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# Introduction

The new SHARC Buoy system aims to provide an IOT solution to remote sensing in Antarctica. The goal of the project is to develop in house, expandable, affordable technology that can be expended into a large-scale network for true coverage of the Southern Ocean. While the project is novel in nature, the state of autonomous sensing has been developing since 2010 with more systems being deployed around the year. While these systems are different in nature, they provide insight into the techniques used in Polar engineering as well as in sight into existing infrastructure and how it is being utilized. In addition, each buoy has a unique purpose and is defined in terms of its objectives, sensors, measurands and processes. This document aims to explore the current state of the art by turning to both institutional and private sector solutions currently being employed and how they overcome the challenges created by the Harsh Southern Ocean Environment

# Methodology

For this report data on 8 Autonomous Platforms was collected and sorted into 3 main categories

1. Power Supply and Management
2. System Hardware Overview
3. Remote Communication
4. Wave Data Strategy

The platform is evaluated against the following criteria. Where possible, certain specifications have been converted into standardized formats. The original data can be found in the publications list found at the end of this document. To ensure a fair evaluation, data was collected from the latest technical publication of each platform where possible. These publications may not contain all relevant data. In this case, the data has been left out or interpolated from another source.

# Structure of this Report

The report is divided into sections based on the categories used to evaluate the system. Each section contains a brief discussion highlighting any significant feature/ commonality amongst the systems. The comparison is provided in a Table form with references available at the end of the report. The order of these sections is as follows:

1. Remote Communication – This chapter explores the infrastructure used to communicate data. Most systems require wireless communication strategies due to their free-floating nature. The discussion will include: Network used, Hardware/Modem, Packet Size and structure, network bandwidth and cost
2. Power Supply Management – This chapter will briefly explore the power source used by each system, Auxiliary power sources and power management strategies
3. System Hardware Overview – This Chapter will explore the overall system. Each buoy will be quantified in terms of Sensors, Sensor types and measurands. In addition, the processors will be listed with their purpose. Finally, an overall data cost (where given) will be provided
4. Wave Data Strategy – This Chapter will identify systems used for wave data measurements in the Polar Region. In this chapter, the measurands are given along with the Sensors used for detection of these variables. A sampling strategy is provided as well as the processing strategy

# Device List

The Table Below shows a list of devices selected for comparison. The list is made up of 8 platforms each designed by a Company/ Institution. The Key collaborators as well as the name of the institution are provided. Where a Buoy name is not given, the device will be named after the key Contributor to the project. These systems have been selected due to their prevalence in global polar/ oceanographic science as well as notability in publications. The devices are as follows:

|  |  |  |
| --- | --- | --- |
| **Device Name** | **Developed By** | **Institution** |
| Waves in Ice (WII) buoy | Jean Rabault | University of Oslo |
| Waves in Ice Observ System (WIIOS) | Alison Kohout | National Institute of Water and Atmospheric Research |
| DOBLE Buoy | Martin Doble | Polar Scientific Ltd, Appin, UK |
| Surface Kinematic Buoy (SKIB) | Pedro Veras Guimarães1 | Université de Bretagne Occidentale |
| SWIFT Buoy | Jim Thomspon | University of Washington |
| Seasonal Ice Mass Balance Buoy (SIMB) | Donald K. Perovich | Dartmouth College |
| UptempO | MetOcean | MetOcean |
| Trident | Trident Sensors | Trident Sensors |

# Remote Communication

All systems that have been deployed in both the Arctic and Antarctic Marginal Ice Zones use Iridium for remote Telemetry Data. Other systems such as Zigbee are alluded to however these systems are only used when device is close by. Notably, The SIMB buoy details consideration for Remote communication using the ARGOS satellite network however, the unreliability of the network resulted in irregular timestamped data. Iridium is a Satellite Network with global coverage and a variety of modems for various IOT uses. The company offers 4 main data services which put constraints on Data transmission rates, bandwidth and modem selection. This is shown in the table below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Service Name | Purpose | Bandwidth | Modems | Payment Plan |
| Short Burst Data (SBD) | Sending Short Messages in bursts | * 340 bytes (upload)/270 bytes (download) * 1960 bytes (upload)/1890 bytes (download) | 9602/9603  Iridium Edge  9522A  9523B | Billing per quantity of data |
| Router-based Unrestricted Digital Interworking Connectivity Solution (RUDICS) | Transfering large Real Time Data from a large array of devices to a host | * 6 – 10 Kbytes/min | 9522A/B  9523 | Billing per duration of transmission |
| Circuit Switch Data (CSD) | Transmitting Large volumes of Data over Dial Up Network using a SIM Card | * 6 – 10 Kbytes/min | 9522A/B  9523 | Billing per duration of transmission |
| Pilot | For mission-critical communication requirements | * 134 KBPS | Iridium Pilot Kit | Billing per duration of transmission |

Table 1: List of data services provided by Iridium, their function, bandwidth as well as supporting devices

These options allow for various data transmission strategies amongst the platforms. In addition, the various processing strategies from each platform have taken into account the aforementioned data serviced and have processed their data packets according to the capabilities of their modem and data service providers. Short Burst Messages may be ideal for this project however, Complex processing strategies are required. Modems with large buffers may increase the overall project cost significantly and consume more power. The modem, Network and data management strategy of each system is shown in the table below:

|  |  |  |  |
| --- | --- | --- | --- |
| **Device Name** | **Communication Technology** | **Modem** | **Bandwidth (bytes)** |
| WII Buoy | Iridium | \*Information unavailable | 340 |
| WIIOS | Iridium | 9602 | 340 |
| Doble | Iridium | Motorola 9522B | 6 - 10 Kbytes/min |
| SKIB | Iridium/Zigbee | 9602 (IR), Xbee Pro | 340 bytes |
| SWIFT | Iridium /Ethernet | Geoforce SmartOne (Tracking)/ SBD Modem (Telemetry), Digi XPress Ethernet Bridge | 1960 |
| SIMB Buoy | Argos/ Iridium | 9603 | 340 |
| Uptempo | Iridium | 9602 | 340 |
| Trident | Iridium | 9603 | 340 |

Table 2: List of divices and the network/s used for remote communication with the user as well as the hardware modem and maximum bandwidth associated

The Transmission information including packet sizes and data rates are shown in the table below

|  |  |  |
| --- | --- | --- |
| **Device Name** | **Transmission Strategy** | **Packet Size (bytes)/rate** |
| WII Buoy | Short Burst Data Message | 340 |
| WIIOS | Short Burst Data Message | (N/A) |
| Doble | RUDICS transmission every minute | 54Kb/hour |
| SKIB | Short Burst Data Message | N/A |
| SWIFT | Short Burst Data Message | 4 - 1228 |
| SIMB Buoy | Short Burst Data Message | 275 |
| Uptempo | Short Burst Data Message | \*User Configured |
| Trident | Short Burst Data Message | 16 |

Table 3: Table Showing the Transmission strategy of each system as well as the date sizes transmitted during regular intervals. Note: Some systems such as the SWIFT buoy have variable sized packets depending on the sensor being sampled

Unanimously, all devices use the Iridium Satellite Network for remote communication with the most common system being the Iridium 9602/3 SBD modem. This choice is justified for its small form factor, low power and easy interfacing however it suffers greatly from limited bandwidth having a maximum transmission size of 340 bytes. Systems that use these modems for transmission of wave data rely on complex data processing algorithms and therefore do not transmit the raw Time Series. The only notable exception to this is the Wave Buoy Developed by M. Doble et. al. which continuously transmitted AHRS and IMU Time Series data once every minute. For this purpose, they used the 9522B modem which allowed for continuous transmission using the RUDICS data service. This modem, along with the SBD modem used for the SWIFT Buoy also has a much larger SBD data buffer (1.92KB) However this comes at the cost of a much higher power consumption and significant price increase.

# System Overview

This section provides an overview of each system. Power systems and sources are given as well as component choices. In addition, the data storage strategies, measurands and deployment locations of the system are provided.

## Power Systems

The power system for each buoy is shown in the table below

|  |  |  |
| --- | --- | --- |
| **Device Name** | **Power Source** | **Voltage** |
| **WII Buoy** | LiFePo4 Solar Recharging +Step up converter | 5V |
| **WIIOS** | Panasonic LR20 Alkaline 1.5 V in Series | 12V |
| **Doble Buoy** | Alkaline Battery Array D-Cells, Lead Acid Battery E-Cell Array + Solar Panel Chagrin | 12V |
| **SKIB** | LiSOCL2 Batteries | 3.6V (from batteries) |
| **SWIFT** | Lithium/ Alkaline Battery Array | 14V |
| **SIMB** | Custom 60 Cell Alkaline D-cell Battery Pack, LMZ12003 Step Down Converter for 3.3V & 5V, MIC29201-12W LDO for 12V power | 18V |
| **UpTempo** | LiSOCL2 Batteries | 12V |
| **Trident** | 4 x Alkaline AA Batteries | 3.3V |

Table 4: Comparison of Power systems for each buoy and the nominal supply voltage of each system

As shown in the table above, all systems use batteries as a source of power. Most systems opt for off-the-shelf Alkaline or Lithium based batteries except for the Buoy by M. Doble et. al. which uses a Lead Acid battery. Systems deployed in the Arctic Marginal Ice Zone have been designed with a recharging system such as a solar Panel in the case of WII Buoy and Doble Buoy however, most long range deployment buoys have opted for non-rechargeable systems composed of Lithium Thionyl Chloride (LISOCL2) or Alkaline batteries that have allowed for survivability up to 6 years. In the case of the high-power buoys (SIMB, WIIOS, DOBLE, UPTEMPO) a battery of 3.3-3.7V cells are connected to provide a nominal voltage in series with a regulator to provide a stable output. The strategy for each system is to pack as many batteries in as possible to satisfy the long-term energy requirements. No power optimization calculations or methodologies are provided

## Electronic Selection

Component selection for each system is based off the original mission for each buoy. These objectives are shown in the table below along with significant deployment locations:

|  |  |  |
| --- | --- | --- |
| **Device Name** | **Measurands** | **Deployment Location** |
| **WII Buoy** | Ice Drift, Waves in Ice, Temperature, Pressure | Marginal Ice Zone, Northeast Barents Sea, Antarctica |
| **WIIOS** | Wave Energy Attenuation, Significant Wave Height, Data Quality | East Antarctic Packed Sea Ice Zone |
| **Doble Buoy** | Ice Drift, Wave induced ice breaking, Temperature, Pressure | Beaufort Sea, Arctic |
| **SKIB** | Ice Drift, Surface Waves | North Atlantic Ocean, France |
| **SWIFT** | Surface Images, Waves, Turbulence Profiles, Current Profiles, Conductivity, wind sensor | Antarctic Marginal Ice Zone, Arctic Marginal Ice Zone |
| **SIMB** | Surface and bottom ice position and snow depth, air pressure and temperature, vertical temperature profile, and GPS location data | Hanover New Hampshire (prototype), Beafuort Sea MIZ (Deployment) |
| **UpTempo** | Sea Ice Drift, Environmental Monitoring | Antarctic Marginal Ice Zone, Arctic Marginal Ice Zone |
| **Trident** | Sea Ice Drift, Battery Voltage, Ambient Temperature | Antarctic Marginal Ice Zone, Arctic Marginal Ice Zone |

Table 5: Each Device is designed to collect data on specific variables. This table outlines the measurands of each system as well as the region these systems have been designed for/deployed in.

The table above shows that most wave buoys have been built for and deployed in the Arctic Marginal Ice Zone i.e. The Beaufort Sea. Technology developed for the Antarctic Ocean typically revolves around Ice drift and environmental Sensing. WII Buoy and WIIOS buoy have been developed as open source, low cost solutions for Wave in Ice measurements, however, lack the robustness of Arctic-focused systems. SWIFT Buoy and SKIB buoy provide advanced solutions to wave surface monitoring however these systems are not intended for long term use

Systems designed specifically for drift will have scaled-down processors, cheaper IMUs with more accurate, more expensive Temperature Sensors and GPSs where systems designed specifically for wave measurements have more powerful, sometimes multiple, processors and advanced IMUs with cheaper tracking and Environmental sensing technology. The components for each system are shown in the table below:

|  |  |  |  |
| --- | --- | --- | --- |
| **Device Name** | **Sensors** | **Storage stratergy** | **Onboard Processing** |
| WII Buoy | GPS, Temp, Pressure, IMU | SD Card | 32-bit Extended Kalman Filter, Low Power Unit, Arduino (Data Logging), Raspberry Pi (Data Compression + Measurement) |
| WIIOS | GPS (MTK3339), Accelerometer, IMU, DS18B20 Temp Sensor | 32 GB SD Card | Dual Core Edison Processor (Wave processing), Atmega328 (Power Controller) |
| Doble Buoy | AHRS sensor, GPS, Barometric Pressure MXP-5100-APAHRS, CPU Load Cycle sensor, Battery Voltage, Internal Temperature, Humidty | None | ACME Systems Fox G20 for Power and control |
| SKIB | GPS (MTK3339), Accelerometer LIS3DK | SD Card | EFM32-M3 : Spectral Proccessing + Controller |
| SWIFT | uCam, Inerital Navigation System (SBG Elipse N), Dippler Profiler (Nortek Signature 1000), Conductivity & Temp Sensor (Aanderaa 4319), Airmar WX200 | SD Card | Sutron Expert for Data processing |
| SIMB | Acoustic Rage Finder for Snow (Maxbrook MB7374)and Underwater (Airmax Echo Ranger), Air Temp Sensor (DS18B20),Temperature Chain Sensor (Bruncin DTC), GPS (MTK3339), Barometer (BME280) | SD Card | ATSAMD21G18 for Data Processing and system control |
| UpTempo | GPS (Navman Jupiter 32), Barometer (Vaisala PTB100) Air Temperature (YSI 44032) | N/A | MetOcean’s Global Platform Transceiver Controller (GPTII) TM |
| Trident | GPS, Temperature Sensor, Battery Monitor (ADC) | 128KB Flash Chips | Microprocessor + Intelligent Smart Unit |

Table 6: Overview of subsystems and component used for each buoy including sensor type and hardware, processor and data management Stratergy

From the table above, we see the methodology for each buoy come into action. The Doble buoy for instance builds its system around the dominant sensor i.e. the AHRS IMU with a single processor controlling all the peripherals as well as allowing for data processing. Drift Loggers such as Trident, and UpTempO feature sparser sets of electronics with smaller, lower powered processors for Power control and peripheral control In contrast, WIOS and WII Buoy compartmentalise subsystems with a cluster of processors handling different aspects from the buoy. This shows a focus on computation rather than sensing as multiple controllers are used to allow the main processor to implement advanced Digital Signal processing. SWIFT Buoy appears as the outlier as the system is built around a dedicated data logger i.e. The Sutron Xpert with integrated processor and Satellite communication link abstracting data processing strategies on the buoy side. Th SIMB buoy has the most advanced and largest number of sensors of all the buoys. A commonality amongst the buoys is the use of off the shelf components and processors. A predominant feature, the GPS is an Adafruit MTK339 device that is low cost as well as SAMD Chips, Raspberry Pis and Arduino boards whereas for Trident and MetOCean, more expensive solutions are used. This shows that developers have opted for readymade that components that are auxiliary to the main measurements. This should explain why some components on a system are more advanced than others.

## Motion Detection Strategy

As Mentioned previously, most systems focus on measuring Sea States and ocean processes. Common measurements of interests are Significant Wave Height and Dominant Wave Frequency. In addition, Wave data can be analysed in terms of its power spectral density. the basis for Wave Data analysis from Ocean buoys comes from A method developed by A. J. Kuik et al where the pitch and roll of an ocean buoy is measured. By using an Accelerometer, Gyroscope or any Inertial measurement system to measure these parameters, it is possible to reconstruct the sea state given a set of data provided the data is of a specific length sampled above the Nyquist frequency of dominant ocean swells.

Another Method was developed by M.D. Earle in 1996 for Non-Directional Wave Analysis. In this method, a digital time series representation of the Vertical Acceleration along with 2 orthogonal Gyroscope measurements and Magnetometer readings relative to the earth’s magnetic field is obtained. The data is analysed in terms of Spectra and cospectra. Data is segmented into a set of N-bins and averaged to produce a statistical result. This approach brings into account the possibility of spectral leakage however, this can be greatly minimised by sampling above the Nyquist frequency of the upper Wave frequency band (generally taken to be 0.5Hz) for a minimum of 1000 seconds (about 16 – 17 minutes)

It is for this reason that almost all Wave measurement buoys contain some Inertial Measurement System (IMS) coupled with a data processing strategy. The first part involves the component selection. Each system has a unique methodology that begins with its choice of IMS as shown in the table below:

|  |  |  |  |
| --- | --- | --- | --- |
| **Device Name** | **# of IMUs** | **Measurand** | **Device** |
| WII Buoy | 1 | Vertical Acceleration, Pitch, Roll | VN100 |
| WIIOS | 2 | 3 Axes acceleration. 3 Axes Gyro, 3 Axes Magnetometer | Kistler 8330B3 ServoK-Beam, TDK Ivensense IMU MPU-9250 |
| DOBLE | 2 | Heave, Roll, Tilt, 3 axes Acceleration | SBG IG-500 |
| SKIB | 1 | 3 axes Acceleration | STM32 LIS3DH |
| SWIFT | 1 | Heave, GPS | SBG Elipse (Inertial Measurement System) |
| SIMB | 1 | Device Tilt and Orientation | Bosch BNO055 |

Table 7: Comparison of Inertial Measurement Systems (IMS) employed by various devices. The list includes systems that have explicitly included an IMS. Systems such as Trident Buoy and MetOcean have been omitted

As mentioned previously, systems such as WIIOS and WII Buoy have built their purpose around wave measurements and therefore have specified High Powered, High Accuracy IMUs for wave measurements. However, WIIOS buoy separates itself from WII Buoy by having a cheaper complimentary 9 d0f IMU to compliment the measurements. SWIFT Buoy and the DOBLE buoy use an integrated system known as an Inertial Navigation System. This device contains a GPS and an Onboard processor for RTK fusion and Kalman filtering whereas other devices use an external processor for filtering. The SIMB Buoy is the only buoy on the list that has an IMU for non-wave related measurements. It uses a cheaper Bosch BNO055 which is used solely for measuring the orientation of the device.

Ocean State Sampling must be performed with careful consideration of the sample frequency and sample window. For remote systems it is important to optimize performance and data acquisition with Power Consumption and Storage constraints. It is also important to include only the important parameters in the data set depending on the measurand of interest. For this reason, sea state measurements systems have different sample parameters that are shown in the table below

|  |  |  |  |
| --- | --- | --- | --- |
| **Device Name** | **Number of Axes** | **Sample Frequency (Hz)** | **Sample Period (minutes)** |
| WII Buoy | 6 | 10 | 25 |
| WIIOS | 9 | 64 | 11 |
| DOBLE | 6 | 1 | Continuous |
| SKIB | 3 | 25 | 10 |
| SWIFT | 2 | 5 | 9 |
| SIMB | 9 | N/A | N/A |

Table 8: Comparison of Sampling stratergies utlilised by each system showing the number of axes sampled during an active window, the sample frequency as well as the sample period.

From the table, all systems chose a data sample frequency of at least 1Hz (2 x the Wave frequency upper band). However, most systems chose to sample for periods 10 minutes or less. A notable point from the table is that all the systems have a finite sample period except for the DOBLE. As mentioned previously, the data strategy for this system is to transmit the Raw sample points over Iridium network once every minute. The system is continuously sampling until it loses contact or runs out of power. Another exception is the SIMB buoy which only samples to determine the orientation of the frame. Insufficient information is provided in the literature regarding the sampling strategy. Of the Ocean Wave Measurement devices, the WII Buoy samples for the longest period followed by The Wiios Buoy. It should be noted that the WIIOS and WII Buoy are both designed specifically for waves in ice and should share similar sampling strategies. However, the WIIOS buoy has the highest sampling rate before processing whereas the WII Buoy has the longest sample window. SWIFT Buoy measures data in bursts of 9 mins every 12 mins for 5 hours. Each burst is recorded as a bin and coupled with other sensors. Finally, SKIB measures data at a frequency of 25 Hz for 10 minutes.

Finally, The Data processing strategy for each system is discussed below:

### WII Buoy

Raw Time series is passed through an Extended Kalman Filter running at 800Hz then a low pass filter. Wave Spectral data is calculated using the method by Earle et. al. (1996) where Co-Spectra is calculated using the Method by Kuik et al. (1988). Significant Wave Height is calculated through double integration. A Fast Fourier transform is applied to the data series to achieve this.

### WIIOS Buoy

Data is filtered using a Butterworth filter with a cut-off frequency of 2Hz. Significant wave height is calculated by double integration using a Fast Fourier Transform. Spectra is calculated using the method by Earle et. al. (1996)

### Doble Buoy

The double buoy is unique as it does not directly calculate wave parameters. However, the raw time series is filtered using an Extended Kalman Filter running at 10Hz

### SKIB

Data collected from a sample window is processed using a classical RC filter to attenuate frequencies below 0.04Hz. M.D. Earle et. al. (1996) Spectra and Co-Spectra Calculation is then applied.

### SWIFT

The Swift buoy is the only device that uses multiple sensors for sea state calculation. First, data is collected more frequently in short intervals (9 minute sample periods every 12 minutes) which include Doppler Profiles, Camera images and IMU data. The INS System outputs a Real-time kinematic (RTK) fusion data series where IMU data is passed through a Coning & Sculling Extended Kalman Filter running at 1KHz while doppler profiler is sampled at 8Hz. Turbulence profile is calculated through time-averaged data fitting of the doppler profiler. Current state is calculated using Stokes drift Equation over a time averaged velocity series. Finally, Wave information is calculated from an image of the sea state.

### SIMB buoy

No Clear Data processing strategy is available in the literature. This may be due to the non-critical nature of the IMU.

# Conclusion

In Conclusion, the motivating choices for each system are heavily influenced by measurement objectives of each System. This motivates the architecture, component choice and power rating for each device as well as the processing complexity. Systems that focus on wave variable measurements tend to have increased processing capabilities with more than one processor present in he system. In addition, specialised systems can easily be identified by their sensor components often opting for state of the art, high accuracy sensors that drive up the cost of the system exponentially. In addition, Most Wave measurement systems have opted for Earl et. Al. or Kuik et. al. as the foundation for their Spectrum and Co-Spectrum measurements which require an IMU with vertical acceleration and atleast 2 orthogonal vectors for accuracy. Finally, the reliance on iridium shows a fundamental lack of infrastructure. We require iridium as a reliable, global network if we wish to deploy SHARC Buoy. This network, however allows for high bandwidth transmission, but this comes at the cost of more expensive, higher powered modems which could drive up the cost of system significantly. Using a narrow bandwidth modem is more ideal however, more advanced processing techniques will be required. For SHARC Buoy to be a low-cost solution to the Polar Climate observation problem, we need to put these factors into consideration to develop our solution to be as robust as possible.

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