IALA GUIDELINE

G1175
ATON EQUIPMENT AND STRUCTURES EXPOSED TO EXTREME ENVIRONMENTAL CONDITIONS

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DOCUMENT REVISION

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1. INTRODUCTION

The role of a competent authority (CA) under SOLAS Chapter V is to provide such Marine Aids to Navigation (AtoN) as the degree of risk and volume of traffic requires, in order to facilitate safe navigation.

It is important as part of this AtoN provision, that the CA considers the effects of extreme environmental variables.

This includes:

- Capturing and utilising environmental information to inform design
- Designing and providing appropriate AtoN that can operate in the relevant environmental conditions
- Monitoring AtoN performance and position
- Promulgating information to all concerned
- Implementing emergency planning procedures

This Guideline assists the AtoN manager to identify the effects of extreme environmental effects and also understand how it may be possible to mitigate those effects. It is anticipated that it will also assist in prompting further research and the design of AtoN equipment appropriate for extreme environmental conditions.

2. SCOPE

This Guideline aims to provide information associated with the effects of extreme environmental conditions on AtoN, including that referenced in other IALA guidelines or references that are considered relevant to AtoN performance. This includes:

- Information on the effects of extreme environmental conditions that could be experienced; and
- Factors to consider when designing and implementing AtoN to mitigate those effects.

Specific information from other guidelines was identified and incorporated as there are already several existing documents that address topics such as how extreme weather conditions (hot or cold extreme temperatures), amongst other variables, can affect AtoN performance.

3. EXTREME ENVIRONMENTAL CONDITIONS

AtoN operation is affected by external forces, including environmental conditions. If these conditions become extreme, they can adversely affect expected AtoN operation, reducing the operating performance and the AtoN's (useful) lifespan. There may also be a requirement to increase and/or modify maintenance.

This document identifies and describes these negative effects as follows:

- Heeling, shifting affecting vertical divergence
- Reduced performance and lifespan
- Stability of the AtoN and damage to the structure
- Damage of the AtoN and its equipment
- Others

Competent authorities should apply their knowledge and experience in order to define solutions for each situation taking into account specific extreme environmental conditions or events, such as tsunamis or hurricanes.

Further information regarding the structural design of fixed AtoN is given in Guideline 1165 Sustainable Structural Design of Marine AtoN. This document provides information on the AtoN structural design process and helps the AtoN manager understand how to ensure environmental loads such as wind, wave and current are incorporated adequately into the design.

3.1. CONDITIONS AND EFFECTS MATRIX

Table 1 has been developed to allow users to quickly identify the interrelation between the occurrence of extreme weather events (variables) and their impact on AtoN and their components.

The effects of the interaction identified in Table 1 will be addressed and explained throughout this Guideline. Moreover, the impact on navigation, channel access, staff health and safety, or port operations can also be identified by means of Table 1. Competent authorities should consider the effects and improve and develop a strategy to mitigate these negative effects.

Table 1 Conditions and negative effects matrix

Section	Extreme environmental conditions	Negative effects on: Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply
3.2	**Wind**	– Stability – Position - swinging radius – Mooring system, e.g., size of chain, mooring length, etc. – Lifespan of protective coatings	– Stability of structure – Access to structure – Lifespan of protective coatings	– Vertical divergence (Buoys) – Damage/orientation (antenna) – Transmission of data	– Wind generators – Solar panels – Cables and transmission lines
3.3	**Waves**	– Stability – Position - swinging radius – Seabed contact in shallow waters – Mooring system, e.g., size of chain, mooring length, etc. – Chain wear	– Transmitted forces on the structure – Seabed (scour causing instability) – Access to structure	– Vertical divergence (Buoys) – Damage/orientation (antenna) – Transmission of data	– Wind generators – Solar panels – Cables and transmission lines – Battery enclosure (inundation)
3.4	**Tidal levels**	– Mooring system, e.g., size of chain, mooring length, etc. – Seabed contact in shallow waters	– Access to structure	– Ground based components (sand inundation)	– Ground based components (sand inundation)

Section	Extreme environmental conditions	Negative effects on:			
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply
3.5	Currents	– Stability – Position - swinging radius – Seabed contact in shallow waters – Mooring system, e.g., size of chain, mooring length, etc. – Accelerates wear on mooring components – Lifespan of protective coatings – Structure (impact) – Access to structure	– Erosion of coastline – Lifespan of protective coatings – Structure (impact) – Access to structure	– Vertical divergence (Buoys)	
3.6.1	Coastal morphology changes	– Accelerates wear on mooring components –	– Stability – Position	–	–
3.7.1	High temperature	– Degradation of protective coating systems – Thermal mechanical force (deformation)	– Degradation of protective coating systems – Thermal mechanical force (deformation)	– Reduction in service life	– Reduction in service life

Section	Extreme environmental conditions	Negative effects on:			
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply
3.7.2	High ultra-violet levels	– Loss of colour and degradation of material properties (plastic parts) – Degradation of protective coating systems	– Loss of colour and degradation of material properties – Reduction in service life	– Reduction in service life – Damage/loss of components	– Reduction in solar panels useful life
3.7.3	Humidity	– Corrosion	– Corrosion	– Reduction in service life by condensation cycle	– Reduction in service life by condensation cycle – Corrosion of terminals
3.7.4	Drifting ice	– Position - swinging radius – Structure visibility - occasional immersions – Loss of retroreflecting film on AtoN	– Structure stability – damage or loss of AtoN (exceptionally)	– Loss of lantern, racon, antennas, sensors, etc. (Buoys)	– Damage to power supply (Buoys)

Section	Extreme environmental conditions	Negative effects on:			
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply
3.7.4	**Precipitation, snow, and ice**	– Buoyancy – Structural integrity – Damage by hail	– Structural integrity – Damage by hail	– Piling on lantern – Visibility of light (blizzard) – Transmission of data – Damage by hail	– Reduction of capacity – piling on solar panels – Influence on battery life – Cables and transmission lines – Damage by hail
3.8.2	**Dust**	– Reduce the performance of day marks – Degradation of protective coating systems	– Reduce the performance of day marks – Degradation of protective coating systems	– Visibility of light – Reduction in service life	– Reduction in performance
3.8.2	**Fire and smoke**	– Access to structure	– Access to structure – Destruction of AtoN	– Visibility of light	– Reduction in performance of solar panels
3.9.1	**Salinity**	– Corrosion	– Corrosion	– Corrosion – Visibility of light	Corrosion of contacts and frames

Section	Extreme environmental conditions	Negative effects on:			
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply
3.9.4	Marine growth	– Buoyancy – Bio-corrosion – Colour recognition – Accelerates wear on mooring components – Degradation of protective coating systems – Excess weight for lifting – Increased maintenance	– Bio-corrosion – Colour recognition – Degradation of protective coating systems – Access to structure	– Reduces sensor performance	
3.10	Bird fouling	– Colour recognition – Corrosion – Health hazard – Increased maintenance – Access to structure (slips)	– Colour recognition – Corrosion – Health hazard – Increased maintenance – Reduced time window for access – Access to structure (slips)	– Visibility of light – Reduction in the performance of the lens	– Reduction in performance of solar panels
3.11	Bird and animal interference (Human health and safety)	– Nesting birds may obscure light or preclude maintenance visits	– Nesting birds may obscure light or preclude maintenance visits		– Destruction of cables and components

3.2. WIND

Wind has particular impact on AtoN performance since, depending on its speed and direction, it generates a "swell effect" which modifies the behaviour of hydrostatic buoys.

In floating AtoN, this effect has a great direct impact on the loads imposed on the mooring system, the buoy position, vertical divergence of the lantern, and the mooring chain deterioration rate. Due to these factors, it is necessary to consider the waves as another variable in the floating AtoN design process.

For fixed AtoN wind loads are also a significant consideration in the design process and material selection.

3.2.1. TROPICAL CYCLONES

A tropical cyclone is a generic term used for low atmospheric pressure systems formed in the oceans generally in homogeneous weather conditions and tropical zones. It is associated with a wide area of clouds, rain and electric storms, along with a superficial wind circulation, which is counter clockwise in the north hemisphere and clockwise in the south hemisphere.

Cyclones are usually called typhoons in the Northwest region of the Pacific Ocean and hurricanes in the Northeast Pacific and North Atlantic Ocean regions.

Depending on the geographical region, there is a scale of wind speed to define cyclone conditions. For example, the Australian Bureau of Meteorology categorizes wind speeds for cyclonic conditions as per the Australian Tropical Cyclone Intensity Scale. Another example is the Saffir–Simpson (Table 2) hurricane wind scale, which is used officially only to describe hurricanes that form in the Atlantic Ocean and northern Pacific Ocean east of the International Date Line. *It is essential that the scale appropriate to the CA region should be used in the design of AtoN.*

According to the Saffir-Simpson scale a hurricane is defined in five categories by wind speed:

Table 2 Wind scale – Saffir – Simpson (displayed as an example only)

Category	Maximum sustained wind speed (km/h)	Damages
1	119 – 153	Minimum
2	154 – 177	Moderated
3	178 – 209	Extended
4	210 – 249	Extreme
5	>250	Catastrophic

In a hurricane, the destructive effect of the wind is directly related to its speed. While tropical depression winds generally will only cause damage weak structures, any system exhibiting speeds of over 170 km/h can seriously affect structures. AtoN have been known to lose their solar panels, top/day marks, marine lanterns and power systems can also be affected. Structures could also be damaged if their design is not suitable to withstand the effect of the winds or depending on their maintenance condition. Wind gusts are especially dangerous as they increase from 1.2 to 1.5 times the effect of the wind during 2 or 3 seconds.

Hurricanes and typhoons are meteorological events causing damage to AtoN annually. Their effects could cause the closure of the waterways by the competent authority for several weeks or at least lead to delays in operations.

Figure 1 AtoN affected by hurricanes

A short-term option to minimize the destructive effects of cyclones on AtoN could be the deactivation and the removal of AtoN components and other accessories for their preservation. This may avoid the loss of valuable equipment providing at the same time the opportunity to recommence operations with minimal delay after the cyclone has passed. This should be undertaken following an organized protocol including provision of timely information to the maritime community in compliance with Regulation 13, Chapter V of SOLAS.

Appendix 1 provides an example of a demobilization protocol in preparation for cyclonic weather conditions (see also Guideline *G1120 Disaster Recovery*).

When planning fixed AtoN construction in a cyclone prone region, consideration should be made to designing a structure resilient to cyclonic effects. This can be achieved by following the appropriate structural design standards and recommendations for the region.

For floating AtoN and mooring systems, design load values for extreme environmental factors such as current, waves and wind during the design return period (gap between one event and the other of the same kind or category) should be used, appropriate to the specific geographic area.

An example of a practical solution to provide more resilient AtoN against extreme wind could be the use of lattice design for towers, daymarks and topmarks. (see Guideline *G1094 Daymarks for AtoN* and Guideline *G1165 Sustainable Structural Design of Marine AtoN*.)

Figure 2 Front leading light with daymark lattice design

3.3. WAVES

The amplitude (height) and period (frequency) of waves can affect AtoN performance.

The wave characteristics can be predicted by means of simulations, weather forecast, or can be measured by special buoys which measure the energy transmitted by the wave to interpret the vicinity wave profile. The following parametres are used to determine wave profiles:

- Significant wave height (Hs)
- Mean direction
- Peak period (Tp)

3.3.1. TRANSMITTED FORCES ON FLOATING ATON

Wave impact can have negative consequences on AtoN which should be considered during design. These consequences are different depending on whether the AtoN are fixed or floating.

In floating AtoN, the waves directly affect the motion of the buoy and, as a result, the vertical divergence of the lantern. If the mooring chain abruptly reaches its end, even in shallow waters, the floating AtoN experiences high peaks of force.

Another parameter to consider is where a wave may break compared to the water depth, which will determine the best location of the AtoN. Guideline *G1066 The Design of Floating Aid to Navigation Moorings* provides guidance on mooring design. It is necessary to obtain the parametres of the wave height at break (Hb) and the depth of break (hb). Obtaining these parametres reduces the uncertainty in the selection of location for the installation of the AtoN.

Wave break criteria that allow estimation of Hb (in the case of regular waves) are based on the characteristics of the waves (Hs, Tp and mean direction) and the profile of the seabed. However, given that in nature the waves are irregular, it is necessary to refer to historical breaking criterion that best suits the study environment. It is important to note that the breaking of the waves transmits a large force to the buoy and the mooring. This event can lead to chain breakage or cause the sinker to shift its position. The use of elastic moorings is a solution to this scenario (see G1066).

According to Sánchez-Arcilla and Lemos (1990), there are basically two types of breaking criteria (for waves at shallow and intermediate depths):

- Criteria that express the breaking conditions as a function of local parameters of the wave and bathymetric characteristics (seabed profile).
- Criteria that specify the wave height at break as a function of bathymetric characteristics (seabed profile) *and* wave super elevation in the offshore zone (H_0 / L_0).

The mooring of a buoy has two contradictory functions. Firstly, it keeps the buoy in position, but also, the mooring has to follow the wave dynamics in order to be able to reduce the loads on the mooring, to absorb the energy created by the movements of the buoy and to compensate for the differences between tide levels, waves, etc. (see Guideline G1099).

3.3.2. TRANSMITTED FORCES ON FIXED ATON

Wave impacts on fixed AtoN e.g., beacons and lighthouses placed on rock outcrops, causes deterioration of the structures particularly in assets approaching the end of their design life.

Trinity House, the Northern Lighthouse Board and the Irish Lights have supported the EPSRC-funded research project STORMLAMP, undertaken by a number of organisations (University of Plymouth, University College London and the University of Exeter University) to investigate the structural response of heritage rock lighthouses to wave loading during storms. They have estimated the wave loading on a number of vulnerable lighthouses using Bayesian-based statistical forecasts, empirical approaches, physical experiments and computational fluid dynamics.

The resulting structural response has been monitored through lighthouse-based instrumentation, and modelled using detailed structural analysis, validated using data obtained in field modal testing. On the basis of the investigations, they have been able to predict the structural vibrations and the survivability of the lighthouses into the future, providing crucial information for operational purposes and maintenance planning (Raby et al., 2019; Antonini et al., 2019).

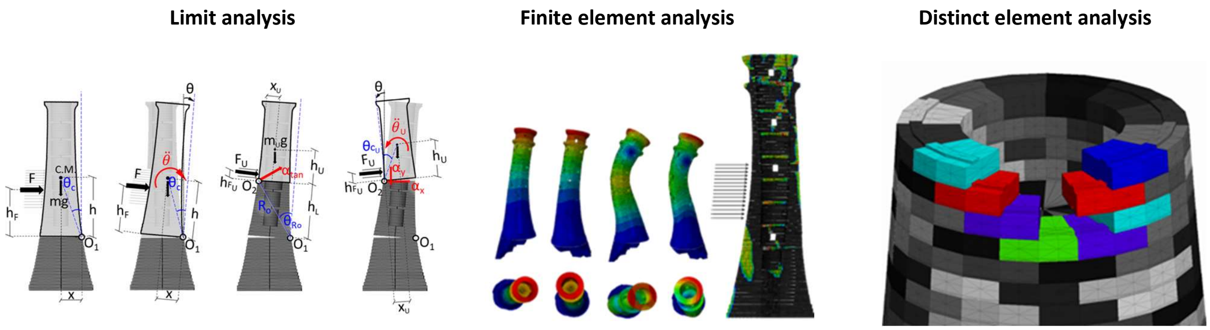

Figure 3 Examples of structural modelling techniques

Tropical cyclones also generate very large waves called swells that can affect 150 to 200 km of coastline and lasting for a few hours. These waves are caused by strong winds and a drop of atmospheric pressure in a shallow water area and can reach up to six metres height.

The combination of swells with astronomic tide when a cyclone is affecting a specific area produces the highest water level at a high tide. This effect is increased by waves moving over this already elevated water level.

Further information regarding the structural design of fixed AtoN is given in Guideline *G1165 Sustainable Structural Design of Marine AtoN*. This document provides information on the AtoN structural design process and helps the CA understand how to ensure environmental loads such as wind, wave and current are incorporated adequately into the design.

3.3.3. TSUNAMIS

Tsunamis are typically caused by undersea earthquakes, submarine/subaerial landslides including island flank collapses, volcanic eruptions and meteorological conditions. There is also some evidence for generation by meteor strikes. Locations affected by tsunamis therefore tend to be close to plate boundaries e.g., the Pacific "Ring of Fire", although the effects of tsunamis may be experienced at large distances from the source.

The effects of tsunamis are generally not severe in deep water, where their height might only be of about 1 m. However, in shallow water where the wave height increases due to the shoaling effect, they may cause extensive damage due to:

- Rising/falling water levels
- Large wave fronts, which can exceed 10 metres

AtoN in deeper water will therefore probably be unaffected by tsunamis. However, damage is likely on structures such as rock lighthouses or operational facilities on or near the shoreline.

The following provide examples of AtoN damage due to tsunamis:

- Navigation buoys and the Great Basses Light and Little Basses lighthouses in Sri Lanka following the 2004 tsunami, where navigational buoys were lost around the coastline, and damage to lighthouses including that to the fuel tanks and glazing.
- The five-storey high Scotch Cap lighthouse on Unimak Island, Alaska was completely destroyed in the 1946 Aleutian tsunami with the loss of 5 men (Patel and Patel, 2012).

A high magnitude and long lasting earthquake closer to the epicentre may result in a major disaster damaging infrastructure, affecting utilities and may even cause injuries and deaths.

An earthquake may also lead to a tsunami that could damage floating and land-based AtoN, port infrastructure and facilities. Although both events, separately, are particularly destructive, their effects can be combined or individual.

The waves of a tsunami can be extremely dangerous and devastating to low-lying coastal areas as they enter shallow water at high speed and hit the shoreline in a short period. Tsunami impact time depends on the distance between the epicentre and the coast, ranging from tens of minutes to hours, and this propagation pattern will affect the areas near its origin.

Emergency preparedness and AtoN system resilience is key to minimize the impact of a tsunami on AtoN systems. Appendix 2 contains an example of the Chilean experience in dealing with Tsunami events and contains an example of an emergency AtoN plan.

3.4. TIDES

The astronomic tide is the variation of the hydrometric level as a response of the gravitational interactions between the sun, the moon and the earth, and it can be predicted with acceptable accuracy. Tidal level predictions are published by local maritime authorities in a document referred to as tide tables. The tidal range can be measured as the vertical difference between a high and a low tide. The largest differences in monthly astronomic tidal values occur according to the lunar phase (full or new moon), when the gravitational force of the sun and the moon are in phase. This kind of tide is known as a spring tide.

Conversely, the meteorological tide has its origins in the daily or seasonal variations of the weather conditions which can occur periodically and can also to a certain extent be predicted.

In river floodplain areas, an extreme tidal event can be caused by an increase in upstream rainfall coinciding with tidal events. Such events can also be linked to climate change as sea levels rise due to global temperature changes

Tides do not usually affect the performance of AtoN, due to tidal height being a parameter considered during design. In the case of extreme tides floating and fixed AtoN can be affected, especially their position when marking a narrow channel where tidal flows are “funnelled” through the channel causing local increases in water level.

3.4.1. EXTREME TIDES

An extreme tidal event is associated with sea level rise or fall created by the simultaneous occurrence of a high astronomic tide and a meteorological event (e.g. storm surge) and their occurrence can also be predicted.

Table 3 contains several examples of extreme tidal ranges.

Table 3   Extreme tidal values

Location	Country	Tidal Range (feet)	Tidal Range (metres)
The Bay of Fundy	Canada	38.4	11.7
Ungava Bay, Quebec	Canada	32	9.8
Avonmouth / River Severn	England	31.5	9.6
Cook Inlet, Alaska	USA	30.3	9.2
Rio Gallegos	Argentina	29	8.8
Hudson Bay	Greenland	28.5	8.7
Granville	France	28.2	8.6
Magellan Strait	Chile	28	8.5
Cancale	France	27.8	8.5
Iles Chausey	France	26.9	8.2

Source: Extract from National Oceanic and Atmospheric Administration (NOAA)

3.4.1.1. Extreme lowest astronomical tide

The Lowest Astronomical Tide (LAT) is a rare event which occurs when the sea moves away from the shore. This rare natural phenomenon occurs together with the gravitational force during a particular lunar phase (full moon) acting on the water mass and the climatic conditions. When LAT occurs, in some situations (e.g. narrow channels), the low tide can cause floating aids to move transversely narrowing the channel further. This effect can be further magnified when coupled with adverse wind speed and direction.

3.4.1.2. Flooding

The sustained and gradual increase of water volume in inland waterways can result in damage to AtoN due to floating debris (e.g., influx of aquatic vegetation or logs) causing impact damage and entanglement in the mooring system. This can result in a floating AtoN sinker dragging, the possible rupture of the moorings or even the loss of or sinking of the AtoN. Floating vegetation can also become entangled in ship’s propellors and rudders which will reduce the ship’s manoeuvrability especially with the higher current speeds in flooded waters.

In addition, floating vegetation and the changing coastline may introduce hazards which can cause confusion for the mariner by creating unchartered references through distortion of the visual marks and the radar image.

Figure 4   Negative effect of floating vegetation

The excess water can also cause instability to the area where fixed AtoN may be located due to erosion or collapse of the coastline. These effects should be considered during the design and selection of AtoN in flood prone area.

Figure 5 River coast flooded

3.5. CURRENTS

The movement of a mass of water is called current which is defined by its direction and speed. Some of the factors affecting currents are density variations within the water, winds and tides.

Extreme water current can affect AtoN in the following ways:

- Stability of fixed AtoN structures through erosion
- Verticality of floating AtoN
- Wear on mooring systems
- Reduced window for safe access

3.5.1. SUPERFICIAL CURRENTS

The breaking of the waves generates a current parallel to the coastline. This current is a function of the angle with which the waves approach the coastline and of its wave height, called a superficial current.

AtoN, mainly buoys could also be affected by the increment of the superficial current. The effects differ depending on their design. They may be driven to the extent of the mooring length or tilted to the point where they could lose their verticality, which will affect the AtoN published characteristics (e.g., visual, luminous and radio propagation ranges).

3.5.2. TIDAL CURRENTS

A tidal current is generated with the rise and fall of the tide in locations near the coastline. The current is created by the vertical movement of the tide near the shore, also causing the water to move horizontally. When the current floods, the tide moves towards the land and away from the sea; when the current ebbs, the tide moves towards the sea and away from land.

In some specific places, the tidal currents can move at very high-speed creating eddies that can be seen on the water surface. When this occurs, mariners must follow the sailing directions and MSI published by the local maritime authorities while navigating these waters.

Places like the Chacao Channel, which separates the Chiloe Island from mainland Chile, experience tidal currents with an average of 8 to 10 knots in the middle of the channel. In the Kirke Channel, near Puerto Natales, tidal currents have also been registered with an average of 10 knots during flood and ebb periods. In this place, in 2014, the MV “Amadeo I” wrecked after crashing into sea bottom rocks due to the fast currents, among other factors.

In 2019, the Chilean Maritime Authority installed a current meter which sent, through VHF Channel, meteorological and current information transmitted by voice and AIS to enhance navigation safety through the channel.

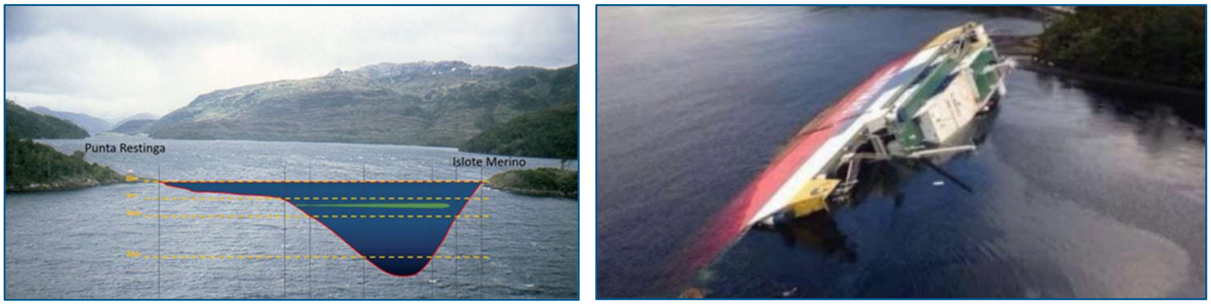

Figure 6 Kirke channel and Amadeo ferry

3.6. GEOPHYSICAL CONDITIONS

3.6.1. SOIL AND COASTAL MORPHOLOGY CHANGES

The changes that take place in the seabed and river coastline require continuous bathymetry and topography survey on behalf of the competent authorities to keep nautical charts updated. It is also necessary for the mariner to ensure they are aware of the most up to date cartography and Marine Safety Information (MSI).

Eventually, the generation of sandbanks or the collapse of the coast associated with significant sedimentation and erosion processes, typical of river behaviour, can affect the stability of the fixed AtoN installed on the coastline. Positioning of AtoN in these areas should be carefully considered and a maintenance plan for proactive relocation of floating and fixed AtoN, where necessary and due to morphological changes is required.

Specifically, in buoy mooring systems, abrasion from sediment movement generally leads to a higher rate of wear in the mooring system.

Figure 7 Erosion process at the coast

3.6.1.1. Soil geomorphology

Currents carrying large quantities of sediments can bury a floating AtoN sinker making it difficult to lift for maintenance. The ship's crane or other lifting means may not be able to retrieve the complete mooring system resulting in the chain having to be cut. This could generate a new environmental condition or a navigational hazard to consider.

3.7. CLIMATIC CONDITIONS

Extreme weather events may include but is not limited to tropical storms, fog, monsoons, cyclones, sand/dust storms, seasonal winds and an increased chance of lightning activity. These weather events present significant engineering and operational challenges and there may be design and installation requirements required in these areas that are not required elsewhere.

3.7.1. Temperature

The effect of the temperature on the AtoN and its components are widely known, and its impact depends on the range of magnitude. In order to assess the effects that the extreme temperature can cause to AtoN, several guidelines have been published to assist AtoN selection. These guidelines include:

- G1136-Ed.1 Providing AtoN Services In Extremely Hot and Humid Climates
- G1108 Providing AtoN Services in Polar Regions
- G1067-0 Selection of Energy Systems for AtoN and Related Equipment
- G1067-3 Energy Storage for AtoN

Under normal conditions, selection of AtoN power supply systems may allow a choice of options, however in areas of extreme temperatures, options may be limited. Guidelines G1067-0 and G1067-3 recommend when mains power is not available, renewable energy should be considered, and where renewable energy sources are not feasible, primary batteries should be used instead. Also contained in these guidelines are tables which serve to guide on the selection of the power supply system and for the recommended storage system which consider extreme temperatures as one of the variables.

These alternative power supplies will be affected by the extreme temperature values. Extremely low or high temperatures can affect the performance of the external equipment; it can shorten the expected useful life of the equipment and make certain materials fragile, compromising the ingress protection index (IP##) provided by the manufacturer or even the structural integrity.

The selection of lubricants to be used in movable parts should also be considered.

Other examples of effects are as follows:

- Batteries will freeze and display poor performance and therefore the type of battery should be carefully selected.
- Freezing of the axis of the wind generators
- The formation of ice in antennas and the concentration of snow can cause several problems in different systems:
  - Low performance of the components of power supply system due to low temperatures.
  - Low temperatures can also generate progressive layers of ice.
  - High temperatures can affect the useful life of the battery.

3.7.1.1. Battery operating temperatures

The range of temperature experienced by the battery during operation will considerably affect its useful life and it is a significant factor in the selection of the battery.

Batteries should operate at the specified temperatures stated by the manufacturer. Their operation outside these ranges will have a secondary effect on its capacity and useful life (life cycle), and it can also be hazardous.

Calculating battery life depends on several factors such as maintenance, percentage of discharge, battery temperature, number of times the battery is discharged, etc.

High temperature of the cell can be generated by the environmental temperature or alternatively, by an excessive charge. In both cases the possible effects can occur:

- Ageing acceleration
- Spontaneous sulphation
- Active matter dissolution

Figure 8 illustrates the rate of lead acid battery ageing in relation to temperature:

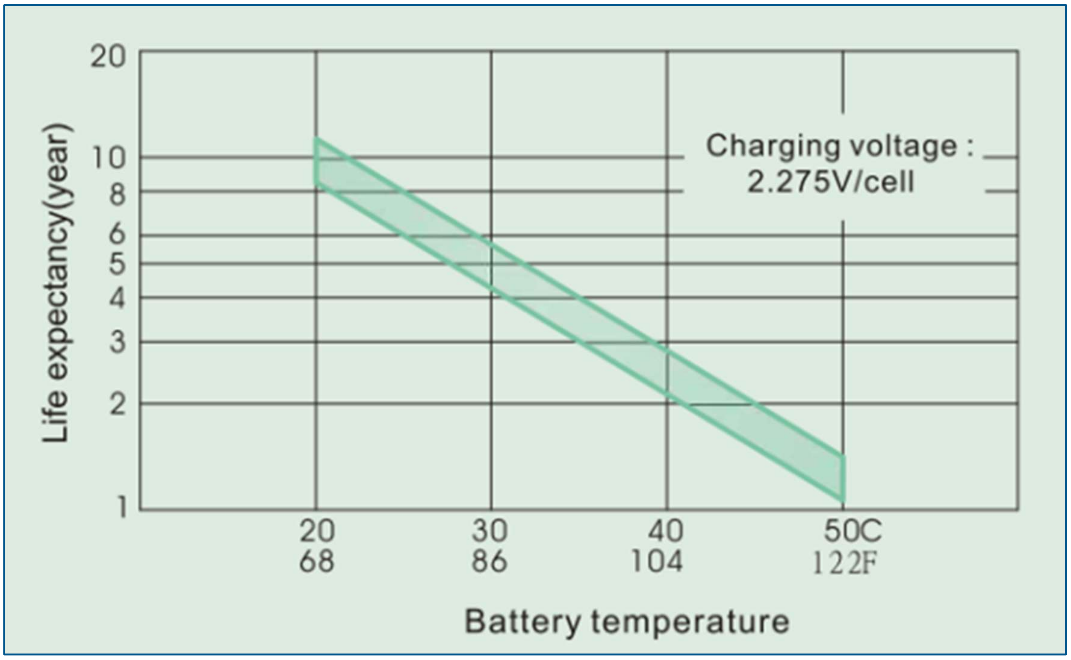

Figure 8 Lead acid battery ageing curve in relation to the temperature

3.7.2. HIGH ULTRA-VIOLET LEVELS

High Ultraviolet (UV) light levels in prolonged periods of strong sunlight can cause degradation of material properties including colour retention, plastic lenses, steel and plastic buoys, structures, coating systems and electrical/electronic equipment and fixtures. UV exposure can also be a significant risk to workers and requires careful management and specific mitigation controls (see Guideline *G1136*).

Careful design considerations should be made when using plastic buoys in very hot climates (equatorial regions) as some effects could severely impair the performance of the equipment. The following are examples of problems that may result from prolonged exposure of plastic material to high temperature. They should be considered to help determine if the design is suitable for the application (this list is not intended to be exhaustive):

- Parts bind or corrode from differential expansion of dissimilar materials
- Materials change in dimension, either totally or selectively
- Packing, gaskets, seals, etc. become distorted, bind, and fail causing mechanical or integrity failures
- Gaskets display permanent set
- Closure and sealing strips deteriorate
- Shortened operating lifetime
- Colour fading, cracking or crazing of plastic materials

The high rates of solar radiation (UV) in these regions can cause surface temperatures to increase by 15 to 30°C above ambient temperatures and surface temperatures can reach 80°C. As a result, it is important to consider studies made by various manufacturers comparing material degradation, reaction and resilience under these extreme conditions (see Guideline *G1006*).

Maintenance of lanterns should include inspection to re-verify the light range as this can be affected by high UV.

Figure 9 High Ultraviolet effect on red buoy

3.7.3. HUMIDITY AND PRECIPITATION

High humidity environments present issues to both AtoN equipment and personnel. Water ingress and the effect of humidity and the build-up of condensation in AtoN equipment can cause electronic failure, thereby negatively impacting availability, reducing reliability and impacting service life. Increased humidity can also have a negative effect on the worksite, worker comfort and output efficiency, thereby increasing the risk of incidents and impacting quality (see *G1136*).

In order to protect the integrity of the equipment installed in areas of extreme humidity, increase its lifespan and ensure its reliability, it is necessary to prevent the condensation cycle from starting during the installation process. In order to achieve this, an IP (Ingress Protection) level should be specified (see *G1136 Annex A*).

Highly humid and saline environments cause corrosion of the AtoN structure and its components increasing the probability of malfunction. It is essential to guarantee the water tightness of enclosed AtoN devices to avoid the generation of condensation cycles that can damage the components.

The UK and Irish General Light Authortities produced a detailed report "*Building Conditioning of Lighthouses, Accommodation, Outbuildings and Associated Structures (IGC5 TASK GROUP REPORT, 2009)*" that described these effects in some detail, with suggested monitoring approaches. (see Guideline *G1007 Lighthouse Maintenance*.)

3.7.4. ICING

In ports and waterways subject to channel ice, floating AtoN may suffer impact damage or even sink due to ice compression and movement. The light range and data transmission of floating and fixed AtoN components, and other day marks can be reduced to the effects of heavy snow.

To reduce the risk of damage to AtoN there may be seasonal deployment of floating AtoN, whereby they will be located during the winter season only at the key points of the fairway to reduce the probability of damage by ice. Alternatively, special designs can be used which generally withstand ice forces due to their shape and design. For example, conical or cylindrical buoy shapes with reinforced bodies. Topmarks may not be used as they can be damaged by the weight of ice accumulation. The choice of AtoN should reflect the specification of the CA, which should consider the extreme environmental conditions.

Figure 10 Effect of ice on buoys

Ice sheets grow and shrink with the seasons and ice-charts may need to be updated frequently. Consideration should be given as to how this information can be managed in an efficient and cost-effective manner to ensure the mariner uses the most up to date information.

The growth and reduction of the ice sheet can also result in land-based systems having to be installed on permanently stable, high ground which may potentially be at sub-optimal locations, distant from the area of navigable waterway being served (see *G1108*).

Figure 11 Example of ice on AtoN structure

3.7.4.1. Typical problems and solutions

- Fixed AtoN on land:
  - The mark could be covered by ice which deforms the visibility of the mark and light.
  - Ice or snow accumulation on the glasses of lantern rooms may severely affect light visibility.
  - Fixtures and aerials or other construction elements may be damaged by ice if they are placed near sea level.

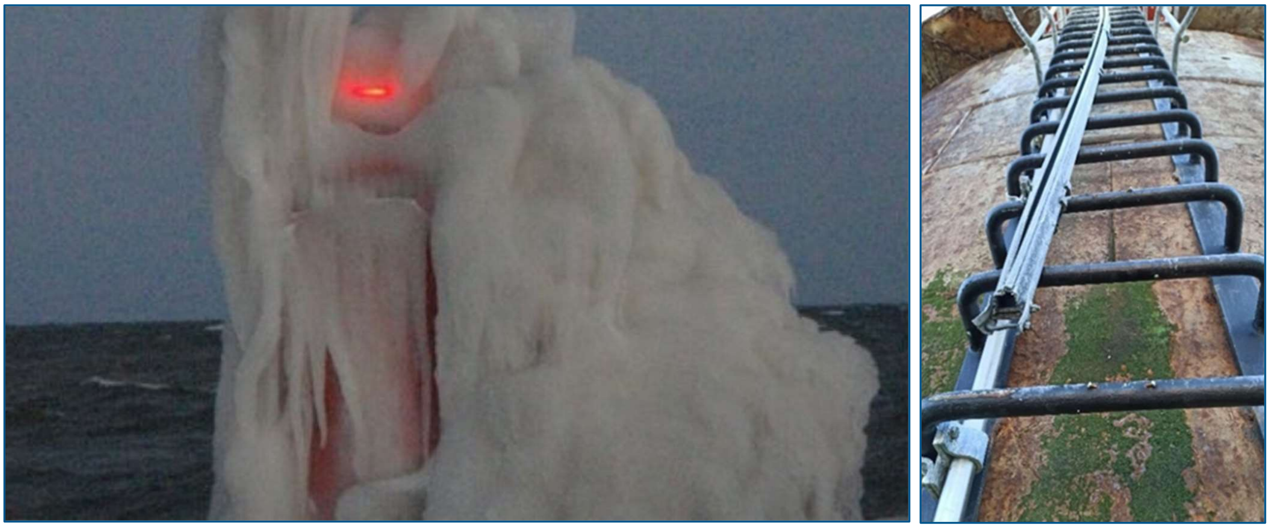

Figure 12 Port entrance mark covered by ice – safety rail bent by ice on Tallinnamadal lighthouse

- Floating AtoN:
  - The resistance offered by an AtoN and its mooring system caught in the drag of moving ice, when released, can produce highly accelerated oscillating movements, which could cause damage in the components (electronic devices, lanterns, etc).
  - Floating AtoN may become submerged under ice and may not be visible to the mariner. MSI should be issued to notify mariners that availability targets may not be met in ice conditions.
  - Ice may damage buoy lanterns and therefore special lanterns or ice protection is needed.
  - Ice accumulation on floating AtoN may create problems with buoy stability.
  - Moving ice or ice accumulation may significantly affect vertical divergence.
  - The internal buoy structure is critical to support the resistance to ice damage. Steel buoys can be reinforced with ribs and the empty voids in plastic buoys may be filled with closed cell foam.
  - The coefficient of thermal expansion of polyethylene (PE) is approximately ten times bigger than steel. In plastic buoys with steel components this can lead to the development of pressure and resulting damage to the buoy hull.
  - Empty compartments of plastic buoys can be damaged by pressure or a vacuum developing within the voids. The risk of this can also be reduced by filling the compartments with cell foam as mentioned above.
  - Heavier sinkers are required to ensure the buoy remains in its position when subject to moving ice.
  - In case of shallow waters with thick ice, the ice may touch the bottom of the seabed and move debris and objects (including anchors) that can move or impact floating AtoN

- Ice often scrapes off retroreflecting films and bird spikes used on buoys. An alternative to retroreflecting film is embedding or recessing of the luminous film within the body of the buoy (see Figure 14).
- Retrieval of off station floating AtoN is sometimes impossible because buoy tenders are not able to operate in severe ice conditions.
- Sometimes it may be problematic to identify the colour scheme of a buoy in ice.

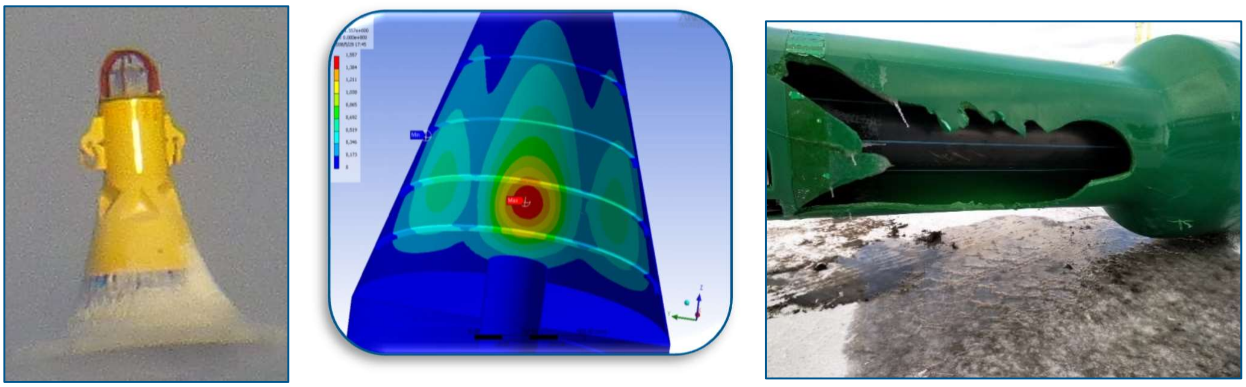

Figure 13 Various buoy conditions in ice

Figure 13 shows (left to right) a buoy with ice protection over polycarbonate cupola, reinforcement ribs on a steel buoy and damaged plastic ice buoy without foam to support its structure.

Figure 14 Example of recessed retroreflective film

An example of a reinforced buoy for use in ice is one built with a “fishbone” stainless steel skeleton, and a streamlined three-section structure with a cylinder in the middle and a cone at both ends, using high polymer polyethylene material. The surface colour of the buoy does not fade or fall off even after long-term use under harsh conditions, and it can effectively resist the impact and collision of floating ice, and float under the ice surface passively when it meets large ice chunks.

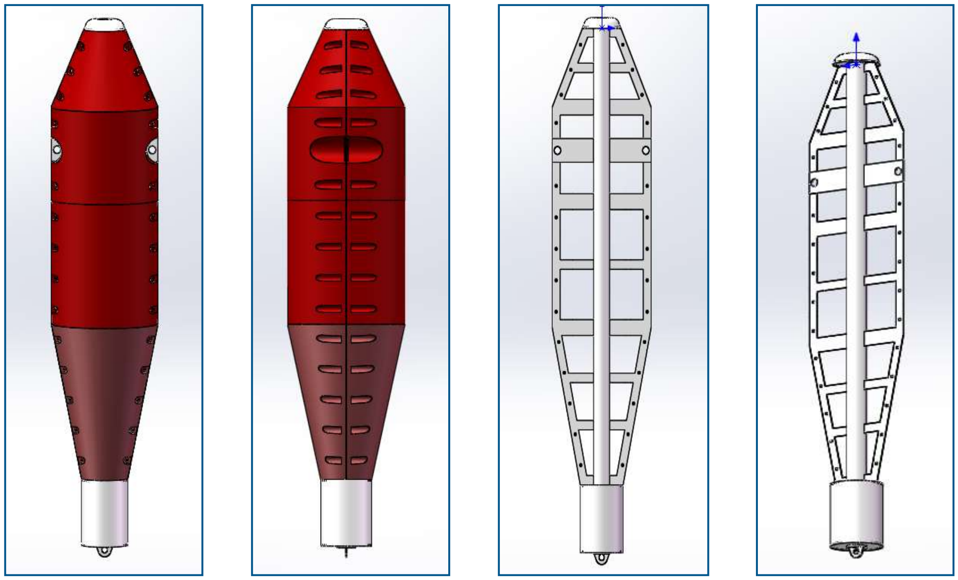

Figure 15 Appearance and skeleton

3.8. ATMOSPHERIC CONDITIONS

3.8.1. VISIBILITY

Fog is an atmospheric phenomenon in which the visibility of the sky is reduced due to the high presence of smoke, dust or any other particles suspended in the air. According to the World Meteorological Organization the darkening on the horizon can be distinguished between mist, ice mist, vapour mist (steam), fog, smoke, volcanic ash, dust, sand or snow.

However, the turbidity can generally be measured by means of the Pollutant Standard Index (PSI) which states the air quality or the pollutant level in it. This index can vary according to the country which consults it, since different indexes are used all over the world, such as the Air Quality Health (reference).

3.8.1.1. Difference between haze, fog, and mist

These three phenomena can result in reduced visibility due to climatic conditions (fog and mist) and in relation to the air pollution (haze). The main difference between these three concepts is that for fog and mist, these are formed by suspended drops of water, whereas haze can be formed by extremely small and tiny particles suspended within the air.

The natural phenomenon of mist occurs when hot air “crashes” against cold surfaces and the humidity “thickens” or condenses resulting in small amounts of water in the air.

Although, mist and the fog are similar phenomena, they are distinguished by the visibility distance, i.e., if the visibility distance is equal to or less than one kilometre, it is often named as mist, but if it is larger than a kilometre, it is called fog.

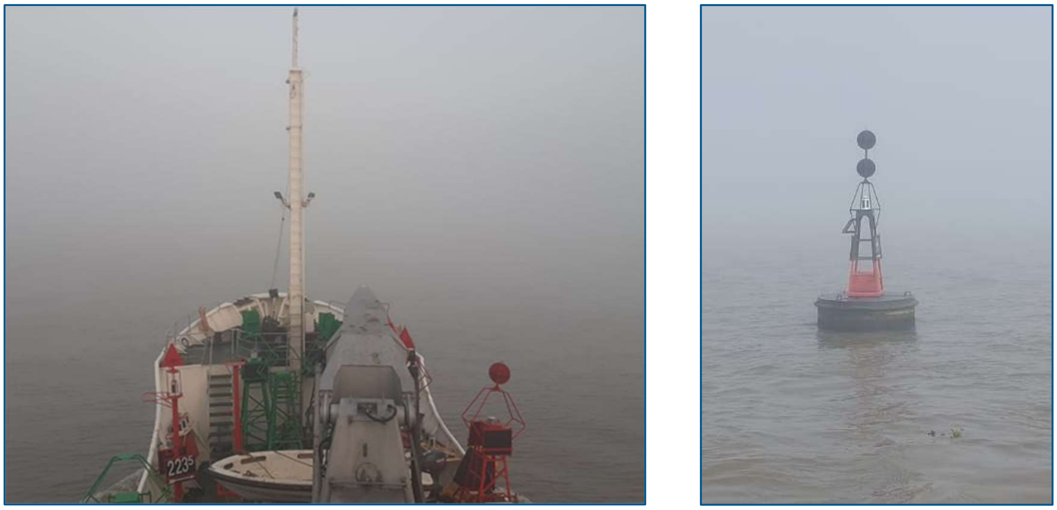

Figure 16 Presence of fog in a waterway

3.8.2. DUST

Guideline *G1136* considers the impact that dust may have on the AtoN's physical properties. Dust can be as the result of industrial activity, as well as naturally occurring. It can interfere with the operation of lamp changers and cover day marks affecting the luminous and visual range, as well as the solar panels which, if covered in dust, can reduce their energy generation capacity. Furthermore, extreme dust also present risks related to health, such as respiratory problems. Dust is considered as a way of transporting pollutants and, can affect the health and safety of AtoN maintenance personnel.

In areas that are affected by dust, the service provider or competent authority should consider the frequency of maintenance visits. The visit interval should be adjusted to be practically and economically feasible.

Generally, sandstorms start as a dark orange cloud followed by heavy winds which can lead to the competent authority to impose restrictions on the navigation in channels, manoeuvring areas, entry to ports or harbours, amongst others.

Dust may cause visibility issues and accumulate on lantern fittings, particularly in Fresnel lenses. The use of Fresnel lenses without dust covers should be avoided or an alternative light source such as LEDs should be used.

Figure 17 Presence of dust on AtoN device

3.8.3. FIRE AND SMOKE

Fires can occur either due to extreme temperatures combined wind and a lack of rain or can be initiated through certain agricultural practices. Climate change effects are resulting in widespread fires in locations where previously such occurrence was a rarity.

Fires produce clouds of smoke which causes loss of visibility for the mariner (see Figure 17), as well as affecting living beings inhabiting the area (fauna and humans). Fire can also destroy land based AtoN (see Figure 18)

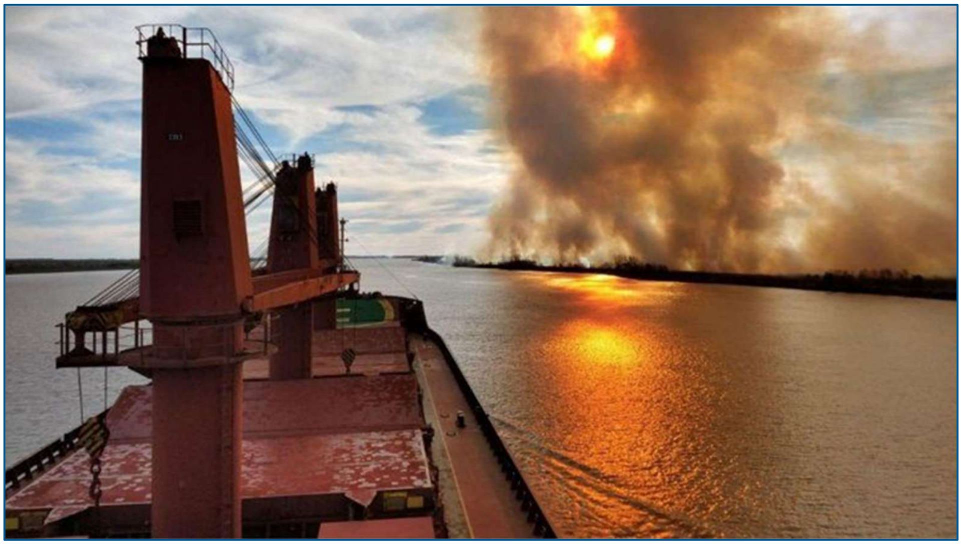

Figure 18 Presence of smoke in a waterway

Figure 19 Example of AtoN destroyed by fire

3.8.3.1. Impact on navigation

The main impact on navigation associated with the loss of visibility or limited visibility due to mist, haze, dust, sand or smoke, is the interruption of maritime operations .

Depending on the CA, the closure may not affect vessel traffic or it may impose a restriction in navigation, such as delays in operations for a period of hours, to reopen again once the visibility conditions have improved.

The loss or reduction of visibility due to the presence of mist or fog does not affect the useful life of AtoN. However, it reduces the visual range and affects the safety of navigation. Reduction of visibility, mentioned in Guideline *G1108* takes into account the different geographical sceneries or navigational routes placed in high or low latitudes (Arctic or Antarctic navigation). Visibility on navigation depends on the adjustment of the human eye or on the contrast between the darkness during the day in winter and the brightness during summer months; both factors affect visibility in navigation.

Guideline *G1090 The Use of Audible Signs* covers the loss of visibility due to the presence of mist and defines a requirement for:

> "establishment of the considerations under which an audible signal can be used and the disadvantages of its use due to the complexity to identify the direction or vicinity from where the sound comes from, as well as stating the patterns in relation to usual range and nominal use."

At present, there exist electronic aids capable of warning the mariners in situations of low visibility. Their implementation, however, depends on cooperation and alignment of AtoN provision between the relevant maritime authorities. For example, it may be possible that the mariner is encouraged to navigate under a bridge during low visibility conditions because appropriate AtoN are installed but the final port destination may restrict operations in its area in low visibility and the vessel may be unable to berth. Criterion should be established and agreed between the maritime authorities regarding waterway operation during temporary periods of low visibility.

An example of how extreme fog can affect the operability of ports and the safety of navigation is the Port of San Antonio, a main Chilean port.

A fog bank is very common during the morning until after noon, while in the afternoon an anticyclonic margin is formed with winds from the SW, which generates the removal of the fog. However, when the fog clears it is accompanied by adverse sea state conditions. Both of these conditions exacerbate the challenge of navigation into the narrow port entrance channel. The hours authorized for entering the port are therefore reduced to night hours. In this situation, the port can utilise new technologies, such as marking the entrance channel with virtual AIS AtoN together with backup systems to support vessel coordination.

Figure 20 Fog bank at the Port of San Antonio

3.8.3.2. Impact on energy generation

Haze, fog, dust or smoke affects the performance of solar panels since the remaining insolation charging hours can be reduced where these extreme conditions occur during autumn or winter. Increased maintenance frequency may be required to reduce the impact on solar panels and other components.

3.9. WATER CONDITIONS

The physical, chemical, and biological composition of marine waters can influence the rate of deleterious effects on both fixed and floating AtoN; such effects are discussed in the following paragraphs.

3.9.1. CORROSION

Salinity, sulphate content, temperature, dissolved oxygen, and pH can all separately, and in combination, influence the corrosion of steel AtoN. Generally, higher temperatures as experienced in tropical waters, and higher levels of dissolved oxygen will combine to increase corrosive mechanisms.

The corrosion of steel in seawater is an electrochemical process, which is exacerbated by increased salinity.

pH of the water also has a variable effect on corrosion. Typically, corrosion rates are high at lower pH due to acidic corrosion and at a higher pH, the corrosion can be caused due to a reaction known as caustic embrittlement. pH of waters can be locally affected by artificial influences such as discharges from oil refineries and chemical plants.

Accelerated low water corrosion (ALWC) of steel structures is found in certain regions. ALWC is an aggressive form of microbially influenced corrosion that may occur on steel in estuarine and marine structures. The rate of corrosion caused by ALWC can be ten times the normal rate of seawater corrosion. Sulphate reducing bacteria, which can thrive under marine growth, are a contributory element. ALWC is characterised by bright orange surface deposits underlain by black slime. The effects are most prevalent in tidal waters and ALWC is often observed around the low water level.

Marine organism can also be the cause of bio-corrosion of steel parts. This bio-corrosion affects both the submerged parts of the buoy and the mooring chains.

Cathodic protection is a means of reducing corrosion in metallic structures and major components exposed to seawater. The system provides sacrificial anodes that corrode in place of the metal. This can reduce the rate of corrosion.

AtoN structures can be painted, wrapped with a bituminous tape or sheathed in a protective jacket to minimise the contact of seawater with the structure.

3.9.2. ABRASION

Mobile sediments made up of abrasive sand such as basalt, can have an abrasive effect on all submerged materials including fixed, marine based AtoN foundations and floating AtoN mooring chains. Abrasive sediments can be moved by the mass of water in stormy weather or speedy current tide and can damage protective coatings and abrade the AtoN material. In steel, this can lead to an entry point for corrosion of bare metal. Steel mooring chains can be damaged by the grinding of granular sediments between the chain links and can undergo abrasion when in contact with the seabed they affect the lower slice of the mooring line. In quiet sea conditions, it is the movement of the ground mooring chain on the sea bottom that undergoes this abrasion while the buoy moves.

Abrasive particles in suspension in the water can damage mooring lines made of steel chains or synthetic ropes. This situation is generally encountered in rivers or estuaries, carrying these particles. Extremely turbid waters can also make inspection and maintenance of fixed, marine AtoN difficult and may require the use of specialist divers who are familiar with the structure.

Maintenance operations will gather information over time regarding the rate of corrosion of steel chains and other mooring components. This allows the material thickness to be sized accordingly, allowing for sacrificial loss of material.

Figure 21 Abrasion and wear on mooring chains

3.9.3. IMPACT DAMAGE

Macro-waste can be natural such as tree trunks or tree branches, or artificial such as drifting fishing nets or drifting steel cable. They are mainly carried by rivers. They can get caught in mooring lines made of chain and generate significant stress. They can also damage synthetic mooring ropes.

One solution on inland waterways is to deploy passive debris collectors (PDC) positioned appropriately on upstream channels to collect debris for removal (see Figure 21).

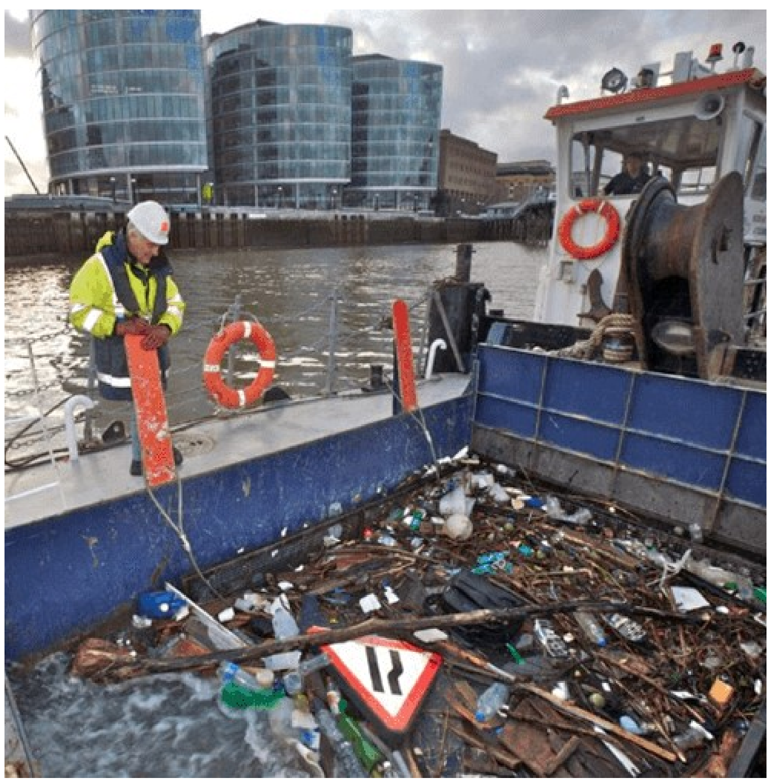

Figure 22 Example of passive debris collector positioned in waterway

3.9.4. MARINE GROWTH

Very warm seawater, associated with extremely hot and humid climates, can cause the rapid growth of dense and sometimes destructive marine organisms on both buoy moorings and the foundations of fixed structures. This can increase the frequency and cost of maintenance, can adversely impact buoyancy and accelerate corrosion (see *G1136*).

Fouling from marine growth may be so severe that the buoy will have to be lifted and cleaned at increased regular intervals. During servicing, fouling should not be removed with mechanical scrapers as these can cause serious damage to the protective coating and shorten the life of the paint system. Marine growth should be removed with water jetting using a suitable pressure that will not damage the protective coating (see *G1077*).

Figure 23 Marine growth

Guideline *G1036* describes the impact that AtoN have in the environment and establishes the general recommendations for the management of waste, acoustic and luminous pollution, and the protection of habitats, flora and fauna, amongst others.

3.10. BIRDS

Bird fouling (guano) derives primarily from birds landing and roosting, or attempting to land and roost, on an AtoN site. The discharge of faecal matter is the primary contaminant but it can also be related to shedding of feathers, nesting debris and presence of rotting food. Bird fouling can have, among others, the following detrimental effects on AtoN sites:

- Excessive guano coverage on lanterns or optics, causing obstruction of the light source, resulting in reduced nautical range or in severe cases, total outage of the AtoN.
- Excessive guano coverage of solar panels, reducing the active area of the panel and severely limiting battery charging capacity, which can lead to negative effects on night-time signalling functions of the lantern and may eventually lead to total battery discharge and subsequent outages of the AtoN.
- Guano coverage on lighthouses or other daymarks can cause a change in the colour, severely affecting the ability of that AtoN to provide clear information to the user.
- Guano is highly caustic and can increase corrosion rates on AtoN structures, fittings and components, resulting in accelerated deterioration and reduced life span, higher maintenance costs and unsafe structures.
- Bird fouling on any site generally pollutes and contaminates, causing a number of associated issues for maintenance teams.

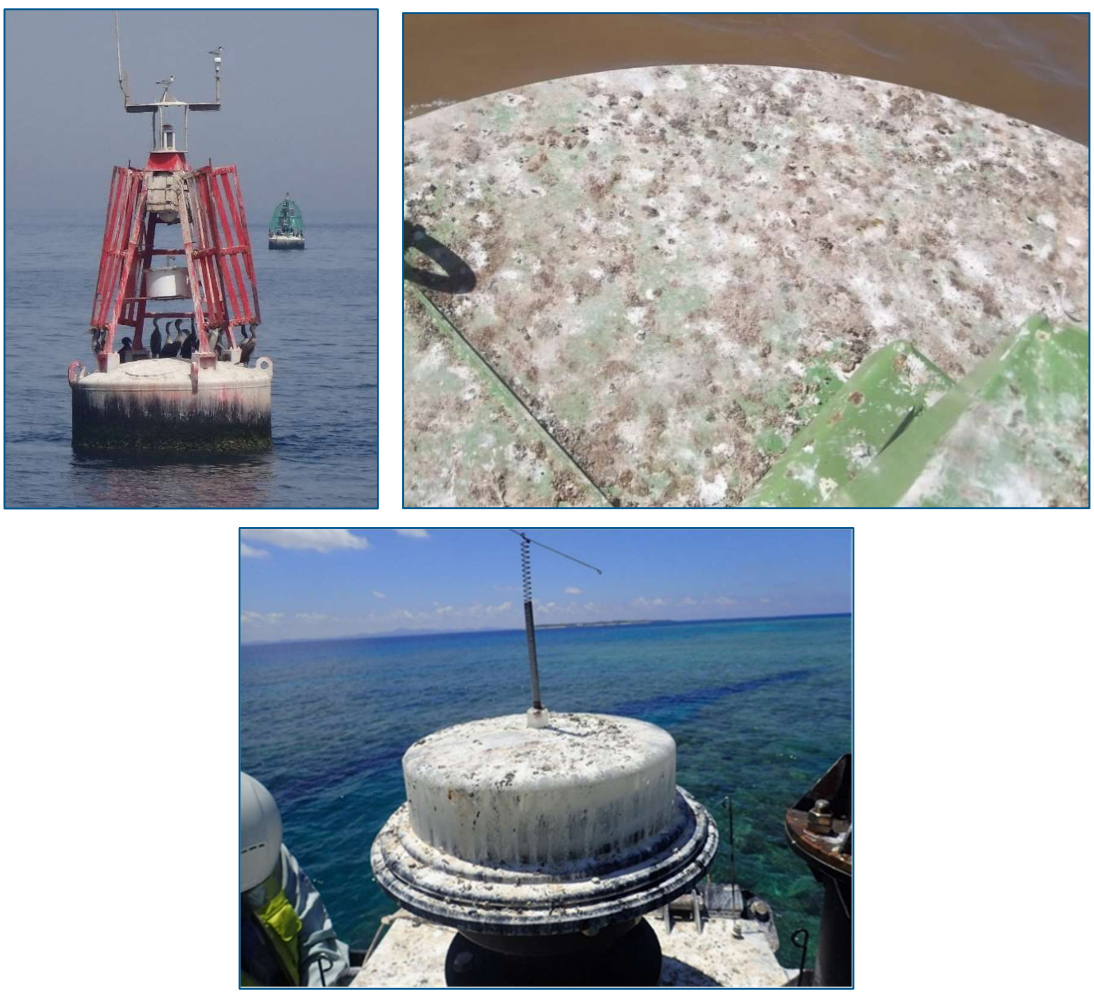

Figure 24 Bird fouling on buoys

Guideline *G1091 Bird deterrent and bird fouling solutions* describes methods to mitigate bird fouling on AtoN structures, such as implementing commercial products and deterrent systems, the application of engineering solutions, structural changes or revised installation methods where it is impossible to deter bird colonies. The exact method should be tailored to suit a particular site, situation and, in some cases, may need to be designed to suit the visitation habits of a particular species of bird (see *G1136*).

A further consideration is that in hot climates is that guano can be baked on due to the extreme heat, making it very difficult and time consuming to remove. Intensive cleaning can create dust which poses inhalation related health and safety risks to workers. Bird deterrents should be used wherever possible to prevent this problem.

Some ways used to prevent this effect:

- Install the most appropriate bird deterrent for the location and bird species - this action prevents the bird fouling.
- Paint over the surface colour with a special ant graffiti product - this action will not prevent the bird fouling but ensure it is easier to remove with water pressure.

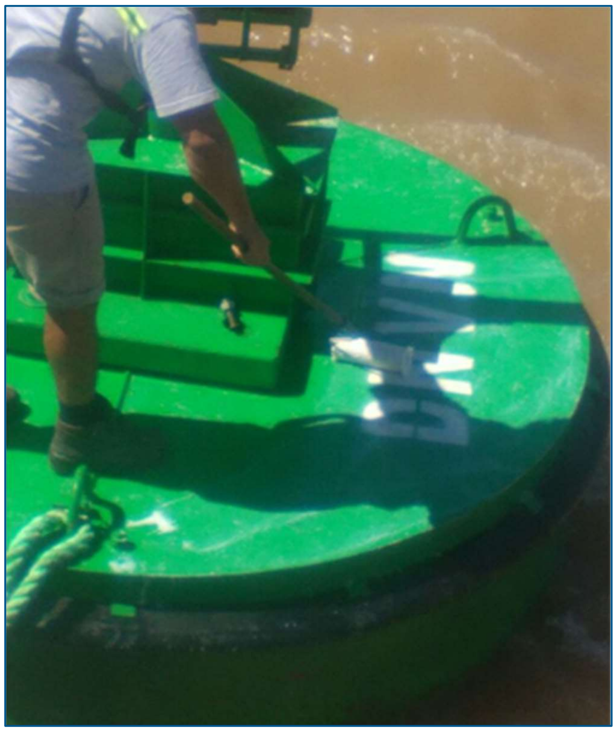

Figure 25 Anti-graffiti product application over the surface colour

Figure 26 Example of AtoN configuration to deter bird roosting

3.11. HUMAN HEALTH AND SAFETY IMPACT

Dust and smoke have a harmful effect on people’s health. They can cause eye irritation and nasal congestion, they can also affect lungs and cause severe headaches. Both phenomena can particularly affect those people with existing allergies and asthma and affect people’s sense of smell.

Some hot and humid climates result in high vegetation cover and growth. The need to constantly control and clear excessive vegetation so that does it not obstruct the operation of an AtoN can be an issue in these regions.

The presence of dangerous fauna in hot and humid regions, such as marine stingers, snakes, scorpions, spiders, venomous insects, crocodiles and sharks can present serious risks to workers and the ability to safely access, operate and maintain AtoN (see *G1136* and Figure 26).

Nesting birds can be aggressive and dangerous to maintenance workers when working at height.

The presence of protected species may require modification to maintenance plans and in some situations may preclude site visits for a temporary period.

Figure 27 Risks of AtoN maintenance associated with wildlife

4. POTENTIAL MITIGATION

Table 4 summarizes the suggestions contained within the Guideline for best practice operation to reduce the impact of the effects of extreme environmental conditions on AtoN. The optimal solution will always depend on site specific conditions, but the table may provide the AtoN manager with ideas for consideration .

Table 4 Potential mitigation of environmental effects on AtoN

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.2	**Wind**	– Ensure wind induced wave variables are incorporated into design process – Select appropriate protective coating system – Select appropriate design of topmark and daymark – Consider redundancy within system	– Ensure appropriate wind design levels are incorporated into structure design – Select appropriate protective coating system – Consider temporary demobilisation procedures – Consider more wind resilient design e.g., reduction in surface area – Consider redundancy within system	– Ensure appropriate wind design levels are incorporated into component design – Consider temporary demobilisation procedures	– Ensure appropriate wind design levels are incorporated into power supply design – Consider temporary demobilisation procedures	G1165 G1099

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.3	**Waves**	– Ensure wind induced wave variables are incorporated into design process – Install wave monitoring buoys to improve parameter understanding and inform site selection – Consideration of elastic moorings	– Ensure appropriate wave loads are incorporated into structure design	– Ensure correct ingress protection (IP) level specified – Consider redundancy within system – Select lanterns designed for the anticipated vertical divergence	– Ensure correct ingress protection (IP) level specified	G1065 G1066 G1066 G1099 G1165

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.4, 3.5	**Tidal levels, flooding, currents and coastal morphology changes**	– Consider position monitoring to identify drifting AtoN – Ensure current flows are incorporated into design process – Install current monitoring buoys to improve parameter understanding and inform site selection – Consider use of skirt buoy to ensure vertical at low water – Select appropriate protective coating system	– Careful selection of location to reduce risk of undercutting or destabilisation – Ensure current flows are incorporated into design process – Select appropriate protective coating system	– Design for vertical divergence in accordance with relevant guidance – Ensure correct ingress protection (IP) level specified	– Ensure elevated position of generators to reduce risk of flooding and spillage of fuel and lubricants – Ensure correct ingress protection (IP) level specified	G1065 G1165 G1099

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.7.1	**High temperature**	– Ensure maintenance programme reflects potential for reduced design life – Ensure material selection is suitable for operating temperature	– Ensure construction materials are appropriate for construction phase temperatures – Ensure maintenance programme reflects potential for reduced design life – Ensure material selection is suitable for operating temperature	– Ensure products selected for anticipated operating temperature range	– Ensure appropriate choice of primary and back up supply – Ensure batteries stored less than 25 degrees C prior to deployment – Ensure maintenance programme reflects potential for reduced design life – Consider use of vented enclosures	G1065 G1136 G1067-1&3 G1039
3.7.2	**High ultraviolet levels**	– Ensure appropriate selection of product material for expected operating temperature range	– Ensure appropriate selection of product material for expected operating temperature range	– Ensure appropriate selection of product material for expected operating temperature range – Ensure checks within inspection programme to verify the light range of reused lanterns	– Ensure appropriate selection of product material for expected operating temperature range – Ensure maintenance programme reflects potential for reduced design life	G1006 G1136

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.7.3	**Humidity and precipitation**	– Ensure adequate paint specification to resist water ingress – Ensure appropriate maintenance regime to reflect potential for moisture ingress and associated deleterious effects	– Ensure adequate paint specification to resist water ingress – Ensure appropriate maintenance regime to reflect potential for moisture ingress and associated deleterious effects – Consider cathodic protection	– Ensure correct ingress protection (IP) level specified – Use of water repellent products on terminals, contacts, etc.	– Ensure maintenance programme reflects potential for reduced design life – Use of water repellent products on terminals, contacts, etc.	G1136
3.7.4	**Drifting ice**	– Consider seasonal and/or strategic deployment of buoys – Specify appropriately reinforced buoys – Ensure survey frequency reflects requirements of ice sheet extent – Consider appropriate mooring system to withstand ice movement – Consideration of virtual AIS	– Ensure selection of AtoN location and type reflects risks of icing – Ensure risk of drifting ice is incorporated into design process	– Ensure selection of light location and type reflects risks of icing – Consider seasonal operation of lanterns	– Ensure maintenance programme reflects potential for reduced design life	G1108

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.7.4	**Precipitation, snow, ice and low temperatures**	– Ensure maintenance programme reflects potential for reduced design life – Consider use of topmarks and lateral daymarks or not depending on potential for ice accumulation – Ensure additional buoyancy requirements are incorporated into design process – Consider using other techniques to retroreflective film	– Ensure additional structural loads are incorporated into design process – Ensure construction materials are appropriate for construction phase temperatures	– Consider redundancy of data transmission systems – Ensure products selected for anticipated operating temperature range – Ensure correct ingress protection (IP) level specified	– Ensure maintenance programme reflects potential for reduced design life – Ensure products selected for anticipated operating temperature range	G1108 G1136

Section	Extreme environmental conditions	Potential mitigation for: Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	Relevant IALA publications
3.8.2&3	**Dust, fog and smoke**	– Consider use of temporary operating instructions for visibility reduction – Adopt appropriate maintenance regime required for cleaning AtoN components – Consider supplementary audible warnings – Consider virtual AIS	– Consider use of temporary operating instructions for visibility reduction – Adopt appropriate maintenance regime required for cleaning AtoN components – Consider supplementary audible warnings – Consider virtual AIS	– Consider use of temporary operating instructions for visibility reduction – Adopt appropriate maintenance regime required for cleaning AtoN components – Ensure correct ingress protection (IP) level specified – Avoid using Fresnel lens without cover or use alternative light source, e.g., LED	– Ensure maintenance programme reflects potential for reduced design life – Consider supplementary power if solar is primary source	G1136

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.9.1 – 3.9.3	Water conditions	– Ensure paint specification appropriate to withstand aggressive corrosion/abrasion – Adopt appropriate maintenance regime required for inspection of damage to paint system – Increase thickness of metal components to provide sacrificial layer – Deploy passive measures to capture water surface debris – Select appropriate protective coating system – Consider use of cathodic protection system	– Ensure paint specification appropriate to withstand aggressive corrosion/abrasion – Adopt appropriate maintenance regime required for inspection of damage to paint system – Increase thickness of metal components to provide sacrificial layer – Deploy passive measures to capture water surface debris – Select appropriate protective coating system – Consider use of cathodic protection system	– Ensure correct ingress protection (IP) level specified	– Ensure correct ingress protection (IP) level specified – Ensure maintenance programme reflects potential for reduced design life	G1036

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.9.4	Marine growth	– Ensure buoy and mooring design considers additional weight potentially imposed by growth – Ensure paint specification appropriate to withstand marine growth removal – Adopt appropriate maintenance regime required for cleaning buoy	– Ensure paint specification appropriate to withstand marine growth removal – Adopt appropriate maintenance regime required for cleaning structure			G1036

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.10	Bird fouling	– Use of bird deterrents, appropriate to the species – Consider bespoke top covers to reduce available landing surfaces – Apply appropriate paint system covering to facilitate removal of debris when cleaning. – Ensure paint specification appropriate to withstand bird fouling removal – Use of appropriate personal protective equipment (PPE) for maintainers	– Use of bird deterrents, appropriate to the species – Consider bespoke top covers to reduce available landing surfaces – Use of appropriate personal protective equipment (PPE) for maintainers	– Ensure correct ingress protection (IP) level specified	– Ensure correct ingress protection (IP) level specified	G1036 G1091

Section	Extreme environmental conditions	Potential mitigation for:				Relevant IALA publications
		Floating AtoN	Fixed AtoN	AtoN components e.g., lanterns, racons, etc.	Power supply	
3.11	Bird and animal interference (Human health and safety)	– Use of bird deterrents, appropriate to the species – Consider bespoke top covers to reduce available landing surfaces – Use of appropriate personal protective equipment (PPE) for maintainers	– Consider timing of maintenance programmes – Use of bird deterrents, appropriate to the species – Consider bespoke top covers to reduce available landing surfaces – Consider audio and visual deterrents – Incorporate pest control in inspection and maintenance programmes – Use of appropriate personal protective equipment (PPE) for maintainers	– Ensure adequate sheathing and routing of cables	– Ensure adequate sheathing and routing of cables	G1036

5. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine AtoN* (IALA Dictionary) and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

6. ABBREVIATIONS

AIS	Automatic Identification System
ALWC	Accelerated low water corrosion
AtoN	Marine Aid(s) to Navigation
HAT	Highest astronomical tide
IMO	International Maritime Organization (Acronym style)
IP	Ingress protection
LAT	Lowest astronomical tide
MBS	Maritime buoyage system
MSI	Marine safety information
PE	Polyethylene
SOLAS	Safety of life at sea
VHF	Very high frequencies

7. REFERENCES

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APPENDIX 1 EXAMPLE OF DEMOBILISATION PROTOCOL – CYCLONES

1. CRITERIA FOR CONSIDERATION

Prior to the hurricane season, a detailed analysis regarding the priorities for the deactivation and further activation process must be conducted, preferably involving the criteria and expertise from the most relevant members of the maritime community such as pilots, maritime administrations, coast guards, navy, shipping companies, meteorological services, among other stakeholders.

For this purpose, the IALA Risk Management Toolbox could be extremely valuable when focused on the risk related to maritime operations that could be present before, during and after the occurrence of such events. Modelling and simulation techniques should be an advantage when performing this analysis to show the possible or forecasted scenarios that must be taken under consideration in a given maritime area or waterway.

This analysis should be run in a yearly basis as some elements related to the operational conditions of a waterway may vary, such as local maritime regulations, AtoN system modifications, among others.

The result of this analysis could be a plan to practically organize the deactivation and activation process, including:

- An Agreement and Cooperation Act to be signed by the process stakeholders, containing the list of AtoNs to be deactivated and activated according to the priorities determined in the analysis, and the means provided by each stakeholder to cooperate with the process.
- A table containing the number of AtoNs with real possibilities to be part of the process, sorted by type of AtoN.
- The composition of each Deactivation and Activation Brigade (DAB) to perform the procedure, means of transportation, waterways to be covered, departure point, trajectory, communications, storage facilities for the preservation of the luminous and power supply system and other accessories, among other practical details. Proper training for the DAB personnel based on local AtoN System conditions should be provided.

This Plan should be submitted for the approval of the competent authorities to ensure its compliance with national, territorial and local regulations.

The criteria to establish the priorities for the deactivation process may include, among others:

- The importance of the AtoN for the maritime operations in a given waterway: the demobilization of AtoN should be prioritized such that critical AtoN for vessel operations are deactivated last, prior to the arrival of the hurricane.
- The meteorological conditions: the deactivation process should start well in advance of the deterioration of the sea conditions in order that service vessels could work safely, especially on buoys. Up-to date information on the current position, trajectory, speed displacement and strength of the hurricane provided by local meteorological services is essential.
- The distance from the departure point of DAB to the farthest AtoN to be deactivated: it would be unpractical trying to deactivate AtoNs located too far away.
- The average time spent undertaking each demobilization, according to the complexity of the AtoN.
- After a hurricane has left an area or waterway, an evaluation of its AtoN system status should be made to assess the damages caused as soon as the meteorological conditions allows to do so, in order to determine the damages and to prepare all the necessary resources to repair or reactivate them.

Subsequently, the criteria to establish the priorities for the activation process may include, among others:

- The urgency to ready the most important waterways: those AtoNs meant to contribute to a safe navigation by these waterways must be activated first.

- The meteorological conditions: the activation process should start as soon as the weather condition allows the deployment of DABs.
- The use of most suitable and reliable equipment available in the AtoN maintenance station or preserved during the deactivation process to ready the most critical AtoN.

APPENDIX 2 EXAMPLE OF CHILEAN TSUNAMI EXPERIENCE AND DEMOBILIZATION PROTOCOL

1. INTRODUCTION

A few minutes after the earthquake, the Pacific Tsunami Warning Center disseminates a tsunami warning to the Pacific Ocean, which will be issued to 53 countries across its basin, including Peru, Colombia, Panama, Costa Rica, Nicaragua, Antarctica, New Zealand, French Polynesia and the coasts of Hawaii.

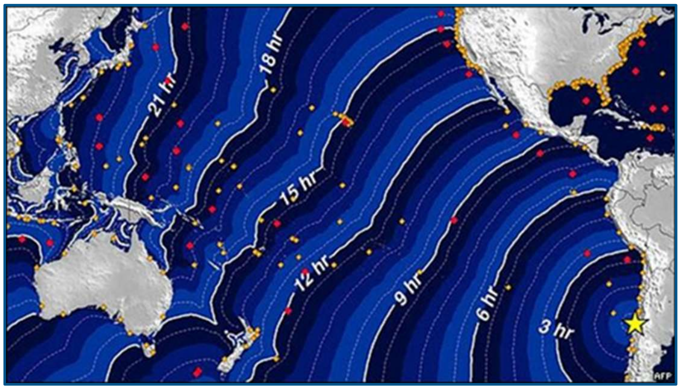

Figure 28 Expansive wave

The height of the wave train will vary upon the area and the impact on the coastline, and it will depend on the type of coastline, slope and other features of the shoreline.

Figure 29 Examples of destructive effects of tsunami

When such natural disasters occur, the personnel usually involved in navigational aid organizations, which in many countries are part of the Navy, is engaged in rescue tasks, community support and restoring basic services, as well as maintaining public order. This is therefore a critical scenario, where AtoN are not necessarily a priority.

Navigational aids located in the disaster area are also vulnerable to damage caused by an earthquake and subsequently a tsunami. However, it is possible to identify or prioritize those affected aids based on parameters, such as type and size of the structure and average height above sea level.

2. EMERGENCY AND CONTINGENCY PLAN

In countries with a seismic culture, such as Chile, Japan or Cuba, where based on experience, special plans have been developed to respond to all types of disasters, AtoN are considered critical infrastructure for their contribution to safety.

The following is an example of the general guidelines to be addressed in the event of extreme environmental disasters such as earthquakes, tsunamis, typhoons or hurricanes.

2.1. SUGGESTED ACTIONS

- Establish an emergency repairs unit made up by specialized personnel to inspect the affected area, in order to assess the condition of the navigational aids, according to the prioritization resulting from the variables of the structures and the average height above sea level.
- Once an initial assessment is completed, a basic corrective maintenance plan should be implemented using adequate equipment to restore damaged aids to normal.
- Provide a team of AtoN trained personnel equipped with the appropriate communications and personal protective equipment, and ready to operate in the event of an emergency.
- Keep written records with the following information:
  - List of personnel and their contact telephone numbers and addresses.
  - List of navigational aids installed at a certain maximum height above sea level, according to areas of action.
  - List of large navigational aids, mainly concrete, according to areas of action.
  - List of navigational aids powered by the public lighting network.
  - Paper charts with flooding plan for the main ports of the country.
  - Keep records of specific beacons.
- Provide operational VHF communications equipment and flashlights.
- Keep a lighthouse relighting kit, with minimum working tools to be shipped as quickly as possible.
- Stock minimum spares inventory and power supply for relighting of navigational aids.
- Implement consumables and spare parts warehouses to supply the necessary equipment.
- Provide a first aid kit.

2.2. POST-EVENT EVALUATION

- Communication systems may be suspended right after an earthquake, and internet, mobile and landline services will not be available. VHF and HF should be considered as a reliable option.
- Radio and television may be the only means of communication available to learn about the status of the catastrophe in the early stages, which could be used as a starting point to respond to uncertainty among local people.

- In addition, both urban and interurban roads may be damaged partially or totally, and thus fuel supply may be affected. Basic services such as electricity, drinking water and gas, may remain unavailable during the first days, even weeks, depending on the existing operational capacities, also for safety reasons.
- Depending on the materials used in fixed navigational aids such as fiberglass or polyethylene towers or beacons, they may not be damaged by the seismic activity, but they will be potentially impacted by the tsunami, which may exceed ten metres upon sea front slope.
- Large old navigational aids made of concrete and iron, which have been manufactured prior to anti-seismic regulations and have been exposed to the effects of the marine environment, may be greatly damaged by the quake even resulting in complete destruction.
- It should be noted that personnel responsible for the maintenance of AtoN might be needed to perform support tasks to assist local citizens, and the navigational aids would not necessarily be an immediate priority.