# A Decade of Impact-Based NSWWS Warnings at the Met Office

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## Introduction

Since its introduction in the wake of the 1987 storm (Burt and Mansfield 1988), the National Severe Weather Warning Service (the UK's public service weather warnings) has evolved from a threshold-based to impact-based warnings system offering warnings for a variety of hazards up to seven days ahead.

The change from a threshold-based to the current impact-based traffic light warning service took place in early 2011. At that time the service went out to five days ahead, catering for impacts from rain, snow, ice, fog and wind. The refreshed service introduced an impact matrix (Figure 1) to communicate probability and magnitude of impacts to two key market sectors – the general public and civil contingency organizations.

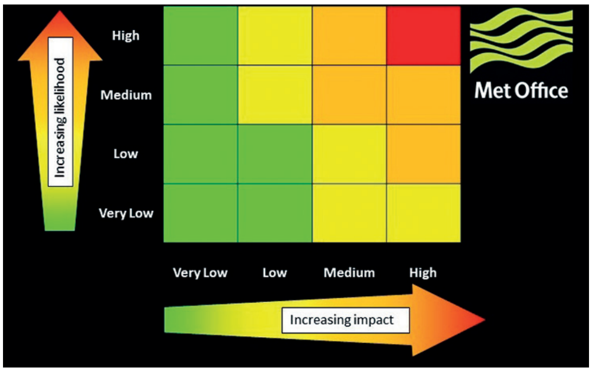


*Figure 1: The NSWWS Impact Matrix.*

In 2018 the service was upgraded to go out to seven days ahead and add lighting and thunderstorms to the list of meteorological elements for which warnings are issued. Adding lighting and thunderstorm warnings allowed differences in the character of impactful dynamic and convective rainfall events to be better highlighted, and associated hazards, such as hail, to be better communicated. Summer 2021 then saw extreme heat warnings incorporated into the service.

This paper outlines the processes by which National Severe Weather Warnings (NSWWS) are made and communicated, showcases some of the impact-based decision aids available to Met Office meteorologists for assessing potential for NSWWS warnings and briefly reviews warnings issued during the last decade.

## Making and Communicating a NSWWS Warning

Warnings are issued based on the potential for impacts from weather rather than a threshold meteorological value. This is because whilst it is recognised that impacts are underpinned by a threshold, these thresholds cannot always be usefully or consistently defined.

The decision-making process for a NSWWS warning is a collaborative one. The Duty Chief and Deputy Chief Operational Meteorologists focus mainly on the meteorology of a severe weather event whilst working closely with both other Met Office teams and some external partners to understand the potential impacts. The Duty Chief Operational Meteorologist has the ultimate responsibility for issue of NSWWS warnings and uses a web-based tool to produce them (Figure 2).

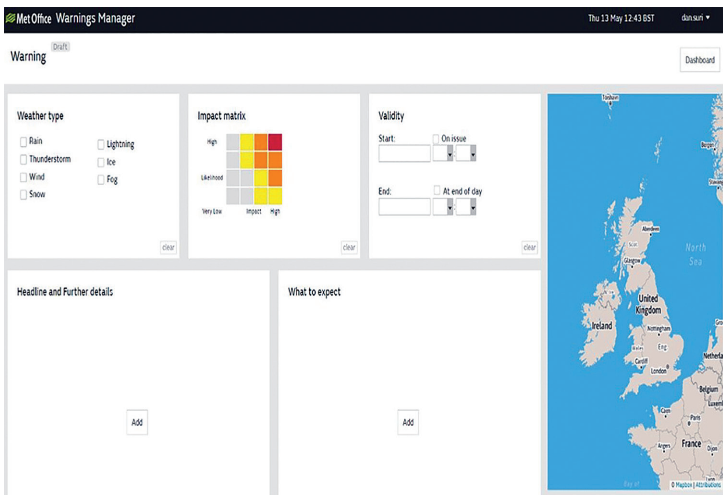


*Figure 2: Screenshot of the web-based tool used to produce a NSWWS warning.*

Input regarding impacts comes primarily from Met Office Civil Contingency Advisors (CCAs). Often trained operational meteorologists, CCAs work closely with local resilience groups and local and central government to understand what sensitivities to weather exist. Subsequently CCAs are essential in the communication of issued warnings to these groups and represent the Met Office should any multi-agency emergency response coordination be required during or as a consequence of severe weather.

Additional information is taken from other forecasting teams, especially from the Met Office's Aberdeen office who provide additional local knowledge for Scotland and Northern Ireland, and from hydrometeorologists liaising with river management authorities around the UK.

Impact statements (Figure 3) for each weather element have been devised in collaboration with the user community to provide a guide as to what impacts could be expected. These are available on the Met Office's website and regular reviews are held with representatives of the user community. These reviews provide a mechanism by which to refine and adjust these impact statements to take into account changes in sensitivity to weather impacts, for example from population expansion or infrastructure changes.

NSWWS warnings, when issued, appear on the Met Office's website and app as well as on Meteoalarm. Additional support for warnings communication is provided by the CCAs, the Met Office Press Office and Media Services Team via videos embedded on the Met Office website and commentary on Met Office social media feeds. Agreements are also in place for NSWWS warnings to be carried by national television broadcasters in the UK.

## Impact-Based Decision Aids

Alongside Met Office NWP, output from other centres, for example ECMWF, is used in considering NSWWS warnings. Meanwhile, a number of specific decision-making aids have been developed to help the forecasting community, some of which are focused on specific impacts.

EPS-W (Neal et al 2014) is an ensemble-based 'first guess' warnings tool which uses a set of guideline thresholds to post-process ensemble data.

| Very Low | Low | Medium | High |
|---|---|---|---|
| Loose debris blown around.<br>A few transport routes affected by difficult driving conditions.<br>Instances of spray and large waves affecting coastal routes, sea fronts and coastal communities. | Some transport routes and travel services affected. Some journeys require longer travel times. Some disruption to road, rail, air and ferry transport.<br>Difficult driving conditions for high-sided vehicles on prone routes, such as cross winds on exposed or high level roads.<br>A few power interruptions.<br>Coastal routes, sea fronts and coastal communities affected by spray and/or large waves. | Injuries and danger to life from flying debris.<br>Some structural damage, such as slates dislodged from roofs.<br>Transport routes and travel services affected. Longer journey times expected. Disruption to road, rail, air and/or ferry transport.<br>Closure of some susceptible and key routes (e.g. some vulnerable bridges).<br>Interruptions to power and/or other utilities and services.<br>Casualties and danger to life from large waves/beach material being thrown onto coastal routes, sea fronts and coastal communities. | Widespread danger to life from flying debris.<br>Widespread structural damage e.g. roofs blown off, mobile homes overturned, power lines brought down.<br>Transport routes and travel services affected for a prolonged period. Long travel delays.<br>Closure of main bridges, road and rail networks in many areas, and significant disruption to air and ferry transport.<br>Widespread and prolonged disruption to power, and/or other utilities and services.<br>Danger to life from large waves/beach material being thrown onto coastal route, sea fronts and |

| Very Low | Low | Medium | High |
|---|---|---|---|
| A few places will have flooding of low-lying land and susceptible roads.<br>A few transport routes affected.<br>Road conditions affected with spray and some standing water in a few places. | Some flooding of homes and businesses and susceptible roads.<br>Some transport routes and travel services affected. Some journeys require longer travel times.<br>Road conditions affected by spray and standing water.<br>Short term disruption to utilities and services in some places. | Flooding of homes and businesses.<br>Danger to life from fast flowing/deep water.<br>Damage to buildings/structures.<br>Transport routes and travel services affected. Longer journey times expected. Some road closures.<br>Difficult road conditions due to spray and standing water.<br>Interruption to utilities and services.<br>Some communities temporarily inaccessible due to flooded access routes. | Widespread flooding of homes and businesses.<br>Danger to life from fast flowing/deep water.<br>Extensive damage to and/or collapse of buildings/ structures.<br>Transport routes and travel services disrupted for a prolonged period. Long travel delays.<br>Widespread road closures.<br>Dangerous driving conditions due to spray and standing water.<br>Prolonged disruption to or loss of utilities and services.<br>Communities become cut off for a prolonged period, perhaps several days, due to flooded access routes. |

*Figure 3: Impact statements for wind (left) and rain (right) taken from https://www.metoffice.gov.uk/weather/guides/severe-weather-advice.*

It converts output from the Met Office global and regional ensembles (MOGREPS-UK and MOGREPS-G) into a format reflecting the NSWWS impact matrix, suggesting where these impactful conditions could best fall on the impact matrix. Guideline thresholds vary by region to account for variations in levels of impact of severe weather across the UK based on time of year and climatological frequency. For example, for gusts it is assumed that impacts from a NSWWS perspective will start at a higher value over sparsely populated islands in northern Scotland. This is because they have few trees and, in a climatological sense, are more used to frequent high wind events than the densely populated southeast of England. Continuing with the example of gusts, summer thresholds for impacts from gusts are considered lower due to trees being in leaf and people being more likely to be participating in outdoor activities. An example use of EPS-W is shown in Figure 4, where the first-guess warnings were able to highlight a high impact wind event several days in advance, leading to a very rare red warning being issued. Met Office meteorologists refined the warning area in consultation with regional responders and after gaining more information from specialised numerical weather prediction output.

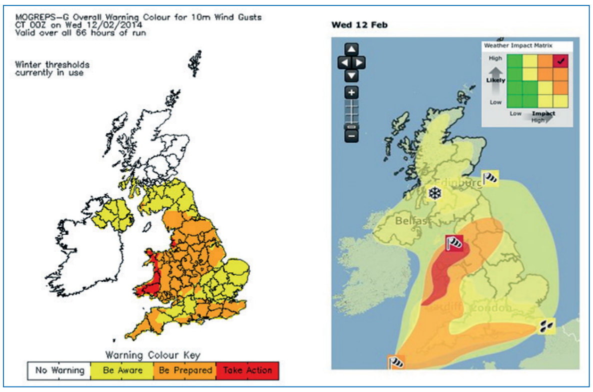


*Figure 4: EPS-W output initialised at 00 UTC 12th February 2014 showing overall NSWWS warning colour at each model grid point (left) and final Chief Operational Meteorologist-issued warning (right) for the same day (courtesy of Robert Neal).*

A number of more specific impact-based decision support tools also exist. Grid-to-Grid is a distributed hydrological model which translates precipitation output from MOGREPS-UK, the Met Office's high-resolution, convection permitting ensemble (Hagelin et al 2017), into surface runoff and river flows. This is to predict potential river flooding, supplementing the UK network of catchment-level hydrological models.

Another flooding decision support tool, this time for surface water flooding, is the Surface Water Flooding Hazard Impact Model (Aldridge et al 2020). This tool tests surface runoff output from Grid-to-Grid (and is thus based on MOGREPS-UK) against nine different flood risk scenarios devised by the UK Environment Agency. These are based on three rainfall return periods and three critical storm durations. Risk maps for level of impact on population, property, infrastructure and transport exist for each of these nine flood risk scenarios. An indication of the likelihood and severity of impacts can then be garnered from knowing whether or not surface run-off output exceeds any of the nine different flood risk scenario thresholds. Impacts are upscaled to the resolution of individual counties to show the severity, likelihood and extent of impactful surface water flooding across England and Wales.

Moving away from precipitation, another impact-based decision aid is the Vehicle Overturning Model (Hemingway and Robbins 2020). Here, MOGREPS-UK wind gust and direction output is applied to the UK road network using thresholds appropriate to different classes of vehicle (for example loaded and unloaded HGVs). The hazard forecast is combined with data on the vulnerability of the network (for example altitude of route segment and accident data) and exposure (the number of vehicles that use the road segment) to provide a more informative assessment of risks of vehicles being overturned. Probabilistic maps illustrate where on the road network there is a heightened risk of vehicles overturning (Figure 5).

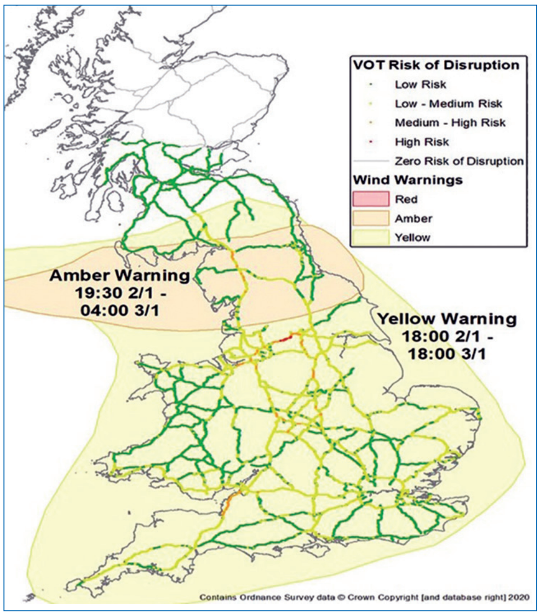


*Figure 5: Map comparing maximum VOT risk forecast and corresponding issued NSWWS wind warning for 1800 2nd January to 1800 3rd January 2018 during Storm Eleanor (courtesy of Jo Robbins).*

## Storm Naming and NSWWS

Storm naming at the Met Office commenced in 2015 in partnership with Met Eireann. The KNMI joined this partnership in 2019.

This initiative has been well-received from a communications perspective and is a powerful way of raising awareness of severe weather (Charlton-Perez et al 2019). Indeed, a recent public perception survey in the UK suggested that the reach and exposure naming a storm gets outweighs that of yellow and amber warnings, highlighting the power of storm naming.

So where does storm naming fit into NSWWS? Procedures used at the Met Office state that a storm is named when either medium or high NSWWS impacts from wind are expected or the storm has the potential to lead to medium or high NSWWS impacts from wind. Additionally, a storm can be named if a NSWWS wind warning is in force and if medium or high impact NSWWS warnings for other associated elements, such as rain or snow, are in force.

Storms such as Storm Ciara (8th to 9th February 2020) or Storm Doris (23rd February 2017) represent examples of more 'traditional' named storms over the UK (Figure 6). In contrast, Storm Christoph (18th to 20th January 2021) saw naming used to reflect the multi-hazard nature of a prolonged severe weather event against the backdrop of societal challenges imposed by COVID-19-related lockdown measures.

Storm naming is, however, not without its challenges. Among two challenges faced are complications from the existence of multiple storm naming conventions and 'false naming' of storms by some media outlets. This happens when it is assumed that a storm signalled in model output – usually at quite long lead times – will be named and thus stories appear highlighting the wind hazard and attaching the assumed name.

Another communications challenge concerns how to separate impacts from a named storm from other generally windy weather events. For example, Storm Brendan (13th to 14th January 2020) occurred during a windy spell of weather over the UK. During this period, some areas received their highest winds during a separate event the day after Storm Brendan had passed. This prompted questions as to why this second wind event had not been named. It was not well understood by the public that Storm Brendan was not named for the region in which these questions came from and that the magnitude of wind was never considered likely to justify storm naming for this area alone. Essentially, when winds are high, there can be an expectation that the associated storm should have been named regardless of level of impact. This is particularly apparent in wind events which bring widespread minor impacts, such as to garden fences, in which there is often a perception that a name should have been applied.

## Verification and Targets

NSWWS accuracy targets are set by the Public Weather Service Customer Group (PWSCG), an independent group made up of representatives of key stakeholders. Only high and medium impact

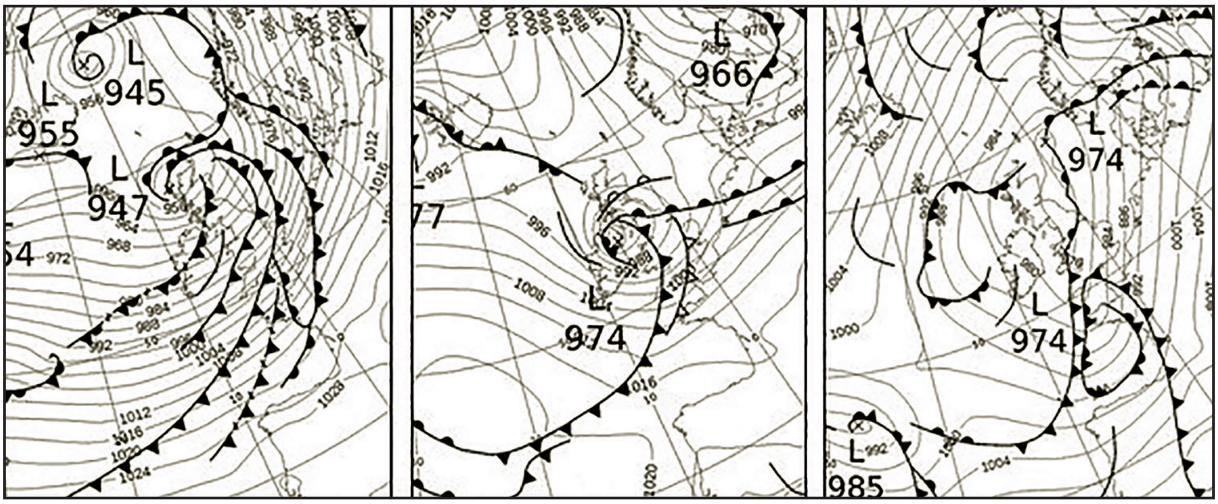


*Figure 6: Met Office surface analysis valid 12Z 9th February 2020 during Storm Ciara (left), 06Z 23rd February 2017 during Storm Doris (centre) and 18Z 20th January 2021 during Storm Christoph (right).*

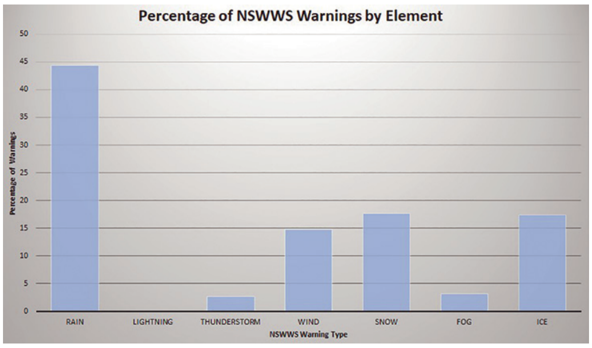


*Figure 7: Percentage of NSWWS warnings by warning element.*

warnings are assessed and the targets currently dictate that, based on a three year rolling mean, 75% of these assessed warnings should provide good guidance.

NSWWS warnings are assessed for accuracy on a monthly basis internally at the Met Office by the CCAs and members of the forecasting community. At these monthly meetings, consideration is given as to whether or not warnings provided good guidance. It is based mainly on customer feedback to the CCAs, extent and magnitude of impacts and timeliness of issue of warning. Cases where a medium or high impact warning could have been missed are also considered. Conclusions from these monthly subjective verification meetings are then presented to the PWSCG for ratification.

No formal objective verification of NSWWS warnings currently takes place internally at the Met Office, partly due to the complex nature of how an impact-based verification service could actually be verified.

## Some Highlights from a Decade of Impact-Based NSWWS Warnings

Between impact-based warnings starting in spring 2011 and the end of 2020, just over 5,000 NSWWS warnings have been issued.

Of these warnings, almost half were for rainfall with snow, ice and wind the elements next most frequently warned for (Figure 7). The relatively low frequency of warnings for thunderstorms reflects that these warnings were only introduced in 2018. Prior to 2018, warnings for thunderstorms would have been included in rainfall warnings. Between 2018 and 2020, thunderstorm warnings accounted for about 12% of NSWWS warnings and rainfall warnings close to 40%. Meanwhile, the very low number of lightning warnings is because these warnings are intended for use during convective events when other typical convective hazards such as rain, hail and wind, are not expected to be impactful. For example, on the rare occasions when deeply convective cold season polar maritime airmasses bring frequent electrical activity (such as happened over northwest Scotland in December 2014).

Recalling the impact matrix (Figure 1) and breaking down warnings into low, medium and high impacts (Figure 8), close to 60% of warnings are for low impacts, nearly 40% medium impact and just under 2% high impact. Compared to these values, wind, snow, rain and thunderstorm events show a greater frequency of medium and/or high impact events, especially thunderstorms. This reflects their relatively high potential for greater societal impacts.

Meanwhile, almost all fog warnings have been for low impact events (Figure 8). This is because fog in the UK tends not be especially persistent. For a fog event to be considered a medium impact, major airports and/or ferry terminals would need to be closed due to fog for at least a couple of days leaving large numbers of passengers heavily delayed or stranded. Most ice warnings are also for low impact events, largely catering for icy patches developing between showers or post-frontal systems. The smaller percentage of higher impact ice warnings relate to freezing rain events which are relatively rare in the UK.

By way of context, examples of high impact events over the UK include very high winds over Scotland during Cyclone Friedhelm on 8th December 2011 and Cyclone Ulli on 3rd January 2012, flooding over southern Scotland and northwest England 5th/6th December 2015 during Storm Desmond,

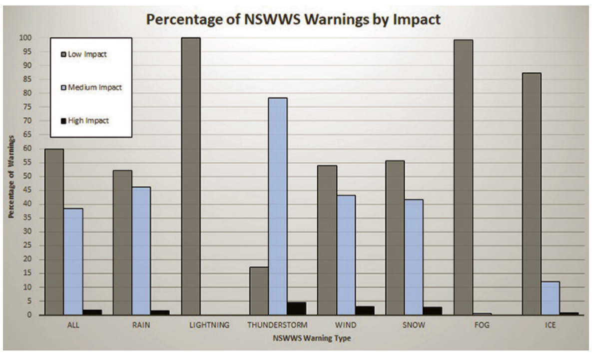


*Figure 8: Percentage of NSWWS warnings by impact level.*

snow over southwest England and southeast Wales during the so-called ‘Beast from the East’ and flooding over south Wales on 16th February 2020 during Storm Dennis. Red NSWWS warnings were in force for parts of the UK during all these events.

Once more recalling the impact matrix (Figure 1) but this time sorting warnings by likelihood, (Figure 9), most NSWWS warnings are medium likelihood. As might be expected, higher frequencies of lower likelihood warnings tend to be for the more unpredictable elements such as snow and thunderstorms. Meanwhile, the relatively high frequency of higher likelihood fog warnings is potentially a reflection of some tendency to issue fog warnings when fog occurs, presumably to minimize the false alarm rate.

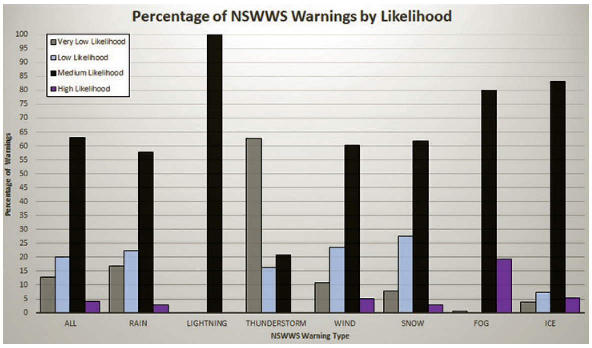


*Figure 9: Percentage of NSWWS warnings by likelihood.*

Projecting the information in Figures 8 and 9 onto the NSWWS impact matrix, it can be seen that for all elements (Figure 10) most NSWWS warnings are low impact and usually medium likelihood. That the higher percentages of medium impact warnings are low or very low likelihood is related to many thunderstorm warnings falling in these categories and reflects the inherent unpredictability of convective events compared to, say, wind and rain events. High impact events are very infrequent with just less than 100 high impact warnings issued. Thunderstorm, wind and snow are the most likely high impact warning elements.

| | | | |
|---|---|---|---|
| High | 3.4 | 0.4 | 0.3 |
| Medium | 56.4 | 6.1 | 0.5 |
| Low | | 19.4 | 0.6 |
| Very Low | | 12.5 | 0.4 |
| | Low | Medium | High |

*Figure 10: NSWWS impact matrix with percentage of warnings (all elements) per location on this matrix.*

Inspecting the temporal frequency of NSWWS warnings (Figure 11), unsurprisingly the number of warnings issued peaks during wintertime, especially when winters are stormy or contain marked snowy/icy periods. A secondary peak is apparent some years, reflecting more active summertime convective periods, for example in 2012. What is also beginning to become apparent is that the number of warnings issued per year has been falling. Why this is the case is something of an open question, but it may be weather-related. For example, some recent winters in the UK have not been especially impactful in terms of wind. The main element for which fewer warnings are issued is rain. Even accounting for the introduction of thunderstorm warnings effectively taking some of the ‘warning space’ that prior to 2018 would have been occupied by rain warnings, there has, since 2015 been a marked drop in numbers of rain warnings. This drop-off may in part be meteorological with recent summers not having seen the kind of prolonged spell of impactful convective days as, say, 2012, and recent winters seeing less of the kind of prolonged wet spells seen in the mid 2010s. It could also be that we are also getting better at forecasting rain events so require fewer updates before and during events.

## And Finally, What of the Next Decade

Having looked back through the last ten years of impact-based NSWWS warnings, perhaps it is appropriate to speculate as to what the next ten years could bring?

We have recently completed a major consultation exercise with NSWWS users - public, responders and broadcasters – to check that the service is effective and valued, and to give direction to its further development over the next 5 to 10 years. The study confirmed that NSWWS works very well whilst also suggesting that its benefits could be further enhanced through increased accuracy, increased tailoring to key user groups and also a greater appreciation of the link between warnings, decision-making and positive action.

To help achieve this, investment in a new supercomputer should generate modelling improvements whist further training and new tools and systems for operational meteorologists will undoubtedly help.

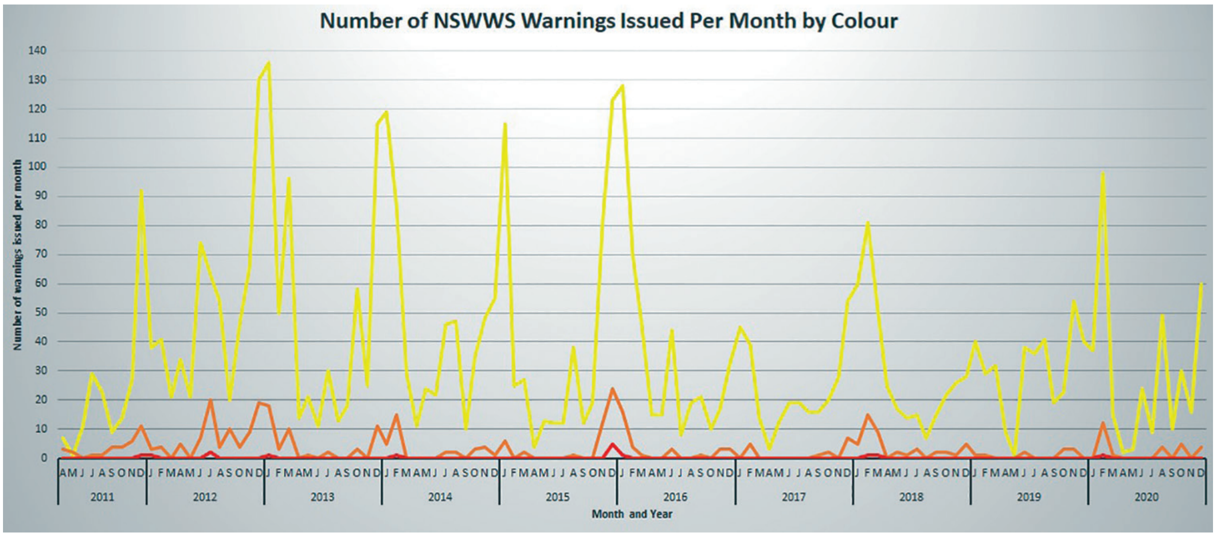


Figure 11: Number of NSWWS warnings issued per month by colour.

Meanwhile, improvements in NWP combined with developments in the observing network, machine learning techniques and working with professional partners to better understand impacts will undoubtedly facilitate development of increasingly sophisticated hazard impact models.

Concurrently, the role of the operational meteorologist is critical in interpreting the increasing amounts of information whilst factoring in deficiencies in this information, for example errors and biases in NWP and developing impacts as an event commences. As new generations of warning services are developed, consideration needs to be given as to what users do with the warnings and how they can best be reached in the face of evolving communications and increasing numbers of users accessing warnings digitally. We need to find better ways to measure the value of warnings as a mitigation and communication tool, the impacts warnings have on society and the associated cost-benefit analysis in taking appropriate and timely action. Greater investment in this area will no doubt lead to better warnings and perhaps more importantly better actions. Margareta Wahlström, former Special Representative of the Secretary-General for Disaster Risk Reduction and Chief of UNISDR puts it succinctly, once saying, "we cannot manage what we cannot measure". This statement is entirely consistent with the above and further resonates with the call to form multi-disciplinary coalitions to build the next generation warning service.

## Acknowledgements

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