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News & Views

Increasing the value of weather-related warnings

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Despite advances in forecasting and emergency preparedness, weather related disasters continue to cost many lives, to displace populations and to cause wide-spread damage. Therefore, High Impact Weather Project (HIWeather), a 10-year research project (https://public.wmo.int/en/resources/bulletin/hiweather-10-year-research-project), was established in 2016 by WMO (World Meteorology Organization) WWRP (World Weather Research Program: https://www.wmo.int/pages/prog/arep/wwrp/new/wwrp_new_en.html). HIWeather aimed at achieving dramatic improvements in the effectiveness of weather-related hazard warnings, following recent advancement in numerical weather prediction at km-scale and in disaster risk reduction. The implementation plan was developed under the concept of warning chain, which comprises all components and the connections between to a successful weather-hazards warning: observations, weather forecast, hazard forecast, impact forecast, the generation of warnings and decision making (Fig. 1). A successful warning relies on information produced by the meteorological and related physical sciences, thus its effectiveness of delivery depends on applications of social, behavioral and economic sciences. The workshop of WMO High Impact Weather Project was held in Beijing during 20–22 November of 2018, attracted a diverse and interdisciplinary group of over 70 scientists from 25 countries in the broad field of physical and social science, during which all elements of the warning chain were discussed critically.

The aims of the workshop were to review progress to date, to refresh the aims and objectives of the HIWeather project, and to identify and plan new activities on how to increase the value of weather-related warnings. Five focal aspects of warning were described in the following sections: (1) what makes a successful warning? (2) Advances in physical processes. (3) Weather-related hazard and impact prediction. (4) Advances in understanding impacts, vulnerability and risk. (5) Measuring skill and value.

Focusing on the question of what makes a successful warning, practitioners and researchers, whose fields encompassed operational meteorology, climate risk management, design and psychology, contributed complementary insights on: the added value of impact-based warning systems; tailoring warnings for specific groups; the role of trust; and the need for effective strategies to communicate uncertainty.

The move towards impact-based warnings (IBW), which emphasize the consequences of severe weather, received broad support from a communication perspective [2]. Experimental evidence shows that combining IBW with behavioral recommendations increases intention to take protective action [3]. Recognizing that different users have different needs was common to all presentations, with practical examples contrasting maritime and land forecast requirements, and ongoing efforts of Australia's Total Warning System to identify and prioritize different user needs. The critical importance of establishing and maintaining user trust and effectively communicating uncertainty were also highlighted [4]. In considering how to address the communication challenges raised, the potential of human centered design approaches to inform the tailoring of warnings to different groups was explored.

The need for continuous evaluation and updating of communication strategies through post-event analysis, user-engagement, user-testing, and awareness of design principles were highlighted. Three key areas were identified for further attention as: (i) communicating forecast updates without reducing trust; (ii) visualizing uncertainty; (iii) communicating the possibility of low-probability high-impact events.

Although there are various meteorological conditions leading to high-impact weather (HIW) events and their associated processes,

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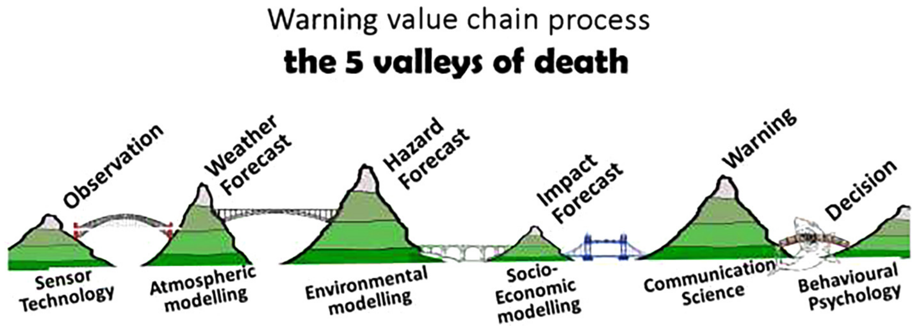

Fig. 1. Conceptual model of warning value chain. Bridges represent inter-disciplinary and/or inter-agency communication [1].

interactions among them were reported to be important in this workshop. For example, coupling of strongly descending dry intrusion and planetary boundary layer turbulence may help initiated convection. Besides, drastic changes in the urban canopy and anthropogenic aerosol over the last decades together have increased the risk of urban flooding in southeast China.

A major challenge is to achieve an overarching understanding of HIW predictability over a range of forecast lead times. Based on the Severe Event Catalogue maintained at ECMWF, a summary of processes that govern predictability of HIW events on different lead times was presented. Projects within "Waves to Weather", a German contribution to HIWeather, address the challenge by (i) quantifying processes that govern amplification of forecast errors at different lead times and spatial scales [5], (ii) exploring the phase space of sensitivities for cloud processes, (iii) explicitly investigating predictability barriers for cyclones and heat waves, and (iv) developing statistical methods for low-predictability regimes to exploit the existing weak couplings with the more predictable larger scales [6].

Future study is inspired by the needs arising from the communication-of-warnings perspective. As the outcome of workshop, HIWeather task teams agreed to perform joint, interdisciplinary case studies of warning value chains to foster this important novel type of study.

Improvement has been made on convective-scale data assimilation for HIW forecasting, coupled modeling of urban flood, modeling and prediction of heat wave, ensemble prediction at the convection-permitting scale, and aviation application of hazardous weather advisory. Despite evident advances in HIW modelling and prediction have been made over recent years, challenges remain [7–9]. Ranging among the top of them, as identified by participants are precision and accuracy of forecasts [10].

The participants recognized that the 0–12 h km-scale convective forecast is a different problem from its longer-term counterpart. High-resolution ensemble plus statistical post processing can potentially provide great benefits to the longer-term forecast, but the 0–12 h km-scale forecast is mainly an initial value problem which benefits most from the assimilation of high-resolution observations. New and existing observations that possess the potential to improve convective-scale analysis and 0–12 h forecast should be explored to evaluate their impact. Although observations from conventional Doppler radar networks have been demonstrated to be crucial for 0–12 h km-scale convective forecast improvement, radar observations are still underused in current NWP models, such as clear-air radial velocity, X-band radar network, refractivity, and polarimetric observations. The potential of new observations from geostationary satellites (i.e., MeteoSat-11 in Europe, GOES-16 in America, Fengyun-4 and Himawari in Asia) for improving km-scale model forecast is yet to be examined. The role of lightning data relative to radar observations for convective forecasting deserves more research as well. Last but not least the massive crowdsourced data and its potential for HIW forecasting should be assessed.

Considerable efforts have been made for coupled modeling in recent years, e.g, atmosphere and hydrology coupling. Continued development is necessary to link meteorological forecasting to hazard/impact forecasting. One critical question is how to design a coupled ensemble forecast system that works well within the constraint of computation cost. Research activities in this area have begun and will be enhanced in the future.

In spite of experimental evidence that impact-based warnings are more effective, there is a need for more observational confirmation. There is some concern that the rush to implement impact-based warnings was being undertaken before adequate understanding and organizational systems had been put in place to predict the impacts of hazardous weather, and particularly, before adequate data on vulnerability were available. A survey and review of impact forecasts in weather services is being undertaken, and a research project on the definition and use of value chain concepts will provide useful input for HIWeather. A near real time forensic disaster analysis, following the methodology established by the IRDR (Integrated Research on Disaster Risk) FORIN (Forensic Investigations of Disasters) group is carried out by the German Center for Disaster Management and Risk Reduction Technology (CEDIM) (FDA Report: https://www.cedim.kit.edu/english/2926.php) [11]. It was shown that most damage occurs in events in the tail of the distribution and the relevant distributions tend to be heavy-tailed, i.e. more extreme events than in a normal distribution with the same mean and variance. Impact depends on prior policies and early information on impact could dramatically improve recovery. Further papers in this session addressed the complexity of wind impacts that are caused indirectly by tree-fall; responses to extreme heat in India, and wintry weather in Canada [12]. The session finished with a look at various approaches for gathering "Volunteered Geographical Information" from the public for impact-based forecasting [13] and warning and a study of using a Chinese vehicle management system to optimize traffic flow in response to the weather.

HIWeather needs effective methodologies for evaluating all parts of the warning value chain. Two dedicated workshops on the value chain in Berlin and Melbourne helped the research community to build these skills. The MesoVICT project (Mesoscale Verification Inter-comparison in Complex Terrain) has shown that observation (analysis) uncertainty can have a significant impact on the conclusions when verifying high resolution spatial ensemble forecasts [14]. The inaugural Verification Challenge highlighted several innovative approaches for user-oriented forecast verification; these were recently published in a special issue of *Meteorologische Zeitschrift* [15]. Non-standard observations can be used to evaluate ensemble forecasts of extreme weather and its impacts, as exemplified by the verification of impact forecasts from the *Met Office Global Hazard Map* using a geospatial database of historical community impacts [16]. Challenges include large uncertainties in the impact data and time lags between some weather events and their impacts, especially for health. The density of tweets correlates well with the hazard impact, suggesting its possibility to verify impact forecasts using Twitter data.

A survey of national meteorological services on their use of ensemble tropical cyclone predictions suggested that forecasters liked having ensemble-based uncertainty information but this did not generally flow through to the warnings. The survey results will guide meteorological services to better develop their ensemble-based products and services. Participation in citizen science projects can also build community resilience to high impact weather events through knowledge creation, participation and trust in science.

Future directions in HIW evaluation research include applying social media and non-standard data in verification, quantifying the socio-economic benefit improved warnings including avoided losses, and meta-analysis of case studies of high impact weather to distil warning best practice.

To consider new areas of activity, two panel discussions were held focusing on specific hazard areas that had had little attention to date in HIWeather: rain-related landslides and urban air quality. The first was led by two short presentations on forecasting challenges in the Himalaya, in Tibet and Bhutan respectively; and the second focused on Chinese experiences. The potential hazard on human health [17] and air quality control in mega-city [18] have been analyzed.

During the workshop, break-out sessions encouraged participants to identify research and knowledge gaps in the forecast and warning chain and to develop concrete plans for HIWeather. The task teams identified key areas for further research activities:

(1) Impact data: review methods for collection and use (purposes, sources, methods, challenges, attributes, QA); promote standardization and promulgate good practice.
(2) Avoided losses: review measurement methods.
(3) Communication of uncertainty: review good practice in communicating low probability/high impact situations.
(4) Citizen science and crowd sourcing: develop standards for social media capture and use; develop guide for using social media to disseminate warnings and for 2-way communication with recipients.
(5) Case studies for communication during HIW events: catalogue available case studies; develop templates; carry out analysis/meta-analysis of groups of studies.
(6) Forecast precision and accuracy: predicting convective storms in the first 12 h: new high-resolution observations needs; initialization in km-scale models; propagation of uncertainty in coupled models. Focus on vulnerable regions and involvement of young scientists.

Another key outcome of the workshop was recognition of the need for greater integration of HIWeather within WMO, linkage to other activities of the World Weather Research Program (WWRP) and the wider WMO, and other global Disaster Risk Reduction endeavors. The sixth Session of the Global Platform for Disaster Risk Reduction (https://www.unisdr.org/conference/2019/globalplatform/home), which will be held at Geneva in May 2019, represents the next important opportunity for the international community to boost the implementation of the Sendai Framework for Disaster Risk Reduction (DRR) (http://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf), the Sustainable Development Goals (SDGs), and the commitments of the Paris Climate Agreement. The Global Platform will be organized under an overall theme entitled "Resilience Dividend: Towards Sustainable and Inclusive Societies" and focus on how managing disaster risk and risk-informed development investments pays dividends in multiple sectors at all levels and throughout social, economic, financial and environmental fields. Prior to and at this meeting HIWeather will explore the contributions that it can make to DRR efforts at the local, national, regional, and global levels.

Conflict of interest

The authors declare that they have no conflict of interest.

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