# 1. PROJECT MANAGEMENT

## 1.1. Title and Approval Page

**Quality Assurance Project Plan for**
**Salt Marsh Unmanned Aircraft System Surveys**
**Pursuant to Buzzards Bay NEP Workplan Task 12, EPA Cooperative Agreements**
**CE-00A00860-0 and CE-00A00887-0**


**Prepared by:**
Daniel G. MacDonald, Ph.D., P.E.
Prof. and Chair - Dept. of Civil & Environmental Eng.
Dept. of Estuarine and Ocean Sciences
University of Massachusetts Dartmouth
285 Old Westport Road
Dartmouth, MA 02747
Phone: 508-910-6334 Email: dmacdonald@umassd.edu


**Prepared for:**
EPA Region 1
5 Post Office Square - Suite 100
Boston, MA 02109-3912

**Project Manager (Grantee):**

____________________________ 04/06/2023

Daniel G. MacDonald, Ph.D., P.E. Date
Prof. and Chair - Dept. of Civil & Environmental Eng.
Dept. of Estuarine and Ocean Sciences
University of Massachusetts Dartmouth
285 Old Westport Road
Dartmouth, MA 02747
phone 508-910-6334 dmacdonald@umassd.edu

**Project Quality Assurance Officer - GIS Analysis**

____________________________ 04/06/2023

Joseph E. Costa, Ph. D., Date
Buzzards Bay National Estuary Program, MCZM
81-B County Road, Suite E
Mattapoisett, MA 02739
774-377-6000, joe.costa@mass.gov

**EPA Program Manager**

_________________________________ _____________

Alicia Grimaldi Date
US EPA, 5 Post Office Square - Suite 100
Mail Code - OEP-06-1
Boston, MA 02109-3912
(617) 918-1538, grimaldi.alicia@epa.gov

**EPA GIS Coordinator**

_________________________________ _____________

Alexandra Dichter, GIS Coordinator Date
EPA New England GIS Center
5 Post Office Square, Suite 100
Mail Code OARM02-1
Boston, MA 02109-3912
Tel. (617) 918-1142, dichter.alexandra@epa.gov

**EPA Quality Assurance Officer**

_________________________________ _____________

Nora Conlon, Quality Assurance Officer Date
EPA New England Laboratory
11 Technology Drive
North Chelmsford, MA 01863
Tel. (617) 918-8335

## 1.2. Acknowledgments

Elements of this QAPP were prepared with the assistance of Joseph E. Costa, Executive Director of the Buzzards Bay National Estuary Program. Survey training was provided by Costa and Rachel Jakuba of the Buzzards Bay Coalition.

1.3. Table of Contents

### 1.4. Distribution List

- Buzzards Bay National Estuary Program, Joseph E. Costa, Ph. D., Executive Director, 81_B County Road, Suite E, Mattapoisett MA 02739. Tel. 508 291-3625 x11 Email: joe.costa@mass.gov.
- Buzzards Bay National Estuary Program, Kevin Bartsch, Stormwater Specialist and GIS Analyst, 81-B County Road, Suite E, Mattapoisett, MA 02739. Tel. 508 291-3625 x14 Email: kevin.bartsch@mass.gov.
- Buzzards Bay Coalition, Rachel Jakuba, Ph. D., Science Director, 114 Front Street New Bedford, MA 02740. Tel. 508 999-6363 Email: jakuba@savebuzzardsbay.org.
- Buzzards Bay Coalition and Woodwell Climate Center, Alice Besterman, Ph. D., Salt Marsh Scientist, 114 Front Street New Bedford, MA 02740. Tel. 508 999-6363 Email: abesterman@towson.edu.
- U.S. Environmental Protection Agency, New England Quality Assurance, Unit 11 Technology Drive, North Chelmsford, MA 01863 R1QAPPS@epa.gov.
- U.S. Environmental Protection Agency, Alexandra Dichter. New England Quality Assurance, Unit 11 Technology Drive, North Chelmsford, MA 01863. Tel. 617 918-8369 Email: dichter.alexandra@epa.gov.
- U.S. Environmental Protection Agency, Alicia Grimaldi, U.S. EPA Project Officer, 5 Post Office Square-Suite 100, Boston, MA 02109-3912. Tel: 617-918-1538 Email: grimaldi.alicia@epa.gov.
- Massachusetts Coastal Zone Management: Marc Carullo, 100 Cambridge Street, Suite 900, Boston, MA 02114. Tel: 617-626-1221. Email: marc.carullo@mass.gov.
- Massachusetts Coastal Zone Management, Adrienne Pappal, 100 Cambridge Street, Suite 900, Boston, MA 02114. Tel.: 617-626-1218. Email: adrienne.pappal@mass.gov.

### 1.5. Project Organization

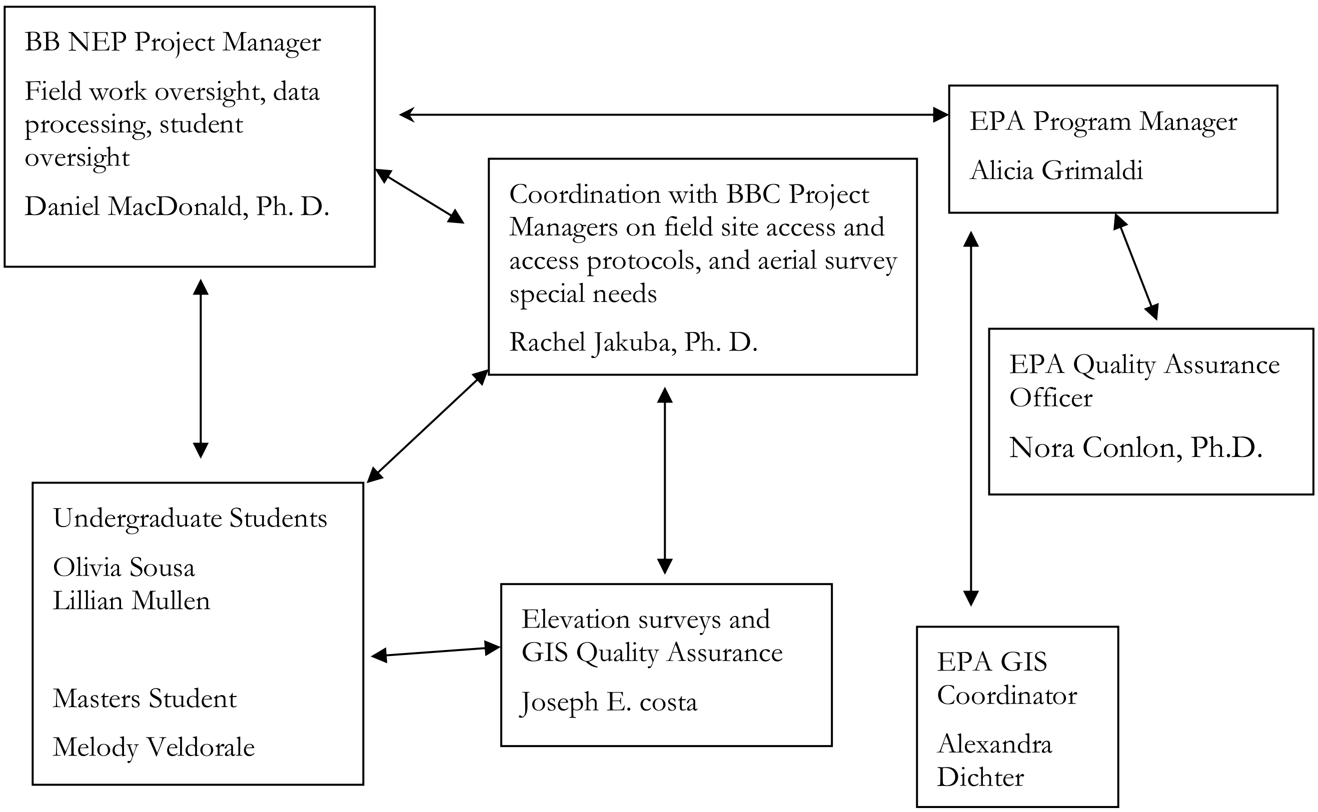
The organizational chart in Fig. 1 shows the lines of communication among these individuals and the U.S. EPA. Below is a description of the positions.

Project Manager: Daniel G. MacDonald, Ph.D., P.E., Proffesor and Chair - Dept. of Civil & Environmental Engineering at the University of Massachusetts Dartmouth, will oversee multiple students in the completion of this work.

Joe Costa, Director of the Buzzards Bay National Estuary Program (NEP) will act as GIS Quality Control Officer and will review the GIS spatial and elevation data to ensure that it is consistent with other state approved digital aerial imagery and digital surface models, conforms to the protocols described here, and contains the appropriate meta data.

Students will coordinate with Rachel Jakuba to avoid conflicts with Buzzards Bay Coalition (BBC) staff collecting field data on vegetation and habitat features.

Fig. 1. Project organizational chart.




## 1.6. Problem Definition/Background

### 1.6.1. Problem Definition

Coastal salt marshes are an important habitat and nursery for many coastal marine species of plants, aquatic and terrestrial vertebrates, and invertebrates. Other functions provided by salt marsh ecosystems include storm damage prevention, prevention of pollution, protection of marine fisheries and wildlife habitat, and a source of primary production of carbon that is the basis of coastal food webs. Salt marshes also contribute to aesthetic values of the coast. Conserving and protecting this valuable resource and habitat fulfills important goals of the 2013 updated Buzzards Bay Comprehensive Conservation and Management Plan.

Historically, many salt marsh areas in Buzzards Bay and elsewhere have been filled or otherwise adversely affected by human activities. More recently, the NEP and BBC have received numerous reports of rapid salt marsh loss around Buzzards Bay[1]. Over geologic time, as sea level has risen hundreds of feet since the last ice age, coastlines and salt marshes have migrated. During recent centuries, with appreciably lower rates of sea level rise, some protected marsh systems with sufficient sources of terrigenous sediments, have nearly

[1] See http://buzzardsbay.org/reports-salt-marsh-loss-buzzards-bay/

kept pace with sea level rise (10 inches per century relative rise in sea level in Southern New England). However, with greater rates of sea level rise and increased frequency of more intense coastal storms, increased climate-related salt marsh losses are a concern. In addition to these physical stressors, other identified threats to salt marshes have included excessive grazing by crabs, and adverse effects of coastal eutrophication from excessive nitrogen inputs, which can cause accelerated decomposition of salt marsh peat and subsidence of marsh channels where nitrogen concentrations are elevated.

.

### 1.6.2. Background

This QAPP supports other ongoing studies by the BBC, NEP, and the Woodwell Climate Research Center focused on the historic loss of salt marshes in Buzzards Bay, and the use of management approaches like runnel construction (Besterman et al 2022). This QAPP exclusively covers the collection of digital aerial imagery using Unmanned Aircraft Systems (UAS) to produce digital orthographic georeferenced imagery, and digital surface models of various resolutions. The work will be undertaken at twelve Buzzards Bay long term salt marsh study sites (Fig. 2 and 0) where the presence of transect markers and elevation benchmarks will facilitate the analysis. For more detailed information on the marsh sites, please refer to earlier QAPPS related to the larger project, including Besterman et al (2020) and Costa et al (2019). Additional site information is available in Jakuba et al (2023) and Costa (2022).

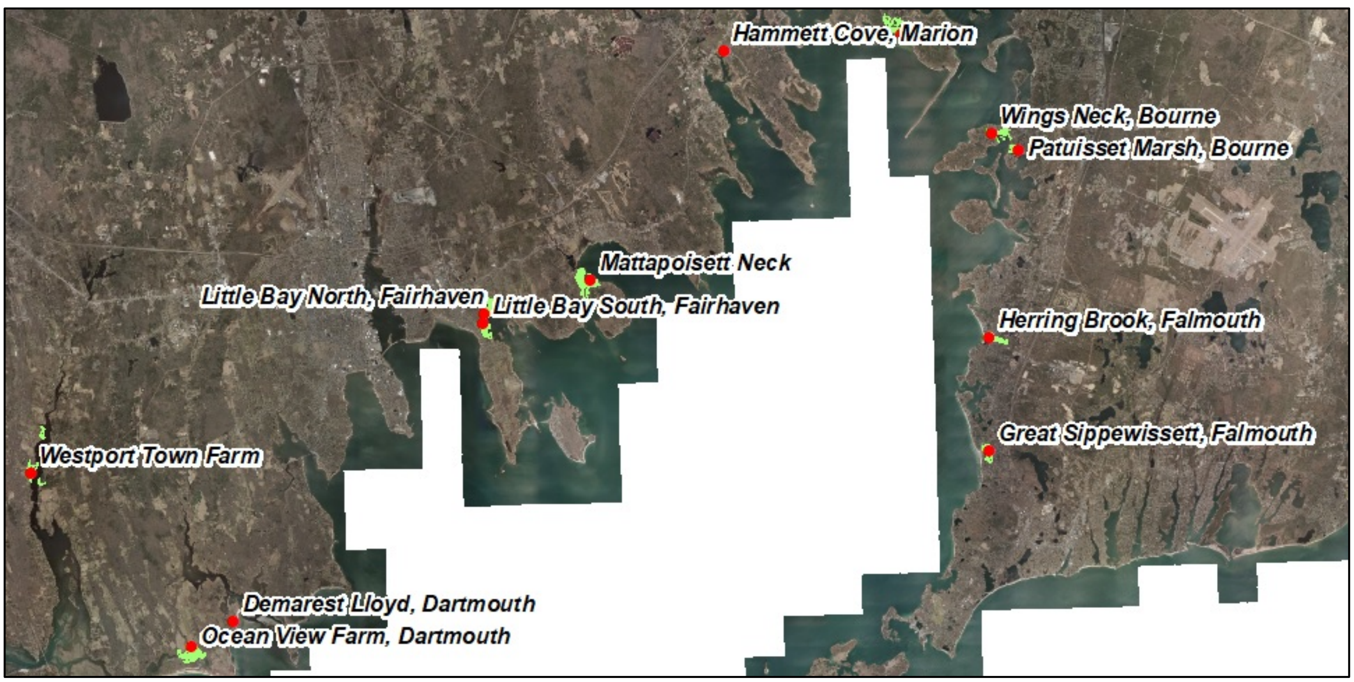



Fig. 2. Buzzards Bay long-term salt marsh study sites.

**Table 1: Buzzards Bay Long-Term Study Sites and 2019 Acreage**

| Site Name | 2019 Acreage (Approx.) |
|---|---|
| 1. Little Bay North, Fairhaven | 4.48 |
| 2. Little Bay South, Fairhaven | 4.745 |
| 3. Hammett Cove, Marion | 1.205 |
| 4. Little Harbor Beach, Wareham | 1.784 |
| 5. Wings Neck, Bourne | 7.952 |
| 6. Patuisset Marsh, Bourne | 2.825 |
| 7. Herring Brook, Falmouth | 0.74 |
| 8. Sippewissett Marsh, Falmouth | 4.89 |
| 9. Ocean View Farm, Dartmouth, | 5.535 |
| 10. Demarest Lloyd Park | 2.14 |
| 11. Westport Town Farm, Westport | 4.467 |
| 12. Mattapoisett Neck, Mattapoisett | 1.0 |

## 1.7. Project/Task Description and Schedule

The University of Massachusetts Dartmouth (UMassD) is working with the NEP to conduct salt marsh surveys in Buzzards Bay for the evaluation of vegetation, edge loss and elevation. UMassD will perform the surveys utilizing UAS having had experience with the operation and video footage processing of DJI Phantom 4 Pro quadcopters. UMassD will process raw footage using 3D photogrammetry software (ESRI Drone2Map) to generate Digital Surface Models (DSM) and georectified true color imagery. UMassD will use existing NGS rod benchmarks on each side along with NEP transect markers to establish control points for each UAS survey. The NEP will provide training on the use of their surveying equipment for setting control points. UMassD students working with the program will obtain their FAA drone licenses and will oversee the UAS survey flights. UMassD will be responsible for obtaining any additional licenses when operating in the vicinity of any airport.

The position of transect markers will be provided by the NEP. This data is collected with a Juniper GEODE GPS under the NEP's approved 2019 Salt Marsh Study QAPP (Quality Assurance Project Plan for Long-term salt marsh vegetation and elevation monitoring in Buzzards Bay Pursuant to Buzzards Bay NEP Workplan Task 12, EPA Cooperative Agreement CE-00A00456, August 2019). The primary focus of this project is to collect digital aerial images with UASs at the 12 sites shown in Fig. 2. Each site will be monitored early in the growing season (low leaf biomass) and late in the growing season (full foliage). At these sites UMassD will deploy permanent or temporary control points of known position and elevation surveyed from the NEP benchmarks. Future survey flights will also employ additional ground control points using the survey equipment to establish position and elevation data. Using the DJI Phantom 4 Pro, Pix4D software for flight planning, and ESRI's Drone2Map software for processing UMassD will create orthographic georeferenced imagery with corresponding digital surface models of each site. A finer breakdown of tasks with organizational leads and estimated schedules are shown in Table 2 for calendar year 2023. Although aerial flights and training missions were conducted during 2022, data collected under these flights were for purposes of developing protocols and deciding upon equipment. This QAPP only covers data collection beginning in March 2023.

Flights are planned and programmed through the Pix4D Capture app on the controlling iPad. This app allows flights to be planned in various modes including polygon and grid for 2D mapping and double grid or circular for 3D mapping. Surveying flights are all planned and flown using the polygon mode to incorporate the study area. The boundaries of the polygon are determined from images provided to UMassD by BBC depicting the study areas. These programmed flights include camera angle (90°, or nadir position, so that the camera is positioned vertically downward for optimal resolution and georectification), image overlap (70% front, 80% side), drone speed (variable depending on if the flight is programmed in fast mode or safe mode), and altitude (150 m). All flights are programmed for still imagery. In safe mode the drone will pause at each photograph position. In fast mode (necessary for the larger sites due to battery consumption and flight time) the drone captures the images while maintaining movement.

Scheduling of flights is determined primarily by tides. Images are captured as close to low tide as possible during daylight hours, though a 2-hour window to either side of low tide is considered acceptable if the daylight levels are sufficient. For the larger sites, safe mode flights can take between 2 to 3 hours (including time for battery changes as each battery provides a maximum flight time of 20 minutes) and these flight times are also accounted for in scheduling. Other scheduling considerations include weather and distance to the site as travel time between sites must also be accounted for in cases where multiple sites are scheduled to be flown on the same day, and some sites require a lengthy walk to reach. Strong winds, fog, and/or precipitation in the forecast require the sites to be flown on more clement days. Seasonal survey flights are generally completed within a 4-week period for all 12 sites, barring circumstances such as weather delays.

The images are uploaded to the ESRI Drone2Map software for processing. This software can convert the images from the drone into orthorectified mosaics, digital surface models, point clouds, and more. The following hardware requirements are the recommended to run the software: Windows 7, 8, or 10 64-bit; quad core or hexa-core Intel i7/Xeon CPU; GeForce GPU compatible with OpenGL 3.2 and 2 GB of RAM for graphics; and an SSD hard drive. For the sites that produce between 101 to 500 raw images that require processing, it is also recommended that the computer have 16 GB of system memory and 30 GB of free disk space on the hard drive. The free disk space required increases to 60 GB for projects with 501 to 2000 raw images, as required at approximately half of the salt marsh sites. In the UMassD drone lab we perform processing tasks on a Dell Precision 3660 Tower with an Intel Core i7-12700 processor (25MB Cache, 12 Core) with 64 GB of system memory, and a 2TB hard drive. The products created for this project are digital surface models and orthorectified mosaics of the study areas.

Images are processed using high point cloud density for dense matching. This increases processing time but improves accuracy. Tie points are pulled from ½ image size and then refined at full image size. Digital Surface Models are developed using 0.1cm contour intervals and the orthorectification method uses dense point clouds, color balancing, and seamlines to create the smoothest and most accurate imagery. The Phantom 4 Pro utilizes the GCS WGS 1984 coordinate system; however images are processed into the NAD 1983 2011 State Plane Massachusetts Mainland FIPS 2001 coordinate system for the project.

As outlined in the Buzzards Bay Coalition QAPP, the Buzzards Bay Coalition is determining elevation of transect stations off NEP installed benchmarks. The NEP, under their QAPP, is also using existing LiDAR survey data to calculate entire marsh unit mean elevations and profiles. The UMass Dartmouth data is expected to be more precise than existing LiDAR datasets, but for individual transect stations, less precise than field surveys. The fall UMD data will be used to help define canopy elevation corrections that must be applied to LiDAR datasets, and to evaluate the replicability of UMass Dartmouth data acquisition.

**Table 2:** Summary of tasks, organization leads, and schedule

| Task | Lead | Jan-23 | Feb-23 | Mar23 | Apr-23 | May-23 | June23 | Jul-23 | Aug-23 | Sept-23 | Oct-23 | Nov23 | Dec-23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prepare QAPP and revise as needed | UmassD | X | | | | X | | | | | | | |
| Phantom 4 Pro drone training | UmassD | | | | | | | | | | | | |
| Spring survey flights (low leaf biomass) | UmassD | | | X | X | | | | | | | | |
| Fall survey flights (high leaf biomass) | UmassD | | | | | | | | | X | X | | |
| Evaluation of processing packages and training | UmassD | | | | | | | | | | | | |
| Processing of data into digital surface model & orthomosaic imagery | UmassD | | | | X | X | X | X | X | X | X | X | X |
| QA/QC of data | UmassD | | | | X | X | | | | | X | X | |
| RTK GPS and drone training | UmassD | | X | X | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

## 1.8. Quality Objectives and Criteria for Measurement Data

This section describes the general objectives of the project and defines the measurement performance needed to meet program objectives. The program consists of two classes of data generated under the QAPP. Initially, aerial surveys conducted during 2022 will be conducted using only established transect markers and elevation benchmarks as control points.

Future UAS flights (commencing Spring 2023) will also incorporate new features and markers deployed in support of this study. These additional benchmarks will be indicated by markers topped with "hats" made from black and white acrylic sheeting, 11.5 inches square, which will be easily visible to the drone. Any additional markers which may need to be placed or painted onto streets and walkways will be recorded along with their elevations. Elevation and position coordinates will be established using an EOS Arrow Gold RTK GPS unit designed to work with the DJI Phantom RTK drone, along with the RTK drone itself, an upgrade from the initial surveys conducted using the DJI Phantom 4 Pro.

The Environmental Systems Research Institute, Inc. (ESRI) recommends that 5-10 control points be used per site for higher accuracy in the final product, preventing warping and stretching of the stitched imagery. Larger, or more complex sites, require the upper end of the range. Smaller or less complex sites are fine in the lower range. These points should be as evenly distributed as possible so that control points appear in multiple images and should not be on the edges of the site where image overlap is reduced. The distribution pattern of the control points should be roughly triangular to reduce the distance between points, thus achieving higher accuracy in the final model. Likewise, control points should not be placed in straight lines to avoid geometric warping of the final product. Points with known coordinates can also be used as checkpoints in the Drone2Map software and their accuracy from initial to computed position will be calculated and displayed in the processing report.

The QA/QC is laid out in the assessment sampling protocol as a system of audits, standard procedures, and training for each section of the data collection. These activities and procedures begin with the assessment protocol conceptualizations, where the data requirements are determined, and continue through sampling, measurement of function, and data management to ensure the data quality meets those standards and are overseen by the Quality Assurance Manager (D. MacDonald) and Project Manager (most senior student employed on the project). The data quality objectives of the monitoring program are described below, with definitions of terminology summarized also below, and the criteria for key parameters summarized in 0. Specific details will be included in the appropriate Standard Operating Procedures.

Precision–- is a measure of mutual agreement among individual measurements of the same variable, usually under prescribed similar conditions. Data precision of the assessment protocol can be checked with replicate field measurements and standard procedures.

Accuracy–- is the degree to which a measurement reflects the true or accepted value of the measured parameter. It is a measure of the bias in a system. Accuracy depends on the technique used to measure a parameter and the care with which it is executed. Standard procedures and QA audits are used to maintain data accuracy.

Completeness is a measure of the amount of valid data obtained compared to the amount expected under normal conditions. Ideally, 100% of the data should be collected. Data may be incomplete due to incomplete data collection, lost, or damaged data forms, or errors in data transcription. Through careful documentation, management, and timely entry of data the QA/QC manager will make every effort to avoid these human errors.

Representativeness–- expresses the degree to which data accurately and precisely represent a characteristic of the parameter measured. Representativeness is established by proper site selection and appropriate spatial arrangement of sampling areas (i.e., site selection stratified by frequency distribution of selected metrics).

Comparability–- expresses the confidence with which one data set can be compared to another. Collection of data by different investigators is the primary cause of variability in the data. Standardized procedures, internal QA audits, and training minimize variability in the data. Field protocols are based on accepted, regional methods that will increase comparability with other salt marsh studies.

### 1.8.1. Objectives and Project Decisions

The Project will pursue collecting data of sufficient quality to characterize map and define marsh vegetation, pans, pools, and ditches relevant to the long-term marsh loss study. Elevations developed with photogrammetry software will be compared to elevation surveys of transects using centimeter accuracy field surveying equipment. Initial flights were conducted without control using only the DJI Phantom 4 Pro. This data will be reprocessed in the future alongside the Spring 2023 flights using the more advanced drone (DJI Phantom RTK) and established control points in addition to the transects. See Appendix A-B for equipment details.

### 1.8.2. Action Limits/Levels

Inconsistencies greater than 6cm horizontal and/or 6cm vertical between field surveys and photogrammetry based digital surface model, or inconsistencies between repeated early and late season surveys that cannot be accounted for by leaf canopy, will prompt a review of data for sources of inconsistency.

### 1.8.3. Measurement Performance Criteria/Acceptance Criteria

The principal data quality indicators (DQIs) are consistency of observations with RTK GPS and/or laser level measurements, and general agreement with recent digital ortho quads (DOQs) adopted by MassGIS (pixel size 30 cm). Data will be judged primarily against Arrow Gold GNSS/RTK GPS positions (cm accuracy) recorded at site check/control points and where available, also compared with past elevation measurements from laser level bare earth field surveys conducted by BBC on multiple dates (mm accuracy). UAS based measurements will be compared against these known points for consistency and general agreement. If any UAS survey does not show general agreement with the DOQs or with past elevation measurements, control points and data processing will be reviewed for potential errors. Where appropriate, the dataset will be rejected, and/or surveys will be repeated.

**Table 3**

| Parameter | Units | Expected Range | Accuracy (+/-) | Precision |
|---|---|---|---|---|
| Elevation: (RTK GNSS) | Meters (m) referenced to NAVD88 | NA | +/- 0.03 m | Repeated readings to verify positions essentially the same |
| Location by coordinates (RTK GNSS) | MA State plane referenced to NAD83 (2011) | NA | +/- 0.02 m<br>Dependent upon a variety of environmental factors | Repeated readings to verify positions essentially the same |

## 1.9. Special Training Requirements/Certification/Safety

### 1.9.1. Training Requirements/Certification

Students working for UMassD will obtain their Federal Aviation Administration (FAA) Remote Pilot Certificate. This will be done by creating an Integrated Airman Certification and Rating Application (IACRA), obtaining an FAA Tracking Number (FTN), and registering for and passing the Unmanned Aircraft General – Small (UAG) test at an FAA approved Knowledge Testing Center.

Knowledge test topic areas include, but are not limited to: applicable regulations relating to small unmanned aircraft system rating privileges, limitations, and flight operation; airspace classification and operating requirements, and flight restrictions affecting small unmanned aircraft operation; aviation weather sources and effects of weather on small unmanned aircraft performance; small unmanned aircraft loading and performance; emergency procedures; determining the performance of small unmanned aircraft; aeronautical decision-making and judgment; and airport operations.

Students will then complete the FAA Form 8710-13 for a remote pilot certificate (FAA Airman Certificate and/or Rating Application) using the electronic FAA IACRA.

Certificate holders must complete an online recurrent training every 24 calendar months to maintain aeronautical knowledge recency

### 1.9.2. Safety Considerations

- Survey flights will always be conducted by two or more persons, unless otherwise approved by the field manager.
- Fieldwork will not be conducted during heavy rain events, storms, or unsafe conditions such as electrical storms or high wind events. Please practice "safety first."
- All persons must carry cell phones or other emergency communication devices while conducting surveys or field work. It is recommended these be waterproof or stored in a waterproof case or zip-lock bag.
- If for any reason access to control point is deemed continuously unsafe after establishment, these will either be moved if feasible or sampling will be discontinued for that site if such a location is unavailable.
- If a field survey is deemed unsafe on a date because of weather, tidal conditions, or other factors, data collection should be suspended on that date. Attempts to access a transect by boat when there are “small craft warning” by the National Weather Service, or where there are atypical tide conditions, safety should be assessed prior to sampling. Should the incoming tide not recede as predicted (i.e., tide is still in flood stage when it should be in ebb stage), monitoring shall be suspended, particularly if access to the site depends upon a low tidal state.
- Good judgment will be used in selecting clothes and personal protection items. Common carried items include extra clothing, sunshade, sunscreen, hats, insect repellent, and boots (knee, hip waders, chest waders) suitable for highest anticipated depths. Staff not dressed appropriately should not participate in field work. Proper footwear is necessary (e.g., no “flip-flops” for field work).
- Good judgment will be used in walking on marsh surfaces; mosquito ditches will be circumvented, or when deemed possible, crossed with caution.
- Certain sites (listed below) require advance notice and approval prior to flights. These sites must be informed of potential flights in advance and permission to visit obtained.
    - Contact for Ocean View Farm: Linda Vanderveer, 508-991-2289, linda@dnrt.org

### 1.10. Documents and Records

The QAPP, including any revisions and updates, as well as data and reports, will be posted on the NEP website buzzardsbay.org. Data sheets and databases will be archived at both the NEP and BBC offices. All data collected will be maintained in raw form (field data forms) and electronic form for at least ten years by UMassD. The QAPP and Standard Operating Procedures (SOP) will be dated in their running heads to distinguish among different versions in case there are revisions made over the course of the project. UMassD will include all reports of the project status in an annual report to NEP, including any problems and the proposed recommended solutions. Annual status reports and final reports will be provided in electronic form to everyone on the distribution list. Hard and soft copies of reports, as well as all electronic data records, will be maintained at NEP for at least five years and posted at buzzardsbay.org. Electronic data records, including results of the assessments and analyses, as well as GIS data generated over the course of the project, will also be maintained at NEP for at least five years.

#### 1.10.1. Quarterly and/or Final Reports

UMassD has provided access to a shared drive for all sites which have been processed through Drone2Map with complete datafiles for use in ArcGIS, designated by site name and timing of flight (e.g., Little Bay North Spring 2022). Under the NEP's subaward UMassD will prepare and submit electronically a draft and final report on the results, and the digital ortho quads and digital surface models of each of the study sites to the extent specified by the NEP. UMassD will provide a report at the end of each flight season with a summary of work done and the appropriate QA/QC metrics for each site.

## 2. DATA GENERATION AND ACQUISITION

This section addresses aspects of project design and implementation to ensure that appropriate methods for the collection of existing datasets are used in this study.

### 2.1. Sampling Design, Long Term Monitoring Transects

This study principally involves collecting aerial imagery and producing digital maps and elevation models from that imagery. The work will be undertaken at the NEP long term study sites. The elevation of georeferencing control points will be established from field surveying from the National Geodetic Survey (NGS) rod benchmarks, and other benchmarks established by the NEP under a separate QAPP.

#### 2.1.1. Protocol for Decontamination of Field Equipment

Inspect all equipment for debris and remove before leaving a site. Dispose of debris in a trash bag or on dry, high ground. Rinse with freshwater or wipe with a freshwater soaked rag, any surfaces exposed to salt water. When possible, leave equipment to air dry and inspect to remove any remaining plant fragments.

### 2.2. Quality Control

Compliance procedures are described below. See sections 3.1 and 3.2 of the QAPP for additional QA/QC measures.

- Use of standardized sampling procedures (precision, accuracy, representativeness)
- Prompt review and documentation of any changes to the SOPs (precision, accuracy, comparability)
- Use of highly qualified field personnel (precision, accuracy, comparability)
- Rigorous training and mentoring of less experienced technicians in both structured and informal settings, the latter on an as needed basis (precision, accuracy, comparability)
- Regular checks to ensure that data forms are completely filled out (completeness)
- The Quality Assurance Manager will review field data, identify inconsistencies, and if possible, take corrective action. Any significant changes in protocols will be made in coordination with BBC.

#### 2.2.1. Interferences

Inclement weather may interfere with our ability to collect representative data on a variety of parameters. Severe weather may delay field data collection due to safety concerns and any inclement weather may cause delays due to poor imagery from the drone.

#### 2.2.2. Corrective Actions

Data quality control ensures high quality data however we are prepared to re-survey any sites within the same season or period of monitoring as needed (e.g., data are missing, data is lost or compromised, etc.). Any plots that contain data that cannot be resolved will be removed from the data set.

#### 2.2.3. Waste Minimization and Pollution Prevention

Care will be taken to avoid transport of vegetation and soil to other sites. This will be done by thorough inspection of all equipment and clothing prior to departure from a site. Invasive plant samples will be disposed of in a way to avoid accidental release into the environment. No litter will be left at the study sites. No chemicals will be used at the study sites. UMassD students will coordinate with BBC to ensure that UAS flights and any necessary excursions into the marshes to establish control points will not cause damage to the ecosystem.

### 2.3. Field Measurement Instruments and Equipment Checklist

Before leaving for the field the Field Manager (most senior student present) will confirm the appropriate equipment and supplies are brought into the field for the specific tasks to be undertaken and that all equipment is in working order with charged batteries.

#### 2.3.1. Instrument/Equipment Testing, Inspection, Calibration and Maintenance

Field equipment will be inspected by the UMassD staff each day before going out to collect field data. At the field site, equipment will be tested prior to data collection to ensure that it is working properly. Equipment will be subject to regular maintenance as needed and as recommended by the manufacturer. Instruments will be calibrated regularly as recommended by the manufacturer. Table 1 summarizes the equipment calibration, inspection, testing, and maintenance schedule.

#### 2.3.2. Field Sampling Supplies and Consumables

Few supplies and consumables will be used in this study. It will be the responsibility of the field managers to ensure that all items in the equipment checklist are available on each survey date.

### 2.4. Data Management

Data and field observations will be collected in the field and entered onto field data sheets. Field data sheets will be inspected and approved by the field team leader before leaving each site. At the end of each survey day, the field team leader will review all field sheets to ensure all required data is accounted for. If significant errors or omissions are detected during on-site inspection, the field team leader will consult with samplers to rectify the situation. Data sheets will be returned to the UMassD Project Manager and stored for data entry weekly. A data entry system will be developed in Excel and formatted to resemble the field data form to reduce data entry errors. One person will be designated to enter data for consistency and all data will be reviewed for quality control by the UMassD QA Manager. The database (MS Excel) will be stored in a private directory on a secured network server and will be backed-up regularly. Only the UMassD Project Manager and QA Manager will have access to the master database. Electronic documentation and data will be stored on individual computers and backed up to the UMassD shared drive. Upon completion of processing, Drone2Map products and data will be posted to the shared drive with BBC for the NEP Director to conduct a review.

**Table 1.** Instrument/equipment calibration, inspection, testing, and maintenance.

| Equipment | Calibration | Inspection/testing | Maintenance |
|---|---|---|---|
| Phantom 4 Pro | NA | Inspect the propeller blades and camera attachment prior to each flight for damage, blockages, and other problems. Confirm that battery is firmly inserted and not loose. | Remove and store propellor blades after every flight. Put camera cover back on prior to placing back in case. For prolonged storage, remove the batteries. |
| Phantom 4 RTK | NA | Inspect the propeller blades and camera attachment prior to each flight for damage, blockages, and other problems. Confirm that battery is firmly inserted and not loose. | Remove and store propellor blades after every flight. Put camera cover back on prior to placing back in case. For prolonged storage, remove the batteries. |
| EOS Arrow Gold RTK GNSS | NA | Units will be inspected weekly for damage or other problems; units will be tested prior to each survey season (at a minimum) using known locations. | Keep batteries charged and in good condition; clean as needed |

# 3. ASSESSMENT AND OVERSIGHT

## 3.1. Assessments and Response Actions

Quality assessment and response will be the responsibilities of the field team leader and Quality Assurance Manager. All corrective actions or changes to surveying and data management protocols will be recorded.

The Project Manager or Field Manager will train and accompany any other staff during UAS flights and review data sheets at the end of each day. Equipment will be checked before and after each field day.

Any inconsistencies in surveying technique, equipment malfunctions, and data entry errors will be addressed as they occur and are recorded.

The Quality Assurance Manager will review all field data and all data entry. Any systemic collection or entry errors will be discussed by the project team and if necessary, changes to the sampling methods will be recorded.

## 3.2. Reports to Management

The Project Manager will include all reports of the project status in the annual report, including any problems and the proposed recommended solutions. Any deviations to the QAPP will be reported.

# 4. DATA REVIEW, VERIFICATION, AND VALIDATION

All GIS data and field elevation data collected with the EOS Arrow Gold RTK will be submitted to the

NEP Project Manager and QA Manager to determine if the data meet QAPP objectives.

### 4.1. Verification and Validation Methods

Elevation and horizontal position data based on the UAS flights will be compared and validated against check point locations at each site obtained using the EOS Arrow Gold RTK. Outlier data will be flagged in the database for measurements that exceed the tolerances identified in Section 1.8.2. If data does not meet specifications, processing will be repeated using the check points as control points, and, if necessary (and if there is time left in the field season, the marsh will be re-flown.

### 4.2. Reconciliation with Data Quality Objectives

After the data has been compiled, verified, and validated, the project team will review the results and compare the data quality to the original data quality objectives. If some of the data do not meet the original data quality objectives, the team will determine whether to discard this data or to change the data quality objectives. All changes and decisions will be recorded.

## 5. REFERENCES

Besterman, A., Jakuba, R. W. (2020). Quality Assurance Project Plan for Evaluating Management Actions to Promote Salt Marsh Resilience. 33 pp.

Besterman, A.F., Jakuba, R.W., Ferguson, W. *et al.* Buying Time with Runnels: a Climate Adaptation Tool for Salt Marshes. *Estuaries and Coasts* **45**, 1491–1501 (2022). https://doi.org/10.1007/s12237-021-01028-8

Costa, J., and R. Jakuba (2020). Quality Assurance Project Plan for Long-term salt marsh vegetation and elevation monitoring in Buzzards Bay Pursuant to Buzzards Bay NEP Workplan Task 12, EPA Cooperative Agreement CE-00A00456, 92 pp.

Costa, J. (2022). Buzzards Bay Salt Marsh Study: Status and locations of benchmarks and transect markers recorded or estimated (Data as of October 26, 2022; previous update October 3, 2022), 40 pp.

Jakuba, R.W., Besterman, A., Hoffart, L., Costa, J. E., Ganju, N., Deegan, L. (2023) Buzzards Bay Salt Marshes: Vulnerability and Adaptation Potential. 32pp.

# Appendix A. DJI Phantom 4 Pro Specifications

## AIRCRAFT

| | |
|---|---|
| Weight (Battery & Propellers Included) | 1388 g |
| Diagonal Size (Propellers Excluded) | 350 mm |
| Max Ascent Speed | S-mode: 6 m/s<br>P-mode: 5 m/s |
| Max Descent Speed | S-mode: 4 m/s<br>P-mode: 3 m/s |
| Max Speed | S-mode: 45 mph (72 kph)<br>A-mode: 36 mph (58 kph)<br>P-mode: 31 mph (50 kph) |
| Max Tilt Angle | S-mode: 42°<br>A-mode: 35°<br>P-mode: 25° |
| Max Angular Speed | S-mode: 250°/s<br>A-mode: 150°/s |
| Max Service Ceiling Above Sea Level | 19685 feet (6000 m) |
| Max Wind Speed Resistance | 10 m/s |
| Max Flight Time | Approx. 30 minutes |
| Operating Temperature Range | 32° to 104°F (0° to 40°C) |
| Satellite Positioning Systems | GPS/GLONASS |
| Hover Accuracy Range | Vertical:<br>±0.1 m (with Vision Positioning) |

±0.5 m (with GPS Positioning)
Horizontal:
±0.3 m (with Vision Positioning)
±1.5 m (with GPS Positioning)

## VISION SYSTEM

| | |
|---|---|
| Vision System | Forward Vision System<br>Backward Vision System<br>Downward Vision System |
| Velocity Range | ≤31 mph (50 kph) at 6.6 ft (2 m) above ground |
| Altitude Range | 0 - 33 feet (0 - 10 m) |
| Operating Range | 0 - 33 feet (0 - 10 m) |
| Obstacle Sensory Range | 2 - 98 feet (0.7 - 30 m) |
| FOV | Forward: 60°(Horizontal), ±27°(Vertical)<br>Backward: 60°(Horizontal), ±27°(Vertical)<br>Downward: 70°(Front and Rear), 50°(Left and Right) |
| Measuring Frequency | Forward: 10 Hz<br>Backward: 10 Hz<br>Downward: 20 Hz |
| Operating Environment | Surface with clear pattern and adequate lighting (lux>15) |

## CAMERA

| | |
|---|---|
| Sensor | 1'' CMOS<br>Effective pixels: 20M |
| Lens | FOV 84° 8.8 mm/24 mm (35 mm format equivalent) f/2.8 - f/11 auto focus at 1 m - ∞ |
| ISO Range | Video:<br>100 - 3200 (Auto)<br>100 - 6400 (Manual)<br>Photo:<br>100 - 3200 (Auto)<br>100- 12800 (Manual) |
| Mechanical Shutter Speed | 8 - 1/2000 s |
| Electronic Shutter Speed | 8 - 1/8000 s |
| Image Size | 3:2 Aspect Ratio: 5472 × 3648<br>4:3 Aspect Ratio: 4864 × 3648<br>16:9 Aspect Ratio: 5472 × 3078 |

# Appendix B. DJI Phantom 4 RTK Specifications

# PHANTOM 4 RTK SPECS

HomeProductsPhantom 4 RTKSpecs

## AIRCRAFT

| | |
|---|---|
| Takeoff Weight | 1391 g |
| Diagonal Distance | 350 mm |
| Max Service Ceiling Above Sea Level | 19685 ft (6000 m) |
| Max Ascent Speed | 6 m/s (automatic flight); 5 m/s (manual control) |
| Max Descent Speed | 3 m/s |
| Max Speed | 31 mph (50 kph)(P-mode)<br>36 mph (58 kph)(A-mode) |
| Max Flight Time | Approx. 30 minutes |
| Operating Temperature Range | 32° to 104° F (0° to 40℃) |
| Operating Frequency | 2.400 GHz to 2.483 GHz (Europe, Japan, Korea)<br>5.725 GHz to 5.850 GHz (United States, China) |
| Transmission Power (EIRP) | 2.4 GHz<br>CECE (Europe) / MIC (Japan) / KCC (Korea)： < 20 dBm<br><br>5.8 GHz<br>SRRC（China） / FCC（United States） /(Taiwan,China)： < 26 dBm |
| Hover Accuracy Range | RTK enabled and functioning properly：<br>Vertical：±0.1 m；Horizontal：±0.1 m<br><br>RTK disabled<br>Vertical：±0.1 m（with vision positioning）；<br>±0.5 m（with GNSS positioning）<br>Horizontal：±0.3 m（with vision positioning）；<br>±1.5 m（with GNSS positioning） |
| Image Position Offset | The position of the camera center is relative to the phase center of the onboard D-RTK antenna under t<br>axis:(36, 0, and 192 mm) already applied to the image coordinates in Exif data. The positive x, y, and z a<br>body point to the forward, rightward, and downward of the aircraft, respectively. |

## MAPPING FUNCTIONS

| | |
|---|---|
| Mapping Accuracy ** | Mapping accuracy meets the requirements of the ASPRS Accuracy Standards for Digital Orthophotos C<br>** The actual accuracy depends on surrounding lighting and patterns, aircraft altitude, mapping softwa<br>factors when shooting. |
| Ground Sample Distance(GSD) | (H/36.5) cm/pixel，<br>H means the aircraft altitude relative to shooting scene (unit: m) |
| Data Acquisition Efficiency | Max operating area of approx. 1 km² for a single flight(at an altitude of 182 m, i.e., GSD is approx. 5 cm/<br>requirements of the ASPRS Accuracy Standards for Digital Orthophotos Class Ⅲ |

## VISION SYSTEM

| | |
|---|---|
| Velocity Range | ≤31 mph(50 kph) at 6.6 ft(2 m) above ground with adequate lighting |
| Altitude Range | 0-33 ft(0 - 10 m) |
| Operating Range | 0-33 ft(0 - 10 m) |
| Obstacle Sensing Range | 2-98 ft(0.7-30 m) |
| FOV | Forward/Rear: 60° (horizontal), ±27° (vertical)<br>Downward: 70° (front and rear), 50° (left and right) |
| Measuring Frequency | Forward/Rear：10 Hz;<br>Downward：20 Hz |
| Operating Environment | Surfaces with clear patterns and adequate lighting(＞15 lux) |

## CAMERA

| | |
|---|---|
| Sensor | 1" CMOS; Effective pixels: 20 M |
| Lens | FOV 84°；8.8 mm / 24 mm(35 mm format equivalent:24 mm)；<br>f/2.8 - f/11, auto focus at 1 m - ∞ |
| ISO Range | Video:100-3200(Auto)<br>100-6400(Manual)；<br><br>Photo:100-3200(Auto)<br>100-12800(Manual) |
| Mechanical Shutter Speed | 8 - 1/2000 s |

| | |
|---|---|
| Electronic Shutter Speed | 8 - 1/8000 s |
| Max Image Size | 4864×3648 (4:3)；<br>5472×3648 (3:2) |
| Video Recording Modes | H.264，4K：3840×2160 30p |
| Photo Format | JPEG |
| Video Format | MOV |
| Supported File Systems | FAT32（≤ 32 GB）；<br>exFAT（> 32 GB） |
| Supported SD Cards | MicroSD, Max Capacity: 128 GB. Class 10 or UHS-1 rating required Write speed≥15 MB/s |
| Operating Temperature Range | 32° to 104° F (0° to 40℃) |

## INTELLIGENT FLIGHT BATTERY(PH4-5870MAH-15.2V)

| | |
|---|---|
| Capacity | 5870 mAh |
| Voltage | 15.2 V |
| Battery Type | LiPo 4S |
| Energy | 89.2 Wh |
| Net Weight | 468 g |
| Charging Temperature Range | 14° to 104℉(-10° to 40℃) |
| Max charging Power | 160 W |

## INTELLIGENT BATTERY CHARING HUB(WCH2)

| | |
|---|---|
| Input Voltage | 17.3 - 26.2 V |
| Output Voltage and Current | 8.7 V，6 A；5 V，2 A |
| Operating Temperature | 41° to 104℉(5° to 40℃) |

# Appendix C. Eos Arrow Gold RTK

EOS Positioning Systems

# ARROW Gold™

ARROW Series™

for 1cm RTK Accuracy, SafeRTK

## World's Most Advanced GNSS receiver for Every Mobile Device

*The Arrow Gold is the first high-accuracy iOS, Android, and Windows Bluetooth GNSS receiver to implement all four global constellations (GPS, GLONASS, Galileo, BeiDou), three frequencies (L1, L2, L5), and satellite-based RTK augmentation. The Arrow Gold works with all apps that run on iOS, Android, and Windows devices. It also supports all planned global satellite constellations as well as all planned signals, giving it an awesome return on investment that will serve you well into the next decade and beyond.*

### RTK Everywhere - Even in Poor Cell Coverage Areas

The Arrow Gold offers a new feature called SafeRTK. There's nothing more frustrating than trying to stay connected to an RTK network in areas with poor cell coverage. This feature is the answer. When the Arrow Gold loses connection to the RTK network, SafeRTK takes over in a few seconds and allows it to maintain RTK-level accuracy for up to 20 minutes, until the Arrow Gold is automatically reconnected to the RTK network. This results in smooth, RTK accuracy even in areas with poor cell coverage.

### No RTK Network Access Available? Pioneering Low-Cost Global Satellite

Do you work in an area without an RTK network available? The Arrow Gold features a 4 cm, real-time satellite correction service available anywhere in the world. Using all four constellations and signals, the Arrow Gold offers convergence times as low as 15 minutes anywhere in the world, at a revolutionary price point that works with all iOS, Android, and Windows devices.

For more details,
**www.eos-gnss.com**

### Key Features:

- Supports GPS, GLONASS, Galileo, BeiDou, QZSS
- Triple-Frequency L1/L2/L5
- 1 cm RTK real-time accuracy
- Long-range RTK baselines up to 50 km
- SafeRTK for poor cell coverage areas
- Worldwide satellite correction service
- 100 % iOS, Android, and Windows compatibility


### The Ultimate Accuracy for Your iOS, Android, or Windows Device

Of course, iOS, Android, and Windows compatibility is our expertise. Eos has the most advanced connectivity with all mobile devices and free software utilities to ensure compatibility with apps like Esri Collector, ArcPad, Survey123, and many other mobile GIS software apps.

# Specifications

## GPS Sensor

| | |
|---|---|
| Receiver Type: | GNSS multi-frequency RTK with carrier phase |
| Signals Received: | GPS: L1CA, L1P, L1C, L2P, L2C, L5 |
| | GLONASS: G1, G2, P1, P2 |
| | Galileo: E1BC, E5a, E5b |
| | BeiDou: B1, B2, B3 (without L5) |
| | QZSS: L1CA, L2C, L5, L1C |
| Channels: | 394-channel, parallel tracking |
| Number of Tracked Satellites: | 12 GPS (15 when no SBAS) |
| | 12 GLONASS |
| | 15 BeiDou |
| | 22 Galileo |
| | 4 QZSS |
| SBAS Support: | 3-channel, parallel tracking |
| | WAAS/EGNOS/MSAS/GAGAN (with SBAS ranging) |
| L-Band (Atlas): | 1 |
| Update Rate: | 1 Hz Default, Optional 10 Hz, 20 Hz, and 50 Hz |
| RTK Accuracy: | 1 cm[1] + 1 ppm Horizontal |
| SBAS Accuracy: | < 30 cm HRMS[1] |
| Atlas Accuracy: | H10: 4 cm |
| | H30: 15 cm |
| | H100: 50 cm |
| Autonomous Accuracy: | 1.2 meters HRMS[1] |
| Cold Start: | < 60 sec typical (no almanac or time) |
| Reacquisition: | < 1 sec |
| Max Speed: | 1,850 kph (1,150 mph / 999 knots) |
| Max Altitude: | 18,288 meters / 60,000 ft |

## Communication

| | |
|---|---|
| Port: | Bluetooth, USB 2.0, Serial (Optional) |
| Bluetooth Transmission: | Class 1, 300 m typical range[2], up to 1 km |
| Frequency: | 2.400 - 2.485 GHz |
| Fully Bluetooth Pre-Qualified: | Bluetooth 2.1 + EDR |
| Supported Bluetooth Profiles: | SPP and iAP |
| Data I/O formats: | NMEA 0183, RTCM SC-104, Binary |
| Output Datum: Autonomous: | WGS-84 (G1674) Epoch 2005.0 |
| SBAS & Atlas: | ITRF08 (current year epoch) |
| RTK: | Same as RTK base |
| Raw Measurement Data: | Binary and RINEX |
| Correction I/O Protocol: | RTCM 2.x, 3.x, CMR, CMR+, proprietary binary |
| GPS Status LEDs: | Power, GNSS, DGNSS, DIFF, Bluetooth |
| Battery Status LED: | 5 LED Indicator |
| Timing Output: (with optional serial port) | 1PPS, CMOS, active high, rising edge sync, 10 kΩ, 10 pF load |
| Event Marker Input: (with optional serial port) | CMOS, active low, falling edge sync, 10kΩ, 10 pF load |

## Power

| | |
|---|---|
| Battery Type: | Field replaceable, rechargeable Lithium-Ion pack (rechargeable inside unit or separately) |
| Battery Autonomy: | 8.5 hrs[3] (Atlas™ OFF) - 7+ hrs[3] (Atlas™ ON) |
| Charging Time: | 4 hours (vehicle charger available) |

EOS Positioning Systems

Eos Positioning Systems Inc.
Terrebonne (Quebec), Canada
Tel: (450) 824-3325
www.eos-gnss.com | info@eos-gnss.com

## Environmental

| | |
|---|---|
| Operating Temperature: | -40°C to +85°C (-40°F to +185°F)[3] |
| Storage Temperature: | -40°C to +85°C (-40°F to +185°F) |
| Humidity: | 95% non-condensing |
| Compliance: | FCC, CE, RoHS and Lead-free |

## Mechanical

| | |
|---|---|
| Enclosure Material: | Xenoy |
| Enclosure Rating: | Waterproof, IP-67 |
| Immersion: | 30 cm, 30 minutes |
| Dimensions: | 12.5 x 8.4 x 4.2 cm (4.92 x 3.3 x 1.65 in.) |
| Weight: | 372 g (0.82 lb) |
| Data Connectors: | Mini USB Type B Receptacle |
| Antenna Connector: | SMA Female |

## Antenna

| | |
|---|---|
| GPS Freq Range: | 1525 - 1606 MHz, 1164 - 1254 MHz |
| Impedance: | 50 OHMs |
| Gain (no cable): | 30 dB (± 2 dB) |
| LNA Noise Figure: | 2.5 dB Max at 25°C |
| Voltage: | +2.5 to +16 VDC |
| Connector: | SMA female |
| Dimensions: | 69 mm diam. x 22 mm (2.72 x 0.87 in.) |
| Weight: | 170 g (0.374 lbs) |
| Temperature: | -40°C to +85°C (-40°F to + 185°F) |
| Humidity: | Waterproof |

## Standard Accessories

| | |
|---|---|
| Li-Ion Battery Pack (Field replaceable) | Pole Bracket and Clamp |
| 12VDC Power Supply | Hard Shell Carrying Case |
| USB Cable | Antenna Cable |
| L1/L2/L5, L-Band GNSS Antenna | Antenna Mounting Plate |

## Field Activated Options

10 Hz, 20 Hz Output Rates

NOTES :
1. Depends on multipath environment, number of satellites in view, satellite geometry, baseline length (for local services) and ionospheric activities. Stated accuracies for baseline lengths of up to 50 km
2. Transmission in free space
3. Lithium-Ion battery performance degrades below -20°C (-4°F)



Made in Canada

Authorized Distributor

RevC-2017/09/19