NASA Flood Risk Workshop 2018

Final Report

Meeting website: https://csdms.colorado.edu/wiki/FloodRiskWorkshop

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Summary

Flooding is the most common natural hazard and affects more people worldwide than any other disaster. Apart from many fatalities and displacements, flooding costs over US$100 billion annually. Recent international community efforts like the 2016 Flood Response Workshop have focused on providing better products and services for flood disaster response assistance worldwide. However, flood *risk* requires more attention—evidenced by its framing in the Sendai Framework for Disaster Risk Reduction. This agenda and agreement calls for researchers to combine flood hazard analysis at a global scale with vulnerability metrics at local scales.

To discuss this need, approximately 80 researchers from different sectors and organizations gathered at the NASA-supported international Flood Risk Workshop. By forming a new Flood Risk Community of Practice (FRCP), the aim of the workshop was to reach consensus on priority actions to address the main challenges in flood risk estimation and align those actions with the goals of the Group on Earth Observations (GEO) Global Flood Risk Monitoring (GEO 2017–2019 Work Programme) and the Sendai Framework for Disaster Risk Reduction.

Figure 1 Aerial view showing flood damage in Colorado on 14 September 2013. Credit: Staff Sgt. Wallace Bonner/U.S. Army

Workshop participants identified a need to better understand availability in data and tools to mitigate flood risk. Addressing this need will facilitate a global methodological comparison between various

Earth-observing data sets, models, and maps while ensuring a focus on local flood risk and impacts of climate change. Together, the attendees defined a 10-year plan to be addressed by FRCP:

Phase I is laying the foundation for FRCP by establishing the following:

interoperability of products through implementing well-established standards (for example, Open Geospatial Consortium standards)

communication of methods and models to encourage transparency and ultimately accelerate scientific advances of the community by building upon knowledge

uncertainty estimation for flood risk mapping and modeling products to better ensure informed decisions by flood risk management

At the end of this 2-year period the FRCP group will have (1) a document that addresses the above-identified topics and (2) a demonstration framework to show how improving products will help societies and the wider community.

Phase II encompasses broadening community consensus by reaching out to key data providers to ensure that required data are open access and globally available, working on improved lead times and confidence in forecasts, and broadening the network of practitioners and data providers, so end users can continue to give feedback to providers.

Phase III is establishing a Global Flood Consortium (GFC). GFC will be a sustained consortium, incorporated as an international not-for-profit and community-run entity. The mission of GFC is to ensure access to global flood hazard and risk monitoring and forecast data and models as well as to provide access to archival data sets. GFC could make use of already available platforms like the Global Flood Partnership.

This summary is published in EOS as a *Meeting Report* and should be cited as:

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Workshop Motivation

People in academia, Non-governmental organizations, industry, insurance, humanitarian aid organizations and government agencies are estimating flood hazards, identifying areas at risk today, and predicting how risk and vulnerability will change across a range of spatial and temporal scales. There is a recognized need to identify flood risk and exposure at global scales with both higher resolution and greater precision. Existing research either leverages satellite data to map hazard and exposure to flooding at typically larger spatial scales, or uses models to make flood predictions for various flow return periods, but with high uncertainty for extreme events at the tail end of historical data distribution. Extant exposure and derived vulnerability data are often licensed or of restricted access, providing challenges in widespread use. New technologies (e.g. micro- and nano-satellites, drones), advances in Artificial Intelligence (AI), improved use of crowd-sourced and social media data, as well as interoperability standards, promise significant and potentially game changing progress in this field for the coming years.

Figure 2. Group photo of the NASA-supported Flood Risk Workshop, CSDMS, 1-3 October 2018, Boulder, CO.

GEO Context

The three-day international Flood Risk Workshop at the University of Colorado - Boulder, October 1-3rd 2018, brought together ~80 people (see also participants list) from many different sectors and organizations, including state and national agencies, humanitarian and aid development agencies, NGOs, private companies active in flood risk or space missions, academia, and (re-)insurance businesses. The aim for the Flood Risk Workshop, the derived goals, keynote speaker suggestions and potential participants were set with input from the workshop Steering Committee (Table 1).

The workshop responded to a timely need to bring together the main actors across various sectors and communities to reassess and rethink the state of flood risk assessments so they can better meet decision making needs.

The aim was to reach a consensus of priority actions as a new Flood Risk Community of Practice (FRCP) to solve the main challenges in flood risk estimation at global scales, and aligning those actions with the goals of GEO Global Flood Risk Monitoring (GEO 2017-2019 Work Programme) and of The Sendai Framework for Disaster Risk Reduction.

Table 1. Flood Risk Workshop Steering Committee

Member	**Affiliation(s)**
Dr. K. Dobbs	National Geospatial Agency (NGA)
Mr. J. Eylander	Army Engineer Research and Development Center
Dr. A. Kruczkiewicz	Columbia University / Red Cross Red Crescent Climate Centre
Dr. J.E. Mitchell	Department of Transportation & Development of Louisiana
Mr. J.J. Murray	NASA Langley Research Center
Dr. K. Saito	World Bank
Dr. A. Smith	Fathom Global
Dr. S. Young	GeoSY Ltd
Mr. A. Zolli	Planet

Link to 2016 NASA Flood Response Workshop

During the 3-day E2 NASA Flood Response Workshop (Greenbelt, MD, June 2016), requirements for moving forward were defined. Among other action items, it was clearly argued that flood risk maps, population maps as well as studies and data on vulnerability are most needed (Table 2). There is thus a urgency to bring together qualified people of agencies, companies, universities and initiatives that each bring to the table access to the proper datasets, clearly define needs and requirements to make progress, create better flood risk and vulnerability information, and generate exposure maps at the global scale while providing actionable material at the local level.

Table 2. Ties to the 2016 Flood Response Workshop outcomes

2016 Workshop Session	**Recommendation**	**Role in Flood Response "Cycle"**	**Comment**
Poster Exercise	Flood Risk Maps, Population Mapping	Preparation	Only relevant suggestions to proposed Flood Risk Workshop are listed
Breakout Session 1: Existing Response Systems	Study and understand vulnerability; tapping more in social sciences; researching risk perception;	Product Dissemination and Delivery	Identified as one of the top priority action items for the coming 1-3 years

The herein reported "Flood Risk Workshop" also brought together various PIs and lead experts from NASA's supported flood projects to discuss and formalize the workshop objectives. It was also discussed how to form new partnerships between the public and private sectors, so that the best efforts and solutions to this global challenge can be made – possibly including Planet, NASA, USACE, the World Bank, Red Cross and various private sector companies and public stakeholders. Representatives of each aforementioned organization was therefore part of the workshop steering committee (Table 1). However, as identified during the 2016 Flood Response Workshop, extrapolation and scalability of a single country or regional paradigms still remains a significant challenge to address as well.

The Flood Risk Workshop was not a typical science meeting nor a research review; rather it was a set of pro-active discussions and working sessions ("Breakouts"), generating actionable output on how to proceed to build a coordinated global effort to create better flood exposure and vulnerability maps with the overall aim to reduce local impacts of flood disasters worldwide.

Workshop Theme and Relevance to NASA ASP Goals and Objectives

The workshop contributed directly to the NASA Applied Sciences (AS Disasters) Program, which has various tasks towards society. The NASA Applied Sciences Program partners with many public and private organizations and facilitates data flow from NASA's environmental satellites and data-based scientific findings to decision-making activities and services to protect the environment, improve quality of life, and strengthen the economy. The workshop addressed exactly this mandate to improve both human and environmental well-being by working across sectors to better leverage publicly generated data into existing flood risk models and rethink how models and data could be better poised to improve flood risk mitigation decision making.

NASA's disasters "toolbox" (https://maps.disasters.nasa.gov) currently comprises but is not limited to multiple satellite-based datasets including SAR, MODIS/VIIRS, Landsat, TRMM, PERSIANN and other mapping products (like GPM) There are other services and data, like NASA Worldview layers (https://worldview.earthdata.nasa.gov), and other satellites and weather datasets, which have all shown great value for both strategic planning and tactical response and damage or exposure assessment. NASA and their relevant Disaster Response Coordinators, as well as their flood product producers understand that future research and product development activities will require an integrated solution for better flood risk management.

The theme and goal of this workshop was to **coordinate efforts to improve mapping and usability of global flood risk data, including vulnerability and exposure**. Such efforts should not be looking at supporting single basin or regional capabilities that are not immediately globally scalable. R&A and SERVIR do that in a number of ways, so a global effort should leverage those capabilities if and when they may be needed. It [a global effort] would also need to leverage and support ongoing international initiatives and programs such as Copernicus, which has proven to be of great value for flood mapping via radar-based satellites such as the Sentinel-1 constellation. Also, with the advent of new technologies, including small and mini satellites (cube satellites) as well as Unmanned Aerial Vehicles (UAVs; like drones) and the use of social media streams (e.g. Twitter) and citizen science, we made sure that actors of these areas were part of the workshop as well (e.g. Planet).

In this context, the proposed workshop was attempting to address the below primary objectives in order to start formalizing requirements for producing detailed global maps of flood risk:

- Identify minimal requirements for mapping global flood risk;
- Start collaborative partnerships;
- Identify achievable short-term goals;
- Determine a multi-year plan on how to achieve the workshop goals.

Workshop Activities

The 3-day workshop included a combination of key invited participants and other interested experts selected from NASA's "expert pool" as mentioned earlier. The workshop started with presentations that outlined state of the art (NASA and non-NASA) flood risk datasets and challenges focusing on vulnerability and exposure, associated impacts, existing methods and issues/limitations, while highlighting new initiatives. The afternoon was reserved to present and discuss the needs and wishes from the various stakeholders and how to address current issues of systems and brainstorm about potential future systems and data collection coordination.

Following were summaries of the current state of (flood) risk maps, revolving around Earth Observation under the present setting of NASA Applied Sciences, presenting outstanding challenges and priorities. Specifically, we aimed to make substantial progress in addressing the following three key questions:

1. *What is required to progress the state-of-the-art for achieving better, more actionable flood risk maps or indices at the global level with local impact assessment*
2. *What are the current three biggest challenges in mapping flood risk, exposure and vulnerability that need addressing?*
3. *What needs to be done to overcome these challenges and allow a more coordinated global effort (action plan)?*

The workshop concluded with a plenary discussion and definition of an action plan.

Keynote talks

This section briefly summarizes the keynote presentations. Table 3 provides access to the online abstracts and video recordings of each of the keynote presentations.

Table 3. Keynote talk presenters and title links to presentations and video recordings

Presenter	Title
ALEXANDER AUGUSTINE, **Lauren**	From Flood Risk to Flood Resilience
Green, **David**	Space for Risk Global Flood Risk Monitoring
Mitchell, **James**	The Spatial and Temporal Factors that Characterize Hydrologic Response
Ryvola, **Rebeka**	What's the forecast for humanitarian use of forecasting tools? Exploring innovative approaches
Slap**, Albert**	Data Needs in Natural Hazard Risk Assessments
Tucker, **Greg**	CSDMS tools for flood modeling
Wagemaker, **Jurjen**	Using online media to connect flood risk management to the ground
Young, **Simon**	Application of EO in parametric insurance instruments for risk financing and climate resilience in support of the 2030 development agenda

National Academy of Sciences: Dr. Lauren Alexander Augustine

Dr. Augustine is the Director of the Program on Risk, Resilience, and Extreme Events at the National Academy of Sciences, Engineering, and Medicine. Since 2010, she served on the World Economic Forum's Global Agenda Council on Risk and Resilience among others as member of the Advisory Board for the American Geophysical Union's Thriving Earth Exchange program, and as juror on the Rebuild by Design resilience competition for recovery after Hurricane Sandy. From 2008-2013, Augustine directed the Disasters Roundtable at the Academy. Her most recent positions at the Academy entail her developing a portfolio on natural disasters and ways that science can inform policy to reduce the risk and elevate society's resilience to them.

Dr. Augustine presentation focused around flood risk and resilience, how to switch from one to the other. She introduced the *Resilient America* program, which is based on four key actions communities could take to build resilience: a) understand and communicate disaster risk; b) build or strengthen partnerships with community stakeholders; c) identify or develop ways to measure disaster resilience; and d) share and get access to information, tools, data, and experts needed to build disaster resilience.

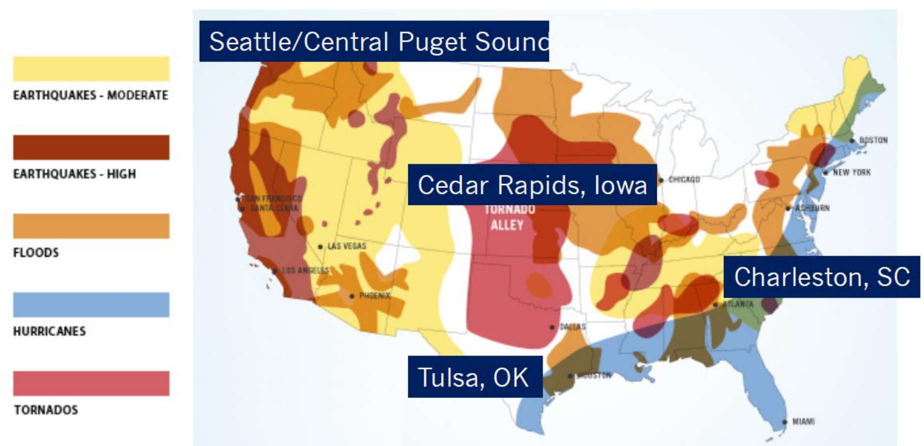

Figure 3. Resilient America pilot communities © Dr. L.A. Augustine / NAS

Another key aspect of her talk, was how science can inform each of the dimensions important to build resilience: physical dimension; information dimension; social dimension; decision-making dimension. She also emphasized that science can help create a more complete picture of who floods, when, how badly, how much it costs, what they should expect, what is driving increased flooding, and what can be done about it.

NASA Disasters Program: Dr. David Green

Dr. Green from the NASA Disasters Program, outlined the Space for Risk era under the GEO Global Flood Risk Monitoring (GEO GFRM) activity work program. Dr. Green outlined the Global Risk Assessment Framework (GRAF) for assessing risk, impact and sustainability. He also described what GEO and its subgroups are doing to support the Sendai Framework targets E, F and G through engagement with UNISDR. The open question is how NASA with GEO, through its Work Programme, support and inform the Global Assessment Report (GAR) on Disaster Risk Reduction and the overarching Sendai Framework.

The vision is to create an innovative information system using Earth Observation to support decision making from global to local scales. NASA Disasters sets out to work towards the following geospatial priorities:

- Disaster-lifecycle relevant data and promoting risk assessment and reduction;
- Tools and services that are stakeholder-responsive and value driven;
- Spatial Data Infrastructure (SDI);
- Technology-enabled collection and consumption.

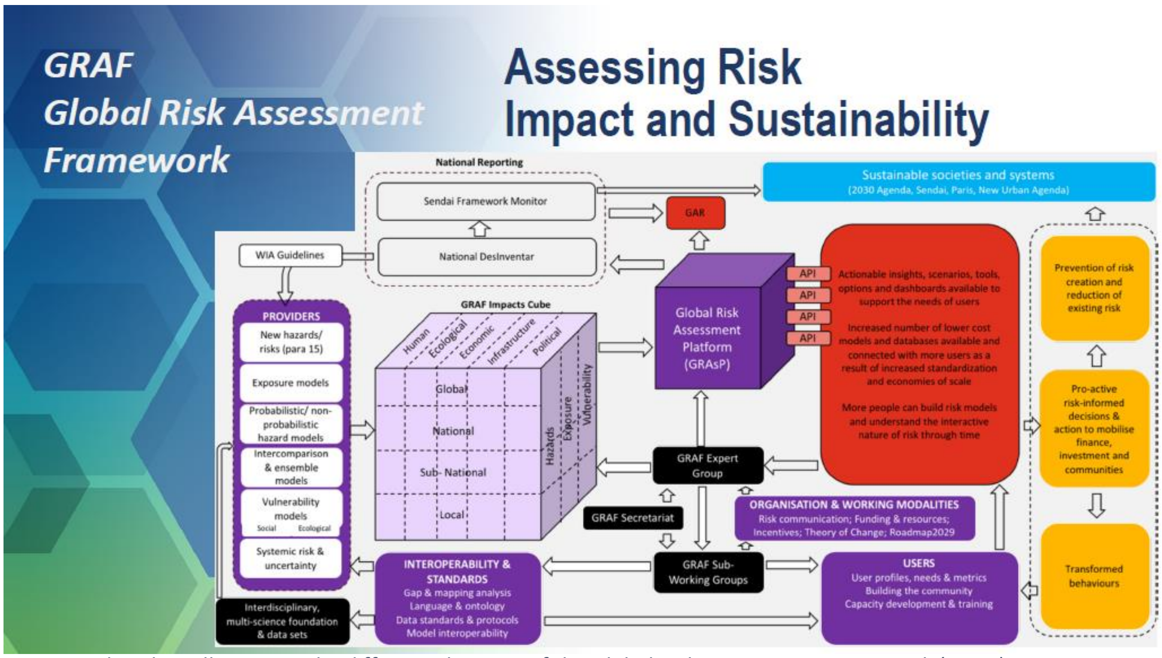

Figure 4. Flowchart illustrating the different elements of the Global Risk Assessment Framework (GRAF).

Office of Technology Services, LA: Dr. James Mitchell

Dr. Mitchell is Geospatial Services Manager at the Office of Technology Services for the State of Louisiana at Baton Rouge. He has more than 25 years of experience in geospatial applications and database management and development in hydrology, water resources, transportation, and emergency operations. Dr. Mitchell's talk focused on discussing the data used to characterize hydrologic response. Hydrology is a science of extremes; droughts and floods. In either case, the hydrologic response arises from the combination of many factors, such as terrain, land cover, land use, infrastructure, *etc*. Each has different, overlapping spatial domains. Superimposed upon these are temporal variations, driven by stochastic weather events that follow seasonal climatic regimes. To calculate risk (expected loss) requires a loss function (damage) and a response domain (flood depths) over which that loss is integrated. Estimating this on a watershed scale provides the spatial domain that collects all these factors.

Red Cross Red Crescent Climate Centre: Rebeka Ryvola

Ryvola co-leads the Red Cross Red Crescent Climate Centre's interactivity team and works across the centre's programs to explore new ways to reach more of the world's most vulnerable people. In addition to helping foster a culture of creativity, innovation and experimentation at the Climate Centre, she supports the team with the interpretation of technical information, the generation of educational and programmatic materials, and the creation of visual tools for learning and advocacy. The Red Cross Red Crescent Climate Centre promotes the integration of climate science into humanitarian policy and practice. With partners, the Centre develops innovative ways to connect forecasting and monitoring products with disaster management teams and disaster risk financing entities around the world. Her presentation was about how this plays out on the ground and she demonstrated this with an interactive game that engaged the workshop participants in actively taking part in forecast-based financing for early action. In this game, the participants collectively explored how the Climate Centre and others are preparing to improve how early warnings and early actions can be linked.

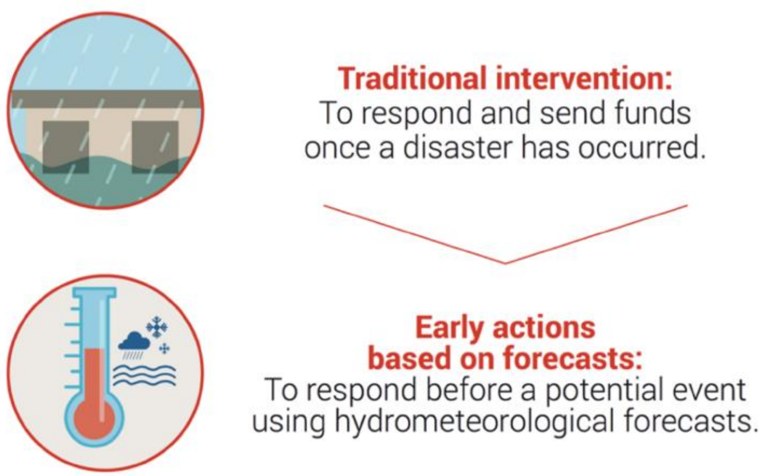

Figure 5. Traditional humanitarian response intervention versus early actions based on forecasts.

Coastal Risk Consulting: Albert Slap

Slap is President and Co-Founder of *Coastal Risk Consulting LLC*, a geospatial technology, modeling and analytics company located in Plantation, FL. *CRC* is a flood and natural hazard risk assessment technology company with a mission to help individuals, businesses and governments in the US and around the world achieve resilience and sustainability. In the past year, Coastal Risk's Technology supported nearly $2 billion in US commercial real estate investment and development. CRC's unique business model combines high-tech, flood, climate and natural hazards risk assessments and high-value, risk communication reports with personalized, resilience-accelerating advice for individuals, corporations and governments. In order to take their system globally, however, they need higher resolution DEMs. The 30m resolution currently available is a big obstacle to going international. This is something that they would like to get from NASA. Also, they are interested in high-resolution, "before-and-after" satellite imagery of flooded areas to compare with our modeling and to help individuals, businesses and governments understand how to better defend against floods.

CRC is considering extending its use of satellite data in the future but challenges may be substantial: The following are some of CRC's plans:

Combine with AI and Machine Learning: use remoted-sensed data to produce intelligence for individualized property data, insurance underwriting including cost to rebuild and damage/loss estimates. Also, satellite data would be valuable for vegetation analysis and wildfire risks

CSDMS: Dr. Greg Tucker

Dr. Tucker is the Executive Committee Chair; CSDMS Executive Director and introduced the Community Surface Dynamics Modeling System (CSDMS) setup, functions and mission. CSDMS is hosted by INSTAAR, where the workshop was held. CSDMS (http://csdms.colorado.edu) supports computational modeling in earth-surface science by engaging community, developing computing resources, and promoting education. CSDMS is hosting a high-performance computing facility and develops standards and middleware for running and coupling models in a "plug-and-play" mode, such as BMI and PyMT for instance. The modeling tools allow model codes to become components, where they can be run stand-alone or coupled to other components. It also provides a framework for service components, e.g., for re-gridding, etc.

FloodTags: Jurjen Wagemaker

Wagemaker is Founder and Director of *FloodTags***,** a social enterprise that analyses online media and user generated content for water management and food security. Jurjen shared how FloodTags uses human observations from online media to detect and analyze new (and past) flood events. He also introduced a new approach to citizen engagement via chatbots in instant messengers. With this, local needs are revealed in detail and low-threshold two-way communication about flood risk is possible, even down to community level. "How can these new techniques be functional in current flood risk management practices" is an open but important challenge question.

Figure 6. FloodTags' web interface page.

Strategic Advisor at Willis Towers Watson: Dr. Simon Young

Dr. Young works as a risk management consultant, providing a broad range of disaster and climate risk management and financing services, including leading the development, implementation and operations of all three of the multi-country parametric insurance risk pools currently in existence (in the Caribbean & Central America, the Pacific and Africa) as well as various other parametric insurance programs and instruments. In addition to ongoing advisory work in Africa, Simon is a Strategic Advisor to the Capital, Science & Policy Practice at Willis Towers Watson, where he continues to lead innovation in the use of hazard and risk data in risk financing instruments to bring greater resilience to sovereigns, other public institutions and the private sector.

Young presented an application of EO data in parametric insurance instruments for risk financing and climate resilience in support of the 2030 development agenda. Parametric insurance represents a major breakthrough in the accessibility of risk financing for natural disasters. Instead of compensating for actual assessed loss, parametric (or index-based) insurance uses measurement of the hazard itself as a proxy for loss, paying out a pre-agreed amount for an event with certain intensity, location and, sometimes, duration. This allows for rapid settlement and reduced costs – of claims adjustment / processing and in the margin added by risk takers for uncertainty in projected outcomes. The quantitative, independent and objective nature of EO data, and also its availability in real time, makes it ideal as a basis for parametric insurance, particularly in the developing world where claims data for policy pricing is non-existent. Examples of parametric products based on EO data already in the market include protection against high and low rainfall, use of vegetation greenness indices, and footprint mapping as a basis for flood protection.

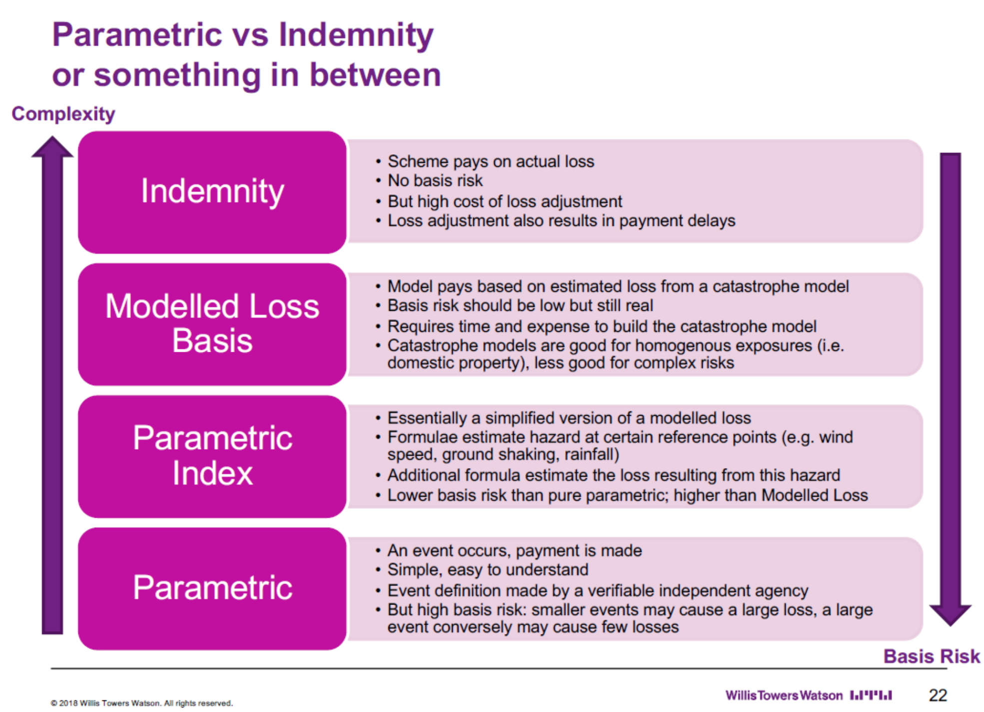

Figure 7. Abstract representation of the complexity of risk in insurance implementation.

Breakout group discussions

Each breakout topic and lead are listed in Table 4. **Error! Reference source not found.** also provides access to the actual breakout session notes, which are summarized as **main challenges and needed actions** in Table 5.

Table 4. Breakout session groups and notes

Lead	Topic	Notes
Andrew Molthan	**Earth Observations (EO)** - Many satellite-based flood EO products are developed over the years. What is out there, what is used/useful (also for urban areas), why isn't it used more, and what are the EO needs for the different communities (first aid & response agencies, insurance companies, research, planners, …)	Notes
Oliver Wing	**Flood Modeling & Forecasting** - Model based flood maps either for forecasting or to determine the e.g. 100-year floodplain are produced at various resolutions. What is out there, what is used/useful (also for urban areas), why isn't it used more, and what are the needs of the various communities (first aid & response agencies, insurance companies, research, planners, …)	Notes
Rebeka Ryvola	**Flood Exposure** - Flood hazard exposure describes who and what may be harmed by a flood - so where do floods occur and what exists in those areas? What are the current products out there that help assessing flood exposure, what is available to the community and where do we need to make improvements?	Notes
John Harding	**Forecast based financing**. By the time money is released to purchase supplies for flood affected areas, the aid often arrives late and evacuation routes become impassable, putting lives at risk. If floods could be predicted before the event (up to 10 days) then funds could be released, mitigation actions taken, and lives spared. Actors at the Red Cross (FATHUM) and World Bank (via CREWS) have already piloted programs or research projects for this purpose. But How good are the forecasting models now? And how much better must they get to be more useful?	Notes
Simon Young	**Developing World Parametric Insurance**. Developing World Parametric Insurance Today 90% of economic losses from disaster in the developing world remain uninsured and vulnerable populations shoulder a disproportionate amount of this burden, living and developing without sufficient protection. Insurance could help buffer these populations and nations against development setbacks from floods. While drought insurance has been implemented, floods are more challenging due to high spatial specificity of damage. What EO is available now and what	Notes

	needs to be developed for this application? Can this be applied in urban areas where remote sensing and modeling is a challenge?	
Matt Reid	**Developed World Insurance**. Even in the developed world, population remain underinsured, and federal programs (like the NFIP National Flood Insurance Program in the USA) suffer from large uncertainties. How can flood risk data improve claims arbitration, coverage, and national schemes? What do insurers need?	Notes
Jurjen Wagemaker & Brian Coltin	**Online and Social Media** - Crawling the internet and social media and mining these massive data streams for useful information about floods is a fast-growing field and one that has gained a lot of momentum in the private sector. What is currently being done/offered (access conditions?) for floods and flood risk and what can be expected in the near future?	Notes
Brittany Zajic	**Commercialization of space** - Sending more and more smaller satellites into space and 'making' space operations cheaper will benefit everyone. Private sector commercialization of space is rapidly growing but what and how much is currently out there and offered by whom and how can this explosion of data help flood risk analysis globally?	Notes
Vladimir Anisimov & Andrew Kruczkiewicz	**In-situ or citizen science** - Inexpensive new in-situ sensor technology enables a citizen (crowd-sourced) science to be defined. This can help many communities better understand data & models, get involved, increase preparedness as well as resilience to floods. What is the current state-of-the-art of in-situ sensor technology & citizen science and how can this be integrated with flood risk models & EO data?	Notes

Table 5. Key discussion items of each breakout session as well as actions needed. Those actions in red represent top priority issues that require immediate attention.

Breakout	*Key Discussion Item / Challenge*	*Key Action Needed*
Earth Observations (EO)	(i) EO data are proliferating (satellites & other sources); More available in developed countries (e.g. hi-res DEM) (ii) EO data latency (iii) Low resolution; often missing interoperability; urban area data & population data lacking	(i) Use Sensor Web technologies and other interoperability standards (ii) Use of models to gap-fill temporal and spatial limitation of EO; manage expectations **(iii) Corrected DEM in urban areas; better global urban infrastructure & socio-economic data for better risk**

	(iv) Validation / accuracy / uncertainty	**estimation; boost citizen science to augment EO data** (iv) Establish common database of use cases for inter-comparison of models / data & collaborations
Flood Modeling & Forecasting	(i) Communication between science / user community to "apply" current models, data, etc. (ii) Communicate uncertainty in an actionable way to the end-user; apply the local context (need social scientists to communicate risk) (iii) "Honestly" communicate accuracy, limitations for appropriate application (maybe more ways of standardizing how to compare models)	(i) Share best practices (e.g. hackathons for scientists, table tops for users) **(ii) Respect needs at various scales (go global, stay local) and focus on all phases of disaster management cycle** (iii) Translate the scientific output to a usable product but solve ownership issues of the final product (open-source vs proprietary) (iv) Better decision-support systems for end-users; better integrate different models and data sets; create more accurate global data sets (esp. exposure; DEM)
Flood Exposure	(i) Much uncertainty (ii) Global data not specific enough for local level & difficulty of gathering info on many variables, including informal settlements (iii) Flood exposure at a global scale	(i) Understanding the relative uncertainties across all variables (topography, flood maps, socio-economic data, demographics) and what affects exposure (ii) Layers, such as manmade infrastructure and others, need to be separate layers of information, including at local level & regularly update typically "static" (and thus outdated) exposure datasets **(iii) Create a global baseline of relevant data-and complement with higher resolution data from collaboration between private, non-profit, etc.**
Forecast based financing	(i) Financial aid typically arrives too late for flood disaster response operations to be most effective (ii) Piloted program initiatives / (research) projects (by e.g. Red Cross, World Bank, WMO) look to build	**(i) Better flood forecasting to predict events** (ii) Information needs to be shared with mandated response agencies, which will help release funds and initiate preventive actions

	sustainable capacity in low income countries	
Developing World Parametric Insurance	(i) EO & models can provide the needed information for parametric insurance (see e.g. African Risk Capacity – ARC: see "Notes" link in Table 4. for details) (ii) Need global, reliable and robust predictive indices (iii) Incentive differences between academic research and remote sensing industry (iv) Portraying uncertainties	(i) Algorithms need to be flexible as policy-related functions, like cost curves, need regular updating **(ii) Global predictive rainfall / flood index is missing** (iii) Need harmonizing differences for best applied research for global risk management index (iv) Look into different best practices for communicating / visualizing uncertainties
Developed World Insurance	(i) Differences between public/government and commercial flood hazard maps (return flows) (ii) Potential to encourage resilience (iii) Need to consider flood water impacts on health (iv) Impact on agriculture / crops (v) More variety of risk profiles offered by models	(i) Better accessible databases **(ii) Geolocation of assets & population** (iii) Rigorous evaluation of hazard models (flood footprint history; social media info): spatial accuracy and uncertainty (iv) Early warnings permitting preparedness (v) Information on flood defences (global)
Online and Social Media	(i) Quantifying where/when flooding occurs and who is impacted for future projections of flooding (ii) Identifying floods in urban areas (iii) Forecaster bias (iv) Identifying flooding in real-time	(i) Building historical records of flooding locations / events from social media for model validation and impact assessment **(ii) Timely estimates of flooded urban areas to validate / complement estimates from models / remote sensing** (iii) Looking at twitter trends compared to average trends in coordination of meteorological information (iv) Using real time twitter data to alert of flood incidents
Commercialization of space	(i) More accuracy estimates / uncertainty sources / metadata (ii) More validation data (for accuracy assessments) (iii) Reduced information latency	**(i) Building footprints and generally asset exposure data, including population estimates (hyper-localized).** (ii) More dynamic and frequently updated

In-situ or citizen science	(i) No system that organizes and stores citizen science data centrally (ii) All social actors are responsible for building resilience	**(i) Role of AI and deep learning for crowd-sourcing & forecasting floods** (ii) Better communicate (flood) risk to all

Plenary session discussion

The Workshop closed with an interactive plenary discussion led by a selected panel. **Error! Reference source not found.** lists the main outcomes (key workshop messages) of this plenary session.

Table 6. Plenary discussion outcomes: key workshop messages

Key point to be worked on	What was missing and should be included in the next meeting
Data sharing needs; availability of information	Risk assessment & forecasting; get other satellite agency providers to contribute more and easily (e.g. ASI); how EO can help operationally to identify impacts? Incorporate activities from other agencies
A lot of government control; a lot of capacity/experience exists already, need to build on that	More multidisciplinary (risk perception/reception/cultural & social aspects)
Information is critical; need products & services already validated and ready to use; documented information	Conveying information →communication skills → helps with two-way feedback → helps build relationships with other sectors and other academic fields
Information: reliable, complete, robust and right resolution for task at hand; historical information is important but often historical too coarse and not easy to validate -> involve capacity from on the ground and local	

Results from surveys of the 2018 NASA Flood Risk Workshop

We developed a survey for the workshop participants, and 23 were returned. Surveyed users (closely matching the breakdown of the participants in the workshop) included 11 academic researchers, 2 participants from the insurance sector, 4 from industry or consulting, and 6 from governments and NGOs. The survey demonstrates a wide variety of uses and desires of EO data. Common to all, however, was a desire for improving satellite consistency (and the ability to see floods under clouds), daily temporal resolution needed for most decisions, and that the need to improve technical capacity and understanding of data use as an important barrier to address.

While most participants use satellites for research (74%) only 1/3 of users report using satellite data for decision making. Most common uses of EO data include for hydrological models and early warning systems (Figure 8). The desired temporal resolution among these uses was fairly common (~daily), but the spatial resolution required varied substantially (Figure 9), from 1-meter resolution requested for making decisions related to infrastructure and disaster aid or rescue, to over 300 meters as an acceptable resolution for land use planning decisions. Most participants use MODIS and Landsat products, with some use of precipitation products (e.g. TRMM, PERSIANN) and commercial satellites. There was interest in using radar satellites more (Sentinel-1, specifically), though some participants had never heard of microwave satellites such as CYGNSS and AMSR-E. Participants most commonly use EO derived or influence products of flood models and stream gauges, with less use of flood forecasts, DFO flood maps, and online media.

The main barriers to use of EO are lack of consistency in the data, followed by low spatial and temporal resolution and technical expertise (Figure 10). Other identified issues were low accuracy and low capacity computer power to process data. Participants equally identified needs for improvement in population, road, and asset data to couple EO data with key socio-economic information. When asked to rank the improvements most needed to existing EO flood data, participants agreed that removing clouds or filling in gaps under clouds to be the most important. This was followed by the ability to detect floods in urban areas and increasing flood map accuracy. Tertiary considerations were improving spatial and temporal resolution, and mapping floods under vegetative canopies (see Figure 11).

Participants were likewise asked to identify priorities features for a new NASA satellite, and improved spatial and temporal resolution was most commonly identified. However, a wide range of other features were mentioned, including, radar, depth, soil moisture, and hyperspectral resolution (addition of more infrared bands was specifically mentioned). However, several participants (n=3) pointed out that the issue was not improved EO data, but access to capacity building, with one participant stating, “I have no input here except to echo what was shared multiple times in the meeting -- we need to better use the data we have before (at least in parallel with) generating additional data.” Another participant specifically suggested, “We need more training opportunities to make these resources available to “non-remote sensing” people, who could use the data. This means topics like:

1. What platform to use to get what data for what applications.

2. How to find these data,

3. How to process the data into a format they can use, focusing on GIS methods.

4. How to interpret the data, once you have it.”

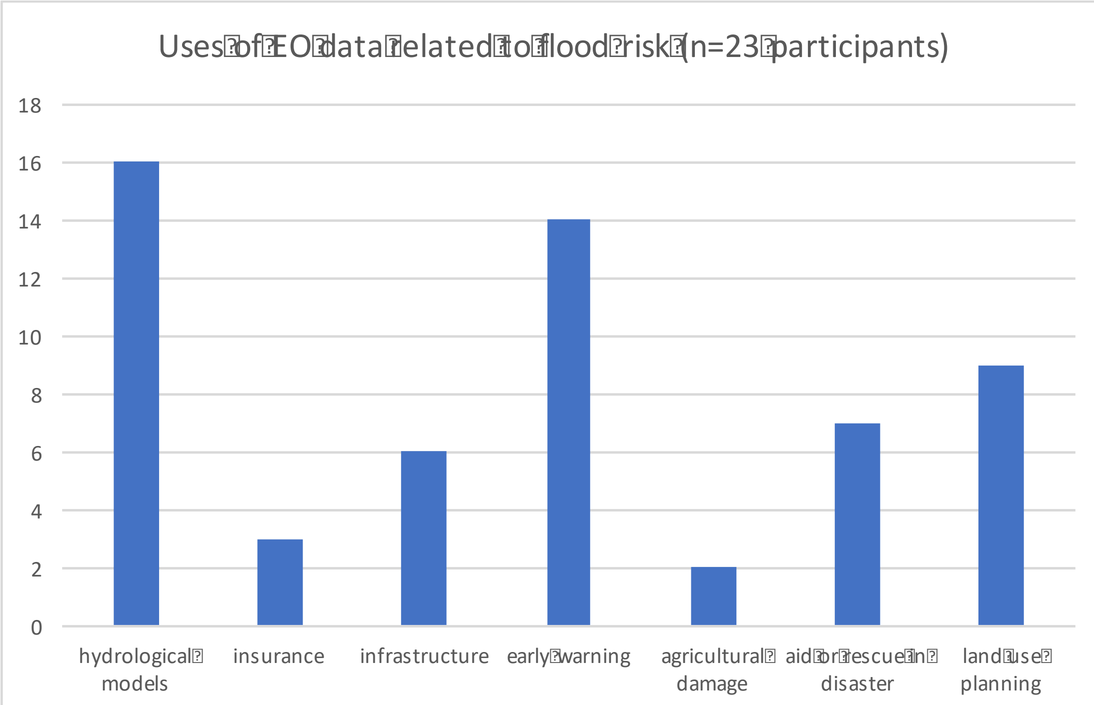

Figure 8. Reported uses of EO data

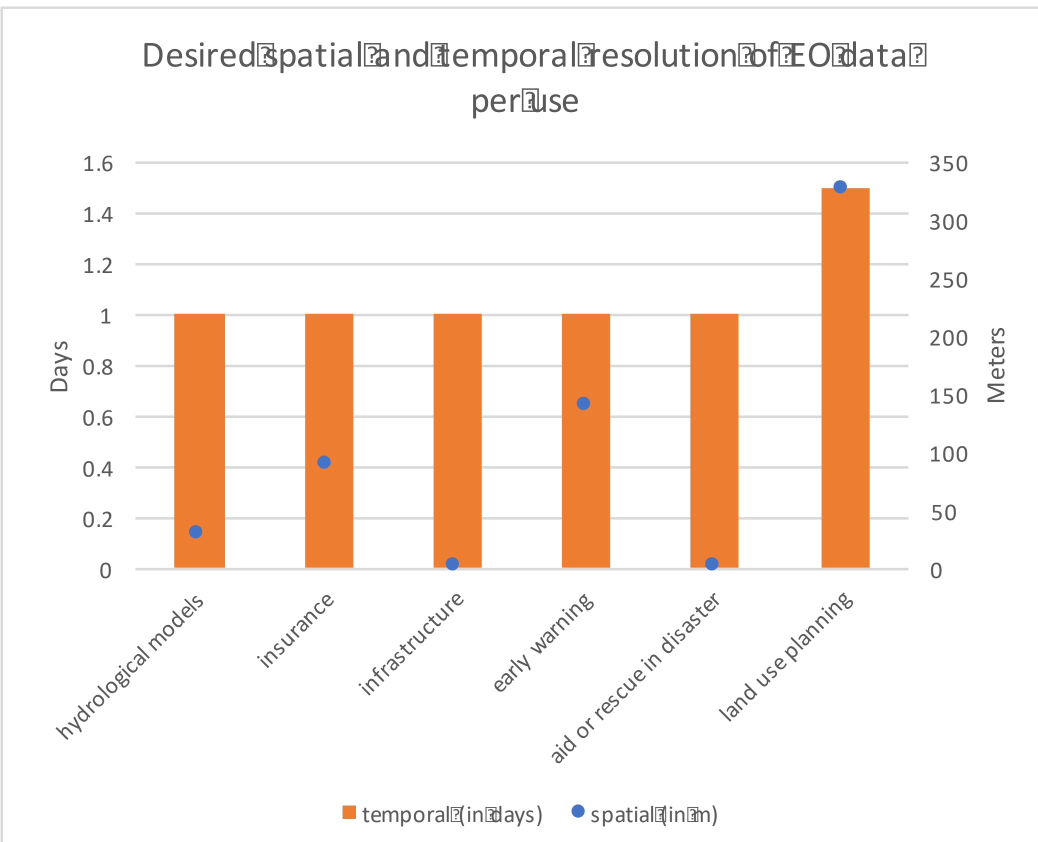

Figure 9. Median spatial and temporal resolution desired for different types of EO use by participants

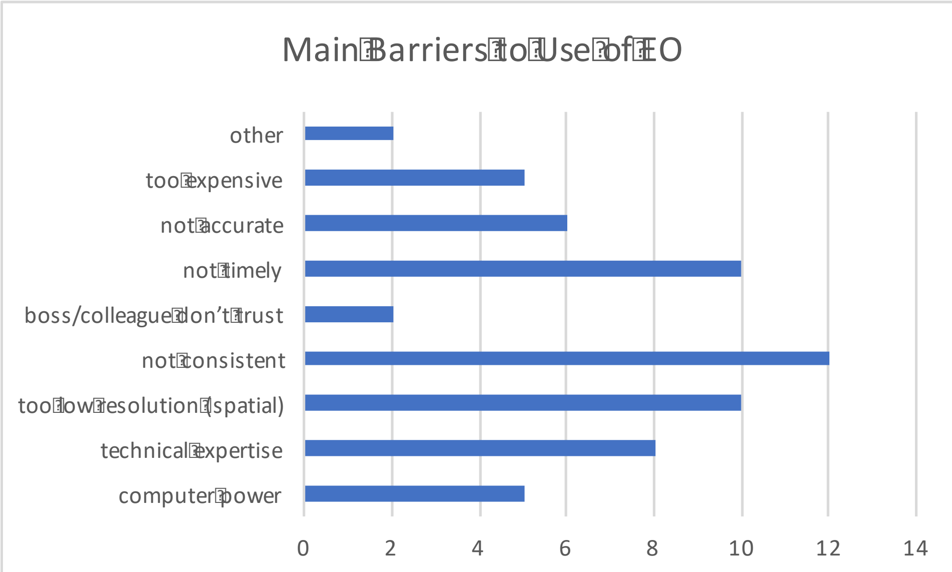

Figure 10. Barriers to use of EO data in decisions (participants circled all that applied)

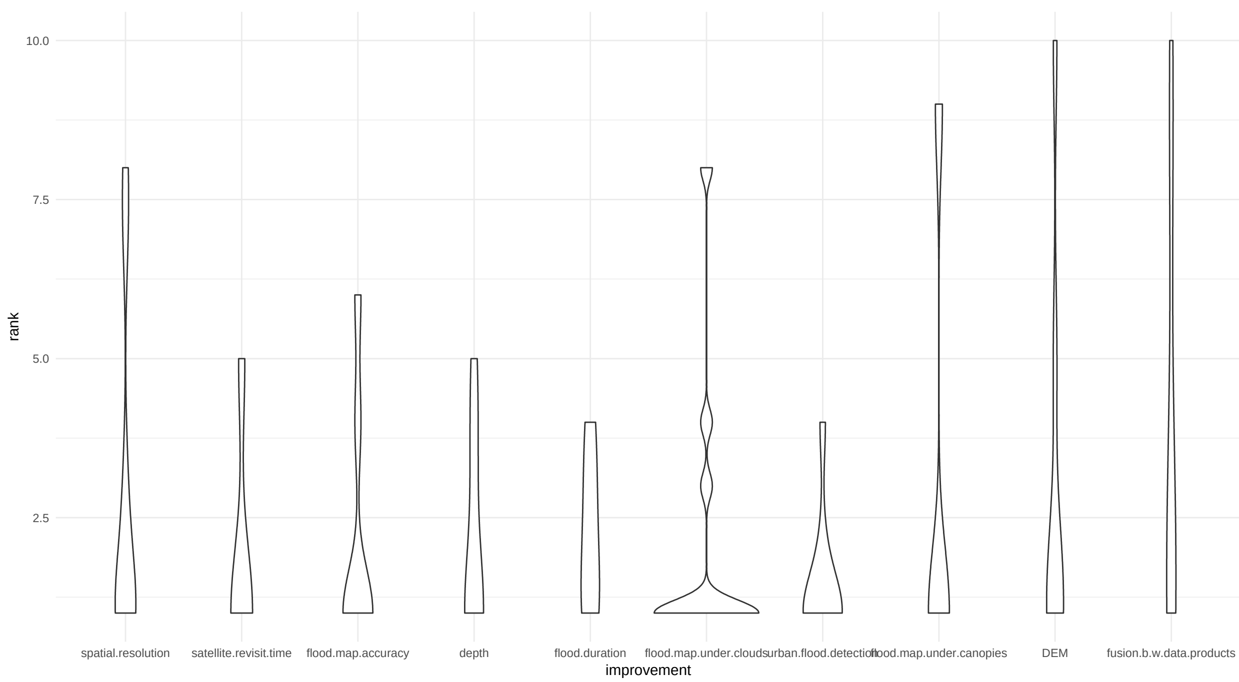

Figure 11. Violin plot of ranking (1-7) the most desired improvement to EO data.

Main Challenges Identified and Next Steps

Priority data challenges

Table 7 below summarizes the main challenges identified during the workshop. The challenges in the table below should be considered priority issues that are to be worked on in the short term. Those are also long-standing items that have been given relatively little attention so far.

Table 7. Main challenges identified.

Challenge	Action	Comment
Corrected DEM in urban areas; better global urban infrastructure & socio-economic data for better risk estimation; boost citizen science to augment EO data	Create a global baseline of relevant data-and complement with higher resolution data from collaboration between private, non-profit, etc. (including better geolocation of assets and population)	Respect needs at various scales (go global, stay local) and focus on all phases of disaster management cycle
Better flood forecasting to predict events	Develop a global and robust flood warning index	Global predictive rainfall / flood index is missing
Timely estimates of flooded urban areas to validate / complement estimates from models / remote sensing	**To Be Discussed** **AI?** **SAR coherence?**	AI and deep learning for crowd-sourcing & forecasting floods (in urban areas)

Immediate next steps

In order to highlight the challenges and actions in Table 7 and make the wider community of EO, global risk and flood modeling fully aware, a short GEO GFRM community white paper as well as a full scientific journal paper (targeted at a policy journal) will be following this workshop report.