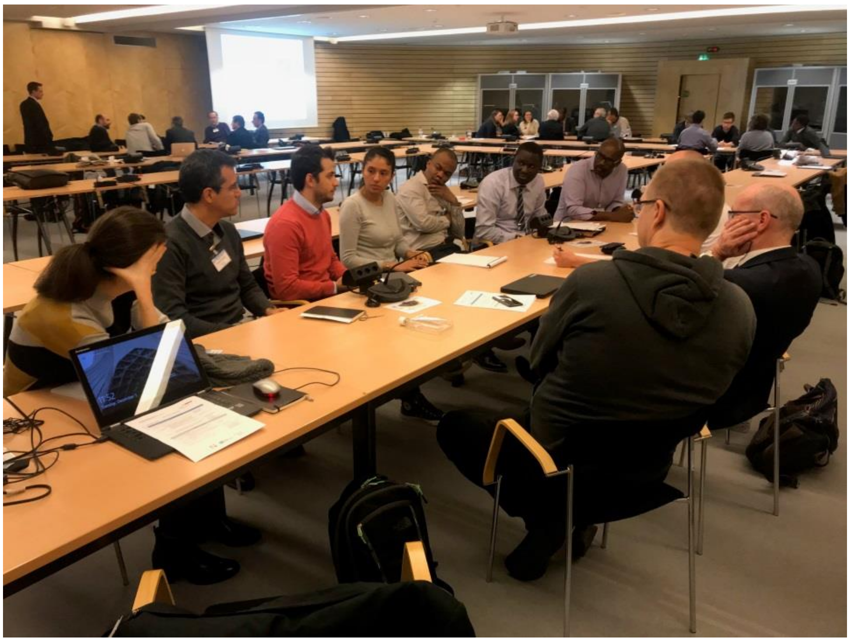
A small number of participants expressed the need for more time for discussions and networking between presentations by either allocating more time or inviting less presentations. In view of a future workshop, it was suggested to broaden the range of participants by inviting more policy makers, practitioners from national services as well as potential investors. This should turn the focus away from research projects and PhD studies towards an audience with more direct links to practical hydrometry.

6 Further reading

WMO meeting webpage with additional material	https://public.wmo.int/en/events/workshops/innovation-hydrometry-from-ideas-operation
All slights are available on MOXXI's meeting page	https://iahs.info/Commissions--W-Groups/Working-Groups/MOXXI/Information/MOXXI-2017.do
"Measurements and observations in the XXI century (MOXXI): innovation and multidisciplinarity to disclose the hydrological cycle", (pre-print, link available soon), F. Tauro et al.	http://dx.doi.org/10.1080/02626667.2017.1420191
"Can assimilation of crowdsourced data in hydrological modelling improve flood prediction?", Mazzoleni et al.	https://www.hydrol-earth-syst-sci.net/21/839/2017/
Quality Assessment using METEO-Cert: The MeteoSwiss Classification Procedure for Automatic Weather Stations, WMO Publication	https://library.wmo.int/opac/index.php?lvl=notice_display&id=19954#.Wk9aDoRuKUk
Guide to Meteorological Instruments and Methods of Observation: (CIMO guide), WMO Publication	http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html
WMO data exchange policies	https://public.wmo.int/en/our-mandate/what-we-do/data-exchange-and-technology-transfer
"Innovative Technology for Low-Cost Surface Atmospheric Observations (UCAR)", WMO News article, Apr 2017	https://public.wmo.int/en/media/news-from-members/innovative-technology-low-cost-surface-atmospheric-observations-ucar

7 Photos





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Meeting Programme

Moderated by Flavia Tauro
University of Tuscia (UNITUS) and Chairperson of MOXXI

Monday, 4 December		
Series of Thematic Sessions organized by IAHS-MOXXI		
13:30-14:00	Opening remarks by Christophe Cudennec (AGROCAMPUS / IAHS) and Johannes Cullmann (WMO)	
14:00-14:30	*Session 1: Gauging Floods*	
	Back to the Future of stream gauging	J. Le Coz
	Gauging Flash-Floods	K. Liechti, S. Boss, B. Fritschi, M. Zappa
	discharge.ch	S. Peña-Haro, B. Lüthi, T. Phillipe, T. Siegfried, L. Bošnjak
	Operational vision-based hydrometry	W. Castaings, T. Barth, G.-M. Saulnier
	LowCost 3D for Extreme Events	H. Sardemann, A. Eltner
14:30-15:00	*Session 2: Satellite-based monitoring*	
	Operational river monitoring from Sentinel-3 radar altimetry	C. M. M. Kittel, P. Bauer-Gottwein
	Geophysical monitoring by new innovation space technology and interface (V)	Y. Ozorovich, Y. Kontar, V. Santiago-Fandino, A. Fournier-Sicre, A. Ivanov, S. Klimov, P. Povinec
	H SAF on CDOP 3	F. Zauli, F. Gattari
15:00-15:30	*Session 3: Dealing with networks*	
	TranscodX: A Generation of Full Stack Environmental Data	P. Celicourt, R. Sam, M. Piasecki
	Quality control of UK hydrometric data	K. Muchan, C. Sefton, S. Turner
	A software for hydrological analysis	M. Vargas, S. Beskow, T. Caldeira, L. Corrêa
Coffee & Tea Break		

Monday, 4 December (page 2)		
16:00-16:30	*Session 4: Monitoring water stress*	
	UAV-based remote sensing for tree responses to water stress	A. Harfouche, R. Ludovisi, F. Tauro, R. Salvati, P. Ibba, A. Gay, G. Scarascia Mugnozza
	Using IR to estimate water stress indicators	J. L. M. P. de Lima, M. M. Vargas, J. M. M. Gonçalves, I. P. de Lima, L. I.V. Santos, G. W. Nagel, J. R.C.B. Abrantes, M. Tudor
	Monitoring Large-Scale Pressurized Irrigation System via surface energy balance	H. Awada, G. Ciraolo, A. Maltese, M. A. Moreno Hidalgo, G. Provenzano, F. Capodici, J. I. Còrcoles
16:30-16:45	*Session 5: Rainfall monitoring*	
	A novel view on rainfall measuring	A. Cagninei, F. Laio, A. Croci, R. Ricupero, P. Cavagnero, M. Ferrabone, P. Mazzoglio, P. Allamano
	Rainfall monitoring using commercial microwave links	A. Overeem, H. Leijnse, R. Uijlenhoet
	Mobile phone network for rainfall measurement in Africa	M. Turko, M. Gosset, F. Cazenave, N. Chahinian, C. Bouvier, M. Alcoba, J.-P. Briquet
16:45-17:10	*Session 6: Water quality and soil monitoring*	
	Electrical conductivity and water quality in rivers	P. Benettin, A. Rinaldo, B. van Breukelen
	Infrared thermography in surface hydrology: Soil water repellency	J.R.C.B. Abrantes, J.L.M.P. de Lima, S.A. Prats, J.J. Keizer, A.A.A. Montenegro, M.I.P. de Lima
	IGRAC's Global Groundwater Monitoring Network and needs for new technology	Claudia Ruz Vargas, Neno Kukuric

Monday, 4 December (page 3)		
17:10-17:40	*Session 7: Citizen science*	
	Flood monitoring with social media, citizen observatory, wireless sensor network, and machine learning (V)	E. M. Mendiondo, C. Restrepo-Estrada, M. C. Fava, S. C. Andrade, J. P. de Albuquerque, N. Abe, J. Ueyama, L. Degrossi, G. Furquim, G. Pessin
	CrowdWater	S. Etter, B. Strobl, I. van Meerveld, J. Seibert
	Contribution of citizen science in flood hazard assessment	B. Sy, C. Frischknecht, H. Dao, D. Consuegra, G. Giuliani
	TAHMO's solution for weather observation in Africa (V)	R. Hochreutener, J. Selker, N. van de Giesen, F. Annor
17:40-18:00	*Session 8: Round table on drones for hydrology (co-organized by the COST Action HARMONIOUS)*	
	Unmanned Aerial Vehicles and hydraulics	F. Bandini, C. M. M. Kittel, B. Lüthi, M. Garcia, P. Bauer-Gottwein
	Usage of drones in local governments: A case study of river stream monitoring	K. Mishev, A. Stojmenski, I. Mishkovski, D. Trajanov
	Exploring the optimal setup for surface flow velocity measurements using PTV	S. Manfreda, S. Dal Sasso
	Thermal particle tracers for very shallow overland flow velocities	B. Mujtaba, J. L. M. P. de Lima
	Image-based non-contact flow monitoring for communities at risk	M. Perks, A. Russell, A. Large
18:00-18:30	Discussion and final remarks	
Networking Reception from 19:00-21:00 in the Attic at WMO		

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Meeting Programme

Moderated by Harry Dixon
Centre for Ecology and Hydrology (CEH) and Chairperson of the WMO HydroHub Innovation Committee

Tuesday, 5 December		
Innovation in Traditional Environments		
09:00-09:20 #1 (20')	Opening Remarks IAHS-MOXXI / WMO HydroHub	Dominique Bérod WMO / HydroHub Flavia Tauro UNITUS / MOXXI
09:20-09:40 #2 (20')	Presentation: Assimilation of crowdsourced data in hydrological modeling to improve flood prediction. • Characteristics of traditional and innovative observation data: static vs crowdsourced sensors • Integration of crowdsourced observations in hydrological models • Economic impact of crowdsourced observations	Maurizio Mazzoleni UNESCO-IHE
09:40-10:40 #3 (60')	Interview-style panel discussion: Sharing experiences and challenges of using innovative technologies in capacity development projects.	Robert Naudascher ETH Zürich / hydrosolutions Paul Kucera UCAR/NCAR Cecile Kittel Technical University of Denmark Krunoslav Premec WMO Secretariat
Coffee & Tea Break		
Innovation meets Operations		
11:00-11:20 #4 (20')	Presentation: "METEO-Cert: process, certification, thinking capacities and lessons learned" • MeteoSwiss' approach to compliance of partner observations	Joël Fisler MeteoSwiss
11:20-12:05 #5 (45')	Break-out group discussions: "How to foster the uptake of innovative observation technologies by National Services?"	All participants
12:05-12:20 #6 (15')	Report back and conclusions	Table discussion leaders
12:20-12:30 #7 (10')	Closing remarks by MOXXI / WMO	Christophe Cudennec AGROCAMPUS / IAHS Johannes Cullmann WMO Climate and Water Dept.

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