Best practice report - Installation Procedures

Deliverable 3.6.2 from the MERiFIC Project

A report prepared as part of the MERiFIC Project
"Marine Energy in Far Peripheral and Island Communities"

March 2014

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MERiFIC was selected under the European Cross-Border Cooperation Programme INTERREG IV A France (Channel) – England, co-funded by the ERDF.

Executive Summary

This report is a deliverable of MERiFIC Task 3. 6: 'Installation Procedures' and has been produced in a cross border collaboration between IFREMER and the University of Exeter. In this report different elements are presented for the planning and organisation of installation operations for the deployment of Marine energy plants. The optimization of installation procedures are discussed and brought in a context to potential costs optimization and the availability of suitable vessels is considered.

Installation procedures, which were also investigated, should include pre-installation surveys so as to optimize the design of moorings and secure laying of the power cable, a specific feature of the commissioning of such Marine energy plants. Attention should also be given to the Health and Safety procedures.

Finally, the influence of the weather conditions on the success of these installation operations was discussed and studied. Especially, "Access time" and "Waiting time" weather windows were assessed for different sites in both areas of south west Cornwall and the Iroise Sea, pointing out the importance of the seasonal variability of the wave climate for the planning of installation operations.

Content

List of figures

List of Tables

Appendices

The MERiFIC Project

MERiFIC is an EU project linking Cornwall and Finistère through the ERDF INTERREG IVa France (Manche) England programme. The project seeks to advance the adoption of marine energy in Cornwall and Finistère, with particular focus on the island communities of the Parc naturel marin d'Iroise and the Isles of Scilly. Project partners include Cornwall Council, University of Exeter, University of Plymouth and Cornwall Marine Network from the UK, and Conseil général du Finistère, Pôle Mer Bretagne, Technôpole Brest Iroise, IFREMER and Bretagne Développement Innovation from France.

MERiFIC was launched on 13th September at the National Maritime Museum Cornwall and runs until June 2014. During this time, the partners aim to

- Develop and share a common understanding of existing marine energy resource assessment techniques and terminology;
- Identify significant marine energy resource 'hot spots' across the common area, focusing on the island communities of the Isles of Scilly and Parc Naturel Marin d'Iroise;
- Define infrastructure issues and requirements for the deployment of marine energy technologies between island and mainland communities;
- Identify, share and implement best practice policies to encourage and support the deployment of marine renewables;
- Identify best practice case studies and opportunities for businesses across the two regions to participate in supply chains for the marine energy sector;
- Share best practices and trial new methods of stakeholder engagement, in order to secure wider understanding and acceptance of the marine renewables agenda;
- Develop and deliver a range of case studies, tool kits and resources that will assist other regions.

To facilitate this, the project is broken down into a series of work packages:

WP1: Project Preparation
WP2: Project Management
WP3: Technology Support
WP4: Policy Issues
WP5: Sustainable Economic Development
WP6: Stakeholder Engagement
WP7: Communication and Dissemination

1 Introduction

Installation operations are a key element in the development of Marine Renewable Energy production sites. They also contribute to a large part in the total effective cost of development for such production plants.

In this report the main elements to be taken into account for optimizing such installation operations while reducing their cost are presented. Availability of suitable vessels is discussed in Section 3 while guidelines for well-prepared procedures are proposed Section 4. Installation costs are discussed Section 5. A good assessment of weather window availability for access to the deployment site is also necessary to minimize waiting time and hence reduce costs. Procedures for evaluating access and waiting time are presented in Section 6 and applied to specific sites in the two regions of the south-west of Cornwall and the Iroise Sea.

It can be noted that additional information, especially details on infrastructures and ports is given in the MERIFIC report 3.6.2 on requirements for Operations and Maintenance.

2 Background

As summarized in [4], given the targets set in the United Kingdom's Renewable Energy Strategy for the supply of electricity from renewable sources (15% of total energy from renewable by 2020) and given that the United Kingdom is an island nation with approximately 11,000 miles of coast line, it is clear that marine renewable energy can play a key part in this required expansion [11].

With a coastline of about 3400 km and a marine area of over 10 million km^2 (including overseas territories) France has a significant potential in terms of harnessing energy from the sea. Marine renewable energy could play a key role in the national program for reduction of the carbon footprint, with the objective of having renewable energies accounting for up to 23% in the total consumption of energy of the country before 2020.

In order to allow marine renewable energy to become a viable energy supply the target costs of generated power need to be reduced. As installation is one significant element in the overall cost for energy generation from marine sources it is important to address the installation and develop solutions that will reduce the costs associated to this operation. The cost breakdown in Figure 1 [1] presents a cost break down separated into installation, device manufacture and other costs. It can be identified that the installation process makes a large contribution (in the order of 29.5%) to the total cost of this project. Therefore, it is reasonable to conclude that cost reduction for installation is essential to allow marine energy projects to firstly become financially viable and secondly to complete with "traditional" generation methods.

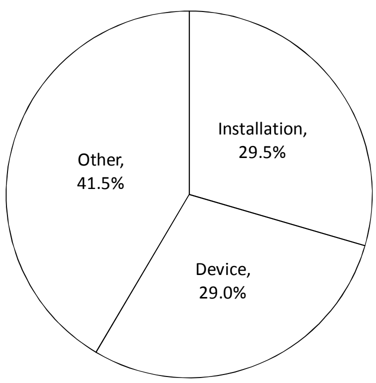


Figure 1: Installation and device costs as a proportion of the total project cost [1]

One of the elements to be considered in the cost assessment of such installation operations at sea is the availability of suitable high capacity installation vessels, such as tugs, supply vessels or crane vessels able to perform marine operations even in harsh weather.

Furthermore, the data presented in Figure 1 considers an installation which is successful at the first attempt and is only for a single device. Often when installing marine energy devices this is not the case. Multiple operations may be required to successfully install a device and this will clearly increase the cost associated with installation, as well as providing an uncertainty to the overall budget required. These further installation efforts may be required for a number of reasons, for example technical difficulties. However, the primary cause of delayed operations is most likely the result due to poor weather conditions, as identified from experience by the International Energy Agency (2005) [13] with respect to offshore wind farms. A summary of standards that are related to installation activities are provided in Appendix 1 (Summary of Applicable Guidelines and Standards).

3 Installation Vessels

Walker [14] stated that sourcing suitable vessels, given the requirements which they are expected to perform to (i.e. heavy lifts in extreme environments) and the shortage of vessels capable of the tasks, is problematic enough without considering cost constraints.

In Table 1 the general vessel capabilities are identified for these offshore vessels, discussing abilities and limitations.

Vessel Type	Abilities	Limitations
Multicat	Typically has a larger load carrying capacity than a workboat. Often has a small crane and/or winches on board	Seakeeping ability in adverse conditions, green water
Workboat	Highly maneuverable and usually able to navigate much shallower water depths than larger vessels	Seakeeping ability in adverse conditions
Offshore construction vessel (OCV)	Can be heave compensated	Risk of loss of heave compensation during lifting operations
Jack-up barge	Stable platform for a variety of installation tasks (e.g. piling). Vessel can remain on station for long periods of time	Risk of vessel lift due to loss of air gap
Anchor Handling Tug (AHT)	Specially designed for the installation and recovery of anchors	Safety of crew from green water on deck
High Lift Vessel (HLV)	Utilised extensively for offshore wind turbine installations	Safety risk due to motion of crane jib

Table 1: Vessel capabilities and limitations (adapted from [1])

In general offshore vessels that could be used for installation procedures include:

- Multicat;
- Workboat;
- Jack-up barge;
- Heavy Lift Vessel;
- Offshore Construction Vessel;
- Anchor Handling Tugs.

Figure 2 : Example offshore vessels (clockwise from top left) Rambiz HLV[1], North Sea Giant OCV[2], Resolution jackup barge[3], MTS Valiant workboat[4], Eurocarrier 2209 multicat[5] and Sea Cheyenne AHT[6]

Walker [1] produced a jack-up barge availability chart for operating water depth (Figure 4a) and vessel operating capabilities superimposed on Wave Hub site characteristics (Figure 4b) showing the upper working limits, in terms of wave height and period, for some of the vessels discussed. Also included are the height to period relationships for i) the minimum period seen at a given wave height ii) the RMS period seen and iii) the maximum period seen. Whilst in most cases the effect of wave period on the upper operable wave height range is limited, in some cases the period can have a significant impact. This is a feature which should be considered when determining if an operation can be successfully executed.

1 http://www.huismanequipment.com/en/products/cranes/wind_turbine_installation_cranes (accessed online: 12/12/2013)

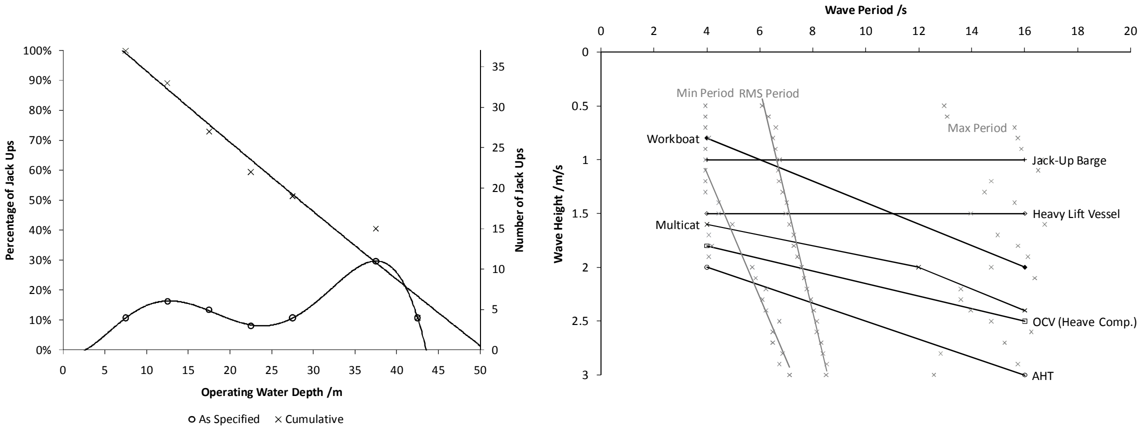
2 http://worldmaritimenews.com/archives/43108/norway-technip-retains-ocv-north-sea-giant/ (accessed online: 12/12/2013)

3 http://news.bbc.co.uk/1/hi/magazine/7206780.stm (accessed online: 12/12/2013)

4 http://www.workboatassociation.org/ (accessed online: 12/12/2013)

5 http://www.dsboffshore.com/vessel.php?id=778&name=Multicat-type-Eurocarrier-2209-for-charter-/-21.6-x-9.04m,-14tbp (accessed online: 12/12/2013)

6 http://www.kepcorp.com/en/news_item.aspx?sid=1604 (accessed online: 12/12/2013)



(a) **(b)**

Figure 3 : a,b: (a) Jack-up barge availability with operating water depth, (b) vessel operating capabilities superimposed on Wave Hub site characteristics [1]

In general consideration needs to be given in terms of the suitability of a vessel for installation activities in terms of their: i) maneuverability, ii) provision of thrusters (i.e. for access between arrays), ii) personnel carrying capacity, iii) equipment payload, iv) safety and regulatory factors, v) weather and sea-state dependency, vi) direct cost (of retaining and using a service), vii) deck spacing, viii) lifting capabilities, ix) deployment location characteristics (offshore, nearshore, shoreline) and x) seabed conditions. In order to make a choice of a suitable vessel for a specific installation operation a list of detailed specification could be:

A) Dimensions
   a. Draft
   b. Length
   c. Deck layout/loading area

B) Capacity
   a. Engine power
   b. Speed
   c. Crane capacity
   d. Winch capacity
   e. Bollard Pull
   f. Structural strength of deck
   g. Stability with load

C) Availability
   a. Mobilisation cost
   b. Day rate
   c. Home port
   d. Owner

D) Other
   a. Station keeping installation (mooring of the installation vessel)
   b. Accurate positioning (example: DGPS)
   c. Experienced crew

The final decision on a vessel for the installation and the possible need to have also support vessels available needs to be based on the characteristics required for the installation of the hardware and site conditions. However, often the choice will be limited by the vessel availability and budget restrictions. A list of some vessels is provided in Appendix 2 with characteristics of vessel specification, length and limiting factors.

With the majority of installation vessels designed for offshore oil and gas operations, the demand from this industry has a direct effect on the cost of suitable installation vessels and hence there can be high levels of fluctuation in the day rates charged [15]. It was noted that these price fluctuations were directly linked to the price of oil and that development of specific installation vessels would de-couple this relationship, potentially bringing some stability to the market.

In order to address the need to reduce marine energy installation costs and to provide vessels that have suitable characteristics at an affordable budget, novel vessels designs are considered.

The South West of England based company Mojo Maritime [16] has developed a novel installation vessel (Figure 5) in partnership with Bauer Renewables, Voith Turbo Marine Engineering, Det Norske Veritas and the University of Exeter, supported by the Technology Strategy Board’s innovation agency through its ‘Marine Energy Supporting Array Technologies’ (MESAT) Programme.

The novel design criteria identified by Mojo Maritime [16] include:

- High performance (hold station in up to 10kts [5.14m/s] of current)
- Exceptional manoeuvrability (symmetric hull form which is efficient in all directions)
- Flexible, modular design (versatile vessel suitable for a range of offshore services)
- Low operating costs (increased operational weather window and optimised manning philosophy)
- Fuel efficient (optimised hull form for high fuel efficiency)
- Large deck space (catamaran configuration increases deck space for operational equipment)
- Environmental friendly (reduced noise and flow speed around Voith Sneider Propellers means decreased environmental impact)

Figure 4 : Novel installation vessel HF4 [16]

Even though multipurpose vessels can be considered a good option for increasing availability, hence reducing costs, the deployment of some devices may require specific capabilities and it might also be worth considering designing dedicated deployment support units, especially when a large number of identical devices are to be deployed in a given production site. An example of such deployment unit is the "OpenHydro-Triskell" current turbines deployment barge built by STX Europe. This high capacity support barge was designed for transportation, deployment and recovery of current turbines weighing up to 1000 tons.

Figure 5 : Tidal turbine deployment barge

4 Procedures

As previously stated it is necessary in order for installation costs to be minimised that deployments are successful at the first attempt. Hence, operations should be carefully planned and prepared and procedures clearly and precisely defined beforehand starting with the pre-installation surveys and taking into account the requirements for decommissioning.

4.1 Pre-Installation

The pre-installation phase should be started well ahead of the deployment in order to identify the possible constraints and select suitable vessels and means necessary for the installation operations. Environmental surveys should be conducted, not only bathymetry but also geophysical surveys to identify the type and quality of the seabed. The following factors will strongly influence the type of mooring or foundation system used[7]:

- Sonar survey to determine bathymetry across the proposed site
- Seabed survey to determine seabed type and holding capacity
- Mooring and foundation analysis to determine optimum mooring design based on Accidental Limited State (ALS), Ultimate Limited State (ULS), Fatigue Limited State (FLS) load states.

7 Further information regarding station-keeping equipment is available in the literature, including the MERiFIC deliverable *D3.5.3 Best practice report - mooring of floating marine renewable energy devices*

4.2 Anchor installation

The determination of anchor and foundation placement should be based on seabed type (as this influences anchor handling capability) and holding requirements (e.g. horizontal, vertical, minimum pullout load, etc.). Whilst the choice of anchor type and installation method can be very complex (i.e. in the latter case due to large dimensions of anchor and chain and due to the difficulty of working in unfavorable weather conditions), a summary of anchor installation criteria has been attempted and shown below:

- The accuracy of anchor/foundation placement is essential
- The type of anchor or foundation is dependent on device and seabed type (e.g. drag embedment, rock/sand screws, gravity based anchors)
- Considerations for mooring line transportation, handling and installation
- Floating devices will either be towed or transported on deck
- Installation process dependent on anchor or foundation type (e.g. drag embedment anchor, piling, rock/sand screws and gravity based)
- Subsequent mooring line tensioning

Anchors with specific design criteria are available, often designed to offshore oil and gas requirements. Example of such anchors are the Fluke/Shank angle anchor [17]. Data of the holding capacity of this type can be found in the 'REF NCEL 87' document [18]. Transportation and handling criteria are discussed in the documentation produced by manufacturer Vryhof [19], whilst anchor chain deployments are discussed in [20] and subsea tensioner are discussed in [21]. Anchor handling operations or subsea tensioner are two commonly used methods. Anchor handling operations are summarized below (based on [19]):

1. The anchor is lowered. The anchor is connected to an angle adjuster with a shear pin
2. When the anchor is close to the seabed, the vessel slowly starts moving forward to ensure that the anchor lands correctly on the seabed
3. When the anchor reaches the seabed, the installation bridle or mooring line is paid out. If the anchor does not land correctly, a rerun should be made immediately
4. When enough line has been paid out, the anchor handling vessel (AHV), using its bollard pull, starts increasing the tension in the mooring line. The anchor starts to embed
5. When the installation load is reached, the angle adjuster triggers the anchor to its normal loading mode. The holding capacity suddenly increases, which stops the AHV to move forward
6. The AHV increases the tension until the proof load: the anchor is installed.

4.3 Power cable and sub-sea hub installation

One of the specific requirements of Marine Renewable Energy production sites is that they must be connected to the power grid on shore by means of a power cable. Additionally, sub-sea connectors should be installed allowing easy connecting-disconnecting of the marine energy devices for maintenance operations. Hence the general connection layout of a marine renewable power plant consists in cables or umbilicals for each marine energy device. These are then connected in subsets to sub-sea hub connectors which are connected to the main power cable laid on the seabed which transmits power to the grid connection point on shore [29].

Prior to any cable laying, surveys should be conducted over the area between the production site and the grid connection point onshore to assess the most suitable path along which the cable can be laid. These surveys should include:

- Sonar survey to determine bathymetry along the cable route.
- Seabed survey to determine seabed type along the cable route.
- Current and wave surveys for hydrodynamic loading on cables and umbilicals.

As marine renewable production sites are more likely to be located in intermediate waters, wave action on the seabed will require cables to be buried wherever possible. Over rocky seabeds or in the vicinity of tidal turbines plants where the scouring effects of the strong currents which prevent the burying of cables, specific mitigation procedures should be applied in order to reduce the effects of abrasion, including deployment of protection pads (as for instance at SEMREV testing site in France).

Figure 6: SEMREV Testing site Power cable laying **(credit Orange Marine)**

Figure 7 : Wave Hub connector deployment

4.4 Deployment operations

Even though not necessarily the most difficult or complex operation in the whole installation procedure, deployment on site is probably the one with the greatest risk as it requires handling of the marine energy device, considered to be the main asset of a production plant project. As a consequence deployment should be properly designed prepared and planned. In the case of multi-device deployment, the procedure should also be optimised so as to be easily repeated after each transit from port. In any case, such deployment operations should be considered "weather restricted" operations, and hence be of limited duration [30]. Weather windows assessment required for planning of installation operations is presented in Section 6 but a specific weather forecast procedure should be formalized which provides the following forecast information at regular intervals:

- Wind (speed and direction);
- Waves (significant wave height, period, direction);
- Current (speed and direction);
- Sea level and tide variation;
- Visibility (rain, fog);
- Temperature, barometric pressure.

The level of complexity of the deployment operation, hence the number and capacity of requested operation vessels (see Appendix 2) will depend on the type of device and selected transportation means. Where a simple towed float would only require tugs for anchor and sub-sea cable connection, barge transported structures or on-site assembled structures would require additional lifting capacities and/or ballasting capacities [31]. A method statement describing the deployment needs to be generated ahead of any deployment addressing aspects such as: i) QHSE policy, ii) project method statement and iii) risk management plan. A more detailed overview of method statement sub-categories are presented in the figure to the right.

Deployment of current turbines, most likely on sites with strong periodic tidal currents, should be considered as a specific operation as operation windows might be of limited duration. Hence, sequenced operations with possible "return to safe position" should be incorporated. Additionally, power of vessels and Dynamic Positioning systems should be defined so as to allow a proper response to the current loading and dynamics [32].

1. Introduction
2. QHSE Policy
2.1. Objectives
2.2. Vision **Error! Bookmark not defined.**
2.3. Mission
2.4. Guidelines
2.5. QHSE Goals
2.6. QHSE Delivery
3. Project Method Statement
3.1. Vessels and Personnel
3.2. Preparation
3.3. Operations**Error! Bookmark not defined.**
3.3.1. Mobilisation of equipment.
3.3.2. Deploy C-Salvor Mooring
3.3.3. Deployment Operations
3.3.5. Moor C-Salvor
3.3.6. Offshore operations
3.4. Recovery of C-Salvor Moorings
4. Risk Management Plan
4.1. Risk Management Method
4.2. Project Organisation
4.3. Key Personnel and Responsibilities
4.4. Risk Identification and Reduction Activities
4.5. Significant Risks Identified
4.5.1. Vessel movements
4.5.2. Marine Operations
5. Appendices

Figure 8 : Example of Method statement sub-categories

4.5 Decommissioning

The Guidance Notes for Industry [2] produced by the DTI in response to the Energy Act 2004 favour total decommissioning, including the complete removal and proper disposal of all equipment. Partial decommissioning, as outlined in the 1989 International Maritime Organisation guidelines [3] may also be acceptable if adequately justified and consent is granted. This option may be taken if the costs of total decommissioning are prohibitively expensive and/or it would result in an adverse impact to the marine environment. Although not a device, the Wave Hub decommissioning procedures give some detail about possible options for subsea equipment removal at the end of the project lifetime. The disposal of equipment is likely to include recycling (e.g. the WaveStar 1:10 concept Nissum Bredning, almost 100% of the system was recycled[8]).

4.6 Health and safety

It is crucial that a strong Health and Safety (H&S) ethic is implemented from the beginning of a project. In order to be safe during the whole process of installation, commissioning and decommissioning, operation and maintenance, some simple steps should be followed by all of the actors of the project, according to BWEA report 'Guidelines for Health and safety in the marine energy industry' [22],[23],[24]:

- Legislative requirements: some legislations are required by all employers, their application is explained in HSEs guidance document: 'Successful health and safety management;
- Management: A global policy with overall H&S objectives should be defined and will strongly influence any business decisions;
- Organisation: H&S should be a collaborative effort to improve communication and coordination, with clearly identified roles and responsibilities. Management should check that the organisation is functional;
- Planning: the policy should be put in practice, by setting objectives and performance standards;
- Measuring and reviewing: A check of the planning needs to be done in order to correct errors and make improvements;
- Assessment of risks is detailed in 'Management of Health and Safety at work regulations 1999';
- Adaptation to possible changes: If any change occurs during the process, H&S should be preserved.

The general recommendations and the following more specific points need to be followed according to BWEA report 'Guidelines for Health and safety in the marine energy industry' [25]:

- Notification: required information has to be given to relevant authorities and third parties before installation, commissioning and decommissioning (HSE construction regulations 2007);
- Documentary control and record keeping: a H&S file has to be created and updated during the project (Managing health and safety in construction, HSE);

8 WaveStar's old 1:10 scale test plant retires http://www.nordicgreen.net/startups/article/danish-wavestar-energy-retires-company-s-old-test-plant-and-plans-ten-fold (accessed online 06/12/12)

- Hazard identification and risk assessments: they have to be used at each step to write methodology;
- Safe system of work: individual tasks have to be described and remaining risks highlighted;
- Information, consultation, training and supervision: appropriate training has to be identified. Duties of the employer are detailed in (Health and Safety at Work act, 1974);
- Competency and fitness: it should be ensured that personnel is competent to carry out its own duties (Managing health and safety in construction, HSE);
- Safe working practices to manage site access onshore:
    - To follow local regulations for offshore navigation (Docks regulations 1988, Safe work in confined spaces 1997 and International Ship and Port security code);
    - To define procedures for device access (sea state limit, training...). Access should be limited to only necessary operations;
    - To follow regulations for towing (appropriate vessel and equipment, sea state limit, etc.). (Merchant shipping regulations 1998, Chapter 1933);
    - To use preferentially ROV (low risk) instead of divers (high risk), manage risks, (Diving at work Regulations, 1997);
    - To certify lifting equipment. (LOLER[9] and PUWER[10]);
- Onshore works: a safe planning has to be defined (for the quay and cable storage and transportation);
- Safety signs: they should be provided for remaining risks (H&S Safety Signs Regulations, 1996";
- Chemicals and substances: hazardous substances have to be registered, first aid facilities adapted (Control of Substances Hazardous to health regulations 2002);
- Security: access should be prevented to unauthorised persons;
- Occupational health: appropriate procedures depending of the carried out work should be available
- Medical facilities and first aid: appropriate level of medical facilities should be defined following (H&S First Aid Regulations, 1981);
- Emergency response planning: self-sufficiency in case of wait for a rescue should be ensured
- Reporting and investigation of accidents and incidents: a procedure should be established and problems investigated.

A summary of UK Health and safety documents are provided in Appendix 3 "Health & Safety references".

[9] Lifting Operations and Lifting Equipment Regulations

[10] Provision and Use of Work Equipment Regulations

5 Costs

5.1 Estimating cost

Estimating the cost of device or array installation is not trivial because the requirements of the installation are highly device specific, dependent on location, the cost and availability of vessels, equipment and trained personnel. With a lack of deployment experience, estimates of installation cost, particularly for large deployments have limited accuracy. However indicative values can initially be used from oil and gas equipment and wind turbine installations. The stage of the project will also determine the cost; the installation of a prototype may be expensive compared to the efficient deployment of many devices at one location due to economies of scale. In studies such as the one conducted for the Scottish Government [5] installation costs (including vessels, logistics base and other installation expenditure) represented 21% of costs incurred up to the deployment stage (Figure 8).

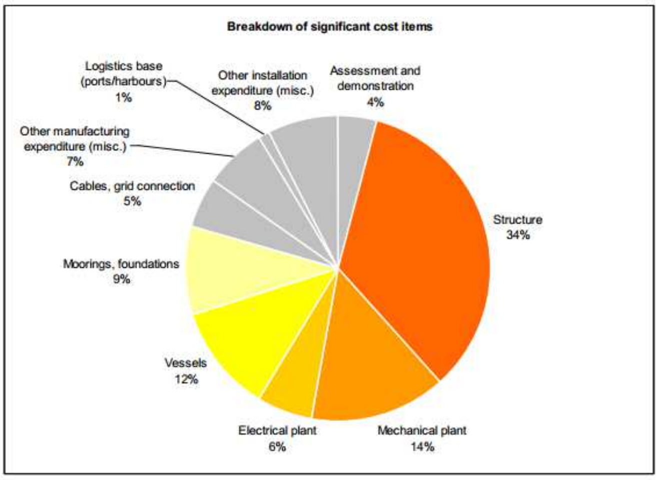


Figure 9 : Construction and installation expenditure for a hypothetical 50MW MRE plant [5]

Based on the values in [5] and Carbon Trust estimates, Walker et al. in [4] estimated that the installation cost is 29.5% of total project costs for a single wave energy device, assuming that the operation is successful at the first attempt. According to the 2011 report Accelerating Marine Energy (prepared by the Carbon Trust and Black & Veatch [6]) installation accounts for 33% of the levelised cost of energy for tidal energy devices.

5.2 Factors affecting installation cost

In this section an attempt has been made to summarise cost factors in three categories i) environmental and geographical factors, ii) equipment factors and iii) logistic factors.

Environmental and geographical factors

- Probability of occurrence of a weather window with accessible conditions (significant impact on cost)
- Distance and route to site during installation and demobilisation (fuel costs, transit time).

- Utilisation of single or multiple ports. Road/rail transportation[11].
- Access Space (between arrays, shared connection points). The risk of impact or entanglement may determine vessel requirements.

Logistical factors

- Size of devices and scale of deployment (i.e. single device or arrays)
- Expected installation duration and extent of contingency measures
- Availability and cost of operations personnel, vessel crew and other specialists (i.e. dive teams, ROV operators)
- Support Infrastructure (i.e. proximity of ports, dockside cranes)
- Port dockside charges (berthing, cranes)
- Insurance costs

Equipment factors

- Vessel capabilities. Operating water depth, wave height and wave period, tidal current, vessel manoeuvrability, on-board equipment such as cranes and winches, ability to wait on station, i.e. crew accommodation.
- Vessel availability. Typically dependent on season.
- Vessel cost. Dependent on season and availability, e.g. Figure 9.
- Access and waiting costs (due to adverse weather conditions). Generic or specialised vessels.
- Availability and cost of auxiliary equipment (i.e. is it best to charter or buy?).

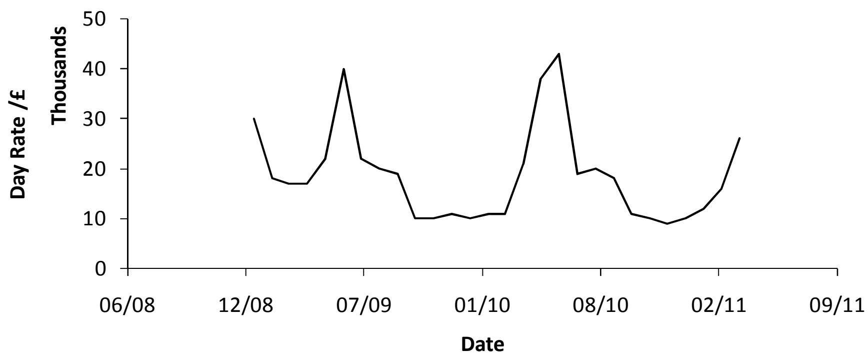


Figure 10 : Example day rates for an anchor handling tug (December 2008 to April 2011) [4]

Walker [14] further identifies fluctuations in vessel rates during recent years (Figure 9). His findings show that the price of vessels, particularly heavy lift vessels (HLVs), seem to follow the increase in oil

[11] References to ports and infrastructures in south west Cornwall in the UK and Finistère in France are given in the MERiFIC deliverable *D3.6.3 Guidelines on Operations and Maintenance*

price, whilst the Anchor Handler Tug (AHT) price fluctuations are dependent on both monthly averages (with peaks in the summer when larger weather windows exist) and on daily averages (Figure 10). It can be determined from this variation that the timing of an operation may be critical to the cost, and therefore its success.

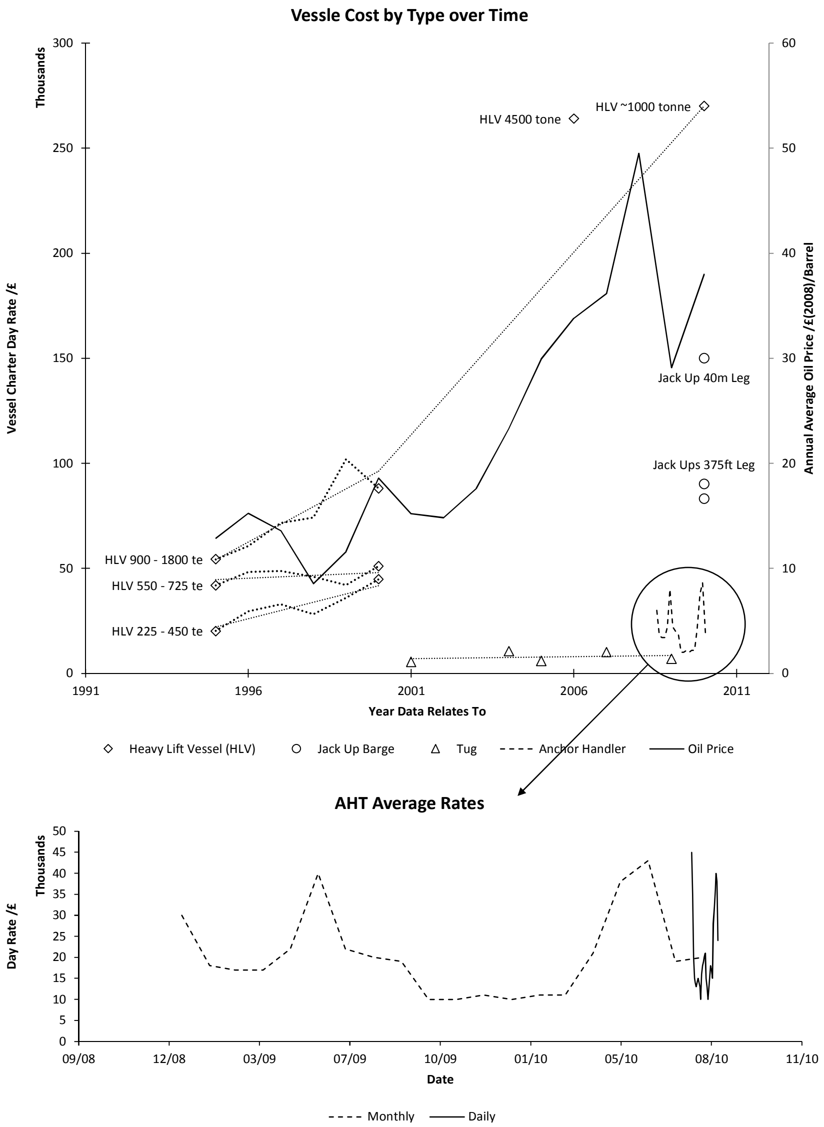


Figure 11 : Vessel day rates, selected vessels, 1995 – 2010 [14]

5.3 Pathways to reducing costs

Clearly installation (as well as operations and maintenance) costs are currently high and therefore cost reductions must be found in order to make MRE commercially viable in the long-term. Several pathways to reducing operations and maintenance costs have been proposed which are also applicable to installation activities[12]. Specific activities to reduce costs are listed in Table 2:

12 A summary of steps which could reduce the cost of offshore MRE operations are summarised in the MERiFIC deliverable *D3.6.2 Best practice report – operation and maintenance requirements.*

Technical	Logistical
Innovation (design for installation and maintenance[13])	Utilisation of local port facilities, expertise and vessels
Specialist vessels which can operate in adverse weather and site conditions (i.e. high current velocity sites[14])	Efficient supply chain liaison to avoid bottlenecks
Shared foundation, structure or moorings to reduce installation times (lower deployment costs per MW)	Utilise experience of the offshore wind industry
Remote commissioning	Use of state-of-the-art weather window planning tools which can simulate several installation scenarios and utilise accurate weather data, vessel charter costs and capabilities
Use of vessel tracking systems (e.g. Figure 11) to track transit progress and to inform future deployments	

Table 2 : Cost reduction pathways for MRE device or array installation

Although many of the pathways to cost reduction are technical in nature, a significant contribution can be made from efficient logistical measures, including the accurate prediction of weather windows that are suitable for installation operations [4,9]. MRE specific software such as Mermaid[15] produced by Mojo Maritime in conjunction with the University of Exeter, can be used to simulate marine operations in order to identify risks and opportunities based on:

- Metocean data, which based on probability techniques developed by Stallard et al. [10] is used to identify the number of access and waiting days
- Acceptable wave height and window length thresholds
- Vessel data (type, availability, characteristics and costs)
- Geographic location of port facilities and installation site

It is possible to use software such as Mermaid to conduct sensitivity analysis of several scenarios, for example mobilisation from several reports to determine the effect on total installation cost, weather windows and vessel availability.

13 Moorings and interconnection systems have been identified as potential areas where designing for installation would be beneficial [7]

14 For example the High Flow Installation Vessel http://worldmaritimenews.com/archives/94136/mojo-maritime-high-flow-project-remains-on-schedule/ (accessed online 03/12/2012)

15 Marine Economic Risk Management AID http://mojomaritime.com/mermaid/ (accessed online 06/12/12)

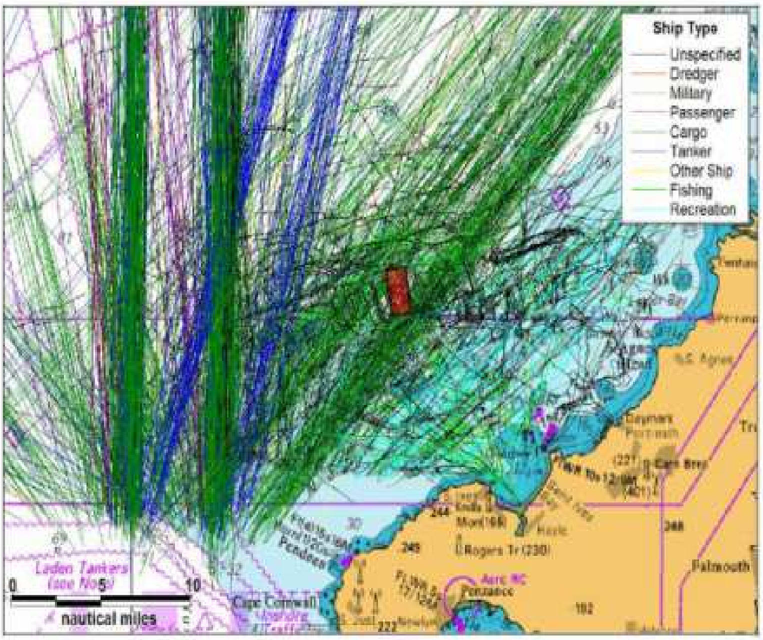


Figure 12: Example ship tracking plots on the north coast of Cornwall, UK. Data taken from a 28 day period in 2005 [8]

6 Weather Windows: Access and waiting time

This section focuses on weather window availability for access to deployment sites which was identified as an important element to be taken into account in the management of installation operations.

The methodology defined in the Equimar protocols [1] and discussed in [1] and [4] was applied for access time and waiting time assessment at the Wave Hub location in South West Cornwall as well as at various sites identified in the Iroise Sea.

6.1 Weather window assessment procedure

The statistical procedure used in this study for the assessment of duration of access time and waiting time weather windows is based on the method described in the Equimar protocols ("Procedures for Assessing Sites Accessibility and Appraisal of implications of Site Accessibility")[10]. It has been implemented here accordingly to the description given in [4]. Hence, only the key elements of the method are presented here.

The objective here is to statistically assess the duration of periods over which the wave height will remain beneath a given level, suitable for operations at a given site.

As a first step, the three parameters of a Weibull distribution law are assessed, based on the available significant wave height data sets in order to characterise the probability of exceedance of a given threshold H_{ac}:

$$P(H > H_{ac}) = e^{\left(-\left(\frac{H_{ac}-x_0}{b}\right)^k\right)}$$

The average duration of the time window during which the significant wave height remains below this threshold is then given by :

$$\tau_{ac} = \frac{1 - P(H > H_{ac})}{P(H > H_{ac})} \frac{A}{[-ln(P(H > H_{ac}))]^{\beta}}$$

The probability for accessible wave conditions to persist for a given normalised duration X_i will be given in the form:

$$P(X_i > X_{ac}) = e^{\left(-c_{ac}(x_i)^{\alpha}\right)}$$

So that the probability of occurrence of a weather window corresponding to a given wave height threshold and duration is given by :

$$P(T > \tau_{ac}) = P(X_i > X_{ac}P(H > H_{ac}))$$

and the associated number of days (or hours) of access N_{ac} for a given duration of weather window D will be given by:

$$N_{ac} = D.P(T > \tau_{ac})$$

while the number of days (hours) of waiting time N_{wa} will be given by :

$$N_{wa} = \begin{cases} \frac{D - N_{ac}.\tau_{ac}}{N_{ac}} & N_{wa} \leq D \\ D & N_{wa} > D \end{cases}$$

It should be noted that this method is very sensitive to the accuracy of the estimation of the Weibull parameters and that specific attention should be given to the procedure implemented when fitting the probability law to the data set. Of course, the quality and suitability of this data set should also be checked.

Even though it has been noted that this method is not so well adapted when considering extremes this is not a limitation in the case of weather window assessment for installation operations as these are usually conducted in mild to moderate weather conditions with significant wave height lower than about 2m to 3m.

6.2 Wave Hub case study

We consider here the case of the Wave Hub site located off the north shore of Cornwall.

Wave Hub Metocean Datasets

Assessment of the variability of available weather windows is dependent on season and input data source. Different data sources were used to create weather window data sets, including hindcast models and field measurements. The study by Walker et al. which applied a Weibull approach [4], used different data inputs for the weather window study and identified that “the main limiting factor of this approach is the availability of input data, both in quality and, as has been demonstrated, quantity […]”.

Figure 12, reproduced from Walker et al., shows the areas of data coverage from both input data sets. It can be seen in both cases that the lowest period and lowest wave height waves are not covered and that the modeled data set covers wave up to 12 meters in height whilst the recorded set has an upper limit of approximately 7 meters.

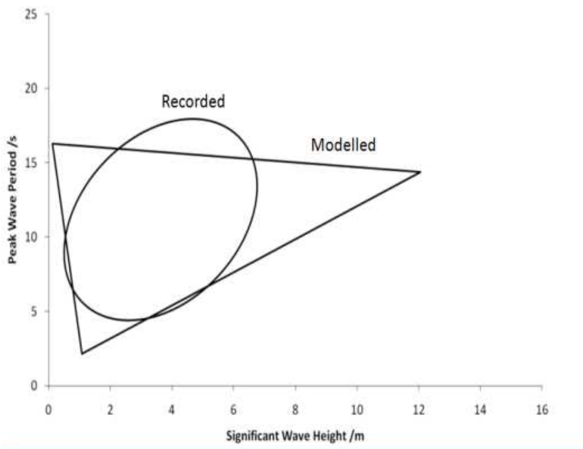


Figure 13 : Data coverage by wave height and period from [4]

A new wave data set was implemented in this study. The data is produced using the SWAN (Simulating WAves Nearshore) model, “a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions.” (The SWAN Team, 2011) This model, introduced below, produces Metocean parameters for the seas surrounding the Cornwall peninsula as illustrated in Figure 13. Here the two computational grids can be seen, one for the entire Cornish peninsula (D0) and a finer resolution grid for the Wave Hub area (D1); grid D0 is used in this study. The data produced is then applied in the aforementioned weather window assessment procedure to produce details of possible access and waiting time.

Plots in Figure 14 show examples of the comparison between the measured and computed datasets for PRIMaRE wave buoys A and D and Looe Bay. These plots illustrate that the performance of the model compared to the measurements is best for medium range wave heights between 0.5 and 3 meters. Above and below these levels the wave heights were often underestimated by a few centimetres by the SWAN model. A more detailed description of the model validation can be found in Nieuwkoop (2012). In conclusion, this validation demonstrates that the model is of sufficient accuracy to be acceptable for use in this study.

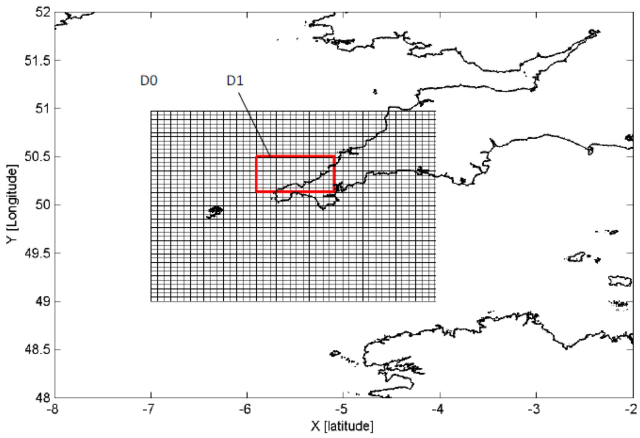


Figure 14 : Hindcast model domain

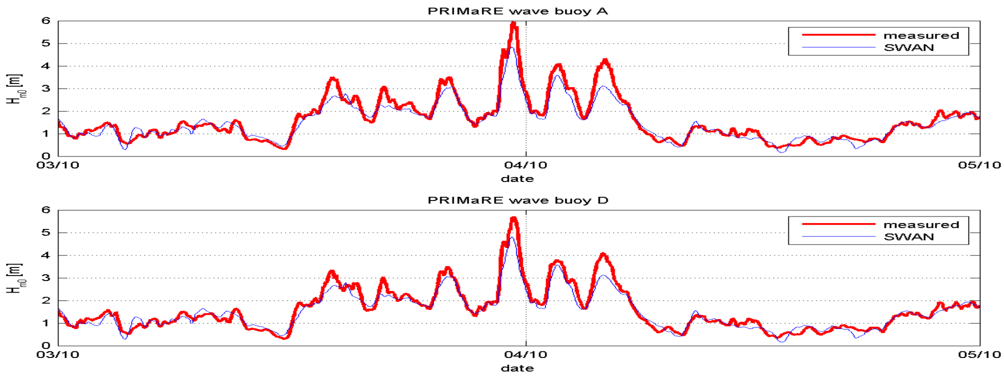


Figure 15 : Validation for PRIMaRE wave buoy D

Studying the data produced by the University of Exeter model, and considering the issues seen previously regarding data coverage, it was seen that the data coverage was significantly improved (Figures 15). This new modeled data is high resolution and covers a full range of wave heights and periods, therefore mitigating the previous issues of i) poor coverage at lower wave heights and periods and ii) data sets without sufficient data points to allow a high level of confidence in the study.

The new modelled data covers significant wave heights from approximately 0 meters to 10 meters and peak wave periods from 2 seconds to 16 seconds. Therefore this data incorporates both storm events, which are detrimental to the installation of wave energy converts and, indeed, to their power production, and calm events, where site access is possible and workability is high.

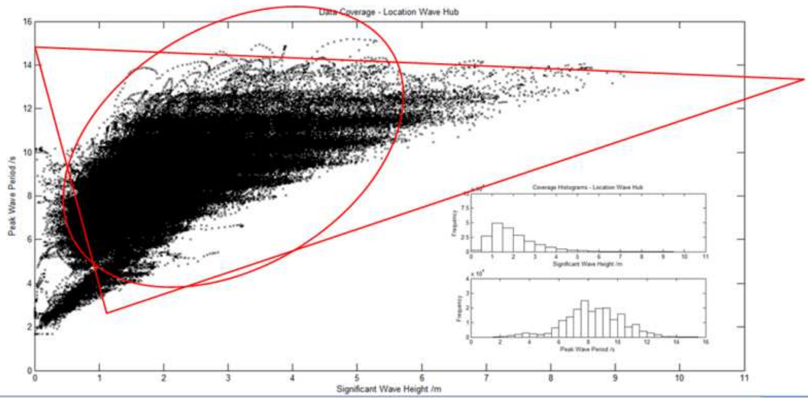


Figure 16 : Data coverage at the Wave Hub, including previous data coverage overlay [walker]

Sites considered for the study

The installation of a marine energy device can be subdivided into three distinct phases:

1. Mobilisation and transit to site, including towing the device.
2. On site activities, the actual installation process
3. Demobilisation and transit to port.

Any analysis of the availability of weather windows for device deployment would be remiss if these three phases were not considered. Therefore a number of data points have been selected to allow such an analysis to occur.

It is thought that operations at the Wave Hub are likely to deploy from Falmouth, although Penzance and Hayle may be capable of handling smaller vessel. Given the tracks seen and the possible port usage the data points indicated in [1] were selected for analysis. The points A to J can be used to assess phases 1 and 3 of an operation whilst the Wave Hub data point is to be used for the actual installation process. Points K, L, M and N cover access down the Bristol Channel and can also be used to assess phases 1 and 3 of an operation.

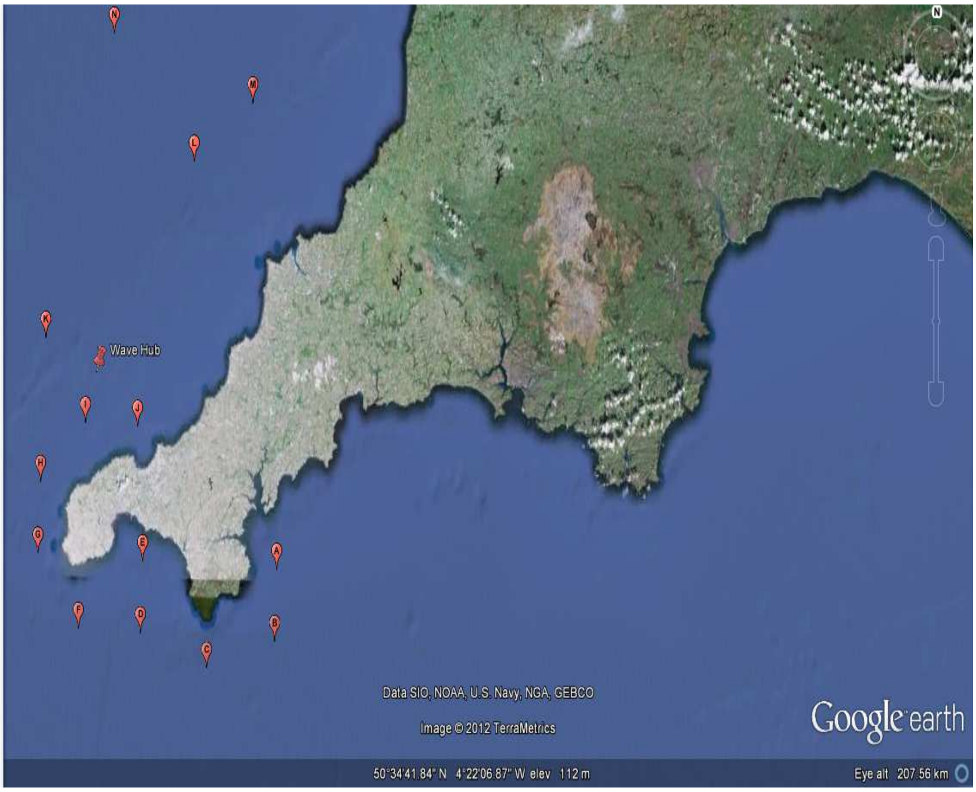


Figure 17 : Area of assessment for SW of England [4]

6.3 Iroise Sea Case Study

A study on the weather conditions and assessment of weather window for access time and waiting time was also conducted for the Iroise Sea area, based on the approach described in 6.1 but using a different data set.

In spite of heavy marine traffic as well as fishing and recreational activities, many locations were identified in Iroise Sea that are thought to be suitable for extraction of marine renewable energy.

Resource assessment [26] showed that the yearly averaged wave power in Iroise Sea can reach up to 45 kW/m which makes it one of the highest potential in Europe.

Additionally, the area is subject to tides with high a tidal range inducing flows with high velocities in specific areas. The Fromveur strait in the Molène archipelago, south of Ouessant Island has currents with velocities up to about 4m/s and has been identified as a potential site for deployment of tidal turbines [28].

Iroise Sea Metocean Dataset

The Iroise Sea covers an area located west of the coast of Brittany, in the north of the Bay of Biscay. The Iroise Sea area selected for this study lies between longitudes 6.0°W and 4.0°W and latitudes 47.6°N and 48.9°N (Figure 17).

The dataset used in this case study was extracted from a 19 years (1994 - 2012) wave hindcast database built using the WaveWatch III wave model with a specific configuration covering the Channel and Bay of

Biscay and using a refined unstructured grid. This dataset was extensively validated through comparison with in-situ measurement data as well as satellite data and another numerical model and proved to be of good quality overall [27].

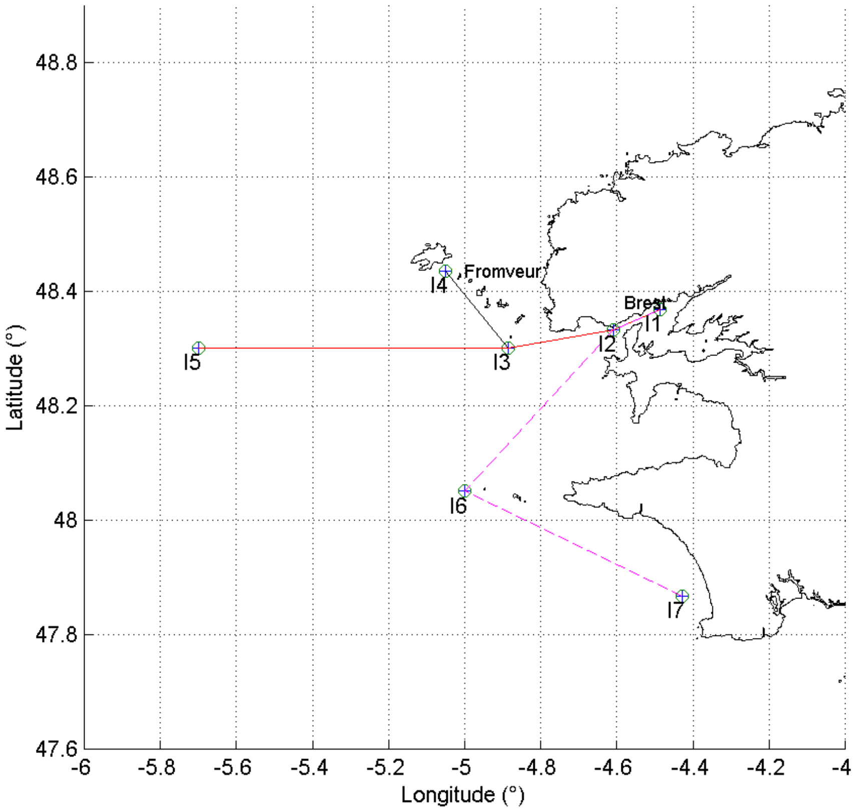


Figure 18 : Iroise Sea case study area

As shown in Figure 18 providing the joint distribution of significant wave heights and peak periods at the reference point I5 with coordinates [48.3°N, 5.7°W], significant wave height over the 19 years period of the data set covers the range [0.36 m - 13.54 m] with joint peak periods in the range [3.3 s - 24.4 s], indicating that all situations including storms and calm periods are well represented in the time series.

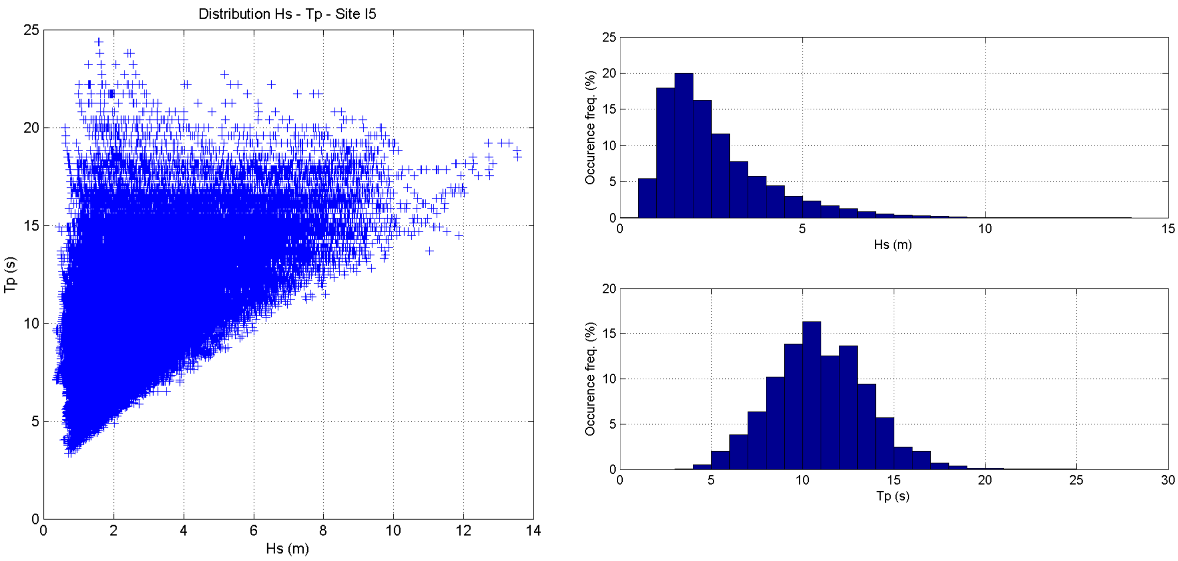


Figure 19 : Joint Distribution Hs-Tp in Iroise Sea

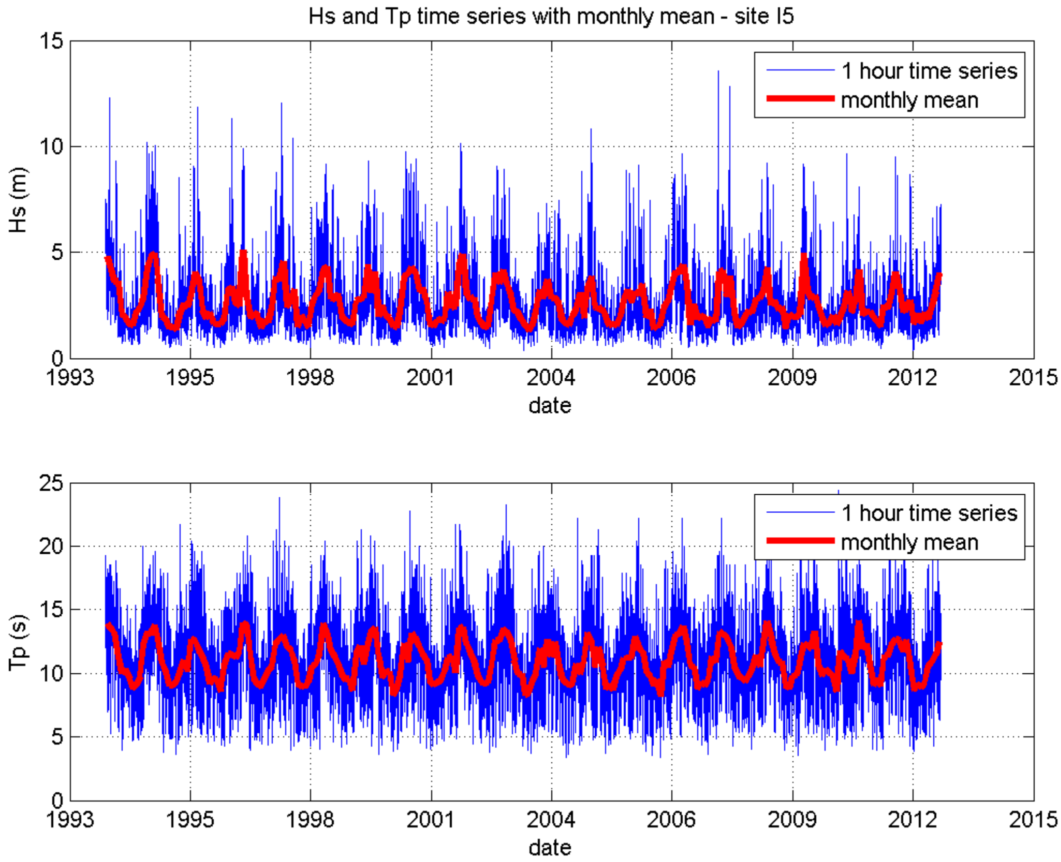


Figure 20 : Seasonal variability in Iroise Sea

Detailed wave climatology in Iroise Sea is described in MERIFIC report WP3.1.5 on resource Assessment [26]. Nevertheless, a strong seasonal variability in both significant wave height and peak period can be observed, with substantially higher significant wave height during the winter season (Figure 19), which can be of prime importance in the assessment of weather windows and access time.

As pointed out by Walker [4], three phases should be taken into account in the installation procedure: i) mobilisation and transit to site, ii) installation and iii) demobilisation and return to port. This means that waypoints along the route to the deployment sites should also be taken into account in the assessment of weather windows.

Sites considered for the study

With this climatology in mind, three locations are selected for this case study on assessment of weather windows for installation operations. Two of them correspond to possible wave energy converters deployment sites, one off-shore (I5) and one near shore (I7). The third one corresponds to the location of a tidal turbine deployment site in the Fromveur strait (I4).

Brest, the main harbor in the Iroise Sea hosts shipyards and ship repair facilities as well as docks with lifting capacities and was identified in the MERiFIC project as one of the main ports suitable for assembling and deployment of marine energy devices.

The map plotted in Figure 17 shows the 3 selected locations (I4, I5, I7) and the routes from Brest harbor. Coordinates of these points and those of intermediate waypoints are given Table 3.

Reference point	Longitude	Latitude
I1	-4.486607	48.367438
I2	-4.607915	48.332689
I3	-4.885512	48.3
I4	-5.05	48.434875
I5	-5.7	48.3
I6	-5.0	48.05
I7	-4.4273	47.867

Table 3: Sites and waypoints coordinates

The main marine channels surrounding Brest are located in an enclosed and sheltered bay where significant wave heights are very limited to the extent that the maximum heights of only 2 meters occur in extreme storms. For this reason weather window analysis should be only conducted for points located outside the bay, in the west of point I2.

One major drawback of the strong tidal currents identified in the Iroise sea is that they can impact on planning of towing and installation operations. A map of the maximum local tidal currents is plotted in Figure 20 and shows that the various transit routes are affected by these currents which should be taken into account when planning towing operations.

The channel at the entrance of the bay (I2) is subject to rather strong tidal currents that will affect all the transits to the any 3 sites. Of course the Fromveur area (I4) and the south of Ouessant island identified as a tidal energy production site will also be largely influenced by these currents. Finally, on the way to the near shore site I7, strong tidal currents also occur in the west of Sein island (I6).

It should be noted that these strong currents will not only affect the planning of the transit operations but will also have an influence on the size and bollard pull of the installation vessels to be used.

Additionally, the strong wave-current interactions that take place in these areas and especially in the south of the Fromveur strait will affect the sea-states characteristics and especially significant wave height, hence will have an influence on the weather windows for access time.

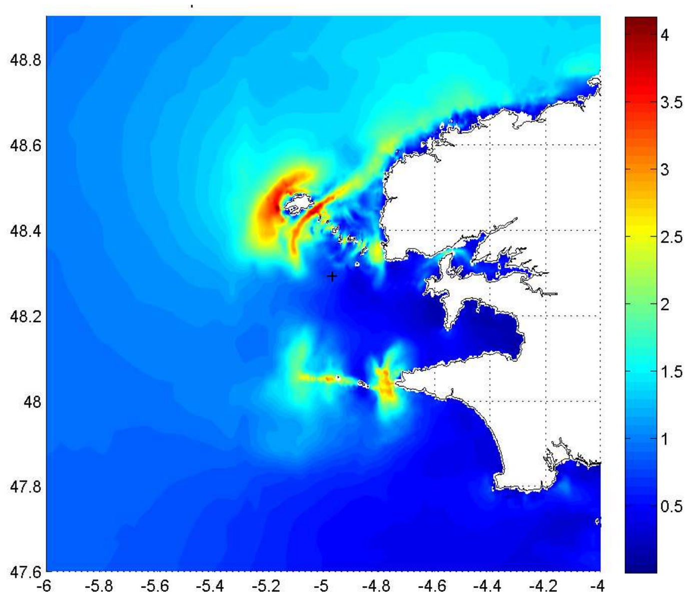


Figure 21 : mapping of maximum local tidal current velocities (m/s)

As an example, estimation of the time of transit to the three selected sites is given in the Table 4 hereafter. In this case, a 5 knots average velocity is considered for transit to site considering towing of the structure while a velocity of 12 knots is considered for return to port after successful installation.

Route	Distance (nautical miles)	Towing time (5 kts)	Return transit time (12 kts)
I1 - I4	27	5h24	2h15
I1 - I5	49	9h48	4h05
I1 - I7	54	10h48	4h30

Table 4 Transit time

Installation weather window assessment

The procedure used for the estimation of weather windows is based on the one presented in the Equimar protocols [10] and used in [4] which has already described in Section 6.1 and discussed for the case study of the south west Cornwall area.

In order to account for the seasonal variability in the Iroise Sea, Weibull parameters were identified for each monthly dataset composed of the significant wave height for each of the 12 months over the 19 years contained within the database.

The average duration τ_{ac} of the time window during which the significant wave height remains below a given threshold was evaluated for each month at each of the 7 considered locations. Results for locations I3 to I7 are presented in Appendix 4. Examples for the months of July and January at locations I5 and I7 are presented in Figures 21 and 22.

At location I5, off-shore, the average duration of sea-states with *Hs* lower than 2 m is of about 12 hours in January and of about 36 hours in July.

At location I7, closer to the coast, average durations are of about 30 hours in January and 86 hours in July for the same threshold.

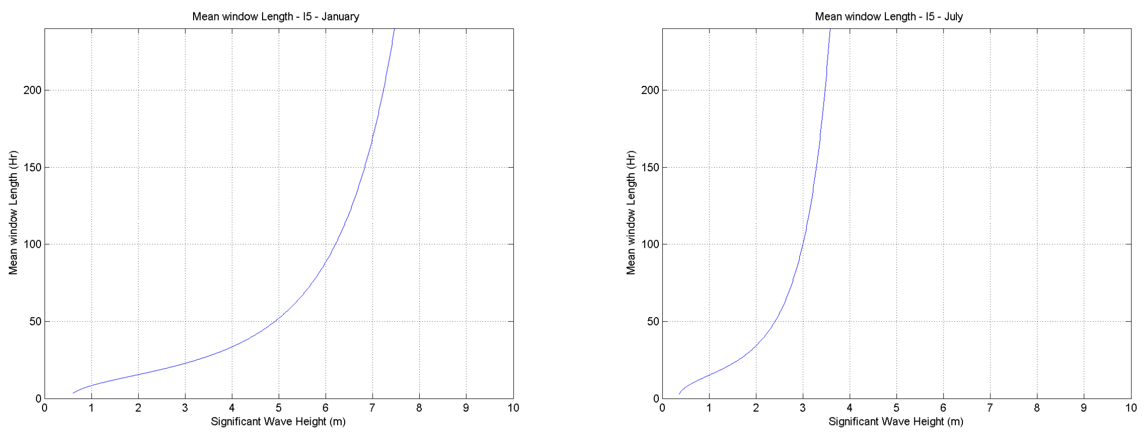


Figure 22 : Mean window length at location I5

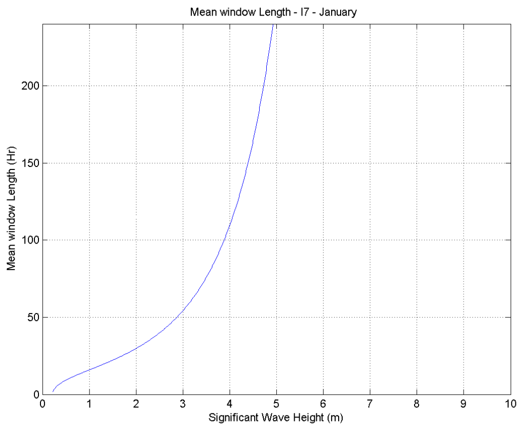


Figure 23 : Mean window length at location I7

Monthly results presented in Appendix 4 show that at location I5, the average duration of intervals with Hs lower than 2 m are less than 48 hours throughout the year and wouldn't last more than one day (24 hours) from October to May. At location I7 for the same threshold, the average duration would be less than 48 hours from October to March but could reach up to 120 hours during the summer months.

The probability of occurrence of weather windows with given duration and a maximum significant wave height were evaluated for the 5 locations I3 to I7 over the 12 months and for 5 different thresholds between 1 m and 3 m and are presented in Appendix 4. Examples of these for locations I5 and I7 and for the months of January and July are presented on Figures 23 and 24 hereafter.

It can be seen that the probability of occurrence of a 48 hours period with Hs lower than 2 m would be of about 1.5 % in January and of about 15% in July at location I5. For a 24 hour window, probabilities would be 3% and 24% for the same months respectively. At location I7 probabilities would be of about 8% and 33% for a 48 hour window and of about 25% and 43% for a 24 hour window.

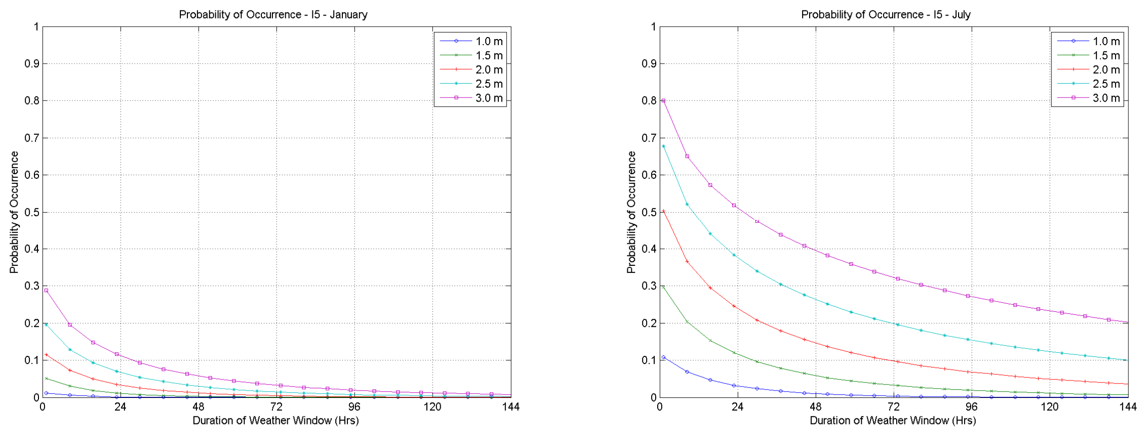


Figure 24 : Probability of occurrence of weather windows at location I5

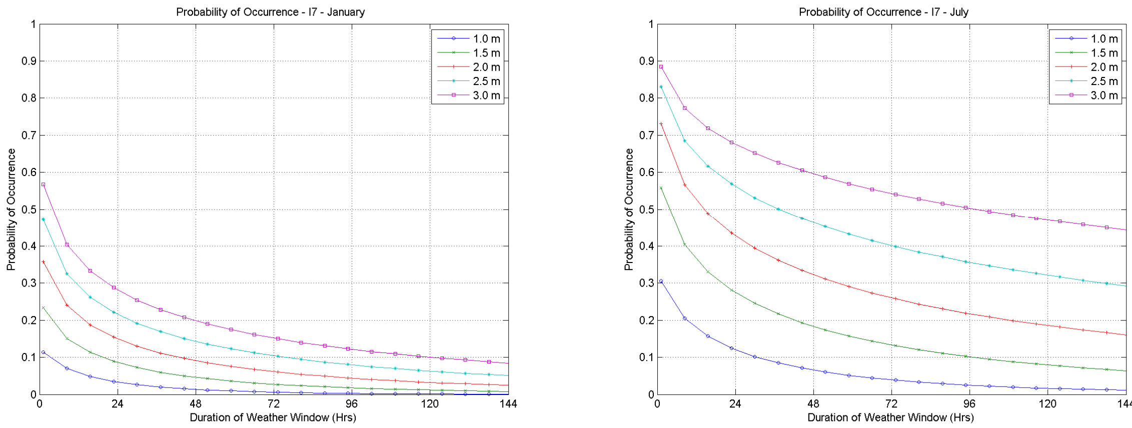


Figure 25 : Probability of occurrence of weather windows at location I7

Finally, the number of events with a given duration and significant wave height threshold occurring on average each month were evaluated for a given set of periods [24 hours, 48 hours and 72 hours] and thresholds [1 m, 2m and 3m] at the five locations I3 to I7. Access times were then derived by multiplying the number of events by the duration of the considered window and waiting time, estimated as the average duration between successive events. All these results are presented in Appendix 4. The case of weather windows with significant wave heights lower than 2 m over a 24 hour window are presented Figure 25 for site I5 and Figure 26 for site I7.

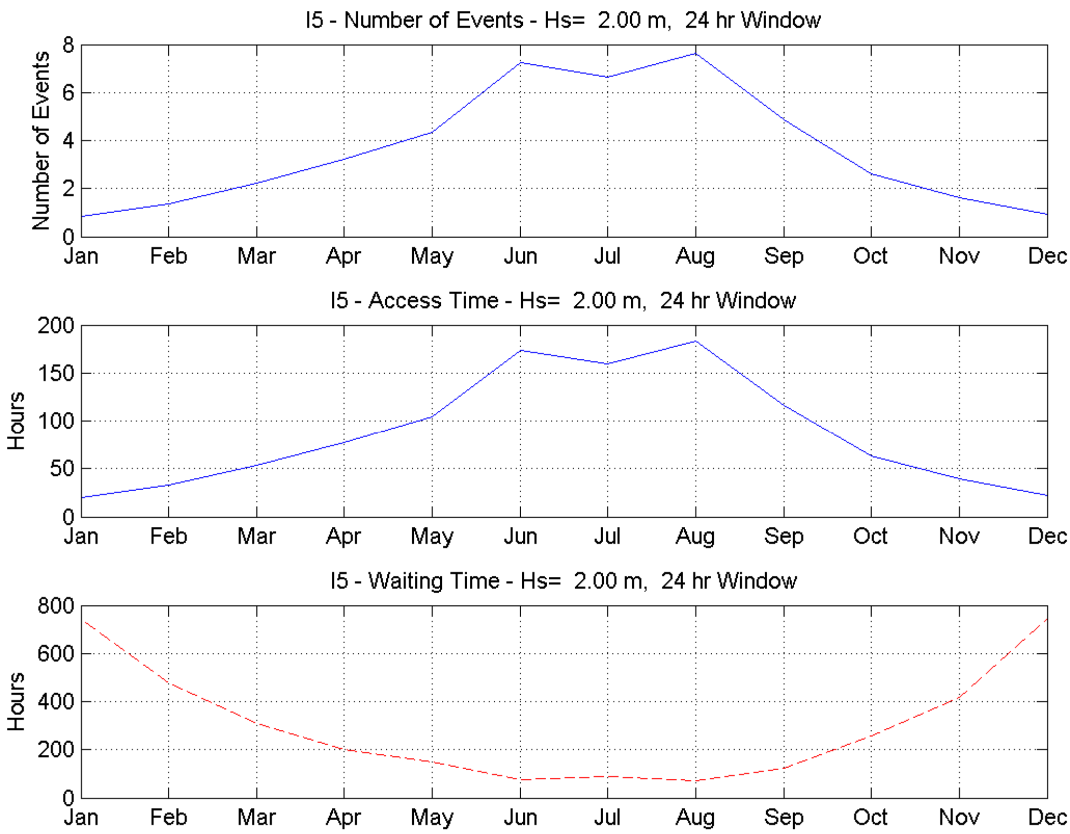


Figure 26 : Access time - Site I5 - Hs=2m, 24hr window

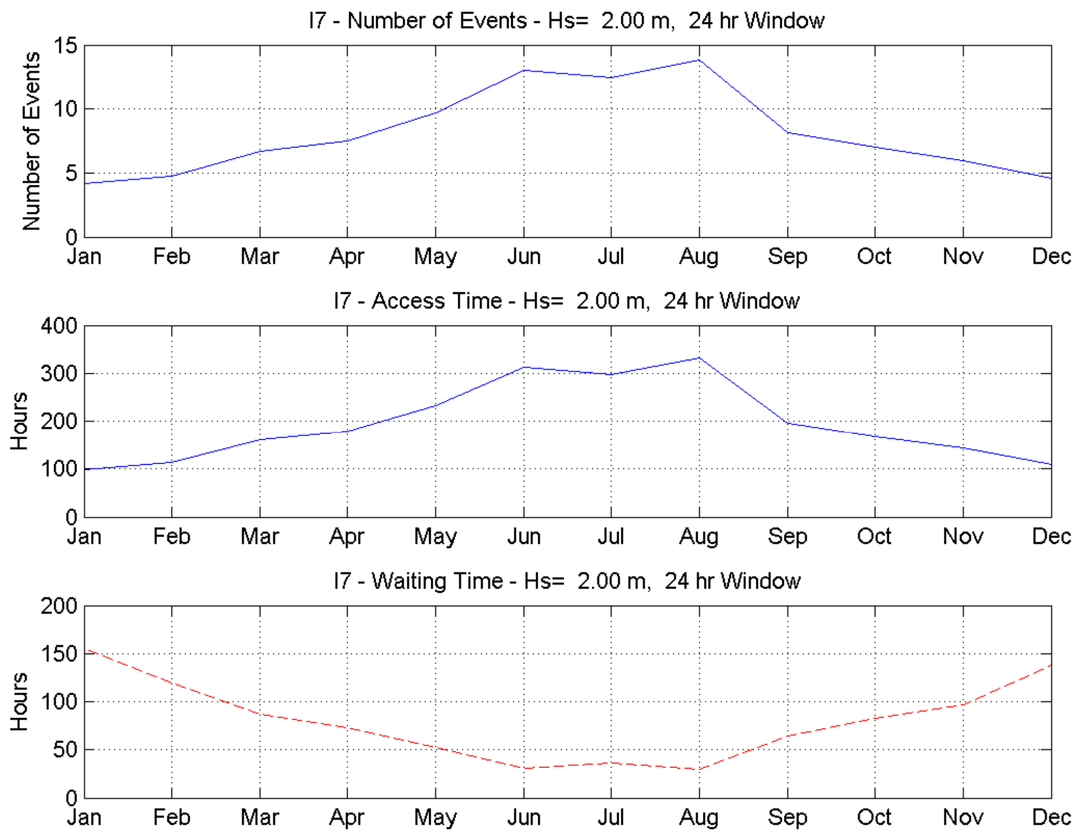


Figure 27 : Access time - Site I7 - Hs=2m, 24hr window

These figures point out the strong influence of the seasonal variability of the wave climatology in the Iroise Sea on the duration and occurrence of the weather windows suitable for marine operations. If the summer period from June to August is the most suitable for all the locations, the probability of occurrence of long periods of calm in the winter time is very limited. In any case, a 72 hour window with a significant wave height lower than 1 m is very unlikely (see Appendix 4).

7 Conclusions

Different elements were presented in this report as guidelines for the planning and organisation of installation operations for the deployment of Marine energy plants with the dual objectives of optimizing installation procedures whilst minimizing associated costs.

The availability of suitable vessels is a key element to be considered together with the impact it can have on the cost of the operations, hence on the overall exploitation cost.

Installation procedures, which were also investigated, should include pre-installation surveys so as to optimize the design of moorings and secure installation of the power cable, a specific feature of the commissioning of Marine energy plants. Attention should also be given to the Health and Safety procedures.

Finally, the influence of the weather conditions on the chances of success of these installation operations was discussed and studied. "Access time" and "Waiting time" weather windows for different sites in south west Cornwall and the Iroise Sea were assessed, highlighting the importance of the seasonal variability of the wave climate for the planning of installation operations.

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APPENDICES

Appendix 1 - Summary of Applicable Guidelines and Standards

Category	Document	Publication year	Author(s)
Sea Trials	Marine energy - Wave, tidal and other water current converters - Part 103: Guidelines for the early stage development of wave energy converters: Best practices & recommended procedures for the testing of pre-prototype scale devices	2014	International Electro Technical Commission
	Protocols for the Equitable Assessment of Marine Energy Converters	2011	EquiMar
	T02-2.1: Guidelines for the Development and Testing of Wave Energy Systems	2010	B. Holmes and K. Nielsen
Installation	Offshore Renewable Energy Installations (OREIs) - Guidance on UK Navigational Practice, Safety and Emergency Response Issues.	N/K	Maritime and Coastguard Agency
	DNV-RP-H103: Modelling and analysis of marine operations	2011	Det Norske Veritas
	BS 6349-1:2000: Maritime structures; Part 1: code of practice for general criteria	2000	British Standards Institution
	MGN 371: Offshore renewable energy installations: Guidance son UK navigational practice, safety and emergency response issues	2008	Maritime Coastguard Agency
	MGN 372: Offshore renewable energy installations: Guidance to mariners operating in the vicinity of UK OCEIs	2008	
	O-139: The Marking of Man-Made Offshore Structures	2008	International Association of Marine Aids to Navigation and Lighthouse Authorities
	Pre-deployment and operational actions associated with marine energy arrays	2010	EquiMar
Decommissioning	Decommissioning of offshore renewable energy installations under the Energy Act 2004	2011	Department of Energy and Climate Change
Site and resource assessment	Marine energy – Wave, tidal and other water current converters – Part 101: Wave energy resource assessment and characterization	2013	International Electrotechnical Commission
	Marine energy – Wave, tidal and other water current converters – Part 201: Tidal energy resource assessment and characterization	2012	
	Assessment of Wave Energy Resource, Assessment of Tidal Energy Resource	2009	European Marine Energy Centre
	UK Wave and Tidal Key Resource Areas Project	2012	The Crown Estate
	Environmental conditions and environmental	2010	Det Norske Veritas

	loads		
	Standards for Hydrographic Surveys. Special Publication No.44	1997	International Hydrographic Organization
	BS 6349-1:2000: Maritime structures; Part 1: code of practice for general criteria	2000	British Standards Institution
	Protocols for the Equitable Assessment of Marine Energy Converters	2011	EquiMar
Environmental Impact Assessment	A Strategic Environmental Assessment (SEA) to examine the environmental effects of developing wave and tidal power	2007	Scottish Government
	Environmental Impacts of Tidal Power Schemes	2009	Wolf, J. et al.
	Environmental Impact Assessment (EIA) – Guidance for developers at the European Marine Energy Centre	2008	European Marine Energy Centre
	Uncertainties regarding environmental impacts	2009	
Health and Safety	Guidelines for Health and Safety in the Marine Energy Industry	2008	British Wind Energy Association and European Marine Energy Centre
	Health and Safety, Galway Bay Ocean Energy Test Site	N/K	Marine Institute
	Offshore Wind and Marine Energy Health and Safety Guidelines	2013	RenewableUK
	Vessel Safety Guide for the development phase of offshore wind, wave and tidal renewable energy projects	2012	
Mooring and Foundations	Marine energy – Wave, tidal and other water current converters - Part 10: The assessment of mooring system for marine energy converters (MECs)	2013	International Electrotechnical Commission
	DNV-OS-E301: Offshore standard - position mooring	2010	Det Norske Veritas
	DNV-OS-E302: Offshore mooring chain	2008	
	DNV-OS-E303: Offshore fibre ropes	2013	
	DNV-OS-E304: Offshore mooring steel wire ropes	2009	
	DNV-RP-E301: Design and installation of fluke anchors in clay	2000	
	DNV-RP-E302: Design and installation of plate anchors in clay	2002	
	Guidance Notes on the Application of Fiber Rope for Offshore Mooring	2011	American Bureau of Standards
	ISO 18692: Fibre ropes for offshore station keeping – Polyester	2007	International Standards Organisation

	ISO 19901-7: Stationkeeping systems for floating offshore structures and mobile offshore units.	2005	
	API-RP-2SK: Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures	1997	American Petroleum Institute
Grid Connection	Guidelines for Grid Connection of Marine Energy Conversion Systems	2009	European Marine Energy Centre
	Guidance protocols on choosing of electrical connection configurations	2009	EquiMar

Appendix 2 : Installation Vessels

Installation Vessels for Offshore operations

Type of boat	Description	Picture	Number of boats in the world	Typical specifications	Length	Limiting factor
Anchor Handling Towing Supply or Anchor Handling Tug/Supply (AHTS)	Tow rigs, powerful winch to lift and position the rig's anchor, can carry moderate amount of supplies		1562 (75% over 20 year old) Specialists vessels, we maybe need to go to North Sea	-horsepower 5000 - 30000BHP -towing capacity 62-110 tons (bollard pull)	Around 50 to 90m	Green water on deck (safety of crew)
Tugs	Push or tow vessels		N/K	-bollard pull 680-3400 BHP -horsepower 40-60 tons bollard pull	15m to more than 50m	Towing capacity
Multi-Purpose Supply Vessels (MPSVs), Multi-cats	Remote subsea intervention services, remote operated vehicle (ROV) operations, deep-water lifting and installation, delivery of supplies, fire fighting, and oil spill recovery.		N/K	-max speed 16 knots, Economic speed 12 knots -clear deck 800m2, helideck -liquid mud,-fresh water 600m3, fuel 2000m3, oil 50m3 -crane 150te -moonpool	Around 60- 90m	Seakeeping, green water on deck
Crane vessel, HLV, VHLV	Lift heavy loads, can be monohull, catamaran or semisubmersible		N/K	-large vertical lift capability (e.g. Vanguard: 110,000te)	Around 200-300m	Acceleration of jib head (safety of operation)

Utility/workboats	Work in support of offshore construction project		N/K	-diverse range of specifications	-diverse range of lengths	Seakeeping ability
Landing craft	Haul Building Materials, Passengers		N/K	-10 knot speed (Teras Archer) -ability to operate in shallow waters (Teras Archer: 3.0m) -high deck strength (Teras Archer: 7.5Mte)	40-90m	Capacity

Support Vessels : Supply vessels providing support during operations

Type of boat	Description	Picture	Number of boats in the world	Typical specifications	Length	Limiting factor
Offshore Supply Vessels (OSVs) Platform Supply Vessel (PSVs)	Deliver drilling supplies		1014 (63% over 20 year old)	-diverse range of specifications	20-100m	N/K
Crew Boats	Transport personnel		500	-fast cruising speed (Sarah Gold: 22 knots)	23-58m	N/K

Standby / Rescue Vessels	Personnel rescue, fire fighting, first aid		235 (mostly in North Sea)	-large range of vessel types	-large range of vessel types	Response time is vessel dependent
Survey vessels	Collect geophysical data to map the bottom, benthic zone, full water column, and surface		N/K	-cruising speed up to 12 knots (Fugro Supporter) -long endurance (Fugro Supporter: 50 days)	75m (Fugro Supporter)	Capabilities of sensing equipment

Other Boats: carry out maintenance work, pollution control, and diving support.

Type of boat	Description	Picture	Number of boats in the world	Typical specifications	Length	Limiting factor
Jack-Up barge	Mobile platform Shallow water (less than 120m)		N/K	-deck area 450m^2 (Haven Searaiser 1) -jacking speed 1.01m/min (Haven Searaiser 1)	~25m	Loss of air gap (loss of station) Permissible deck loads low
Emergency Towing vessels	All-weather towing vessels for emergency operations including pollution mitigation capacity		N/K	High bollard pull, up to 200 tons	~80m	Limited commercial chartering

Appendix 3 : Health & Safety References

BWEA. (2008). Guidelines for Health and safety in the marine energy industry.

HSE. (1974). Health and Safety at Work etc act 1974.

HSE. (1996). Health and Safety (Safety Signs and Signals) Regulations.

HSE. (1997). Safe work in confined spaces.

HSE. (1998). Simple guide to the Lifting Operations and Lifting Equipment Regulations.

HSE. (1998). Simple guide for the Provision and Use of Work Equipment Regulations.

HSE. (2007). Construction regulations.

HSE. (2007). Managing health and safety in construction.

IMO. (2003). International Ship and Port security code.

UK Government. (1988). Docks regulations.

UK Government. (1998). Merchant shipping regulations.

UK Government. (1997). Diving at work Regulations.

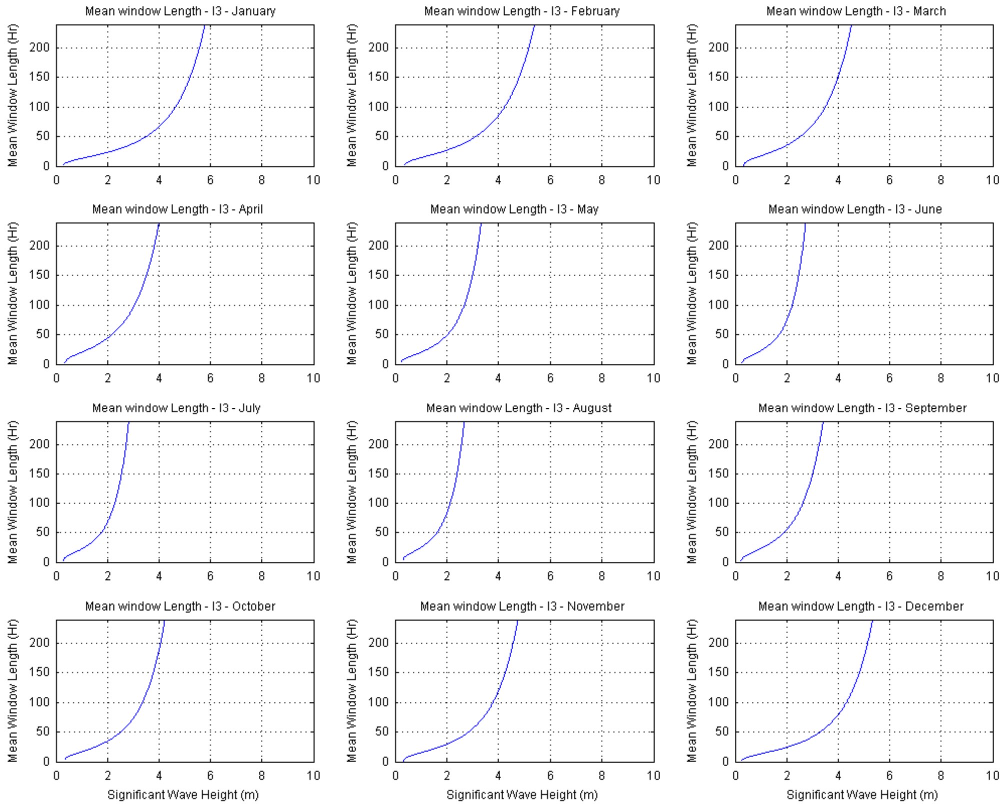
UK Government. (2002). The Control of Substances Hazardous to Health Regulations.

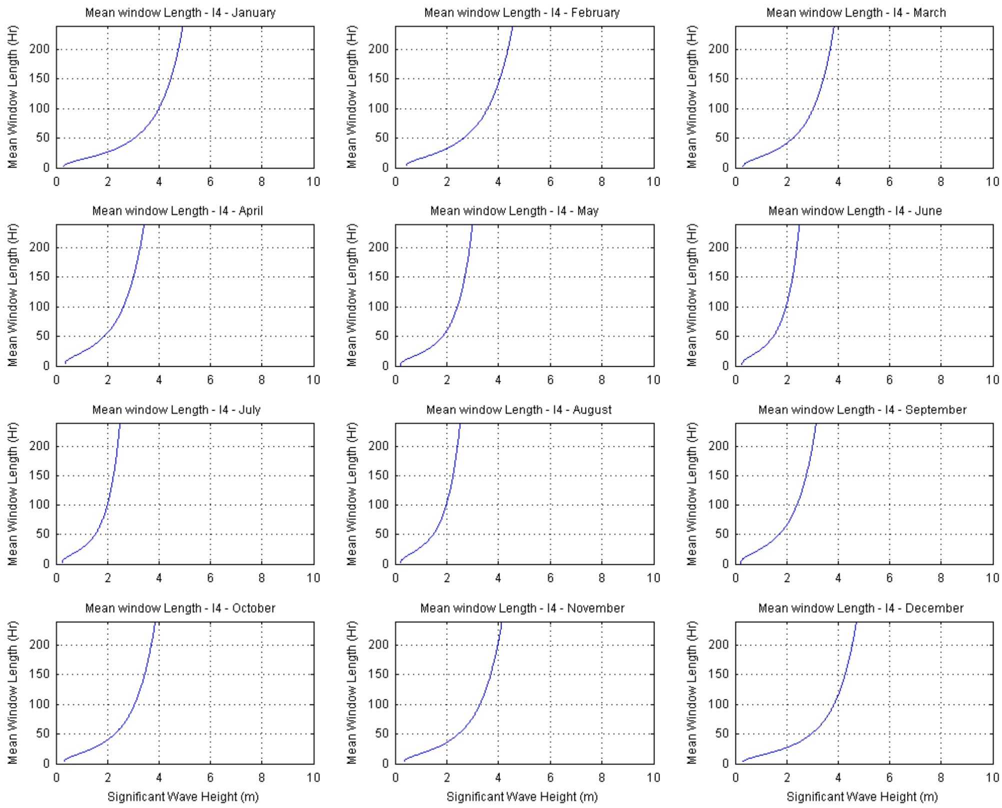
Appendix 4 : Weather window analysis for the Iroise Sea Area

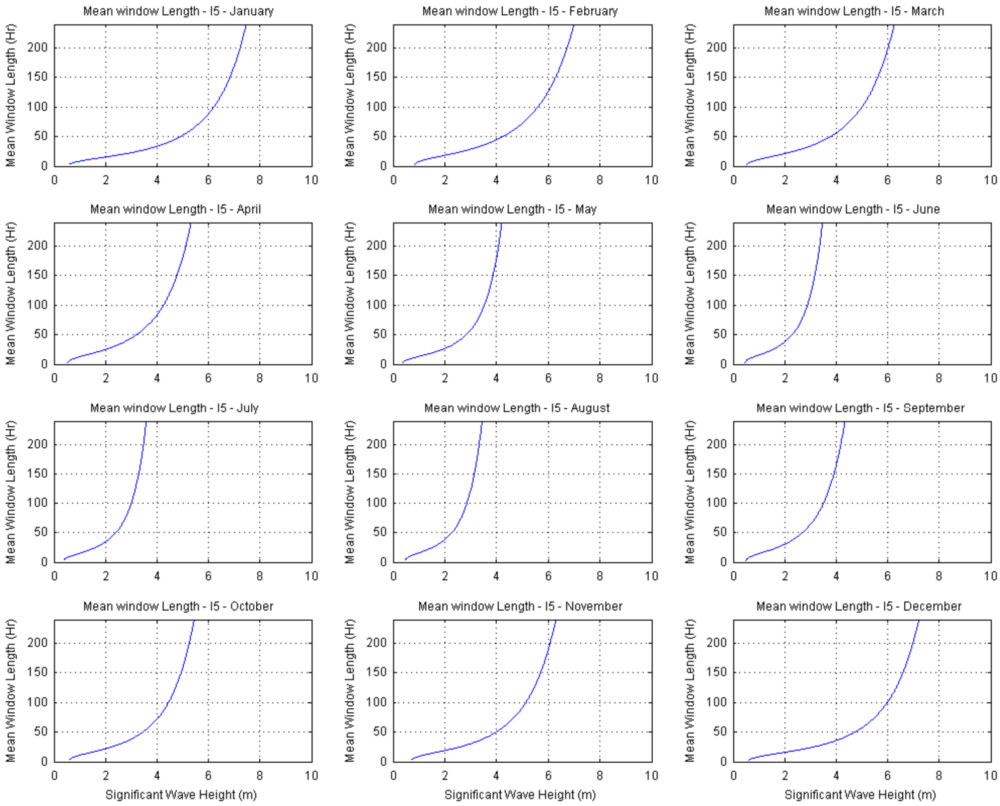
- Average window length at sites I3, I4, I5, I6 and I7.

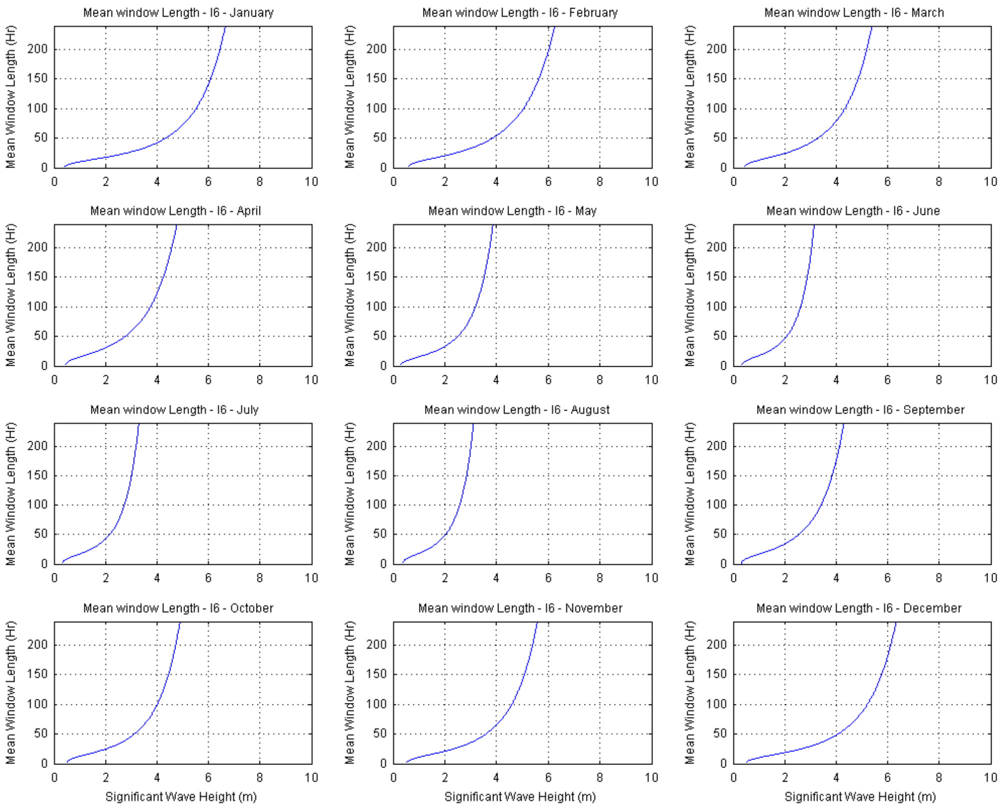
- Probability of occurrence for weather window with given duration for various significant wave thresholds [1m, 1.5m, 2m, 2.5m, 3m] at sites I3, I4, I5, I6 and I7.

- Number of events with given duration [24hr, 48hr, 72hr] and given significant wave height threshold [1m, 2m, 3m], access time and waiting time at sites I3, I4, I5, I6 and I7.


Mean window Length - I3 - January
Mean window Length - I3 - February
Mean window Length - I3 - March
Mean window Length - I3 - April
Mean window Length - I3 - May
Mean window Length - I3 - June
Mean window Length - I3 - July
Mean window Length - I3 - August
Mean window Length - I3 - September
Mean window Length - I3 - October
Mean window Length - I3 - November
Mean window Length - I3 - December
Mean Window Length (Hr)
Significant Wave Height (m)


Mean window Length - I4 - January
Mean window Length - I4 - February
Mean window Length - I4 - March
Mean window Length - I4 - April
Mean window Length - I4 - May
Mean window Length - I4 - June
Mean window Length - I4 - July
Mean window Length - I4 - August
Mean window Length - I4 - September
Mean window Length - I4 - October
Mean window Length - I4 - November
Mean window Length - I4 - December
Mean Window Length (Hr)
Significant Wave Height (m)


Mean window Length - I5 - January
Mean window Length - I5 - February
Mean window Length - I5 - March
Mean window Length - I5 - April
Mean window Length - I5 - May
Mean window Length - I5 - June
Mean window Length - I5 - July
Mean window Length - I5 - August
Mean window Length - I5 - September
Mean window Length - I5 - October
Mean window Length - I5 - November
Mean window Length - I5 - December
Mean Window Length (Hr)
Significant Wave Height (m)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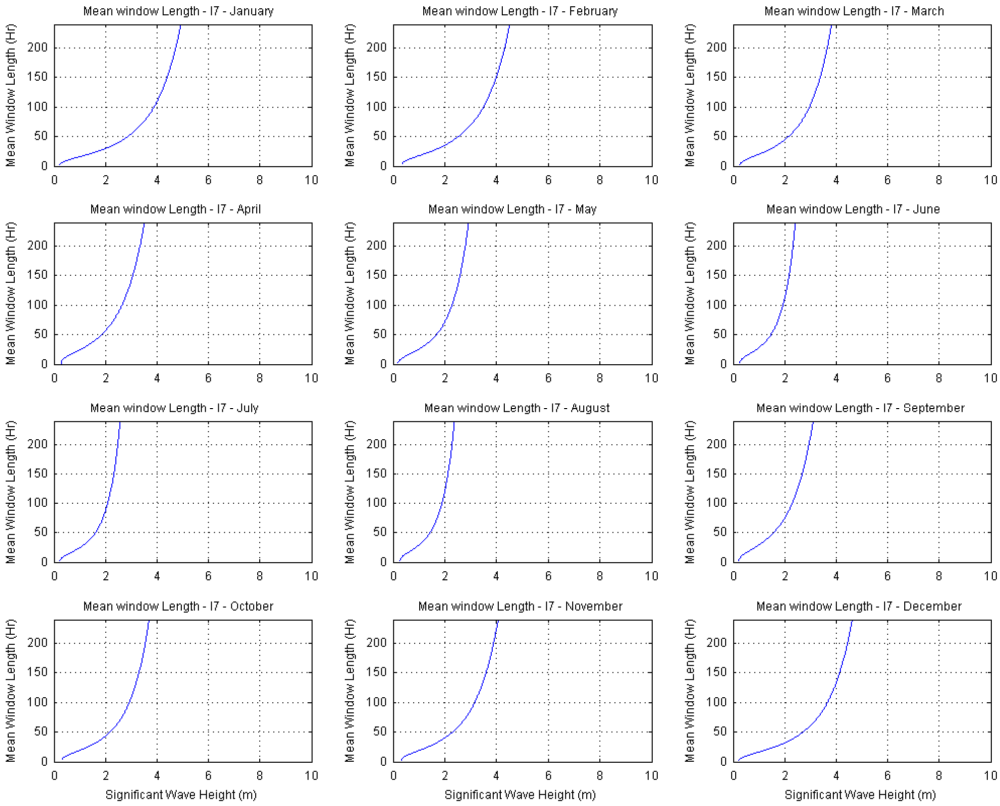
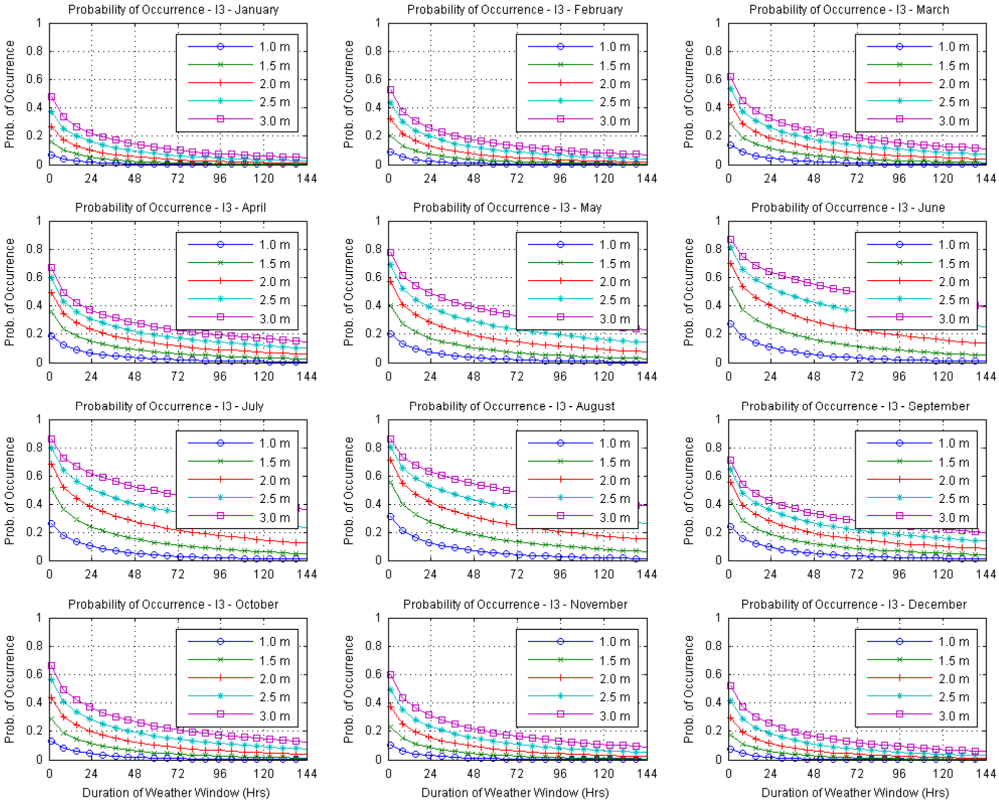
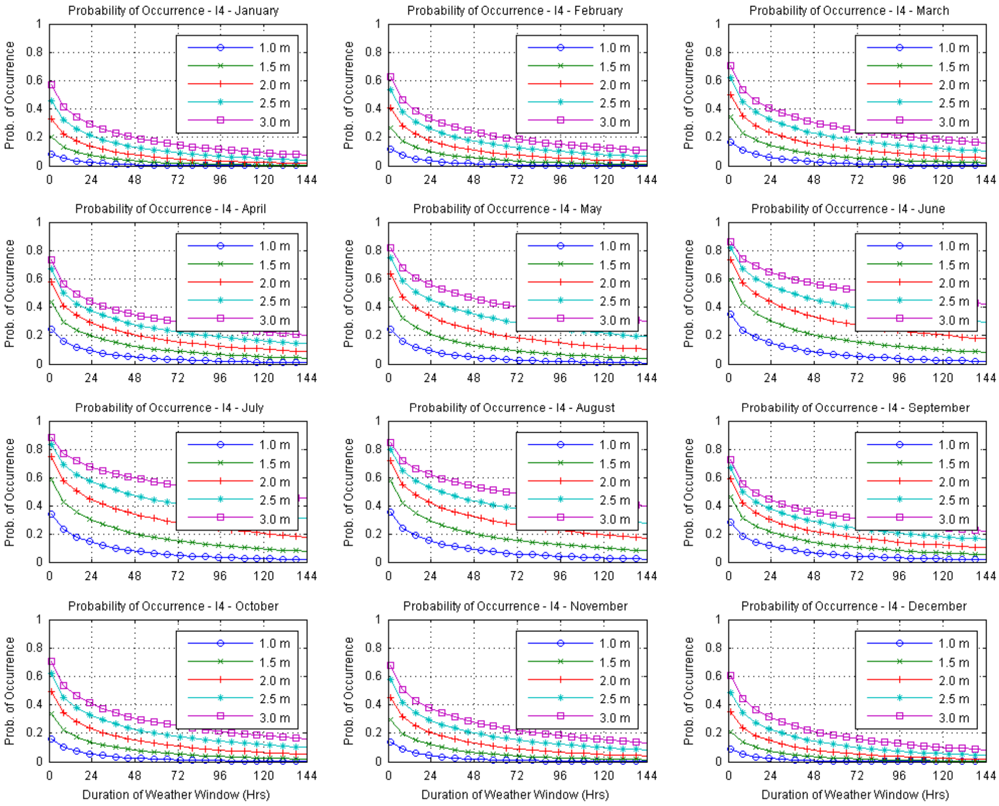
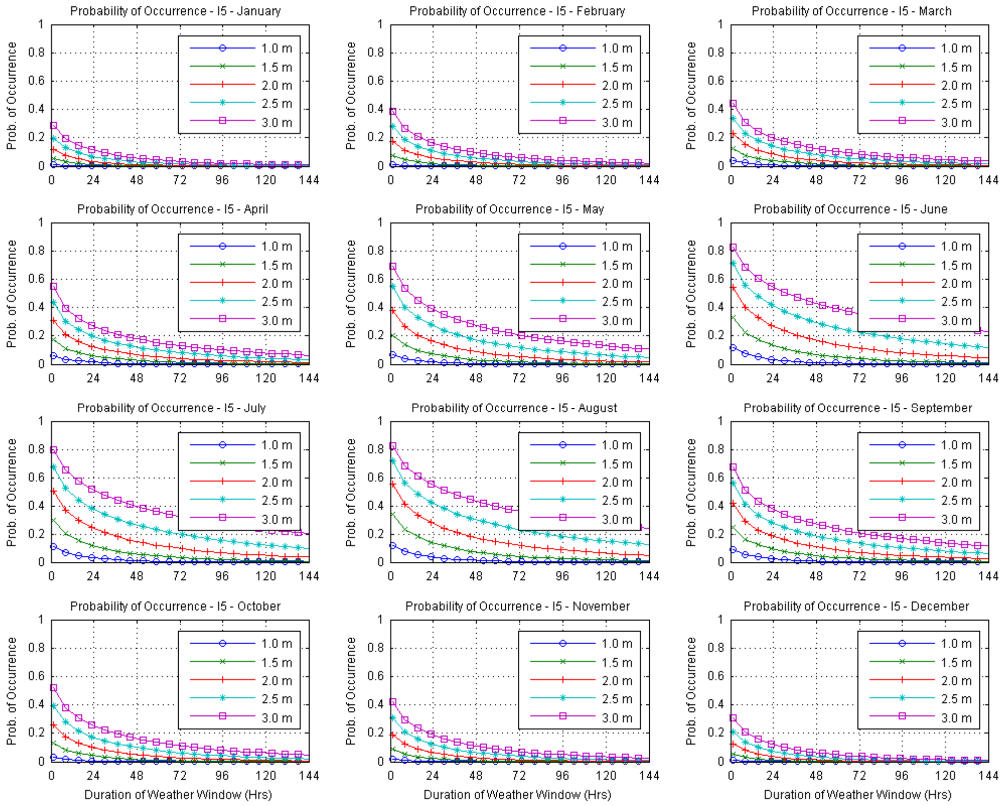
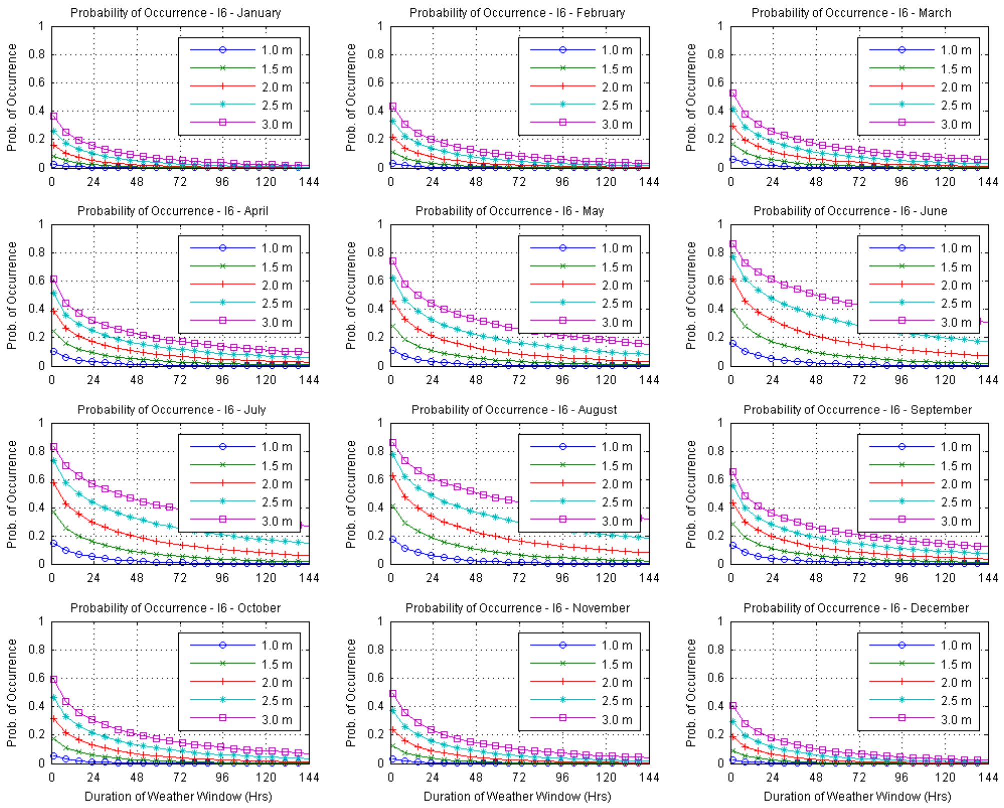
Mean window Length - I6 - February
Mean window Length - I6 - March
Mean window Length - I6 - April
Mean window Length - I6 - May
Mean window Length - I6 - June
Mean window Length - I6 - July
Mean window Length - I6 - August
Mean window Length - I6 - September
Mean window Length - I6 - October
Mean window Length - I6 - November
Mean window Length - I6 - December
Mean Window Length (Hr)
Significant Wave Height (m)

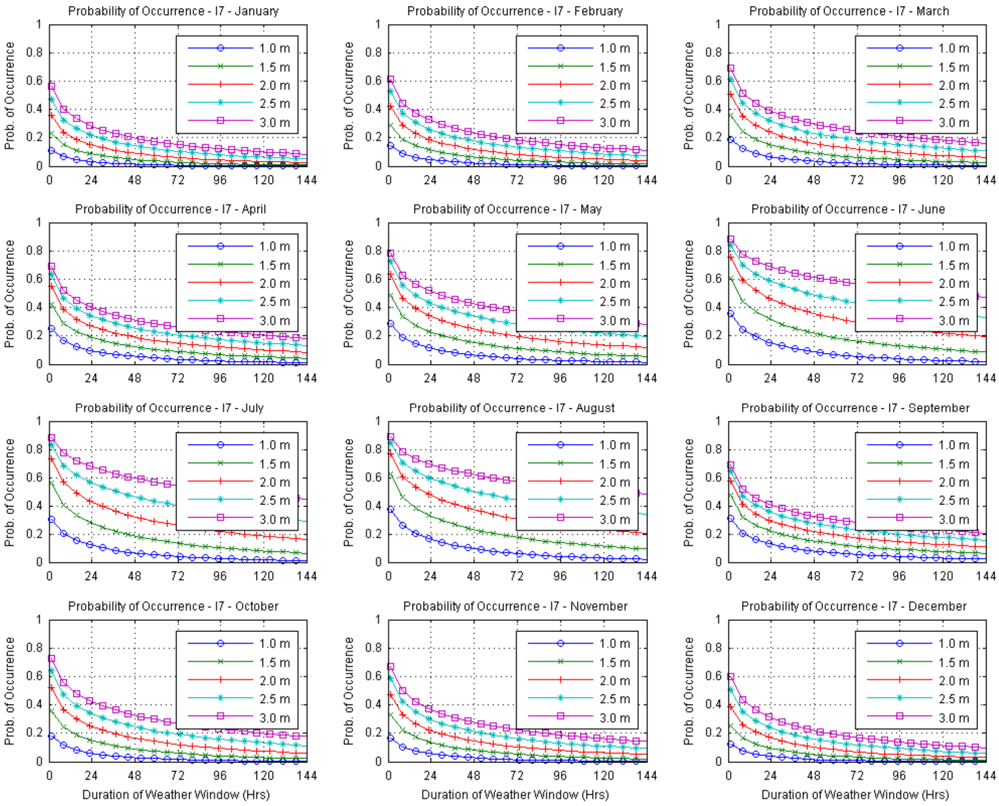

Mean window Length - I7 - January
Mean window Length - I7 - February
Mean window Length - I7 - March
Mean window Length - I7 - April
Mean window Length - I7 - May
Mean window Length - I7 - June
Mean window Length - I7 - July
Mean window Length - I7 - August
Mean window Length - I7 - September
Mean window Length - I7 - October
Mean window Length - I7 - November
Mean window Length - I7 - December
Mean Window Length (Hr)
Significant Wave Height (m)

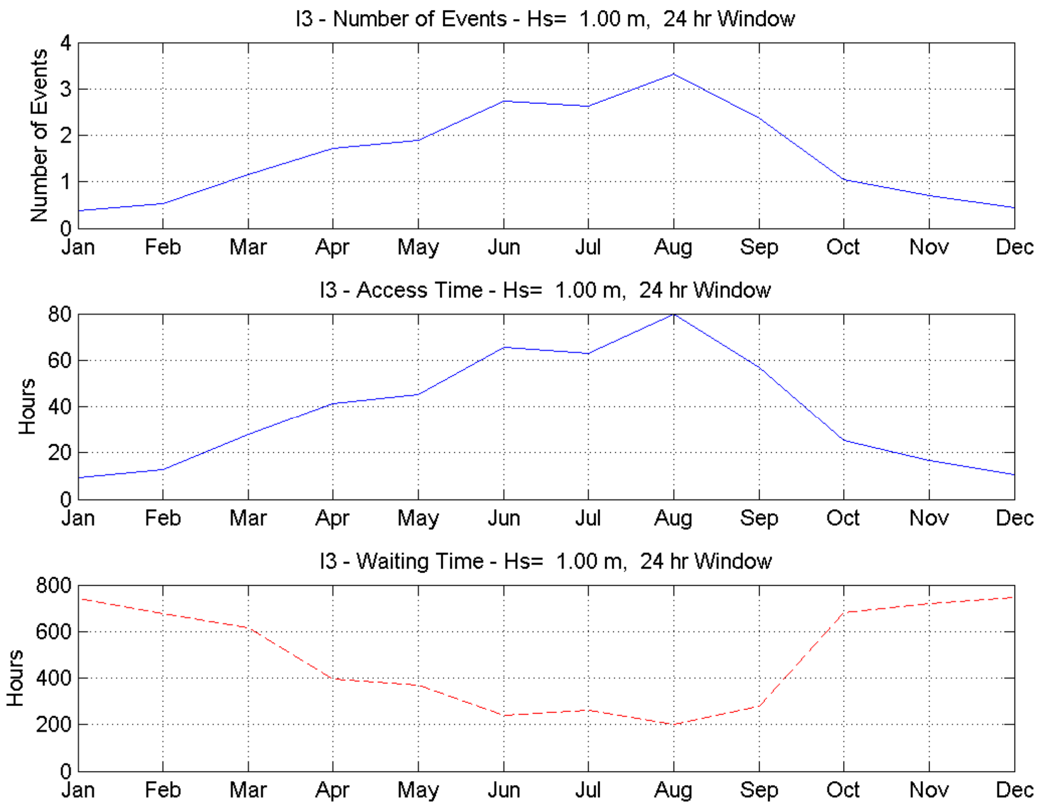

Probability of Occurrence - I3 - January
Probability of Occurrence - I3 - February
Probability of Occurrence - I3 - March
Probability of Occurrence - I3 - April
Probability of Occurrence - I3 - May
Probability of Occurrence - I3 - June
Probability of Occurrence - I3 - July
Probability of Occurrence - I3 - August
Probability of Occurrence - I3 - September
Probability of Occurrence - I3 - October
Probability of Occurrence - I3 - November
Probability of Occurrence - I3 - December
1.0 m
1.5 m
2.0 m
2.5 m
3.0 m
Prob. of Occurrence
Duration of Weather Window (Hrs)

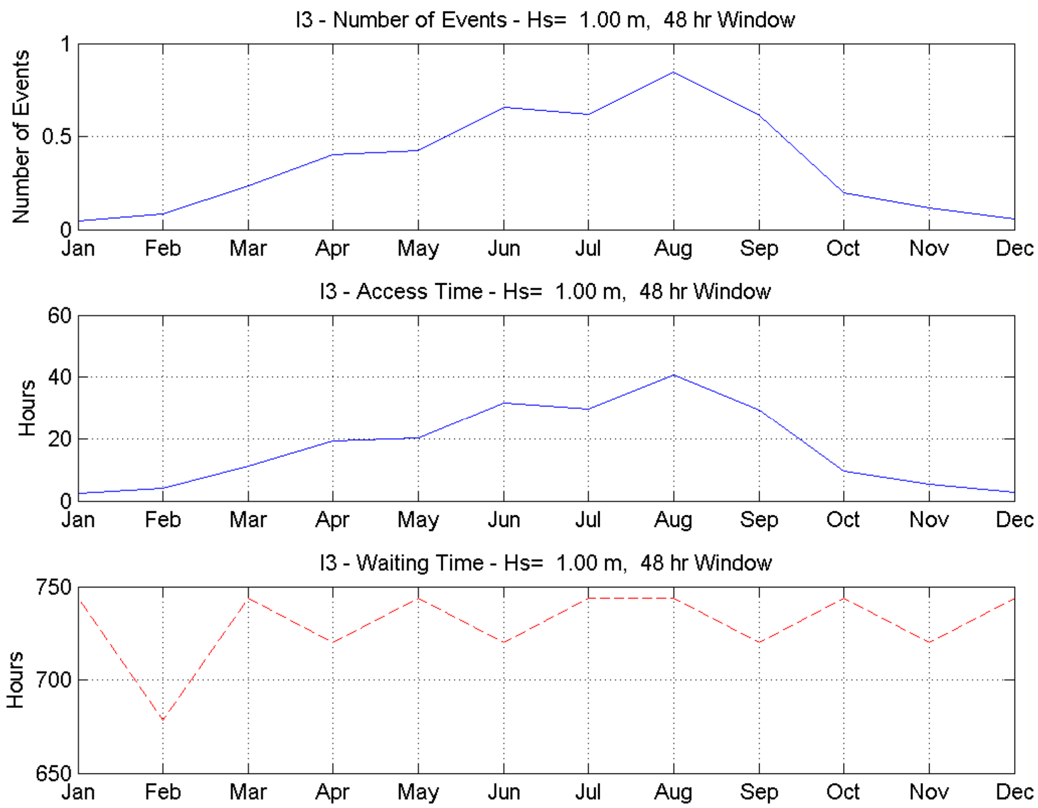

Probability of Occurrence - I4 - January
Probability of Occurrence - I4 - February
Probability of Occurrence - I4 - March
Probability of Occurrence - I4 - April
Probability of Occurrence - I4 - May
Probability of Occurrence - I4 - June
Probability of Occurrence - I4 - July
Probability of Occurrence - I4 - August
Probability of Occurrence - I4 - September
Probability of Occurrence - I4 - October
Probability of Occurrence - I4 - November
Probability of Occurrence - I4 - December
1.0 m
1.5 m
2.0 m
2.5 m
3.0 m
Prob. of Occurrence
Duration of Weather Window (Hrs)


Probability of Occurrence - I5 - January
Probability of Occurrence - I5 - February
Probability of Occurrence - I5 - March
Probability of Occurrence - I5 - April
Probability of Occurrence - I5 - May
Probability of Occurrence - I5 - June
Probability of Occurrence - I5 - July
Probability of Occurrence - I5 - August
Probability of Occurrence - I5 - September
Probability of Occurrence - I5 - October
Probability of Occurrence - I5 - November
Probability of Occurrence - I5 - December
Prob. of Occurrence
Duration of Weather Window (Hrs)
1.0 m
1.5 m
2.0 m
2.5 m
3.0 m


Probability of Occurrence - I6 - January
Probability of Occurrence - I6 - February
Probability of Occurrence - I6 - March
Probability of Occurrence - I6 - April
Probability of Occurrence - I6 - May
Probability of Occurrence - I6 - June
Probability of Occurrence - I6 - July
Probability of Occurrence - I6 - August
Probability of Occurrence - I6 - September
Probability of Occurrence - I6 - October
Probability of Occurrence - I6 - November
Probability of Occurrence - I6 - December
Prob. of Occurrence
Duration of Weather Window (Hrs)
1.0 m
1.5 m
2.0 m
2.5 m
3.0 m


Probability of Occurrence - I7 - January
Probability of Occurrence - I7 - February
Probability of Occurrence - I7 - March
Probability of Occurrence - I7 - April
Probability of Occurrence - I7 - May
Probability of Occurrence - I7 - June
Probability of Occurrence - I7 - July
Probability of Occurrence - I7 - August
Probability of Occurrence - I7 - September
Probability of Occurrence - I7 - October
Probability of Occurrence - I7 - November
Probability of Occurrence - I7 - December
Prob. of Occurrence
Duration of Weather Window (Hrs)
1.0 m
1.5 m
2.0 m
2.5 m
3.0 m


I3 - Number of Events - Hs= 1.00 m, 24 hr Window
Number of Events
0
1
2
3
4
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Access Time - Hs= 1.00 m, 24 hr Window
Hours
0
20
40
60
80
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Waiting Time - Hs= 1.00 m, 24 hr Window
Hours
0
200
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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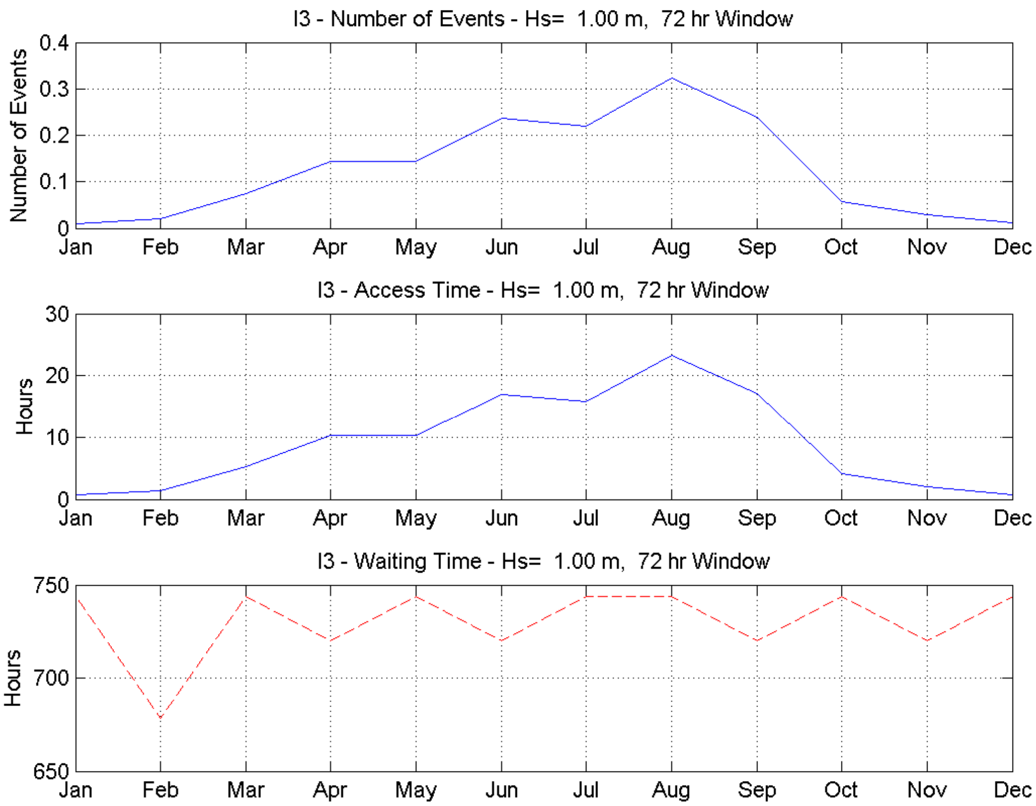
Number of Events
0
0.5
1
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Access Time - Hs= 1.00 m, 48 hr Window
Hours
0
20
40
60
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Waiting Time - Hs= 1.00 m, 48 hr Window
Hours
650
700
750
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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Number of Events
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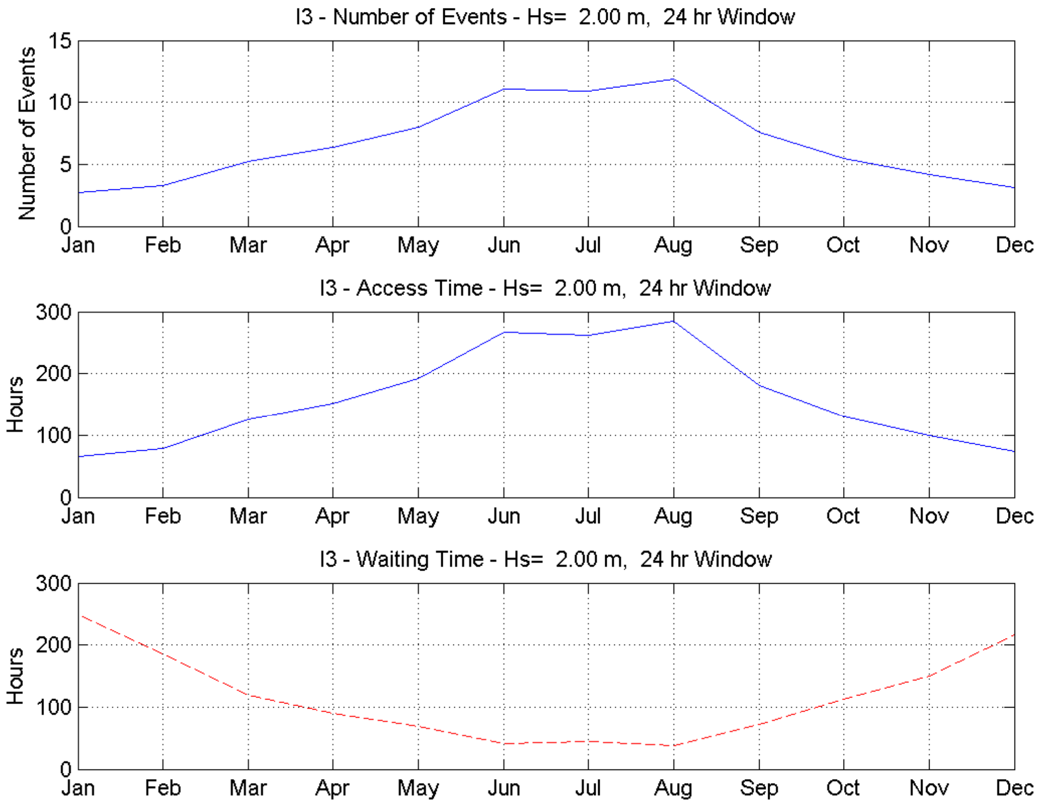
0.3
0.2
0.1
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Access Time - Hs= 1.00 m, 72 hr Window
Hours
30
20
10
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Waiting Time - Hs= 1.00 m, 72 hr Window
Hours
750
700
650
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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Number of Events
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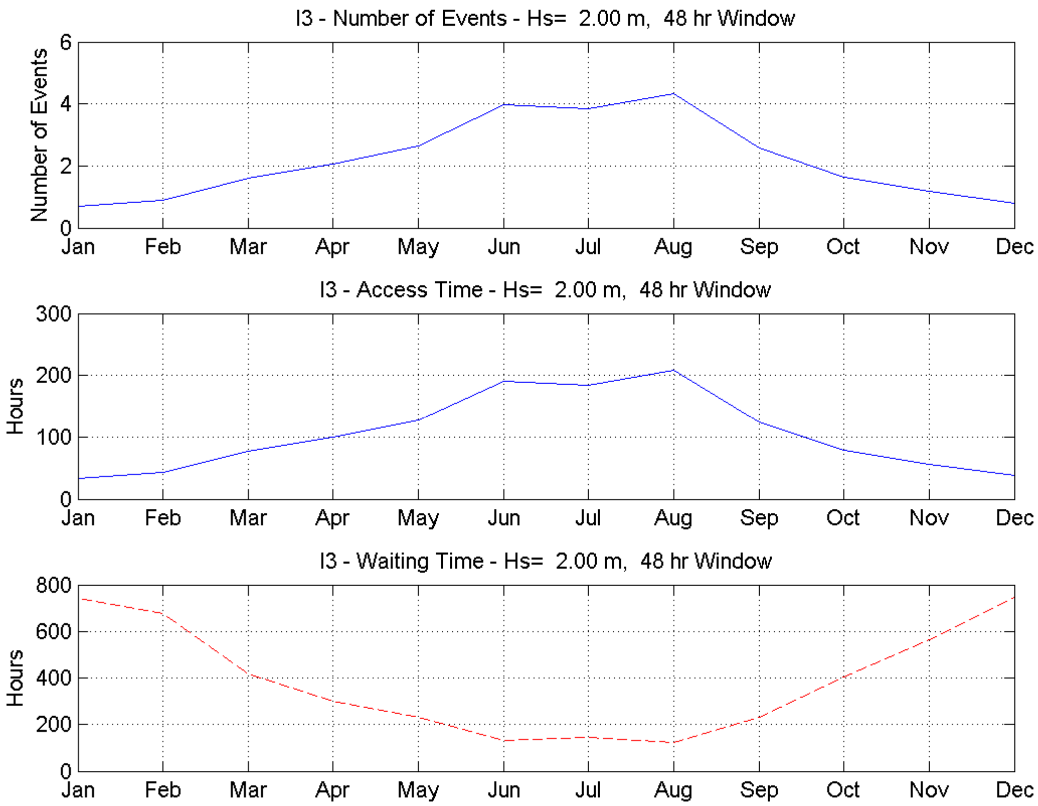
5
10
15
I3 - Access Time - Hs= 2.00 m, 24 hr Window
Hours
0
100
200
300
I3 - Waiting Time - Hs= 2.00 m, 24 hr Window
Hours
0
100
200
300
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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Number of Events
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2
4
6
I3 - Access Time - Hs= 2.00 m, 48 hr Window
Hours
0
100
200
300
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Hours
0
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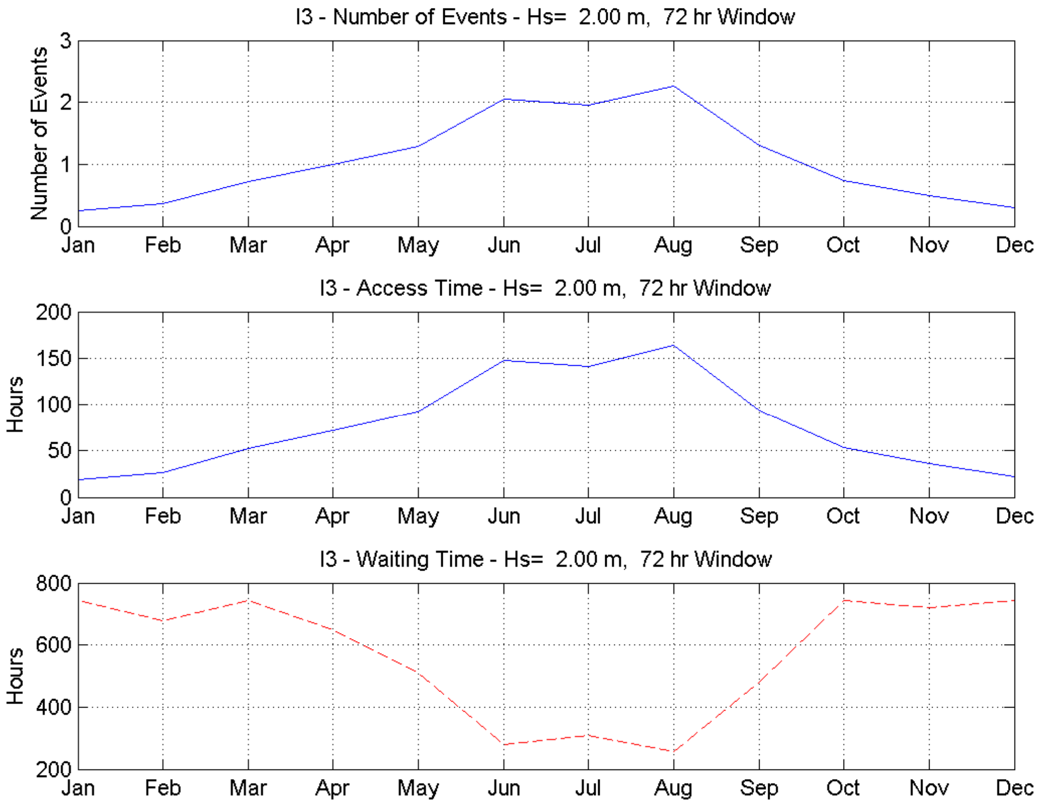
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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Number of Events
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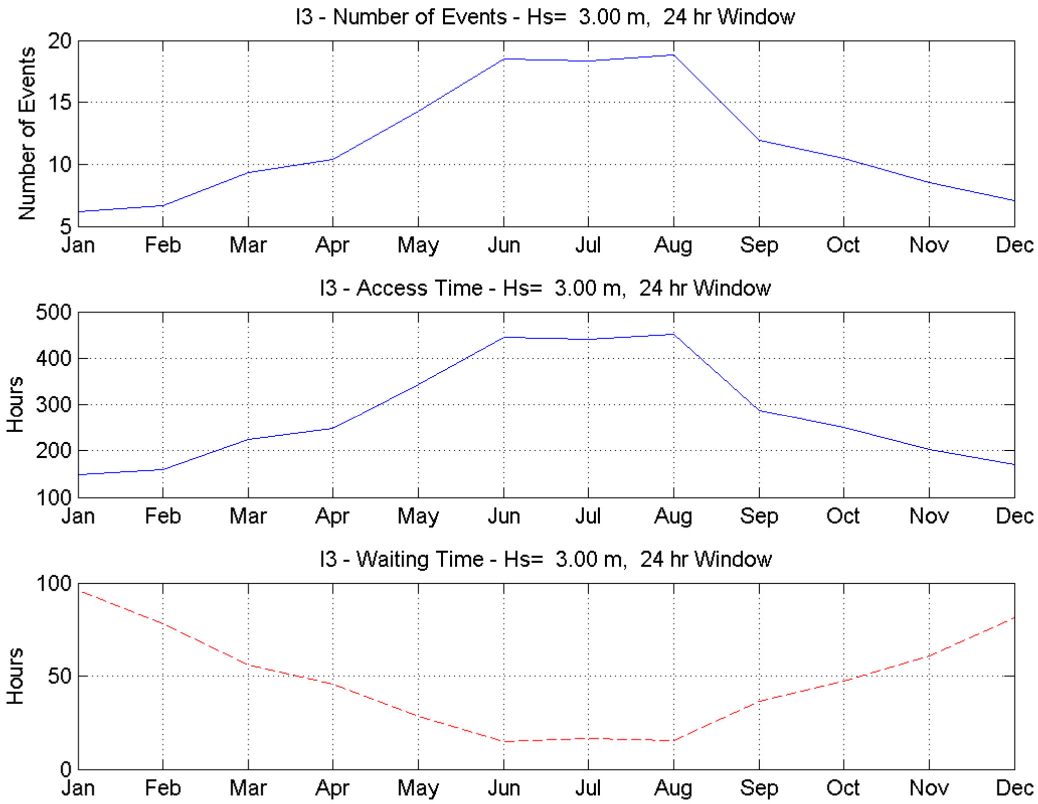
1
2
3
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Access Time - Hs= 2.00 m, 72 hr Window
Hours
0
50
100
150
200
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Waiting Time - Hs= 2.00 m, 72 hr Window
Hours
200
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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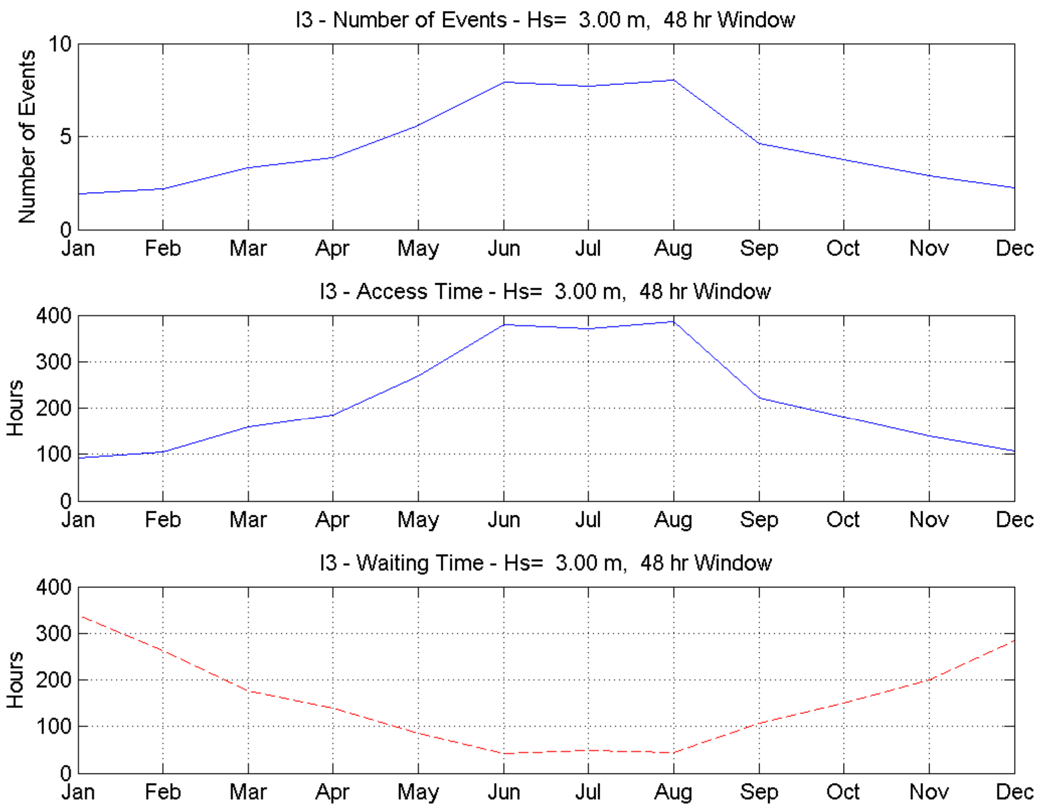
Number of Events
20
15
10
5
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Access Time - Hs= 3.00 m, 24 hr Window
Hours
500
400
300
200
100
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Waiting Time - Hs= 3.00 m, 24 hr Window
Hours
100
50
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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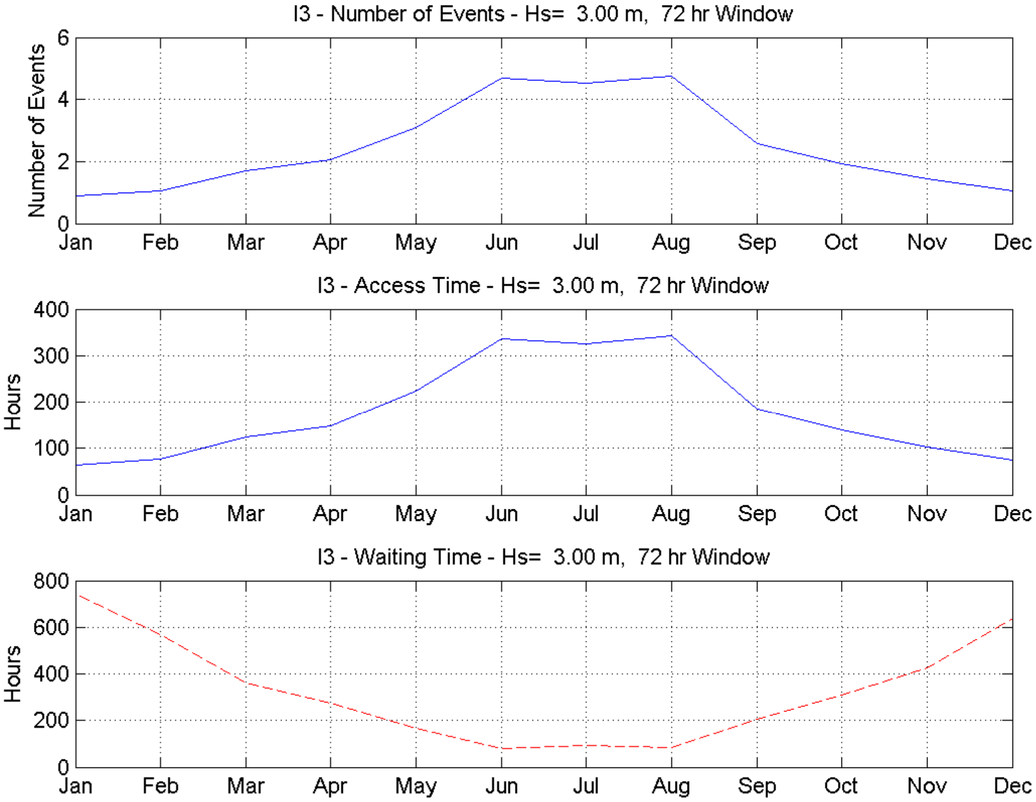
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Access Time - Hs= 3.00 m, 48 hr Window
Hours
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I3 - Waiting Time - Hs= 3.00 m, 48 hr Window
Hours
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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Number of Events
0
2
4
6
I3 - Access Time - Hs= 3.00 m, 72 hr Window
Hours
0
100
200
300
400
I3 - Waiting Time - Hs= 3.00 m, 72 hr Window
Hours
0
200
400
600
800
Jan
Feb
Mar
Apr
May
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Aug
Sep
Oct
Nov
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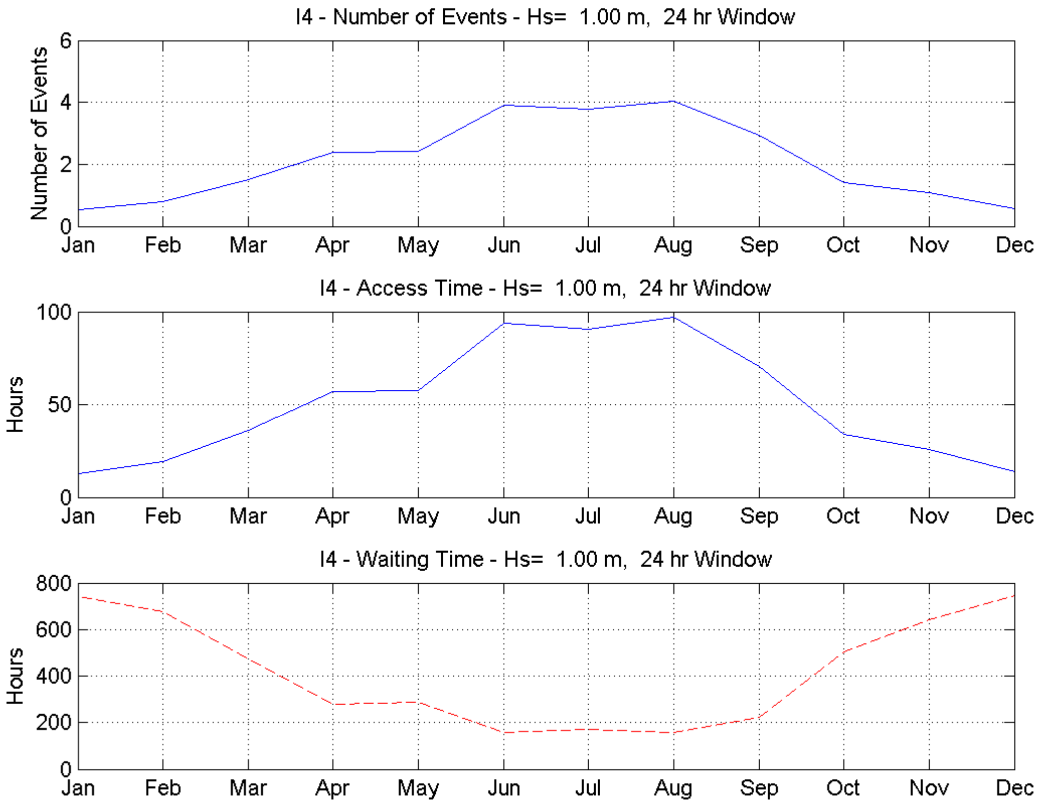
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Hours
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Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
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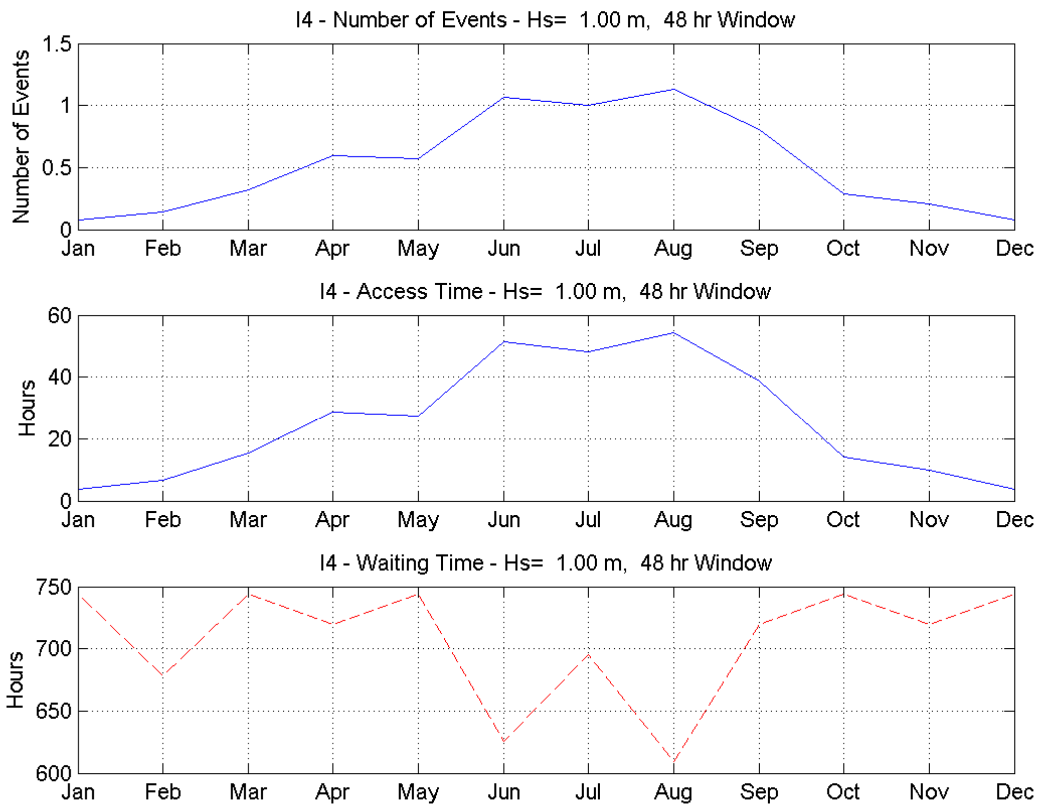
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1.5
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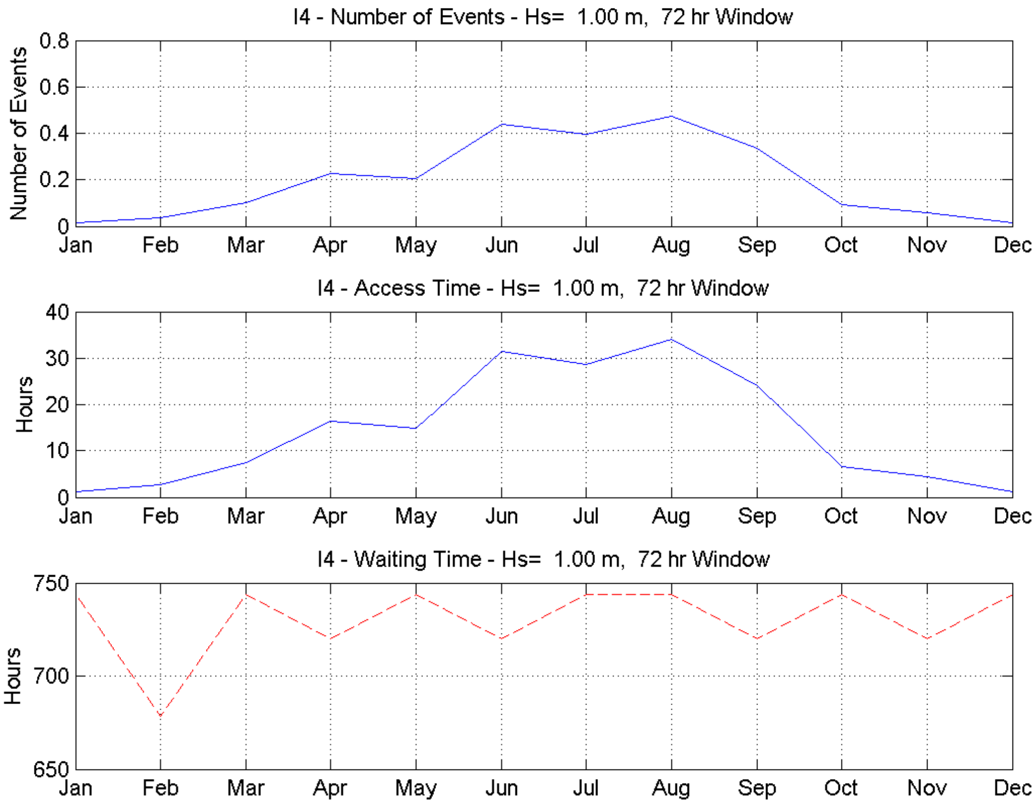
I4 - Access Time - Hs= 1.00 m, 48 hr Window
Hours
0
20
40
60
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Waiting Time - Hs= 1.00 m, 48 hr Window
Hours
600
650
700
750
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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Number of Events
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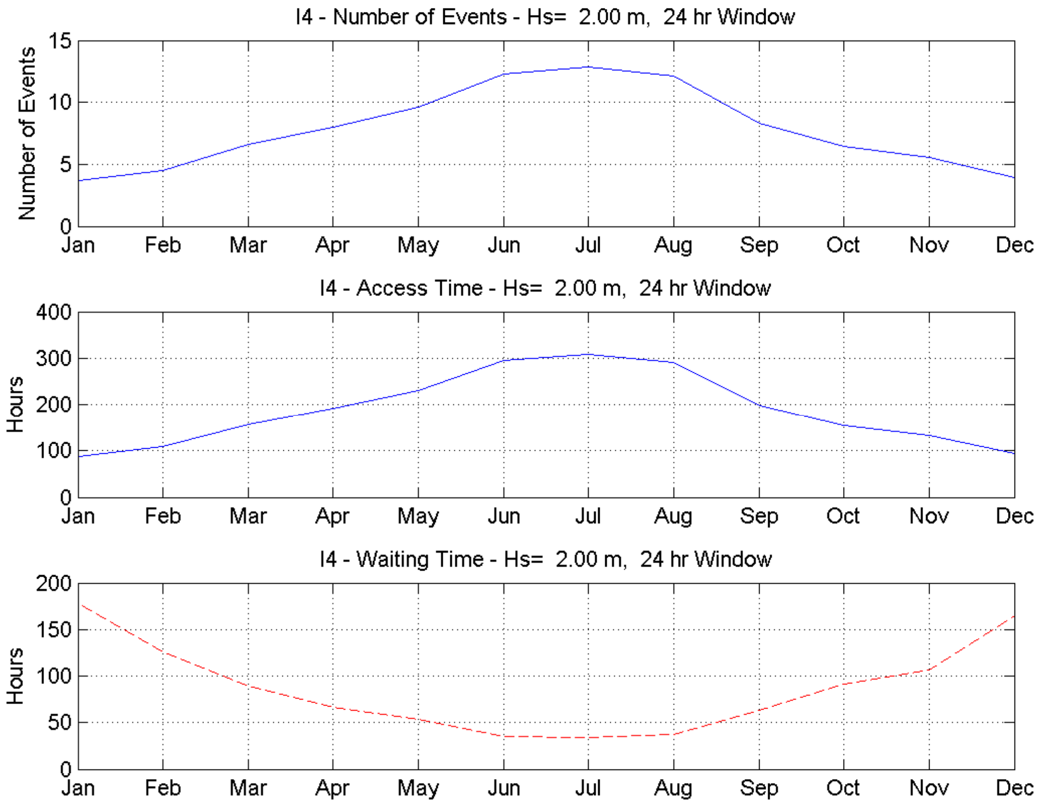
0.6
0.4
0.2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
I4 - Access Time - Hs= 1.00 m, 72 hr Window
Hours
40
30
20
10
0
I4 - Waiting Time - Hs= 1.00 m, 72 hr Window
Hours
750
700
650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Number of Events
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5
10
15
I4 - Access Time - Hs= 2.00 m, 24 hr Window
Hours
0
100
200
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Hours
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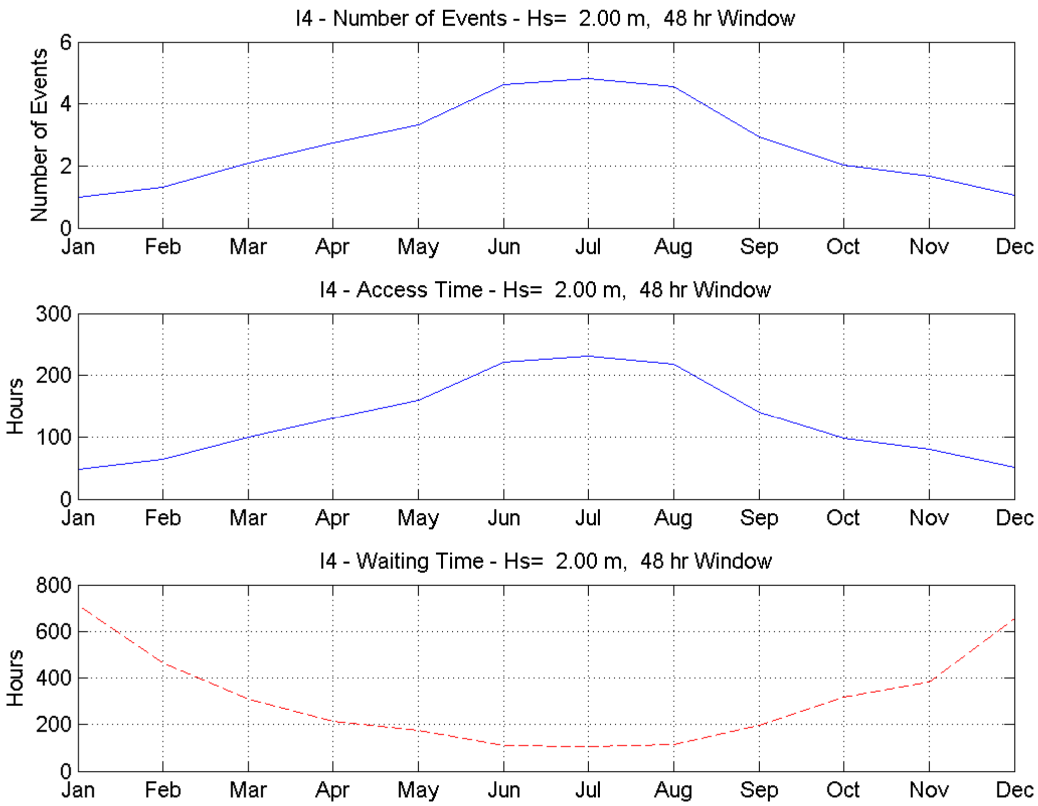
100
150
200
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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Number of Events
0
2
4
6
I4 - Access Time - Hs= 2.00 m, 48 hr Window
Hours
0
100
200
300
I4 - Waiting Time - Hs= 2.00 m, 48 hr Window
Hours
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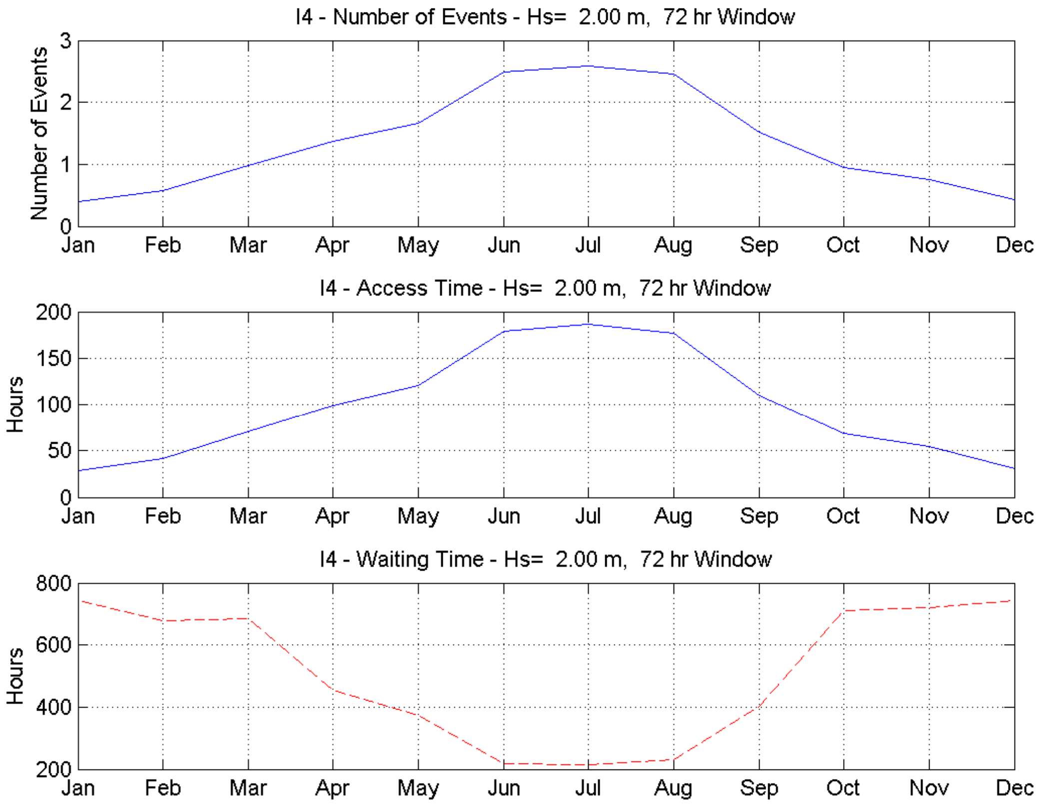
200
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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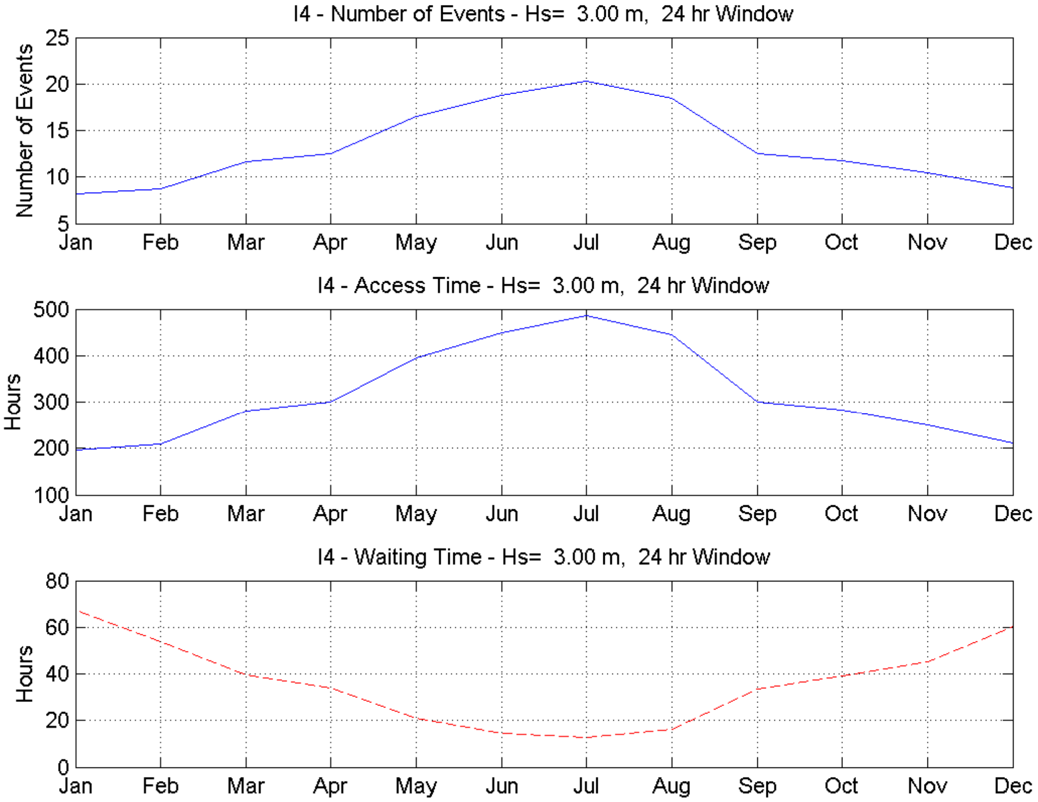
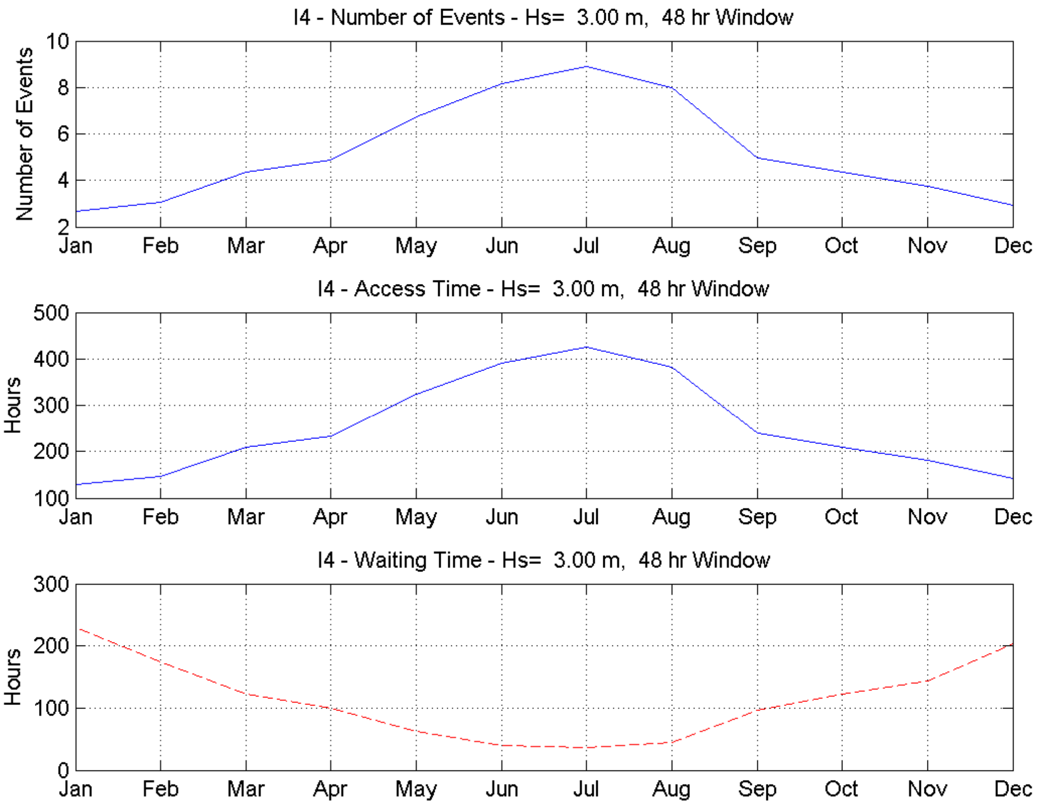
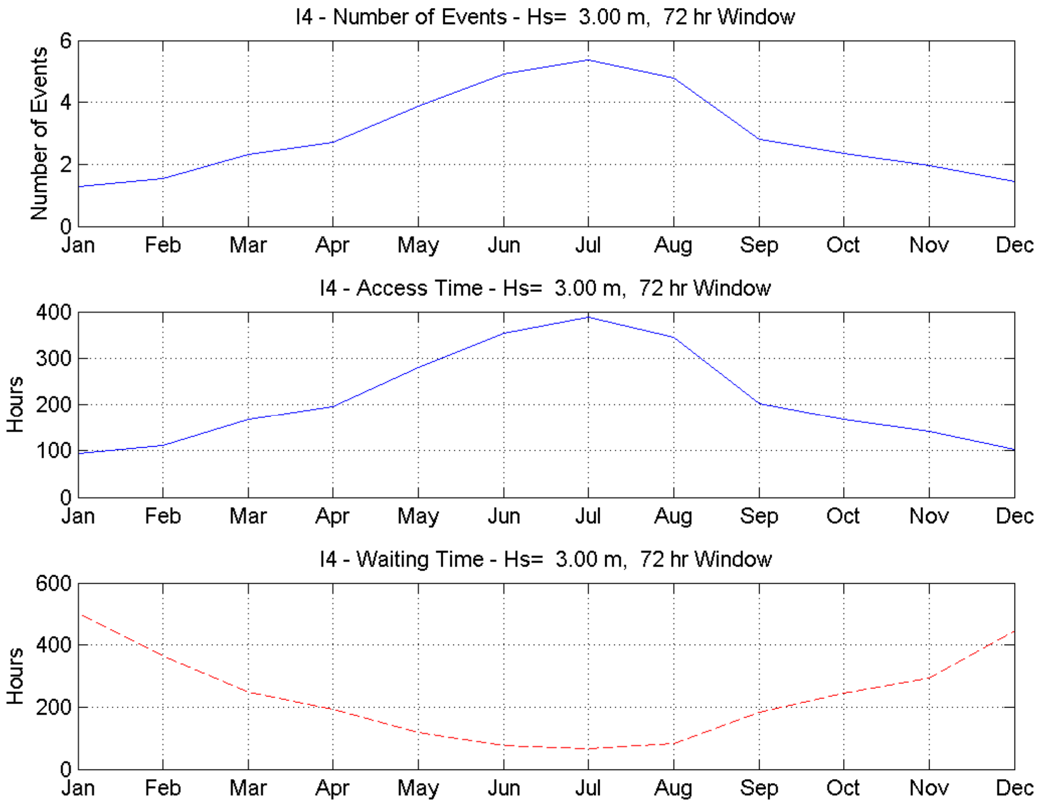
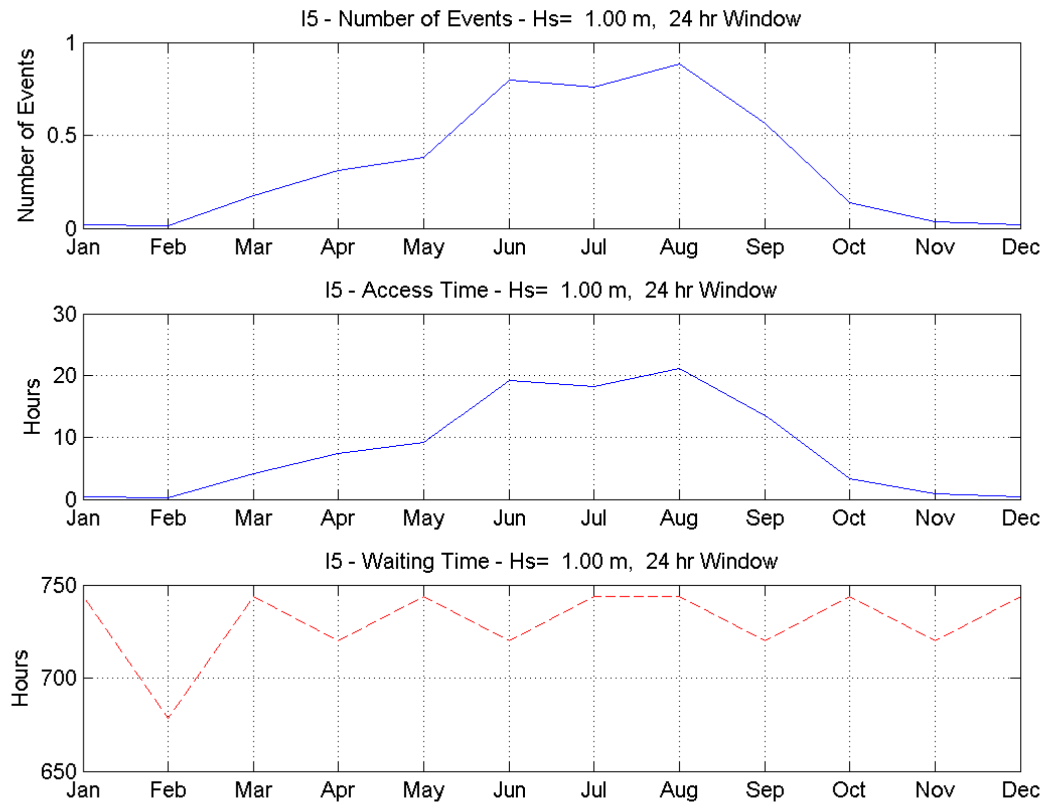
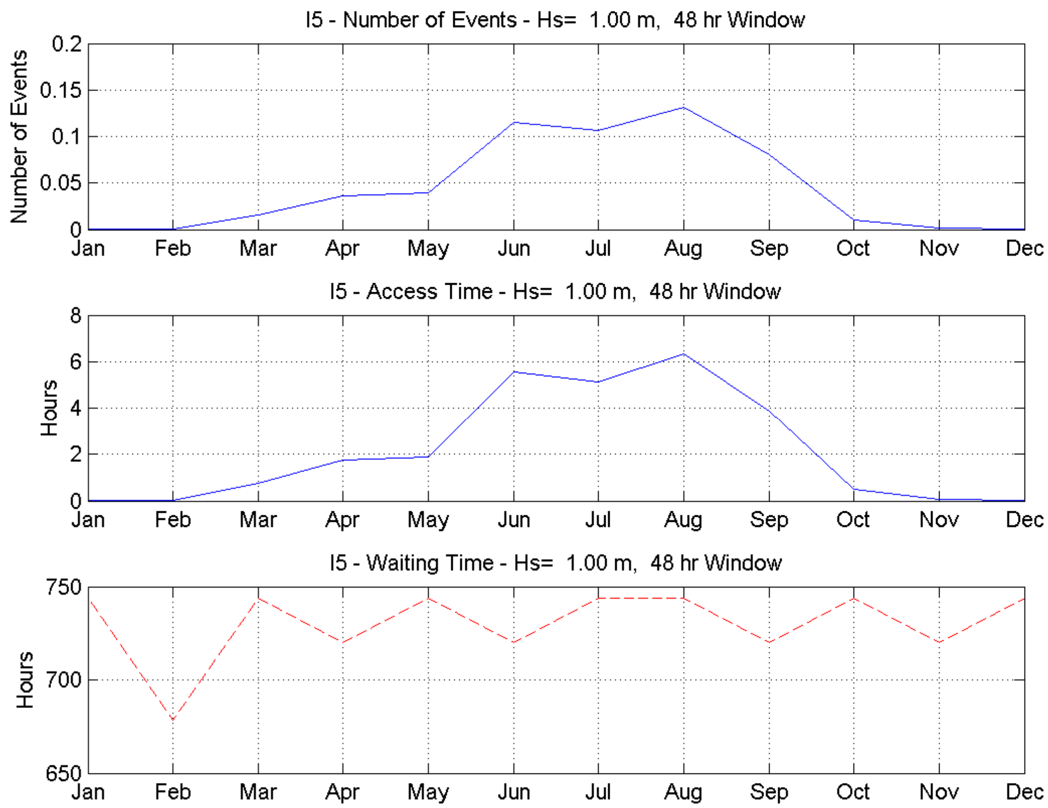
0
1
2
3
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Access Time - Hs= 2.00 m, 72 hr Window
Hours
0
50
100
150
200
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Waiting Time - Hs= 2.00 m, 72 hr Window
Hours
200
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

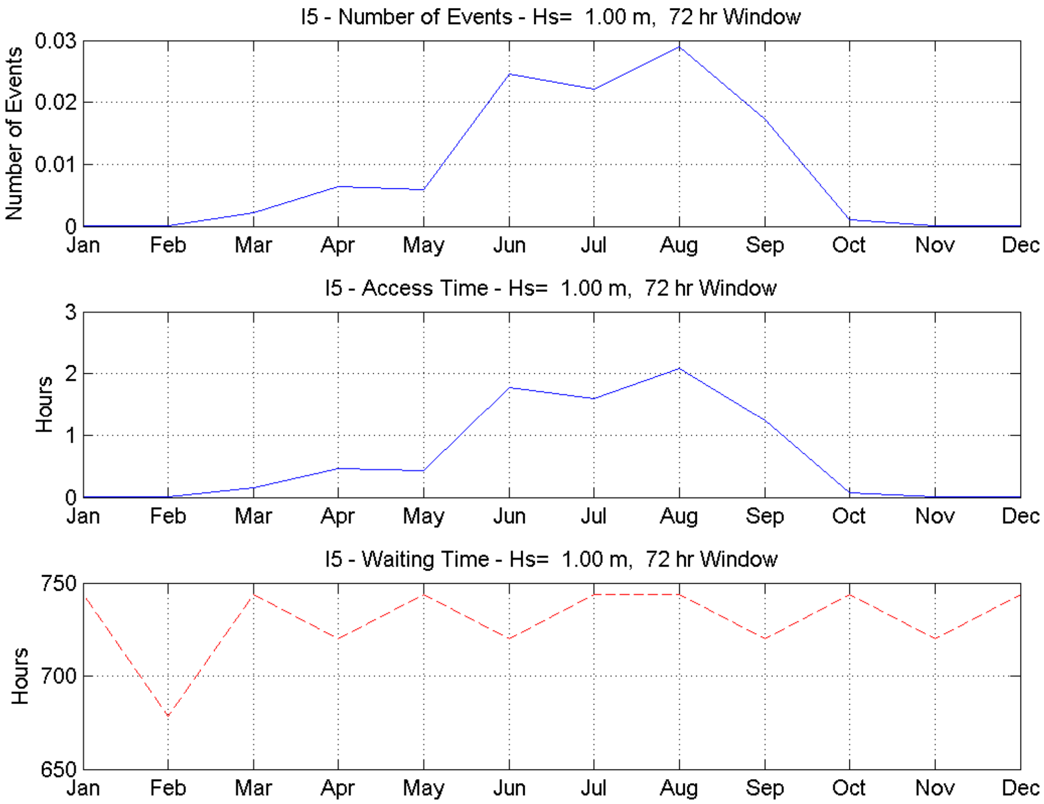

I4 - Number of Events - Hs= 3.00 m, 24 hr Window
Number of Events
25
20
15
10
5
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Access Time - Hs= 3.00 m, 24 hr Window
Hours
500
400
300
200
100
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Waiting Time - Hs= 3.00 m, 24 hr Window
Hours
80
60
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

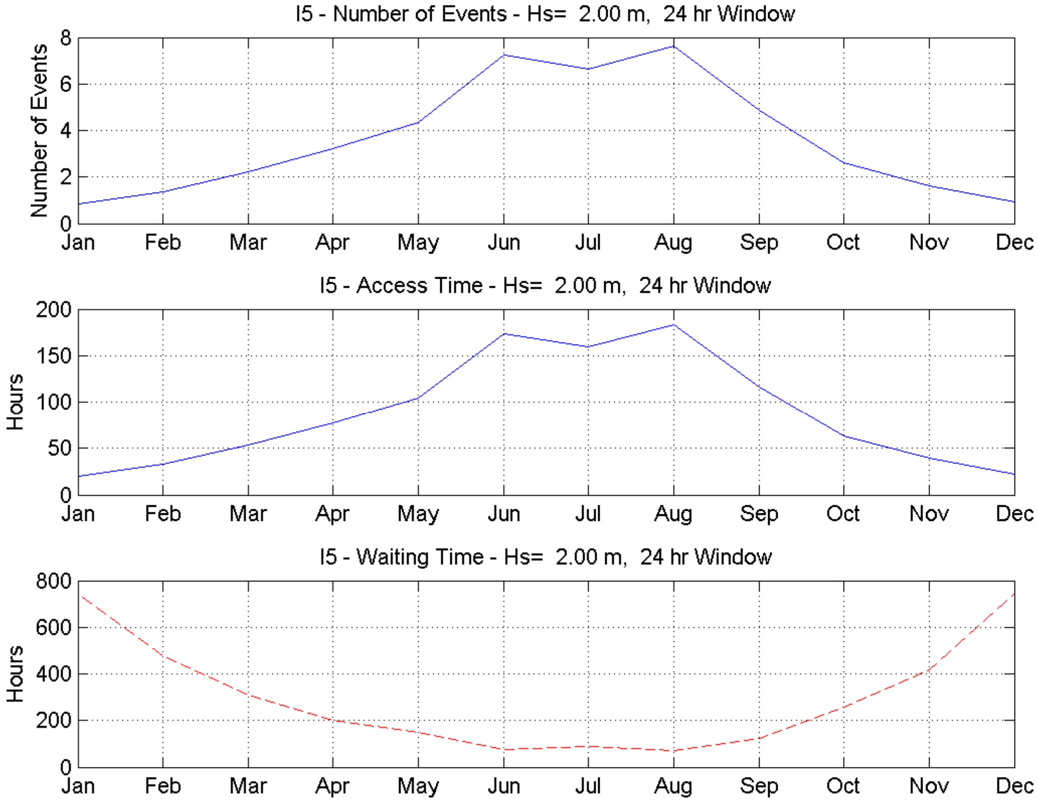

I4 - Number of Events - Hs= 3.00 m, 48 hr Window
Number of Events
10
8
6
4
2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Access Time - Hs= 3.00 m, 48 hr Window
Hours
500
400
300
200
100
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Waiting Time - Hs= 3.00 m, 48 hr Window
Hours
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

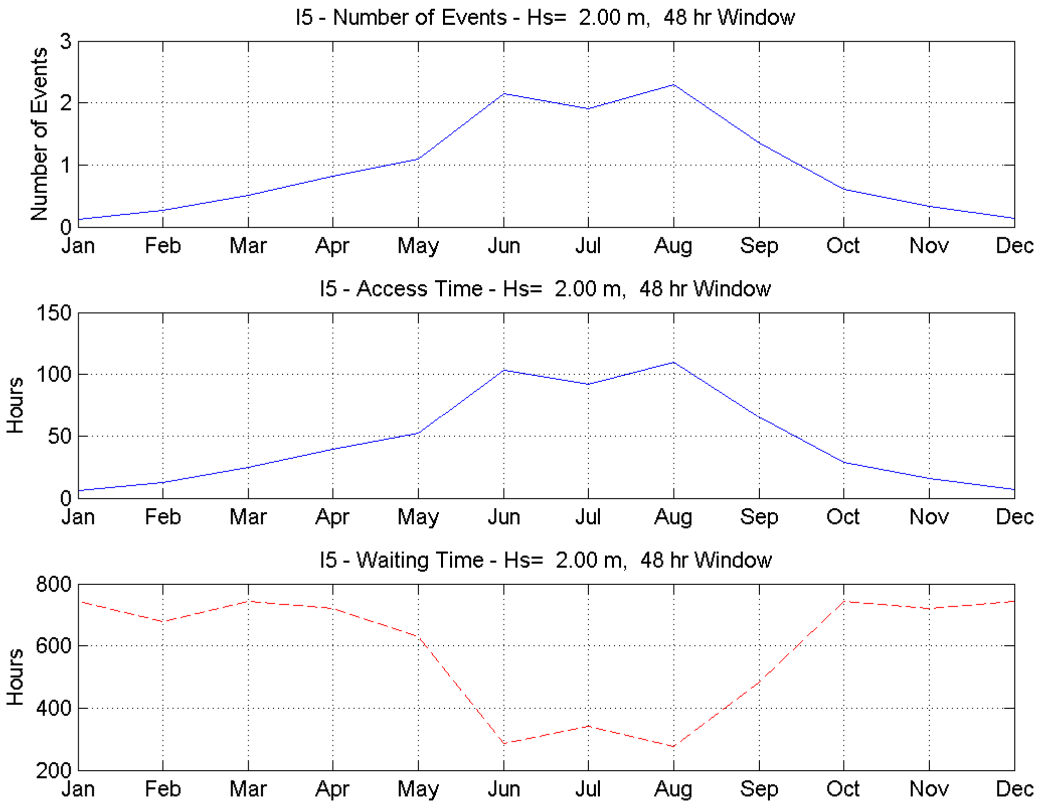

I4 - Number of Events - Hs= 3.00 m, 72 hr Window
Number of Events
0
2
4
6
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Access Time - Hs= 3.00 m, 72 hr Window
Hours
0
100
200
300
400
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I4 - Waiting Time - Hs= 3.00 m, 72 hr Window
Hours
0
200
400
600
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

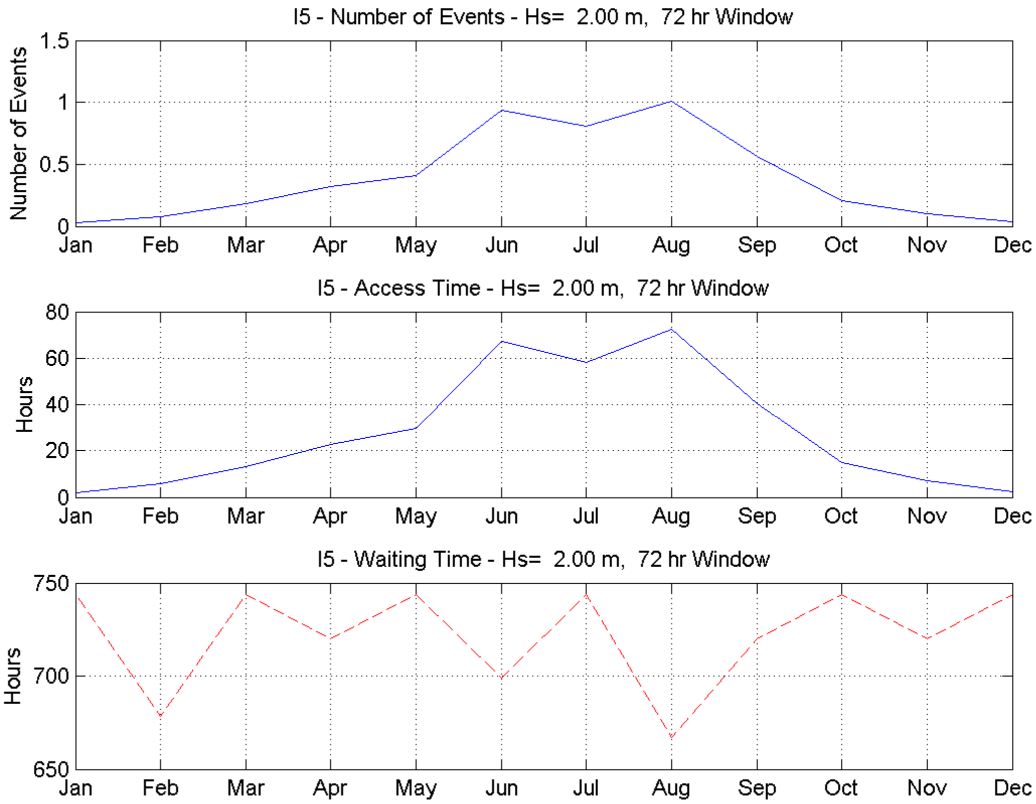

I5 - Number of Events - Hs= 1.00 m, 24 hr Window
Number of Events
0
0.5
1
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Access Time - Hs= 1.00 m, 24 hr Window
Hours
0
10
20
30
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Waiting Time - Hs= 1.00 m, 24 hr Window
Hours
650
700
750
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

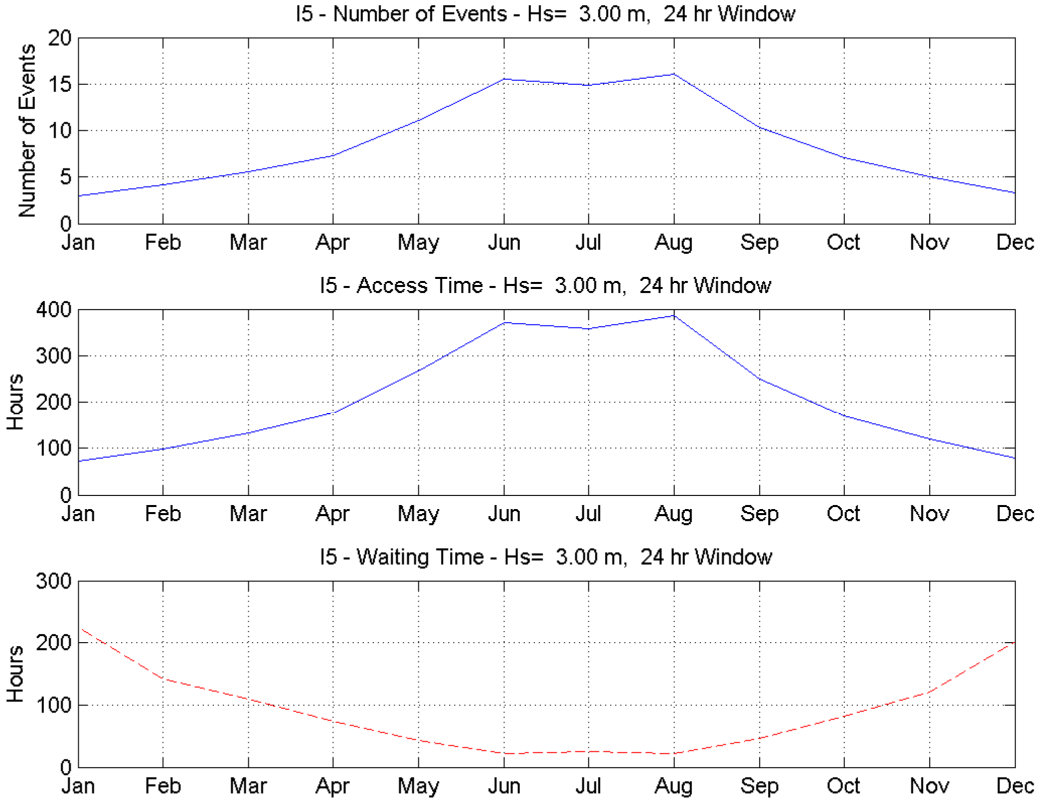

I5 - Number of Events - Hs= 1.00 m, 48 hr Window
Number of Events
0
0.05
0.1
0.15
0.2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Access Time - Hs= 1.00 m, 48 hr Window
Hours
0
2
4
6
8
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Waiting Time - Hs= 1.00 m, 48 hr Window
Hours
650
700
750
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

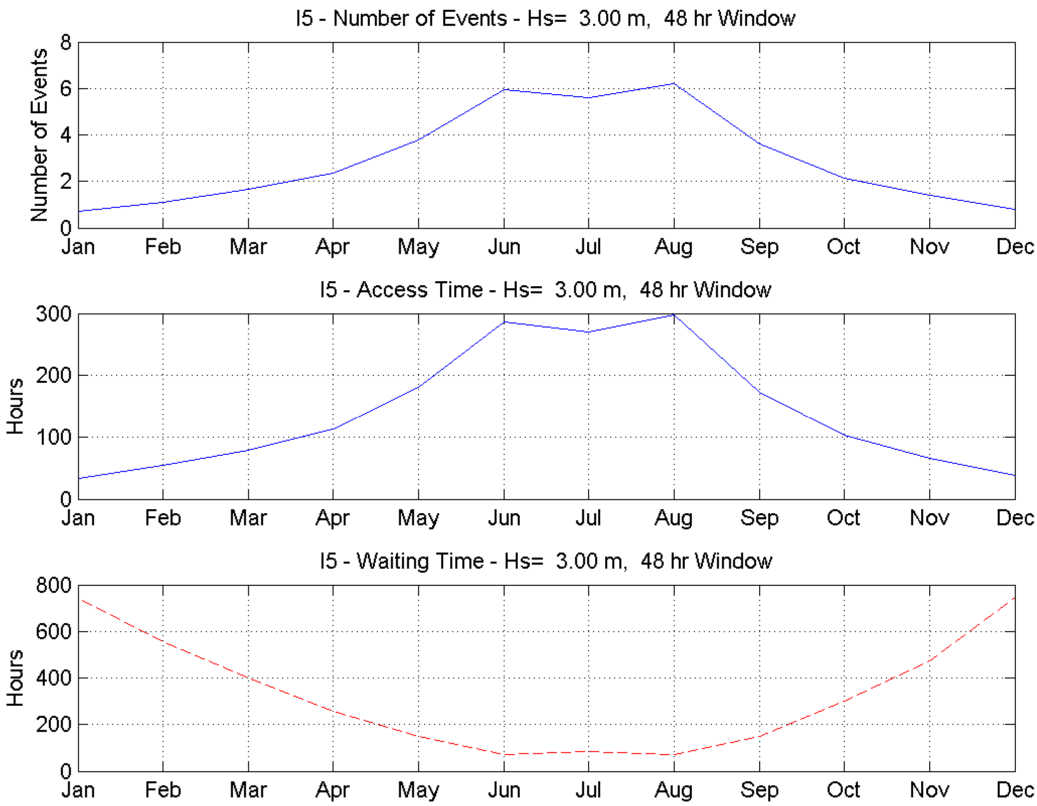

I5 - Number of Events - Hs= 1.00 m, 72 hr Window
Number of Events
0.03
0.02
0.01
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
I5 - Access Time - Hs= 1.00 m, 72 hr Window
Hours
3
2
1
0
I5 - Waiting Time - Hs= 1.00 m, 72 hr Window
Hours
750
700
650

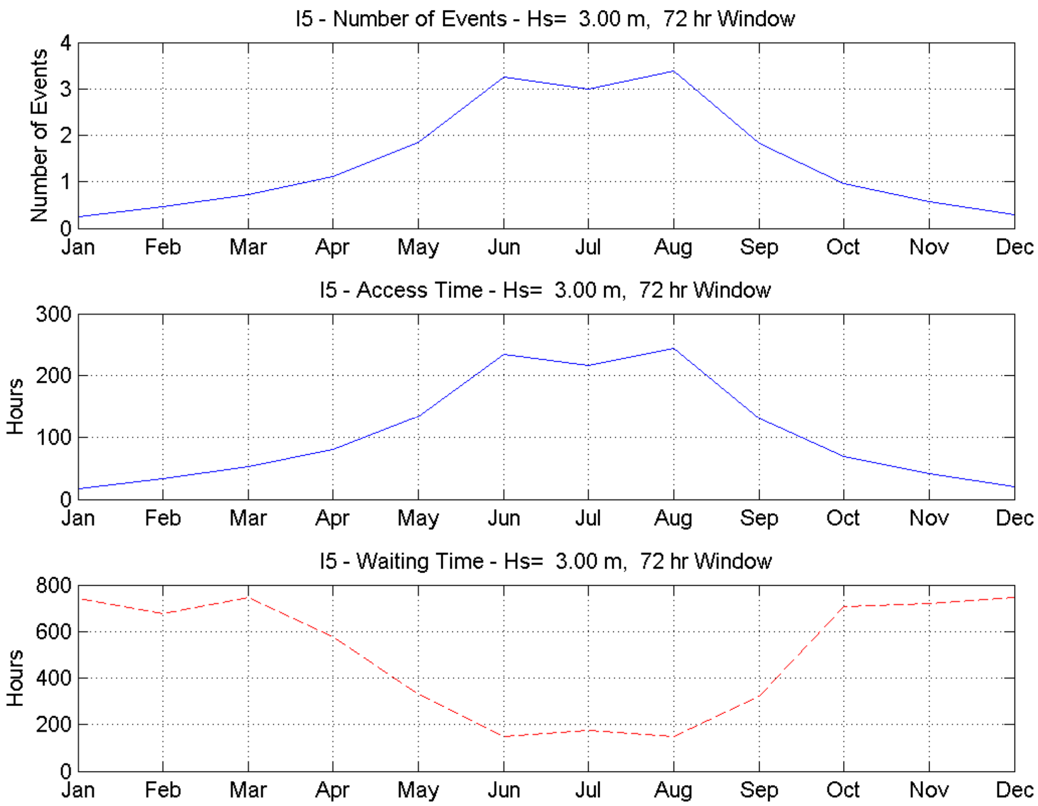

I5 - Number of Events - Hs= 2.00 m, 24 hr Window
Number of Events
I5 - Access Time - Hs= 2.00 m, 24 hr Window
Hours
I5 - Waiting Time - Hs= 2.00 m, 24 hr Window
Hours
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

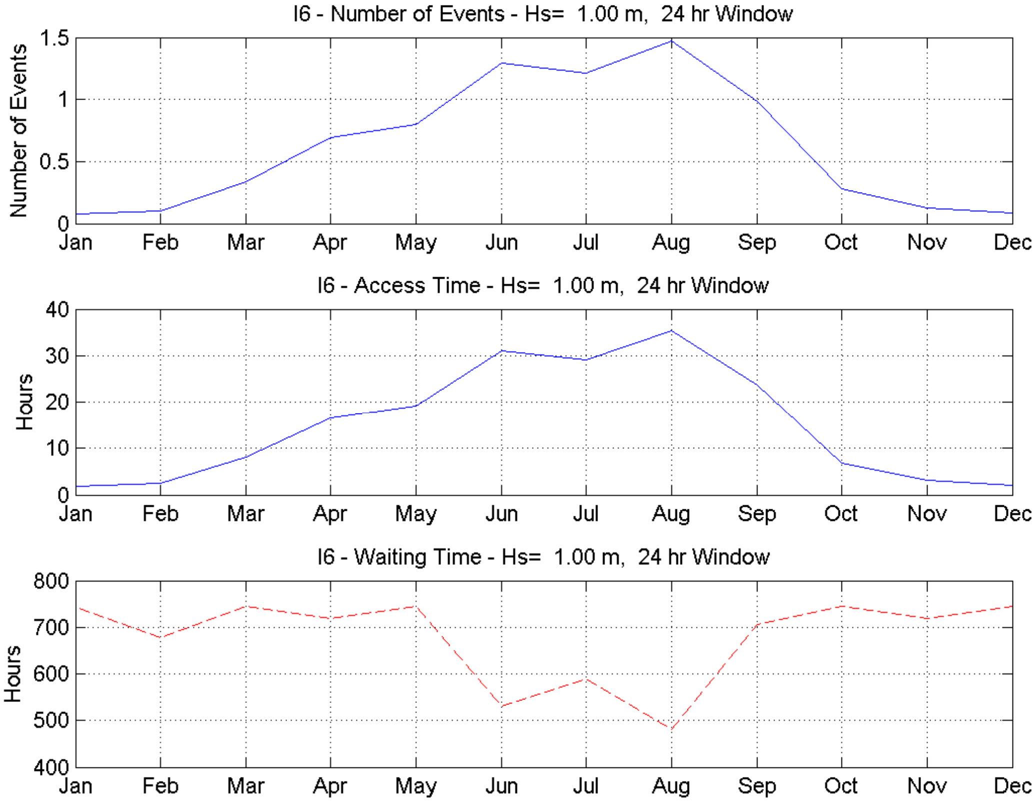

I5 - Number of Events - Hs= 2.00 m, 48 hr Window
Number of Events
I5 - Access Time - Hs= 2.00 m, 48 hr Window
Hours
I5 - Waiting Time - Hs= 2.00 m, 48 hr Window
Hours
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

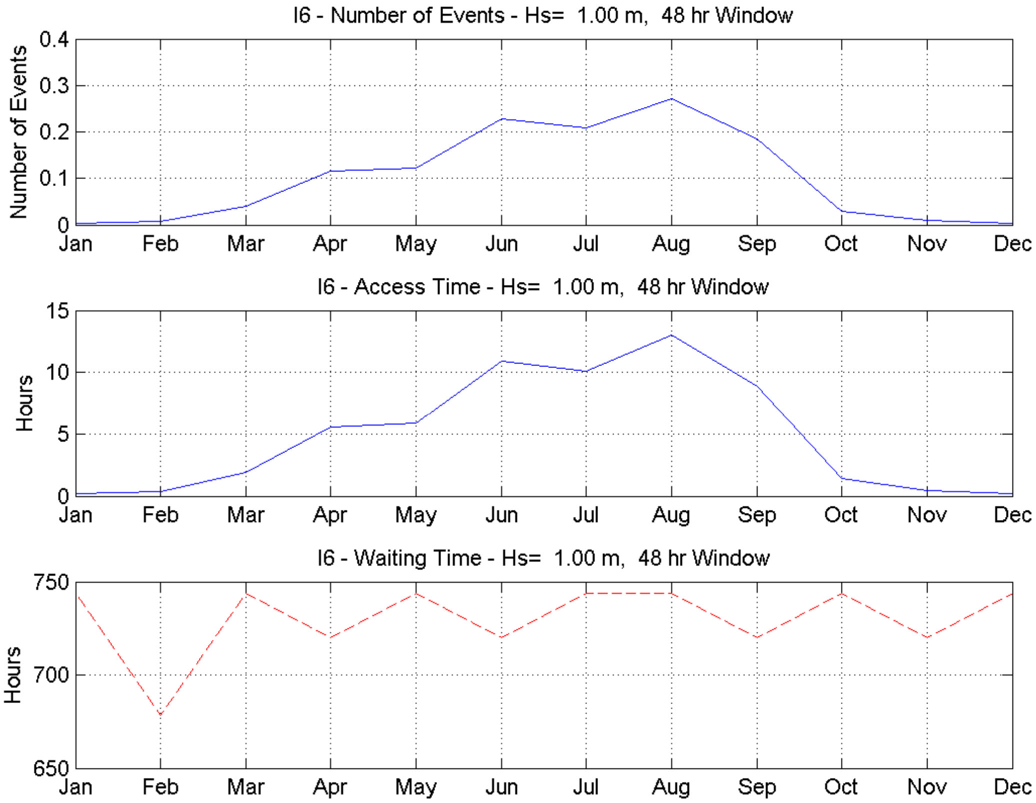

I5 - Number of Events - Hs= 2.00 m, 72 hr Window
Number of Events
1.5
1
0.5
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Access Time - Hs= 2.00 m, 72 hr Window
Hours
80
60
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Waiting Time - Hs= 2.00 m, 72 hr Window
Hours
750
700
650
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

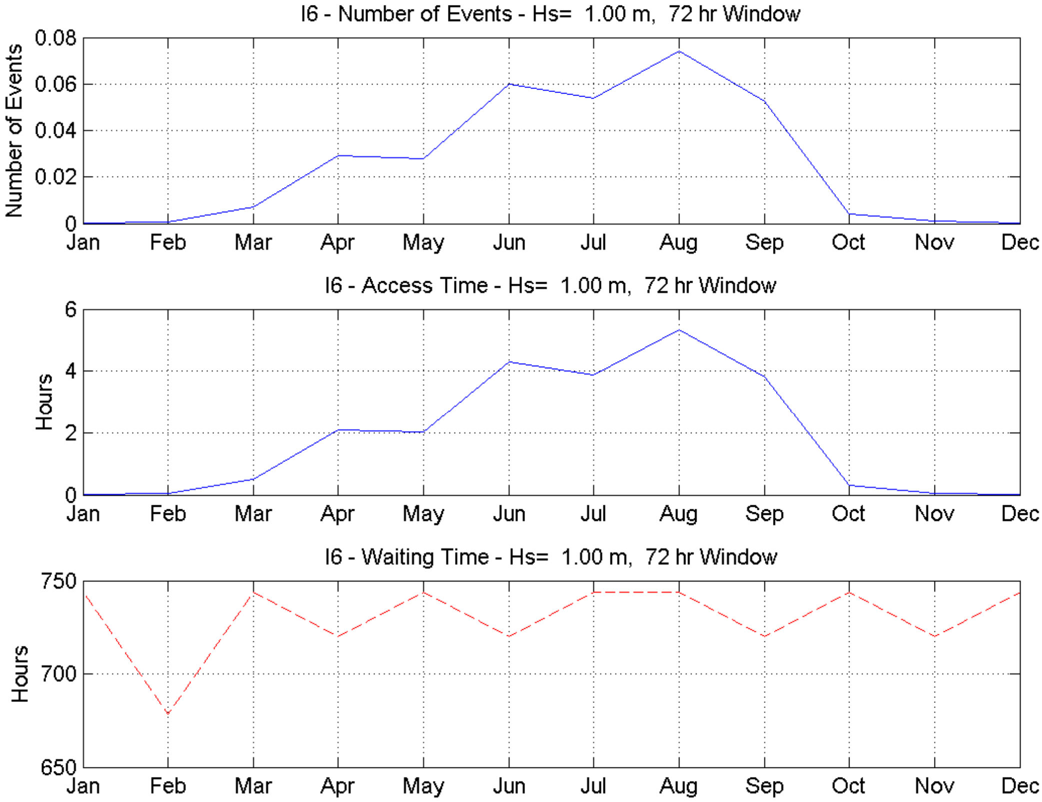

I5 - Number of Events - Hs= 3.00 m, 24 hr Window
Number of Events
20
15
10
5
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Access Time - Hs= 3.00 m, 24 hr Window
Hours
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Waiting Time - Hs= 3.00 m, 24 hr Window
Hours
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

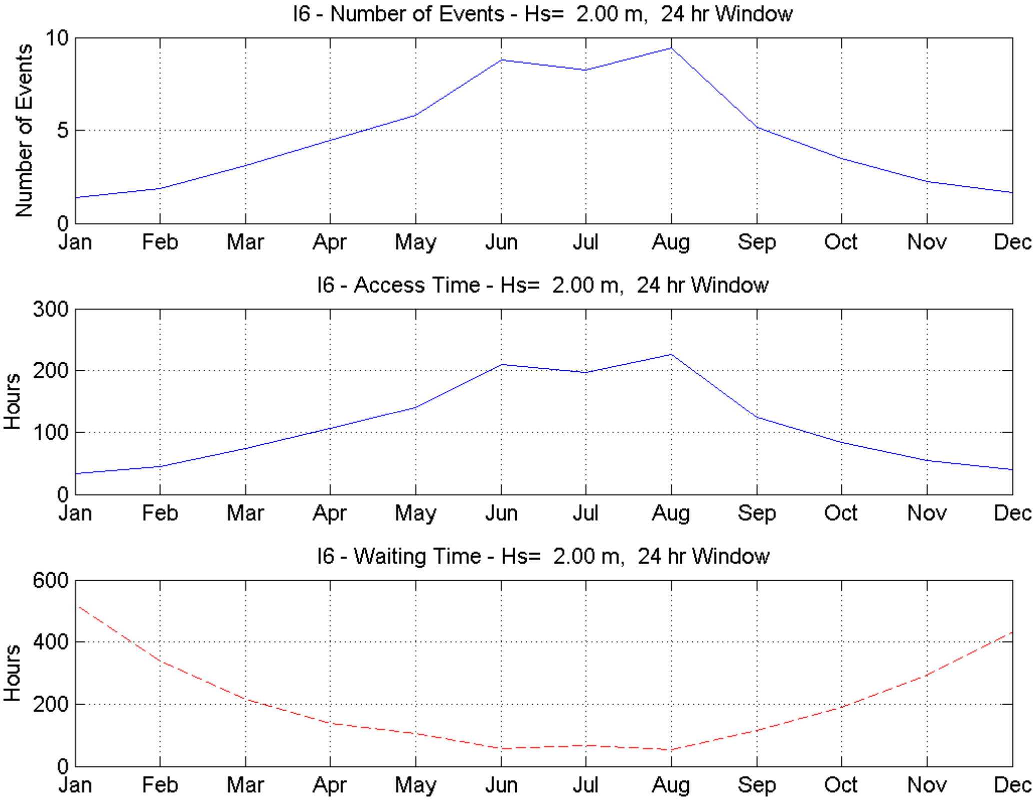

I5 - Number of Events - Hs= 3.00 m, 48 hr Window
Number of Events
8
6
4
2
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Access Time - Hs= 3.00 m, 48 hr Window
Hours
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Waiting Time - Hs= 3.00 m, 48 hr Window
Hours
800
600
400
200
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

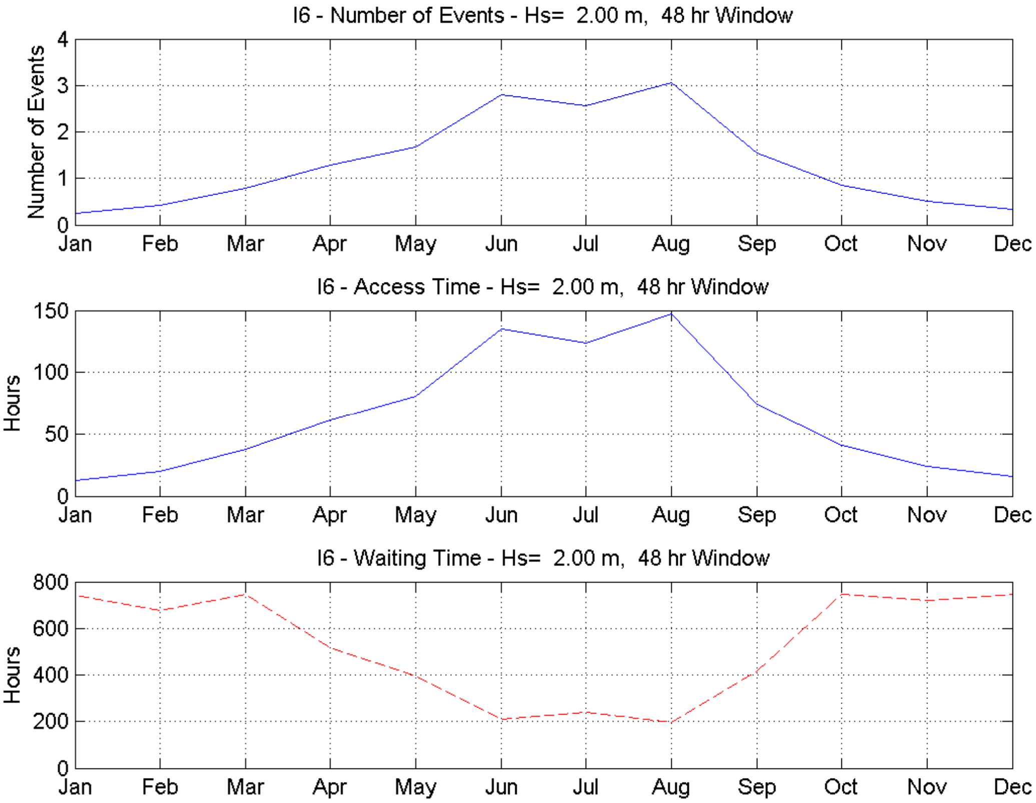

I5 - Number of Events - Hs= 3.00 m, 72 hr Window
Number of Events
0
1
2
3
4
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Access Time - Hs= 3.00 m, 72 hr Window
Hours
0
100
200
300
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I5 - Waiting Time - Hs= 3.00 m, 72 hr Window
Hours
0
200
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

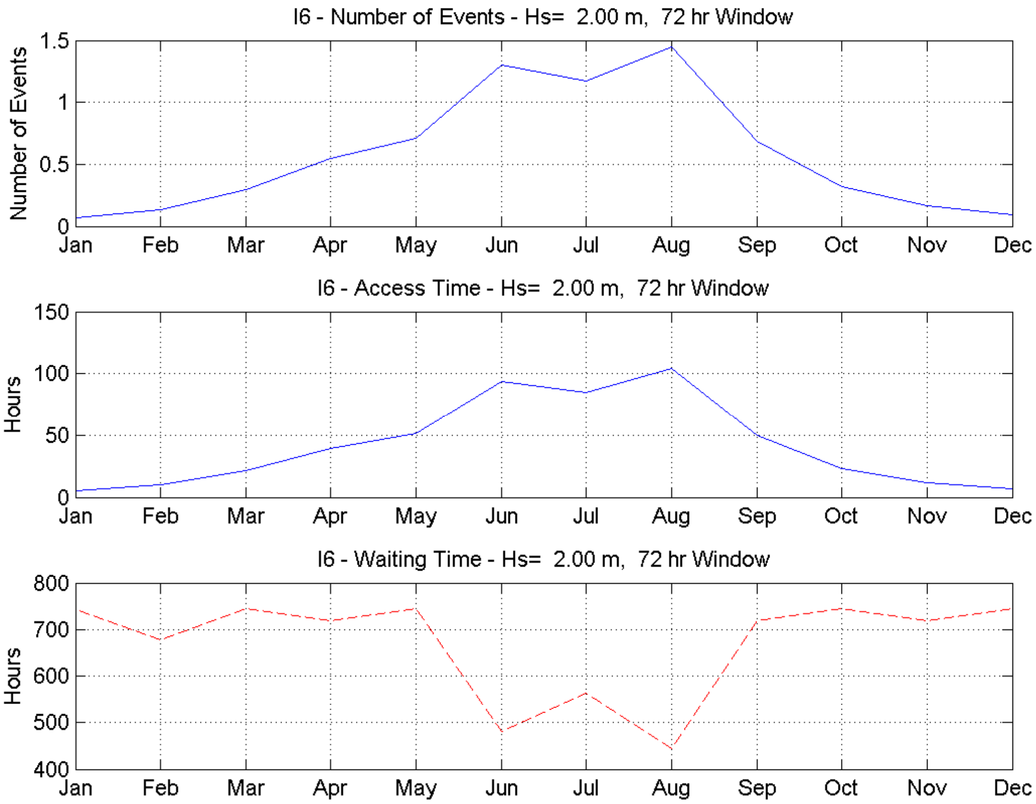

I6 - Number of Events - Hs= 1.00 m, 24 hr Window
Number of Events
I6 - Access Time - Hs= 1.00 m, 24 hr Window
Hours
I6 - Waiting Time - Hs= 1.00 m, 24 hr Window
Hours
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

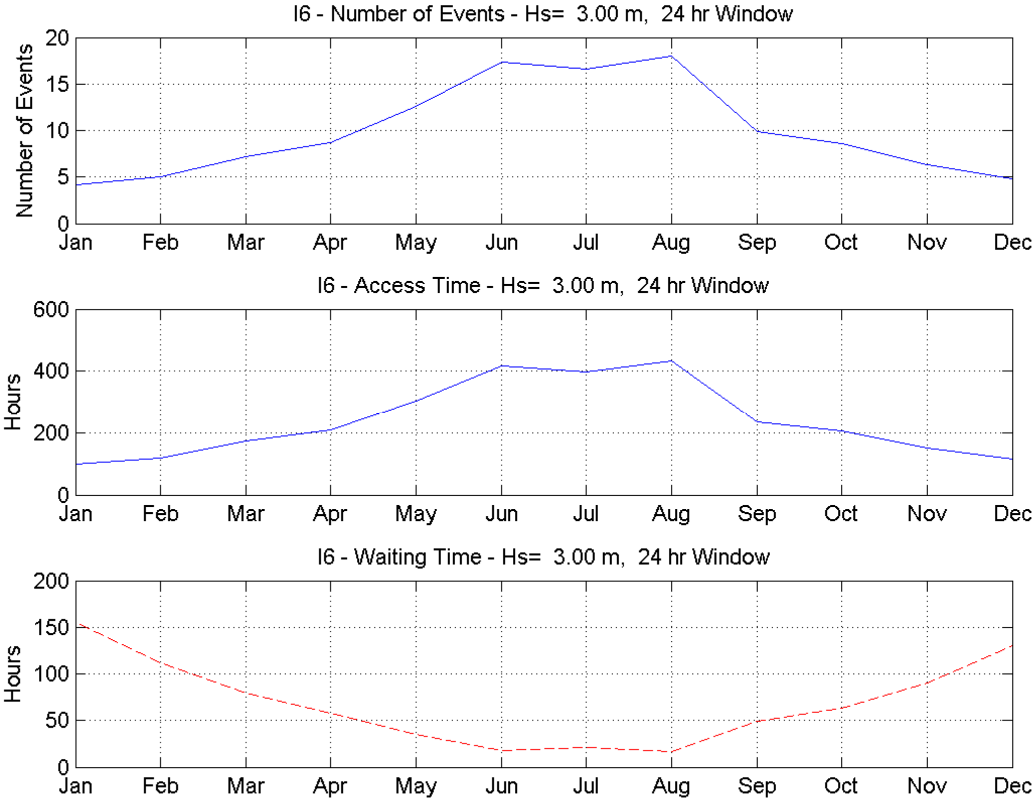

I6 - Number of Events - Hs= 1.00 m, 48 hr Window
Number of Events
I6 - Access Time - Hs= 1.00 m, 48 hr Window
Hours
I6 - Waiting Time - Hs= 1.00 m, 48 hr Window
Hours
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

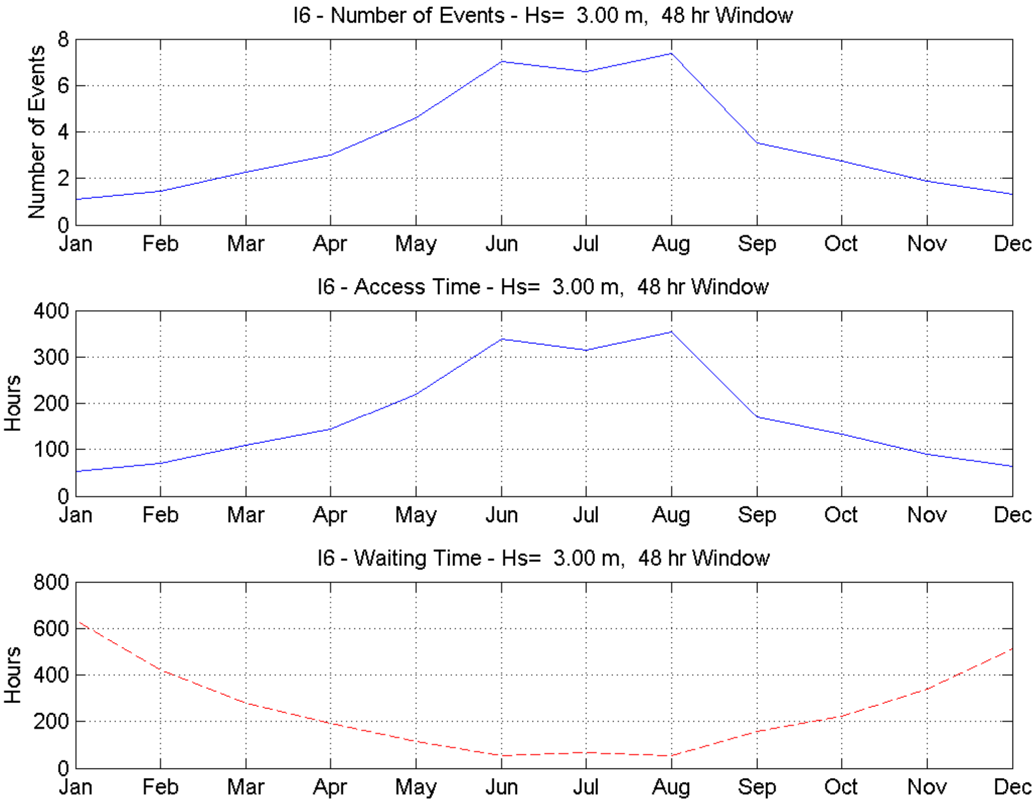

I6 - Number of Events - Hs= 1.00 m, 72 hr Window
Number of Events
0.08
0.06
0.04
0.02
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I6 - Access Time - Hs= 1.00 m, 72 hr Window
Hours
6
4
2
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I6 - Waiting Time - Hs= 1.00 m, 72 hr Window
Hours
750
700
650
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

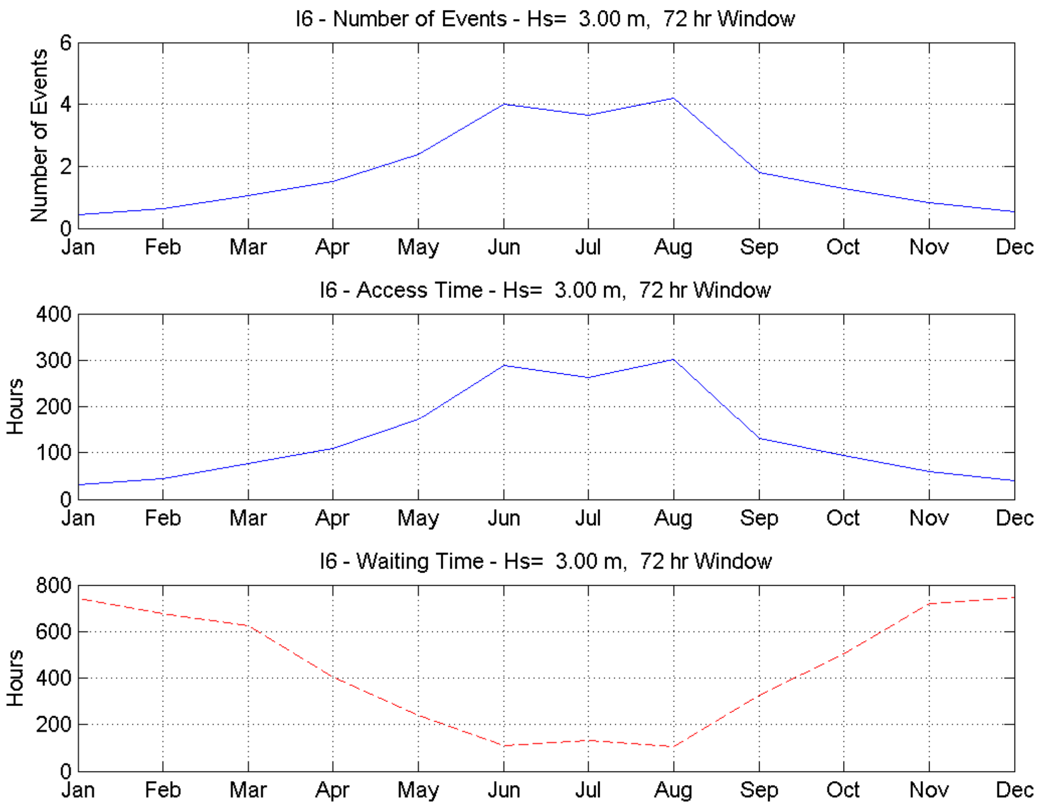

I6 - Number of Events - Hs= 2.00 m, 24 hr Window
Number of Events
0
5
10
I6 - Access Time - Hs= 2.00 m, 24 hr Window
Hours
0
100
200
300
I6 - Waiting Time - Hs= 2.00 m, 24 hr Window
Hours
0
200
400
600
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I6 - Number of Events - Hs= 2.00 m, 48 hr Window
Number of Events
0
1
2
3
4
I6 - Access Time - Hs= 2.00 m, 48 hr Window
Hours
0
50
100
150
I6 - Waiting Time - Hs= 2.00 m, 48 hr Window
Hours
0
200
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I6 - Number of Events - Hs= 2.00 m, 72 hr Window
Number of Events
1.5
1
0.5
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I6 - Access Time - Hs= 2.00 m, 72 hr Window
Hours
150
100
50
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I6 - Waiting Time - Hs= 2.00 m, 72 hr Window
Hours
800
700
600
500
400
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I6 - Number of Events - Hs= 3.00 m, 24 hr Window
Number of Events
0 5 10 15 20
I6 - Access Time - Hs= 3.00 m, 24 hr Window
Hours
0 200 400 600
I6 - Waiting Time - Hs= 3.00 m, 24 hr Window
Hours
0 50 100 150 200
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I6 - Number of Events - Hs= 3.00 m, 48 hr Window
Number of Events
0 2 4 6 8
I6 - Access Time - Hs= 3.00 m, 48 hr Window
Hours
0 100 200 300 400
I6 - Waiting Time - Hs= 3.00 m, 48 hr Window
Hours
0 200 400 600 800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I6 - Number of Events - Hs= 3.00 m, 72 hr Window
Number of Events
0
2
4
6
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
I6 - Access Time - Hs= 3.00 m, 72 hr Window
Hours
0
100
200
300
400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
I6 - Waiting Time - Hs= 3.00 m, 72 hr Window
Hours
0
200
400
600
800
Jan
Feb
Mar
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May
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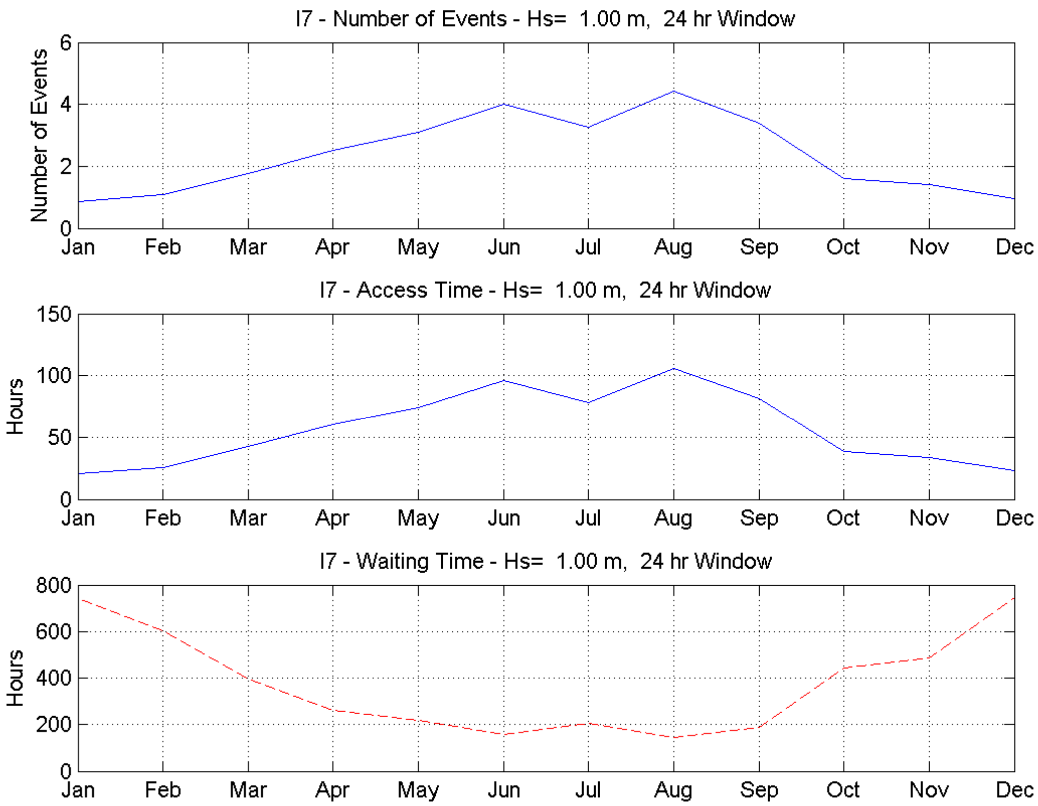
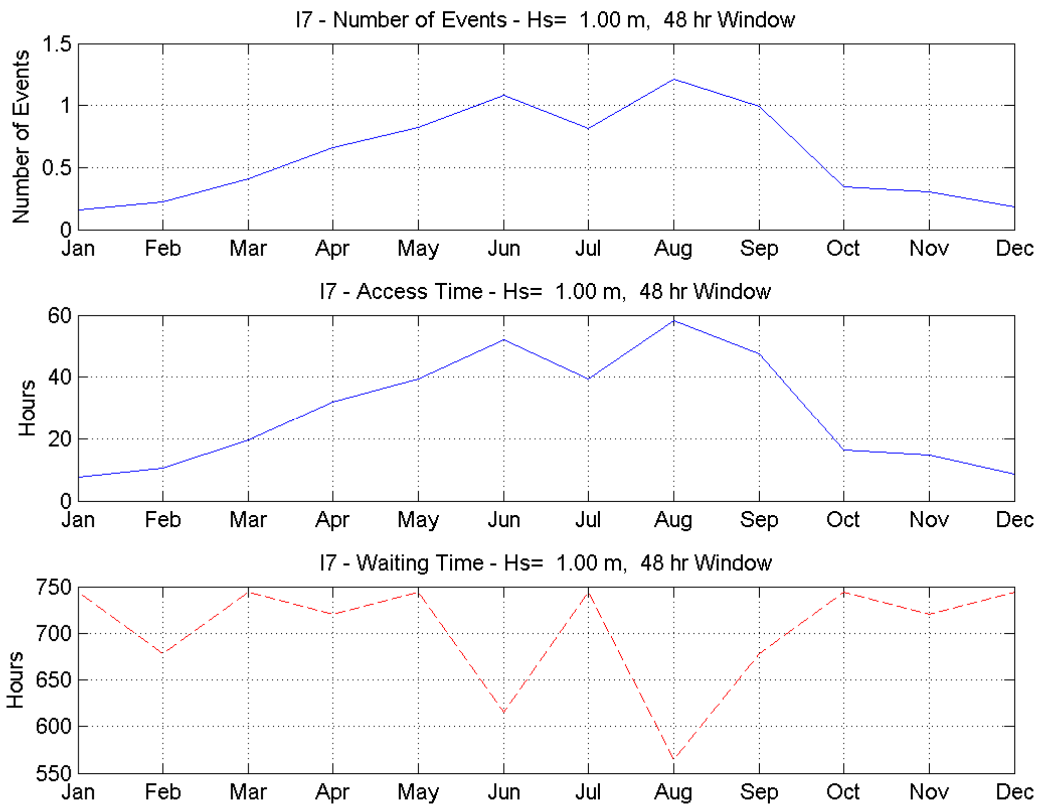
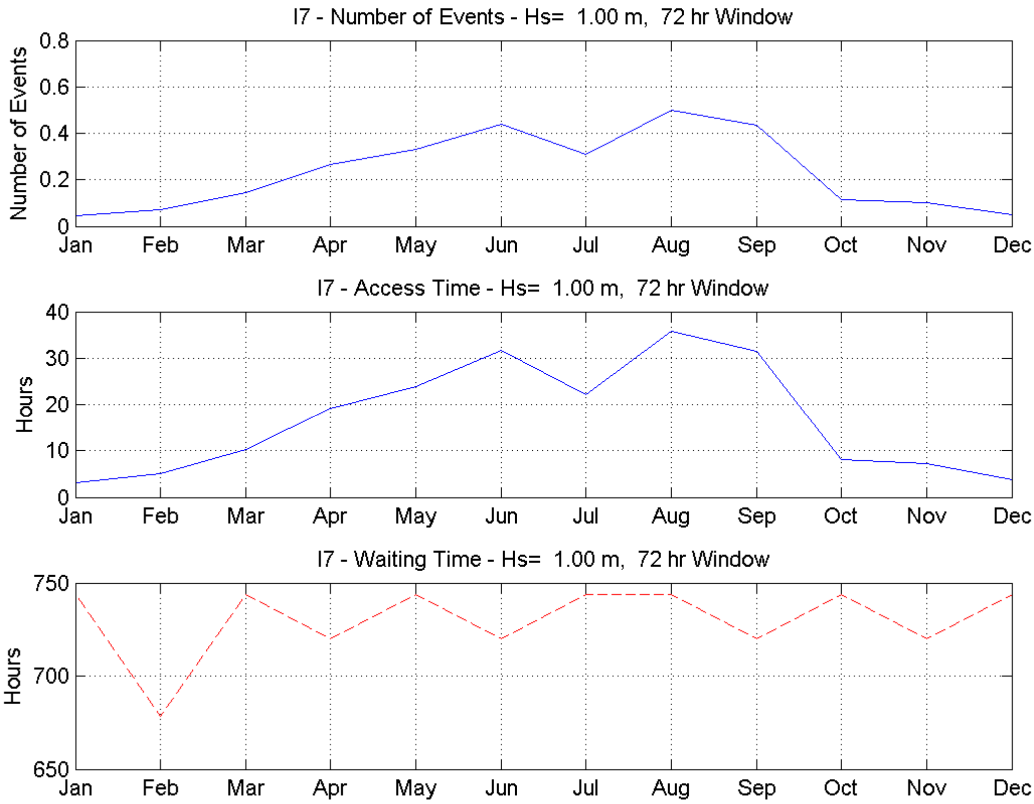
Sep
Oct
Nov
Dec


I7 - Number of Events - Hs= 1.00 m, 24 hr Window
Number of Events
0
2
4
6
I7 - Access Time - Hs= 1.00 m, 24 hr Window
Hours
0
50
100
150
I7 - Waiting Time - Hs= 1.00 m, 24 hr Window
Hours
0
200
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I7 - Number of Events - Hs= 1.00 m, 48 hr Window
Number of Events
0
0.5
1
1.5
I7 - Access Time - Hs= 1.00 m, 48 hr Window
Hours
0
20
40
60
I7 - Waiting Time - Hs= 1.00 m, 48 hr Window
Hours
550
600
650
700
750
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I7 - Number of Events - Hs= 1.00 m, 72 hr Window
Number of Events
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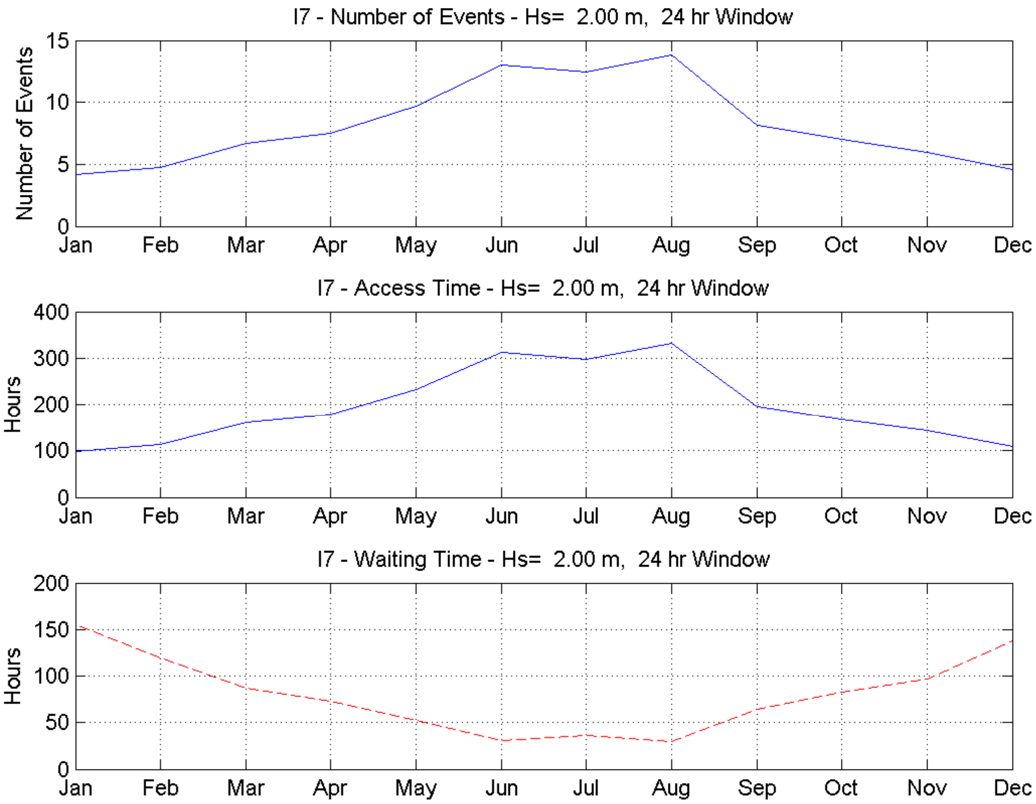
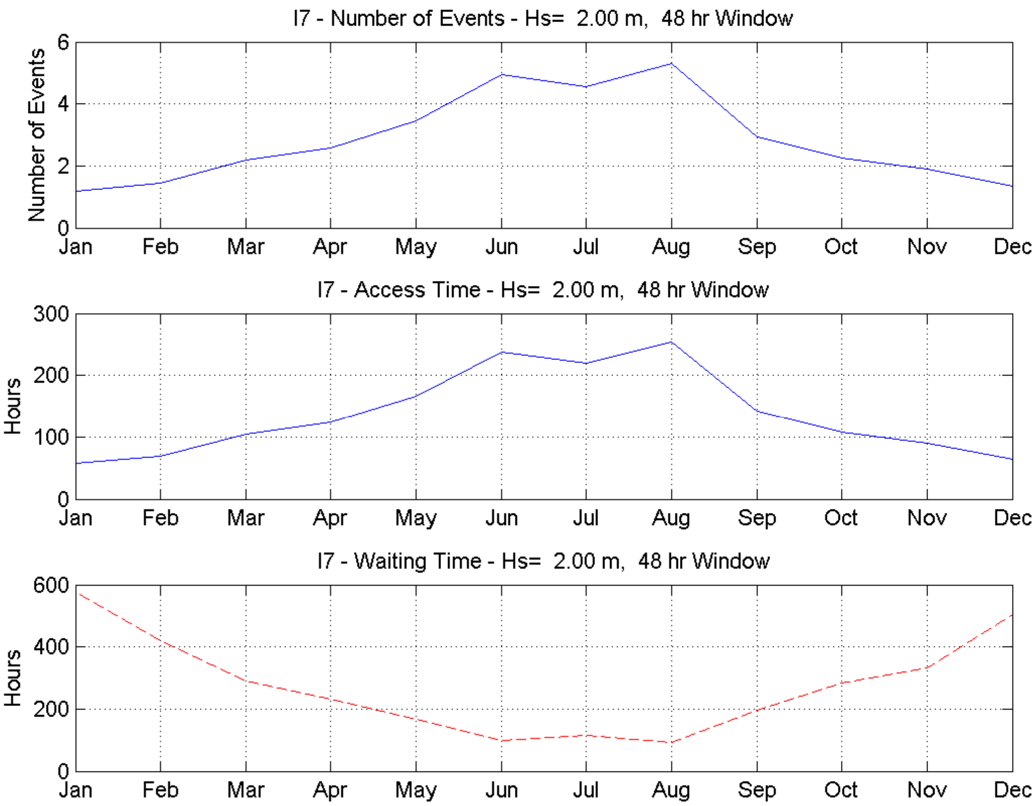
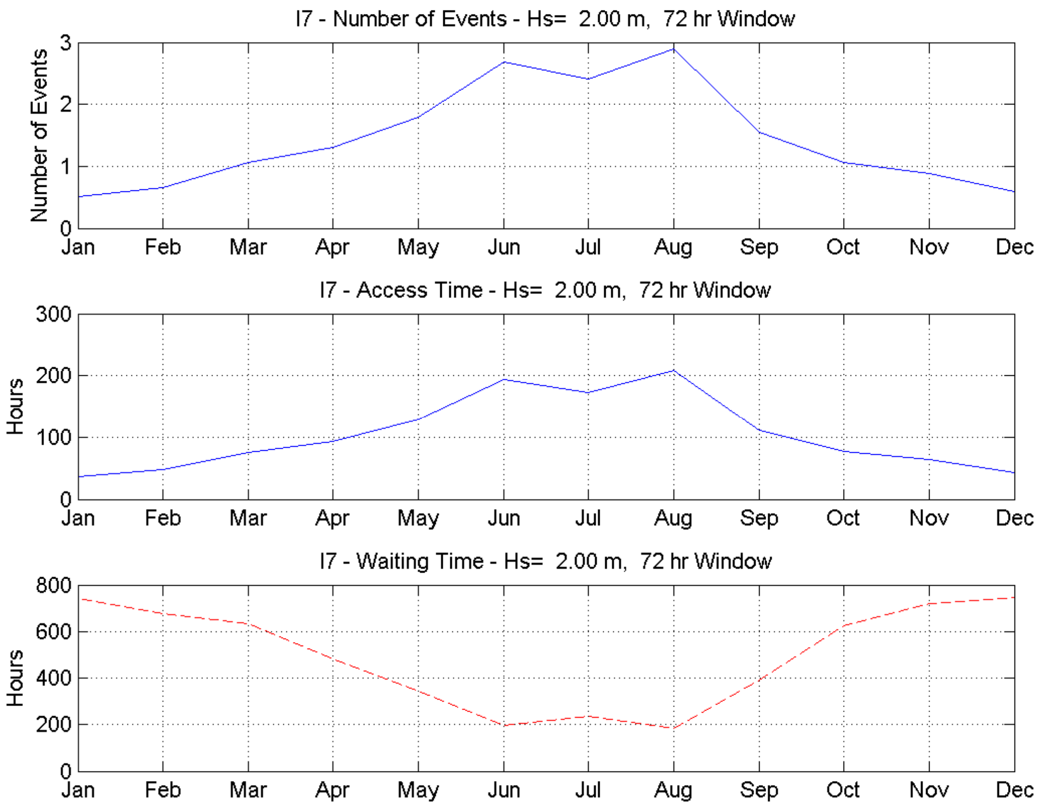
0.6
0.4
0.2
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I7 - Access Time - Hs= 1.00 m, 72 hr Window
Hours
40
30
20
10
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I7 - Waiting Time - Hs= 1.00 m, 72 hr Window
Hours
750
700
650
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I7 - Number of Events - Hs= 2.00 m, 24 hr Window
Number of Events
I7 - Access Time - Hs= 2.00 m, 24 hr Window
Hours
I7 - Waiting Time - Hs= 2.00 m, 24 hr Window
Hours
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I7 - Number of Events - Hs= 2.00 m, 48 hr Window
Number of Events
I7 - Access Time - Hs= 2.00 m, 48 hr Window
Hours
I7 - Waiting Time - Hs= 2.00 m, 48 hr Window
Hours
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I7 - Number of Events - Hs= 2.00 m, 72 hr Window
Number of Events
0
1
2
3
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I7 - Access Time - Hs= 2.00 m, 72 hr Window
Hours
0
100
200
300
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I7 - Waiting Time - Hs= 2.00 m, 72 hr Window
Hours
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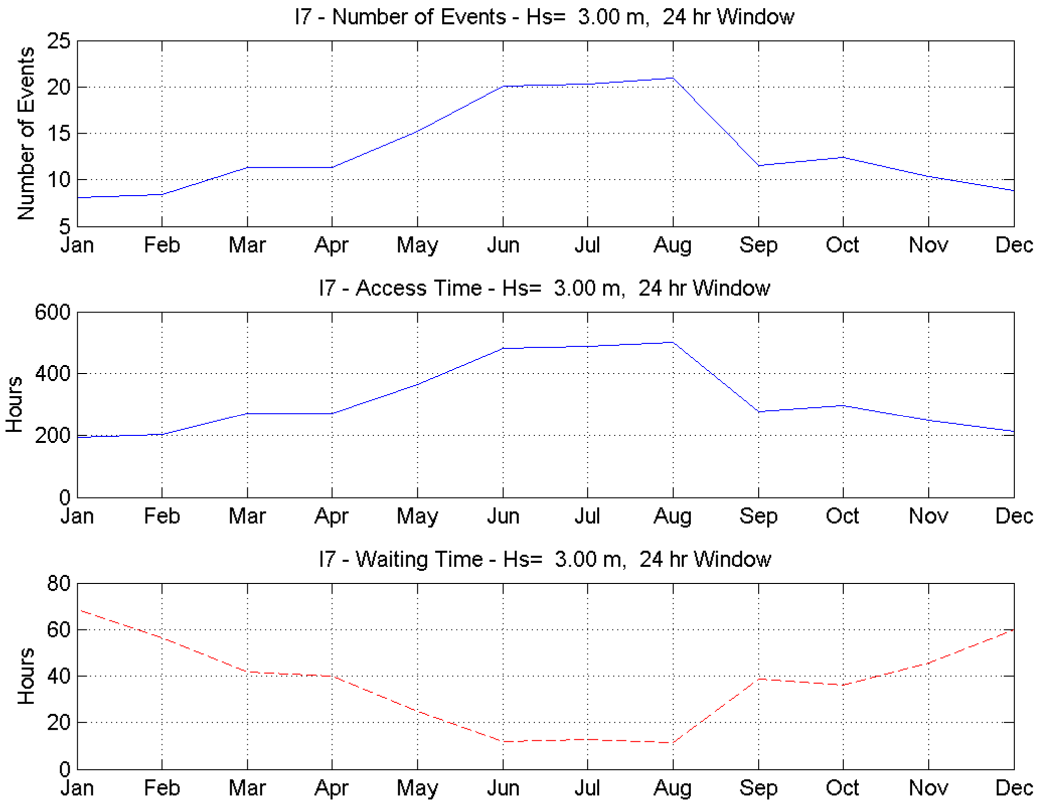
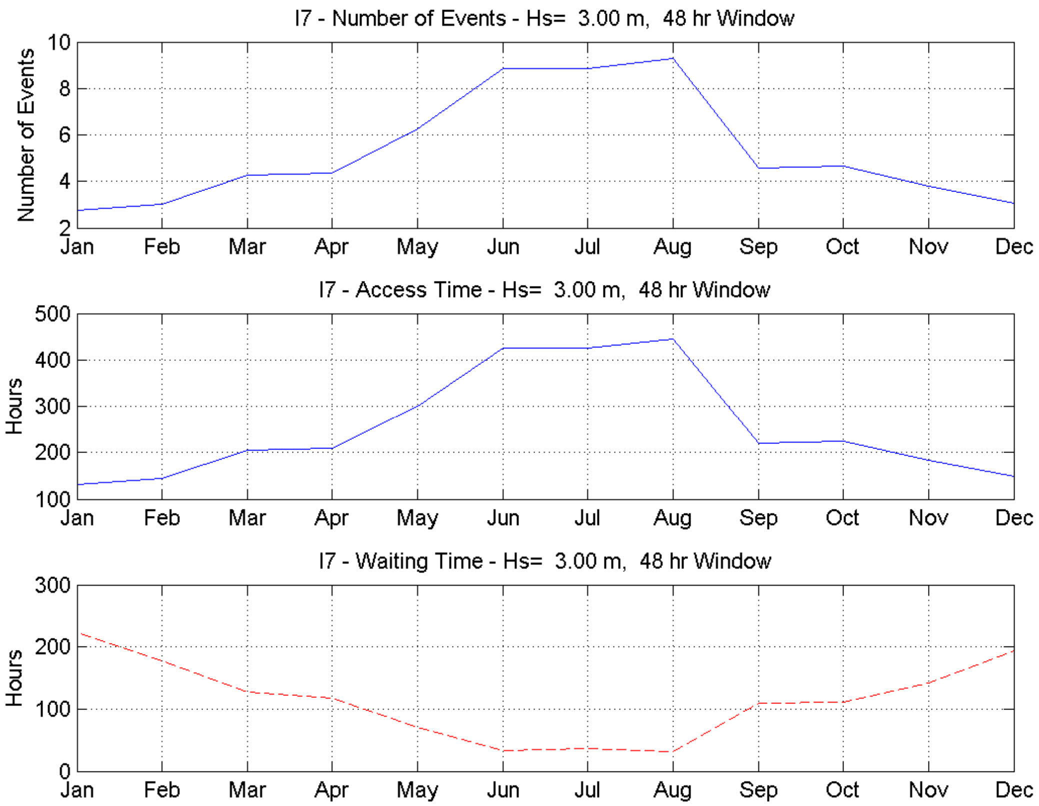
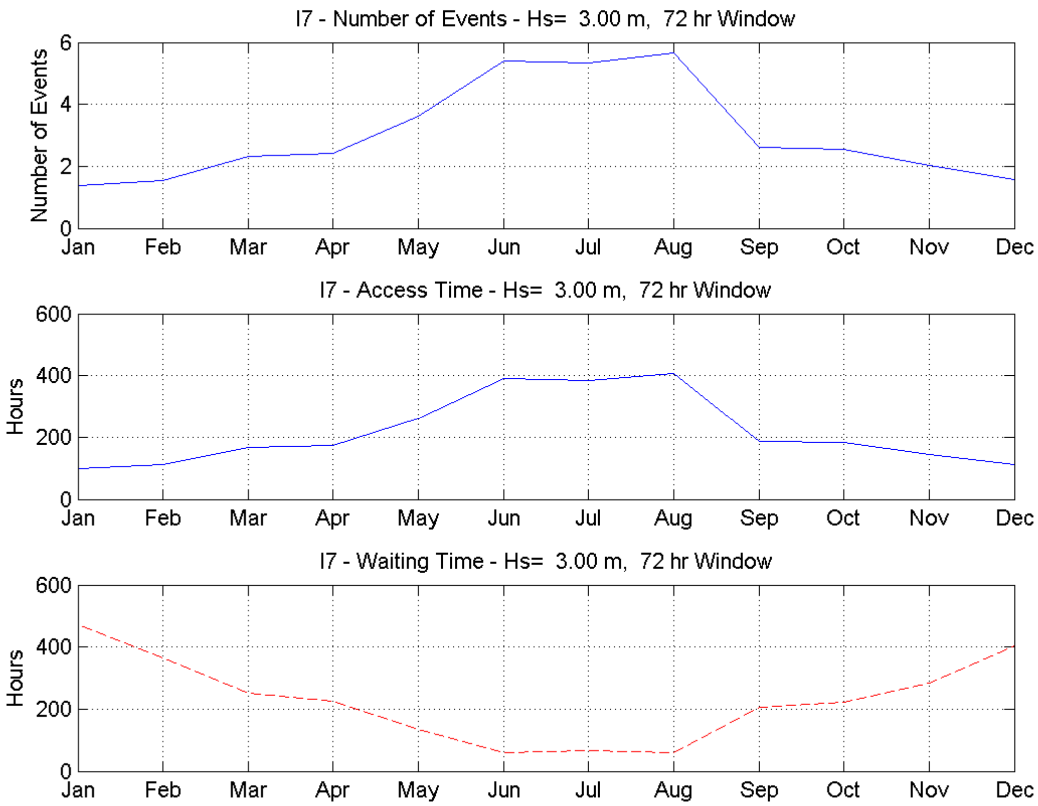
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I7 - Number of Events - Hs= 3.00 m, 24 hr Window
Number of Events
25
20
15
10
5
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I7 - Access Time - Hs= 3.00 m, 24 hr Window
Hours
600
400
200
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I7 - Waiting Time - Hs= 3.00 m, 24 hr Window
Hours
80
60
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I7 - Number of Events - Hs= 3.00 m, 48 hr Window
Number of Events
10
8
6
4
2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I7 - Access Time - Hs= 3.00 m, 48 hr Window
Hours
500
400
300
200
100
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
I7 - Waiting Time - Hs= 3.00 m, 48 hr Window
Hours
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


I7 - Number of Events - Hs= 3.00 m, 72 hr Window
Number of Events
0
2
4
6
Jan
Feb
Mar
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May
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Jul
Aug
Sep
Oct
Nov
Dec
I7 - Access Time - Hs= 3.00 m, 72 hr Window
Hours
0
200
400
600
I7 - Waiting Time - Hs= 3.00 m, 72 hr Window
Hours