# APPLYING A SERVICE-ORIENTED APPROACH TO THE DEVELOPMENT OF NOWCASTING CAPABILITIES

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## EXECUTIVE SUMMARY

Analysis of a 2014 survey of WMO Members' nowcasting capability and aspirations has highlighted the broad range of approaches used to nowcasting across NMHSs, from traditional human-based methods using limited data, to automated and integrated systems using a wide array of observational data in tandem with probabilistic, high resolution NWP and post-processing. However, the results also suggest that many nowcasting capabilities, however sophisticated, may lack both alignment with user needs and long-term sustainability, with common concerns regarding training and resources to operate, maintain and upgrade them. We present some simple guidelines and recommendations for those developing effective and sustainable nowcasting services, using the principles outlined in the WMO Strategy for Service Delivery and its Implementation Plan.

## PART I - BACKGROUND

Most NMHSs have a responsibility to provide continuous monitoring of weather conditions, either at specific sites or for entire nations, and most will also be expected to update forecasts accordingly based on this monitoring. These forecasts may be for a range of end users including the general public, the media, civil protection and aviation, and may form part of warning systems designed to notify users of imminent high-impact or otherwise significant weather. They are also increasingly used to aid prediction of other natural hazards, such as river flooding, in which they provide updated information for downstream models and warning systems.

Thus providing a 'Nowcast' (defined here as a 0-6hr analysis and prediction) might be seen as a fundamental element of a modern NMHS's capability, and the process of monitoring, assessing and improving the quality of forecast products on short timescales should be given due priority alongside development of other forecasting capabilities. But it is also essential that nowcasting capabilities are planned, delivered and operated with the needs of forecasters, decision-makers and end users in mind.

Nowcasting can, of course, be achieved via a 'traditional' approach by which a human forecaster or end-user monitors and reacts to separate sources of observational data and the latest NWP information. But in recent years, the capability has been develop to integrate *in situ* observational data (e.g. from rain gauges) with remote sensing data and with NWP forecasts. We define this integrated, often automated approach as a '**Nowcasting System'**.

The WMO Strategy for Service Delivery, and its accompanying Implementation Plan, are powerful tools to help NMHSs develop high-quality, cost-effective and user-oriented services and products. These principles also apply to the development of the systems, which underpin these services. However, it is recognised that very often development, including that of nowcast systems, can be driven by expediency - such as the availability of system components or an opportunity to make use of systems designed elsewhere – rather than by structured, end-to-end planning. Acknowledging this issue, CBS requested that the PWS programme provide guidance to Members on the applications of new technology to nowcasting, and the CBS-OPAG/PWS Expert Team on Service and

Production Innovation and Improvement (ET/SPII) agreed to produce guidelines and examples of how the principles of the Strategy for Service Delivery and its Implementation Plan (SDIP) could be applied specifically to nowcasting systems. This document presents those guidelines, following the results of a 2014 survey of the nowcasting capabilities of WMO Members.

There is a staged approach to planning nowcasting services, and each NMHS should judge which service model is most appropriate given its particular capabilities. But, as with many aspects of good service delivery, this also suggests a risk-based approach to planning systems based on prioritising the needs, and impacts upon, users and customers as well as the resources available for development and sustainability of systems.

## PART II - A SURVEY OF NOWCASTING CAPABILITIES

### Methodology

A draft questionnaire for Members was compiled by ET/SPII during and following its 2012 meeting in Stony Brook, New York, USA. Following additional review and input from the President of the Commission for Instruments and Methods of Observations (CIMO), the finalised questionnaire was distributed to NMHSs via the Global Data-processing and Forecasting System (GDPFS) annual survey early in 2014. A copy of the questionnaire is included in Annex 1 of this document.

Responses were gathered via the SurveyMonkey online survey tool (www.surveymonkey.net) in mid-2014 (July to September) and initial results were collated and analysed late in 2014. Additional analysis was undertaken in preparation for the completion of this document during Summer 2016.

### Results and Analysis

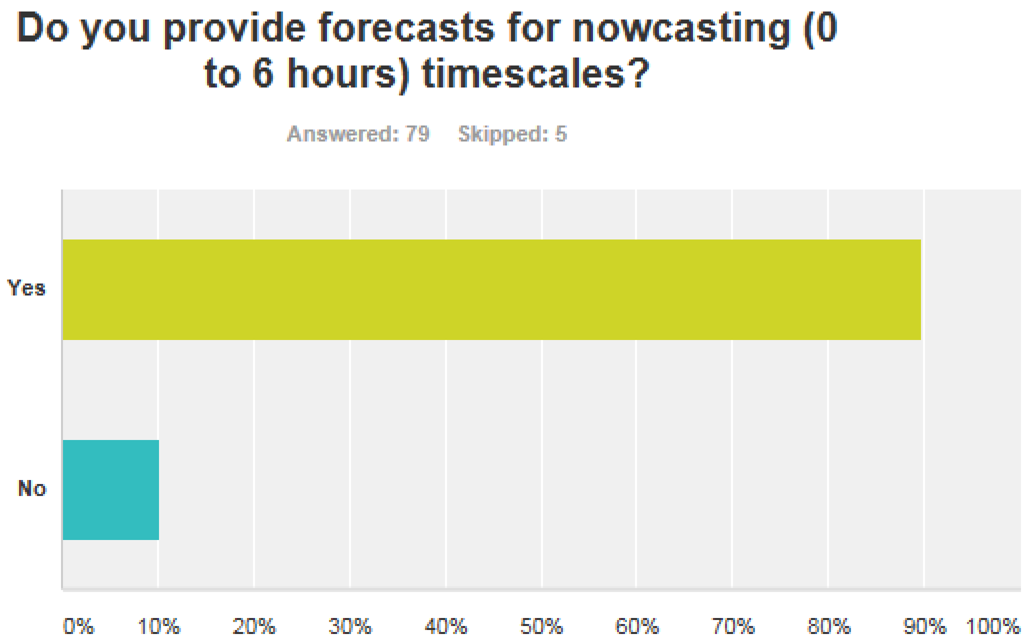
Below is a brief summary of responses to survey questions Q1-Q17.

#### *Q1. Level of engagement*

There were 85 responses to the survey. Omitting duplication, there were responses from 65 individual WMO Members. This sample is assumed to be large enough to draw valid conclusions from, and a suitably broad range of NMHSs is represented in terms of size, resources and scope of responsibilities and geographical area covered. It should be noted that the statistical analysis and graphs presented below are based on the larger sample of 85, meaning that though broad trends and signals remain valid, the precision of the figures quoted may not be reliable.

#### *Q2. Provision of Nowcasting Services*

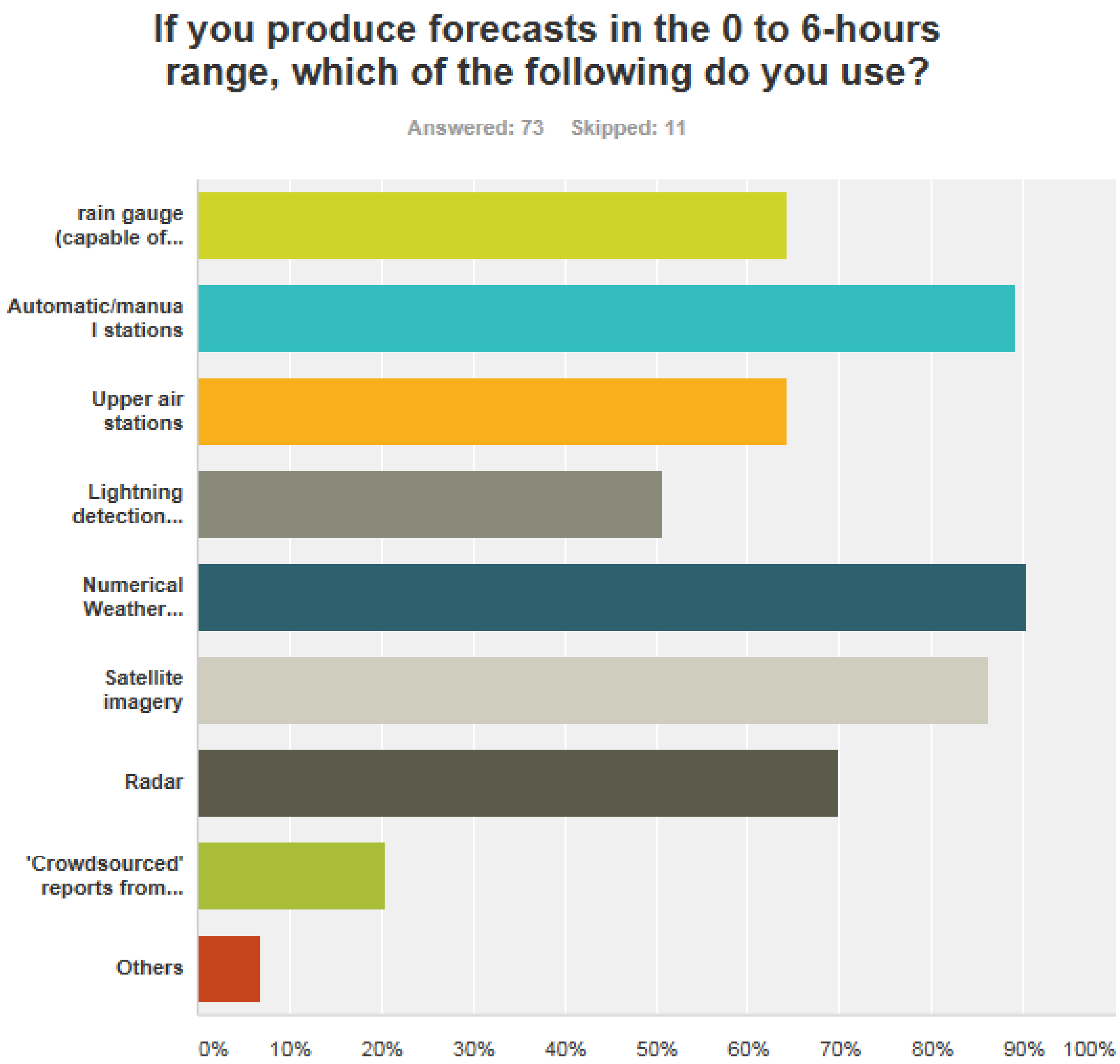
Almost all (90%) of responding NMHSs provide some kind of nowcast forecast. Of the 8 who said that they did not, some did not (as of 2014) recognise the need to provide such forecasts, though others' ability to produce nowcasts was affected by limited resource, including lack of key technical systems and lack of suitably trained staff.



### *Q3. Sources of Data Used*

Almost all responding NMHSs use a variety of inputs into their nowcasts, with a preference for a 'surface observations/satellite imagery/deterministic NWP' combination. It is notable that, in comparison to these data, radar and rain gauge data appear less widely used for nowcasts. But the fact that nearly 90% use automatic or manual surface stations indicates that some kinds of precipitation observations are used in nowcasting. We speculate that the lower (64%) proportion indicating use of rain gauge data refers more to a lower use of gauge systems capable of transmitting hourly observations. Lightning detection systems are relatively little used (51%). Some NMHSs do not have these tools, and it is probable that even if they have, they are not able to fully utilise radar etc. data, for example by combining it with NWP. We also believe that remote sensing instruments (such as radar or lightning detection systems) require advanced quality control procedures, which may beyond the resources of some NMHSs.

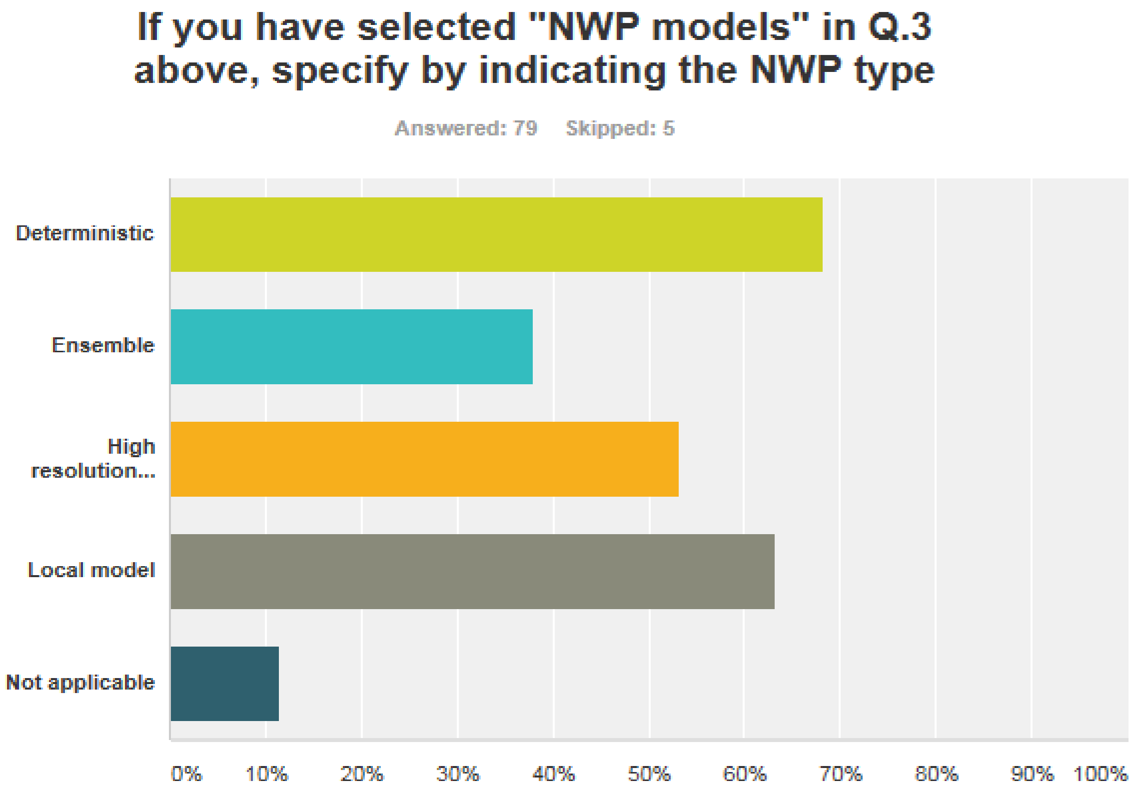
By 2014, there were already a significant number (20%) of NMHSs using crowdsourced/public reports, and it would be reasonable to assume that this proportion will have grown further, perhaps substantially so, since then.



### *Q4. Types of NWP used*

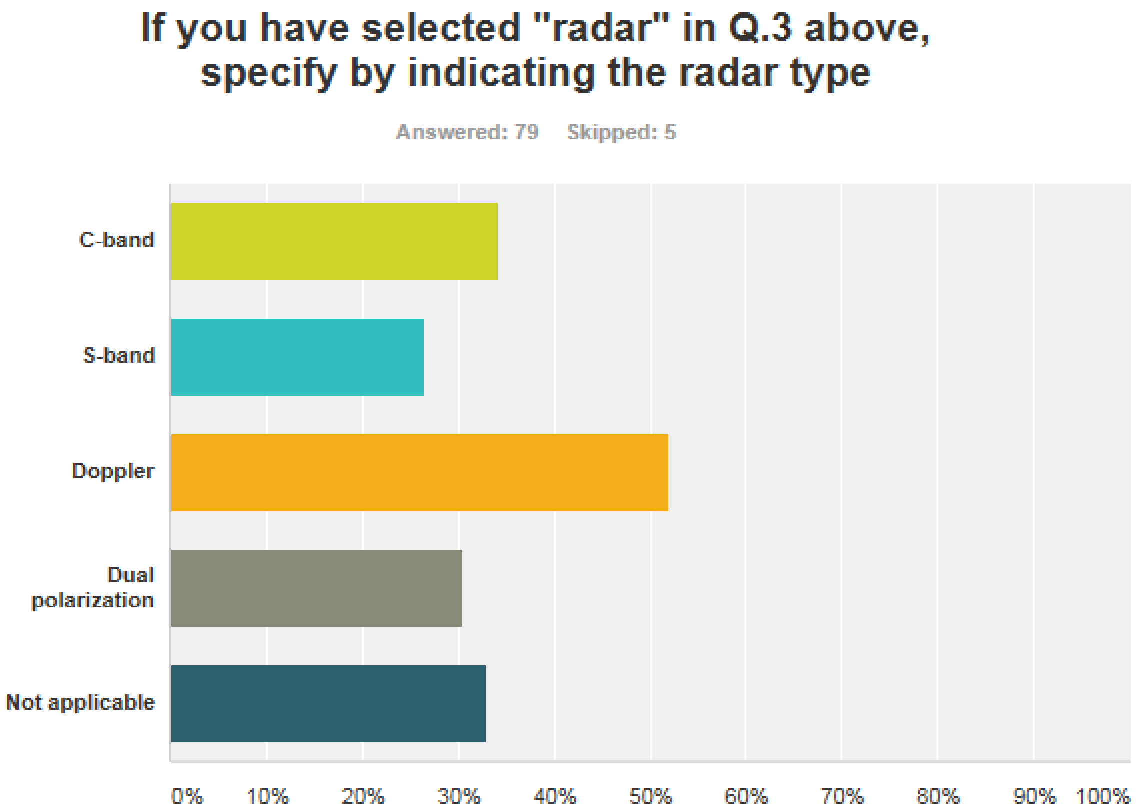
The wide use of NWP, some of which has become freely available online, in nowcasting (90% use in Q3 above) is a desirable trend. Amongst the survey responses, there is a clear preference for deterministic, local-scale NWP models. This is not surprising as historically there has been a focus on deterministic modelling. But the 38% use of Ensemble Prediction Systems (EPS) is very encouraging and suggests NMHSs are at least beginning to adopt a mixed deterministic/probabilistic approach which enables them to estimate uncertainty (and therefore risk).

But it should be noted that a nowcasting system cannot consist of NWP alone, and that use of actual observations is necessary. Indeed, it is these 'real' observations, such as surface reports or radar data, which can provide the most valuable information to forecasters and end users, and that an optimised nowcast system will use NWP carefully to maintain or enhance, rather than attempt to replace, the value of these observations throughout the nowcasting period.



### *Q5. Type of Radar Used*

Of the radar users, 51% have Doppler capability and 30% have dual polarisation. It is of course encouraging that the latest radar technology is increasingly available to NMHSs. But it is questionable whether many NMHSs make use of, or *need* to use these advanced capabilities. It may be that some have used valuable resources to develop or purchase radars with advanced features at the expense of arguably more important and more fundamental capabilities, such as radar *quality*, which often have greater relevance to end users.



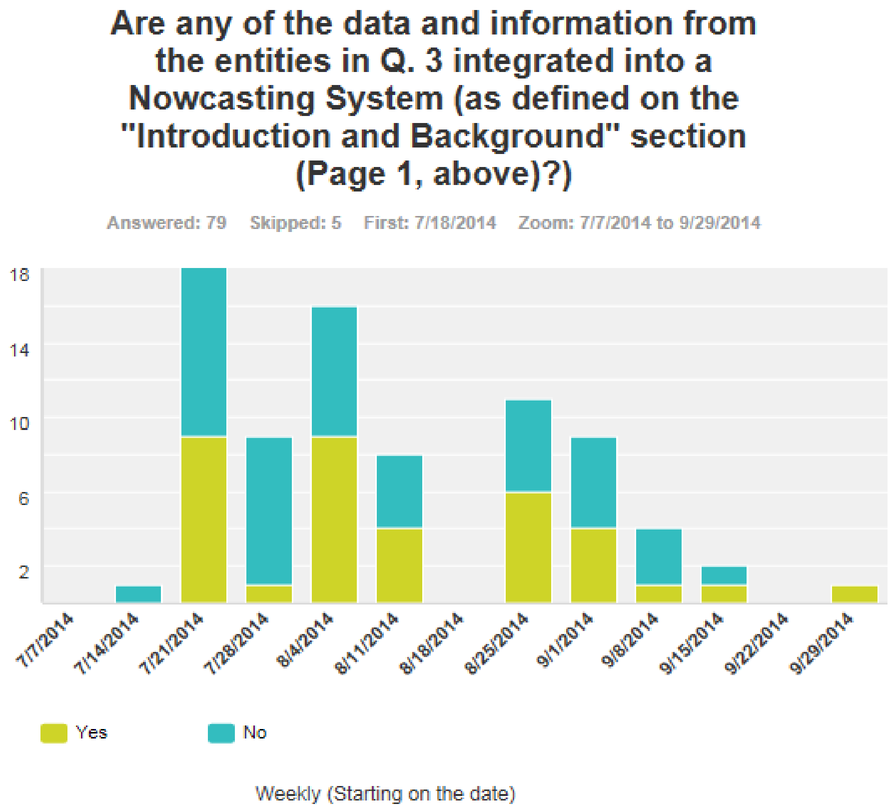
### Q6. *Other data sources used*

Survey responders indicated that a wide range of additional sources of data are used in their nowcast processes. These include LIDAR, wind profilers and AMDARs. Several responses mentioned integrated nowcasting systems, such as INCA or NowcastMix, which are explored more fully in the subsequent questions.

### Q7. *Are these sources combined into an ‘Integrated‘ Nowcasting System’?*

A surprisingly high 46% claimed to be combining data into such systems, though there is a suspicion that some approaches involved conventional, human monitoring and nowcasting of separate data sources for use in downstream production processes such as systems for the issuing of warnings, rather than utilisation of genuine, integrated and automated systems.

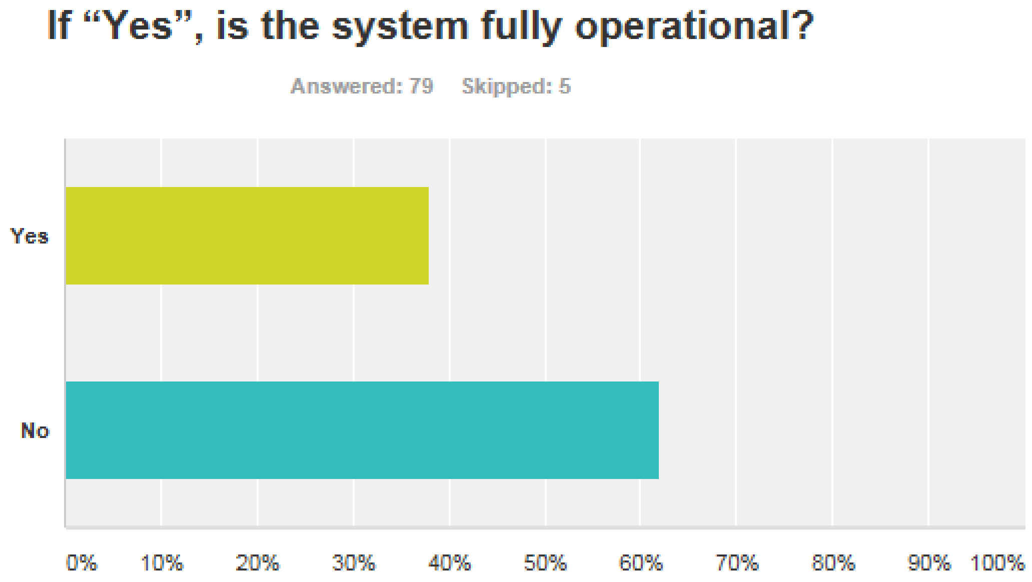
Nevertheless, even allowing some misinterpretation of this concept, there is clearly a large variety of systems integrating different combinations of data sources, and NMHSs are increasingly realising the benefits of an integrated approach to nowcasting rather than one based on separate sets of observational and NWP data.



### *Q8. Is the system ‘fully operational’?*

It is interesting, even alarming’, that the majority (62%) of integrated systems mentioned in Q7 are not deemed ‘fully operational’. It may be that some are still in the developmental stage, or that development has stalled. It may also be that the system was only ever conceived as a research project, without a plan to become operational, or that the NMS lacks the resources to make best use of the system for operational purposes. It also requires more investigation to find out whether it is merely the ‘integrated’ aspect of the nowcasting process which is not operational, and whether the NMHS is still using a non-integrated approach operationally.

In all the above cases, the common theme is that there may be a disconnect between the development of nowcasting systems and their ultimate purpose – meeting the needs of users on a day-to-day basis.



### *Q9. Type of Nowcasting System*

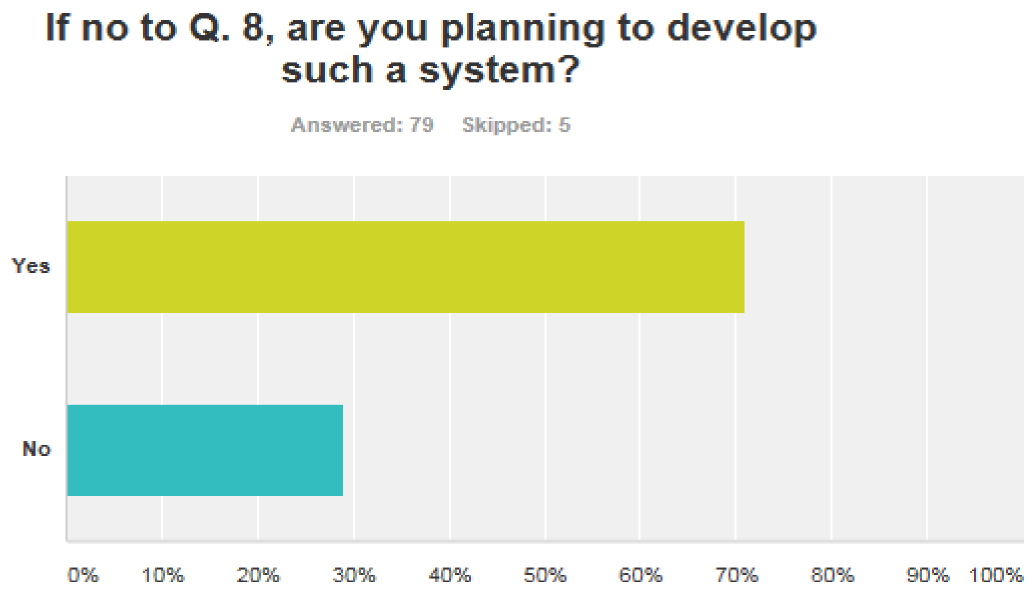
As noted in Q6 above, there are many different approaches to the design of nowcasting systems. Though the integrated approach usually implies a certain level of resources and is usually associated with the larger NMHSs, we should recognise that nowcasting systems are not exclusively the domain of the richest organisations in the most developed nations. Using a service-oriented approach can help NMHSs develop effective integrated systems with limited resources if they are tailored carefully to user needs, and these ideas will be explored further in Part III of this report.

Amongst the survey responses, we also not the prevalence of 'off the shelf' nowcasting systems which may be available via consortia or through partnership with other NMHSs. These include systems such as the European INCA system, or those nowcasting tools available through Meteo France's Synergie system. There is great benefit to using cost-effective, well-established and well-supported systems if they are sufficient to meet user needs. The wider benefits of partnership and collaboration, whether internal to a nation, with neighbouring NMHSs or with international consortia, should also be emphasised, and are discussed further in Part III of this document.

A selection of nowcasting systems, demonstrating the wide range of approaches across NMHSs, is given in Annex 1.

### *Q10. Are you planning to develop a Nowcasting System?*

Of those 54% who answered 'no' to Q8, 71% plan to develop one. Thus 35% of all responders are planning to develop a nowcasting system. It should be recognised that introduction of such systems can require substantial financial resources which are difficult in many cases. But given the obvious demand, this highlights the need for the cost-effective, carefully-planned and tailored approach to development suggested in Q9.



### *Q11. Details of Nowcasting Systems*

Again, the wealth of different systems described in the responses to this question demonstrates that there is no single, perfect nowcasting solution, and that NMHSs should consider and develop the most suitable and feasible system for them.

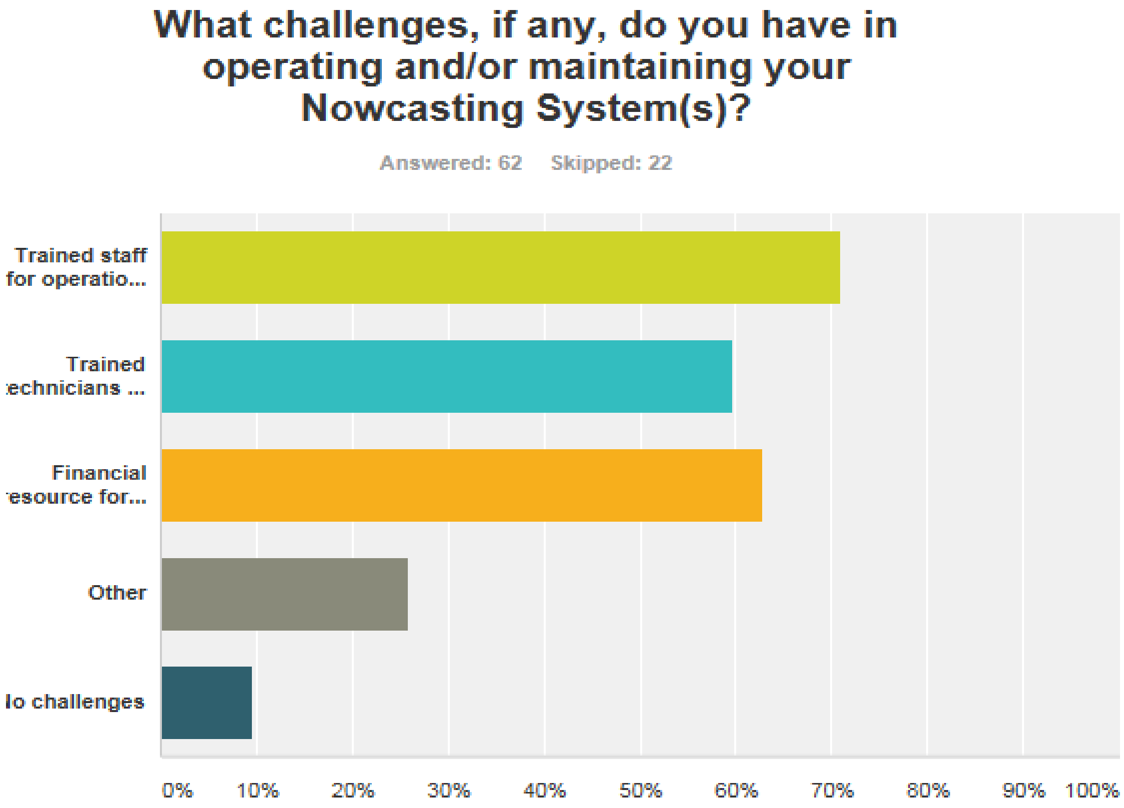
Perhaps the most important theme arising from these responses is the wide range of answers to the question ‘how can we improve the systems?’. Responses here included details of technical upgrades, both in observations and modelling as well as the integration process, but also improved user and customer understanding of the systems and their outputs. So again, the need for an end-to-end rather than purely technology-led approach is highlighted.

### *Q12. Challenges*

Though the range of options presented to responders to this question was limited, there was a very strong signal in the survey results that the majority of NMHSs see the difficulty of obtaining trained staff for operation and maintenance of nowcasting systems as a major problem. Alongside this, there is a general concern of the lack of financial resources for developing and maintaining the systems, which is presumably a factor in some of the barriers to operational status discussed in Q8.

The training issue is very important. One possible factor, which can be common to all NMHSs, is that the requirements of the operational users (usually forecasters) may not be sufficiently well shared and understood within an NMHS. Conversely, forecasters may not fully understand the capabilities which have been developed for them to use. Mutual understanding - between operational staff, technical and research teams, financial staff and managers – is particularly critical when adopting an integrated nowcasting approach.

Another cause of the training problem that may be more common in less well-resourced NMHSs, particularly in developing countries who receive support from other NMHSs, is that systems may have been installed without full consideration of the need to ensure staff can operate and maintain them on a long-term basis. It is possible that the initial support and expertise offered externally at the time of installation may no longer be available, and the local NMHS is left with a system which lacks the resources or levels of training to maintain.



***Q13. Other challenges.***

Amongst other challenges described in the survey responses, many focussed on the difficulty of obtaining and processing appropriate observations as an input to the system - e.g. radar calibration through gauge-data or similar.

On a less technical note, two responses were particularly interesting:

*“The dissemination of these forecasts to the users is a challenge considering the short lead time and perishable nature of the generated information into the public domain to support decision making by users which can be achieved by automatic dissemination of warnings for disastrous weather events like severe thunderstorms, hail, squalls etc. to all mobile users of that particular area, for which warning is issued, through SMS alerts”*

*“The increasing use of automated nowcast data e.g. on web and phone apps can still conflict with the 'human generated' forecast, though this problem is less than when using the data without a nowcast correction. Another problem is that the nowcast suite is so complex and involves so many different subsystems and techniques that it becomes difficult for scientists/developers to maintain expertise in all aspects without having 'single points of failure'”*

These both allude to the common problem of achieving a ‘single authoritative voice’ with consistent information to users on the timescales they need, and in this respect the use of new technology such as SMS, web and phone apps can be both an opportunity and a challenge. The complexity of the nowcasts systems is another important issue; as complexity increases, the systems become more and more of a ‘black box’, even to forecasters, and the level of resource required to train users grows further still.

### *Q14. How are users’ needs captured?*

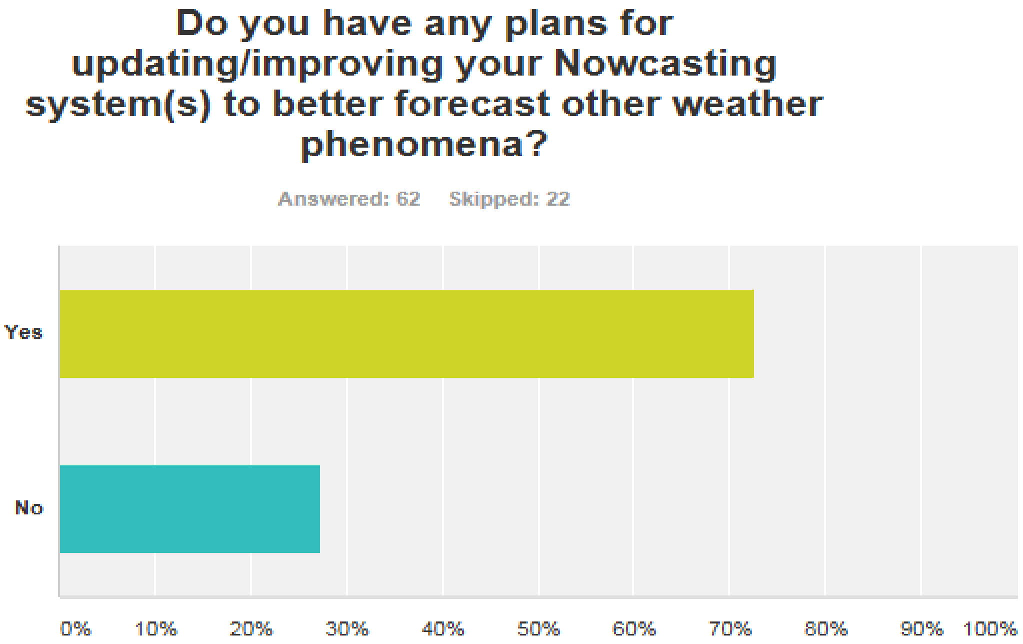
Discussion above around earlier questions already emphasises the importance of capturing the requirements of users: expert decision-makers such as forecasters and hydrologists, as well as end-users such as the public, government bodies, emergency services, aviation and businesses. This is an essential early stage of the Service Delivery approach described in more detail in Part III of this report.

The responses reveal a wide range of examples of engagement with users, including through workshops, post-event reviews and consultation with user-groups. This is very encouraging, and suggests that many NMHSs already have, or are adopting, a service-oriented approach.

However, many of the responses perhaps lack the level of detail required to be considered a strong user requirement. A generic argument is that ‘improving the system improves the accuracy of forecasts and thus benefits the end user’. This, in a broad sense, is true. But given limited resources, there is often a need to prioritise and tailor development to a much more thorough understanding of the users’ need, including the impacts of the hazards, the confidence levels and lead-times required for notification and action.

### *Q15, 16 Planned improvements*

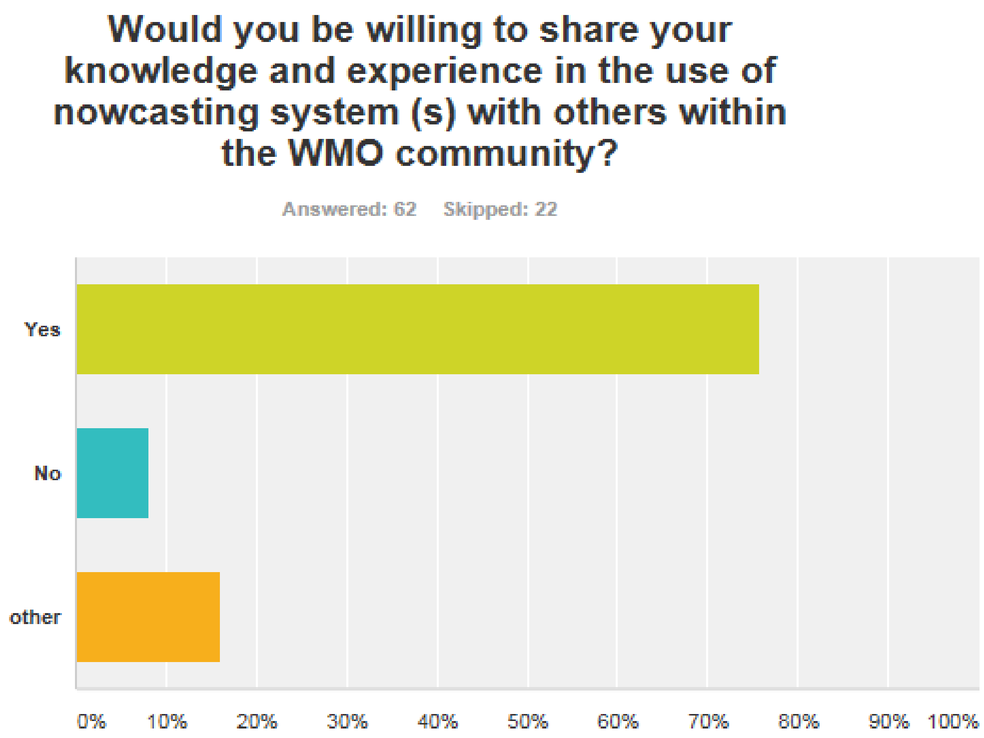
Most (73%) or responders planned to expand their nowcasting capabilities, indicating that there is recognition of the need for improvement. These might include incorporation of additional observational elements, or improved accuracy in measurement and data assimilation. But tt should be noted that improvements may take many forms, and that the end-to-end nowcasting process – from observations to integration to monitoring to issuing of timely and relevant updated forecasts to end users – need to be considered to assess where improvement may be most beneficial and thus where resources for development should be focussed.



### *Q17. Knowledge and experience sharing.*

The vast majority (76%) of responding NMHSs are willing to share their knowledge and experiences in developing nowcasts and nowcasting systems. **At least two responding NMHSs (from the Maldives and Chad) used the survey to explicitly request help in developing their capabilities.**

It is appropriate that WMO can utilise this will to collaborate to assist NMHSs with no (or less developed) nowcasting services. Rapid support may be encouraged of those which lack capability to *nowcast* high-impact weather, particularly between adjacent nations with differing capabilities and through WMO initiatives such as the Severe Weather Forecasting Demonstration Projects (SWFDP).



## PART III – GUIDELINES FOR DEVELOPING NOWCASTING CAPABILITIES USING THE WMO SERVICE DELIVERY STRATEGY

### Summary of the Service Delivery Strategy

The WMO Strategy for Service Delivery and its Implementation Plan (SD and SDIP respectively) were published in 2014. The SD's goal is to help NMHSs improve service delivery standards for products and services to users and customers. The SDIP then provides a flexible methodology for evaluation and subsequent improvement of NMHSs' service delivery processes. Service delivery as a concept sits alongside ideas such as the importance of Quality Management Systems (QMS), and closely related to strategies for development of impact-based and multi-hazard forecasting and warning systems.

Central to the SD/SDIP is a cycle of four stages of service development:

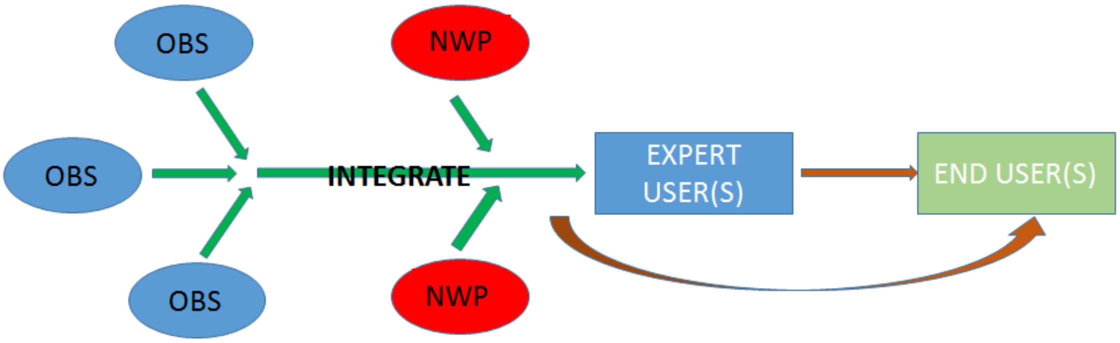
In addition, there are six elements necessary for moving towards a service-oriented approach:

1. Evaluating user needs and decisions
2. Linking service development and delivery to user needs
3. Evaluating and monitoring services performance and outcomes
4. Sustaining improved service delivery
5. Developing skills to sustain service delivery
6. Sharing knowledge and best practice

### Application to Nowcasting - Building Blocks Approach

Analysis of the survey results in Part II has already emphasised that nowcasting should be considered as an end-to-end process, a chain from science to service, and that the principles of Service Delivery apply as much to this chain as to any other product or service.

Firstly, observations are gathered and combined, then sometimes integrated with NWP data. Then in many cases, particularly in the context of Public Weather Services and warnings of high-impact weather, this integrated information is passed to an expert user, usually an operational meteorologist for quality control and decision making. Sometimes there may be additional expert users, with, for example, hydrologists working with the assessment provided by the meteorologist for further decision-making. Then commonly the decision is made to update the forecast for, or issue a warning to, the end-user, the final beneficiary of the service – examples include the public, government, civil protection, aviation or businesses. Some Nowcasting Systems also seek to automate some, or all of, the expert monitoring and decision-making, and in these cases, the update or warning is sent directly to end users. This conceptual model of the process is shown in the diagram below.



The development of the system must also be considered carefully to ensure that, given the available resources, each stage of the process is optimised to meet the needs of the later stages, including all of the users. Systems should also be planned with the longer term in mind, with measures to ensure sustainability of the system, i.e. it must *continue* to meet users' needs.

The development of a nowcasting service may be considered in terms of building blocks in which the service evolves in controlled fashion accompanied by a parallel and sustainable development of the infrastructure required to support it.

### ***Building Blocks Approach – An Example***

The most common application of nowcasting is for short-term prediction of heavy rain and its impacts, primarily flooding. Here we consider how a nowcasting service may be developed in a logical fashion, from the minimum viable capabilities based on qualitative assessment of precipitation, to the advanced systems for quantitative precipitation estimation and forecasting used in integrated nowcasting systems.

Consider first an NMHS which initially has no observing or modelling capabilities of its own. How should it develop nowcasting solutions?

#### Stage 1 – Using externally sourced satellite products

A range of satellite imagery is available from many sources and accessible via the internet. Accompanied by appropriate levels of training, loops of imagery alone can prove an effective means of rainfall nowcasting, at least in qualitative terms. This is particularly true given access the satellite derived products also commonly available, which are often designed for nowcasting.

For example, Meteosat imagery is widely available, and there are software packages and derived products for nowcasting which have been developed under the Eumetsat Satellite Application Facilities (SAFs). A set of nowcasting tools for use with satellite imagery are available via the NWC SAF, coordinated by AEMET in Spain, and these tools can be applied to other sources of satellite data besides Meteosat.

#### Stage 2 – Using externally sourced Global NWP

In addition to satellite data, there are also many sources of NWP with global coverage which can be accessed online, often freely, and applied to any nation or region. In combination with satellite imagery, access to appropriate model data can form a crude yet effective nowcasting capability. Examples of models often accessible online are the ECMWF models and their derived products, and GFS model data.

#### Stage 3 – Additional sources of external data

To further improve on the capabilities described above, there may also be additional types of data which may be available cheaply or without cost online. A developing NMHS might consider using radar data or surface observations from neighbouring nations, particularly where the nation lies 'upstream' is thus often affected first by significant rainfall. It may also be the case that radar coverage from adjacent nations lies across parts of the home NMHS's territory.

Stages 1 to 3 consider only sources of data sourced externally to an NMS. Building from here, we consider which elements of an internal capability might logically be developed next, given appropriate funding.

### Stage 4 – Developing an Internal Surface Observations Network

The next stage should concern the development of a ‘homegrown’ surface observations network (SYNOPS, rain gauges, etc.) At this stage *quality* should be considered above *quantity*, and the number, location and type of stations should be selected carefully to allow real-time communication, collation and calibration of accurate observations, along with a support infrastructure to service and maintain the instruments. Thus investment is best focussed on making a small network work well, rather than a larger, less accurate and less reliable capability. It is also easier to enhance the capability of existing sites, e.g. by enabling hourly rainfall reports, than to add additional sites.

### Stage 5 – Expanding the Surface Network

Once quality has been achieved from a small-scale network, only then should additional investment be used to grow the network by introducing new sites. And this growth should be undertaken in a manner which preserves the quality and resilience of the original network.

### Stage 6 – Developing Radar Capability

Note that a ‘homegrown’ radar capability which is to be used for quantitative rainfall forecasting (and therefore flood forecasting) is reliant on calibration from surface observations. This development of the radar capability itself should follow that of a quality surface network. And as with the surface network, there should be a strong focus on also developing the infrastructure to support quality, real-time radar capabilities, including technical support and the communications systems required to transmit the observations.

### Stage 7 - Expanding and Calibrating a Radar Network

Once a single, or small number of radar sites can be maintained and their data collected and combined with the quality and speed necessary for nowcasting, then consideration may be given to increasing coverage, ideally to the extent where the entire areas to be forecast for are covered, along with areas ‘upstream’ from which rainfall can propagate on nowcast timescales. Having scaled-up this capability, appropriate coverage to produce quality composite radar will naturally develop.

### Stage 8 – Local NWP, Other Data and Towards an Integrated Nowcasting System

A well-calibrated radar network, supplanted with satellite imagery and surface observations, will provide a very effective nowcasting capability for rainfall, and will be the ultimate goal for many NMHSs. However, some will have the resources, aspiration and requirement to progress towards incorporating other sources of data and then to a fully integrated nowcasting system. Locally run, high-resolution model data, both in deterministic and EPS forms, can greatly enhance a nowcast capability, especially in the latter half (3-6 hrs) of the nowcast timescale. Other data may be used, and possibly assimilated into the system, such those from radiosondes, lightning detection systems.

wind profilers, GPS and crowdsourced observations. As with all earlier stages, the appropriate investment should be made in training, infrastructure and the quality of data and communications systems.

When planning to develop and maintain a nowcasting capability, a useful approach is to consider the six elements in turn:

### ***1. Evaluating user needs and decisions***

Analysis of the survey results above suggests that nowcasting capabilities are, in many cases, developed via expediency (what is available?) and capability (what can we do?). But the SD/IP strongly recommends that user needs are just as, and often more, important, and that their understanding is prioritised at the beginning of the development process. It states that

*"Users should be able to see that a service has been developed and delivered with their particular needs in mind, rather than being provide with a generic product or one created for another purpose."*

When considering the needs for nowcasting of a particular phenomenon, NMHSs might consider the following questions:

> *Who is affected?*
>
> *What are the impacts? (e.g. urban flooding, aviation delays, incidence of respiratory illness)*
>
> *Are particular locations at higher risk (through increased exposure or vulnerability), or is the risk uniform across your area?*
>
> *What actions can end users take to mitigate the risk?*
>
> *Are end users able to act? How often, and what are the costs and impacts of this action?*
>
> *How much notice is required for end users to act?*

### ***2. Linking service development and delivery to user needs***

Questions similar to those in the previous section will then inform the meteorological and then the technical requirements which will influence development and delivery. At this stage we might determine the following:

> *Which weather elements are to be predicted, and for where?*
>
> *From amongst these elements, are there any thresholds or ranges for the parameters which are critical to the users?*
>
> *How confident do the predictions need to be to trigger user actions? How accurate? Should we use a probabilistic approach?*
>
> *Can we issue relevant nowcasts quickly enough for the users?*

These questions then in turn help define the composition and performance standards of the nowcast system:

*What instruments do we need?*

*How frequent/accurate are the observations?*

*Do we need hourly (or less) rain gauge data?*

*Do we need a Doppler or dual polarisation radar capability?*

*Do we need to partner with other organisations/departments to create this system (such as those which might have more expertise in hydrology or air quality)?*

*Should we use a 'traditional' manual nowcasting approach, or is an integrated nowcasting system needed?*

*What are the costs and benefits of each approach?*

*How will the various elements of the nowcasting chain interact effectively?*

This approach should ideally result in a set of options for nowcasting development which are each tailored to the particular problem and the users, and solutions can be chosen which are most appropriate given the available resources. It may be that cost-effective 'off the shelf' solutions offer much more than is required to address an NMHS's particular risks. And there may be economies of scale from developing a nowcasting capacity which addresses several risks, or areas of risk. Nevertheless, care should be taken to select solutions which fit the situation well, else it can easily arise that the eventual solution does not match the problem to be addressed, or that the solution is excessively complex and resource-intensive to operate and maintain.

## 3. Evaluating and Monitoring Service Performance and Outcomes

Once a nowcasting capability has been developed, its performance should be monitored as with any other service. Naturally there will be a need to evaluate quality of meteorological data – the observations and how any integrated outputs compare with reality. This is the domain of standard forecast verification methods. But to use a Service Delivery approach means that a number of user-oriented measures should also be employed to ensure service quality is maintained and that users needs are met.

It may be that formal agreements such as Service Level Agreements (SLAs) exist between the NMHSs and the end users (the aviation authority, for example). Or it may be that the levels of performance for severe weather warnings agreed with the government and/or civil protection play such a role in defining the standards required by the end user. In addition, it can be useful to define *internal* metrics based on quality of service upstream of the expert decision makers, or those based on the quality and timeliness of their subsequent actions. All of these elements may combine into a single key message, that the nowcasting service provided does what it is supposed to do, servicing the customers to the agreed standard in a resilient and sustainable manner within the available resources.

Within the context of the nowcasting services sampled in the survey described in Part II, it is clear that there have been barriers to many systems achieving 'operational' status. This term inevitably has different meanings between NMHSs, but the common theme is that survey responders were unable to claim that their services met the quality standards required to be considered ‘operational’ for key elements such as system resilience. This suggests either a lack of forward planning to translate experimental systems into operational services, a realisation that the developed system is not fit for purpose, or more likely the lack of resources to do so. Thinking of nowcasting as a service from the outset should help NMHSs to define and achieve operational status – based on performance against the metrics described above.

## 4. ***Sustaining Improved Service Delivery***

Having designed and implemented a system which meets the needs of users, it is necessary that this level of service is maintained, and that the service can adapt to anticipate and respond to changing customer requirements. Other factors such as changing exposure and vulnerability to hydrometeorological hazards (such as through climate change and urbanisation) should also be considered.

So mechanisms should be implemented to make sure that levels of service are regularly checked and demonstrated, and that a dialogue with users is maintained to gauge changing needs. This means both routine contact with, and feedback from, the customers (government, aviation etc) and with the internal users of the systems (forecasters, hydrologists).

## 5. ***Developing Skills Needed to Sustain Service Delivery***

One of the strongest messages arising from the 2014 nowcasting survey was that there was very often a lack of resource (trained staff or finance) to ensure that systems could be a) operated and b) maintained. We have already noted that as systems become more complex, more training is required to use and run them, and that organisations can become less resilient and more vulnerable if there are single points of expertise (and thus failure) in nowcasting. Some responses indicated a complete lack of trained staff to undertake either nowcasting development and operations.

It should be emphasised that nowcasting should be considered as chain of processes, from ‘science to service’ rather than merely as a research activity or purely mechanised system. Many systems require trained staff, the ‘expert users’ to operate them and interpret output to create advice for end users. And even if these internal processes are fully automated, there is still a necessity to maintain adequate levels of expertise to maintain the system.

Indeed, it may be considered that the full range of skills required to support an operational nowcasting service consists of **at least** the following:

- Instrumentation designers and technicians
- NWP and post-processing specialists
- Forecasters and other expert-users (eg hydrologists, disaster managers, civil protection)
- Customer-facing managers
- Budget holders

## 6. ***Sharing Best Practice and Knowledge***

An essential part of the cyclic nature of Service Delivery improvement is the ability to feed back experiences, including successes and lessons learned, back into the subsequent phases of the development process, for both the original service and for others.

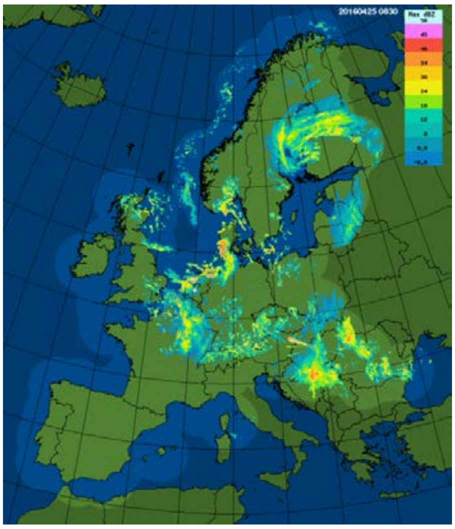
The survey also notes the number of Members who are prepared to share knowledge with other NMHSs (through WMO initiatives such as SWFDP, or through regional activities such as Europe's EUMETNET ASIST project). Conversely, there are Members who would welcome advice from others, and it is proposed that nowcasting support be actively encouraged by WMO Members.

### **Developing Partnerships**

When considered as an end-to-end service, it becomes clear that non-meteorological factors are often the most critical in terms of impacts on users, and that often other expert users and systems may form part of a nowcasting service. In the case of flooding, for example, many NMHSs will have a hydrological remit and capability, but in some nations this responsibility lies elsewhere. Thus it is beneficial, both operationally and financially, and often politically, if nowcasting for flooding can be conducted as a partnership between the meteorological authority and the hydrological authority, and services should be designed to make best use of these links.

On the broader scale, a nation's nowcast capability will very often be co-dependent on those of adjacent nations. This is particularly true in the case of radar data, where it will often be necessary for cross-border cooperation and sharing of data (and perhaps interpretation) for an effective precipitation nowcast capability. For example, Ireland and the UK share radar data for nowcasting purposes, and data from both are combined into a single composite for monitoring and nowcasting purposes, with the UK particularly dependent on Ireland's radars for the nowcasting of rain-bearing systems rapidly moving in from the Atlantic.

Within Europe, collaboration between many European NMSs, under the EUMETNET OPERA project, has developed the tools to operationally combine radar data into a single Europe wide radar composite available through ODYSSEY data hub. An example of an ODYSSEY composite radar reflectivity map is shown below. A similar effort is underway in South East Asian countries, under the auspices of a Regional WIGOS implementation plan.



There should always be opportunities for partnership and collaboration between NMHSs, which can be facilitated by WMO and other organisations either at global or regional level. Links can also be developed between NMHSs with very developed nowcasting capabilities and those looking to develop their capabilities further, and WMO should promote this ‘twinning’ between NMHSs.

## PART IV – RECOMMENDATIONS

Based on survey results and the further analysis presented above, ET-SPII proposes that WMO and its Members adopt the following guidelines:

1. That Members develop nowcasting services and systems according to the principles defined in the WMO Service Delivery Strategy and its Implementation Plan.

2. That in particular, Members should engage with users, understand their requirements and incorporate these needs into the development and evolution of nowcasting services. This might be via user groups, surveys or other forms of feedback.

3. With knowledge of these user needs, Members should be fully aware of the particular problem they need to address with a nowcasting service (such as heavy rain in sensitive areas bringing flooding).

4. That NMHSs plan to meet users’ needs in sustainable fashion, supporting the infrastructure the service requires. Members should consider the elements which comprise a nowcasting capability as part of a broader, end-to-end service, considering the need for the skills and resources needed to build, maintain the service and ensure it remains aligned to user needs.

5. That when planning nowcasting services, consideration be given to the many advantages (and some disadvantages) of sharing capabilities and data with other organisations, including neighbouring NMHSs.

6. Another recommendation is to partner with NMHSs elsewhere who can offer advice, experience and shared capabilities for nowcasting.

7. WMO will circulate this document and its recommendations to Members.
8. WMO will also work to ensure that these guidelines are used as Best Practice by those involved in capacity-building activities in the nowcasting area.
9. WMO will actively promote ‘twinning’ between NMHSs seeking to develop services with those with experience and expertise in nowcasting development.

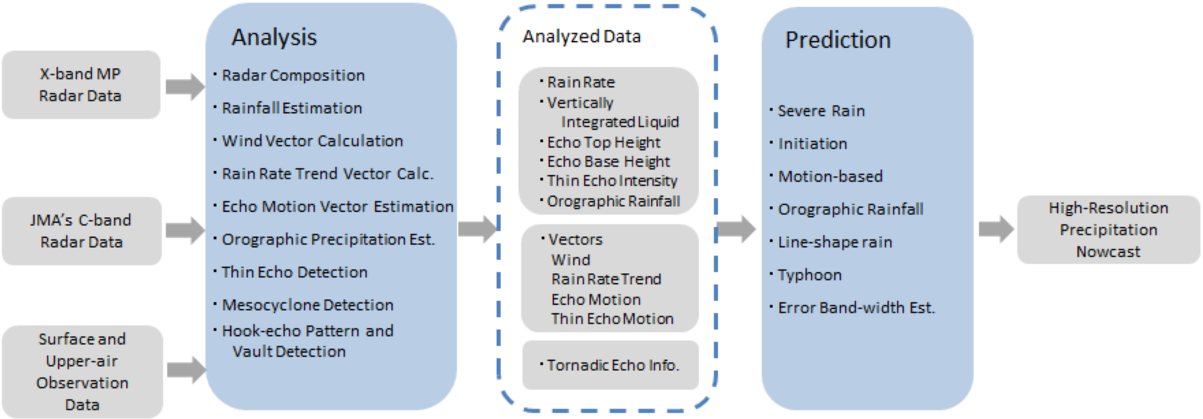
______________

## ANNEX 1– Example of Nowcasting Systems

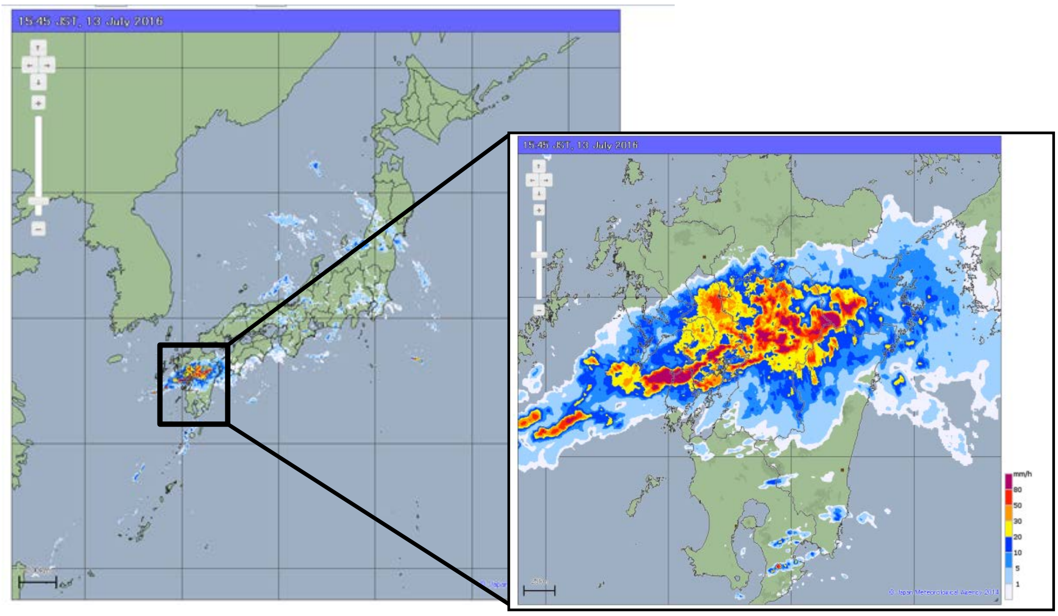
This section outlines a variety of nowcasting systems, sourced from the NMHSs of the members of ET/SPII.

### High-resolution Precipitation Nowcasts (HRPNs) of the Japan Meteorological Agency (JMA)

HRPNs of JMA provide short-range precipitation intensity predictions with a spatial resolution of 250 m. They are derived from weather radar data and other types of meteorological information. JMA observes precipitation distribution all over Japan using 20 Doppler radars. Between April 2012 and March 2014, the previous radars were replaced with units featuring a 250-m radial resolution (offering twice as much detail as before) for improved observation of local downpours. HRPN derivation also involves the use of raingauge data, wind profiler data, radiosonde observation data and other radar observation data (such as those from X-band radars managed by Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT)) in addition to weather radar data. The data are first analyzed to create a three-dimensional structure of the precipitation area, and forecasts of precipitation intensity distribution with a spatial resolution of 250 m covering the period up to 30 minutes ahead are then made. The HRPNs are combined with forecasts of precipitation intensity distribution with a spatial resolution of 1km from 30 minutes to 1 hour ahead and are updated every five minutes. The Algorithms used for HRPNs generation are shown in the diagram below.



The Japanese system is designed to address the particular problem of pluvial flash flooding in highly urbanised areas, and the outputs are optimised to enable users to access and understand the predictions on the short timescales they require to respond effectively.



Technical details of JMA's High Resolution Precipitation Nowcast are available online;

http://www.jma.go.jp/jma/en/Activities/Techniques_of_Precipitation_Analysis_and_Prediction_developed_for_HRPNs.pdf

## Nowcasting in Hong Kong, China

Another example of nowcasting system developed by the Hong Kong Observatory (HKO) is the Short-range Warning of Intense Rainstorms in Localized Systems (SWIRLS), which uses observations from radar, rain gauge, GPS, as well as geostationary satellite (Figure (a)) to generate quantitative precipitation estimate (QPE) and forecast (QPF) in the next 6-9 hours. The system also blends with the products from the Observatory's mesoscale NWP model with horizontal resolution up to 2 km to enhance QPF. Together with other forecast guidance generated from NWP models, SWIRLS is in use by HKO's forecasters to support decision making in the operations of Rainstorm Warning Systems in Hong Kong (Figure (b)). The rainfall products generated by the SWIRLS is also disseminated automatically to support the location-based rainfall nowcast service in Hong Kong delivered through the mobile app MyObservatory (Figure (c)).

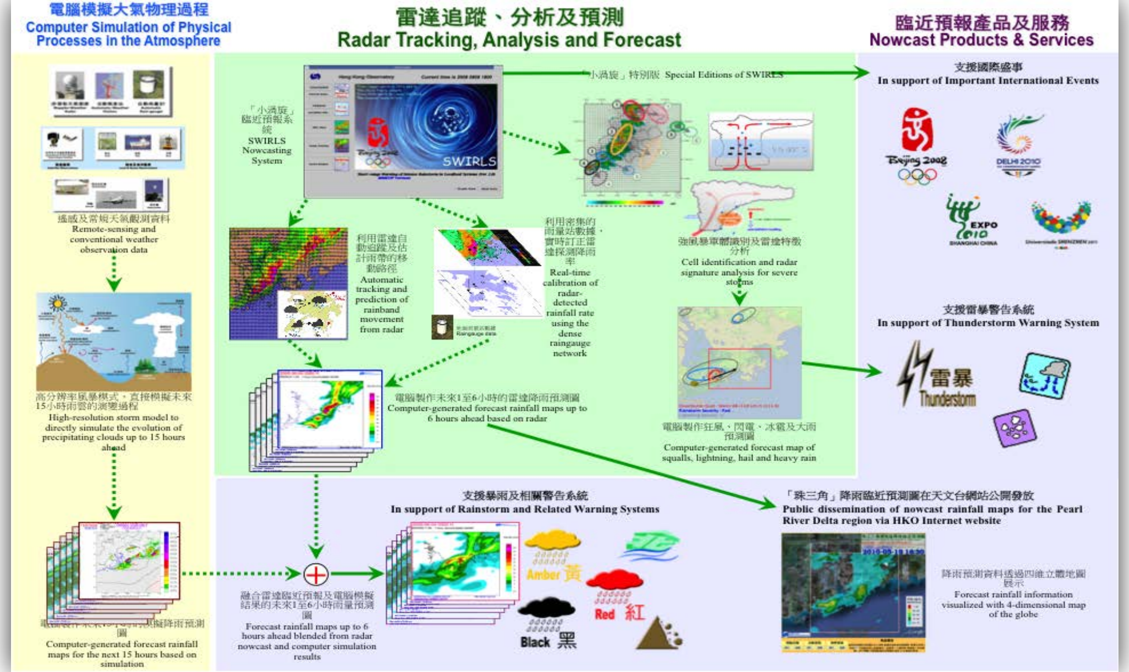
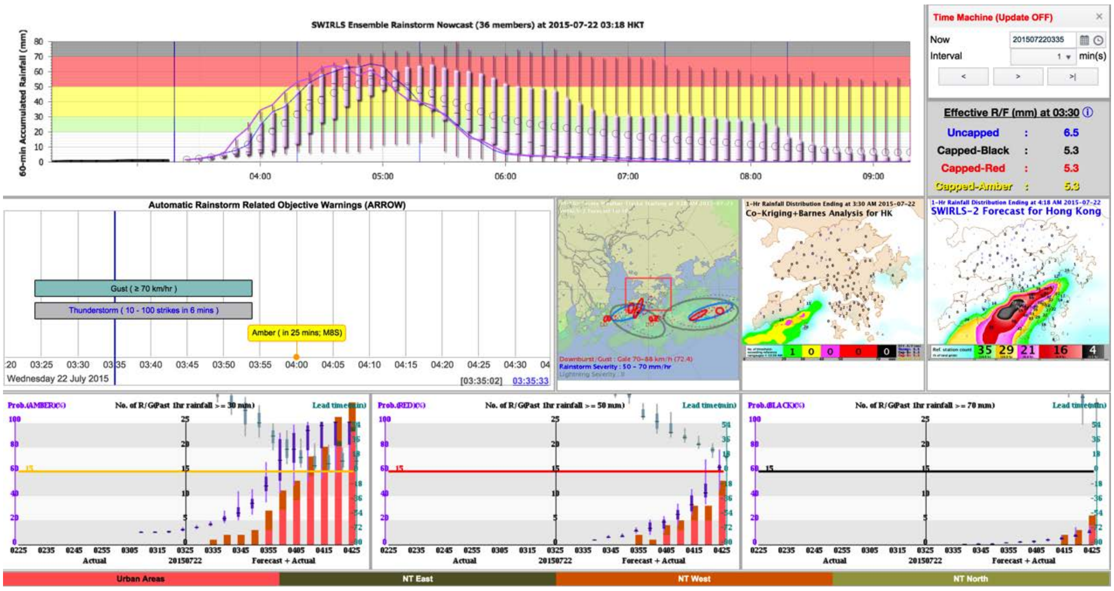


Figure (a) – Schematic Diagram of the SWIRLS



Effective R/F (mm) at 03:30

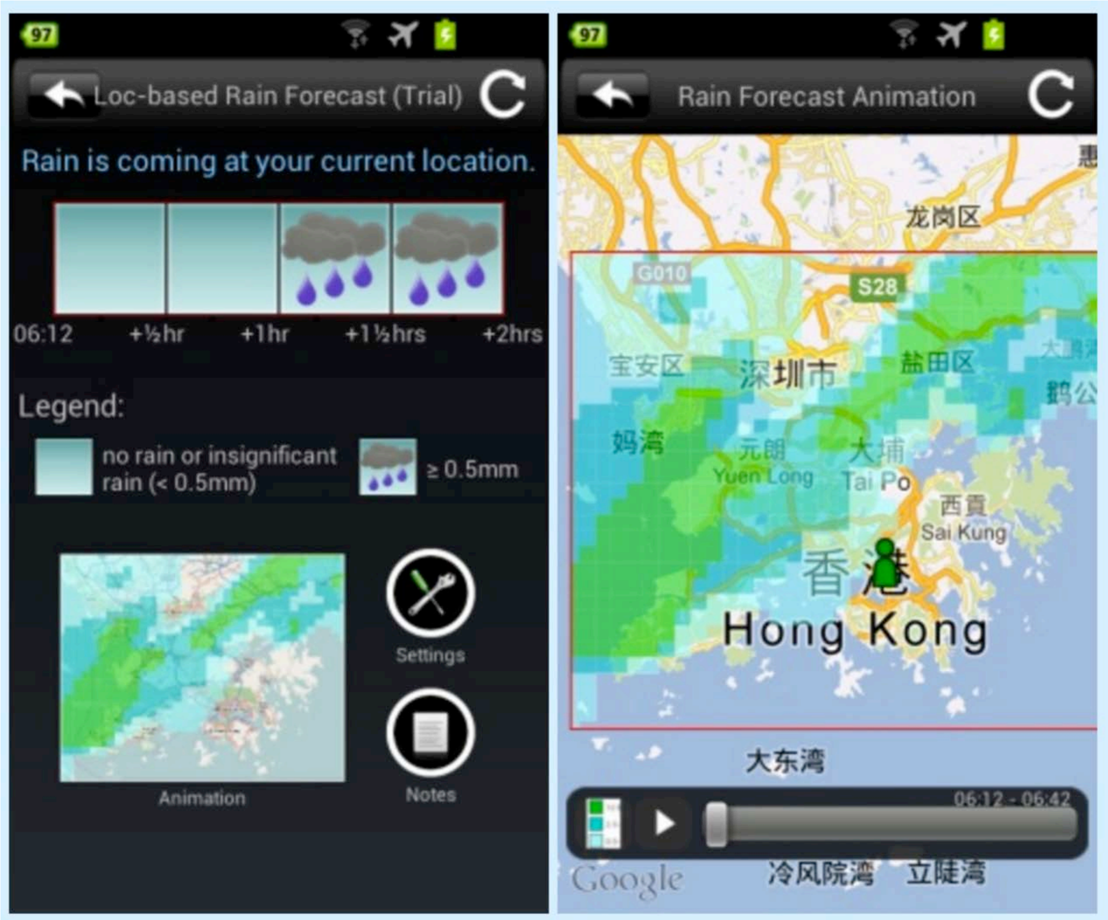
Uncapped : 6.5

Capped-Black : 5.3

Capped-Red : 5.3

Capped-Amber : 5.3

Figure (b) – Integrated Panel to support warnings operations in the Hong Kong Observatory



Rain is coming at your current location.

Figure (c) – Sample Screen of Location-based Rainfall Nowcast Service on the MyObservatory mobile app

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## Nowcasting in Russia

Roshydromet is currently developing two nowcasting systems. The first is the radar-based precipitation nowcasting system. In recent years a programme has been implemented by which several tens of Doppler C-band radars are to be installed across the whole territory of Russia. By now about 20 radars have been installed and operationally used in weather monitoring and forecasting (mainly in the European part of Russia). This gives a good chance to develop radar-based nowcasting. The system is based on the STEPS (Short Term Ensemble Prediction System) technique developed by the UK Met Office and Australian Bureau of Meteorology. It is currently being adapted to the Russian Doppler C-band radar network and it is planned that the system will provide the forecasts with the lead time up to 2.5 hours both for the separate radars and for the composite radar field.

The second nowcasting system represents a mix of the observational data (including basic data of meteorological parameters from weather stations) and NWP model outputs. The principle is that both sources of data are jointly used and different weights are assigned to them: as the lead time increases, the greater weight is assigned to the NWP output data and vice versa.

## Nowcasting in the USA

The NWS AutoNowCaster (ANC) was developed as a tool to assist forecasters with thunderstorm nowcasting. ANC ingests WSR-88D radar, satellite, sounding, and surface data. The ANC includes algorithms for identifying and tracking thunderstorm movement, identifying boundaries, and wind retrieval from radar. The system produces two primary products: a Convective Likelihood Field and the Final Thunderstorm Nowcast. The system also generates verification for these products which is available both visually and statistically.

The ANC Convective Likelihood Fields have a dynamic range from -1 to 1, where increasing positive values indicate regions of increasing likelihood of storm initiation and/or sustainment, and vice-versa. Values of the convective likelihood field >= 0.7 are considered indicative of convective initiation in the next 60 minutes.

ANC's Final Thunderstorm Nowcast depicts the 60-minute extrapolation of storms, including growth and decay, where a storm is defined to exist anywhere the radar reflectivity >= 35 dBZ, and areas where new storms are likely to develop, with three levels of increasingly likely initiation represented by 25, 30, and 32 dBZ, respectively. ANC's Final Thunderstorm Nowcast provides forecasters valuable information about the evolution of both thunderstorms and the convective environment in the next 60 minutes.

The ANC is interactive nowcast tool that allows forecasters to overlay the location of surface boundaries across the forecast area. Forecasters can monitor the convective initiation field and make adjustments as necessary using a polygon tool. They can also set the convective regime that is most appropriate for a given day and puts the ANC to that regime. Figure 1 is an example of the ANC Convective Initiation Likelihood field for September 17, 2012, with forecaster augmentation.

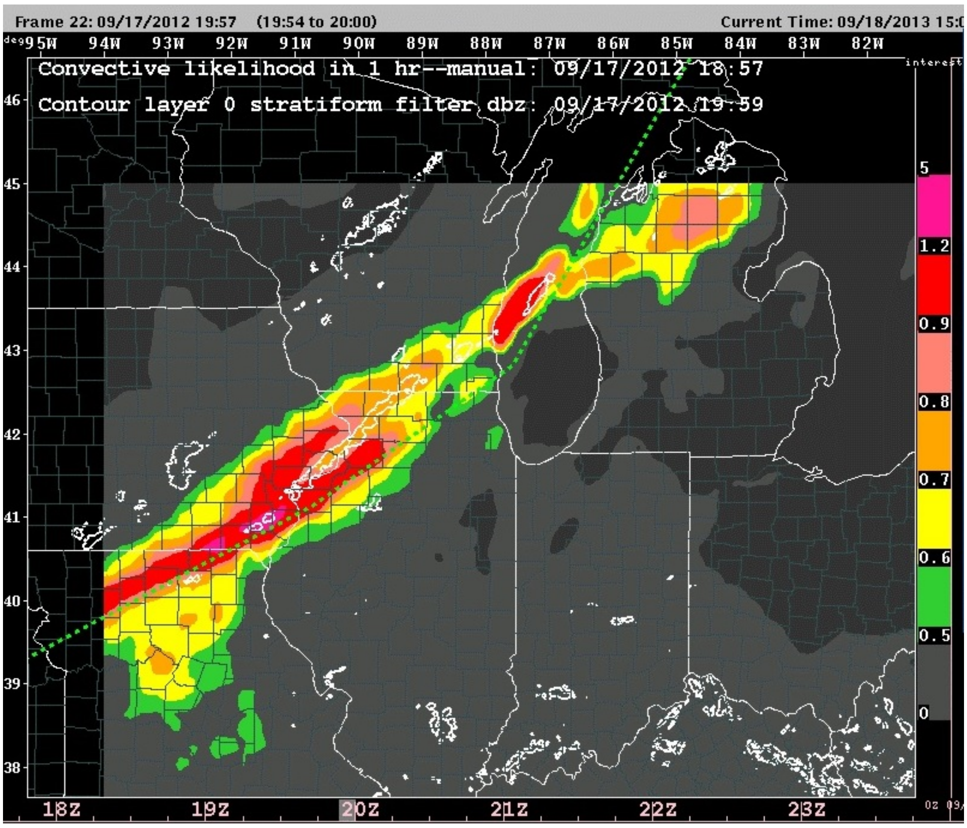


Figure 1. ANC Convective Initiation Likelihood with radar observation at valid time. Colour indicates the likelihood of initiation, with increasing positive values used to indicate regions of increasing likelihood of storm initiation. White contours show radar reflectivities >= 35 dBZ; the dotted green line is the boundary entered by a forecaster; it represents the cold front that prevailed during this event.

## NowCastMIX at the German Weather Service – optimized automatic warnings from continuously monitored nowcasting systems based on fuzzy-logic evaluations of thunderstorm attributes

The German Weather Service’s AutoWARN system integrates various meteorological data and products in a warning decision support process, generating real-time warning proposals for assessment and possible modification by duty forecasters before dissemination to customers. On nowcasting timescales, several systems are continuously monitored to capture rapidly developing mesoscale events, including radar-based cell tracking methods, 3D radar volume scans, lightning strike locations, calibrated precipitation extrapolations and live synoptic reports. Numerical forecast model data is also monitored to provide assessments of the near-storm environment. To help the forecasters manage this large volume of rapidly changing data, NowCastMIX processes it into an integrated grid-based analysis, providing an optimal warning solution with a 5-minute update cycle. The integration of NowCastMIX into the AutoWARN process at DWD is shown in Fig. 1.

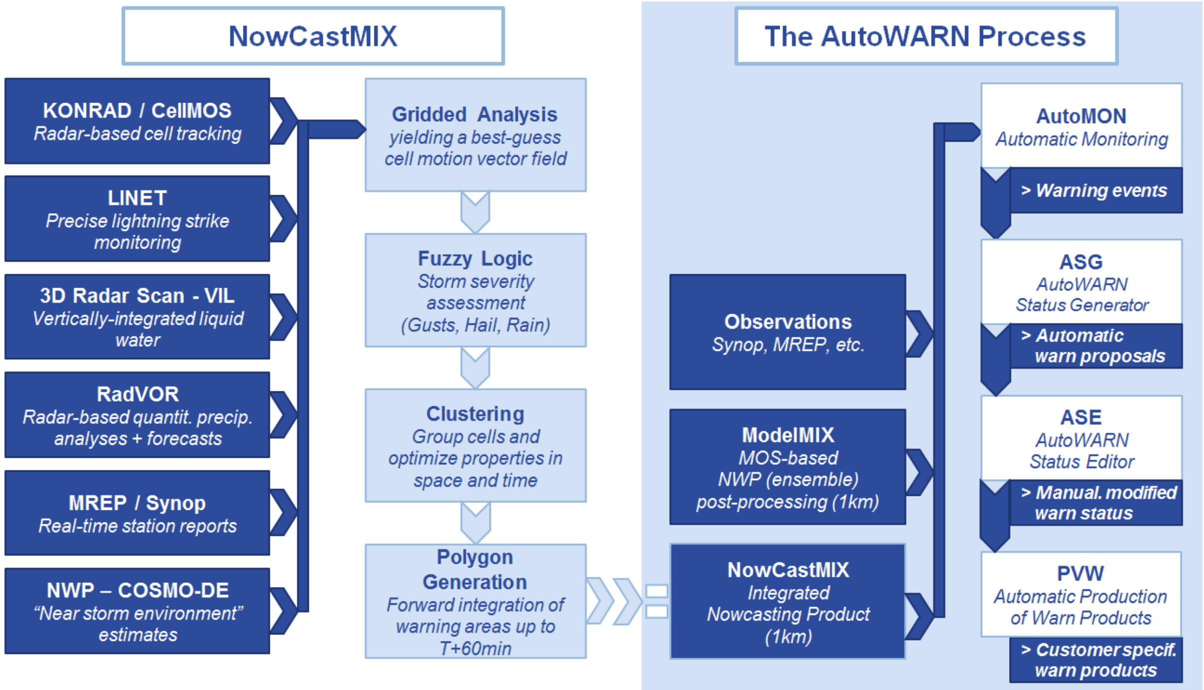


**Fig.1: The processing chain in NowCastMIX within AutoWARN**

Estimates for the storm cell motion vectors are computed by combined explicit cell tracking information with radar-based pattern-matching vectors. A verification of NowCastMIX forecasts against its own analyses indicates how the trajectories used for determining the areas requiring imminent storm warnings can be optimized from weighted combinations of the different available tracking methods. Hence, the impacts of newly developing cells, which tend to form somewhat rightwards of the existing raw trajectories before optimization, can be then captured more effectively.

Input datasets are combined using a hierarchy of fuzzy logic sets for estimating the likelihood of the various thunderstorm attributes, such as severe gusts, large hail and torrential rain, shown in Fig. 2.

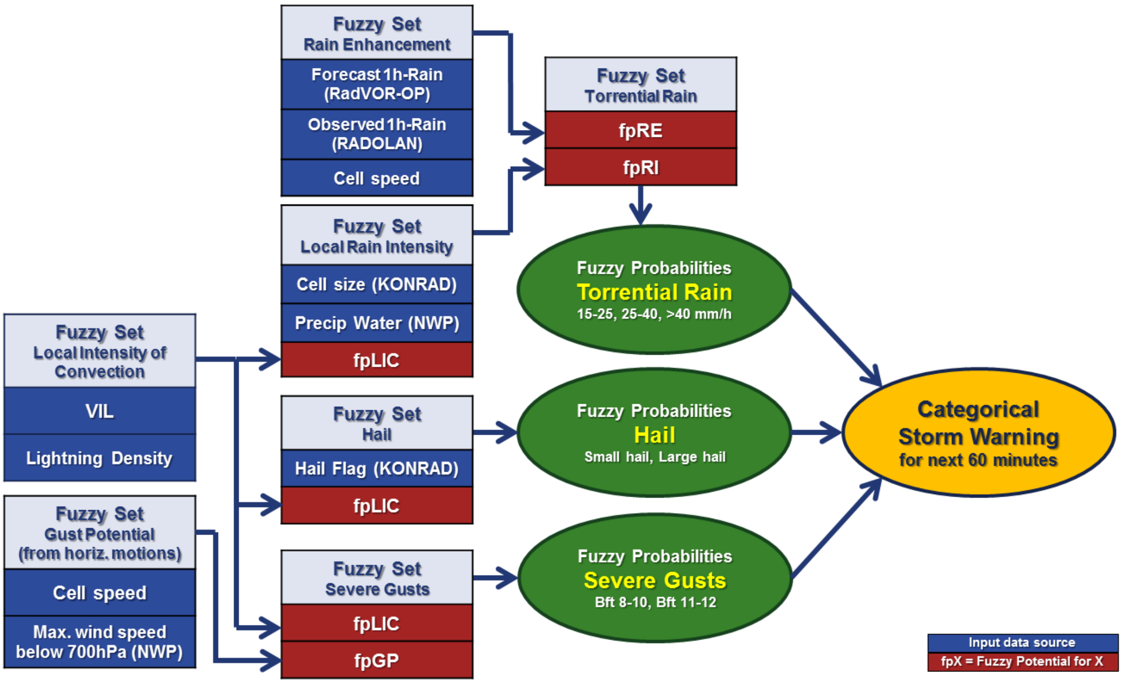
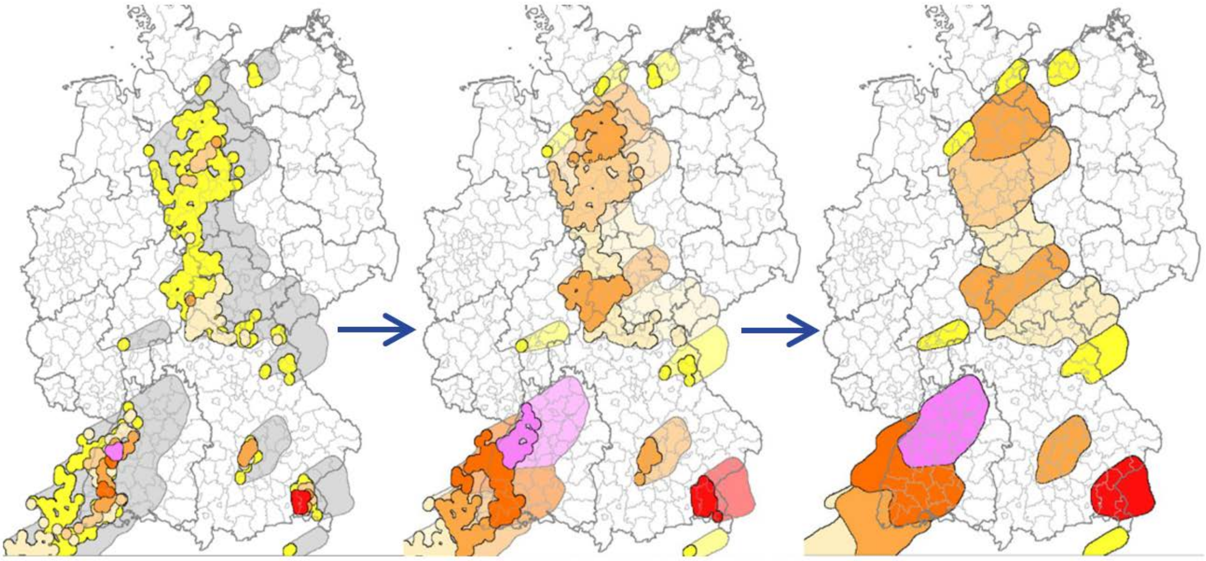


**Fig.2: The fuzzy-logic hierarchy in NowCastMIX for assessing thunderstorm severity**

An adaptive ensemble clustering optimisation is then deployed to reduce the spatial complexity of the resulting warning fields and smooth out noisy temporal variations to a manageable level for the duty forecasters to deal with. The progression from thunderstorm analysis with motion vector assessment through to clustered warning polygons is illustrated schematically in Fig. 3. NowCastMIX thus delivers an on-going real-time synthesis of the various input data to provide consolidated sets of most-probable short-term warning forecasts for the whole of Germany. The system has run over six summer convective seasons, yielding a comprehensive, high resolution dataset of thunderstorm analyses and corresponding warnings. This provides a valuable research resource for developing methods to improve quality.



**Analysis* + Warning areas**
* 20 minute time window

**Clusters + Warning polygons**

**Warning situation for the next hour**

**Fig.3: From thunderstorm analysis and motion vector assessment to clustered warning polygons (schematic)**

NowCastMIX is also being developed further to generate warning suggestions for AutoWARN in winter nowcasting situations, covering snowfall and freezing rain events. For these warnings, radar information is combined with NWP data and synoptic reports for assessing surface conditions and vertical temperature profiles to highlight regions where ice or snow is a risk presently or in the immediate future. For snowfall warnings these also include statements about the altitude above which snowfall is likely, since these may only be relevant in mountainous regions in some cases.

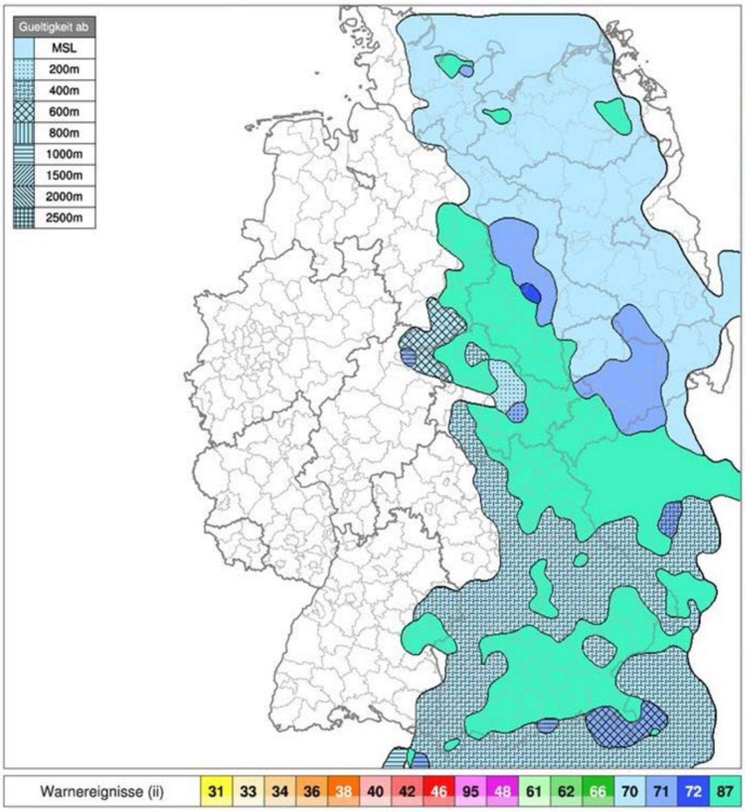


**Fig. 4: Winter nowcasting situation with freezing rain (turquoise) and snowfall warnings of different intensities (blue colours) and / or snow altitudes (shadings)**

## ANNEX 2– The Nowcasting Questionnaire

## Introduction/Background

At its 14th Session, the WMO Commission for Basic Systems (CBS-XIV, Dubrovnik, Croatia, 2009), requested the WMO Public Weather Services Programme to assist Members to improve their national PWS programmes by providing guidance on the application of new technology and scientific research in data acquisition and use, especially for nowcasting and multi-hazard warnings.

The development of early warning systems is seen as part of the operational responsibility of NMHSs. The primary objective of a warning system is to empower individuals and communities to respond timely and appropriately to the hazards in order to reduce the risk of death, injury, property loss and damage. The prerequisite to effective warnings and response is timely, accurate forecasts and “nowcasts”. These forecasts generally are based on four components: Observational Data and Monitoring Systems; Numerical Weather Prediction; Conceptual Models; and, Situational Awareness.

## The Goal of the Survey

As part of the mandate of the PWS Programme, the CBS Open Programme Area Group (OPAG) on PWS Expert Team on Services and Products Innovation and Improvement (ET-SPII) was tasked to survey Members on existing Nowcasting Systems. The results of this survey, are intended to provide information on the variety, strengths and weaknesses of nowcasting systems used in the WMO community. This will allow those Members who are contemplating the development of nowcasting systems to benefit from the experience of others.

Nowcasting Systems: Nowcasting generally refers to weather forecasting for the following 6 hours* via the analysis and extrapolation of the weather systems as observed in radar, satellites, and other observational data, and via the application of short-range numerical weather prediction. The technique is often applied to the near-term forecast of smaller scale weather systems such as thunderstorms, which cause tornadoes, flash floods, lighting strikes, and destructive winds. During the last two decades, the ability has been developed to digitalize and merge the remote sensing observational data with in situ observational data such as rain gauge data, and with NWP forecasts. Despite the usefulness of these techniques, nowcasting is still a science being actively researched. More information on nowcasting research may be found on the WMO WWRP Website at the following weblink: http://www.wmo.int/pages/prog/arep/wwrp/new/nowcasting_research.html

Nowcasting Services: based on the output of nowcast systems, useful products and services may be developed to enable the public and users undertaking weather- sensitive operations, to take mitigation measures to reduce risk of damage and loss caused by approaching high-impact weather. With Internet technology, quantitative nowcast products may now be presented to the users in graphical 3-D format.

The wealth of new forecasting and nowcasting solutions now available makes it increasingly important for WMO Members to have access to scientifically proven and correct, and timely information. This will enable them to make informed decisions to invest their resources wisely when deploying new technologies in servicing user needs.

You are kindly invited to complete this questionnaire in conjunction with your annual Joint WMO Technical Progress Report on the GDPFS including NWP Research Activities for 2013, and return the report with your relies to this questionnaire to WMO.

-------- * From the Manual on GDPFS (WMO No.485) - Nowcasting is defined as description of current weather parameters and zero- to two-hour description of forecasted weather parameters.

Note: For more information on Nowcasting, refer to: "Guidelines on Early Warning Systems and Application of Nowcasting and Warning Operations (PWS-21, WMO/TD No. 1559)" available online at: http://library.wmo.int/pmb_ged/wmo-td_1559_en.pdf

***1. From the drop-down list below, please select the WMO Member on whose behalf you are completing this survey**

***2. Do you provide forecasts for nowcasting (0 to 6 hours) timescales?**

☐ Yes

☐ No

**3. If you produce forecasts in the 0 to 6-hours range, which of the following do you use?**

☐ rain gauge (capable of transmitting hourly observations)

☐ Automatic/manual stations

☐ Upper air stations

☐ Lightning detection network

☐ Numerical Weather Prediction (NWP) models

☐ Satellite imagery

☐ Radar

☐ 'Crowdsourced' reports from the general public (eg via social media)

☐ Others

***4. If you have selected "NWP models" in Q.3 above, specify by indicating the NWP type**

☐ Deterministic

☐ Ensemble

☐ High resolution global model

☐ Local model

☐ Not applicable

***5. If you have selected "radar" in Q.3 above, specify by indicating the radar type**

☐ C-band

☐ S-band

☐ Doppler

☐ Dual polarization

☐ Not applicable

**6. If you selected "others" in Q. 3 above, indicate them below:**

### *7. Are any of the data and information from the entities in Q. 3 integrated into a Nowcasting System (as defined on the "Introduction and Background" section (Page 1, above)?)

○ Yes

○ No

### *8. If “Yes”, is the system fully operational?

○ Yes

○ No

### *9. If yes to Q. 8, What Nowcasting System(s) do you have? Please list:

1. Name of system

i. Brief description

ii. When did you start using it?

iii. Which weather events does this system help you forecast?

2. Another system: Name of system

i. Brief description

ii. When did you start using it?

iii. Which weather events does this system help you forecast?

3. Another system: Name of system

i. Brief description

ii. When did you start using it?

iii. Which weather events does this system help you forecast?

Not applicable

### *10. If no to Q. 8, are you planning to develop such a system?

○ Yes

○ No

## *11. For each of the systems described in Q. 9, please also answer the following questions:

| | |
|---|---|
| 1. Name of system | |
| i. What actual data and forecasting products does the system use and what equipment was installed and/or developed? (Components might include radar data, satellite data, synoptic and upper air/boundary layer observations, GPS water vapour data, lightning detection systems, servers/computers, numerical models, data visualisation applications etc.) | |
| ii. How effective is this system?: Accuracy (Choose from Usually, sometimes, or rarely gives good guidance) | |
| iii. How effective is this system?: Increase in Lead Time compared to forecasting without using the system | |
| iv. Are verification results available? (Verification results showing the improvement due to the use of the system) | |
| v. How does this system benefit end users? | |
| vi. How might the system be improved? | |
| 2. Another system: Name of system | |
| i. What actual data and forecasting products does the system use and what equipment was installed and/or developed? | |
| ii. How effective is this system?: Accuracy (Choose from Usually, sometimes, or rarely gives good guidance) | |
| iii. How effective is this system?: Increase in Lead Time compared to forecasting without using the system | |
| iv. Are verification results available? (Verification results showing the improvement due to the use of the system) | |
| v. How does this system benefit end users? | |
| vi. How might the system be improved? | |
| 3. Another system: Name of system | |
| i. What actual data and forecasting products does the system use and what equipment was installed and/or developed? | |
| ii. How effective is this system?: Accuracy (Choose from Usually, sometimes, or rarely gives good guidance) | |
| iii. How effective is this system?: Increase in Lead Time compared to forecasting without using the system | |
| iv. Are verification results available? (Verification results showing the improvement due to the use of the system) | |
| v. How does this system benefit end users? | |
| vi. How might the system be improved? | |
| Not applicable | |

***12. What challenges, if any, do you have in operating and/or maintaining your Nowcasting System(s)?**

☐ Trained staff for operation and application of outputs

☐ Trained technicians for maintenance

☐ Financial resource for operation, maintenance and upgrade

☐ Other

☐ No challenges

**13. If you selected "Other" in Q. 12, please specify below:**

***14. How are the needs of users and customers reflected during the development of your Nowcasting systems?**

***15. Do you have any plans for updating/improving your Nowcasting system(s) to better forecast other weather phenomena?**

○ Yes

○ No

**16. If your answer to Q.15 above is "yes" please specify**

***17. Would you be willing to share your knowledge and experience in the use of nowcasting system (s) with others within the WMO community?**

○ Yes

○ No

○ other

**18. If your question to Q.17 above is "Other", specify any conditions that apply for sharing information**