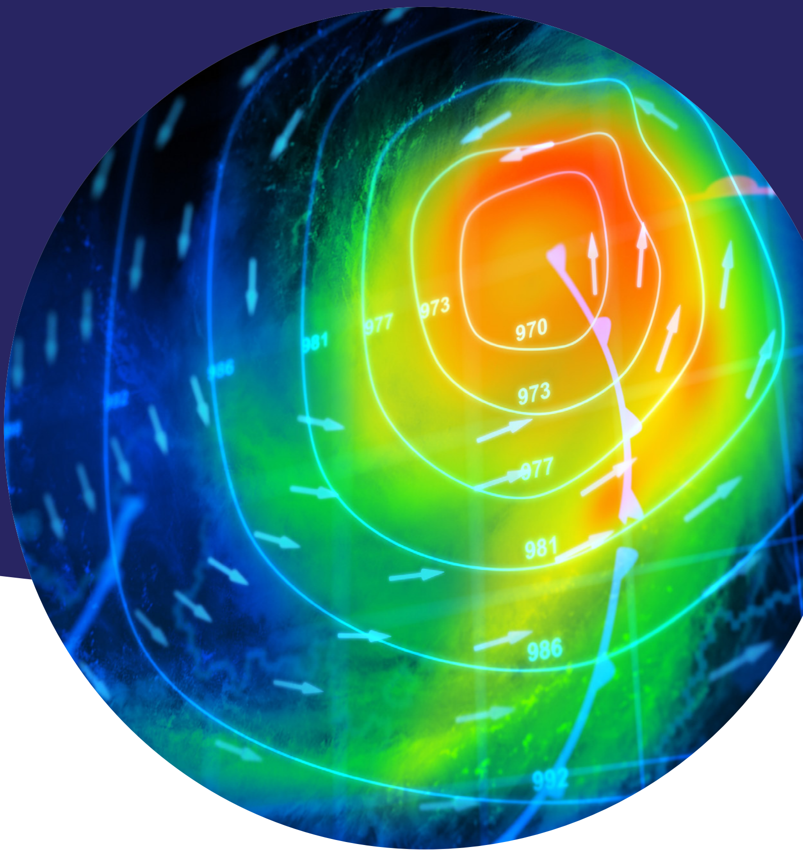
EI 3622

Good practice guidelines

G+ Severe weather preparedness

First edition



G+ Global Offshore Wind
Health & Safety
Organisation

In partnership with

energy institute

GOOD PRACTICE GUIDELINES

G+ SEVERE WEATHER PREPAREDNESS

First edition

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FOREWORD

This is the first edition of these good practice guidelines. The document provides a structure for accountable organisations to identify offshore renewable risks and the contingency measures that are required in relation to severe weather events.

Furthermore, region-specific sections were developed to help with the implementation of these. These sections include Japan, South Korea, Taiwan and the USA.

The document is intended to operate as a living document, and its content will evolve as new experiences are gained and more regional guidance is added.

It is recommended that these guidelines be used together with the self-assessment sheet, *EI3622-1 Severe weather preparedness checklist*.

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1 INTRODUCTION

These guidelines do not fundamentally define or mandate any new industry standards or requirements, but they do consolidate a consensus approach to managing severe weather, taking account of existing and emerging industry good practice. These guidelines aim to provide a framework of how to manage the risks arising from severe weather events.

It is important to differentiate between severe weather and adverse weather. International Marine Contractors Association (IMCA) (M220 *Guidance on operational activity planning*), International Maritime Organization (IMO) (SOLAS) and Det Norske Veritas (DNV) (DNVGL-ST-N001 *Marine operations and marine warranty)* all offer definitions of adverse and severe weather. Adverse weather is generally described as weather conditions exceeding operational limits. Severe weather is variously described as weather conditions that threaten the safety of operations (IMCA), referenced in relation to design or emergency planning for events such as cyclones or conditions classified as exceeding safe design limits (DNV), and impair the safety of the vessel and crew (IMO). For the purposes of the good practice guidelines (GPG):

Severe weather should be considered as conditions that require explicit consideration to mitigate threats to the safety of personnel, vessels or equipment.

These guidelines set out an approach that all accountable organisations are encouraged to apply, considering the specific risk profile of their projects and their legal and contractual obligations. Accountable organisations throughout the life cycle of an offshore wind or marine energy project continue to be responsible for ensuring compliance with regulatory and contractual obligations, and so must make their own assessment of the relevance and suitability of any guidance provided.

In the context of this document, the term accountable organisation is used to identify the organisation with primary responsibility and control of the project and site. In most cases it is likely to be the client/developer or owner/operator, dependent on project phase.

A Responsible Individual is a nominated individual from the accountable organisation who has the ultimate responsibility for the safety of all personnel within a specified work location. In most cases, this is the duty holder, person in control or the employer.

This document does not recommend an accountable organisation or who the Responsible Individual should be, but recommends that a single organisation and individual is identified and recognised by all participants.

Beyond these roles, there will likely be responsibilities on the contractors for elements of severe weather management. These are termed Designated Individuals for the purposes of this GPG. The Designated Individual should have appropriate knowledge and decision-making authority.

The goal is to provide consistency and good practice regarding severe weather preparedness across the wind industry and allow operators and contractors to produce or verify their severe weather preparedness procedure against a set of industry standard guidelines.

The structure of the document includes a commentary in section 1 on key principles that apply to all severe weather types.

– Clarity in definition of severe weather.

- Clarity in responsibilities.
- An introduction to the main types of weather forecast and the need for forecast verification. This also briefly addresses data for forecast verification.

This guidance considers the following severe weather types:

- extra-tropical storms (commonly termed gales in northern Europe);
- tropical cyclones (commonly termed typhoons, hurricanes or cyclones depending on region);
- lightning;
- extreme heat, and
- extreme cold.

Each severe weather type is considered in a separate section. The severe weather sections provide:

- Severe weather type introduction:
  - A brief characterisation of the severe weather under consideration. This includes ways of identifying severe weather events and use of hindcast/reanalysis data to help characterise events at a site-specific level.
  - A recommendation on the type of forecast that should be used to inform decision-making.
  - The hazards that are associated with the severe weather type.
- Planning phase:
  - Risk assessment and identification of mitigation measures.
- Severe weather event actions:
  - Ensuring personnel safety.
  - Implementation of mitigation measures.
  - Monitoring severe weather to enable end to be determined.
- Post-severe weather event recovery:
  - Personnel accounting and return-to-work protocols.
  - Assessment of damage to assets.
  - Management of change to safely plan damage repair and certification.

The contents of the section should be considered as the minimum requirements to adhere to the good practice for that weather type.

1.1 SCOPE

This guidance addresses severe weather preparedness associated with an offshore renewable energy development (ORED) (wind or marine).

It is recognised that there is not a globally accepted nomenclature for all elements of an ORED or structures within it. The following terms are adopted throughout the GPG:

– ORED – offshore renewable energy development

The ORED includes all location and assets associated with a wind farm development.

– OREI – offshore renewable energy installation

An OREI is an individual asset or location within the ORED, for example a wind turbine or offshore sub-station.

The guidance is based on the good practice identified by individual G+ members and meteorological initiatives such as the World Meteorological Organization (WMO) guidance.

The geographical scope of the guidance covers the locations of the physical infrastructure of a wind farm development comprising:

– the offshore wind farm comprising turbines, inter-array cables and offshore transformer;
– export cable routes;
– coastal operations including marshalling and manufacturing ports;
– coastal infrastructure including cable landfalls and transformers, and
– operational routes.

Severe weather hazards impacting terrestrial infrastructure and personnel are not considered.

Activities across the project life cycle are considered including:

– development;
– construction (transport and installation), and
– operations and maintenance.

The guidance is intended to work alongside existing G+ good practice guidelines, including:

– EI3395 *Integrated offshore emergency response (G+ IOER) – Good practice guidelines for offshore renewable energy developments.*
– EI3429 *G+ Offshore wind farm transfer*.
– EI3563 *Safe by design – Good practice guidance for the offshore wind industry*.

2 KEY PRINCIPLES

Key principles that should apply:

- Defined scope.
- Clarity in responsibilities: the accountable organisation should ensure that there is clarity in the responsibility for activities outlined in 2.2.
- Management of change.
- Types of weather forecast and their application. Weather forecasts should be verified.

2.1 DEFINED SCOPE

An ORED (wind or marine) should be clearly identified in terms of:

- geographical coordinates;
- marshalling and manufacturing ports;
- OREIs;
- air and marine points of embarkation/disembarkation, and
- transit routes.

The impact of severe weather on any of these requires consideration.

2.2 CLARITY IN RESPONSIBILITIES

The responsibility for both planning and execution of actions in response to severe weather should be defined contractually to ensure the operator, contractors and subcontractors understand their respective roles and responsibilities. The responsibilities will vary with:

- severe weather type;
- project phase, and
- operation.

Ultimately, the operator should manage the risk with respect to its impact on the wind farm development, construction or operation. As previously described, the operator will likely be the accountable organisation and its health, safety and environment (HSE) procedures should address severe weather preparedness. It may be appropriate to use a bridging document to ensure other parties comply with these procedures.

The accountable organisation should appoint a Responsible Individual who shall have oversight of severe weather risks and their management (see Figure 1). Often the risk management may be undertaken by contractors, who may appoint one or more Designated Individuals to undertake risk assessments and ensure operations are fully informed of severe weather risk through appropriate forecasting and observations, adoption of risk mitigation measures and post-event actions.

Figure 1: Clear structure of responsibility

To help inform good practice, it is recommended that the accountable organisation create a clear matrix of responsibilities that should address the following planning activities for each operation that is considered in development, construction and operation:

- Identification of the geographic scope, e.g. offshore array, export cable, landfall, marshalling yard.
- Identification of severe weather types that occur within the ORED (wind or marine), including seasonal assessment.
- Definition of a severe weather event.
- Identification of engineering controls.
- Identification of risks associated with severe weather.
- Identification of mitigation measures to undertake in preparation for severe weather.
- Identification of appropriate weather forecast products, prioritisation of forecasts (if more than one) and verification.
- Establish appropriate emergency response plan (ERP) having regard to the G+ IOER GPG and the local regulatory environment, e.g. self-reliant, whereby national agencies do not support emergency response, which may require a paramedic or vessel medic to be employed, depending on distance/time to medical facilities.
- Identification of severe weather onset and communication protocols.
- Responses to predicted onset of severe weather event.
- Implementation of mitigation measures prior to a severe weather event.
- Identification of the conclusion of the severe weather event and communication protocols.
- Activities to undertake following a severe weather event.

It is recommended that the identification of severe weather types should be undertaken by the accountable organisation, to provide the boundaries of weather types that require consideration within an ORED to all parties. The other activities may be undertaken by the operator and/or contractors, but with oversight by the accountable organisation to ensure that the overall project risk is appropriately managed.

The responsible person of a vessel is the Master. The definition of responsibilities should reflect IMO SOLAS Regulation V/34.1, which states: ‘The owner, the charterer, the company operating the ship as defined in regulation IX/1, or any other person shall not prevent or restrict the master of the ship from taking or executing any decision which, in the master's professional judgement is necessary for safety of life at sea and protection of the marine environment. As such the ultimate responsibility for the safety of a vessel and its crew/ passengers must lie with the master.'

2.3 COMMUNICATIONS PLAN

Effective communication is critical during severe weather events to ensure the safety of personnel and continuity of operations. The entity responsible for implementing the communication plan should be specified. The plan should include:

- How the responsible parties identified in 1.2 communicate.
- Interfaces and communication channels for government agencies such as coastguards.
- How the severe weather management plans and actions are communicated to the broader workforce including awareness of the onset and relaxation of severe weather conditions.
- Communication trees to include key contacts.
- Primary communication channels: radio, satellite phones, mobile alerts, emergency messaging systems.
- Alert protocols – issue weather warnings with clear instructions (e.g. shelter places, evacuate, suspend operations, etc.). Use standardized codes and language to avoid confusion.

2.4 MANAGEMENT OF CHANGE

It should be noted that severe weather events are relatively rare, as opposed to adverse weather which may occur frequently. As such, they may create scenarios that may not have been considered during the risk assessment. For example, the impact of tropical cyclones on marshalling yards during construction and access structures or other equipment or infrastructure during operation of a wind farm. As such, a clear management of change process should be implemented to ensure that recovery operations consider the actual status of equipment and infrastructure, and appropriate planning and risk assessments are undertaken. The entity responsible for implementing the process should be specified.

2.5 ENGINEERING CONTROL

Safety by design and engineering controls that are needed to help manage severe weather should be identified and raised with the equipment supplier, during equipment acquisition and/or during the technical due diligence, hazard identification (HAZID) and hazard and operability study (HAZOP) phases.

In addition to consideration of the structural integrity, as required by design codes, assessment of the need for the installation of specific severe weather-related equipment (e.g. anemometers, lightning detectors, lightning conductors, surge protection, weather-proofing materials, shelters, etc.) should be undertaken.

Following the development and/or modification of structures and assets and before operation, location-specific 'area' risk assessments must be undertaken, to ensure safe plant and equipment and safe means of access and egress, considering the potential for severe weather conditions.

2.6 SAFE SYSTEMS OF WORK AND ADMINISTRATIVE CONTROLS

The processes and activities identified in 1.2 should be reinforced with contemporaneous and recurring risk assessments completed by managers/supervisors in control of the work, as the weather can be variable and sometimes unpredictable. Before attendance at site, local weather forecasts should be checked and the need for any additional controls implemented. In addition to the generally available weather forecast media, consideration should be given to *in situ* measurements and situation reports from others working in the local area. The responsibility for these actions should be clearly documented.

- Clear communications for severe weather warnings and instructions to people working on/attending the ORED sites should be implemented.
- Site access and work activities shall only proceed if adequate control measures are in place considering specific severe weather criteria.

Prior to commencing a task, workers shall conduct a last-minute risk analysis (LMRA)/dynamic risk assessment, which considers current and forecast weather conditions. If there are any doubts/safety issues due to adverse weather, the work should not be started or should be ceased, and working parties withdrawn.

2.7 AWARENESS AND BEHAVIOURAL ASPECTS

Workers should receive appropriate training to promote awareness of severe weather risks and appropriate behaviours. The expected behaviours include:

- Adherence to local procedures and work instructions.
- Appropriate use of equipment (including personal protective equipment (PPE)) considering the conditions in which they are working.
- Conduct LMRA/dynamic risk assessment before starting work and consideration of changing weather conditions.
- Empowerment not to commence, or to cease, work if they consider weather conditions unsafe.

A safety culture, whereby workers behave in a reasonable manner that does not put themselves or others at risk of harm, should be promoted.

Personnel attending the ORED sites should contact project offices and operational control centres prior to the commencement of work. People who attend and work at the organisation's sites and premises must remain vigilant, be aware of surroundings and monitor weather conditions, **particularly when forecasts predict potential severe weather**.

Communication links with offsite support must be checked and maintained. Mobile phone/radio batteries should be kept adequately charged. Portable radio communications should be established where mobile phone coverage is not adequate. A form of emergency communication must always be available. Good housekeeping standards must be maintained, particularly when adverse weather conditions are expected. Floors, walkways and work areas should be kept in a clean and tidy state, limiting the existence, or increased risk, of slip and trip hazards during periods of adverse weather.

2.8 WEATHER FORECASTS

Weather forecasts are an essential safety tool and offer significant value to severe weather preparedness as well as routine operational planning. The potential safety and commercial implications of forecasts should be considered when choosing a provider. To manage the risk of severe weather appropriately, careful consideration should be given to:

- the type of forecast procured;
- the accuracy of forecasts;
- its frequency of delivery (e.g. twice or four times daily);
- the potential for rapid changes to forecast conditions, and
- the ability of offshore decision-makers to understand forecasts and their uncertainty.

These aspects of weather forecasting are discussed in sections 2.8.1 to 2.8.6. It should also be noted that many operations require two forecasts to be procured to satisfy marine warranty expectations. It should be noted that many forecast providers use the same underlying model data, so they may not be totally independent. In the event of the two forecasts differing, an objective means of establishing the primary forecast should be established. This may be as simple as adopting the most conservative forecast, or determining which forecast performs the best under the synoptic conditions through continuous verification (benchmarking).

There are two main types of weather forecast that may be used to inform decision-making for severe weather. These are described in 2.8.1 and 2.8.2. It should be noted that the reliability of forecasts generally reduces with the forecast horizon, i.e. the further into the future, the less reliable the forecast. This should be considered when assessing time available to implement mitigation measures.

The interpretation of forecasts is essential to safe operations. It is essential that users of forecasts understand the meteorology and oceanography (metocean) parameters they contain, and also at a high level how forecasts are generated to provide an understanding of their inherent uncertainty. It is recommended that both planners and decision-makers are provided with metocean awareness training that includes the interpretation of both deterministic and ensemble forecasts. Such training can generate significant value in the management of severe weather and normal operations.

2.8.1 Deterministic forecasts

A deterministic forecast provides a single view of future conditions. Generally, a deterministic forecast is provided for seven days. It may be generated automatically from forecast model data or informed by an operational forecaster. The former is not recommended for severe weather applications due to potential poor performance of models, particularly in synoptic conditions that give rise to rapid changes in conditions.

A deterministic forecast that is prepared by a forecaster makes use of the forecast model data, *in situ* observations, earth-observing data and the forecaster's regional knowledge. The forecaster adds significant value, with this type of forecast generally being more reliable than a forecast driven by a single model.

2.8.2 Ensemble forecasts

Ensemble weather forecasting is a technique used to improve the accuracy and reliability of weather predictions. Instead of relying on a single forecast model, ensemble forecasting uses multiple models or multiple runs of a single model with slightly varied initial conditions or physics.

A key tenet of ensemble forecasting is that each ensemble member has the same probability of occurrence as every other member. Combining the ensemble members allows probabilistic forecasts to be generated, and the term probabilistic forecast is sometimes used rather than ensemble forecast. These forecasts can provide:

- Information on the probability that a parameter threshold will be exceeded.
- A view of the variability between the individual ensemble members, and hence the likely confidence in the forecast.
- A view on the worst-case forecast scenario.

The information may be provided for a single location or spatially. Ensemble forecasts are particularly useful when considering transitory severe weather events such as storms.

The probabilistic nature of ensemble forecasts aids in better decision-making for weather-sensitive activities, such as marine operations, aviation and emergency management. Overall, ensemble weather forecasting enhances the robustness and reliability of weather predictions by considering a wider array of possibilities.

2.8.3 Forecast verification

Forecast verification is an important consideration across the range of operational limits. To undertake verification, *in situ* observations must be representative of the forecast location, parameters and times of the forecast. It is also important to quality control the measurements prior to verification activities. It should be noted that such observations, when made available to the forecast contractor, can help improve the quality of the forecast and provide significant value with respect to the timing and magnitude of events. If the data are made available to the forecaster, they may also be used to efficiently generate verification products, precluding the need for the Designated Individual to set up forecast data feeds and verification algorithms.

Guidance on forecast verification is provided in International Organization for Standardization (ISO) 19901-1 *Oil and gas industries including lower carbon energy – Specific requirements for offshore structures*.

2.8.3.1 Deterministic forecasts

Verification may be undertaken in a number of ways. Firstly, the error in the forecast can be statistically characterised by calculating bias, root mean square error, etc. However, for threshold-driven responses to severe weather conditions, the use of a binary verification is recommended. The four outcomes are provided in Table 1:

Table 1: Forecast outcomes

Description	Observations	Forecast
Hit	Event occurs	Event forecast
Miss	Event occurs	Event not forecast
False alarm	Event does not occur	Event forecast
Correct rejection	Event does not occur	Event does not occur

The outcomes can be evaluated at different forecast horizons to understand how far into the future the forecast can be considered reliable. Many measures of forecast skill can be calculated using the outcomes (detailed in ISO 19901-1 *Oil and gas industries including lower carbon energy – Specific requirements for offshore structures*). Those commonly used and readily understood include:

$$\text{Proportion of correct forecasts} = \frac{\text{Hit} + \text{correct rejections}}{\text{Number of forecasts}}$$

$$\text{Hit rate} = \frac{\text{Hits}}{\text{Hits} + \text{misses}}$$

$$\text{False alarm rate} = \frac{\text{False alarms}}{\text{False alarms} + \text{correct rejections}}$$

2.8.3.2 Ensemble forecasts

Ensemble forecasts may be verified using a discrete or probabilistic approach. The verification techniques are relatively complex with respect to the statistical techniques applied and interpretation is not straightforward. As such, training may be required to ensure the results of the verification are fully understood.

2.8.4 Rapidly changing conditions

Forecasts are generally provided twice or four times daily, with most forecast models being run four times per day. As such, forecasts may not reflect rapidly changing conditions. Other approaches will be required to provide awareness of potential risk arising from this. Additionally, if a forecast is incorrect, and this is evident from observations, it may be necessary to provide additional warnings to forecast recipients to advise them that the forecast is not reliable.

Forecast companies can offer monitoring of conditions based on earth observing systems such as meteorological satellites, and *in situ* observations if they are provided in near real time. The inclusion of monitoring of conditions in near real time in the forecast services scope of work should be considered if rapidly changing conditions are likely to be encountered. Additionally,

Additionally, personnel should be trained to identify rapidly changing conditions, and processes developed to maintain the safety of personnel and assets.

2.8.5 Forecast training

Many offshore incidents arise due to a lack of awareness or knowledge of end users of metocean information. Metocean information comprises weather forecasts and real-time displays of metocean data. To avoid such incidents, and to ensure that severe weather processes are properly applied, it is recommended that companies provide training to key decision-makers in the interpretation of weather forecasts and real-time data.

2.8.6 Forecast innovation

Innovation is occurring rapidly in the weather forecast domain due to digitalisation and artificial intelligence/machine-learning technologies. The ability to blend observation and model data allows for improved forecasts, with recent observations allowing updates to a forecast at frequencies greater than forecast model runs. Although many of these services are yet to be commercialised, they offer significant potential to improve support to severe weather responses.

2.9 SAFE HAVENS

A safe haven means a harbour or shelter of any kind that affords entry, subject to prudence in the weather conditions prevailing, and protection from the forces of weather. In the context of this document, safe havens are relevant to planning for extra-tropical storms and tropical cyclones, as they may offer shelter from such storms. In addition to harbours, vessels may also move to offshore anchorages that offer shelter, or move away from the impact of a storm into a sea area affording less severe conditions.

The approach to safe havens is generally different for extra-tropical storms and tropical cyclones. In many jurisdictions, the coastguard is central to tropical cyclone responses. Many implement tropical cyclone response plans, in association with regional ports, based on the tropical cyclone warnings from the National Weather Service. For extra-tropical storms, safe haven selection and operations are generally contractor-led in association with port or harbour authorities. This is discussed in further detail in 2.2 and 3.2.

2.10 DIGITAL SOLUTIONS

Digital technologies offer a robust solution to the management of severe weather, allowing multiple data streams to be harnessed to inform objective decision-making (see an example in Figure 2). Such solutions have been applied in the oil and gas industry to manage severe weather risk from tropical cyclones for a number of years. Typical data streams include forecast data and *in situ* observations, which may be combined with data from marine coordination software and geo-referenced personnel and asset-tracking systems. Company severe weather policy is coded within the systems, in compliance with national response requirements, allowing appropriate risk levels to be implemented and adhered to. Such systems allow time for impact to be considered and the specific actions and checklists to be implemented in a way that simplifies the administrative side of the process and provides ease of communication across all parties working on a development.

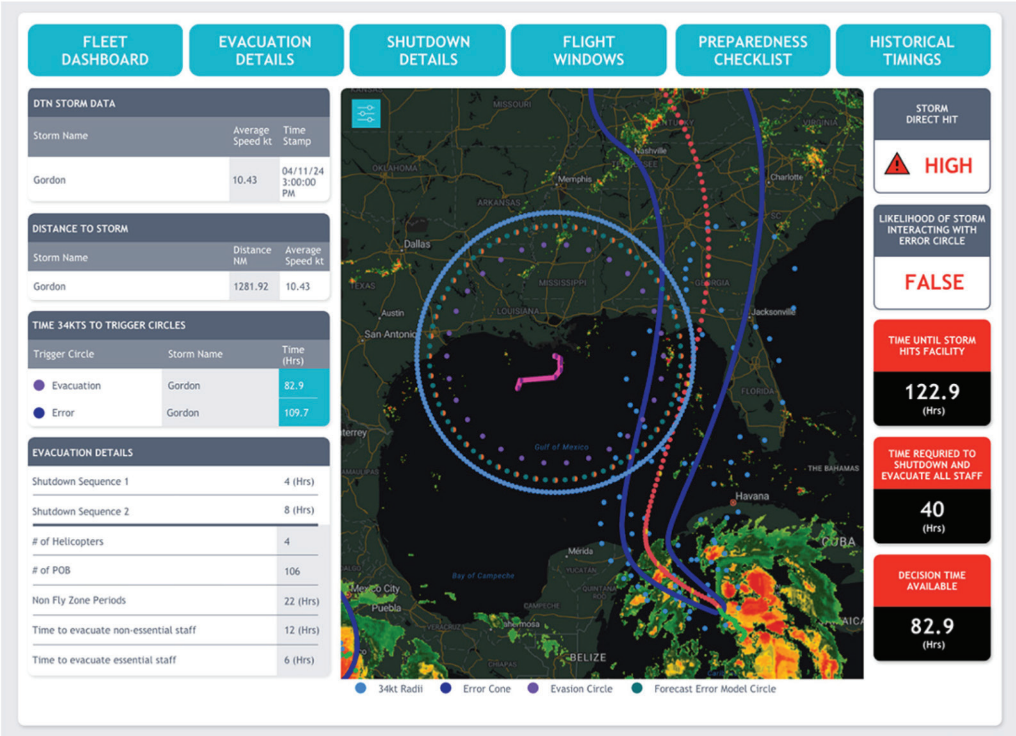


Figure 2: Example digital solution (copyright Fennex)

3 EXTRA-TROPICAL STORMS

3.1 INTRODUCTION

3.1.1 Extra-tropical storm characterisation for severe weather preparedness

Extra-tropical storm is the meteorological term for cyclonic systems that occur in latitudes 30°–60°. They are the ubiquitous gales that occur in Northern Europe and across the Northern United States. They are generally seasonal in nature occurring from autumn through spring. Where scheduling allows, operations that are particularly sensitive to this type of weather impact should be planned outside this period. They can persist for many days as they track across the ocean but are likely to impact a site for one to two days due to their forward speed.

High winds, large waves and heavy rain may be experienced during the passage of extra-tropical storms. The presence of high waves is dependent on long fetch lengths, so waves have a dependency on the directionality of the storm trajectory and wind speed.

Although extra-tropical storms may be named by national meteorological offices, the geographical range of the storms may mean that a particular named storm has no impact on an offshore wind project. As such, the onset of severe weather is perhaps less clear than during a tropical cyclone event (see section 4). Historical storm tracks and intensities can be used to develop a view of the potential lead time, between storm development and impact, to evaluate the time available to implement mitigation measures.

The Physical Science Basis chapter of the Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Seneviratne, 2021) states that there '*is low confidence in past changes of maximum wind speeds and other measures of dynamical intensity of extratropical cyclones. However, poleward shifts in the storm tracks could lead to substantial changes in extreme wind speeds in some regions (medium confidence)*'.

In the USA, the frequency of spring severe convective storms is projected to increase, leading to a lengthening of the severe convective storm season (*medium confidence*); evidence in other regions is limited.

To minimise the risk of climate change impacts, the climate within an ORED should be monitored using available *in situ* measurements, models, climate models and predictive analytics. Changes to the climate over the timescales of a project are particularly hard to predict given the uncertainty in emission scenarios. Therefore, trend analysis from recent years may offer some guidance, although removal of inter-annual and decadal climate signals can be challenging.

3.1.1.1 Additional weather hazards

In addition to the large-scale extra-tropical storms, a number of other hazards may occur within the extra-tropical storms, or as a different type of cyclonic system:

Sting jets are associated with extra-tropical storms but are rare events that generally occur in high return period storms. Sting jets are small-scale features that are typically <125 miles (200 km) in width and last several hours and can drive tropical cyclone force winds (up to 125 mph (56 ms^{-1})). Sting jets are difficult to forecast and typically are not considered in extreme values calculated for operations or engineering design. Sting jets are generally visible in satellite data, and therefore it is essential that the forecaster considers near real-time data to identify potential development of sting jets to provide warning of these events. It should be noted that sting jets form within extra-tropical storms, so mitigation provided for these events may be sufficient to remove personnel and mobile assets from the path of sting jets; however, fixed infrastructure may be impacted.

Polar lows are cyclonic features that have horizontal length scales of 320–620 miles (200–1 000 km). They give rise to gale-force winds, often accompanied by heavy snow showers. Their powerful winds can lead to the formation of large waves, driven by the influence of a moving fetch that enhances wave growth. Polar low-driven significant wave heights up to 11 m have been reported (Rojo, 2019). As such, they represent a severe weather hazard. Polar lows are not generally well represented in forecast models, and as such must be monitored using satellite data and, if available, *in situ* observations.

3.1.2 Weather forecasting

It is common practice to use deterministic forecasts for regions in which extra-tropical storms occur. These provide a single prediction of future conditions and typically include minimal information on the trajectory of cyclonic features, rather focusing on a single location or area. As such, it is difficult to understand the uncertainty associated with the predicted trajectory of the cyclonic low and associated area of high winds and whether minor deviations to the predicted trajectory could lead to impact on personnel and assets.

ISO 19901-1 *Oil and gas industries including lower carbon energy – Specific requirements for offshore structures* recommends the use of probabilistic forecasts to better understand potential storm tracks, and a probabilistic approach to the exceedance of parameter thresholds that trigger mitigation measures. Examples of such forecast products are shown in Figure 3. The top panel shows a time series of significant wave height from the individual ensemble members; the centre panel shows the probability of exceedance of a threshold at the same location, and the lower panel provides a spatial view of the probability of significant wave height exceeding a 6 m threshold. The spread of significant wave height estimates in the top panel helps to understand the confidence in the predictions; if all the models are closely aligned, then confidence is high. If the time series shows significant divergence, then the models may be exhibiting differences in magnitude or timing of events.

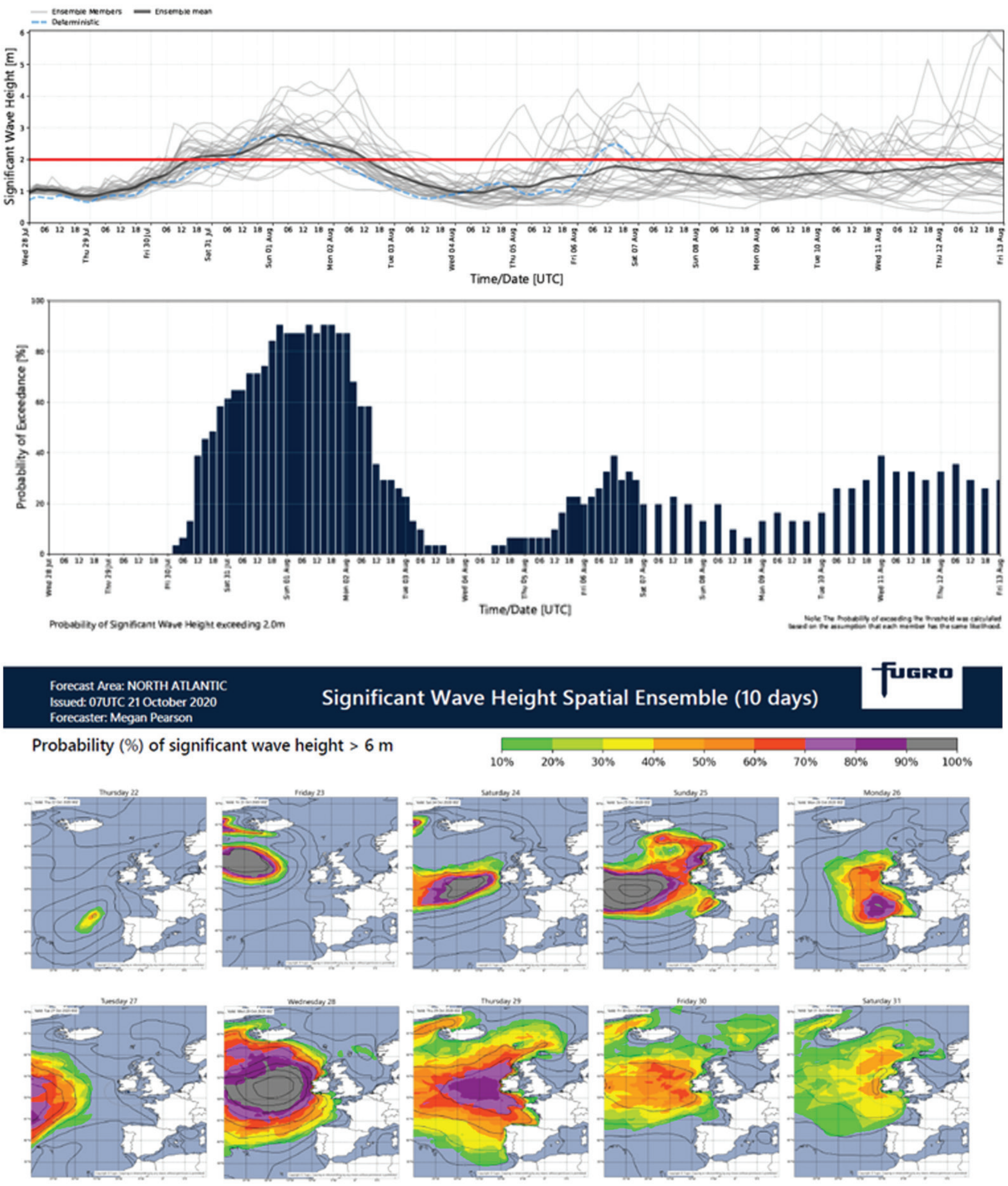


Figure 3: Example probabilistic forecast products (copyright Fugro)

3.1.3 Extra-tropical storm hazards

Hazards resulting from extra-tropical storms may include:

- high wind speeds;
- high wave heights;
- heavy rain, and
- poor visibility.

Each of these hazards should be evaluated with respect to the risk to the offshore wind farm personnel and infrastructure. This should be undertaken for each phase of the project and across all activities to allow the appropriate responsible party to be identified as part of this process, e.g. operator, contractor, regulatory body, etc. As this type of storm is a regular winter occurrence, with minimal impact on routine operations other than weather downtime, a definition for severe conditions should be established.

This could be considered from a metocean perspective, for example relating the threshold to a particular return period such as 10 years. Although this is relatively easy to implement, it does not address the practical limits on metocean parameters that trigger significant responses to severe weather. The use of return periods is common in the design of sea fastenings (for example, DNVGL-ST-N001 *Marine operations and marine warranty*), and perhaps for vessels transporting components during the construction phase, this offers a reasonable approach.

However, it is recommended that the best approach is to consider the parameter thresholds (e.g. maximum significant wave heights, wave period, surface and at height wind speeds, minimum visibility, etc.) that drive significant responses to mitigate a severe weather impact. The latter approach has been adopted in the oil and gas industry as good practice for evacuation of manned platforms with reduced airgap.

In practice, a hybrid approach may be required, depending on the phase of the project and associated activity.

3.2 PLANNING

OREIs should develop extra-tropical storm preparation plans for areas in which extra-tropical storms are credible scenarios and can impact the safety of personnel or the operations of the site. Extra-tropical storm preparation plans should include a timeline of activities to shut down the operations (if necessary) and should address the following, at a minimum:

- Activities that could be impacted by an extra-tropical storm.
- Roles and responsibilities for key personnel associated with initiation and implementation of the plan.
- Scenario planning for impact of extra-tropical storms on coastal fabrication/ marshalling yards, and identification of engineering measures to minimise damage.
- Use of meteorological service(s) to monitor weather and sea conditions and provide real-time alerts using forecasting tools.
- Timeline of events, with T-times that indicate when the activities are to occur in relation to the anticipated time of impact. The T-time is the transition time, typically in hours, it takes to secure a wind turbine generator (WTG)/platform/vessel and evacuate/evade the weather event. The timeline should include the following information:
  - timeline and method for evacuation of staff;
  - movement of marine vessels, including the location of where the vessels will travel to for shelter;
  - relevant coastguard port conditions as they may affect vessel movement, and
  - shutdown of operations.
- Method of communication and accounting for employees during the evacuation.
- Establish back-to-work procedures.

3.2.1 Risk assessment

Extra-tropical storm risk is likely to vary significantly across the project phases, and the party responsible for managing the risk will vary too.

The risk assessment should:

- Identify the metocean parameter thresholds (wind speed, wave height, etc.) under extra-tropical storm conditions that could give rise to:
  - a major incident (threat to life or assets no longer being deemed safe for personnel);
  - the need for personnel/vessel/other evacuation, and
  - protection of people from and during response to a severe weather event.
- Identify the mitigation measures for the identified risks.
- Evaluate the time required to implement mitigation measures.
- Determine the criteria with respect to distance of high winds/waves from the assets that is required to provide sufficient time to implement mitigation measures.

A number of generic risks were identified for each phase of the life cycle, and these are outlined in 3.2.1.1 to 3.2.1.3.

The accountable organisation should ensure that the risk assessment undertaken by the responsible party ensures the overall project is not exposed to unacceptable risks. In some instances, i.e. particularly strong storms, it will be appropriate for the accountable organisation to declare the ORED closed to operations to protect assets from potential damage from vessels.

3.2.1.1 Development

During the development phase, the main risks will be to survey contractor's personnel and vessels. As such, it is likely that the responsibility for managing the risk will primarily lie with the survey companies. A number of generic impacts are shown in Table 2. The requirement to undertake a project-specific risk assessment that addresses severe weather remains.

Table 2: Extra-tropical storm generic impacts and mitigation – development

Potential impacts	Mitigation measures
Exposure of personnel and vessels to high winds and waves	Identify safe havens (ports, sheltering behind land masses, etc.) and move based on appropriate percentage probability of being impacted by storm Ensure safe haven has sufficient capacity for vessels operating in region, not just those within the scope of this risk assessment
Delays to schedule and impact on subsequent analysis and use	Schedule in favourable season

It is noted that safe havens in nations experiencing extra-tropical storms are not generally led by a national body, such as coastguard, but rather contractor-led. Responsible and delegated individuals should establish appropriate processes for safe havens.

The accountable organisation should also consider later phases and consider mitigation of risk through safety by design.

3.2.1.2 Construction

The risks during the construction phase should consider the potential impact on incomplete structures, both offshore and in marshalling and manufacturing ports. There may be a large number of contractors working within the geographical scope of the development, each with vessels and operations that may be impacted.

In addition to the impacts identified in Table 2, the impacts in Table 3 may require consideration. The requirement to undertake a project-specific risk assessment that addresses severe weather remains.

Table 3: Extra-tropical storm generic impacts and mitigation – construction

Potential impacts	**Mitigation measures**
Exposure of partially completed structures to severe winds and waves	Identify safe break points for construction activities that allow partially completed structures to withstand severe weather impacts Secure site in a safe state
Exposure of components in marshalling and manufacturing ports to high winds	Identify safe conditions for components and ensure they are adhered to on approach of storm Undertake evacuation drills and practice securing components Ensure shelters and emergency equipment are available on site
Exposure of vessels with limited mobility to severe winds and waves	Identify procedures to allow vessel to regain mobility and proceed to a safe haven. For example, cable-layings vessel may have to drop the cable and move off station
Inability to adhere to work time regulations – marine crew, construction technicians, passengers	Ensure appropriate crewing levels are in place

3.2.1.3 Operations

Extra-tropical storms will likely give rise to conditions above routine operating thresholds, and given the ability to forecast such events several days out, it is unlikely that there should be a need to expose any personnel to the conditions experienced during the passage of an extra-tropical storm.

Mobile assets, such as service operation vessels (SOVs), and any vessels supporting intervention may be at increased and unacceptable risk and, if so, should be moved to a safe haven. The generic impacts and mitigation are similar to those contained in Tables 2 and 3. An additional potential impact is highlighted in Table 4. The requirement to undertake a project-specific risk assessment that addresses severe weather remains.

Table 4: Extra-tropical storm generic impacts and mitigation – operations

Potential impacts	Mitigation measures
Exposure of cables due to scour or geomorphological changes	Engineering design to address storm impacts on cables

3.3 EVENT ACTIONS

Prior to the onset of the severe weather conditions, the appropriate mitigation measures should be implemented. Guidance on mitigation measures for vessels is provided in Annex B. These are based on the *Heavy weather precautions* published by the Shipowners' Club (2023).

3.3.1 Evacuation of personnel and equipment

It is highly preferable that adequate provision is given to the planned and controlled evacuation of personnel from offshore structures and any work in progress secured in a safe state. This includes:

- Sufficient passage time for the vessels to leave the site and reach a safe haven.
- Helicopter flight times, either to leave the area or to undertake evacuation flights.

In the event that personnel become stranded on a structure, the relevant ERP should be activated. Wind turbines should be equipped with emergency equipment for personnel abandonment which typically contain water and food for two days and sleeping bags for six people. Regular communication checks should be established with stranded teams to ensure their continued welfare and keep them informed of potential rescue opportunities.

3.3.2 Vessel management

Specific actions to ensure safety of vessels, at sea and in port, are provided in Annex B.

3.3.3 Storm monitoring and declaration of safe conditions

In situ observations and forecasts should be monitored. When the accountable organisation has declared the ORED closed to operations, it should have clarity on conditions that allow it to reopen. This should be communicated to responsible parties, who can then assess if the conditions comply with their return-to-work limits.

3.4 POST-STORM RECOVERY

3.4.1 Personnel safety

All personnel should be accounted for and clear return-to-work procedures adhered to.

3.4.2 Evaluation of infrastructure for damage

3.4.2.1 Construction

Manufacturing and marshalling ports may have suffered damage following extra-tropical storm passage and access control measures implemented to minimise risks to personnel. Inspection of the facilities and components/structures should be undertaken by qualified personnel in accordance with the following:

1) Visual survey of components and structures in manufacturing and marshalling ports. Care should be taken to ensure observations are undertaken safely. Any damage should be noted and a management of change process applied to ensure the damage is safely addressed, and the condition is acceptable for further use.
2) Visual survey of the facilities including cranes, access platforms, etc.

The damage status should be reported to the Designated Individual who is responsible for aggregating the damage information. The damage should be verified and appropriate measures undertaken to undertake corrective action. A formal process should be applied to ensure the damage is safely addressed/rectified, and the condition should be certified as acceptable for further use.

Offshore assets may require visual survey by unmanned aerial systems (UAS), vessel, autonomous underwater vehicles (AUV), remotely operated vehicles (ROV) or helicopter across the ORED to identify structural damage. UAS operations should be managed in compliance with EI3576 *G+ Good practice guidelines for unmanned aircraft systems in the offshore wind industry.*

The Designated Individual should implement a management of change process to ensure the damage is safely addressed/rectified, and the condition should be certified as acceptable for further use.

3.4.2.2 Operations

The supervisory control and data acquisition (SCADA) data can be a useful indicator to identify defects on a particular structure.

Offshore installed closed-circuit television (CCTV) systems can also provide visual indications of structural defects and damage. Of particular importance is the access infrastructure.

Visual survey by UAS, vessel, AUV, ROV or helicopter may be required across the site to identify structural damage, including mooring system for floating wind. UAS operations should be managed in compliance with EI3576 *G+ Good practice guidelines for unmanned aircraft systems in the offshore wind industry*.

A visual survey or geophysical survey of cable routes is recommended if seabed conditions give rise to risk of exposure under storm conditions.

Any damage should be noted and a formal process applied to ensure the damage is addressed/rectified in a safe manner. The criteria for the acceptable condition of damaged structures/equipment should be clearly defined.

3.4.3 Restoration of operations

3.4.3.1 Development

Procedures for the restoration of survey operations should be documented and implemented. Once the accountable organisation has declared the site open, these procedures should be followed, bearing in mind that the ultimate decision for vessels lies with the master.

3.4.3.2 Construction

When meteorological conditions have returned to acceptable and post-storm actions have been completed, under the direction of the Designated Individual, the marine coordinator may open the site to construction operations. Where available, *in situ* observations should be used to inform decision-making. Since there may still be heavy swells that affect the operability of vessels, it would be the decision of the vessel master whether it enters the site.

3.4.3.3 Operations

When meteorological conditions have returned to acceptable and post-storm actions have been completed, under the direction of the severe weather management team (or emergency response team), the marine coordinator may open the site to operations. Since there may still be heavy swells that affect the operability of vessels, it would be the decision of the vessel master whether it enters the site. Both the vessel crew and technicians/personnel entering the offshore structure have a responsibility to assess the condition of the asset. The following guidance is common to crew transfer vessels (CTVs), SOVs, and walk-to-work or bring-to-work systems:

- On approach to the OREI, keep a good visual lookout for:
  - anything in the water around the OREI;
  - potential objects overhead that may represent a falling object hazard;
  - debris or ropes entangled in the foundation, and
  - loose equipment, deck plates or items around the point of entry to the deck level.
- When the top of the ladder is reached, the technician should visually inspect the state of the deck for loose gratings, damaged fittings, obstructions and objects that could fall from height.
- If a davit crane is fitted, this should be visually inspected and functionally tested in accordance with manufacturer’s instructions before being used for lifting equipment.
- When accessing the internal structure, check for water ingress, signs of electrical fire around cabinets, cable damage, adequate lighting and positioning of safety and emergency equipment.
- In wind turbines, visually inspect and functionally check the lift system in accordance with manufacturer’s instructions.
- In wind turbine nacelles, check for unsecured items that could have caused damage, fluid leaks and spills resulting from the sway of the tower.
- On the roof/upper deck of the structure, check for damaged aerials, monitoring equipment and lighting/visualisation systems.

At each step of the first entry after a severe weather event, the circumstances should be assessed before moving on to the next step and declaring the asset fit for operational use. If it is unsafe to continue the access procedure, the operation should be aborted, and personnel should egress the structure. Dynamic risk assessment should be a continuous consideration, and a clearly defined management of change process established.

3.4.3.3.1 CTVs

When attempting access to structures by CTV via the ladder, the following actions are advised:

- If the fall arrest/access system appears damaged, it should not be used. Depending on site rules, this may prohibit access, or technicians may be required to revert to double-hook climbing.
- On approach to the ladder, visually inspect the straightness of the legs and rungs, any apparent defects in the fixing of the ladder to the structure and condition of the fall arrest/access system.

3.4.3.3.2 Walk-to-work or bring-to-work systems

When attempting access to structures by walk-to-work or bring-to-work systems, the following actions are advised:

- Visual check of the system prior to test connection.
- Make a test connection to assure the integrity of the bracket/push-on plate.

3.4.4 Lessons learned

Safety incidents and near misses associated with storm events should be reviewed and lessons learned applied to future activities to prevent future recurrence. Where structural damage has occurred, consideration should be given to potential amendments to engineering of the structure in terms of retrofit or to take forward in other projects.

The activation and decision-making process undertaken by the severe weather management team should be reviewed for lessons learned since these events are infrequent.

Lessons learned should be documented according to the responsible party's HSE plan. Sharing should be to similar projects internally and where appropriate as industry learnings through the G+ Learning from incidents initiative or other appropriate channels.

4 TROPICAL CYCLONES

Tropical cyclones are commonly known as hurricanes in the Americas, typhoons in Southeast Asia and cyclones in Australia. Tropical cyclones can often include multiple hazards, such as extreme winds and waves, heavy rainfall, storm surge and flooding, lightning and tornadoes. Due to their broader societal impact, the WMO has dedicated entities called Tropical Cyclone – Regional Specialized Meteorological Centres (TC-RSMCs) and Tropical Cyclone Warning Centres (TCWCs) that provide advisories and bulletins with up-to-date first-level basic meteorological information on all tropical cyclones, hurricanes and typhoons everywhere in the world. The Tokyo TC-RSMC supports Southeast Asia (Japan, South Korea, Taiwan, China), Miami TC-RSMC supports the USA and the Melbourne TCWC supports Australia.

A tropical cyclone is a rapidly rotating storm that is fuelled by the heat contained in tropical oceans. They are seasonal in nature and can persist for many days as they track across the ocean. As a storm develops from a tropical depression, it is named by the regional centre once the 1-minute or 10-minute (dependent on centre) wind speed exceeds 34 knots. This is typically used as the definition for the presence of a tropical cyclone; however, for the purposes of operational planning, the proximity of the storm track generally defines when responses are made to the hazard.

Historic track and storm information including wind speed, central pressures and other parameters is available from a variety of sources including *The International Best Track Archive for Climate Stewardship (IBTrACS)* project. Historic tracks for the Americas are illustrated in Figure 4 and those for Southeast Asia in Figure 5. Different centres use different scales for the wind speeds, such that the Americas is colour coded according to the Saffir–Simpson Hurrican Wind Scale and Southeast Asia according to the Japanese Meteorological Agency scale.

Climate change will have an effect on future tropical cyclone frequency, intensity, forward speed and tracks. The warming ocean offers a greater heat source from which tropical cyclones draw their energy. Additionally, the geographical range of the minimum sea temperature to maintain tropical cyclones, nominally 26 °C (79 °F), is likely to move poleward. Seneviratne (2021) states that:

- The global proportion of category 3–5 tropical cyclones has increased over the past 40 years.
- In the USA, the forward speed of tropical cyclones has likely slowed since 1900, which increases wave heights and storm surges.
- The proportion of intense tropical cyclones, average peak tropical cyclone wind speeds and peak wind speeds of the most intense tropical cyclones will increase on the global scale with increasing global warming (*high confidence*). The total global frequency of tropical cyclone formation will decrease or remain unchanged with increasing global warming (*medium confidence*).

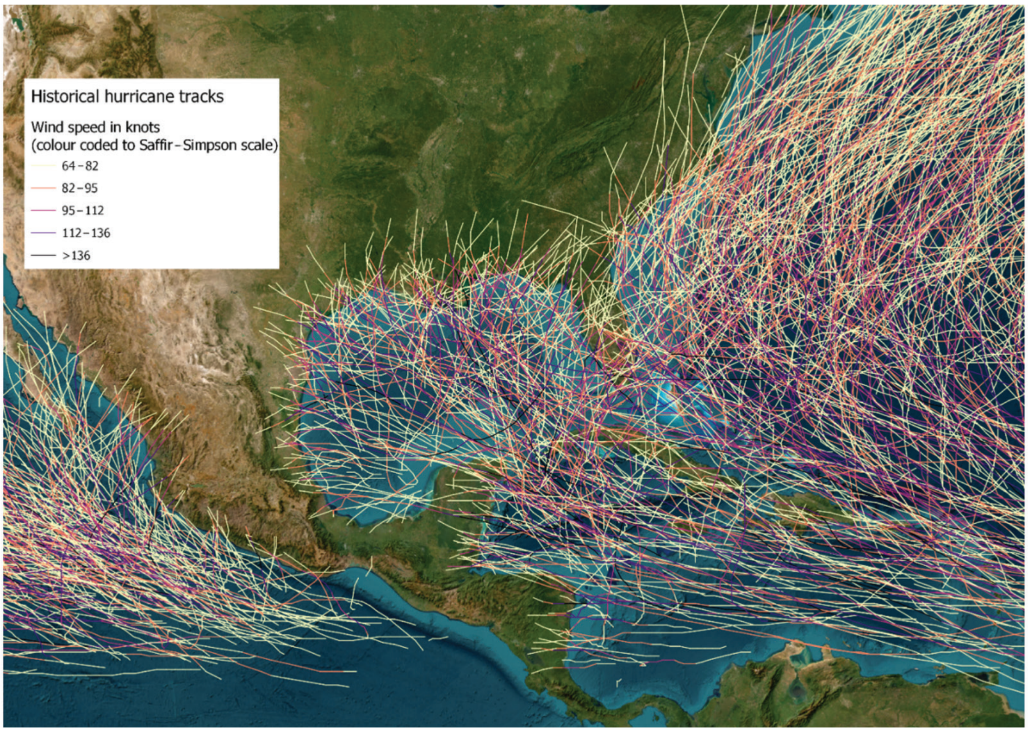


Figure 4: Historical hurricane tracks (Americas)

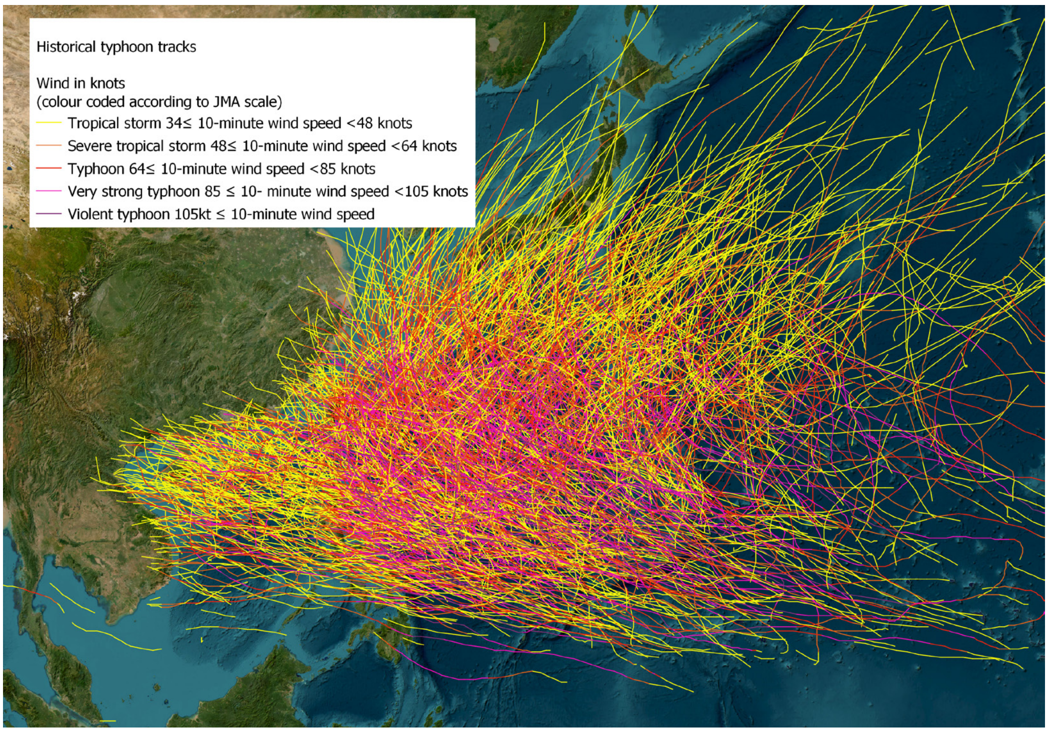


Figure 5: Historical typhoon tracks (Southeast Asia) JMA, Japanese Meteorological Agency

4.1 INTRODUCTION

4.1.1 Tropical cyclone characterisation for severe weather preparedness

To understand the potential risks posed by tropical cyclones, consideration should be given to historical cyclone tracks and strengths. For a particular location, it is recommended that the lead times between the development of historical tropical cyclones and their impact on the wind farm and associated assets be assessed to provide a view of the lead time that will be available for evacuation.

Where wind farms are not close to the generation region of tropical cyclones, there will likely be significant lead time; however, analysis of historical storm tracks will allow the forward speed of storms to be assessed and hence the likely lead time to enable evacuation of personnel and assets to safe havens.

4.1.2 Tropical cyclone forecasting

A range of weather forecast types is available for tropical cyclones. It is considered best practice to use a probabilistic forecast product. Probabilistic forecasts utilise the predictions from a number of forecast model runs (ensemble) that may use different physical parameterisations and/or perturbations to the initial conditions. Having multiple predictions of the future allows probabilistic forecast products to be generated.

Examples of ensemble forecast products for tropical cyclones are shown in Figure 6. The individual ensemble track forecasts shown in the left panel readily show the variation in estimated storm track and strength. The right panel shows the probability of a storm passing within 300 nm of a location, with the date/time of the centre of the storm shown at various forecast horizons. Many other spatial and time series products are available. These include spatial maps showing the probability of a wind speed threshold being exceeded, and time series showing the percentage probability that wind speeds may fall within certain wind speed bands.

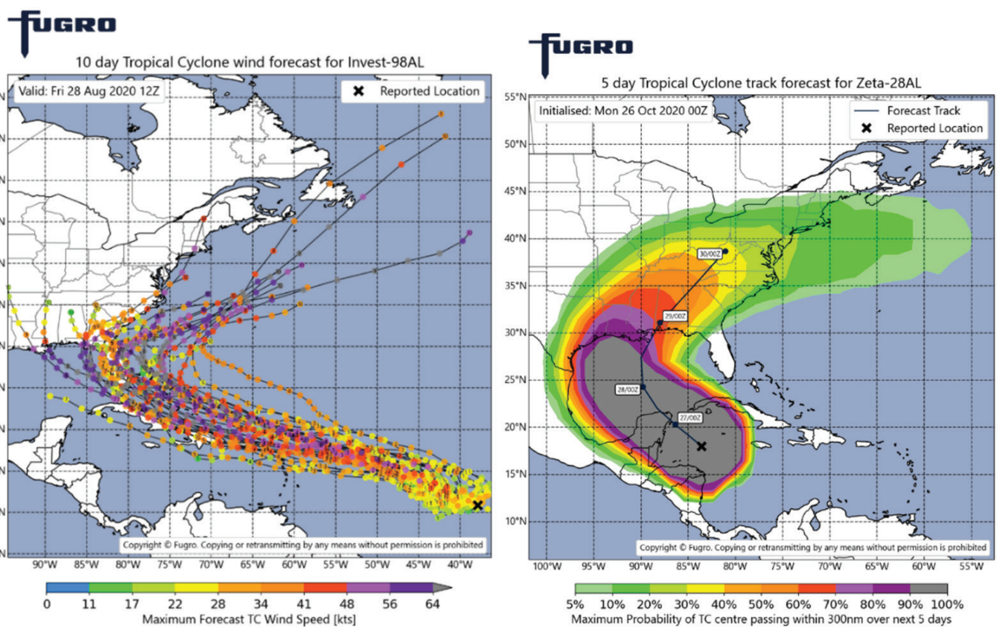


Figure 6: Examples of probabilistic spatial forecast (copyright Fugro)

It should be noted that in some jurisdictions, the government tropical cyclone forecast agency issues forecasts to inform the response of ports and/or coastguard in their readiness procedures. As such, it will be critical to ensure that the choice of forecast provider is aligned to local regulations.

4.1.3 Tropical cyclone hazards

Tropical cyclones give rise to strong winds and large waves that are hazardous to vessels and potentially to infrastructure offshore and in the coastal region.

Additionally, positive storm surge and wave action will likely cause flooding of coastal sites. Intense rainfall may lead to pluvial flooding (i.e. surface drains unable to cope with rainwater) at the coast.

Negative storm surge may also occur during the passage of a tropical cyclone, which may result in reduced under-keel clearance. Additionally, tropical cyclones often result in changes to bathymetry, which may impact navigation channels.

The rotating nature of the cyclone means that the directionality of the winds may well change rapidly during the passage of a storm. For example, if a storm tracks north directly across a site, the leading edge of the storm will have easterly winds (northern hemisphere) and once the eye has passed over the site westerly winds will prevail. If an asset is subject to the passage of the tropical cyclone eye, it is essential that the turbine remains in parked (standing still or idling) until the tropical cyclone has passed, and that the turbines do not move to start-up following passage of the eyewall. As the other side of the eyewall passes over, a very rapid increase in wind speed and change in direction will occur that will likely result in damage.

4.2 PLANNING

Designated Individuals should develop storm preparation plans for areas in which tropical cyclones are credible scenarios and can impact the safety of personnel or the operations of the site. Tropical storm preparation plans should include a timeline of activities to shut down the operations (if necessary) and should address the following, at a minimum:

- Establish a tropical cyclone control centre. Consideration should be given to the redundancy of power and communications of the centre and whether its location may be impacted by the same storm as the ORED. It is common for a redundant centre to be maintained to ensure the control centre can operate for the duration of tropical cyclone conditions.
- Activities that could be impacted by a tropical cyclone.
- Roles and responsibilities for key personnel associated with initiation and implementation of the plan.
- Use of a meteorological service to monitor weather and sea conditions and provide real-time alerts using forecasting tools.
- Timeline of events, with T-times that indicate when the activities are to occur in relation to the anticipated time of impact. The T-time is the transition time, typically in hours, it takes to secure a platform/vessel and evacuate/evade the weather event. The timeline should include the following information:
  - timeline and method for evacuation of staff;

  - movement of marine vessels, including the location of where the vessels will travel to;
  - helicopter flight times for evacuation of personnel, or removal of helicopter if already deployed at an asset;
  - relevant coastguard port conditions as they may affect vessel movement;
  - shutdown of operations, and
  - method of communication and accounting for employees during the evacuation.
- Establish back-to-work procedures.

4.2.1 Risk assessment

The risk assessment should:

- Identify the extreme metocean parameter thresholds (wind speed, wave height, etc.) under tropical storm conditions that could give rise to:
  - a major incident (threat to life or asset no longer being a safe haven);
  - the need for personnel/vessel/other evacuation, and
  - protection of people from and during response to a severe weather event.
- Identify the national regulations relating to tropical cyclones and the parties responsible for tropical cyclone management of ports and vessel traffic.
- Identify the mitigation measures for the identified risks.
- Evaluate the time required to implement mitigation measures.
- Determine the criteria with respect to distance of high winds/waves from the assets that is required to provide sufficient time to implement mitigation measures.

Responsible Individuals should develop tropical cyclone preparation plans for areas in which tropical cyclones may occur and can impact the safety of personnel or the operations of the site. Tropical cyclone preparation plans should include a timeline of activities to shut down the operations (if necessary) and should address the following, at a minimum:

- Activities that could be impacted by a tropical cyclone.
- Roles and responsibilities for key personnel associated with initiation and implementation of the plan.
- Use of a meteorological service(s) to monitor weather and sea conditions and provide real-time alerts using forecasting tools.
- Timeline of events, with T-times that indicate when the activities are to occur in relation to the anticipated time of impact. The T-time is the transition time, typically in hours, it takes to secure a platform/vessel and evacuate/evade the weather event. The timeline should include the following information:
  - timeline and method for evacuation of staff;
  - movement of marine vessels, including the location of where the vessels will travel to;
  - relevant coastguard port conditions as they may affect vessel movement;
  - shutdown of operations, and
  - securing loose material and making facilities storm-safe and secure.
- Method of communication and accounting for employees during the evacuation.

A number of generic risks were identified for each phase of the life cycle, and these are outlined in 4.2.1.1 to 4.2.1.3.

The accountable organisation should ensure that the risk assessment undertaken by the responsible party ensures the overall project is not exposed to unacceptable risks. In some instances, i.e. particularly strong storms, it will be appropriate for the accountable organisation to declare the ORED closed to operations to protect assets from potential damage from vessels.

4.2.1.1 Development

During the development phase, the main risks will be to the survey contractor's personnel and vessels. As such, it is likely that the responsibility for managing the risk will primarily lie with the survey companies. A number of generic impacts are shown in Table 5. The requirement to undertake a project-specific risk assessment that addresses severe weather remains.

Table 5: Tropical cyclone generic impacts and mitigation – development

Potential impacts	Mitigation measures
Exposure of personnel and vessels to high winds and waves	Identify safe havens (see 4.2.2) and transit move based on appropriate percentage probability of being impacted by storm Identify safe havens (see 4.2.2) and lead times to allow safe evacuation based on percentage probability criteria of being impacted by storm
Delays to schedule and impact on subsequent analysis and use	Schedule outside tropical cyclone season to remove risk
Changes to bathymetry	Ensure all vessel operators maintain awareness of notice to mariners advising impacts on navigation

The accountable organisation should also consider later phases and consider mitigation of risk through safety by design.

4.2.1.2 Construction

The risks during the construction phase should consider the potential impact on incomplete structures, both offshore and in marshalling and manufacturing ports. There may be a large number of contractors working within the geographical scope of the development, each with vessels and operations that may be impacted.

In addition to the impacts identified in Table 5, the impacts in Table 6 may require consideration. The requirement to undertake a project-specific risk assessment that addresses severe weather remains.

Table 6: Tropical cyclone generic impacts and mitigation – construction

Potential impacts	Mitigation measures
Exposure of vessel to severe winds and waves	Identification of safe havens
Exposure of partially completed structures to severe winds and waves	Identify safe break points for construction activities that allow partially completed structures to withstand severe weather impacts Secure site in a safe state
Exposure of marshalling and manufacturing ports to high winds	Identify safe conditions for components and ensure they are adhered to on approach of storm Identify safe conditions for plant (cranes, shelters, etc.) and ensure they are adhered to on approach of storm Tie down ladders and consider dismantling platforms for working at height Relocate fabrication equipment such as welding machines to protected locations
Exposure of marshalling and manufacturing ports to flooding	Ensure risk of flooding is addressed with port owners during contract negotiations Identify areas that may suffer from flooding and implement preventative measures Ensure drainage is clear of debris Remove pollutants that may be waterborne
Risks from utilities	Isolate utility lines (gas, electricity)
Exposure of vessels with limited mobility to severe winds and waves	Identify procedures to allow vessel to regain mobility and proceed to a safe haven. For example, cable-laying vessels may have to drop the cable and move off station
Inability to adhere to work time regulations – marine crew, construction technicians, passengers	Ensure appropriate crewing levels are in place

4.2.1.3 Operations

Tropical cyclones will give rise to conditions above routine operating thresholds, and given the ability to forecast such events several days out, it is unlikely that there should be a need to expose any personnel to the conditions experienced during the passage of an extra-tropical storm.

Mobile assets, such as SOVs, and any vessels supporting intervention may be at increased and unacceptable risk and, if so, should be moved to a safe haven. The generic impacts and mitigation are similar to those contained in Tables 5 and 6. The requirement to undertake a project-specific risk assessment that addresses severe weather remains.

4.2.2 Safe havens

In many jurisdictions, the coastguard is central to responses, with many implementing tropical cyclone response plans based on the tropical cyclone warnings from the national weather service. Guidance on national implementation of safe havens is provided in Annex C.

4.2.2.1 Ports

Ports are often identified as safe havens. Ports in tropical cyclone regions typically address tropical cyclone impact within their safety management systems (SMS) with risks addressed and operating protocols documented.

Port facilities are vulnerable to the following:

- Changes to bathymetry/debris in channels resulting in reduced under-keel clearance.
- Damage/disruption to aids to navigation.
- Oil spill and hazardous substance releases.
- Vessel groundings, allisions and collisions.
- Bridge damage – reduced clearance for vessels.
- Damage to wharfage equipment.
- Damage to equipment in storage/loading areas.
- Overcrowding when large numbers of vessels are simultaneously seeking a safe haven.

The risks should be evaluated with respect to the potential impact on the ORED project and if appropriate, further risks identified and mitigation measures adopted. This is particularly true for manufacturing and marshalling ports where the accountable organisation may have greater responsibility.

Typically, ports implement procedures, triggered by time horizons to the impact of wind speed thresholds, such as:

- Request vessels in port to notify port authority of intention to depart or remain in port.
- Implement port conditions that control vessel traffic and also address risk to port infrastructure from vessels remaining in port.
- Require vessels remaining in port to unload if load is considered hazardous to the port infrastructure.
- Communicate port conditions with the maritime community.
- Offer specific mooring arrangements depending on the intensity and direction of the typhoon.

The party responsible for these activities varies with jurisdiction, for example in the USA the US Coast Guard is responsible, whereas in Taiwan the Taiwan International Ports Corporation Limited is responsible. Further details can be found in Annex C.

4.2.2.2 Designated anchorages

Designated anchorages are normally controlled by a port. The port will provide specific instructions for offshore anchorages including whether vessels are permitted to remain at anchor. The anchoring method for tropical cyclone conditions is likely to vary from normal anchoring methods, with greater lengths of anchor chain required. Additionally, multiple anchors may be required. The anchoring method should be clearly documented in the vessel's SMS to mitigate against the anchor dragging.

A risk assessment should include consideration of vital infrastructure (e.g. liquefied natural gas (LNG) berths, subsea cables, pipelines, etc.) and other anchoring ships. If the planned anchorage changes from that in the risk assessment, then a management of change process should ensure the anchoring remains safe.

During periods of anchoring, an anchor watch should be implemented on the bridge, appropriate alarms on position should be set and the vessel response to the conditions (yaw and sway) should be monitored. The anchor watch should also monitor vessels in the vicinity to be aware of potential collision. Vessels' propulsion plants should be kept in a higher state of readiness should they need to respond to a dragging anchor of their own or nearby vessels.

4.2.2.3 Evacuation from tropical cyclone impact

Where no appropriate port or anchorages can be found, it may be necessary to evacuate a vessel to avoid impact by the typhoon. This will require careful consideration of the predicted track of the tropical cyclone, including potential outliers in a probabilistic forecast. Typically, in the northern hemisphere, winds and waves are less severe to the left of the storm track.

4.3 EVENT ACTIONS

Prior to the onset of the tropical cyclone or storm conditions, the appropriate mitigation measures should be implemented.

4.3.1 Evacuation of personnel and equipment

It is highly preferable that adequate provision is given to the planned and controlled evacuation of personnel from offshore structures and any work in progress secured in a safe state. This includes sufficient passage time for the vessels to leave the site and reach a safe haven.

In the event that personnel become stranded on a structure, the relevant ERP should be activated. Wind turbines should be equipped with emergency equipment for personnel abandonment, which typically contain water and food for two days and sleeping bags for six people. Regular communication checks should be established with stranded teams to ensure their continued welfare and keep them informed of potential rescue opportunities.

4.3.2 Vessel management

Specific actions to ensure the safety of vessels, at sea and in port, are provided in Annex B.

4.3.3 Storm monitoring and declaration of safe conditions

In situ observations and forecasts should be monitored. When the accountable organisation has declared the ORED closed to operations, it should have clarity on conditions that allow it to reopen. This should be communicated to responsible parties, who can then assess if the conditions comply with their return-to-work limits.

4.4 POST-STORM RECOVERY

4.4.1 Personnel safety

All personnel should be accounted for and clear return-to-work procedures adhered to.

4.4.2 Evaluation of infrastructure for damage

4.4.2.1 Construction

A visual survey of components and structures in manufacturing and marshalling ports should be undertaken. Care should be taken to ensure observations are undertaken safely. Any damage should be noted and a management of change process applied to ensure the damage is safely addressed, and the condition is acceptable for further use.

Visual survey should be undertaken by UAS, vessel, AUV, ROV or helicopter across the site to identify structural damage. UAS operations should be managed in compliance with EI3576 *G+ Good practice guidelines for unmanned aircraft systems in the offshore wind industry*.

Any damage should be noted and a management of change process applied to ensure the damage is safely addressed/rectified, and the condition should be certified as acceptable for further use.

4.4.2.2 Operations

The SCADA data can be a useful indicator to identify defects on a particular structure.

Offshore installed CCTV systems can also provide visual indications of structural defects and damage. Of particular importance is the access infrastructure.

Visual survey by UAS, vessel, AUV, ROV or helicopter may be required across the site to identify structural damage. UAS operations should be managed in compliance with EI3576 *G+ Good practice guidelines for unmanned aircraft systems in the offshore wind industry*.

A visual survey or geophysical survey of cable routes is recommended if seabed conditions give rise to risk of exposure under storm conditions.

Any damage should be noted and a management of change process applied to ensure the damage is addressed/rectified in a safe manner. The criteria for the acceptable condition of damaged structures/equipment should be clearly defined.

4.4.3 Restoration of operations

4.4.3.1 Development

Procedures for the restoration of survey operations should be documented and implemented. Once the accountable organisation has declared the site open, these procedures should be followed, bearing in mind that the ultimate decision for vessels lies with the master.

4.4.3.2 Construction

When meteorological conditions have returned to acceptable and post-storm actions have been completed, under the direction of the Designated Individual, the marine coordinator may open the site to operations. Where available *in situ* observations should be used to inform decision-making. Since there may still be heavy swells that affect the operability of vessels, it would be the decision of vessel master whether it enters the site.

4.4.3.3 Operations

When meteorological conditions have returned to acceptable and post-storm actions have been completed, under the direction of the severe weather management team (or emergency response team), the marine coordinator may open the site to operations. Since there may still be heavy swells that affect the operability of vessels, it would be the decision of the vessel master whether it enters the site.

When attempting access to structures by CTV via the ladder, the following actions are advised:

- On approach to the OREI, keep a good visual lookout for:
  - anything in the water around the OREI;
  - potential objects overhead that may represent a falling object hazard;
  - debris or ropes entangled in the foundation, and
  - loose equipment, deck plates or items around the point of entry to the deck level.
- On approach to the ladder, visually inspect the straightness of the legs and rungs, any apparent defects in the fixing of the ladder to the structure and condition of the fall arrest/access system.
- If the fall arrest/access system appears damaged, it should not be used. Depending on site rules, this may prohibit access or require technicians to revert to double-hook climbing.
- When the top of the ladder is reached, the technician should visually inspect the state of the deck for loose gratings, damaged fittings, obstructions and objects that could fall from height.
- If a davit crane is fitted, this should be visually inspected and functionally tested in accordance with manufacturer's instructions before being used for lifting equipment.
- When accessing the internal structure, check for water ingress, signs of electrical fire around cabinets, cable damage, adequate lighting and positioning of safety and emergency equipment.
- In wind turbines, visually inspect and functionally check the lift system in accordance with manufacturer's instructions.
- In wind turbine nacelles, check for unsecured items that could have caused damage, fluid leaks and spills resulting from the sway of the tower.
- On the roof/upper deck of the structure, check for damaged aerials, monitoring equipment and lighting/visualisation systems.
- At each step of the first entry after a severe weather event, the circumstances should be assessed before moving on to the next step and declaring the asset fit for operational use. If it is unsafe to continue the access procedure, the operation should be aborted, and personnel should egress the structure. Dynamic risk assessment should be a continuous consideration, and a clearly defined management of change process established.

4.4.4 Lessons learned

The efficacy of the removal of personnel and assets from harm should be assessed.

Where structural damage has occurred to construction equipment (cranes, platforms, etc.) and/or wind farm components, consideration should be given to ensure that future mitigation measures minimise commercial risks arising from damage and delays to programmes.

Lessons learned should be documented according to the responsible party's HSE plan. Sharing should be to similar projects internally and where appropriate as industry learnings through the G+ *Learning from incidents* initiative or other appropriate channels.

5 EXTREME HEAT

5.1 INTRODUCTION

5.1.1 Extreme heat characterisation for severe weather preparedness

Extreme heat should be considered relative to a location's climate; the same meteorological conditions can constitute extreme heat in one place but not another. Similarly, if the workforce is not acclimatised to the local climate, their threshold for physiological responses to extreme heat may be lower. Most meteorological services define extreme heat as the 95 or 97,5 percentile air temperature, i.e. the temperature that historically has exceeded 5 or 2,5 % of the total time. This may be done on an annual or seasonal basis. This concept is illustrated in Figure 7. The plots show all-year and July statistics of the minimum, 1, 2, 5, 5, 10, 20, …, 80, 90, 95, 97,5, 99 and 100 % values of non-exceedance of air temperature at 2 m. The extreme heat conditions can be considered as the right-hand tail of the distribution which shows a steep gradient, and the values of the 95 and 97,5 percentiles are provided in Table 7.

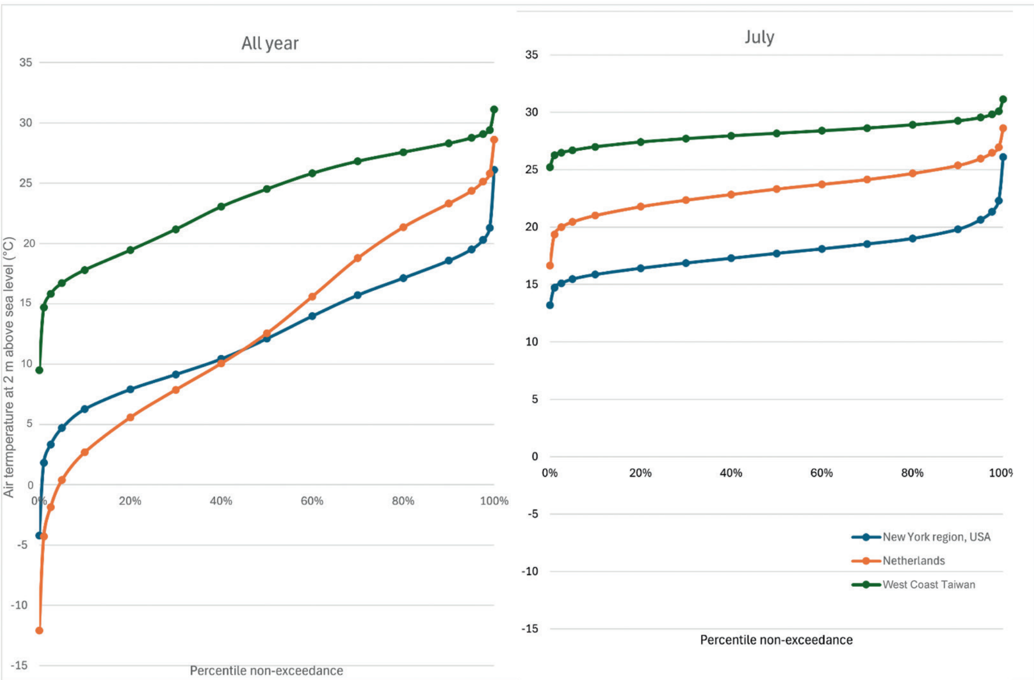


Figure 7: Temperature distributions for the USA, Netherlands and Taiwan

Table 7: Statistical values of 2 m air temperature for extreme heat

Location	Annual						July					
	95 %		97,5 %		Maximum		95 %		97,5 %		Maximum	
	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Netherlands	24,4	75,9	25,1	77,2	28,6	83,5	26,0	78,8	26,5	79,7	28,6	83,5
New York, USA	19,5	67,1	20,3	68,5	26,1	79,0	21,3	70,3	22,3	72,1	26,1	79,0
Taiwan	28,8	83,8	29,0	84,2	31,1	88,0	29,5	85,1	29,8	85,6	31,1	88,0

Extreme heat cannot be considered as air temperature alone, as this does not provide a good indicator of the human thermal environment. Heat stress can be assessed using simplified biometeorological indices, composed of one, two or multiple meteorological variables (e.g. air temperature, relative humidity, solar radiation and wind speed), or heat-budget models – numerical models that attempt to describe, in mathematical terms, the body's heat gains and losses. Simple biometeorogical indices are often termed heat indices. These may be calculated from *in situ* measurements or forecast model data and represent good practice.

Several heat indices are available to support decision-making with respect to extreme heat, and the use of such indices may be considered good practice. However, such indices provide a measure for shady areas and do not address direct sun (solar radiation). It is suggested that a heat index that has been developed by a local meteorological service be utilised as this is likely to be familiar to personnel and addresses the location's climate. An example of a heat index from the US National Weather Service Heat Index is provided in Figure 8. This example has been provided as it is simple to calculate and the possible heat disorders have been assigned to the various categories of heat index.

Air temperature		Relative humidity (%)												
°F	°C	40	45	50	55	60	65	70	75	80	85	90	95	100
110	43,3	136	-	-	-	-	-	-	-	-	-	-	-	-
108	42,2	130	137	-	-	-	-	-	-	-	-	-	-	-
106	41,1	124	130	137	-	-	-	-	-	-	-	-	-	-
104	40,0	119	124	131	137	-	-	-	-	-	-	-	-	-
102	38,9	114	119	124	130	137	-	-	-	-	-	-	-	-
100	37,8	109	114	118	124	129	136	-	-	-	-	-	-	-
98	36,7	105	109	113	117	123	128	134	-	-	-	-	-	-
96	35,6	101	104	108	112	116	121	126	132	-	-	-	-	-
94	34,4	97	100	103	106	110	114	119	124	129	135	-	-	-
92	33,3	94	96	99	101	105	108	112	116	121	126	131	137	-
90	32,2	91	92	95	97	100	103	106	109	113	117	122	127	132
88	31,1	88	89	91	93	95	98	100	103	106	110	113	117	121
86	30,0	85	87	88	89	91	93	95	97	100	102	105	108	112
84	28,9	83	84	85	86	88	89	90	92	94	96	98	100	103
82	27,8	81	82	83	84	84	85	86	88	89	90	91	93	95
80	26,7	80	80	81	81	82	82	83	84	84	85	86	86	87

Category	Heat index	Possible heat disorders
Extreme danger	130°F or higher	Heat stroke highly likely
Danger	105–129°F	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme caution	81–105°F	Heat stroke, heat cramps or heat exhaustion possible with prolonged exposure and/or physical activity
Caution	80–90°F	Fatigue possible with prolonged exposure and/or physical activity

Figure 8: US National Weather Service Heat Index
Annex C contains the descriptions of heat warnings utilised by national weather services.

In addition to the heat indices described in Figure 8, consideration must be given to:

– Solar radiation, which has an impact on the physiological response of humans to heat. Exposure to bright sunshine will increase the core temperature of a worker. Therefore, suitable precautions such as adopting light-coloured clothing to reflect the heat, and the use of awnings/shelters to provide working environments within shade should be considered.
– How strenuous a particular task is, as this will impact the physiological response, and the duration of exposure to heat. The cumulative impact of heatwaves is well documented.
– Existing medical conditions such as high blood pressure and diabetes. Support from an occupational health professional may be required to identify groups at risk and appropriate support measures.

Where direct sun (solar radiation) is experienced by workers, it is generally more appropriate to use a wet-bulb globe temperature (WBGT), which is available through both measurement and forecast models. If measured, three temperature measurements are required: nature wet-bulb temperature (NWB), dry-bulb temperature (DB) and globe/black bulb temperature (GT). In direct sunlight, the WBGT is calculated as follows:

$$\text{WBGT} = 0{,}7\ \text{NWB} + 0{,}2\ \text{GT} + 0{,}1\ \text{DB}$$

The WBGT may also be used where there is no solar radiation, i.e. shaded areas or indoors. In this case only two measures of temperature are required, and the WBGT is calculated as:

$$\text{WBGT} = 0{,}7\ \text{NWB} + 0{,}3\ \text{GT}$$

The use of the WBGT is common in Japan and the USA (recommended by the Occupational Safety and Health Administration (OSHA)).

5.1.2 Extreme heat forecasting and observation

Forecast models are generally reliable with respect to predictions of air temperature and relative humidity. Therefore, the type of forecast used may be either deterministic or probabilistic. Good practice suggests the use of an appropriate heat index, and that appropriate thresholds should be identified, for example Figure 8. This would allow appropriate mitigation to be implemented.

In addition to forecasts, it is important to recognise the different working environments, for example the nacelle, support structure, etc. The heat index in these environments is likely to be greater than that in the open air. Therefore, it is recommended to monitor the temperature and relative humidity in the different working environments and where practical provide ventilation, if using a heat index approach. These parameters, together with the heat index, should be available to workers. If using a WBGT approach, a system approach can be utilised whereby individual temperatures are measured and the WBGT calculated, or alternatively an appropriate WBGT device can be used.

To ensure operational efficiency, it is recommended that the data are transmitted to allow working conditions to be assessed prior to accessing the OREI. Additionally, the data should be available in displays, or via an app, to allow *in situ* workers to monitor the conditions in real time across the different working environments within the OREI.

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (IPCC, 2022) states that in all regions extreme heat events have resulted in human mortality and morbidity (*very high confidence*). Climate change is not only likely to bring about changes in the frequency and duration of extreme heat events in regions that presently experience them, but will likely alter the geographical distribution of extreme heat events (IPCC, 2022; 2023). Heatwaves could very well occur in locations where there is no previous history of occurrence because of the poleward shift of the mean summer maximum and minimum isotherm and an altered pattern of atmospheric and land-surface moisture due to atmospheric circulation changes.

5.2 PLANNING

5.2.1 Extreme heat impacts

5.2.1.1 Personnel

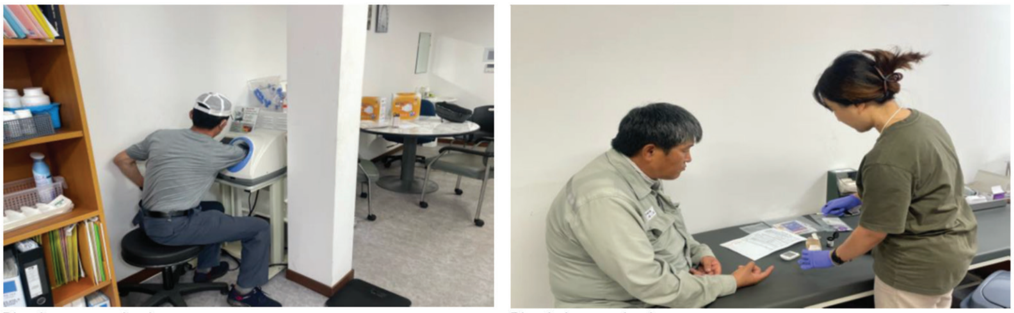
Excessive heat can cause the development of:

– heatstroke;
– heat exhaustion;
– heat cramps;
– heat syncope;
– heat oedema, and
– heat rash.

Further details of these conditions are provided in McGregor et al. *Heatwaves and health: guidance on warning-system development* (2015) and EI 3234 *The influence of climatic factors on work performance in the oil and gas industry* (2013).

Existing medical conditions may influence the physiological responses of individuals to exposure to extreme heat. Figure 9 shows facilities where pre-existing conditions can be monitored. For example, low blood pressure is a symptom of heat exhaustion, such that somebody already suffering from low blood pressure is at greater risk. Additionally, the following medications are known to increase the risk of heat-related disorders:

– allergy medication (antihistamines);
– cough and cold medication;
– blood pressure and heart medication;
– irritable bladder or bowel medication;
– laxatives;
– mental health medication;
– seizure medication;
– thyroid medication, and
– water pills (diuretics).



Blood pressure check   Blood glucose check

Figure 9: Facilities to monitor pre-existing conditions (courtesy Hai Long Offshore Wind)

5.2.1.2 Vessels

Excessive heat may cause:

– damage to marine equipment;
– damage to cooling systems, and
– increased hotel load.

5.2.2 Training

Training should be provided to personnel on the impacts of extreme heat, and this should be considered compulsory. Routine refresher training is recommended. The training should cover:

– risks of heat stress in their work;
– what symptoms to look out for;
– safe working practices, and
– emergency procedures.

Guidance on the treatment of hyperthermia can be found in EI3234 *The influence of climatic factors on work performance in the oil and gas industry* (2013).

5.2.3 Risk assessment

Several generic risks have been identified and these are included in Table 8. A site-specific risk assessment should be undertaken to look at the risks associated with particular sites, for example heat within a support structure or WTG, and appropriate mitigation measures identified. Further guidance on mitigation, including acclimatisation, maintaining fluid balance, cooling techniques (including clothing) and appropriate work/rest cycles, may be found in EI3234 *The influence of climatic factors on work performance in the oil and gas industry* (2013).

Table 8: Extreme heat generic impacts and mitigation

Potential impacts	Mitigation measures
Personnel not used to hot conditions severely impacted by heat	Acclimatisation – allow workers to acclimatise to their environment and identify which ones are assessed as fit to work in hot conditions
Personnel at greater risk due to inexperience, nature of role, e.g. strenuous work; medication; or a condition making them more vulnerable to heat stress, e.g. heart disease	Identify workers who are more susceptible to heat stress, and implement appropriate control measures
Heat-related disorders	Adopt a buddy system and undertake routine checks for symptoms of heat stress Provide cool water, ice packs and/or cool vests Create areas of shade to allow periods out of sun (see Figure 10) Establish mandatory water drinking schedule Establish work/rest schedule to ensure appropriate breaks are implemented Revise working hours to avoid extreme heat of the day ERP should address extreme heat outcomes and ensure appropriate treatments are available at the site Ensure ventilation of hot structures or consider implementation of AC capability
Burns to skin from hot structures	Appropriate PPE to avoid burns from handrails, etc Avoid touching hot metal surfaces
Damage to marine equipment Damage to cooling systems	Maintaining vessel temperatures through boundary maintenance – e.g. ensuring doors are closed when in use

The ERP should include guidance on where medical care is provided and by whom.

Figure 10: Shade provided by awning in marshalling yard (courtesy Hai Long Offshore Wind)

5.3 EVENT ACTIONS

5.3.1 Personnel

On declaration of extreme heat conditions, the mitigation measures identified in the risk assessment should be implemented and maintained until the extreme heat conditions have passed. If required, appropriate measures within the ERP should be implemented.

The following amendments to work cycles should be considered during extreme heat conditions:

- Schedule work to minimise heat exposure.
- Schedule the hardest physical tasks for the coolest part of the day.
- Rotate work activities or use additional workers to reduce heat exposure for each member of the workforce.
- Allow for slower-paced work during the hottest periods of the day.
- Move or relocate the work away from direct sunlight or radiant heat sources whenever possible.
- For outside work, schedule routine maintenance and repair work during cooler seasons of the year.
- For inside work, schedule routine maintenance and repair work for time when hot operations are shut down.

Work/rest cycles may be amended to provide greater rest periods. An example of work/rest cycles for activities requiring different levels of PPE that impact the physiological response to extreme heat is provided in Table 9.

Table 9: Example of work/rest cycles for extreme heat

Work plan for employees not using protective coveralls or respiratory protection	
40/20	Employees can work 40 minutes per hour with 20 minutes spent at rest in the shade
Work plan for employees using protective coveralls or respiratory protection	
20/40	Employees can work 20 minutes per hour with 40 minutes spent at rest in the shade

A description of treatment protocols for extreme heat-related injuries, including rehabilitation and back-to-work protocols, is provided in EI3234 *The influence of climatic factors on work performance in the oil and gas industry* (2013).

5.3.2 PPE requirements

Protective clothing or equipment may expose the employee to heat stress. Therefore, alternative PPE or clothing may require consideration. Specialised personal protective clothing is available which incorporates, for example, personal cooling systems or breathable fabrics. This may help protect workers in certain hot environments.

5.3.3 Heat monitoring and declaration of safe conditions

A clear protocol for defining the end of an extreme heat event should be defined. Ideally, this would use a combination of *in situ* measurements and forecast data to allow verification of the present forecast conditions.

5.4 POST-EVENT RECOVERY

5.4.1 Personnel safety

Personnel should be monitored for heat-related disorders for a period following the end of an extreme heat event. The period of monitoring should be informed by their exposure to extreme heat and also any existing medical conditions.

5.4.2 Evaluation of infrastructure for damage

Extreme heat is unlikely to cause damage to infrastructure; therefore, no actions to check for damage are required.

5.4.3 Restoration of operations

Where extreme heat has caused an interruption to operations, restoration of operations post-event must consider the recovery of personnel to undertake normal work/rest cycles.

5.4.4 Lessons learned

Any occurrences of heat-related disorders should be evaluated following each extreme heat event to assess whether sufficient mitigation measures have been implemented. Consideration should be given to the type of work being undertaken by those experiencing heat-related disorders, their work/rest cycles and any underlying medical conditions or medication.

Lessons learned should be documented according to the responsible party's HSE plan. Sharing should be to similar projects internally and where appropriate as industry learnings through the G+ Learning from incidents initiative or other appropriate channels.

6 EXTREME COLD

6.1 INTRODUCTION

6.1.1 Extreme cold characterisation for severe weather preparedness

Extreme cold should be considered relative to a location's climate; the same meteorological conditions can constitute extreme cold in one place but not another. Similarly, if the workforce is not acclimatised to the local climate, their threshold for physiological responses to extreme cold may be lower. The climatological air temperature distributions for three locations are shown in Figure 12. The left-hand tail of the distribution shows a rapid drop-off in temperature which may be considered extreme cold temperatures for the region and is tabulated for minimum, 2,5 and 5 percentiles in Table 10.

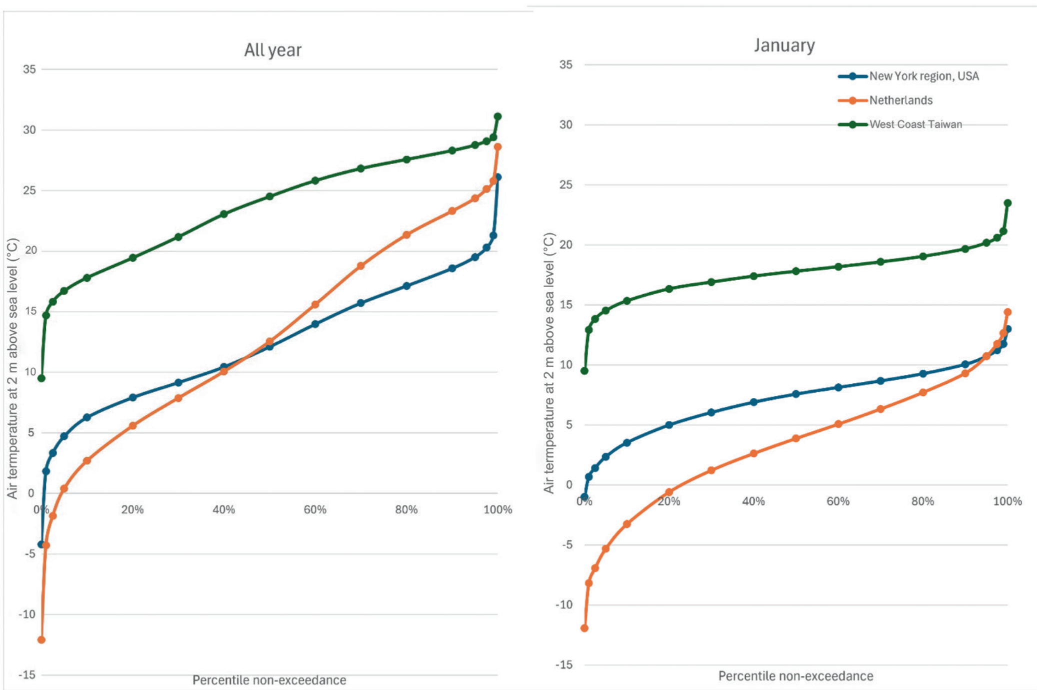


Figure 11: Temperature distributions for the USA, Netherlands and Taiwan – All year and January

Table 10: Statistical values of 2 m air temperature for extreme cold

Location	Annual						January					
	Minimum		2,5 %		5 %		Minimum		2,5 %		5 %	
	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Netherlands	–12,1	10,2	–1,9	28,6	0,4	32,7	–11,9	10,6	–6,9	19,6	–5,3	22,5
New York, USA	–4,2	24,4	3,3	37,9	4,7	40,5	–1,0	30,2	1,4	34,5	2,3	36,1
Taiwan	9,5	49,1	15,8	60,4	16,7	62,1	9,5	49,1	13,8	56,8	14,5	58,1

Extreme cold cannot be considered as air temperature alone. Wind speed also has an impact on the physiological response to extreme cold. As the wind speed increases, it draws heat from the body, driving down the skin temperature and eventually the internal body temperature. This is commonly termed wind chill and is the temperature that the body effectively feels as a combination of air temperature and wind speed. There is no global standard for calculating wind chill; however, a widely used formula is that developed by the Joint Action Group for Temperature Indices (JAGTI) to realistically measure wind chill. This calculates wind chill by measuring how much heat is lost from a person's bare face at a walking speed of 3 mph. As such the 10 m wind speed is reduced to 5 ft (1,5 m), based on the assumption that a human is exposed at ground level. JAGTI wind chill (at ground level) for combinations of temperature and wind speed is shown in Table 11, along with times to the onset of frostbite. Alternative wind chill calculations should be applied for working at elevation.

Table 11: Wind chill index with colour coding showing time (minutes to frostbite)

Temperature		10 m wind speed (mph)											
°F	°C	5	10	15	20	25	30	35	40	45	50	55	60
40	20,4	36	34	32	30	29	28	28	27	26	26	25	25
35	17,7	31	27	25	24	23	22	21	20	19	19	18	17
30	14,9	25	21	19	17	16	15	14	13	12	12	11	10
25	12,1	19	15	13	11	9	8	7	6	5	4	4	3
20	9,3	13	9	6	4	3	1	0	–1	–2	–3	–3	–4
15	6,6	7	3	0	–2	–4	–5	–7	–8	–9	–10	–11	–11
10	3,8	1	–4	–7	–9	–11	–12	–14	–15	–16	–17	–18	–19
5	1,0	–5	–10	–13	–15	–17	–19	–21	–22	–23	–24	–25	–26
0	–1,8	–11	–16	–19	–22	–24	–26	–27	–29	–30	–31	–32	–33
–5	–4,6	–16	–22	–26	–29	–31	–33	–34	–36	–37	–38	–39	–40
–10	–7,3	–22	–28	–32	–35	–37	–39	–41	–43	–44	–45	–46	–48
–15	–10,1	–28	–35	–39	–42	–44	–46	–48	–50	–51	–52	–54	–55
–20	–12,9	–34	–41	–45	–48	–51	–53	–55	–57	–58	–60	–61	–62
–25	–15,7	–40	–47	–51	–55	–58	–60	–62	–64	–65	–67	–68	–69
–30	–18,4	–46	–53	–58	–61	–64	–67	–69	–71	–72	–74	–75	–76
–35	–21,2	–52	–59	–64	–68	–71	–73	–76	–78	–79	–81	–82	–84
–40	–24,0	–57	–66	–71	–74	–78	–80	–82	–84	–86	–88	–89	–91
–45	–26,8	–63	–72	–77	–81	–84	–87	–89	–91	–93	–95	–97	–98
Frost bite times	30 minutes				10 minutes					5 minutes			

6.1.2 Weather forecasting

Forecast models are generally reliable with respect to predictions of air temperature and wind speed. Therefore, the type of forecast used may be either deterministic or probabilistic. Good practice suggests the use of an appropriate wind chill, and that appropriate thresholds should be identified, which trigger appropriate mitigation to be implemented.

In addition to forecasts, it is important to recognise the different working environments, for example turbine, support structure, etc. As previously discussed, wind chill is commonly calculated at ground level. Alternative calculations for wind chill, which effectively calculated the wind speed at the elevation of the exposed worker, would be required to accurately assess wind chill when working at heights.

Weather forecasts should be routinely assessed for reliability through comparison with available *in situ* measurements.

6.1.3 Extreme cold impacts

Extreme cold has two major physiological impacts: hypothermia (risk can be assessed from the wind chill temperature) and frostbite (time to frostbite can be assessed using a combination of wind speed and temperature). Detailed information on cold sensitivity and associated injuries including hypothermia and frostbite is provided in the Energy Institute's report EI3234 *The influence of climatic factors on work performance in the oil and gas industry*.

6.1.3.1 Personnel

There are three stages of hypothermia which are outlined in Table 12, obtained from the Canadian Centre for Occupational Health and Safety *Cold environments – Health effects and first aid*.

Table 12: Stages of hypothermia

Stage	Body temperature	Physical expression
1	Decreases by 1 or 2 °C (1,8 or 3,6 °F)	Shivering; goose bumps on skin; numb hands; breath can become quick and shallow; feeling tired and/or sick to your stomach, and a warm sensation, which means your body is entering stage 2 of hypothermia
2	Decreases by 2–4 °C (3,8–7,6 °F)	Muscles are uncoordinated and movements are slow and laboured; mild confusion; skin becomes pale, and lips, ears, fingers and toes may turn blue

Table 12: Stages of hypothermia (continued)

Stage	Body temperature	Physical expression
3	Drops below 32 °C (89,6 °F)	Shivering will stop but difficulty in speaking, thinking and walking; potential amnesia; exposed skin becomes blue and puffy; hard to move muscles and irrational behaviour; heart may be beating quickly but pulse and breathing will decrease, and risk of dying

In addition to the effects of hypothermia, extreme cold can cause damage to skin and tissue due to exposure. Frostnip is generally a precursor to frostbite. Awareness of the symptoms of frostnip, such as red, numb and tingling skin, and knowledge of appropriate responses are strong mitigations to onset of frostbite.

Frostbite occurs when tissues freeze. The damage caused by frostbite often looks similar to that of a thermal burn. There are four degrees of frostbite as outlined in Table 13.

Table 13: Degrees of frostbite

Degree	Physical expression	Outcome
First	Like frostnip but additional discoloration.	Irritates the skin and pain
Second	The outer skin may feel stiff and frozen with throbbing and aching pain Blisters form on the exposed skin within 24 hours, and red, swollen skin surrounds the blisters	Blisters but has no major damage
Third		Involves all layers of the skin and causes permanent tissue damage
Fourth		Occurs when the bone and tendon freeze

6.1.3.2 Structures

Structures and equipment may suffer from freezing and the formation of ice. Frozen surfaces cause additional hazards to personnel through slips and falls.

6.2 PLANNING/PREPARATION FOR EVENTS

Workers should receive training to identify the symptoms of hypothermia and frostbite. A buddy system should be operated to ensure that workers frequently check each other for signs of hypothermia or frostbite. If symptoms of either condition are noticed, the worker should be removed from the cold environment and receive appropriate medical care. The ERP should include guidance on where the medical care is provided and by whom.

6.2.1 Risk assessment

Several generic risks have been identified and these are included in Table 14. A site-specific risk assessment should be undertaken to look at the risks associated with particular sites, for example potential icing of walkways or ladders, and appropriate mitigation measures identified. LMRA or dynamic risk assessments should always be undertaken prior to commencing any work.

Table 14: Extreme cold generic impacts and mitigation

Potential impacts	Mitigation measures
Personnel not used to cold conditions severely impacted by cold	Acclimatisation – allow workers to acclimatise to their environment and identify which ones are assessed as fit to work in cold conditions
Personnel at greater risk due to inexperience, nature of role, medication or a condition making them more vulnerable to heat stress, e.g. heart disease	Identify workers who are more susceptible to hypothermia, and implement appropriate control measures
Cold-related disorders	Personnel Wear sufficient clothing suitable for extreme cold weather Keep clothes dry; change clothes if exposed to water Avoid leaving skin exposed Prevent bare skin coming into contact with metallic objects Work in pairs to look out for each other
Cold-related disorders	Physical/work controls Provide adequate workplace heating, such as portable heaters, to ensure work areas are warm enough when they are occupied Design processes that minimise exposure to cold areas and cold products Reduce drafts while maintaining adequate ventilation Provide insulating floor coverings or special footwear when workers need to stand for long periods on cold floors
Cold-related disorders due to long exposure	Changes to working practices: Limit exposure by introducing systems such as flexible working patterns or job rotation Provide enough breaks to allow workers to get hot drinks or warm up in heated areas

6.2.2 Vessels

Vessel operators should include instructions in their vessel's SMS for preparing various equipment to withstand adverse cold weather conditions. These instructions should cover:

- Preparing navigation/communication equipment receivers, antennas and scanners.
- Ensuring readiness of mooring and anchoring systems.
- Checking and preparing accommodation and pilot ladders.
- Inspecting deck cranes.
- Verifying the functioning of deck levers and valves.
- Monitoring for formation of topside icing and icing on decks.
- Treating decks with ice-melt to prevent slips, trips and falls.
- Maintaining heat in storerooms.
- Ensuring fuel capable of withstanding extreme low temperatures.
- Applying special polar-resistant greasing to wires, davits and other moving parts that may require it.
- Drain freshwater systems if necessary.
- Checking and preparing hydraulic and electrical systems.
- Ensuring ballast systems are functioning.

6.2.3 ORED sites – inspection and maintenance

Once sites/assets are established and equipment installed, it is essential that they are regularly inspected and maintained in accordance with manufacturer's/supplier's instructions and relevant engineering standards. This includes not only periodic inspection and maintenance regimes but also the necessary preparations considering extreme cold, such as preparing workplace and equipment, for example checking:

- frost protection measures;
- anti-freeze levels;
- insulation integrity;
- expansion joint condition, and
- salt/grit stock levels and associated equipment is available.

6.2.4 Training

Vessel operators and facility managers should provide training to offshore and shoreside personnel, appropriate to their roles, to enable them to support operations adequately. This training may encompass:

- Navigating and manoeuvring in or near ice.
- Meteorological training to understand and analyse ice development.
- Training for engineers to understand the impact of extreme cold weather and how to mitigate associated risks.
- First-aid training for frostbite, hypothermia or other cold weather-related injuries.

– Familiarisation training in systems or equipment specifically related to the safe operation of the ship in cold climates.
– Understanding and practising appropriate behaviour while working on deck, considering the impact of wind chill, etc.

6.3 DURING EVENT ACTIONS

6.3.1 Personnel monitoring

Working in a cold climate requires an understanding of the interplay between ambient temperature, wind speed, relative humidity, PPE and the task at hand. All external activities should be carefully planned and time outside limited to avoid any frost-related injuries. Personnel should be well versed in wind chill and its effects on exposure, along with recommended outdoor working times at specific temperatures.

The following amendments to work cycles should be considered during extreme cold conditions:

– Schedule work to minimise cold exposure.
– Rotate work activities or use additional workers to reduce cold exposure for each member of the workforce.
– For outside work, schedule routine maintenance and repair work during warmer seasons of the year.

In the event that personnel become stranded on a structure, the relevant ERP should be activated. Wind turbines should be equipped with emergency equipment for personnel abandonment which typically contain water and food for two days and sleeping bags for six people. For cold environments, consideration must be given to means of keeping personnel warm, which may require the provision of heat packs or similar. Regular communication checks should be established with stranded teams to ensure their continued welfare and keep them informed of potential rescue opportunities.

6.3.2 PPE requirements

Appropriate PPE should be provided to all personnel and training provided in its use where necessary. Where personnel are transferring to/from an installation, the PPE requirements should be in line with the EI3429 *Good practice guideline: Offshore wind farm transfer*.

6.3.3 Cold monitoring and declaration of safe conditions

A clear protocol for defining the end of an extreme cold event should be defined. Ideally, this would use a combination of *in situ* measurements and forecast data to allow verification of the present forecast conditions.

6.3.4 Equipment

Vessel operators must ensure that all firefighting equipment remains operational and readily available. This includes implementing heating in areas where essential firefighting equipment, such as fire pumps and firefighter outfits, is stored to protect them from frost. Protection measures for the fire line should be in place to prevent any frost damage, including draining exposed section when not in use. Regular testing of fire dampers is essential to confirm their operational status. Air vent should be clear of ice accumulation.

Life-saving appliances must also be protected for full operational capability and accessibility. For lifeboats and rescue boats, a fuel capable of withstanding extreme low temperatures should be used, and engines should be able to start in extreme cold conditions. Consideration should be given to protecting essential survival equipment, such as water, food rations and other necessities, from the impact of cold climate. Maintenance of davits and launching equipment is crucial to prevent malfunctioning during low temperatures.

6.4 POST-EVENT RECOVERY

6.4.1 Personnel safety

Personnel should be monitored beyond the cold period to ensure that no residual physical symptoms of hypothermia remain.

6.4.2 Evaluation of infrastructure for damage

In the event of icing or the presence of sea ice, visual survey by UAS, vessel, AUV, ROV or helicopter may be required across the site to identify structural damage, including the mooring system for floating wind. UAS operations should be managed in compliance with EI3576 *G+ Good practice guidelines for unmanned aircraft systems in the offshore wind industry*.

6.4.3 Restoration of operations

After an icing event, or the presence of sea ice, has passed, surveys for structural damage should be undertaken. If the surveys are acceptable, the Designated Individual may declare the work site to be safe for working.

Consideration should be given to the timing of reinstating normal work/rest cycles following extreme cold conditions.

6.4.4 Lessons learned

Any occurrences of cold-related disorders should be evaluated following each extreme cold event to assess whether sufficient mitigation measures have been implemented. Consideration should be given to the type of work being undertaken by those experiencing cold-related disorders, their work/rest cycles and any underlying medical conditions or medication.

Lessons learned should be documented according to the responsible party's HSE plan. Sharing should be to similar projects internally and where appropriate as industry learnings through the G+ Learning from incidents initiative or other appropriate channels.

7 LIGHTNING

7.1 PRE-EVENT PLANNING/PREPARATION

7.1.1 EXTREME LIGHTNING CHARACTERISATION FOR SEVERE WEATHER PREPAREDNESS

Lightning is a sudden, electrostatic discharge that is characteristically seen as a flash or spark. It occurs within thunderstorm cells and can be tracked from satellites and lightning detector networks.

There are several types of lightning (see table 15), a number of which occur in the atmosphere and offer no risk to personnel or infrastructure. The most common type of discharge is intracloud lightning which occurs roughly 5–10 times more often than cloud to ground. Lightning risk to personnel and infrastructure is that which occurs from cloud to ground.

Table 15: Lightning types

Lightning type	Abbreviation	Characteristics
Negative cloud to ground	–CG	A channel of negative charge moves in a zigzag pattern from the cloud towards the ground. As it nears the ground, the negative charge is attracted to a channel of positive charge which may be a structure or person. When the two channels meet, a powerful electrical current flows. The return stroke which is the bright visible flash often known as fork lightning travels at about 60 000 miles per second, with one flash comprising as many as 20 strokes
Positive cloud to ground	+CG	A channel of positive charge moves from the cloud towards the ground. This type of lightning is normally associated with supercell thunderstorms and trailing stratiform precipitation regions behind squall lines. This type of lighting is particularly bright and associated with very loud thunder
Ground to cloud	GC	An upward-moving leader initiates a discharge between cloud and ground from an object on the ground. This type of lightning is prevalent in tower structures greater than 100 m. This type of lightning typically has a lower current than cloud to ground

Lightning detection networks allow the risk of lightning to be evaluated at the development stage of a project. The likelihood of lightning should be assessed statistically on a monthly basis for the different areas of the ORED. A number of commercial providers routinely collect lightning data and can provide statistics on the occurrence of lightning including counts and densities of lightning activity over time, broken down by type, polarity and intensity.

7.1.2 Weather forecasting/nowcasting/earth observation

Although lightning is not a specific parameter output by forecast models, the presence of lightning is often predicted using proxies or parameterisations. Simple combinations of parameters such as convective available potential energy (CAPE) and vertical wind shear have been used historically; however, new approaches using machine learning have been successfully developed.

For more reliable information, real-time observations are essential. Lightning detectors can be readily deployed to provide site-specific information, although frequently existing global networks of sensors are used to track lightning. A lightning detector identifies electromagnetic pulses and allows the time of arrival to be calculated, along with the direction from which they arrive. Using multiple sensors allows triangulation to pinpoint the lightning source and information on the type of lightning strike (cloud to cloud or cloud to ground), the strength of the strike as well as polarity of the strike to be obtained. Typically, sensors have a range of several hundred kilometres, which is why the global networks may cover an operating region.

If lightning poses a threat, it is essential to check that existing networks cover the operating region, and if not, extend the network to allow warnings to be provided. However, these detection systems are not perfect. They can miss weak strikes, generate spurious strikes and mislocate strikes. It should also be noted that while cloud-to-ground detection efficiency is good, ground-to-cloud lightning, which can cause considerable damage to wind farm blades, is not detected.

An appropriate means of communicating lightning warnings is critical to mitigating the risk. Lightning systems offer various warning mechanisms: e-mails, sirens, apps, etc. Typically, watch circles are applied to operating areas, and when lightning is detected within a certain radius, an auto-generated warning is issued. The warning normally comprises distance to lightning, type of lightning and intensity with respect to peak current.

An important point around the use of these warning systems and auto-generated alerts is that in situations with isolated lightning strike activity, the initial alerting strike could be to the wind farm, giving no warning of an imminent strike or time for personnel to go to safe zones or be removed from the turbines.

Also, in wind farms, the rotation of the turbine blades creates an electrostatic charge, which can trigger lightning discharges that may not have otherwise occurred – known as turbine-induced lightning. Again, automated alerting systems will give no warning to the risk of impending turbine-induced lightning.

Satellite detection of lightning is also available with systems such as the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Meteosat third-generation satellites and National Oceanic Atmospheric Administration's (NOAA) geostationary operational environmental satellite (GOES) satellites providing information on strike locations and type of lightning. This information is often consumed by forecast companies and is available to forecasters to generate warnings.

Safety processes should aim to remove personnel from turbines before the event of a lightning strike. This typically requires an hour's notice before the expected lightning strike event. The best way to safely mitigate against the risk posed by lightning in this instance is to have forecasters actively monitor rainfall radar and satellite imagery for storm motion and life cycle developments, and issue alerts accordingly. This way alerts can be issued with adequate lead time before the storm arrives, so personnel can be removed from turbines in a calm and controlled manner.

7.1.3 Lightning hazards

7.1.3.1 Personnel

Lightning strikes may be grouped into four categories:

- Direct strike: lightning directly hits the person.
- Orifice entry: may occur if lightning strike occurs near the head entering eyes, ears and mouth to flow internally.
- Side splash: lightning jumps from the location of primary strike to a nearby person.
- Contact injury: injury that occurs when a person is touching an object on the pathway of lightning.
- Ground current: lightning strikes nearby and the current travels through the ground to the person.

The impacts of lightning on people can be severe and varied:

- Cardiac arrest: lightning can cause heart attacks.
- Physical injuries: lightning can cause burns and sometimes blunt trauma.
- Neurological damage: lightning can also cause damage to the central and peripheral nervous system.
- Hearing damage: lightning can cause injury to the audio-vestibular system due to either blast trauma or electrical injury.

7.1.3.2 Infrastructure

The risk to infrastructure from lightning is well known, and engineering protection from lightning is documented in the International Electrotechnical Commission (IEC)'s 61400-24 *Wind energy generation systems – Part 24: Lightning protection*. In addition to protection, this document provides guidance in characterising lightning events for engineering purposes and assessing the risk of damage. The following components of the wind turbine are considered:

- blades;
- nacelle and other structural components;
- mechanical drive train and yaw system;
- electrical low-voltage systems and electronic systems;
- earthing of wind turbines, and
- structural components.

These hazards are not addressed within this GPG as IEC 61400-24 *Wind energy generation systems – Part 24: Lightning protection* provides comprehensive guidance.

Offshore substations and internal components are generally protected as the metal casing acts as a Faraday cage against the electromagnetic field. However, some external equipment may be exposed to direct lightning strikes, e.g. cranes and meteorological masts.

Similarly, vessels act as Faraday cages but access to the upper or external decks should be avoided during electrical storms.

Portside cranes are points of attraction for lightning, so lifting operations should be suspended during electrical storms.

7.1.4 Preparation for events

7.1.4.1 Risk assessment

The following environments place workers at risk from lightning:

- working on the outside part of the nacelle or nacelle's roof;
- working on blades;
- stepping out of the wind turbine's nacelle or tower;
- standing next to the tower;
- climbing ladders, and
- touching or working on electrical circuits and/or hardwired communication systems.

To protect workers against lightning risk, it is necessary to remove them from these environments. Therefore, safe locations for lightning should be identified and clearly communicated to all workers. IEC 61400-24 *Wind energy generation systems – Part 24: Lightning protection* includes information on personal safety, including definition of safe stay locations for service technicians during elevated lightning activity (storms).

During the risk assessment, the time taken to relocate from the working environment to the safe location should be assessed. As lightning is often associated with thunderstorms, the evacuation of personnel from a turbine will likely be required due to deteriorating weather conditions. Lightning warning systems should allow sufficient time for all workers to either evacuate a turbine structure or move to a safe location.

The ERP should address the need for medical attention if a worker is impacted by lightning.

7.1.4.2 Training

Appropriate training should be provided to workers, with respect to the risks associated with lightning, the warning system that is used to advise workers of risk of lightning and appropriate safe places for their areas of work. Additionally, training in the medical care of lightning casualties may be required.

Personal lightning detectors are available, and these provide various levels of information, from a simple audible warning of lightning present to information on distance and direction of lightning strikes. Such devices would ensure that workers are aware of the presence of lightning. A number of these devices also offer information on the heat index.

7.1.4.3 Infrastructure

Engineering controls, in accordance with IEC 61400-24 *Wind energy generation systems – Part 24: Lightning protection*, should be implemented to protect infrastructure.

7.2 DURING EVENT ACTIONS

7.2.1 Personnel monitoring

All personnel should remain in designated safe zones until the lightning has moved away from the operational area.

7.3 POST-EVENT RECOVERY

7.3.1 Personnel safety

Post-event, a positive check-in, with all deployed personnel and assets, should be conducted to ensure no impacts, injuries or severe damage have occurred.

7.3.2 Evaluation of infrastructure for damage

Lightning systems do not record lightning strikes, therefore visual inspection and assessment of damage using the SCADA system will be required. Particular attention should be given to the condition of the blades, which may experience multiple types of damage including:

- tip detachment;
- debonding and shell detachment;
- debonding, and
- delamination.

Procedures for assessment of lightning damage through visual inspection and SCADA data should be established. Consideration should be given to the potential for falling objects and in-water hazards post-lightning events.

7.3.3 Restoration of operations

Due to the build-up and dissipation of static electricity on wind turbine blades during electrical storms, it is recommended that entry to wind turbines should be prohibited for an hour after an electrical storm has passed.

7.3.4 Lessons learned

Lessons learned should be documented according to the responsible party's HSE plan. Sharing should be to similar projects internally and where appropriate as industry learnings through the G+ learning from incidents initiative or other appropriate channels.

ANNEX A

A.1 GLOSSARY

For clarification, the terms listed will have the following meaning within the GPG.

Contacts Register	Documented list of all agreed contact points and methods of communication and where applicable authorisation protocols.
Designated Individual	The individual responsible for undertaking severe weather planning and ensuring implementation of mitigation measures for a particular operation within a contractor organisation.
Deterministic forecast	Forecast providing a single view of future conditions based on model data, observations and the knowledge of the forecaster.
Duty Holder	The entity that has the greatest extent of control over the site should be the duty holder and therefore take the responsibility of being the person in control. During construction that could be a principal contractor or asset owner. During operation that could be the lead operator or asset owner. This does not remove any legal duty from any other duty holder to ensure that they cooperate with the organisation with the greatest extent of control.
Emergency	An event of any kind, which can require evacuation, escape or rescue.
Ensemble forecast	Forecast data from multiple models that offer the ability to produce probabilistic forecasts.
Escape	The process of leaving the offshore renewable energy installation in an emergency when the evacuation system has failed; it may involve entering the sea directly and is a ‘last resort’ method of getting persons off the installation.
Evacuation	Leaving an offshore renewable energy installation and its vicinity, in an emergency, in a systematic manner and without directly entering the sea.
First aid	In cases where a person will need help from a medical practitioner or nurse, treatment for the purpose of preserving life and minimising the consequences of injury and illness until such help is obtained and treatment of minor injuries which would otherwise receive no treatment, or which do not need treatment by a medical practitioner or nurse.
Master	Responsible person of a vessel.
Metocean	Meteorology and oceanography. The application of these sciences supports offshore engineering and operations.

Offshore renewable energy development (ORED)	A generic term to specify all location and assets associated with a wind farm development. This extends from coastal facilities such as marshalling yards, cable landfalls, export cables and all infrastructure within the wind farm (turbines, inter-array cables, offshore substations, etc.).
Offshore renewable energy installations (OREI)	An individual asset or location within the ORED, for example, a wind turbine or offshore sub-station.
Percentile	The *n*th percentile of a set of data is the value at which *n* percent of the data is below it.
Responsible Individual	A nominated individual from the accountable organisation that has the ultimate responsibility for the safety of all personnel within a specified work location. In most cases, this is the duty holder, person in control or the employer.

A.2 ABBREVIATIONS AND ACRONYMS

AUV	autonomous underwater vehicle
BSEE	Bureau of Safety and Environmental Enforcement
CAPE	convective available potential energy
CCTV	closed-circuit television
CMA	Central Meteorological Administration
CTV	crew transfer vessel
DB	dry-bulb temperature
DNV	Det Norske Veritas
EI	Energy Institute
ERP	emergency response plan
EUMETSAT	European Organisation for the Exploration of Meteorological Satellites
GOES	geostationary operational environmental satellite
GPG	good practice guidelines
GT	globe/black bulb temperature
HAZID	hazard identification
HAZOP	hazard and operability study
HSE	health, safety and environment
IBTrACS	The International Best Track Archive for Climate Stewardship

IEC	International Electrotechnical Commission
IMCA	International Marine Contractors Association
IMO	International Maritime Organization
IOER	Integrated Offshore Emergency Response – Renewables Guidance
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JAGTI	Joint Action Group for Temperature Indices
JCG	Japanese Coast Guard
JMA	Japanese Meteorological Agency
LMRA	last-minute risk analysis
LNG	liquefied natural gas
NHC	National Hurricane Center
NWB	nature wet-bulb temperature
NWS	National Weather Service
NOAA	National Oceanic and Atmospheric Administration
ORED	Offshore renewable energy development(s)
OREI	Offshore renewable energy installation
OSHA	Occupational Safety and Health Administration
PPE	personal protective equipment
ROV	remotely operated vehicle
SCADA	supervisory control and data acquisition
SMS	safety management system
SOLAS	(International Convention for the) Safety of Life at Sea
SOV	Service operation vessel
TC-RSMC	Tropical Cyclone – Regional Specialized Meteorological Centres
TCWC	Tropical Cyclone Warning Centres
UAS	unmanned aerial system
USCG	US Coast Guard
WBGT	wet-bulb globe temperature
WMO	World Meteorological Organization
WTG	wind turbine generator

ANNEX B

B.1 VESSEL MANAGEMENT FOR EXTRA-TROPICAL STORMS AND CYCLONES

B.1.1 Preparation

Vessels at sea

- When expecting adverse weather, rig lifelines in appropriate locations on deck.
- Inspect deck cargo lashings and other areas for storage of cargo/parts and ensure they are suitably lashed/secured.
- Secure the anchors and fit the hawse and spurling pipe covers.
- Keep access chambers and other deck accesses closed.
- All drains on deck and scuppers for drainage of water must be free to prevent any accumulation of water on deck.
- Coil wires and ropes and store them securely.
- Alternate routes, shelter anchorages, ports of refuge to be included in the passage plan.
- Stability conditions to be assessed including minimising free surface effect. If necessary, heavy weather ballast to be taken up in accordance with the stability booklet.
- Bilges to be kept dry, bilge alarms and pumping arrangements to be checked and tested.
- Drip tray/save-alls to be emptied.
- Personal items in cabins and loose items in communal areas to be secured away.
- Galley staff review menu to avoid deep fat frying, pots of boiling water or soup on galley range.

Vessel at berth

- Assessment to be made if it is safer to stay alongside or head out to sea, shift to another safer berth or to a more sheltered anchorage.
- Shore leave suspended and due consideration given to whether it is safe for crew to remain onboard.
- Request a standby tug if needed and feasible.
- All non-essential personnel to be asked to leave the vessel.
- Gangway to be lifted clear of jetty and/or obstructions on the quay.
- Vessel to be secured as if it were proceeding to sea (weather/watertight integrity to be maintained).
- Any shoreline connections to be disconnected and coiled.

Note: With respect to the safety of life at sea, the Master has the overriding authority to halt any marine operation when judged necessary for the safety of life, environment and the vessel, before limiting criteria are reached.

B.1.2 During the event

Vessels at sea

- Nobody should be on deck in adverse weather unless it is necessary for the safety of the ship or life at sea. If possible, delay the work until conditions have improved.
- If necessary, the Master should authorise any work on deck during adverse weather and the bridge watch should be informed. A risk assessment and permit to work may be necessary for:
  - any seafarer who needs to go on deck during adverse weather should wear a life jacket suitable for working in, a safety harness for attaching to lifelines and waterproof PPE including full head protection and consider a head-mounted torch;
  - seafarers should work in pairs or teams and be supervised by a competent person, and
  - seafarers should have handheld water-resistant radio communications.
- When conditions allow, inspect deck cargo lashings and other areas for storage of cargo/parts and ensure they are suitably lashed/secured.
- As is feasible, the weather/watertight integrity of the vessel to be monitored.
- If damage/water ingress is suspected, damage stability of the vessel to be checked.
- Announcements to be made to inform crew and passengers what they can/cannot do until further advised.

Vessels at berth

- Mooring lines to be checked regularly and additional lines to be deployed as necessary.
- Main engine to be in a state of readiness.
- No repairs/overhauling of machinery to be undertaken.
- Condition of shore bollards, wharf, fenders to be monitored and any deficiencies brought to the attention of the local agent/port authority.
- Monitor the condition of the vessels berthed forward and aft of own vessel to ascertain if they are moored correctly.
- Keep a lookout for floating debris that may contact the hull.

B.1.3 Post-storm recovery

- Check crew/passenger injury/illness.
- If ventilation to storerooms or other compartments has been stopped, personnel should not enter until enclosed spaces entry procedure has been completed.
- Clean up spillages (oils, grease, chemicals, etc.) as soon as practicable.
- Treat areas made slippery with sand or other suitable substance.
- Nature and extent of damage to be assessed and shore management/class/flag informed as appropriate.
- All tanks, bilges and void spaces to be sounded.
- Stability to be reassessed especially if there has been any ingress of water, shifting of cargo, etc.

ANNEX C

C.1 NATIONAL PROCEDURES

C.1.1 Japan

Typhoons
In Japan the Japanese Coast Guard (JCG), port authority and other local administrations form a coordination meeting to agree on:

– Typhoon mitigation measures that should be taken.
– Timing to evacuate and ships to take necessary measures.

Coordination will be made on the promulgation of notice, etc., for evacuation (Article 35/Act on Maritime Traffic Safety).

The information is distributed via the vessel traffic scheme and through the JCG website: www.kaiho.mlit.go.jp/mission/kaijyoukoutsu/soubyo.html.

Following an incident in which a vessel at anchor dragged its anchor and impacted an access bridge to Kansai International Airport, the Japanese Coast Guard issued guidance on sheltering from typhoons using appropriate anchorage and anchoring methods. This guidance formed a partial amendment of the Act on Maritime Traffic Safety. Regional information useful for selecting anchorage and anchoring method is available from local JCG office and District Transport Bureau.

Extreme heat
The Japanese Meteorological Agency utilises both a heat index approach and wet-bulb globe temperature. The following warning system for extreme heat issues heat stroke alerts via their website: www.wbgt.env.go.jp/en/.

Air temperature (typical value)	**WBGT**	**Guides to how much exercise can be safely performed**	
≥35 °C	≥31	Danger (exercise prohibited)	At a WBGT of 31 or above, the actual temperature is higher than the skin temperature, so body heat cannot escape, and except for special cases, all exercise should be stopped.
31–35 °C	28–31	Severe warning (heavy exercise prohibited)	At a WBGT of above 28, the danger of heat illness is high, so events that require heavy exercise or events where the body temperature will rise, like endurance races, should be avoided. When such events are held, rest periods should be provided often and water replenishment conducted aggressively. People who are weak or not used to the heat should stop the exercise.

Air temperature (typical value)	**WBGT**	**Guides to how much exercise can be safely performed**	
28–31 °C	25–28	Warning (rests should be provided often)	At a WBGT of above 25, the danger of heat illness increases, so rest periods should be provided often and water replenishment conducted. Rest periods should be provided every 30 minutes for events requiring heavy exercise.
24–28 °C	21–25	Caution (water should be replenished often)	At a WBGT of above 21, there is the danger of fatal accidents due to heat illness, so caution is advised, and water replenishment should be promoted during exercise.
<24 °C	<21	Almost safe (appropriate water replenishment suggested)	At a WBGT below 21, normally the danger of heat illness is small, but appropriate water replenishment is necessary. Heat illness can occur even under these conditions in events such as citizen marathons, so caution is advised.

C.1.2 South Korea

Typhoons
Companies should familiarise themselves with the requirements of the Regulations on Maritime Traffic Safety Act. This includes regulations pertaining to departure control for various vessel types. Any vessels with a gross tonnage of less than 7 000 tonnes operating in Korean waters is subject to departure control.

Extreme heat
The Korean Meteorological Administration issues extreme heat warnings between June and September when the daily maximum heat index of greater than 33 °C is expected for over two days.

Extreme cold
The Korean Meteorological Administration issues extreme cold warnings when any of the following is expected between October and April:

- Morning minimum temperature is predicted to drop by more than 10 °C than the previous day to below 3 °C and to lower by 3 °C compared to the climatological normal year.
- Morning minimum temperature of –12 °C or less is expected for more than two days.

– Serious damage is expected due to rapid temperature drop.

C.1.3 Taiwan

Typhoons
Taiwan International Ports Corporation has implemented regulations for vessels during the approach and passage of typhoons. The regulations require a number of activities to be undertaken, which are initiated by the Central Meteorological Administration (CMA) issuing a typhoon warning at sea and on land until 24 hours after the warning has been lifted. The CMA provides typhoon warnings through its website: www.cwa.gov.tw/V8/E/P/Typhoon/TY_WARN.html

Control of ship entry and exit from ports is initiated for wind speeds of 17,2–20,7 m/s (Beaufort Scale Force 8) at a minimum forecast horizon of 6 hours. The rules for leaving and berthing during the period of an active typhoon warning are formulated according to the type of ship and tonnage classification.

The rules for Taichung Port (the principal offshore wind port in Taiwan) are as follows:

General:

- Control of ship entry and exit shall be implemented when the average wind speed exceeds Beaufort Force 8 (17,2 m/s); all vessels will be prevented from entering or leaving port.
- In the event of an accident that causes damage to the port company, or a third party, the ship owner and the dedicated terminal chartering company shall be liable for damages.

Offshore wind power working vessels:

- Vessels carrying large WTG components shall leave the port. If the vessels want to berth in port, the vessels shall unload the components onboard to the shore and berth in port without components.
- If the turbine components on deck cannot be unloaded and the master refuses to leave the port, then the following rules shall be followed.
    1. If berthing at a public wharf, the vessel owner or its agent shall sign a waiver to voluntarily stay in the port area for shelter from the typhoon and, in accordance with the relevant provisions of the port regulation/rules, take pollution prevention measures and strengthen mooring and other typhoon prevention safety measures. If an accidental disaster occurs during the stay in the port, causing losses to the port, the vessel owner shall be liable for damages.
    2. If the vessel berths at a special wharf, it must first obtain the consent of the wharf leasing party and provide a waiver in accordance with the provisions of (1) before it can remain at the port for shelter. If an accidental disaster occurs during the stay in the port, causing losses to the port, the vessel owner shall be liable for damages.
- The order of berthing of offshore wind vessels during a typhoon is as follows:

1. All types of towing vessels with limited operating capacity (non-powered platforms and barges) must submit an application 24 hours in advance and enter the port to take shelter within 12 hours.
2. Crew transportation vessel (CTV).
3. Service operation vessel (SOV) and other support vessels (supply boat).
4. Multi-purpose vessels and cable-laying vessels used for riprap, etc.
5. Jack-up barge/vessel for installing wind turbine blade tower and its underwater foundation.
6. Heavy lift vessels for storage of wind turbine components.

Extreme heat
The Taiwan Central Weather Administration issues heat warnings through its warning system: www.cwa.gov.tw/V8/E/P/Warning/W29.html. This uses the following criteria for extreme heat.

Signal	**Criteria**
Yellow	Daily maximum temperature reaches 36 °C
Orange	Daily maximum temperature reaches 36 °C for three consecutive days or daily maximum temperature reaches 38 °C
Red	Daily maximum temperature reaches 38 °C for three consecutive days

C.1.4 USA

Hurricanes and other severe weather
The National Weather Service (NWS) provides weather forecasts and warnings for the USA, its territories, and for coastal and offshore zones out to 200 NM. Throughout the year, gale, storm and thunderstorm warnings issued by the NWS are indicators of impending severe weather. During hurricane season in the USA, 1 June–30 November, the National Hurricane Center (NHC) provides daily updates for tropical storm systems including 7-day outlooks for hurricane and tropical storm developments and trajectories. Requirements to report vessel, personnel and asset status to other federal agencies are often based upon NWS and NHC warnings.

The US Coast Guard (USCG) is the body responsible for port and maritime safety and works proactively with mariners and ports to ensure safety in response to hurricanes and severe storms. USCG Captains of the Port will set port conditions prior to and during severe weather events that will direct vessel and port requirements. The coastguard is divided geographically into a number of districts, and it is recommended that the appropriate district is contacted to understand the regional approach to the management of hurricane and severe weather risk. Furthermore, port infrastructure and geographic constraints (e.g. sizes of anchorages, pier and facility flooding risk, hurricane barriers, etc.) will greatly affect where and how vessels will shelter during periods of severe weather.

The Bureau of Safety and Environmental Enforcement (BSEE) is the lead federal agency charged with improving safety and ensuring environmental protection related to the US offshore energy industry. The bureau vigorously regulates oversight of worker safety, emergency preparedness, environmental compliance and conservation of resources. BSEE requires reporting before tropical storm or gale force winds impact a project stating whether all personnel working on the lease are evacuated or remaining on the lease in a safe location.

BSEE may also issue notices to leaseholders with additional reporting requirements and actions required to ensure safety during severe weather events.

Extreme heat
The use of a wet-bulb globe temperature is recommended by OSHA. The following table provides guidance from the National Weather Service (www.weather.gov/tsa/wbgt).

Suggested actions and impact prevention		
WBGT (°F)	**Effects**	**Precautionary actions**
<80		
80–85	Working or exercising in direct sunlight will stress the body after 45 minutes	Take at least 15 minutes of breaks each hour if working or exercising in direct sunlight
85–88	Working or exercising in direct sunlight will stress the body after 30 minutes	Take at least 30 minutes of breaks each hour if working or exercising in direct sunlight
88–90	Working or exercising in direct sunlight will stress the body after 20 minutes	Take at least 40 minutes of breaks each hour if working or exercising in direct sunlight
>90	Working or exercising in direct sunlight will stress the body after 15 minutes	Take at least 45 minutes of breaks each hour if working or exercising in direct sunlight

ANNEX D

D.1 REFERENCES

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