HIWeather Flagship Project –
Value Chain Approaches to Evaluate the End-to-End Warning Chain
A joint concept proposal from the WWRP HIWeather Project and SERA Working Group

Summary
The information value chain provides a framework for characterising the production, communication, and use of warnings in terms of its processes, inputs and outputs, relationships, contributions, and operational contexts of stakeholders. Different representations of the value chain or network may appropriate for describing warning chains of different complexity. This project will investigate value chain approaches and apply them to analyse the forecast and warning chain for case studies of actual high impact weather events. These events and an array of relevant attributes will be collected in a database and made available to National Meteorological and Hydrological Services (NMHSs) and researchers for analysis. The project will examine and interrogate the case studies to discern better practice in warning chains, resulting in guidelines for NMHSs.

1. Introduction
Since the generation of weather warning and climate services has become more complex, both technically and organizationally, the notion of the value chain has become a popular conceptual tool in studies trying to assess the use and the net benefits of such services (e.g. Perrels et al. 2020). Relative to the pre-internet era, weather and associated warning services are developed and provided through a multitude of complex and malleable value chains (networks), often established through co-design, co-creation and co-provision.

The value chain approach, especially in its broad-scoped meaning, facilitates the understanding of the different relationships, processes, inputs, contributions, outcomes, and operational contexts of each stakeholder (culture, behaviour, practices) in the warning chain. The chain can be analysed with different, yet complementary, methods, each emphasizing different sets of characteristics of the value chain. Figure 1 represents a value chain as a sequence of different scientific disciplines reprocessing information from previous segments and adding additional, unique information. This is a fairly technical representation of how information segments link. Other representations, for example, emphasize when and by whom in the value chain value accrues, in connection to positions of different actors in the weather and climate information service 'market' (Figure 2). Thanks to these decomposition capabilities, the value chain approach enables assessment of the effectiveness of the design and delivery process, and options for improvement.

Such analyses must be supported by evidence. Case studies are an effective mechanism to collect and catalogue successes and failures of warning chains for instances of high impact weather. Applying value chain approaches to case studies to characterise and measure the effectiveness of the tools, processes, partnerships, and infrastructure embedded in existing warning chains can provide the evidence to identify shortfalls and propose investments in new capability and partnerships. Furnishing open access to a database of case studies contributed by the global weather community, along with a demonstrative analysis, will encourage NMHSs to conduct similar analyses of their own warning chains.

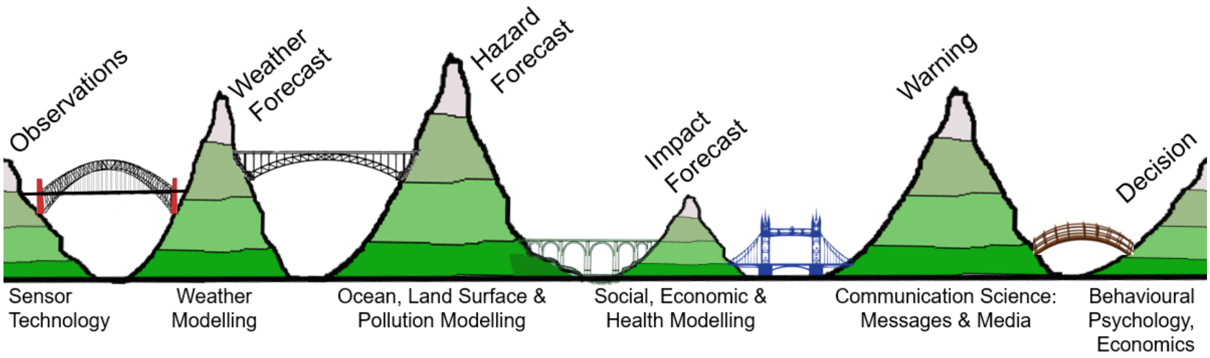

***Figure 1**. Schematic value chain for high impact weather warning showing the capabilities and outputs (green "mountains") and information exchanges (bridges) linking the capabilities and their associated communities. (from Golding et al. 2019)*

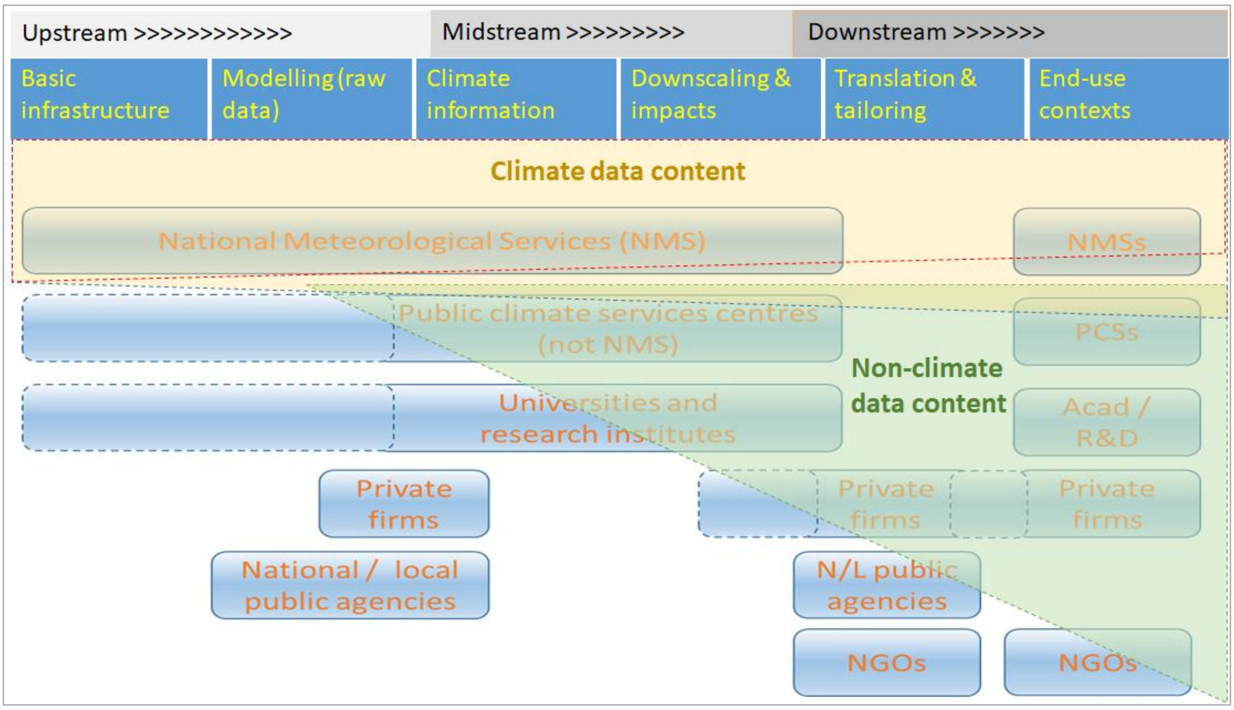

Figure 2. Value chain illustrating the progress in information processing stages in relation to cumulating value added associated with the use of climate data and non-climate data (the latter being more conducive for economic value added) and typical positions or degree of multistage coverage of different types of actors (reworked from Cortekar et al. 2017; Perrels 2018)

2. Objectives

This project has two main aims:

(1) To review value chain practices used to describe weather, warning and climate services to assess and provide guidance on how they can be best applied in a weather warning context that involves multiple users and partnerships;

(2) To generate an easily accessible means for scientists and practitioners involved in researching, designing and evaluating weather-related warning systems to review relevant previous experience and assess their efficacy using value chain approaches.

To achieve the first aim we propose to review and assess current broad scoped value chain practices with respect to the use of socio-economic insights in development and delivery of weather, warning and climate services. This will include identifying shortfalls and suboptimal applications of methods. Based on this assessment we seek to critique and identify the 'value added' of applying a value chain and provide guidance and examples and how it can be applied in a useful, flexible and robust way to analyse complex warning chains. We will engage with on-going and recently completed applications and studies of the value chain concept in weather, warning and climate services. We will consult key experts in the WWRP programmes, in several national weather services and various other institutes. We will develop an inventory of value chain applications, catalogue of usage types, and value chain guidance and tools.

To achieve the second aim we will catalogue, analyse, and supplement where feasible, information from case studies of the performance of warning chains, review the information available about the organisation and performance of warning chains, and perform detailed evaluations of warning chains in selected case studies, noting that catalogued case studies should capture both successes and failures. The collected information will be organised in a Warning Chain Database with an intuitive web-based user interface designed to enable warning events and warning systems to be interrogated and compared easily. The database will provide a valuable source of evidence for what constitutes an effective warning system: one that is useful, usable and used; from which to identify and promote best practice in warning for and reporting on high impact weather so as to support the development of improved warning services.

The first and second objectives support each other through defining and demonstrating effective value chains for weather warnings (Figure 3).

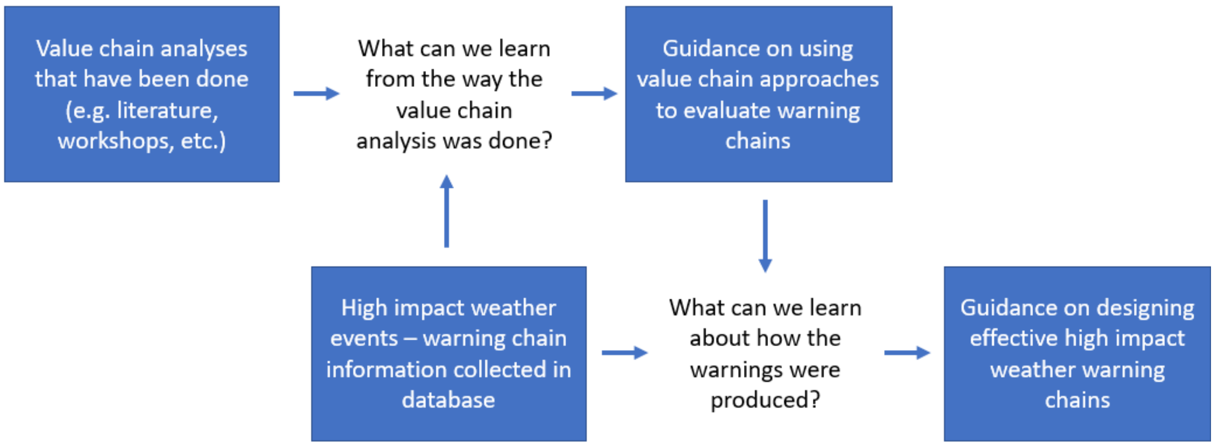

Figure 3. Interaction between the first and second objectives of the project (top and bottom row, respectively).

Outcomes

(1) By using the value chain as an analysis approach to facilitate co-production of new knowledge, NMHSs, partners and researchers are better equipped to

- Understand how value chain/network approaches can help them understand and improve aspects of their forecast and warning chain

- Apply value chain approaches to better understand their warning chain, and understand the effects of both technical and organisational conditions on value propagation
- Target and measure improvements to their forecast and warning chain based on changes in information use, decisions, behaviour, and outcomes and associated social and economic value (for instance, as measured through benefit/cost analysis)

(2) By collecting and documenting hazardous event case studies in an easily accessible database to support analysis of the end-to-end warning chain, NMHSs, partners and researchers are better equipped to:

- Access data and information on past events
- Characterise and analyse warning chains used in high impact events to extract learnings and discern best practice
- Know what data and information to collect to create useful case studies
- Contribute to the case study database by entering data and information on recent hazardous events (to be confirmed)

Outputs

1. A high level value chain framework tool for decision makers
2. Guidance and tools for more specific and context-appropriate usage of value chain approaches
3. A glossary of value chain and warning chain terminology in a hydrometeorological context
4. A living database of hazardous weather events with rich information covering (as much as possible) the components of the forecast and warning value chain, that complements WMO efforts such as the WMO Catalogue of Hazardous Events (WMO 2019).
5. Analysis and advice on best practice warning value chains (from simple to complex) analysed from the database
6. Exchange and integration of practical experiences (NMHSs and partners) and weather-related natural, social, and interdisciplinary science (research community)

3. Components

3.1. Review of value chain approaches

3.1.1. Conceptual framework

Development of the conceptual value chain framework will include

- Socializing this proposal with other WWRP initiatives, through interviews and email survey to build an understanding of how the term 'value chain' is being used.
- Preparation of an institutional framework including WWRP key action areas' scope and describing how WMO forecast and user systems should develop in the future, building on the valuable joint efforts of WWRP and WRCP in the Science to Services partnership.
- Preparation of a conceptual framework of value chain for hydrometeorological services to be released as a WMO briefing.

3.1.2. Inventory of value chain practices

We will develop an inventory of existing examples of where the value chain has been applied, based on a systematic review of academic and grey literature and workshops. Where an example describes a high impact weather warning its data will be included in the Warning Chain Database (refer to 3.2.1). Description of the value chain will include information such as given below.

Elements describing value chains

- The methodology used
- Components of the value chain, their interactions and contributions to the 'complete whole'
- The question the value chain tried to answer (i.e., is it related to the outcome? the impact? the process? or the input?)
- The processes and products (were they co-developed by users? If so, who was the user and how did the user influence the design, execution and usage?)
- Sequence of actions (was it different than a linear chain?)
- Metrics and analysis used to quantify/attribute the components of the chain, resulting in a valuable product.
- Was the value chain approach assessed? How were the components assessed and did this differ from how the 'complete whole' was assessed? Was it repeated to assess efficiency? Under what conditions are the processes replicable?
- How useful was the approach, where and what were the constraints and challenges?
- Did the value chain alter change policy or decision processes?
- Which sector was the value chain applied in?

3.1.3. Catalogue of value chain usage types

Based on the inventory of Value Chain practices (3.1.2), we will create a catalogue of usage types according to their suitability for planning and execution, project assessment and evaluation, quality control, and efficiency/scenario assessment and testing replicability.

A gap analysis will be conducted in order to (1) review the catalogue examples to assess where gaps exist in the critique and application of the value chain approach; (2) review whether the examples focus more on evaluating some parts of the value chain more than others; and (3) review its methodologies and identify opportunities for enhancing and even reframing the notion of a value chain that is reflexive of local context and circumstances.

3.1.4. Metrics and measuring intangibles

An overview of value chain metrics will be prepared, including:

- What metrics are being used (i.e., type, analysis method, measuring techniques, standards/rules of the metrics being applied)?
- Where are these metrics being used within the value chain?
- Are there appropriate metrics to evaluate intangible aspects of the value chain?
- Identify other metrics from other fields that might be relevant.
- Is metric uncertainty quantified, described? Using what methods?
- Identify and develop propositions on how to capture and measure intangibles outcomes (unquantifiable) of value chains.

3.1.5. Synthesis, guidance and tools

Based on the outcomes of the previous four stages, we will prepare (1) a high-level framework tool for decision makers, and (2) guidance and tools for more specific usage according to the Value Chain applications areas and sectors involved.

3.2. Warning chain collection and evaluation

3.2.1. Collect cases of high impact weather events

We will collect information on relevant high impact weather events from case studies, post event reviews/enquiries (e.g. UK Pitt Review 2007; US Harvey Review 2017; Australian Black Saturday Review 2011) and Warning Service Assessments (e.g. NWS Service Assessments https://www.weather.gov/publications/assessments), etc.

Relevant high impact weather events include those for which:

- Lessons learned from the event are relevant to current technology and capability. For forecast accuracy this may imply less than 10 years old, whereas for governance, useful lessons may be learned from 50 years ago or more.
- The event should involve one or more of the hazards focussed on by HIWeather (wildfire, urban flood, localised extreme wind, urban heat wave and air pollution and disruptive winter weather).
- Information should ideally be available on the hazard(s), impact(s), forecasts & warnings and response, together with an assessment of what worked and what didn't.

The information will be recorded in a metadata database, containing links to as much relevant information as possible. Each entry should be referenced to the source in such a way that it can be recovered by subsequent users (for example, using a universally unique identifier (UUID) number for each event).

Tasks include:

- A project lead to create an interim database (an Excel spreadsheet on Google Drive?), that can be accessed by all task team members, formatted to receive the required information and with one or two example entries made.
- A team of volunteers to collect information on selected cases that they have access to and to add it to the database. Members may have preferred access to national evidence and/or to specific parts of the warning chain.

Key data attributes are described in Appendix 1. An early worked example is shown in Appendix 2.

3.2.2. Review selected warning systems

We will review the governance, structure and organisation of selected weather-related warning systems, identifying the type of value chain used (refer to 3.1.3) and cross-referencing to relevant cases in the database where appropriate, including any documentary evidence underpinning the choices made.

Tasks include:

- A collaborative team activity (perhaps including a workshop) to draw and record conclusions about the warning chain performance in each case, using value chain metrics where possible (refer to 3.1.4).
- A project lead to identify sources (possibly in or through WMO) of information on national weather-warning systems and to define an outline database classification. (Juyeon Bae has produced an index of WMO surveys of weather warnings that will form the starting point for this part of the project.)
- A team of volunteers to extract information on selected national weather warning systems that they have access to and to record it in the database.
- A project lead to relate the information in the event database to the warning system classification.

3.2.3. In-depth analysis of selected events

We will identify events that highlight an issue of importance to some or all of the warning chain, for in-depth analysis. Ideally, common cases will be selected that address the concerns of SERA and multiple HIWeather task teams but this is not essential. The objective is to relate the warning process to current understanding of best practice, to assess improvements that current best practice might have brought to the outcomes, and to revise and extend best practice where required. Questions for research and analysis are given in Appendix 3.

Tasks include:

- Scientists or groups of scientists to undertake detailed analysis of selected cases to identify the potential benefits of applying a best practice warnings chain.

3.2.4. Build the database

We will design and build a data storage and access system to enable easy use of the information to answer questions identified by practitioners.

Tasks include:

- Team of scientists to create a user requirement for a database and web-based access tool for the collected data.
- Funded project to build a searchable database to contain the collected data, with a web front end for addition of new cases and to enable intuitive searching & display of the results as defined by the user-requirement activity.

4. Leveraging other activities

This project will have limited or no capacity to generate original data (e.g. model runs, surveys) for high impact weather events; rather, it will build on existing case studies and collections. By *linking* science and (meta-)data on weather hazards to existing DRR databases, post-event reviews and case studies, this project will enable research that spans the complete warning chain. Some relevant activities that our project can leverage include:

- EM-DAT, DesInventar, and other DRR databases
- WMO Catalogue of Hazardous Events (WMO-CHE; under development, WMO, 2019)
- ECMWF Severe Event Catalogue
- United States value chain activity led by Jeff Lazo

5. Timeframe

This project will kick off at the 2020 HIWeather Workshop in December 2020. The initial components (value chain review and initial case study collection and organisation) are expected to take two years.

Building the Warning Chain Database will require funding and is expected to begin in the second or third year of the project. It should be informed by WMO-CHE with a long-term goal of linking the Warning Chain Database to the WMO-CHE database.

6. References

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Golding, B., Ebert, E., Mittermaier, M., Scolobig, A., Panchuk, S., Ross, C. and Johnston, D. (2019). A value chain approach to optimising early warning systems. Contributing paper to GAR2019. UNDRR, https://www.preventionweb.net/publications/view/65828.

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World Meteorological Organisation (WMO) (2019). WMO cataloguing initiative. https://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/2019.11.21_Ardhasena_Cataloging_Initiative_ET-WCS.pdf

Appendix 1. Data to collect

Summary information about the event

- Unique identifier
- Name of event
- Date including start, end, duration
- Location and spatial extent
- Hazard(s) of concern
- Relevant antecedent conditions
- Impact summary (damage, disruption, deaths)
- Causal weather
- Forecasts issued
- Warnings issued
- Exposure
- Vulnerabilities (pre-conditions, demographics, etc.)
- Interventions/mitigating actions taken
- Social extent and variation
- Subsequent lag/enduring effects

Information about the weather processes and predictability

- Causal weather
- Available (high-resolution) observational data from diverse sources, including satellite and aircraft data, ground-based remote and in situ measurements, social media posts
- Weather models run on the case
- Weather model system name and version
- Spatial resolution
- DA method and observations assimilated
- Ensemble size
- Forecast length
- Spread of key variables/ EFIs/ SOTs at different lead times
- Representation of weather process uncertainty in models
- Severity of the event relative to climatology

Information about modelling/predicting the hazard

- Hazard models run on the case
- Hazard model system name and version
- Spatial resolution
- DA method and observations assimilated
- Ensemble size
- Forecast length
- Representation of hazard process uncertainty in models
- Severity of the hazard event relative to climatology

Information about the impact (chronic-acute; direct, indirect, induced; gross, net)

- Exposure
- Vulnerabilities (pre-conditions, demographics, etc.)
- Health impacts - mortality, morbidity (injury, disease, physical and mental illness),
- Dislocation (temporary, permanent) and mobility
- Damage to critical infrastructure damage and service disruption (water supply, wastewater treatment, electricity, fuels, transportation, emergency response, health care, etc.)

- Other property damage (destruction, repairable/replaceable, premature deterioration, social and business disruption, environmental damage, insured and uninsured losses, economic impact (direct, indirect, induced)

Information about communicating the warning

- Who issued the warning
- Reach/penetration of the warning (e.g. by source and channel)
- Content and format of the warning
- Copy/description of any graphics used
- Details of uncertainty
- Timing and frequency of warning issuance
- Warning thresholds (level and foundation, e.g. impact or hazard) and levels issued, timing of those
- Survey on risk perceptions (including trust and perceived success of warning) and actions taken by receivers
- Timing and content of communication between warning issuers and response agencies (interagency communication)
- Any issues/challenges experienced to do with communication
- Topic of rumours and how/if they were controlled
- Warnings ‘passed on’ by other response agencies
- Post-event surveys/investigations and reports

Information about verifying the forecasts / evaluating the warning chain

- Information about the observations/data used to verify/evaluate the forecast (weather, hazard, impact)
- Forecast verification approaches used
- Quality/accuracy of forecasts and warnings
- Timeliness of forecasts and warnings
- Survey results for user satisfaction and warning response
- Partners / players in the value chain (probably need to divide the value chain in key steps)
- Information exchange processes along the value chain (machine-to-machine, briefings, online platforms, etc.)
- Documentation of beliefs, decisions, actions, responses, policies and/or practices by actor type, institution, sector:
    - NHMSs and public safety/civil protection partners (communication of predictions, warnings, recommended behaviour/calls-to-action)
    - Traditional media
    - Other public agencies
    - Private sector (breakout by industrial classification; employment or other measure of size) and business associations
    - Non-government and non-profit organizations (e.g., aid/community support sector
    - Public (and/or specific socio-economic demographic segments reflective of varying vulnerability, capacity to response)
- Metrics used to evaluate the value chain
- Mitigating actions taken
- (Avoided) accidents, fatalities or losses to measure the success of a warning
- Lessons learned from the event (e.g. from inquiries, post-event reports, etc.)

Appendix 2. Worked example

The following example shows some of what could be included in a case study entry, based on information from the review of the "great storm" of 1987 in the UK. Note the example includes where more information can be found.

1. Identifier: 1987-UK-1
2. Name: Great Storm
3. Date: 17th October 1987
4. Location: South-East England
5. Causal hazards: Strong wind (Beaufort force 10 over coastal land; force 9 inland)
6. Impacts: Many trees blown down, roads blocked, power and communication lines brought down.
7. Causal weather: Rapidly developing secondary depression – see ERA5 for reanalysis fields
8. Forecasts: good medium range forecasts; poor 24-hour forecasts; good 6-hour forecasts – see Met Office (1987). The Storm of 15/16 October 1987. London: HMSO; Met Appl. 2004/ 2005, Jung et al, ECMWF ensemble reforecasts of three major European storms Pts 1,2.
9. Warnings: warnings to shipping, railways, airports, offshore operators and London fire brigade issued 6-12 hours ahead; warnings issued to public through media when high winds first observed – 1-3 hours before the worst damage. – see Met Office (1987). The Storm of 15/16 October 1987. London: HMSO.
10. Exposure (property, people, infrastructure etc): trees, power networks, communication networks, transport networks.
11. Vulnerabilities identified: trees still in leaf and wet soil resulted in greater tree fall than a winter storm would produce.
12. Interventions: trains? ships? airports? offshore operators?
13. Avoided impacts: none known.
14. Brief analysis: Day 3-4 medium range NWP correctly forecast a vigorous depression. Day 1 NWP took the depression over France, making the main threat to southern England from rain. Warnings were issued in good time for sea areas to the south of England, and for specific users with agreed warning thresholds. Public warnings were limited to a maximum lead time of 3 hours and were not issued until after midnight because of this. Infrastructure operators were not aware and were unable to prepare for recovery.
15. Lessons learned: Need for longer lead time public warnings; Need for infrastructure operators to receive warnings; need for better observations to the southwest of UK; need for higher resolution NWP. Ref: Met Office (1987). The Storm of 15/16 October 1987. London: HMSO.

Appendix 3. Research questions that could be addressed

The questions below were proposed by the SERA Working Group and HIWeather Task Teams.

SERA	
Questions for each value chain example	**Questions for comparative analysis and synthesis**
• A description of the methodology used. • The components of the value chain and the way that they interact between them and contribute with the ‘complete whole’. • The question the value chain tried to answer (i.e., is it related to the outcome? or even impact? the process? or the input?) • Considering the processes and products (were they co-developed by users? and if so, who was the user? how did the user influence the design, execution and usage?) • Was there a sequence of actions different than a linear chain? • Identifying metrics and analysis that were used to quantify/attribute the components of the chain, resulting in a valuable product. • Was the value chain approach assessed? How were the components assessed and did this differ from how the ‘complete whole’ was assessed? Was it repeated to assess efficiency? Under what conditions are the processes replicable? • How useful was the approach, where and what were the constraints and or challenges to such an approach? • Did the value chain alter change policy or decision processes?	• Does the value chain answer the question for which it was designed for? • How does the value chain impact intangible aspects of projects and disciplines, such as building long lasting social networks, consolidating communities of practice, and bridging formal and informal systems in decision-making processes? • Is the notion of a value chain useful in the operating context? If not, then why not? • How does the notion of value chain address discrepancies between output metrics (number of outputs) and quality considerations in measuring or determining success or failure of interventions?

Predictability and Processes	
Questions for each case	**Questions for comparative analysis and synthesis**
• How predictable were the atmospheric conditions associated with the HIW event and how did predictability vary with spatial scale and forecast lead time (e.g., did forecast trajectories bifurcate on the convective scale in a meso-scale environment with little forecast uncertainty)? • What were the dominant processes governing i) the HIW event and ii) its predictability? • What other factors contributed to the severity of the event (e.g., pre-conditioning,	• How does predictability relate to severity of the HIW event? • What are the average predictability horizons for different types of HIW events and how do these horizons relate to the dominant governing processes? • Does predictability relative to a typical predictability horizon for that type of HIW event provide a more helpful view on predictability than estimates based on a reliable ensemble, in which rare events should be at the tail of any forecast

stationarity, compoundness), and how did they impact predictability? • How did multiple NWP models perform and what are the reasons for good/poor performance? • What diagnostic tools would assist in identifying HIW events in forecasts, better understanding the physical processes underlying them, and assessing their predictability?	distribution and thus exhibit little predictability by design? • How can observations from a diverse array of sources (e.g., satellite and airborne data, surface observations, social media posts), improve process understanding and representation in models? How would this improve predictability of the HIW event?

Multi-scale Modelling of Hazards	
Questions for each case	**Questions for comparative analysis and synthesis**
• What models were used for the weather and the hazard? • Description - Spatial resolution? Update frequency? Ensemble size? Coupled? DA? etc. • How were ensembles used, e.g. probabilities, scenarios? • What additional observational data were used as model input, nowcasts and verification, e.g. non-traditional data? • How did the models & nowcasts perform?	• Do convection-permitting models help improve hazard forecasts? • If yes, is it contributed by advanced methods of mesoscale DA, the inclusion of high-resolution observations, or better NWP models? • If the convection-permitting models do not produce any additional value for the hazard warning, is it because the forecasts are poor (e.g., too many false alarms), or/and have not enough lead time? Or is it because of lacking necessary post-processing and any communication issues?

Impacts, Vulnerability and Risk	
Questions for each case	**Questions for comparative analysis and synthesis**
• What were the impacts of this event? • How were the impacts measured? • What vulnerabilities and exposures were important in producing the impacts? • What socioeconomic data were used to assess risk? • Were impacts predicted (i.e. impact-based forecast or impact forecast) and how? • How did risks and impacts evolve over time? • How did users make decisions (thresholds)? • What were the responses to the event?	• Do we understand vulnerability well enough yet to be able to model it? • To what extent have we been able to define, measure, model, and predict constitutive aspects of risk (dynamic exposure, vulnerability, sensitivity) for individual and cumulative (multi-hazard) threats? • What is the efficacy of co-producing/ communicating/sharing this risk and impact knowledge with various actors (i.e., as measured in terms of comprehension, application/use in decision- or policy-making, behavioural intent, behavioural response, impact outcomes)?

Communication	
Questions for each case	**Questions for comparative analysis and synthesis**

• Which providers issued communications and to which users? • What level of trust do those providers have in the community? • What proportion of the community were exposed to the 'official' warnings/information? • How were the communications made (channels, protocols)? How do you know these channels are most appropriate? • What was the timing and frequency of message delivery? How was that perceived (too often, not frequent enough, too late, too early)? • What elements were included in the message and in what order (source, hazard, impact, guidance, location, time to take action, time of issuance, time of message expiry, time of next message, links to further information)? • Which graphics/visualisations/augmented reality techniques were used (if any), specifically the colour, labels, scales, communicating uncertainty, comprehension, links to products used? • What does the warning system consist of (number of levels, labels, definitions)? • What level of warning was issued for this event? • What level of detail was given about potential impacts/guidance messaging (if any)? (e.g. local/detailed information, or nationwide?) • How was uncertainty conveyed? Was it understood? • Was the warning perceived to be successful, by all parties? • How did the message influence the receiver's perceptions (threat, concern, efficacy, credibility/trust/belief of the message, comprehension of the message (including languages, jargon), understanding about the potential hazard and impacts)? • What was the behavioural response(s) as a result of receiving the message? If no response - why not? • How were NMHS warnings added to/changed by response agencies (who passed the message on)?	• What are the most important predictors for effective behavioural response? • What elements of a warning (e.g. hazard, impact, guidance; text, graphics, analogies; scenarios, probabilities, likelihood terms) can be tweaked to ensure a more effective warning and response? • What is more effective in prompting a response – impact-based warnings, or those based on more traditional meteorological/hazard thresholds? Or something else? • Does including warning graphics lead to better responses? What type? Which graphics are most effective, in terms of colour, labels, scales, communicating uncertainty, comprehension? • How to define a 'successful' warning, by whom? What is a 'better response'? • What are the roles of rumours and rumour control (especially on social media) in terms of perceptions and behavioural response? • What is the most effective way to communicate uncertainty?

User-oriented Evaluation

Questions for each case	**Questions for comparative analysis and synthesis**
• What were the error characteristics for the weather, hazard, and impact (if predicted) components of the forecast? • How did error propagate along the warning chain? • How did uncertainty (e.g. estimated from ensembles) propagate along the warning chain? • What evaluation was done along the forecast/ warning chain and was it effective? • Did forecast users have access to quality information? • What and how much value was added/lost along each part of the warning chain/network (apply value chain methodologies)? • What were the strongest and weakest links? • How did end users respond to the warning? • What were the overall benefits of the warning (avoided losses, e.g. $, lives, etc.)? • Did the warning evolve due to the changing forecast (e.g. TC track uncertainty) leading up to the event, and how did the value chain itself change? What were the implications for warnings and messaging?	• What information exchange processes were most effective in not distorting the information along the warning chain? • How does the magnitude of the forecast error relate to the severity / rarity of the event? • What links in the value chain are working well / not well in general? For certain hazards? • How are social media data assisting in evaluating warning effectiveness? • What were the key institutional/legal barriers (if any) in the warning value chain process? • How does the level of uncertainty in the forecast affect the overall impacts i.e. did cases with higher forecast certainty result in better outcomes in terms of action to prevent impacts than those cases with more uncertain forecasts? And if so why?