
# IVAQ Finder

## SoBigData ChallengeUs Kick-Off Presentation

01st July 2024

IVAQ
MOUNTAIN RESCUE DRONES

Diego Sánchez Franco

# IVAQ Finder

# SoBigData ChallengeUs Kick-Off

## AGENDA

**IVAQ**

- Problem & Solution
- Team & Roadmap
- Short & Medium Term Planning
- Product & Service
- Strategy Change 05/2024
- Finder Prototype v2 Architecture
- Avalanche Beacons
- Short & Medium Term Planning

**So BigData Challenge**

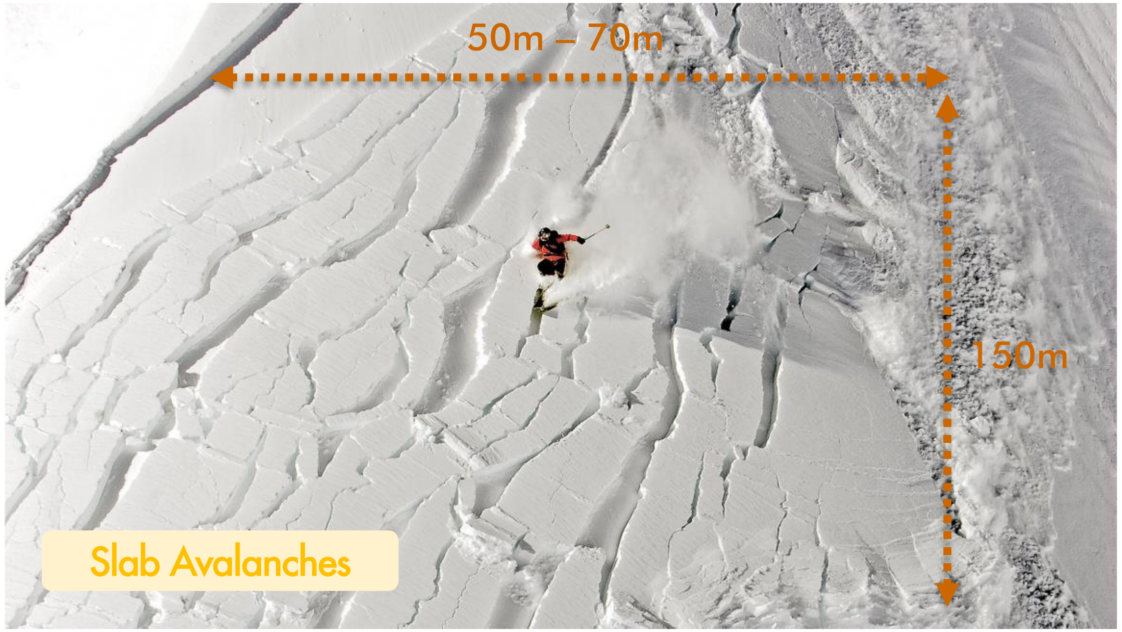
- Goal
- Data
- Proposed Solution

# IVAQ – Problem & Solution

- ✓ **Snow avalanches** are natural events, that propagate incredibly fast and are really difficult to predict.
- ✓ In 2023 around **400 people got buried** in avalanches all around the world. **Only half survived.**
- ✓ **Rescue time** is a **key factor** predicting the **survivability of the victim**. Survivability, or probability to survive, decreases exponentially with the time of burial.
- ✓ The **basic safety avalanche equipment** consists of 3 elements: **avalanche beacon, probe and shovel.**
- ✓ The **goal of IVAQ** is to **accelerate enormously the search** by introducing a 4th element:

**IVAQ Finder**

A drone capable of locating up to **4 Avalanche Beacons** in an area of **200mx200m** in less than **5 minutes**.



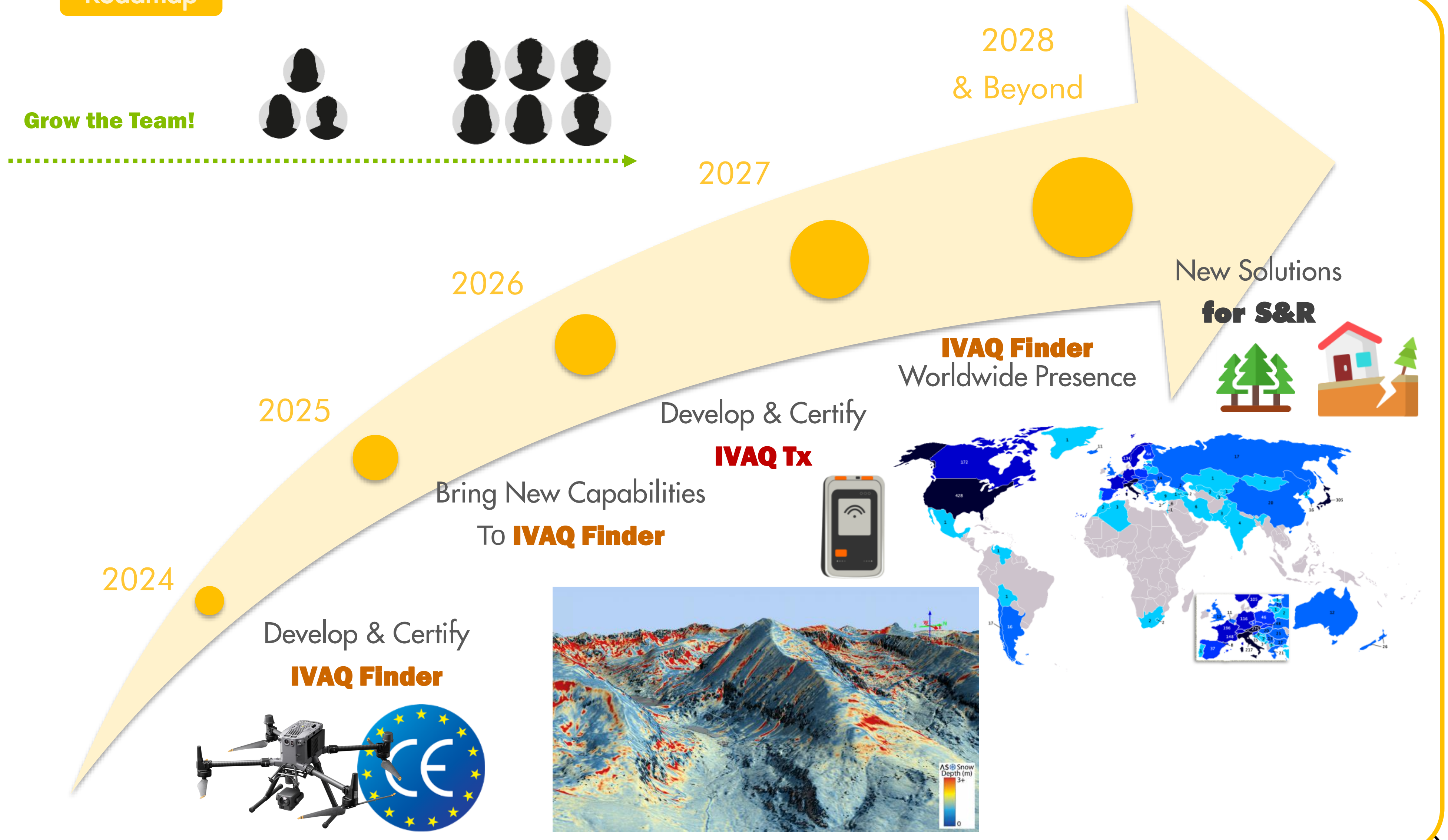

# IVAQ – Team & Roadmap

## Team

**Diego Sánchez Franco**
*Software Wizard & Business Brainiac*

**Alberto Sánchez López**
*Hardware Hero & Money Master*

## Roadmap



# IVAQ – Short & Medium Term Plan

## Planning

esa BUSINESS INCUBATION CENTRE Madrid Region

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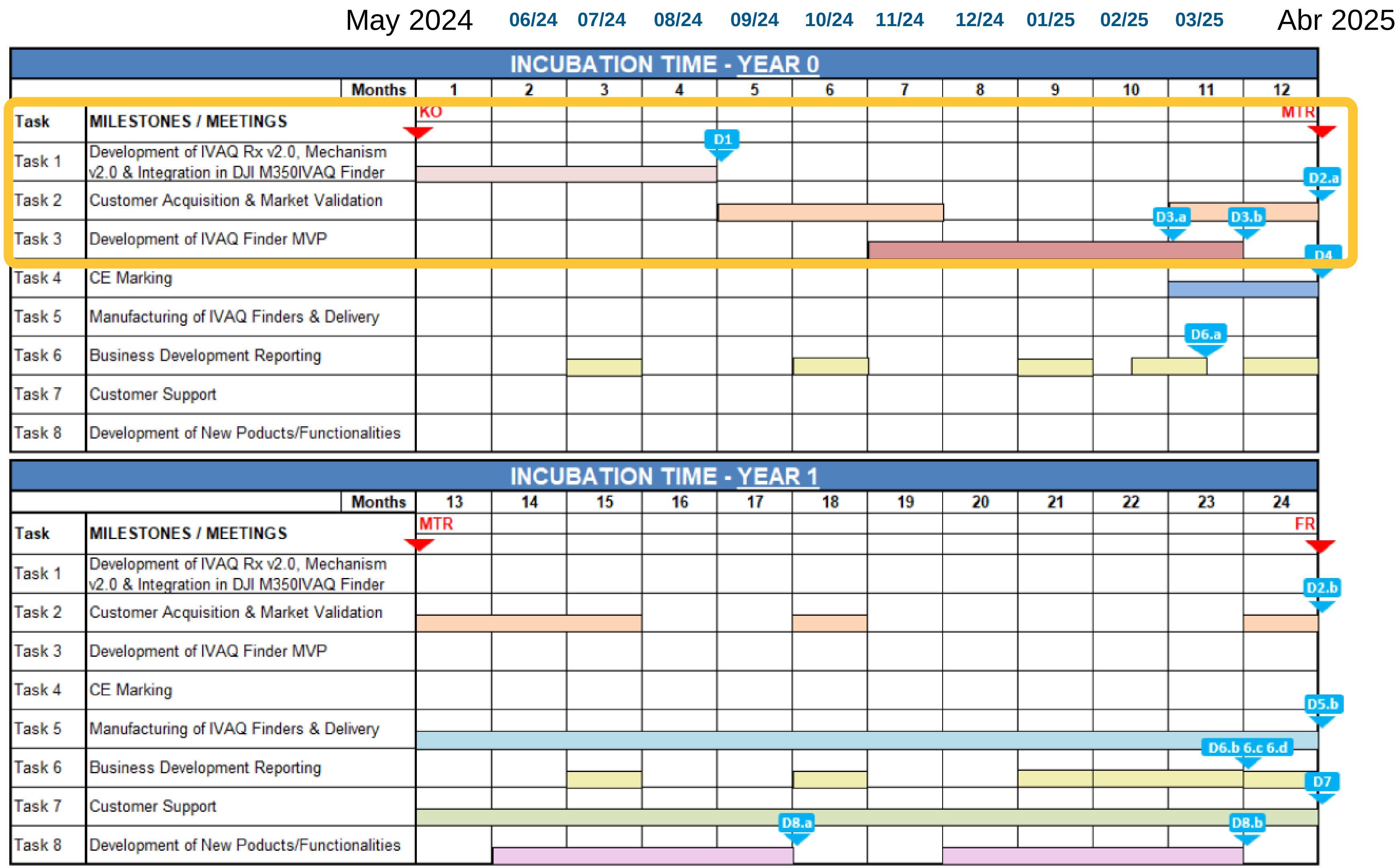
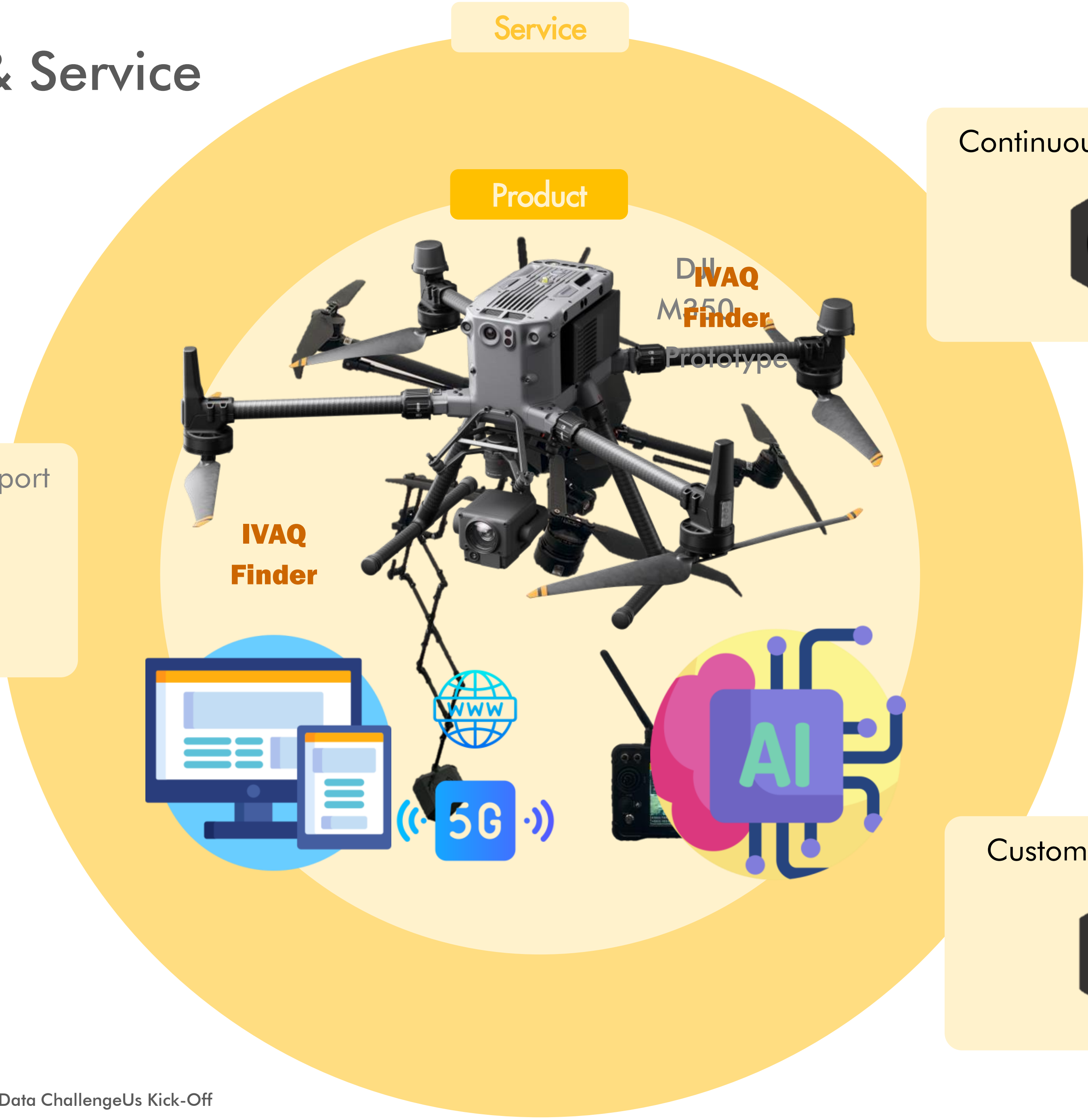



*Figure 1. IVAQ's 24-month ESA-BIC Incubation Program Planning.*

# IVAQ – Product & Service




Continuous Improvements

Free Maintenance Support

Customization Features

# IVAQ – Strategy Change 05/2024

## Before

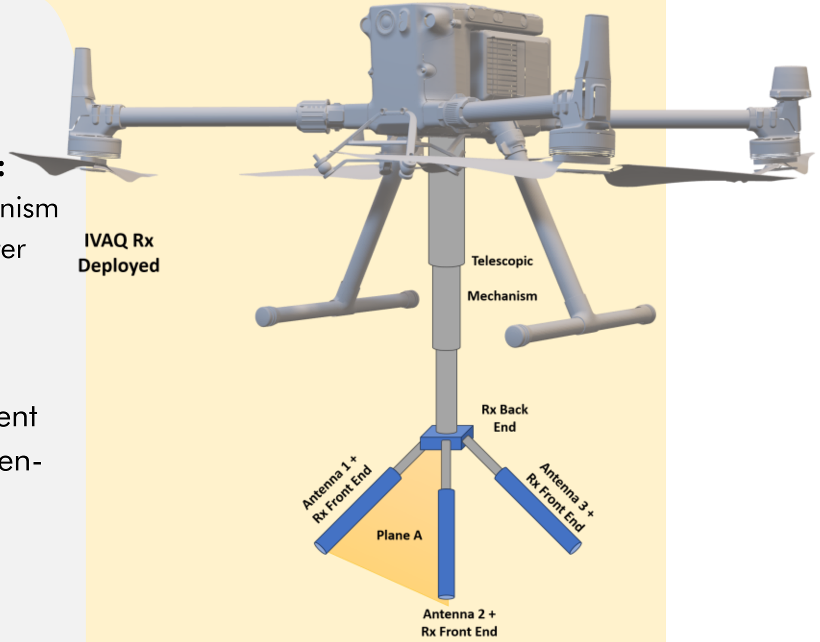
### IVAQ Finder Prototype v1

- **Complete system:**
  - ✓ Drone
  - ✓ Receiver + Mechanism
  - ✓ Android App (QGC modified)
- **Proprietary HW & SW in IVAQ Receiver**
- **Proprietary SW** over Open-Source in **Autopilot & Ground Station**
- **Drawbacks:**
  - Drone Design & Certification
  - Mission Control only possible from GS
  - Complex Mechanism
  - 1-antenna Receiver

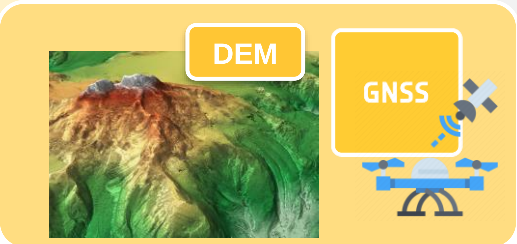
## After

### IVAQ Finder Prototype v2

- **Drone COTS (DJI M350)**
- **Focus on Payload:**
  - ✓ Receiver + Mechanism
  - ✓ On-board computer
  - ✓ Web App
- **Drawbacks:**
  - Drone Development Ecosystem not open-source
- **Advantages:**
  - Drone highly performant & reliable
  - Mission Control from every platform & from everywhere.
  - Simpler Mechanism
  - 3-antenna Receiver

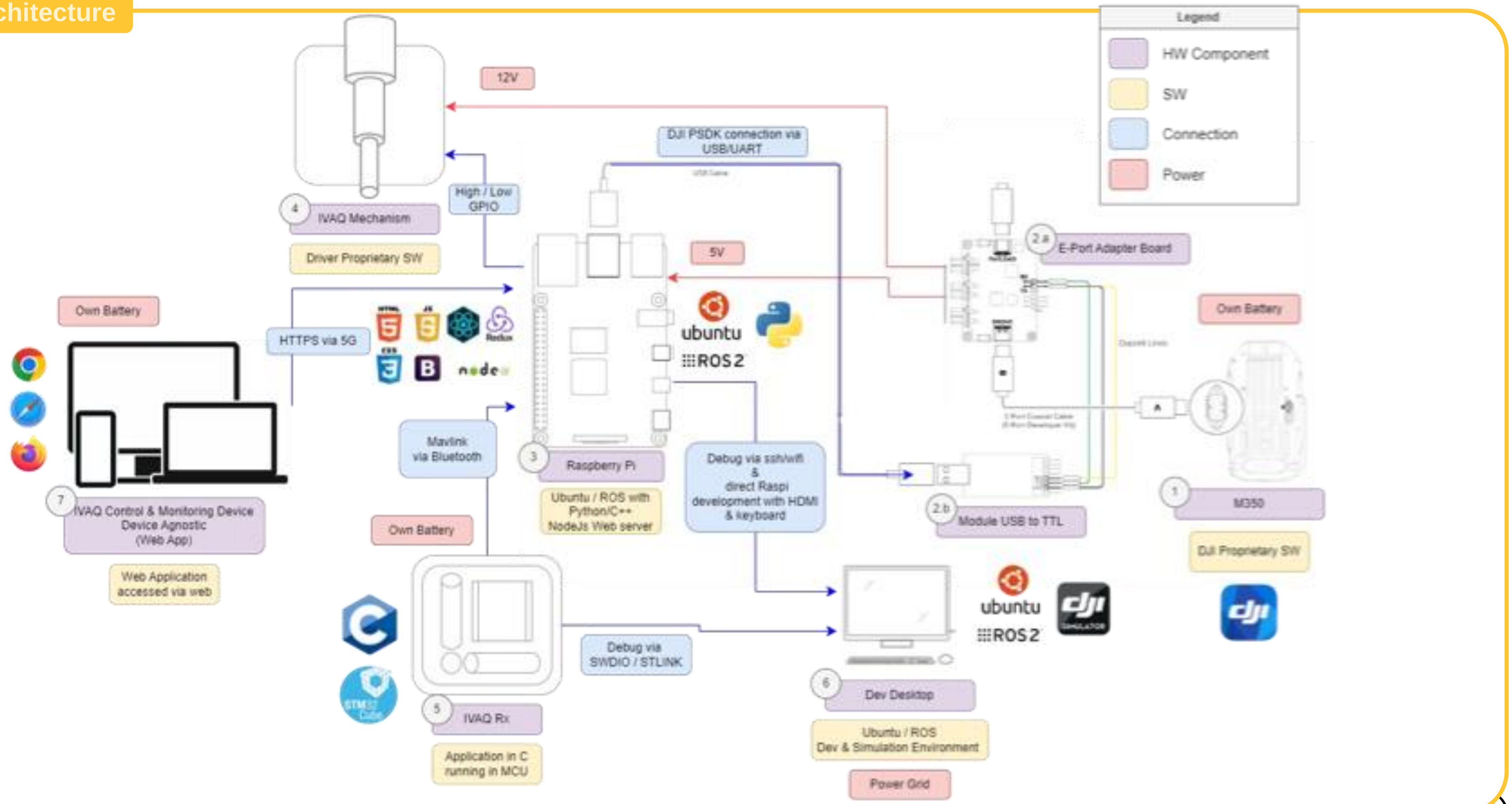






# IVAQ – Finder Prototype v2 Architecture

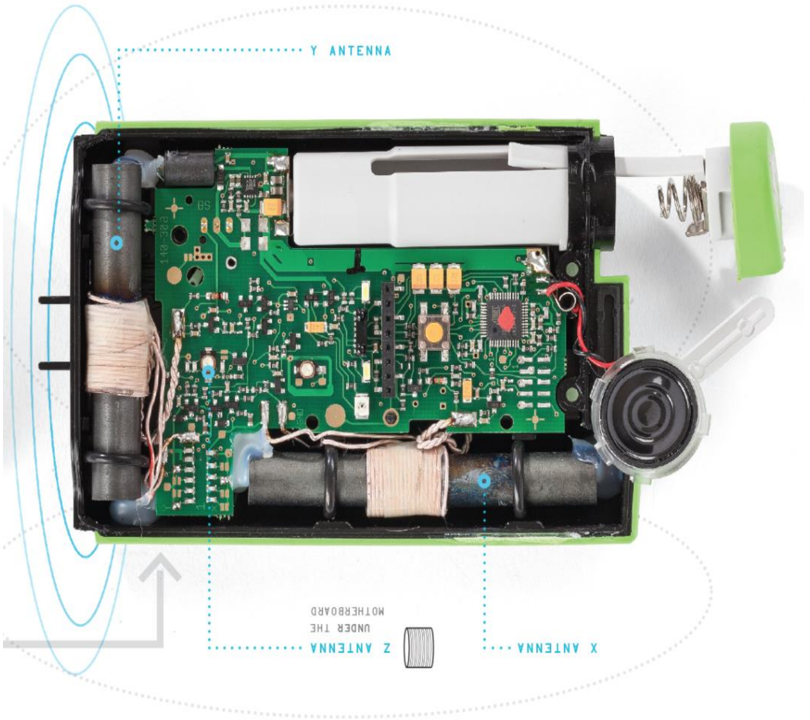
## Architecture

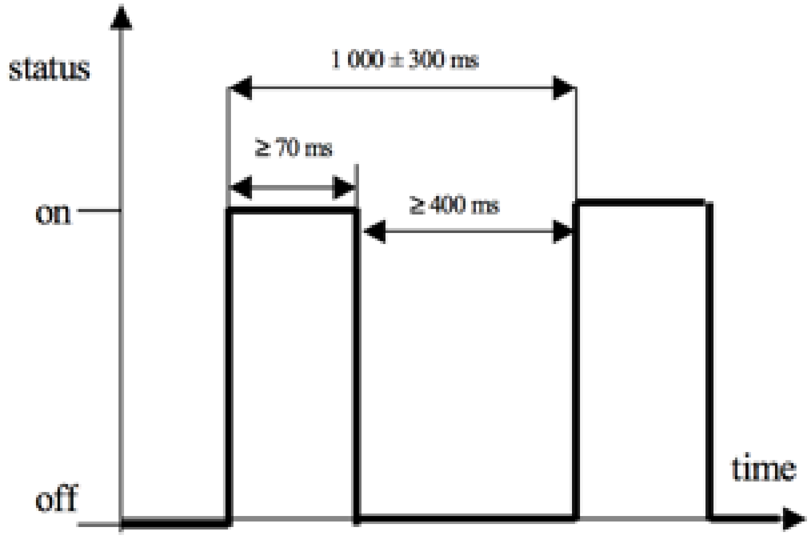


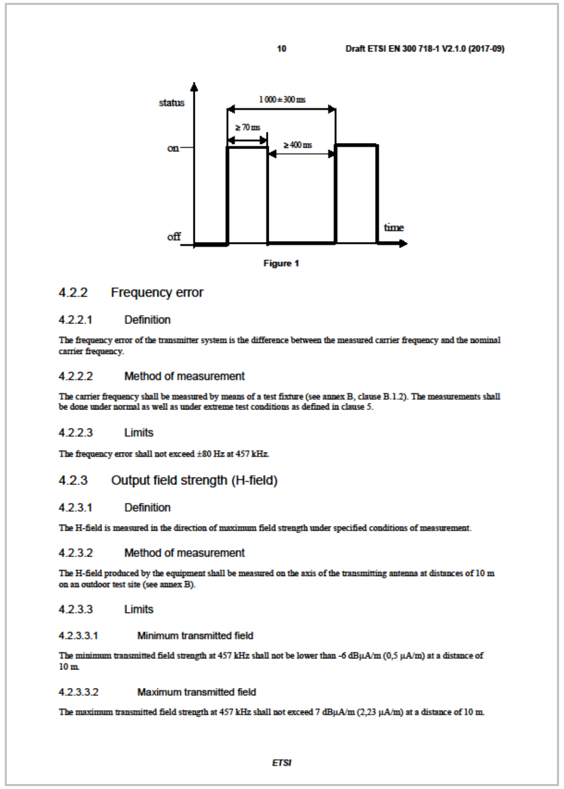
# IVAQ – Avalanche Beacon (I)

## Transmitter

The harmonized standard of the European Telecommunications Standards Institute (ETSI) EN 300 718-2 (4), which complies with EU Parlament Directives 2014/53/EU and 2011/65/EU, specifies that the **modulation** of this signal shall be of **type A1A**, with a carrying keying as shown below, where the **frequency of the carrier is 457kHz** with a +- 80Hz tolerance.



10 Draft ETSI EN 300 718-1 V2.1.0 (2017-09)



**Figure 1**

#### 4.2.2 Frequency error

##### 4.2.2.1 Definition

The frequency error of the transmitter system is the difference between the measured carrier frequency and the nominal carrier frequency.

##### 4.2.2.2 Method of measurement

The carrier frequency shall be measured by means of a test fixture (see annex B, clause B.1.2). The measurements shall be done under normal as well as under extreme test conditions as defined in clause 5.

##### 4.2.2.3 Limits

The frequency error shall not exceed ±80 Hz at 457 kHz.

#### 4.2.3 Output field strength (H-field)

##### 4.2.3.1 Definition

The H-field is measured in the direction of maximum field strength under specified conditions of measurement.

##### 4.2.3.2 Method of measurement

The H-field produced by the equipment shall be measured on the axis of the transmitting antenna at distances of 10 m on an outdoor test site (see annex B).

##### 4.2.3.3 Limits

4.2.3.3.1 Minimum transmitted field

The minimum transmitted field strength at 457 kHz shall not be lower than -6 dBµA/m (0,5 µA/m) at a distance of 10 m.

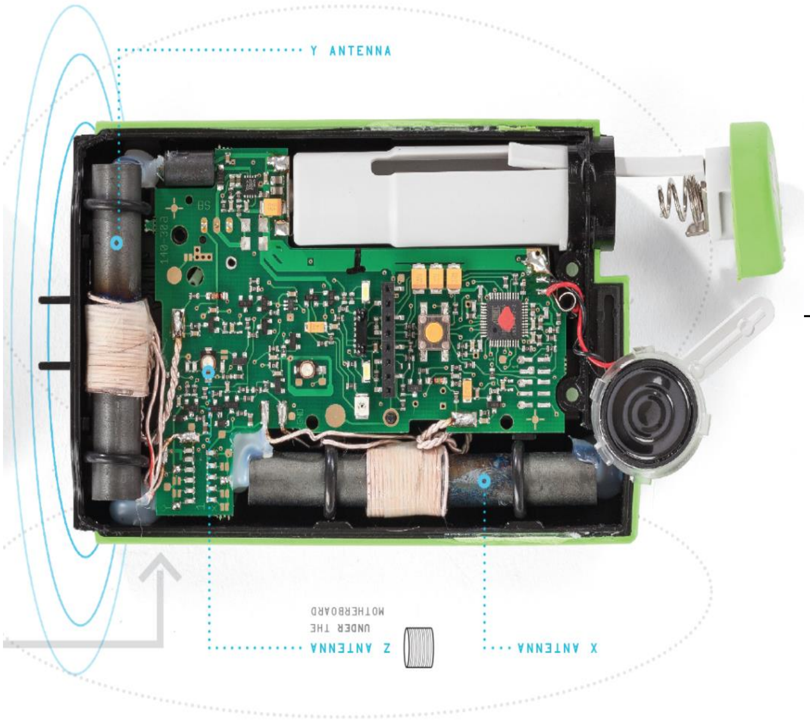
4.2.3.3.2 Maximum transmitted field

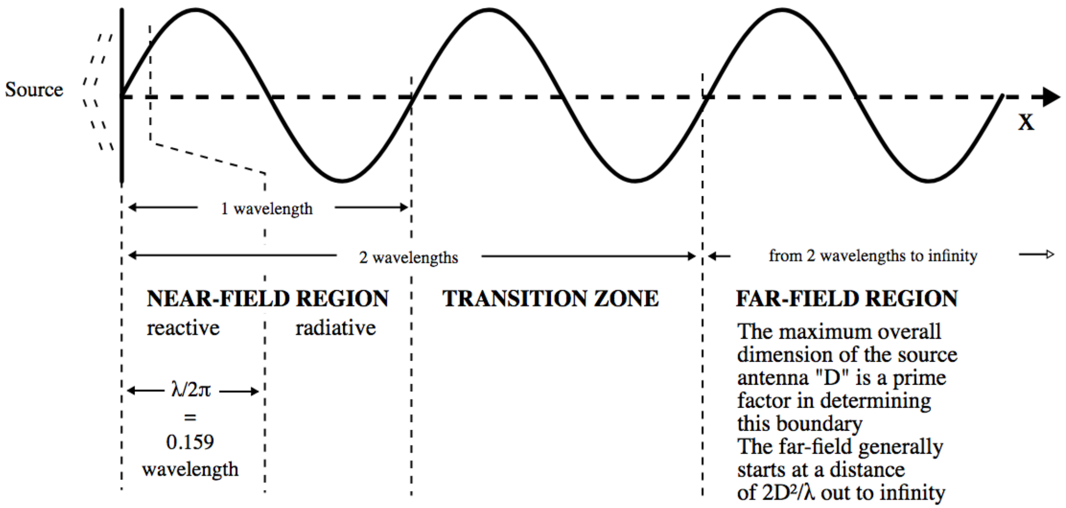
The maximum transmitted field strength at 457 kHz shall not exceed 7 dBµA/m (2,23 µA/m) at a distance of 10 m.

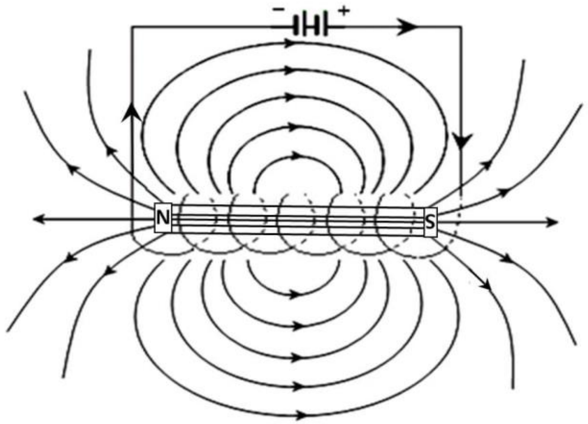
*ETSI*

# IVAQ – Avalanche Beacon (II)

## Receiver Physiscs




$$\mathcal{E} = -\frac{d\Phi_B}{dt} \quad where\ \Phi_B = \oint \vec{B} \cdot dA$$

# IVAQ – Avalanche Beacon (III)

## Current Search Methodology

### Search Phases

In an avalanche search, the following phases are distinguished:

using transceiver

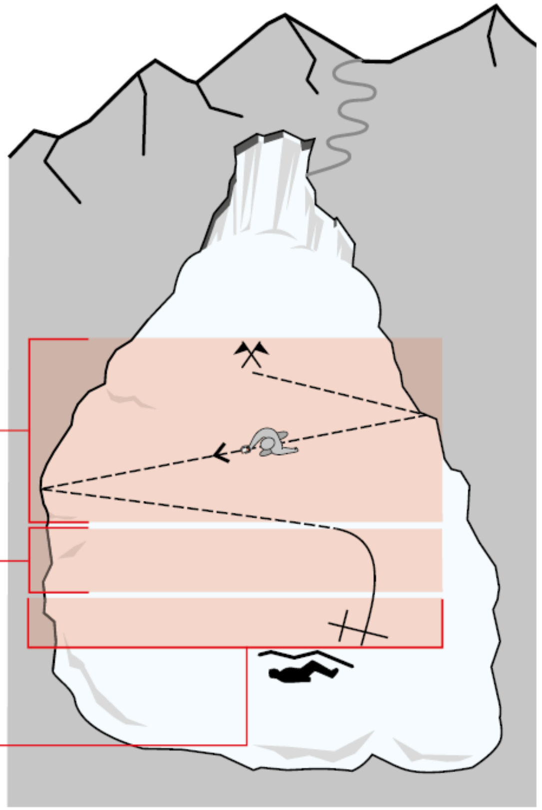
using probe

**1 Signal search**
Search area to the point where the first clearly audible signal can be detected.

**2 Coarse search**
Search area starting from the reception of the first signal until the immediate vicinity of the buried subject. In this phase the signal search pattern is abandoned in order to follow the signals leading to the buried subject.

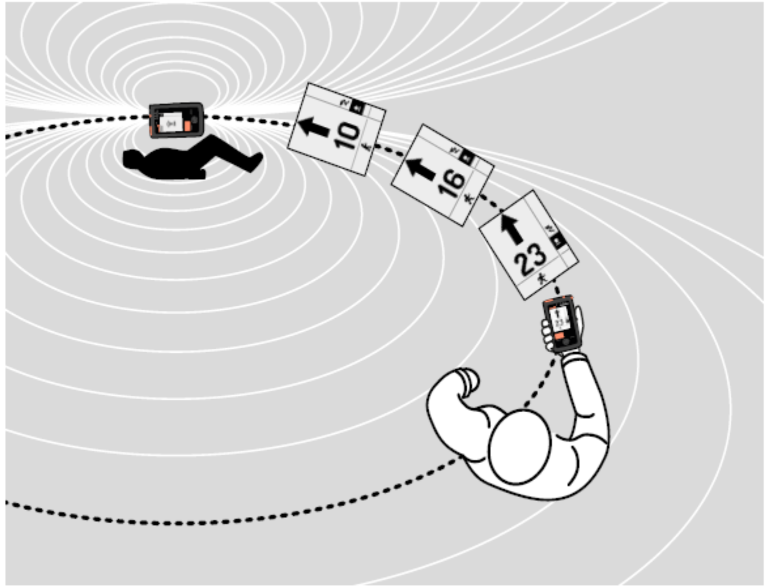
**3 Fine search**
Search area in the immediate vicinity of the buried subject.

**4 Pinpointing**
First use of the probe until probe hit.



2

Search Along the Field Line: Flux Line Search




**BARRYVOX®S** **EXTENDED REFERENCE GUIDE** **SEARCH** **29**

# IVAQ – SoBigData ChallengeUs (I)

## Goal

Develop a **Localization Algorithm** based on **Neural Networks** (or any other architecture that the RIs see fit) that **based on simulation & experimental data** is capable of locating the **position of an emitter** avalanche beacon in **3D space** (x, y, z) and its orientation $(\theta, \phi)$.

## Requirements

Ideally the localization algorithm should be:

- Capable of running in a **computationally-constrained on-board computer**, such as a Raspberry Pi (Nvidia Jetson may be considered)
- **Fast**
- **Independent of drone's navigation loop** (not requiring a feedback loop with the navigation system that depends on the real-time results).
- **Coded in Python or C++** to integrate it seamlessly into the ROS software architecture.
- Capable of locating at least 1 beacon, and ideally more than 1.

# IVAQ – SoBigData ChallengeUs (II)

## Data

Localization Algorithm will be based in 2 sources of data:

1) **Receiver´s Position:** For this exercise (at least in a first approximation) the position of the Receiver will be considered known at all times.
2) **Receiver´s Perceived Signal strength:** The signal received by each antenna (induced voltage) in the receiver is proportional to the magnetic field ($\boldsymbol{B} = \mu \cdot \boldsymbol{H}$). The magnetic field sensed by the antenna is function of: receiver´s position and orientation (known), transmitter position & orientation (not known), transmitter´s magnetic moment (kind of known).

→ Two sources of data: theoretical & experimental.

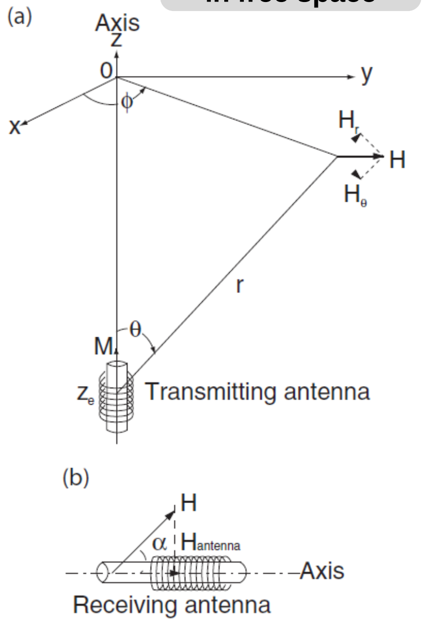
**Update Post-Meeting: Signal Propagation Model provided by IVAQ (& Partially Validated)**

## Theoretical Data

Work from Universidad de Zaragoza:

1. A deep insight into avalanche transceivers for optimizing rescue — Documento Adobe Acrobat
2. A computational Channel Moel for magnetic inuction-based subsurface applications — Documento Adobe Acrobat
3. Fast localization of avalanche victims using sum of Gaussians — Documento Adobe Acrobat

### Magnetic Dipole in free space




**2. Basics of search by avalanche transceivers**

*2.1. Avalanche transceivers as magnetic dipole transmitters and receivers*

An avalanche transceiver transmitter drives a 457 kHz current through a wired ferrite core loop. Details are specified in the standard *ETS 300718* (ETSI, 2001). This results in a magnetic dipole that generates a magnetic moment $M$ according to the description shown in Fig. 1a

Traditionally, the surrounding media is considered a vacuum and the effects of the snow and underlying soil are discarded. Therefore, the near field limit is assumed as the transmitter-to-receiver range, $r$, satisfies the condition $r \ll \lambda_0/2\pi \approx 104$ m where $\lambda_0$ is the free-space wavelength. Consequently, the magnetic field intensity due to a magnetic dipole source centered at the origin and transmitting along the z-axis can be conveniently written in the spherical coordinate system as:

$$H_r = \frac{M}{2\pi r^3}\cos\theta \tag{1}$$

$$H_\theta = \frac{M}{4\pi r^3}\sin\theta \tag{2}$$

$$H_\phi = 0 \tag{3}$$

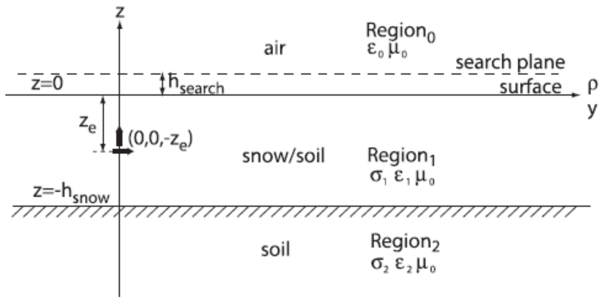
and the magnitude of the field as

$$H = \frac{M}{4\pi r^3}\sqrt{1 + 3\cos^2\theta}. \tag{4}$$

For a single antenna device, on reception the sensed magnetic field is determined by the relative orientation, $\alpha$, between the magnetic field and the axis of the receiving antenna (see Fig. 1b):

$$H_{antenna} = H \cdot \cos\alpha. \tag{5}$$

### Magnetic Dipole in three-layered space




Formulation **a lot more complex** to solve and **not really needed**! (See refs. 1 and 2)

**Link to GitHub Repository!**

# IVAQ – SoBigData ChallengeUs (III)

## Data

Localization Algorithm will be based in 2 sources of data:

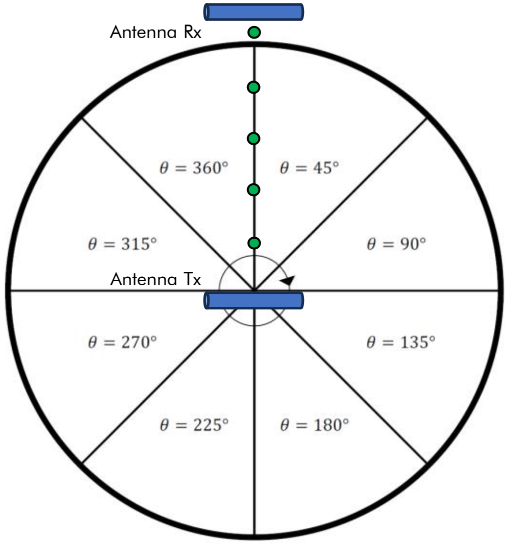
1) **Receiver´s Position:** For this exercise (at least in a first approximation) the position of the Receiver will be considered known at all times.
2) **Receiver´s Perceived Signal strength:** The signal received by each antenna (induced voltage) in the receiver is proportional to the magnetic field ($\boldsymbol{B} = \mu \cdot \boldsymbol{H}$). The magnetic field sensed by the antenna is function of: receiver´s position and orientation (known), transmitter position & orientation (not known), transmitter´s magnetic moment .

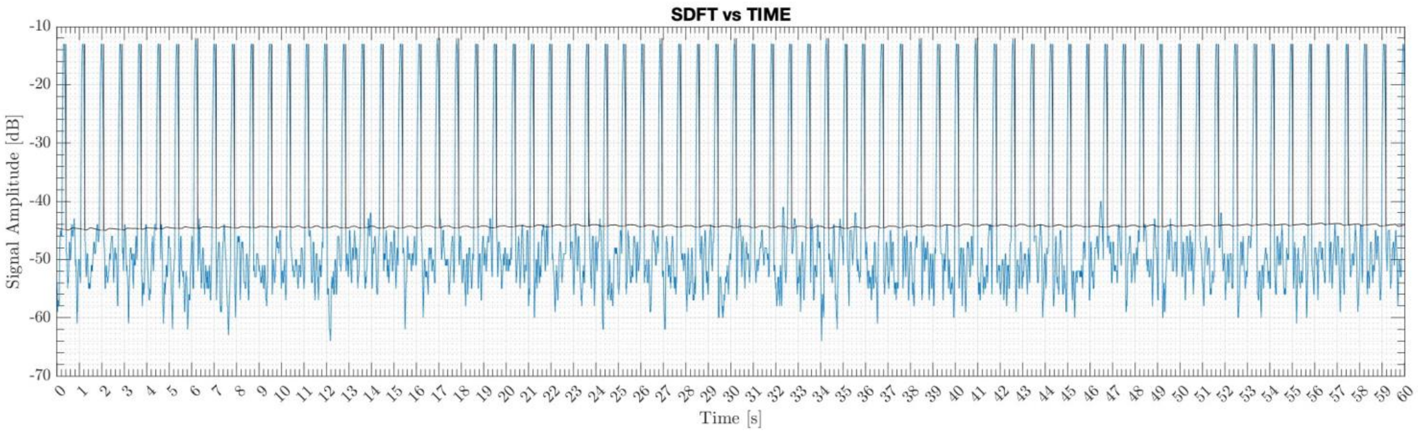
→ Two sources of data: theoretical & experimental.

**Update Post-Meeting: Signal Propagation Model provided by IVAQ (& Partially Validated)**

## Experimental Data

With **IVAQ Receiver v1**, we can obtain experimental data to **validate propagation model**:




20m Fixed-Distance from emitter.
Antennas in Parallel.
2 Amplification Stages On

# IVAQ – SoBigData Cl

Data

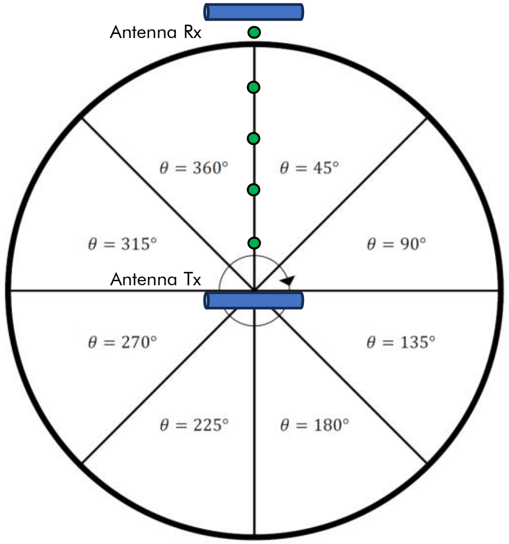
Localization Algorithm will be base

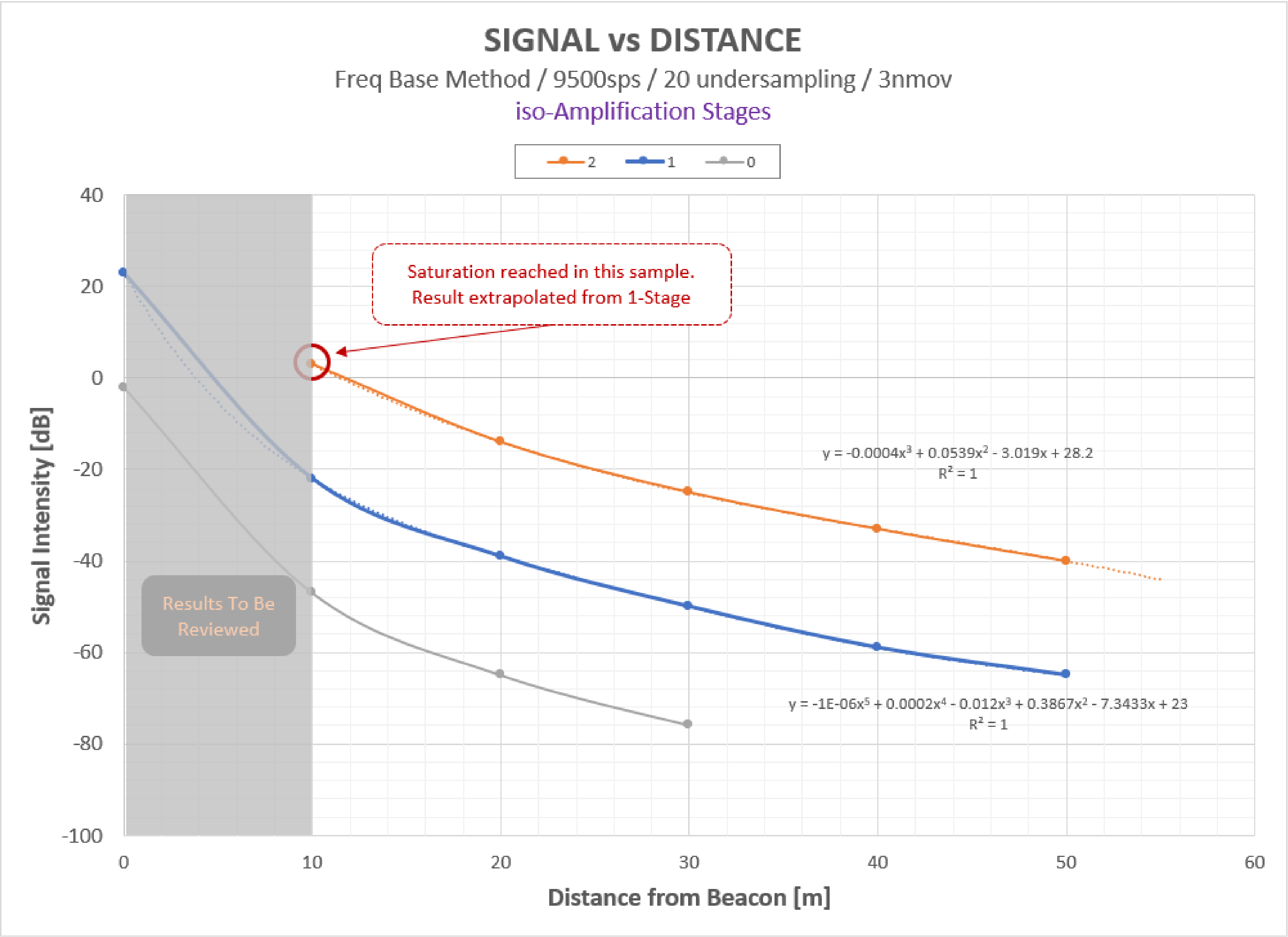
1) **Receiver´s Position:** For this e

2) **Receiver´s Perceived Signal**
magnetic field ($\boldsymbol{B} = \mu \cdot \boldsymbol{H}$). The
transmitter position & orientati
→ Two sources of data: theoret

**Experimental Data**

With **IVAQ Receiver v1**, we can o



# IVAQ – SoBigData Challenge

Solution Proposal

**Search in 2 phases**

**Phase 1: Signal Search "without accuracy"** (Readings every 20m aprox.)

- Red spiral trajectory:

$$d = \sum_{n=1}^{10-1} n\,(2 * 20m) + 9 * 20m = 1980m$$

*At 15m/s in 70ms (pulse width) the drone has travelled ~1m → acceptable*

$$v = 15\ m/s$$

$$t = \frac{d}{v} = 2.2min$$

**Phase 2: Accurate localization of position and inclination of the emitter using NN or other optim. method**
(readings every 2m aprox.) in Phase 1 high intensity areas

- Yellow spiral trajectory:

$$d = \sum_{n=1}^{10-1} n\,(2 * 2m) + 9 * 2m = 198m$$

$$v = 2\ m/s$$

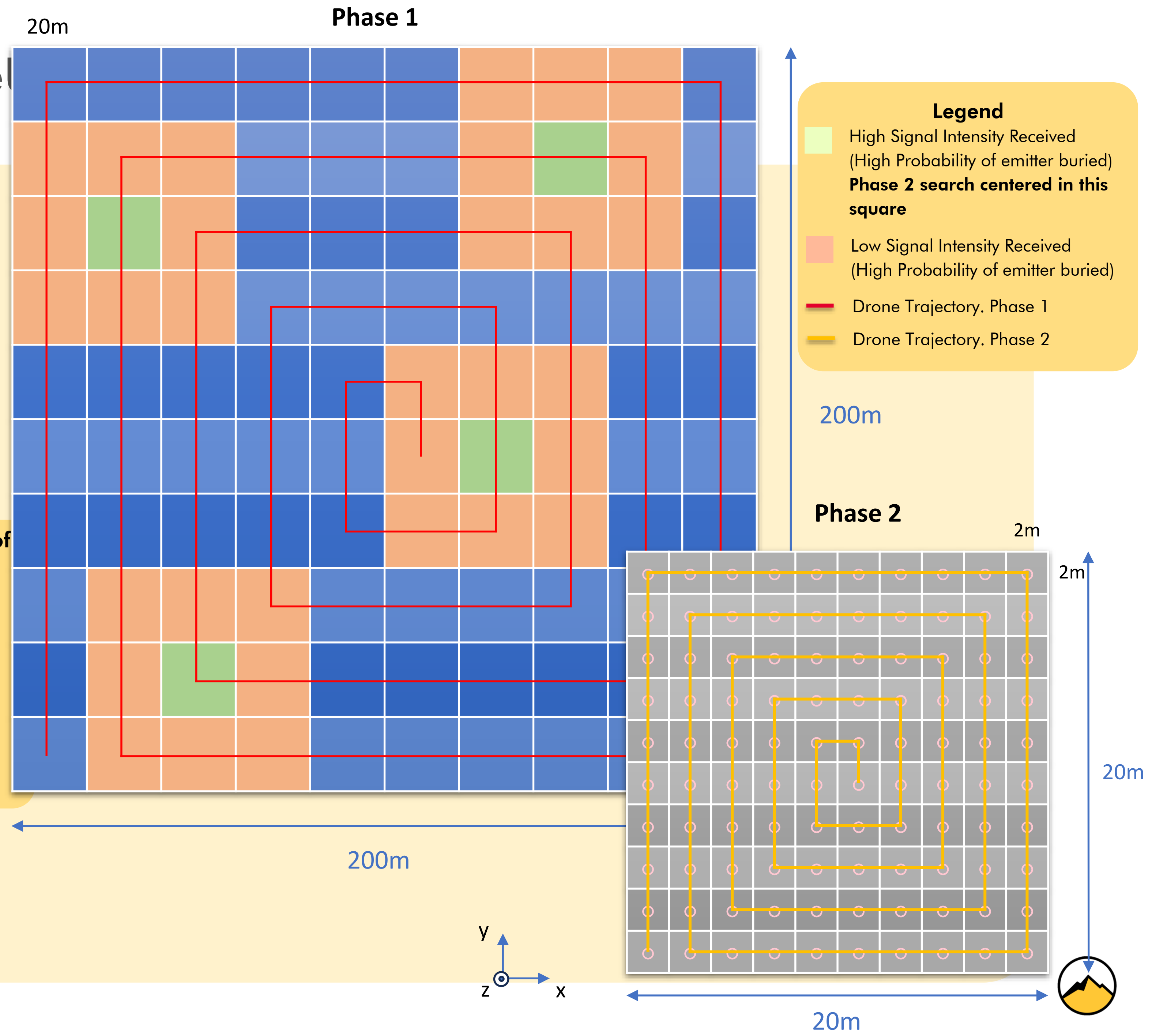
$$t = \frac{d}{v} = 1.65min$$

**SoBigData** Challenge **Task**

**Conclusion:**

✓ Time to find:

- 2 victimes: 132+2*99 = 330s =**5.5min**
- 4 victimes: 132+4*99 = 330s =**8.8min**



# IVAQ – SoBigData ChallengeUs

Solution Proposal

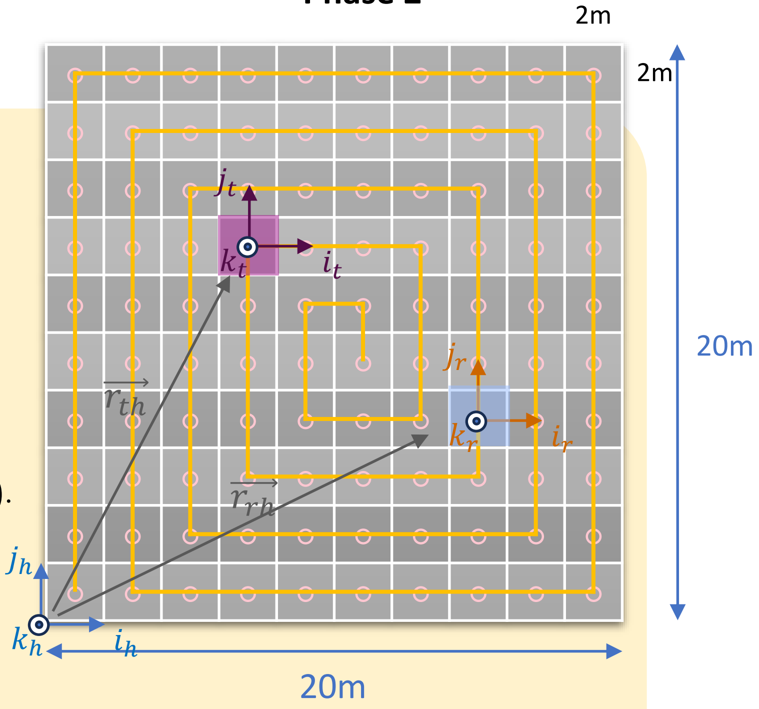
**Slide Added Post-Meeting:**

**Phase 2: Accurate localization of position and inclination of the emitter using NN, Optimization algorithms or similar method**

❖ **Hypotheses:**

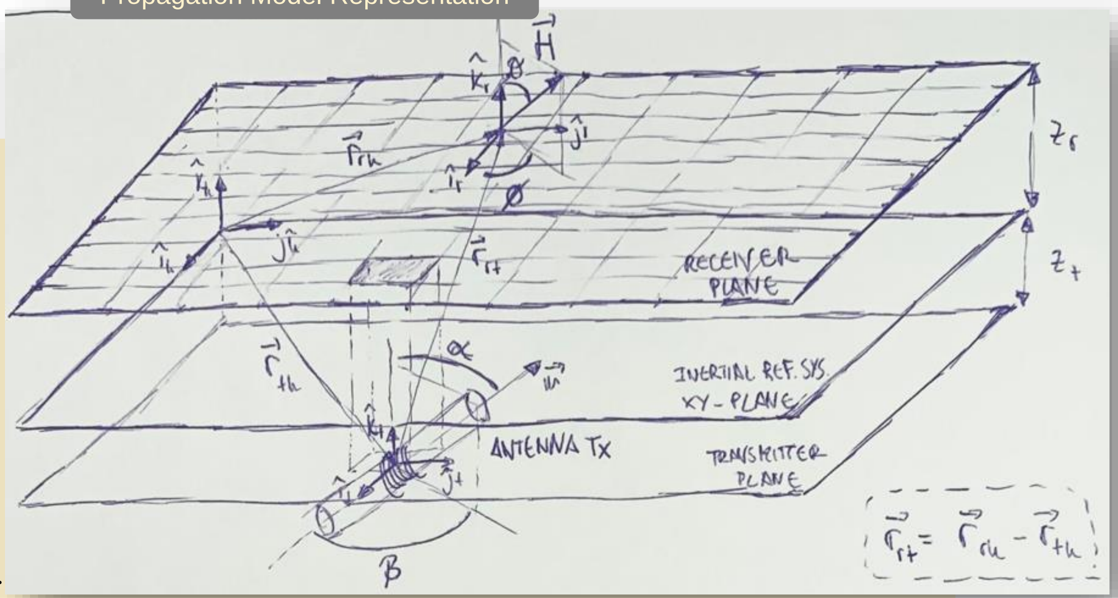
- Drone flies at constant altitude over terrain = 2m. Drone flies at constant speed over terrain = 2m/s
- Drone's (and therefore Receiver's) position is perfectly known.
- Transmitter Avalanche Beacon is buried between [0-3]m from the Surface, at location $\overrightarrow{r_{th}} = [x_t, y_t, z_t]$.
- Search Area is considered a 20m x 20m square.
- Squared Search Area is divided into a grid of squares of *d* m in length (*spatial resolution*, e.g. 2m in the picture).
  - *d* length could be a parameter to vary in further analysis.
- Coordinate systems (see also next slide for sketch reprerestation):
  - **Inertial Reference System** (considered "fixed"): $[i_h, j_h, k_h]$
    - The unknowns $(x_t, y_t, z_t)$ shall be obtained in this reference system
  - Buried Transmitter Reference System: $[i_t, j_t, k_t]$
    - Origin at transmitter´s location. Unitary vectors parallel to $[i_h, j_h, k_h]$. Constant translation wrt Inertial Reference System, $\overrightarrow{r_{th}} = [x_t, y_t, z_t]$
    - The transmitter could have an inclination wrt Inertial Reference System. This inclination is not considered as a rotation of $[i_t, j_t, k_t]$ wrt $[i_h, j_h, k_h]$. Instead, it is managed by introducing two angles $\alpha, \beta$ that parametrize the inclination of the magnetic dipole (because of the cylindrical symmetry of the transmitted H-field, we only need two parameters):
      - $\alpha$: angle wrt $k_t$ (measured in the $i_t$- $k_t$ plane.
      - $\beta$: angle wrt $i_t$ (measured in the $i_t$- $j_t$ plane.
  - Receiver Reference System: $[i_r, j_r, k_r]$
    - Origin at receiver location. Unitary vectors parallel to $[i_h, j_h, k_h]$. Varying translation wrt Inertial Reference System $\overrightarrow{r_{rh}} = [x_r, y_r, z_r]$
    - The receiver could have an inclination wrt Inertial Reference System but **we will consider that this rotation has been already taken care of.**
- Antennas sense the induced voltage ($\varepsilon$) by the presence of a magentic field ($\vec{H}$). The relation between $\varepsilon \rightarrow \vec{H}$ is considered known for the issue at hand. Thus, **we will work directly with the magnetic field ($\vec{H}$).**

**Phase 2**



# IVAQ – SoBigData ChallengeUs

Propagation Model Representation




Solution Proposal

**Slide Added Post-Meeting:**

**Phase 2: Accurate localization of position and inclination of the emitter using NN, Optimization algorithms or similar method**

❖ **Inputs:**

- **Propagation model *"tx_main.py"*** (see next slide) provides the magnetic field components $\vec{H} = [H_x, H_y, H_z]$, its **module normalized with the máximum signal strength** $|\vec{H}|$ (in dB) and its inclination angles $[\theta, \phi]$ sensed by the Avalanche Beacon Receiver at several positions described by $\overrightarrow{r_{rh}} = [x_r, y_r, z_r]$.
  - **SUGGESTION:** start by using **only** $|\vec{H}|$ to train the model.
- The magnetic field $\vec{H}$ is always sensed at a constant altitude above the terrain, $z_r = 2m$.
- The magnetic field $\vec{H}$ is sensed at several $[x_r, y_r]$ positions spaced by a *spatial resolution* that we can vary for the study. However, we need to consider that the higher the spatial resolution the lower the speed at which the drone can move, as the receiver only receives one pulse of signal each second.
  - **SUGGESTION:** start with *spatial resolution* = 2m, which translates in 100 sensed positions, where $z_r = 2m$ and $[x_r, y_r] = [1{:}2{:}19, 1{:}2{:}19] = [1{,}1], [1{,}3], [3{,}1], \ldots [19{,}19]$
- The transmitter could be buried at any distance between [0-3]m from the Surface.
  - **SUGGESTION**: start, for instance, by generating datasets at four discrete buried distances, $z_t = [0, -1, -2, -3]m$ . Precission in $[x_t, y_t]$ is more important than $[z_t]$
- The transmitter could be buried in any orientation.
  - **SUGGESTION**: start, for instance, by generating datasets at each 45 deg of orientation up to 180deg: $\alpha = [0{,}45{,}90{,}135]deg$ , $\beta = [0{,}45{,}90{,}135]deg$. With this domain exploration we should avoid symmetries, such as $[\alpha, \beta] = [45{,}45]$ deg $= [135{,}225]\ deg$ or $[\alpha, \beta] = [45{,}0]$ deg $= [135{,}180]\ deg$

❖ **Outputs:**

- The unknowns are the position of the transmitter, $\overrightarrow{r_{th}} = [x_t, y_t, z_t]$, and the orientation of the transmitter antena $[\alpha, \beta]$.
- The **position of the transmitter is the important unknown → focus here**

❖ **Case Studies:**

- Several case studies have been defined by order of priority (see slide 20)

# IVAQ – SoBigData ChallengeUs

Solution Proposal

**Slide Added Post-Meeting:**

**Phase 2: Accurate localization of position and inclination of the emitter using NN, optimization algorithms or similar method**

❖ **Inputs:**

- **Propagation model "*tx_main.py*"** provides the magnetic field components $\vec{H} = [H_x, H_y, H_z]$, its module normalized with the máximum signal strength $|\vec{H}|$ (in dB) and its inclination angles $[\theta, \phi]$ sensed by the Avalanche Beacon Receiver at several positions described by $\overrightarrow{r_{rh}} = [x_r, y_r, z_r]$.

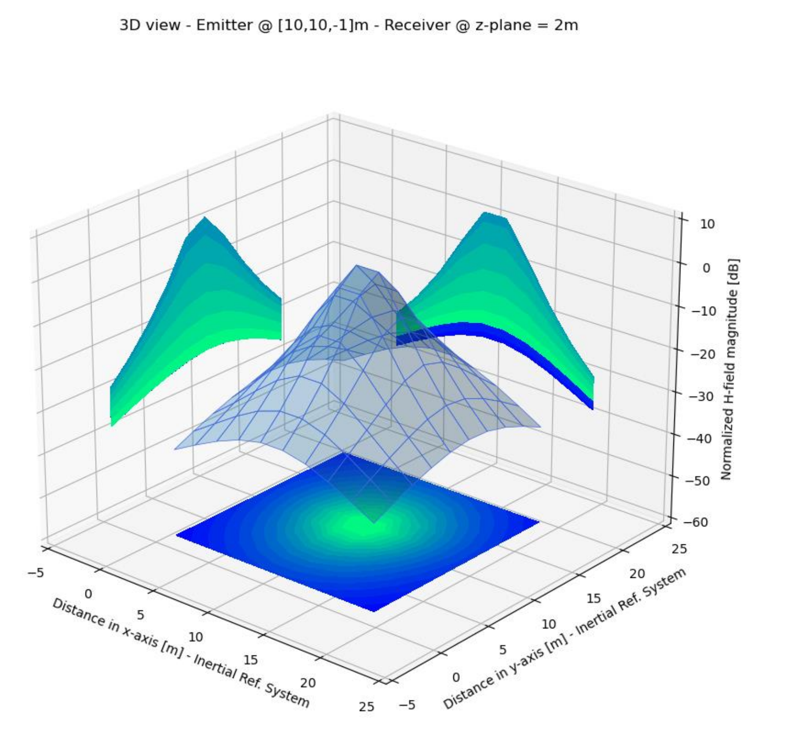
❖ **Example:**

Input Definition

tx_main.py

```python
import numpy as np
import matplotlib.pyplot as plt
# ------------------
# Constants
# ------------------
m = 1  # Arbitrary magnetic dipole moment. It should be irrelevant due to normalization of H-field module.

# ------------------
# Inputs
# ------------------

# emitter
x_t = 10 # Position in x-axis [m] of emitter (wrt Inertial reference system [i_h, j_h, k_h]
y_t = 10 # Position in y-axis [m] of emitter (wrt Inertial reference system [i_h, j_h, k_h]
z_t = -1 # Position in z-axis [m] of emitter (wrt Inertial reference system [i_h, j_h, k_h]

alpha = 45 # Inclination of magnetic dipole [deg] wrt to z-axis where 0 is a magnetic dipole aligned with positive z-axis
beta = 0 # Inclination of magnetic dipole [deg] wrt to x-axis where for alpha=90deg & beta=0deg is a magnetic dipole aligned with positive x-axis

# receiver
z_r = 2 # Position in z-axis [m] of emitter (Inertial reference system [i_h, j_h, k_h]

# options
plot_flag = 1 # Flag to ask for plots
plot_2d_flag = 0 # Flag to plot H-field magnitude and inclination [just theta], useful to compare with univ. Zaragoza
plot_colormap_flag = 0 # Flag to plot 2D map (contour) of H-field magnitude normalized with max. magnitude [in dB]
plot_3d_flag = 1 # Flag to plot 3D map of H-field magnitude normalized with max. magnitude [in dB]

spatial_resolution = 2 # Distance in [m] between consecutive readings in x and y axis
```

Output



# IVAQ – SoBigData ChallengeUs

Legend
- Rx Sensed Position
- Rx Not Sensed Position
- Tx Position (example)

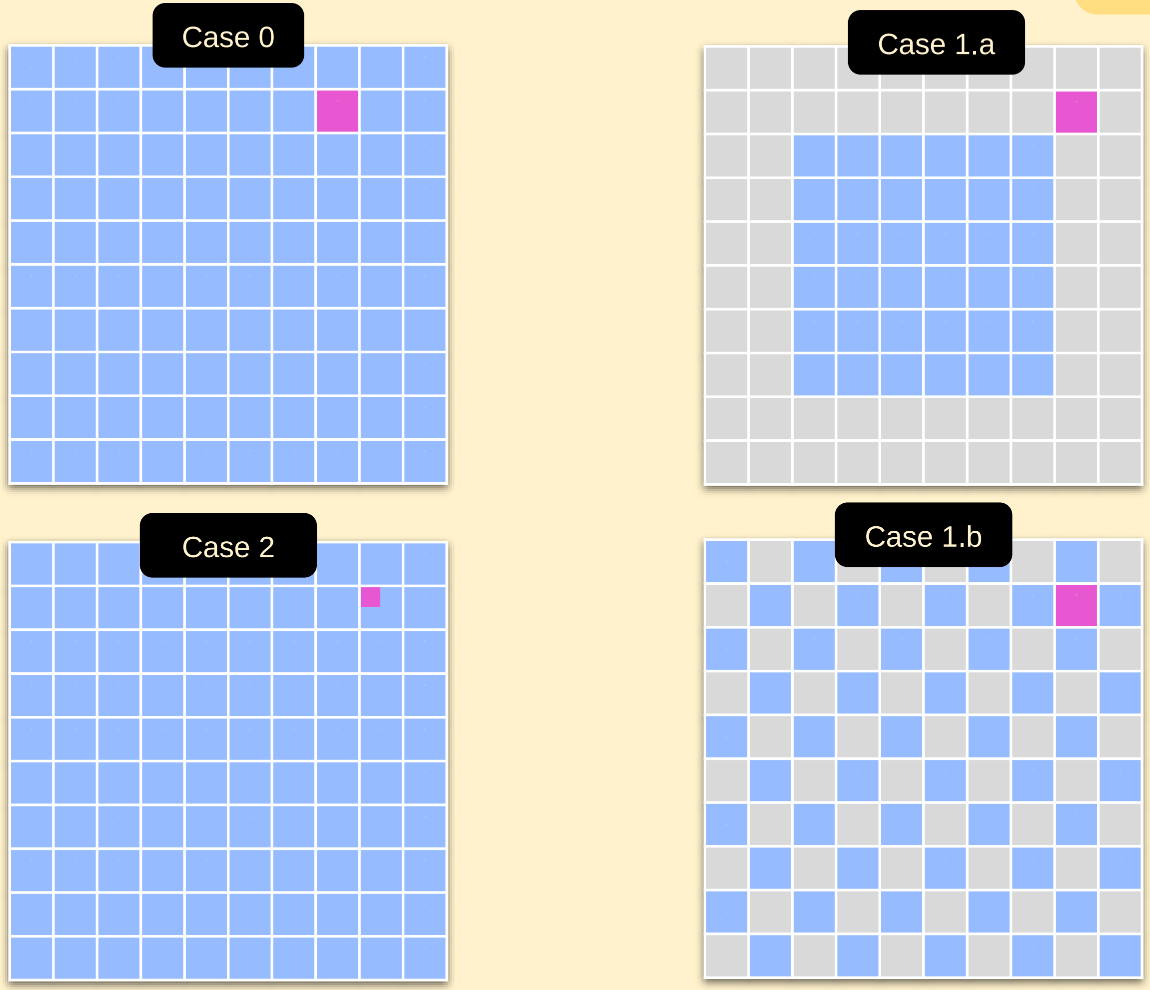
Solution Proposal

**Slide Added Post-Meeting:**

**Phase 2: Accurate localization of position and inclination of the emitter using NN, optimization algorithms or similar method**

❖ **Case Studies (TBD):**

- **Case 0 – Baseline:**
  - 1 Tx, spatial res = 2m, 100 sensed positions
- **Case 1 – Partial Input:**
  - 1.a: 1 Tx, spatial res = 2m, 36 sensed positions
  - 1.b: 1 Tx, spatial res = 2m, 50 sensed positions
- **Case 2 – Higher Output Precission:**
  - 1 Tx, spatial res = 2m (Rx) & 1m (Tx), 100 sensed positions




**Training Dataset Size**
**Case 0 & 1:** 100 Tx positions in x,y , 4 Tx positions in z, 4x4 orientations = 6400 scenarios
**Case 2:** 400 tx positions in x,y , 4 tx positions in z, 4x4 orientations = 25600 scenarios

**Addditional Case Studies**
- **Case 3:** Several Tx Av.Beacons
- **Case 4:** Different Terrain Slope Incliations

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Thank you!
Questions?