EM-Bird Sensor Data

Product User Guide and Technical Specifications

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History of Modifications

Version	Date	Description of Modification	Chapter/Sections
1.0	2020-11-03	Initial Version	

1 Purpose of this Document

This document provides a brief overview of the concept of sea-ice thickness sounding using airborne electromagnetic induction, the geophysical parameters sensed by a specific sensor type as well as a technical description of the content and format of the data files containing the unprocessed sensor data. The description of the higher-level geophysical data products is not part of this document and can be found in the scientific literature. Rather, the information here is intended to document the raw sensor data and the general method concept to ensure any use of the raw data in future applications.

2 Sensor and Method Basics

This section provides a brief overview of the sensor, the recorded parameter and how these are related to the method of sea-ice thickness retrieval.

2.1 Applicable Sensor Types

The technical description in this document is applicable sensor data from EM-Birds built by Ferra Dynamic Inc that include a SBC6748 data acquisition unit. For EM-Bird of the Alfred Wegener Institute that applies to the EM-Bird "LEO" with data files from 2014 and later, as well as the EM-Bird "Orphan" with data files from 2018 and later.

2.2 Frequency Domain Electromagnetic Induction Sounding

The sensor design is based on the frequency-domain electromagnetic method that resolves the structure of the sub-surface based on its electrical conductivity. A full description of the application to sea-ice and its implementation with the EM-Bird's is given in [1].

The underlying principle of sea-ice thickness retrieval is the estimation of the range of the sensor to the ocean surface, by inducing electrical currents in the ocean using a magnetic dipole emitting a very-low frequency harmonic electromagnetic (EM) field and measuring the surface response. This is realized by a receiver and transmitter coil acting as an induction magnetometer. An additional laser altimeter measures the range to the sea ice surface and the difference to the EM-derived distance is the thickness of the sea ice layer including snow, if present.

The observational parameter used in the geophysical retrieval is the relative secondary field (Hs/Hp), with Hp being the primary field from the transmitter at the location of the receiver and Hs the surface response at the receiver location. The relative secondary field can be described by its amplitude and its phase with respect to the primary field, or by the Inphase (real part) and Quadrature (imaginary part). Since the secondary field is lower by several orders of magnitude than the primary field the target unit for Inphase and Quadrature is parts per million (ppm).

2.3 Data Acquisition

The data stream in the raw data files is aggregated from the different sensor components of the EM-Bird with added real-time processing and then transmitted to the operator PC via a wireless data link with observation frequency of 10Hz.

The content of recorded data falls into four categories, which characteristics are further outlined in the following sub-sections.

> In term of processing level, the data files should be regarded as processing Level-0 (uncalibrated sensor raw data) as post-processing is required, despite calibration procedures of the real-time Inphase/Quadrature solution.

2.3.1 EM-Subsystem

Data from the EM-Subsystem falls into two categories: Voltages describing the amplitude and phase of the transmitter and receiver coils and the real-time Inphase/Quadrature solution of the Hs/Hp. The parameters are recorded after analog/digital conversion and demodulation of the harmonic measurement of the coils that is presented as a complex number. The temporal resolution of the EM data is 100 msec.

Interpretation of the values needs to take the technical implementation into account:

1. transmitter voltages are not measured at Tx itself, but with a so-called pick-up coil that is attached to the transmitter coil. Any drift observed in the Tx voltages is therefore aggregated over the changing physical state of two coils.
2. The receiver system lacks the dynamic range to measure the sum of primary and secondary field. Instead, a bucking or compensation coil (Bx) is wired directly to the receiver coil with the purpose to cancel out by the primary field component at the location of Rx. In the idealized concept, in the absence of a secondary field Rx voltages are zero. In addition, the proximity of Bx to Tx results in a negligible contribution of the magnetic moment from the sub-surface, so that the bucking coil always only compensates the primary field. In practice however, the compensation is imperfect and a residual Tx contribution to the Rx voltages remains. In addition, Hs can become sufficiently large enough at the location of the Bx that the resulting overcompensation must be corrected in post-processing [2].
3. Rx voltages may contain the contribution of a calibration coil (Cx) that is manually activated by the operator and produces a signal of known properties. The presence of the Cx contribution on Rx are marked by a flag in the house keeping data stream.

2.3.2 Altimeter

The height of the sensor above the surface is measured with a laser distance meter. The data stream usually oversamples the EM data by a factor of 10 (temporal resolution 10 msec) and contains the range as well as a reflectivity of amplitude of the surface

2.3.3 GPS

The GPS sub-system provides geolocation and the reference time. The pulse-per-second (PPS) is used as the main trigger for the other sub-sensors

2.3.4 Housekeeping Data

In addition to the sensor data, the data output contains flags and parameters describing the state of the data acquisition system, such as the activation of the calibration coil, an event added by the operator

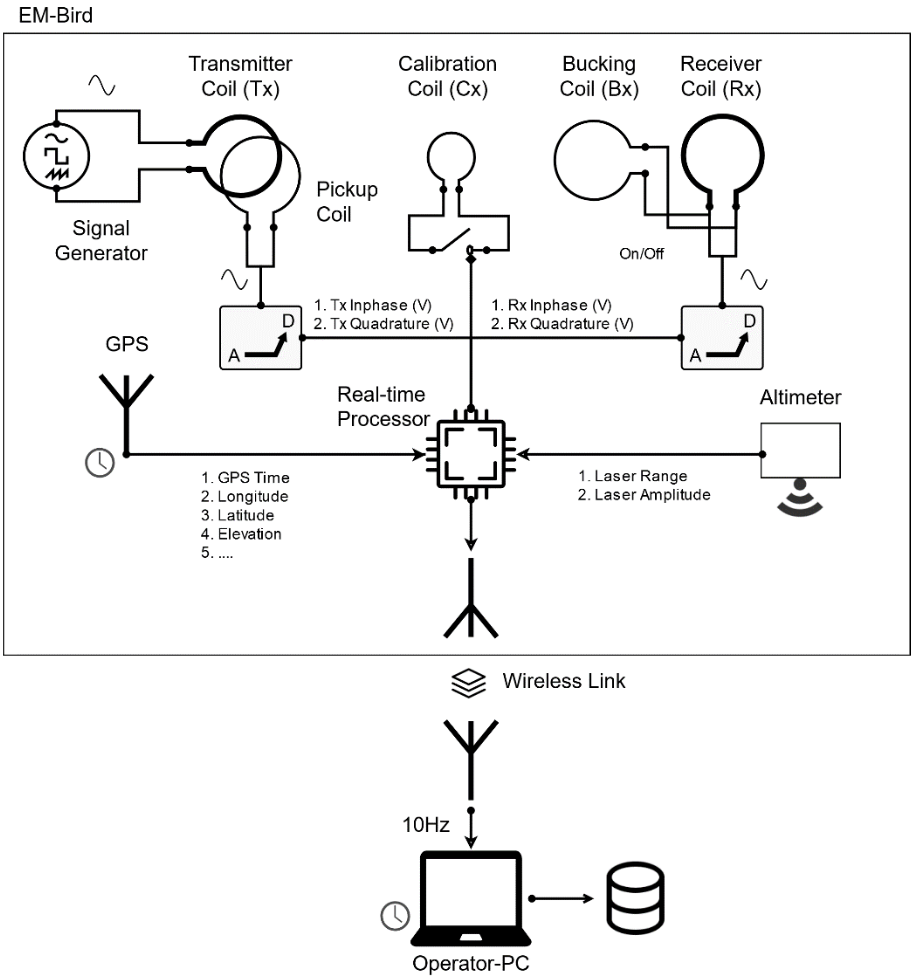

Figure 1: Sensor diagram and data flow chart of the EM-Bird (simplified)

2.4 Observation Strategy and Expected File Content

This section provided information on the intended content of single data file to enable the assessment of completeness and data quality. The running assumption is that the data contains sensor drift that cannot be modelled by the housekeeping data but must be corrected at dedicated segments of the flight profile. The standard procedure is the following:

1. The flight segment starts and ends with data at high altitude (laser range > 60 m/300 ft). At this altitude, the strength of the secondary field is negligible and the resulting Rx voltages contains a residual component, caused by imperfect compensation of the Tx voltages or interference. It must be assumed that the residual component is always changing with time, e.g. caused by temperature drift of the coils or amplifier.

2. Observations at high altitude also include the activation of the calibration coil, providing a change of both Inphase and Quadrature channels with known amplitude. The amplitude is provided in the metadata section of the data output.

3. The real-time Hs/Hp solution in ppm is based on constant empirical relation of the Rx voltages. A Hs/Hp solution in post-processing is possible, but only empirically as the data stream does not contain all information to convert the measured voltages to actual magnetic field strength.

The empirical relation can be constructed from measurements over open water if the electrical conductivity of the sea water is known.

3 Data Format and Content

3.1 Sensor Raw Data

The section describes the direct output of the data acquisition software. One file is generated between the action “record start” and “record stop”.

3.1.1 Filenaming Convention

The filename contains the date and time when the data recording was started. The timestamp is generated from the local computer that is running the data acquisition software. The time of this computer is usually not synchronized with a GPS, therefore a drift against UTC time of this timestamp is to be expected.

```
        <year><month><day><hour><minute>.dat
Example 202004040807.dat
```

3.1.2 File Content

Data is written into ASCII files that contain a header followed by the 10Hz data records. Parameter in the metadata and record entries are associated by a name tag, which are defined by “$” as the first character. The end of the header and the start of the data records is marked by two tags. Each data record spans over multiple lines and following records are separated by the END OF TEXT [ETX] character (ASCII code 3):

```
< start header lines >
…
< end header lines >
$SETUPEND
$DATA_START
< start data record #1 >
…
< data record #1 >
[ETX]
< data record #2 >
…
< data record #2 >
[ETX]
…
```

3.1.3 Metadata Content

The content of the metadata serves several purposes: It provides information on the version of the EM-Bird hardware, values for technical specifications, as well as a description of the data records in the data section.

Table 1: Header parameters

Line (in order of appearance)	Description
`$BYTES 00002025 Descriptor length (bytes)`	Header size
`$DATE, Saturday April 04 2020 08:07:25,`	Operator PC time
`$FILENAME_IS, 202004040807.dat,`	Filename
`$VERSION, (Ver: Win10) (2018 Oct 10 - AWI(Orphan)),`	Software version
`$TX_FREQUENCY, 4060.000000, Hz,`	Transmitter frequency in Hz (likely sample)
`$TX_AMPLITUDE_SAMPLE, 11.236231, volts,`	Number format and unit of Tx amplitude
`$TX_PHASE_SAMPLE, -0.930644, radians,`	Number format and unit of Tx phase
`$RX_AMPLITUDE_SAMPLE, 4.693635, volts,`	Number format and unit of Rx amplitude
`$RX_PHASE_SAMPLE, 2.719728, radians,`	Number format and unit of Rx phase
`$GPS_TIME_SAMPLE, 81336.000000, secs,`	Number format and unit of GPS time
`$GPS_POS_LONG_SAMPLE, 84.675757, degs,`	Number format and unit of GPS longitude
`$GPS_POS_LAT_SAMPLE, 12.761203, degs,`	Number format and unit of GPS latitude
`$GPS_POS_HEIGHT_SAMPLE, 121.430000, meters,`	Number format and unit of GPS ellipsoidal height
`$CX_CALIBRATION_II, 1060.000000, ppm,`	Expected inphase response of calibration coil
`$CX_CALIBRATION_QQ, 1060.000000, ppm,`	Expected quadrature response of calibration coil
`$CX_CALIBRATION_GAIN, 5000.000000, ppm/volt,`	Microvolts to ppm conversion factor
`$CX_CALIBRATION_PHASE, 0.000000, radians,`	Microvolts to ppm conversion factor
`$RAW_WIND_RECT left, right, top, bottom:{ 0, 0, 0, 0,}`	GUI parameter
`$VERSIONDATE_OWNER_BIRDNAME, 2018 Oct 10 - AWI(Orphan),`	Sensor ID
`$COILPAIR_1_FREQ_TXRXSEP, 4060 Hz, Tx-Rx 2.68 m,`	Frequency and separation of primary coil pair
`$COIL_1_TX_INDUCTANCE, 4060 Hz, 24.4, mH,`	Inductance of primary transmitter coil
`$COILPAIR_2_FREQ_TXRXSEP, none,`	Frequency and separation of secondary coil pair
`$COIL_2_TX_INDUCTANCE, none,`	Inductance of secondary transmitter coil
`$ENABLE_BESTPOS_GPS, OFF,`	GPS setting
`$FLIGHT_NUMBER, Flight:  3,`	Flight parameter (not used)
`$FLIGHT_TXSTART, TxStart:  0,`	Flight parameter (not used)
`$FLIGHT_SECTION, Section:  1,`	Flight parameter (not used)
`$FILTER_PL, ON,`	Powerline filter setting
`$DEFINE, $FID, N, HH:MM:SS,`	line format (fiducial number operator PC)
`$DEFINE, $FID_LONG, N,`	line format (time in seconds)
`$DEFINE, $BIRDFID, N,`	line format (fiducial number EM-Bird)
`$DEFINE, $EM_TX_4060HZ, ii, qq, volts,`	line format (transmitter voltages)
`$DEFINE, $EM_RX_4060HZ, ii, qq, volts,`	line format (receiver voltages)
`$DEFINE, $EM_RX_PPM, ii, qq, gain, (PPM, PPM, PPM/volt),`	line format (real-time ppm solution)
`$DEFINE, $GPS, time, xx, yy, zz, delay, quality, numSVs, hdop,`	line format (GPS parameters)
`$DEFINE, $GPS_PPS, 1-ON, 0-OFF,`	line format (GPS PPS flag)
`$DEFINE, $ALT_AVG_10HZ, hh, meters,`	line format (averaged altimeter range)
`$DEFINE, $ALT_100HZ, num, 10, samples(1-num)` `Per sample: ([range (m), delay(ms), amplitude(num)]),,`	line format (full resolution altimeter range)
`$DEFINE, $EM_TIMING, trigger, load, transfer, sent, msecs,`	line format (EM timing values)
`$DEFINE, $GPS_TIMING, trigger, load, transfer, sent, msecs,`	line format (GPS timing values)
`$DEFINE, $ALT_TIMING, trigger, load, transfer, sent, msecs,`	line format (Altimeter timing values)
`$DEFINE, $CAL_SWITCH1, cx1, cx2, cx3, 0-open, 1-closed,`	line format (calibration coil flag 1)
`$DEFINE, $CAL_SWITCH2, cx1 is phase circuit, cx2 is I=Q circuit, cx3-none,`	line format (calibration coil flag 2)
`$DEFINE, $EVENT, event1, event2, event3, event4, 0-off, 1-on,`	line format (events)
`$DEFINE, $UDP_DATA, isEM, isGPS, isALT, 1-yes, 0-no,`	line format (udp package flags)
`$RECORD DESCRIPTION`	End of record description
`$FILEAGE 2018`	file version

3.1.4 Data Record format

Each record of the 10Hz data telegram is stored in several lines, each started with a tag describing the following content. The meaning of the parameters is given in the header and repeated here for clarity.

Table 2: Description of 10Hz data record

Line Example	Description
$FID, 4161, 08:07:25	$FID, N, HH:MM:SS, Fiducial number and time of operator PC
$UDP_DATA, 1,1,1,	$UDP_DATA, isEM, isGPS, isALT, 1-yes, 0-no, Flag of UDP package reception for the sub-sensor data packages
$FID_LONG, 1585987627.1	$FID_LONG, N, Timestamp of operator PC (seconds since Jan 01 1970)
$BIRDFID, 4411	$BIRDFID, N, Fiducial number of the Bird (can diverge from corresponding value operator PC in case of data package loss)
$EM_TX_4060HZ, 6.7115870, -9.0114822,	$EM_TX_4060HZ, ii, qq, volts, The complex transmitter voltage as measured by the pickup coil
$EM_RX_4060HZ, -4.2822762, 1.9217790,	$EM_RX_4060HZ, ii, qq, volts, The complex receive voltage
$EM_RX_PPM, -12.04, -47.57, 5000.00,	$EM_RX_PPM, ii, qq, gain, (PPM, PPM, PPM/volt), Real-time Inphase/Quadrature ppm solution with conversion factor between receiver voltages and ppm solution
$GPS, 81336.20, 84.67567000, 12.76120800, 121.12999725, 17,1,11,0.80,	$GPS, time, lat, lon, elev, delay, quality, numSVs, hdop, GPS parameters
$GPS_PPS, 1	$GPS_PPS, 1-ON, 0-OFF, GPS pulse per second flag
$ALT_AVG_10HZ, 130.780,	$ALT_AVG_10HZ, hh, meters, Altimeter range in meters averaged to 10 Hz telegram
$ALT_100HZ, 10, 10, 131.070, 0, 816, 130.920, 10, 877, 130.870, 20, 935, 130.890, 30, 845, 130.800, 40, 912, 130.750, 50, 952, 130.660, 60, 697, 130.650, 70, 944, 130.560, 80, 894, 130.610, 90, 865,	$ALT_100HZ, num, 10, samples(1-num) Per sample: ([range (m), delay(ms), amplitude(num)]), Full resolution altimeter range data including time range, time delay and amplitude
$ALT_TEMP_10HZ, 7.9,	$ALT_TEMP_10HZ, temperature (degrees), Value of the temperature sensor (optional line)
$CAL_SWITCH, 0, 0, 0,	$CAL_SWITCH, cx1, cx2, cx3, 0-open, 1-closed, cx1 is phase circuit, cx2 is I=Q circuit, cx3-none, Calibration flag for three calibration types
$EVENT_FLAG, 0, 0, 0, 0,	$EVENT, event1, event2, event3, event4, 0-off, 1-on, Flags for 4 event types
$EM_TIMING, 212, 219, 220, 0, 0,	$EM_TIMING, trigger, load, transfer, sent, msecs, Timing values of EM data
$GPS_TIMING, 218, 134, 218, 220,	$GPS_TIMING, trigger, load, transfer, sent, msecs Timing values of GPS data
$ALT_TIMING, 697, 130, 70, 944,	$ALT_TIMING, trigger, load, transfer, sent, msecs, Timing values of altimeter data
[ETX]	Ascii code to signal end of record

3.2 Pre-Processed Sensor Data (ISIT)

The original sensor raw data is often archived together with a second, pre-processed version with the similar consistent data content but separated into different files depending the data stream. These files are usually to be found in a sub-folder termed `isit` and are used for a specific processing workflow.

The file naming closely follows the convention of the original source file with an additional tag signaling the content of the files.

3.2.1 Altimeter

The altimeter data file contains the full resolution of the altimeter measurements.

	<year><month><day><hour><minute>_alt.dat
Example	202004040807_alt.dat

Each file contains a header line and the following columns:

1. Fiducial number (serves as timestamp)
2. Laser range (height) in meter (Fill value: 999.99)
3. The echo strength (dummy value for some altimeter type)
4. Data rate per 10Hz telegram

3.2.2 GPS

The GPS data file contains the full resolution of the altimeter measurements.

	<year><month><day><hour><minute>_gps.dat
Example	202004040807_alt.dat

Each file contains a header line and the following columns:

1. GPS week (0: dummy value for newer file versions)
2. GPS seconds of the week (or seconds of the data if GPS week is dummy value)
3. Latitude in degrees north
4. Longitude in degrees east
5. WGS84 elevation in meter
6. Fiducial number (serves as timestamp)
7. GPS speed in meter/sec (0.0: dummy value for newer file versions)
8. True heading in degrees (0.0: dummy value for newer file versions)

3.2.3 Receiver/Transmitter Voltages

This content of this file is deprecated except for the fiducial number (first column).

	<year><month><day><hour><minute>_f1.dat
Example	202004040807_f1.dat

3.2.4 Events

This file contains a list of events together with the time and location.

	<year><month><day><hour><minute>_evt.dat
Example	202004040807_evt.dat

3.2.5 Real-time Hs/Hp

This file contains the real-time solution of the Hs/Hp observable in ppm. The file only contains Inphase (first column) and Quadrature (second column) in ppm. Any colocation with the other data streams (GPS and altimeter) must be made with the fiducial number of the file with the receiver/transmitter voltages (`*_f1.dat`).

	`<year><month><day><hour><minute>_ppm.dat`
Example	`202004040807_ppm.dat`

4 References

[1]	Haas, C. , Lobach, J. , Hendricks, S. , Rabenstein, L. and Pfaffling, A. (2009): Helicopter-borne measurements of sea ice thickness, using a small and lightweight, digital EM system , Journal of Applied Geophysics, 67 (3), pp. 234-241, doi:10.1016/j.jappgeo.2008.05.005
[2]	Hunkeler, P. , Hendricks, S. , Hoppmann, M. , Farquharson, C. , Kalscheuer, T. , Grab, M. , Kaufmann, M. S. , Rabenstein, L. and Gerdes, R. (2016): Improved 1D inversions for sea ice thickness and conductivity from electromagnetic induction data: Inclusion of nonlinearities caused by passive bucking , GEOPHYSICS, 81 (1), WA45-WA58 . doi: 10.1190/GEO2015-0130.1