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| **World Meteorological Organization****Joint Session of the Expert Team on Operational In Situ Technologies (ET-OIST) and the Expert Team on Developments in In Situ Technologies (ET-DIST)**Geneva, Switzerland, 21-23 June 2017 | **CIMO/ET\_A1\_A2/Doc. 8.4/2**  |
| Submitted by:Ian Miller/ Jane Warne20.06.2017 |

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 **Guidelines for instruments and measurement infrastructure in extreme environmentS - Part 2**

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| **Summary and purpose of document**This document provides guidance on how to identify hazards, there impact on particular infrastructure and sensing technology, and suggested mitigations. |

**Action proposed**

The Meeting is invited to take notice of the findings reported in this document and to provide feedback on the contents. Also the Meeting should decide whether the document is suitable for publication as a separate IMOP report or whether information should be included in the CIMO guide.

**Appendix: I** Table of event types, hazards, impacts and mitigations

**Instruments and Measurement Infrastructure in Extreme Environments**

# Approach to development of guidelines for Instruments and Measurement Infrastructure in Extreme Environments

The basis of the approach to guidelines for Instruments and Measurement Infrastructure in Extreme Environments is provided in the first paper. This document is a draft tool, designed for the identification hazards, impacts and mitigations. The tool starts with the key mechanism or event such as extreme cold, the result of a particular weather patterns; the resultant hazard, such as cyclones which bring with them extreme winds, and particular impacts such as flying debris, and water inundation. For each hazard there are impacts on the infrastructure and sensors that require mitigation on the short and longer term.

A table of the Events, Hazards, Impacts and Mitigations can be found in Appendix A

# Events

For this study the primary events considered are meteorological and include examples such as cyclones, thunderstorms, blizzards, dust storms, storm surge, drought, heat wave etc. Causes of damage such as animal attack, insect infestation, and chemical deterioration have been excluded but may be included in a second version of this table.

# Hazard

The hazards that result from the events are often common between events such as wind, water current, water inundation, dust ingress, but there are also a number of unique examples such as land movement. The intent was to class as many in common as possible so that ultimately the mitigations would be identifiably common.

# Impact

While the hazard between events may be common the extent or severity maybe be distinctly different and varies significantly between infrastructure and sensors. It also varies between long and short term.

# Mitigation

These are the suggested approaches to addressing the impact and either eliminated or mitigating the consequence. Some are referenced where these were available.

# Guidance Table

The table in Appendix A is intended as a look-up table for organisation for planning and to commence dealing with issues in the field. As improved approaches to problems are identified if can be added to and likewise as new problems are identified this can be added for others to assist with resolution.

# Recommendation

3.1 That the meeting consider the suitability, or modify the form, of the tool for inclusion in CIMO Guide.

3.2 That the members of both ET A1 and ET A2 provide additional input as appropriate.

# References

Guo 2015 Guidelines for instruments and measurement infrastructure in extreme environment

Sure 2017 <http://surefootfootings.com.au/>

Denso 2017 <http://www.denso.net/sapvc.htm>

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| Appendix I – Table of Event Types, Hazards, Impacts and Mitigations |
| ***Event Type*** | ***Breakdown*** | ***Dominant Hazard*** | ***Impact to Infrastructure examples*** | ***Mitigation*** | ***Impact to Sensors examples*** | ***Mitigation*** | ***Longer Term Impacts to***  | ***Mitigation*** |
| ***Hail*** | Characteristic of a weather system | Impact | * damage to Radomes, dints and holes
 | * Component designed radomes that allow for panel changes
 |  |  |  |  |
|  |  |  |  | * Use of high strength materials e.g. carbon fibre (Guo 2015)
 |  |  |  |  |
|  |  |  | * observer shelters, breakage of louvers, damage to protective coatings
 | * Use of high strength materials e.g. carbon fibre (Guo 2015)
 | * mechanical anemometers damage to cups in particular. Small and light weight plastic cups are particularly vulnerable.
 | * Use of heavy-duty sensors, e.g., heavy-duty anemometers.
 | * deterioration of painted surfaces
 | * Use of high strength materials e.g. carbon fibre (Guo 2015)
 |
|  |  |  |  |  |  | * Use of high strength materials e.g. carbon fibre (Guo 2015)
 |  |  |
|  |  |  | * damage to light weight masts
 | * Use of high strength materials e.g. carbon fibre (Guo 2015)
 | * ultrasonic anemometers, damage to arms and detectors causing miss alignment
 | * Use of symmetric, aerodynamic designed anemometers
 |  |  |
|  |  |  |  |  |  | * Use of high strength materials e.g. carbon fibre (Guo 2015)
 |  |  |
|  |  |  | * damage to solar panels and electronics enclosures
 |  |  |  |  |  |
| ***Flood*** | Result of certain weather systems | Water Ingress | * ground mounted equipment undermined or washed away
 | * use mounting systems that stabilise the surrounding soil such as "Surefoot" which causes minima soil disturbance while spreading the load
* (Surefoot 2017)
 | * any non-submersible sensor
 | * Mount DAQ system enclosure as high as practical when the sensor can be submerged (water stage station for example)
 |  |  |
|  |  |  |  |  |  | * use appropriately "IP" rated enclosures for equipment, typically IP67 and above for waves and splash
 |  |  |
|  |  |  |  |  | * equipment in close proximity to high water flow (direct contact or erosion) submerged
 | * use appropriately "IP" rated enclosures for equipment, typically IP68 and above
 |  |  |
| ***Event Type*** | ***Breakdown*** | ***Dominant Hazard*** | ***Impact to Infrastructure examples*** | ***Mitigation*** | ***Impact to Sensors examples*** | ***Mitigation*** | ***Longer Term Impacts to*** | ***Mitigation*** |
|  |  |  | * equipment damaged by exposure/immersion in salt water.
 | * use materials such as marine grade stainless steel, galvanised iron, plastics, avoid the use of aluminium
 | * equipment damaged by exposure/immersion in salt water.
 | * Ensure electronics are appropriately sealed and potted to avoid corrosion or mold
 | * corrosion of metal component, particularly connectors, welds, joints
 | * coat welds, joints and nuts with grease e.g. silicon, even butter (Guo 2015).
 |
|  |  |  |  | * Selection of materials to avoid electrolysis. i.e. avoid use of dis-similar metals or separate with non-conducting material
 |  |  |  |  |
|  |  |  |  | * Ensure all connectors are wrapped in "Denso Tape" or similar product to prevent corrosion (Denso 2017)
 |  |  | * damage to protective coatings
 | * ensure all powder coating is pit free.
 |
|  |  | Debris | * damage from large debris in stream flow impacting towers and screens
 | * reinforce lower sections of towers to expected flood height
 |  | * damage from large debris in stream flow impacting towers and screens
 |  |  |
| ***Land/Mudslide*** | Result of rainfall in combination with certain ground conditions | Water Ingress | * nearly all, total destruction
 |  | * any non-submersible sensor
 | * Mount DAQ system enclosure as high as practical when the sensor can be submerged (water stage station for example)
 |  |  |
|  |  |  |  |  |  | * use appropriately "IP" rated enclosures for equipment, typically IP67 and above for waves and splash
 |  |  |
|  |  | Water Current | * nearly all, total destruction
 | * use mounting systems that stabilise the surrounding soil such as "Surefoot" which causes minima soil disturbance while spreading the load (Surefoot 2017)
 | * nearly all, total destruction
 | * use appropriately "IP" rated enclosures for equipment, typically IP68 and above
 |  |  |
|  |  | Mud | * nearly all, total destruction
 | * site equipment on local mounds or sculpture land to redirect mud and water around equipment
 | * nearly all, total destruction
 | * use appropriately "IP" rated enclosures for equipment, typically IP68 and above
 |  |  |
|  |  | Debris | * nearly all, total destruction
 | * reinforce lower sections of towers to expected land/mud slide height
 |  |  |  |  |
| ***Tropical Cyclone*** | Type of weather system, has many characteristics | Wind | * severe damage to Radomes, caused by pressure differentials and flying debris
 | * \*Component designed radomes that allow for panel changes
 | * nearly all
 | * Use of heavy-duty sensors, e.g., heavy-duty anemometers.
 |  |  |
| ***Event Type*** | ***Breakdown*** | ***Dominant Hazard*** | ***Impact to Infrastructure examples*** | ***Mitigation*** | ***Impact to Sensors examples*** | ***Mitigation*** | ***Longer Term Impacts to*** | ***Mitigation*** |
|  |  |  |  | * Guy wires on tower/tripod, attached to suitable anchors e.g. concrete or "surfoot"
* (Surefoot 2017)
 |  | * Use High strength nylon rope to support anemometer arm (Guo 2015)
 |  |  |
|  |  | Water | * equipment/observer shelters severely damaged
 | * Guy wires on tower/tripod, attached to suitable anchors e.g. concrete or "surfoot"
* (Surefoot 2017)
 |  |  |  |  |
|  |  | Debris | * towers severely damaged
 | * Use of tower/tripod with appropriate wind load rating.
 |  |  |  |  |
| ***Thunderstorms*** | Characteristic of a weather system associated with lightning | Wind | * tall equipment like towers
 |  | * sensors with exposure and no tolerance for direct or indirect lightning strikes
 | * Use of Grounding Rod/Plate, Finial, etc. on weather station tower/tripod.
 |  |  |
|  |  | Water |  |  |  | * Use of Surge Suppression devices between sensors and data acquisition system to protect the DAQ.
 |  |  |
|  |  | lightning | * electrical surge
 | * electrical surge protection
 | * sensors with exposure and no tolerance for direct or indirect lightning strikes
 | * Use of Grounding Rod/Plate, Finial, etc. on weather station tower/tripod.
 |  |  |
|  |  |  |  | * appropriate earthing of infrastructure
 |  | * Use of Surge Suppression devices between sensors and data acquisition system to protect the DAQ.
 |  |  |
|  |  |  |  |  |  | * Surge or earth transient protection devices need to be employed appropriately for all systems including communications, DAQ and power.
 |  |  |
|  |  |  |  | * Lightning rod
 |  |  |  |  |
|  |  | Debris | * towers severely damaged
 | * Use of tower/tripod with appropriate wind load rating.
 |  |  |  |  |
| ***High Wind*** | Characteristic of a weather system | Wind | see Tropical Cyclone |  | see Tropical Cyclone |  |  |  |
|  |  | Debris |  |  |  |  |  |  |
| ***Event Type*** | ***Breakdown*** | ***Dominant Hazard*** | ***Impact to Infrastructure examples*** | ***Mitigation*** | ***Impact to Sensors examples*** | ***Mitigation*** | ***Longer Term Impacts to*** | ***Mitigation*** |
| ***Tornado*** | A weather sub-system characterized by high winds and blowing debris | Wind | see Tropical Cyclone |  | see Tropical Cyclone |  |  |  |
|  |  | Debris |  |  |  |  |  |  |
| ***Storm Surge*** | Results of cyclones and Severe Wx | Water | see Flood |  | see Flood |  |  |  |
|  |  | Current |  |  |  |  |  |  |
|  |  | Debris |  |  |  |  |  |  |
| ***Tsunami*** | Independent of meteorological factors | Water | see Flood |  | see Flood |  |  |  |
|  |  | Current |  |  |  |  |  |  |
|  |  | Debris |  |  |  |  |  |  |
| ***Snow/Blizzard/Icing*** | Both a type of weather system, and associated characteristics | Cold | * shelters
 | * investigate the use of use of ice phobic coatings and materials
 | * mechanical anemometers
 | * Use of Heated Sensors if possible
 |  |  |
|  |  |  |  |  |  | * Application of heat tape to systems without built in heating (Caution needs to be taken to ensure minimal impact on measurement)
 |  |  |
|  |  |  |  |  |  | * Application of low freezing point fluids (e.g. ethanol) during events
 |  |  |
|  |  |  |  |  | * Humidity sensors
 | * Use heat cycling sensors
 |  |  |
|  |  | Mast | * towers
 | * Masts with a slightly flexible mast to vibrate
 | * ultrasonic anemometers
 | * Use of sensors (anemometers) that have Icephobic coatings
 |  |  |
|  |  | Wind | * platforms
 |  | * Snow/Ice cover on optical sensors
 | * Mount wind sensor on slightly flexible mast (wind surfer mast used by some)
 |  |  |
|  |  | Water | * Snow/Ice cover on solar panels eventual loss of power
 |  | * Snow/Ice cover on pyranometers/radiation sensors
 | * Tilt Solar Panels as close to vertical as possible to prevent snow/ice accretion
 |  |  |
|  |  |  |  |  | * Snow/Ice cover on Temp sensors & screens causes incorrect data (much higher Time Constant)
 |  |  |  |
| ***Event Type*** | ***Breakdown*** | ***Dominant Hazard*** | ***Impact to Infrastructure examples*** | ***Mitigation*** | ***Impact to Sensors examples*** | ***Mitigation*** | ***Longer Term Impacts to*** | ***Mitigation*** |
| ***Avalanche*** | Result of snowfall in combination with certain ground and atmospheric conditions | Mass | * nearly all
 | * Do not locate weather station in avalanche path
 | * nearly all
 |  |  |  |
|  |  |  | * Snow/Ice cover on solar panels - eventual loss of power
 | * Construct tower with multiple solar cells at various height
 | * Snow/Ice cover on optical sensors
 | * Construct tower with multiple sensor suites at various height
 |  |  |
|  |  |  |  |  | * Snow/Ice cover on pyranometers/radiation sensors
 |  |  |  |
|  |  |  |  |  | * Snow/Ice cover on Temp sensors & screens causes incorrect data (much higher Time Constant)
 |  |  |  |
| ***Dust Storm*** | Result of high winds in combination with certain ground conditions | Wind | * equipment that can be damaged by sandblasting or burying.
 | * avoid the use of coated materials
 | * aspirated equipment drawing dust
 | * stop aspiration when wind above a set point, or above a particle count
 |  |  |
|  |  | Dirt |  |  | * clogging of non-aspirated equipment
 | * Increased inspection of equipment to remove dust build up
 |  |  |
|  |  |  |  |  |  | * Use of well- sealed (high IP rated) enclosures for DAQ, e.g. IP68
 |  |  |
|  |  |  |  |  |  | * Increased replacement of filter in dusty environments
 |  |  |
|  |  |  |  |  | * optical and solar radiation equipment
 | * for light coverage consider daily automated cleaning
 |  |  |
| ***Fire*** | Result of certain weather systems | Heat | * anything built with combustible materials
 | * Construct of non-combustible materials e.g. metal
 | * nearly all
 |  |  |  |
|  |  | Dust | * see dust ingress
 |  |  |  |  |  |
|  |  | Debris | * Damage from fall debris
 | * site equipment in fire prone areas with appropriate clearance from potential falling structures and trees
 |  |  |  |  |
| ***Event Type*** | ***Breakdown*** | ***Dominant Hazard*** | ***Impact to Infrastructure examples*** | ***Mitigation*** | ***Impact to Sensors examples*** | ***Mitigation*** | ***Longer Term Impacts to*** | ***Mitigation*** |
| ***Drought*** | Result of  certain weather conditions | Dust | * equipment bases in clay soils (cracking, erosion)
 | * use mounting systems that stabilise the surrounding soil such as "Surefoot" which causes minima soil disturbance while spreading the load (Surefoot 2017)
 | * few, if any
 | * check for dry joints in electronics
 |  |  |
|  |  | Erosion | see dust ingress |  |  |  |  |  |
| ***Heat Wave*** | Characteristic of a weather system | Heat | * few, unless exterior surfaces have low temperature tolerance
 |  | * sensors damaged by heat effects (sensing elements or housings)
 | * ensure sensors are correctly rated for use in the climate they are being deployed in. e.g. 20 to 30 C above the climatic max for electronic and 5 to 10 C above for the measurement range
 | * ageing of welds and joints
 | * More frequent inspections for metal fatigue and deterioration
 |
|  |  |  |  |  |  | * use canvas or similar to shade electronics and reduce thermal stress on systems (Guo 2015)
 | * Discolouration and ageing of plastic components
 | * More frequent inspections distortion and deterioration
 |
| ***Earthquake/Volcano*** | Independent of meteorological factors | Land movement | * Volcano; burying by fallout, destruction from direct contact with flow.
 |  | * Volcano; dust contamination
 | see dust above |  |  |
|  |  |  | * Earthquake; most infrastructures.
 | * use mounting systems that stabilise the surrounding soil such as "Surefoot" which causes minima soil disturbance while spreading the load (Surefoot 2017)
 | * Earthquake; weighing gauges, loosely mounted sensors e.g. TBRG
 |  |  |  |
|  |  |  | * Ash cover on solar panels - eventual loss of power
 | * include back up batteries and alarms on loss of voltage and current supply
 | * Ash cover on optical sensors
 | * for light coverage consider automated cleaning
 |  |  |
|  |  |  |  |  | * Ash cover on pyranometers/radiation sensors
 | * for light coverage consider automated cleaning
 |  |  |
| ***Event Type*** | ***Breakdown*** | ***Dominant Hazard*** | ***Impact to Infrastructure examples*** | ***Mitigation*** | ***Impact to Sensors examples*** | ***Mitigation*** | ***Longer Term Impacts to*** | ***Mitigation*** |
| ***Security*** | Independent of meteorological factors | Human Intervention | * Theft, vandalism
 | * Fencing
 | * Theft, vandalism
 | * Non-removable fittings
 |  |  |
|  |  |  |  | * Remoteness
 |  |  |  |  |
|  |  | Large Animals | * Rubbing against
 | * Fencing
 | * Rubbing
 | * Fencing
 |  |  |
|  |  |  |  | * Electrical wire fencing
 |  |  |  |  |
|  |  | Small Animals | * chewing
 | * armoured cables, conduit
 |  |  |  |  |
|  |  |  |  | * Buried cabling
 |  |  |  |  |
|  |  | Insects & Small Animals | * Infestation / nesting
 | * Sealed conduit
 |  |  |  |  |
|  |  |  |  | * Stuff conduit with coiled metal shavings
 |  |  |  |  |
|  |  |  | * chewing
 | * avoid timber, especially soft or low oil timber
 |  |  |  |  |
|  |  | Birds | * Perching / nesting
 | * Wire deterrents
 |  |  |  |  |
|  |  |  | * chewing
 | * minimise exposed soft timber, plastics etc
 | * chewing
 | * minimise exposed soft timber, plastics etc
 |  |  |