Mechanical Line Fit Model to Monitor the Position of KM3NeT Optical Modules from the Acoustic and Compass/Accelerometer Sensor System Data

Dídac D.Tortosa
on behalf of the KM3NeT collaboration

e-mail: didieit@upv.es
PhD student

ECSA-6

KM3NeT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

CAMPUS DE GANDIA

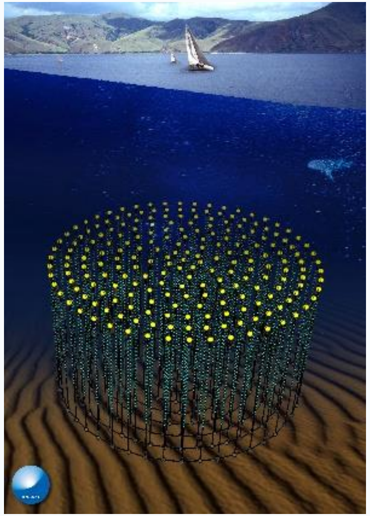
IGIC

INDEX

INTRODUCTION
KM3NeT

KM3NeT: underwater neutrino's detector developing in Mediterranean Sea to study the neutrino's oscillations (ORCA) and neutrino's astronomy (ARCA)

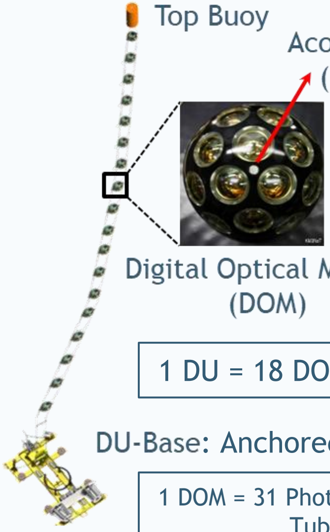
- → ORCA: 120 DU (height 200 m, 2500 m depth)
- → ARCA: 220 DU (height 700 m, 3500 m depth)



Detection structure

Location of ORCA and ARCA

Detection Unit (DU)

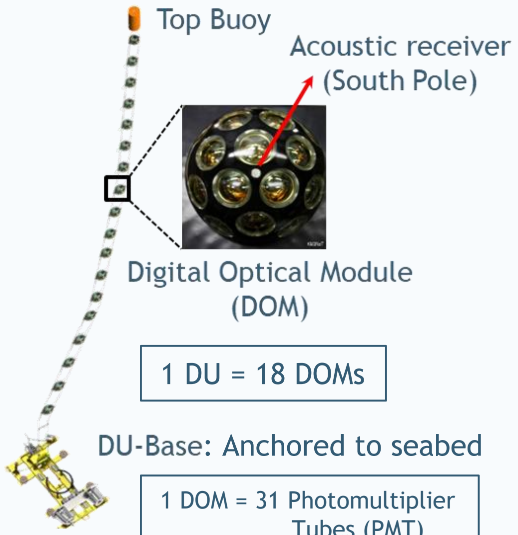


INTRODUCTION
KM3NeT

KM3NeT: underwater neutrino's detector developing in Mediterranean Sea to study the neutrino's oscillations (ORCA) and neutrino's astronomy (ARCA)

→ ORCA: 120 DU (height 200 m, 2500 m depth)
→ ARCA: 220 DU (height 700 m, 3500 m depth)

Detection Unit (DU)



The problem:
The DOMs are not quiet by sea current. To reconstruct neutrino's path (detection) is necessary monitoring the position of DOMs.

The solution:
Installed an APS and an AHRS on the detectors to know the location and orientation of every DOM.

In principle, all DU-bases will install a hydrophone

INTRODUCTION
Mechanical Line Fit Model

INPUTS for Mechanical Line Fit Model

- APS data → **LOCATION** of acoustic receivers $\{x, y, z\}$
- AHRS data → **ORIENTATION** $\{YAW, PITCH, ROLL\}$

Data from every DOM

Mechanical Model

- **Effective sea current velocity:** v
- **Effective sea current direction:** ω
- ***Mechanical properties.***

OUTPUTS for Mechanical Line Fit Model

- **LOCATION** of DOMs $\{x, y, z\}$
- CORRECTED **ORIENTATION** $\{YAW, PITCH, ROLL\}$

Mechanical Line Fit Model is necessary:

- To filter bad data
- To convert to the location of the center in the DOM
- If some sensor presents failures
- If some data is missing (fail detection or registration)

MECHANICAL LINE FIT MODEL

Acoustic Positioning System (APS)

For the moment, ORCA has deployed 4 DUs and ARCA 1 DU.

Each detector have 3 Autonomous Beacons (AB), that they are emitting every 10 min and they are anchored in a known position. By a triangulation method is possible know the **location** of each acoustic receiver (DOMs).

3 ABs before their installation

MECHANICAL LINE FIT MODEL

Acoustic Positioning System (APS)

$\boldsymbol{i}: from\ AB_i$
$\boldsymbol{j}: to\ DOM_j$
$\boldsymbol{k}: to\ DOM_j$
Distance: $R_{k,i}$

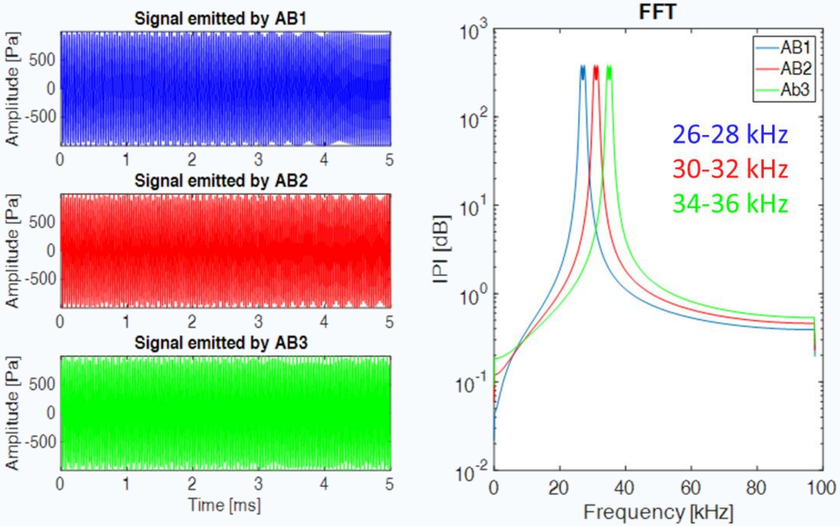
AB (SPL of 180 dB re 1µPa @1m): Sweeps signals of 5 ms every 10 minutes

To the reference receiver (DOM1 or hydro in $\boldsymbol{DU_{base}}$): $\mathbf{ToA_{i,ref}}$ 1

In the rest of the DOMs: $\boldsymbol{ToA_{i,j}}$ 2

Then, it is possible obtained the ToE from every AB:

3 $$\boldsymbol{ToE_i} = ToA_{i,ref} - ToF_{i,ref} = $$
$$= ToA_{i,ref} - \left(\frac{R_{k,i}}{c_{sound}}\right)$$



Sweep signals of each AB

If the reference of APS is the DOM1, because the hydro on the base is not available, the error in APS data is increasing, because the DOM1 is assumed fix it (it's an approximation).

Now, we can calculate:

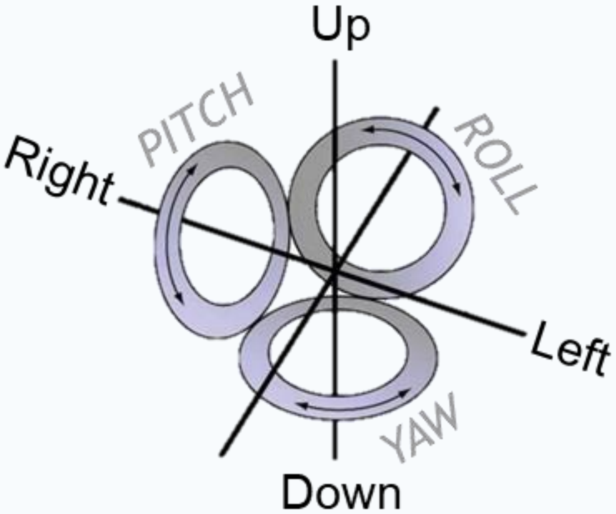
4 $$\boldsymbol{ToF_{i,j}} = ToA_{i,j} - ToE_i$$

$\boldsymbol{ToF_{i,j}} \cdot \mathbf{c_{sound}}$ (distance) is used to triangulate and obtained the **location** of receivers

Dídac D.Tortosa
on behalf of the KM3NeT collaboration

MECHANICAL LINE FIT MODEL

Attitude and Heading Reference System (AHRS)

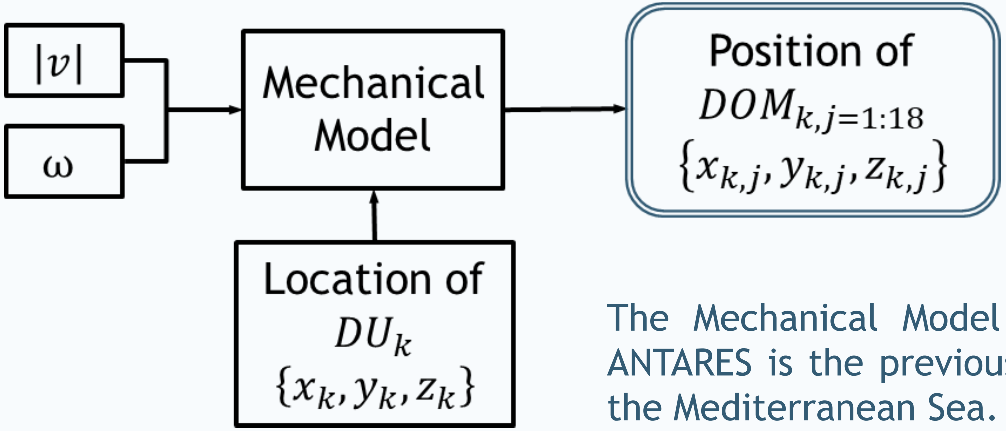


The boards on DOMs used are developed within the KM3NeT collaboration and are calibrated before their installation. The accuracy of the system is estimated to be smaller than 3.5 degrees .

The AHRS data provides the **orientation** of each DOM (YAW, PITCH and ROLL)

MECHANICAL LINE FIT MODEL

Mechanical Model (MM)

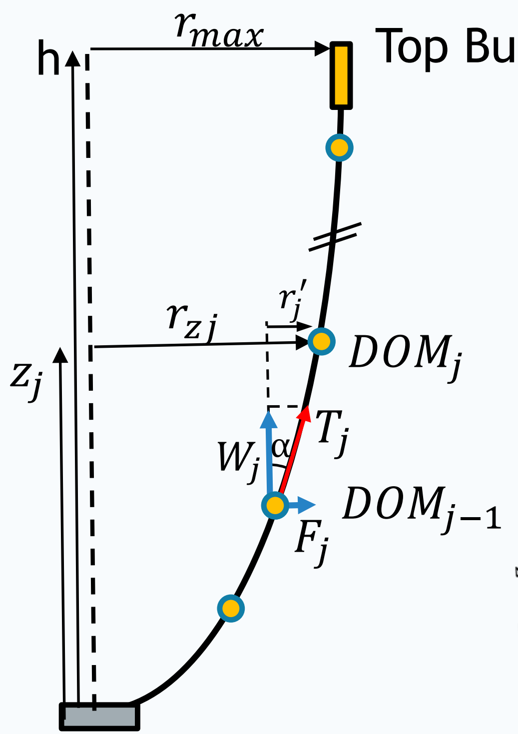


The Mechanical Model is based on ANTARES DU Line Fit. ANTARES is the previous underwater detector of neutrinos in the Mediterranean Sea.

If you know the location of a specific DU-base, from an effective sea current velocity and direction, the MM can predict the position of every DOM.

MECHANICAL LINE FIT MODEL

Mechanical Model (MM)

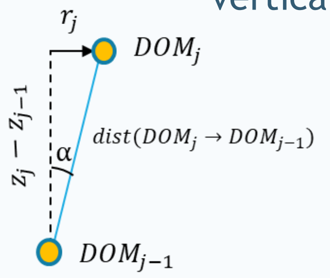


MM considers the drag force (F) and buoyancy *(W) in every item on the line (depending of its height, z):*

$$F(z) = f(z)v^2 = \left\{\left[\sum_{i=1}^{18}\left(f_{DOM} + f_{cable_i}\right) + f_{long\ string}\right]\left(\frac{h-z}{z}\right) + f_{top\ buoy}\right\} v^2$$

$$W(z) = \left[\sum_{i=1}^{18}\left(W_{DOM} + W_{cable_i}\right) + W_{long\ string}\right]\left(\frac{h-z}{z}\right) + W_{top\ buoy}$$

MM calculates the displacement of every DOM from their vertical axis *(r)*. It uses a specific sea current velocity value:

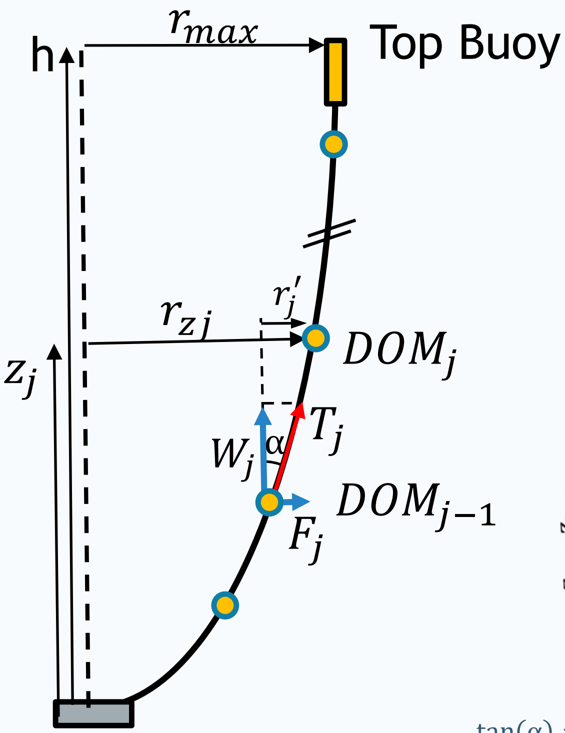


$$\boxed{r(z) = \int_0^z g(z)\ dz = \left[\frac{n}{q}z - \left(\frac{mq-nq}{q^2}\right)\ln\left(1-\frac{q}{p}z\right)\right] v^2}$$

$$\tan(\alpha) = \frac{F(z)}{W(z)} = g(z)$$

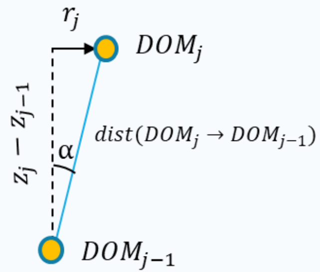
MECHANICAL LINE FIT MODEL

Mechanical Model (MM)



MM considers that the displacement r is $\boldsymbol{MM_{const}}$ times v^2:

$$\boxed{r(z) = \int_0^z g(z)\ dz = \underbrace{\left[\frac{n}{q}z - \left(\frac{mq - nq}{q^2}\right)\ln\left(1 - \frac{q}{p}z\right)\right]}_{MM_{const}(z)} v^2}$$



$$\tan(\alpha) = \frac{F(z)}{W(z)} = g(z)$$

Where:

$$m = \left\{\left[\sum_{i=1}^{18}\left(f_{DOM} + f_{cable_i}\right)\right] + f_{long\ string}\right\} + f_{top\ buoy}$$

$$n = \left\{\left[\sum_{i=1}^{18}\left(\frac{1}{h}f_{DOM} + f_{cable_i}\right)\right] + \frac{1}{h}f_{long\ string}\right\} + \frac{1}{h}f_{top\ buoy}$$

$$p = \left\{\left[\sum_{i=1}^{18}\left(W_{DOM} + W_{cable_i}\right)\right] + W_{long\ string}\right\} + W_{top\ buoy}$$

$$q = \left\{\left[\sum_{i=1}^{18}\left(\frac{1}{h}W_{DOM} + W_{cable_i}\right)\right] + \frac{1}{h}W_{long\ string}\right\} + \frac{1}{h}W_{top\ buoy}$$

MECHANICAL LINE FIT MODEL

Mechanical Model (MM)

$f_j = \frac{1}{2} C_{w,j} A_j \rho \ [Ns^2/m^2]$

$\rho: Density\ of\ the\ water\ [kg/m^3]$

$A: Cross\ section\ [m^2]$

$C_w: drag\ coeficient$

$W_j = WIW_j \cdot g\ [N]$

$Gravitacional\ acceleration\ [m/s^2]$

$Weight\ In\ Water\ [kg]$

$buoyancy$

Detector	Property	Elements(*)		
		DOM	Long string	Top Buoy
ARCA	$f\ [Ns^2/m^2]$	52.86	659.10	482.66
	$W\ [N]$	125.57	0	1030.05
ORCA	$f\ [Ns^2/m^2]$	52.86	283.92	482.66
	$W\ [N]$	125.57	0	1226.25

(*) The distance of cables between DOMs are not the same, so their f and W are calculate for each case

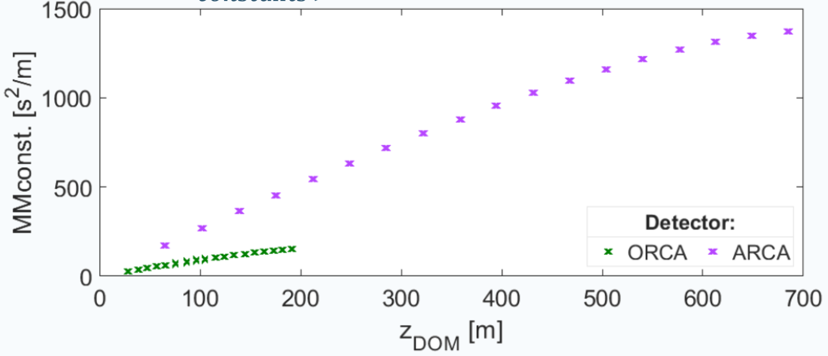
PROCEDURE TO RECONSTRUCTION

Explanation

- **What do we expect?**

  Improve the position in reconstruction of DUs taking into account the uncertainty and inconsistencies of measures and analysis.

$MM_{constants}$ *for each DOM on the detector*



- **How to obtain v and ω from the acoustic data?**

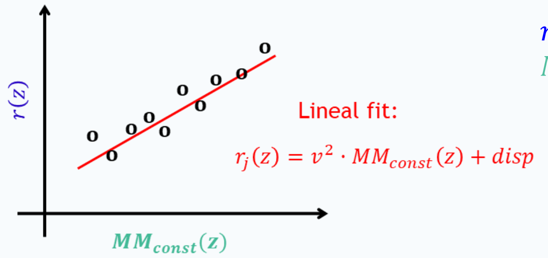
$$r(z) = MM_{const}(z) \cdot v^2 \rightarrow \boldsymbol{v} = \sqrt{\frac{r_j(z)}{MM_{const}(z)}}$$

$$\boldsymbol{\omega} = atan2(diff_y, diff_x)$$

$diff$: Difference from item reference

$\boldsymbol{MM_{const}(z)}$

$$r(z) = \int_0^z g(z)\ dz = \boxed{\left[\frac{n}{q}z - \left(\frac{mq - nq}{q^2}\right)\ln\left(1 - \frac{q}{p}z\right)\right]} v^2$$

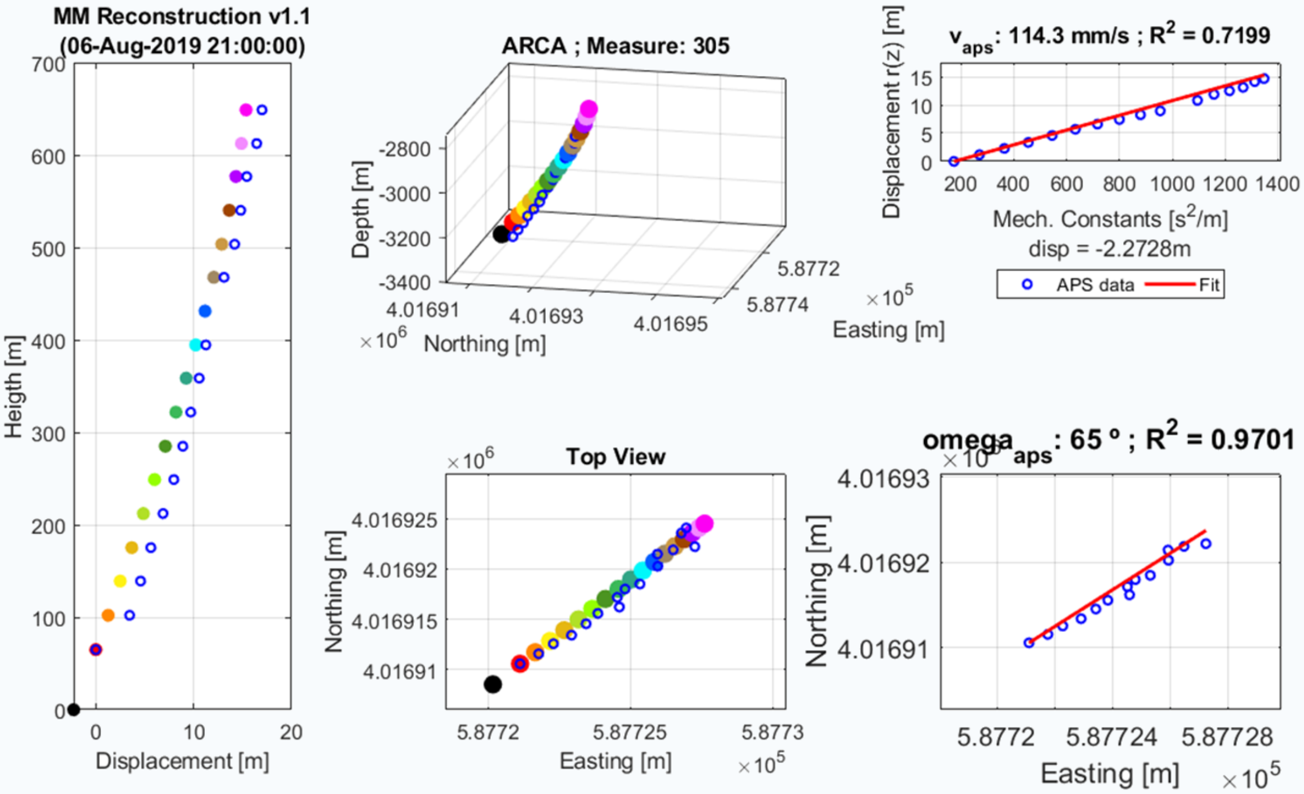


$r(z)$: from APS data

$MM_{const}(z)$: from MM

PROCEDURE TO RECONSTRUCTION

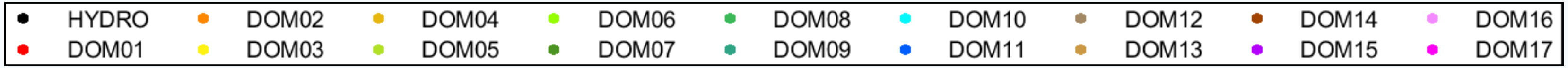
Results



DU Line Fit reconstructs the shape of the DU using a Mechanical Model using an effective value of sea current (v and ω) and the inputs APS and AHRS data and some mechanical properties of the items in the DU.

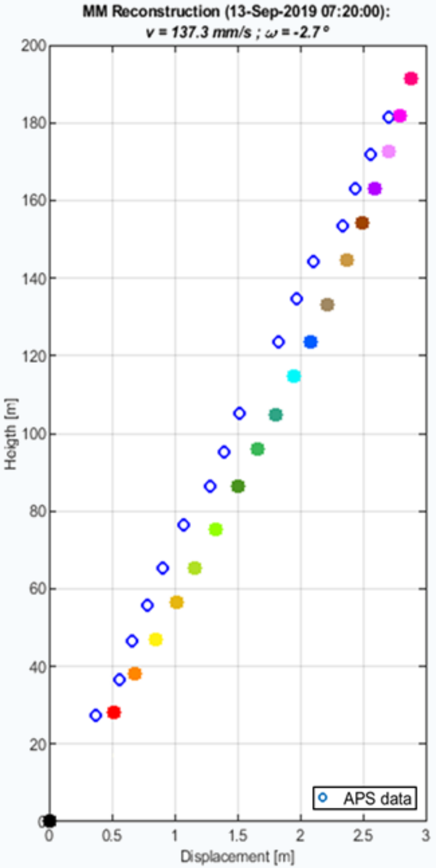
Reconstruction exemple in ARCA for specfic measure

Reconstruction legend

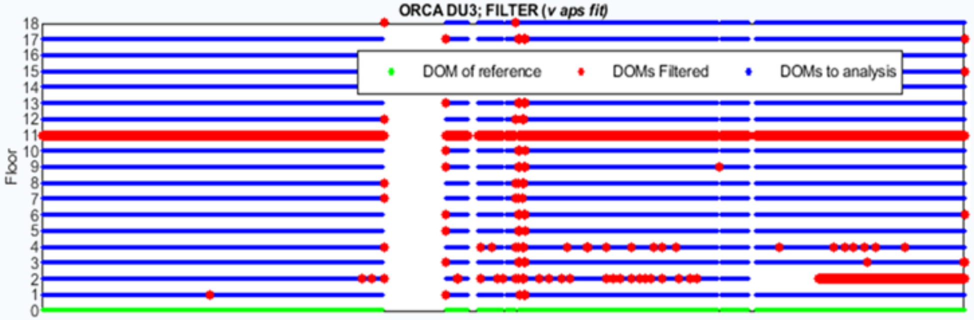


PROCEDURE TO RECONSTRUCTION

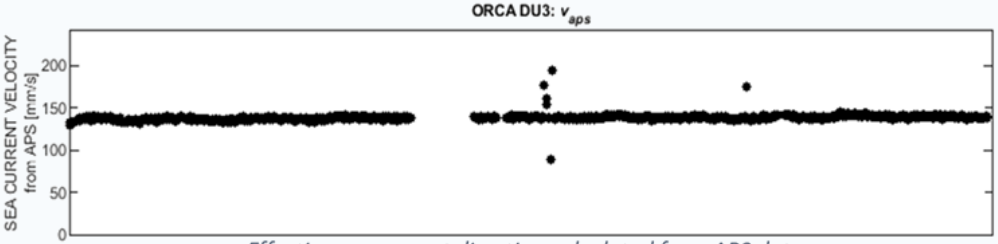
Results



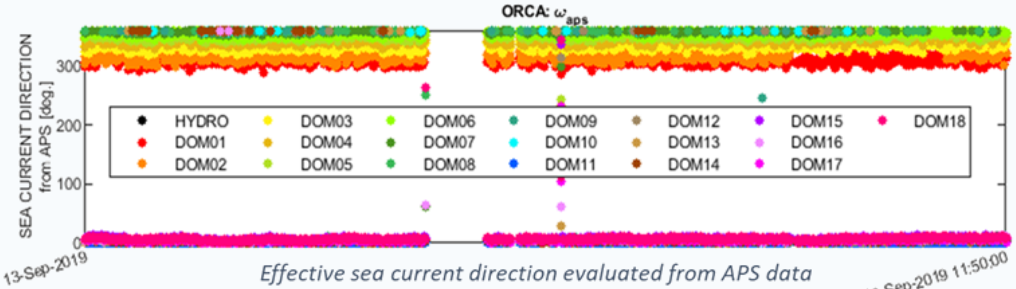
Example of Mechanical Line Fit Model reconstruction in a measure



APS filter applied to the data



Effective sea current direction calculated from APS data



Effective sea current direction evaluated from APS data estimated for all over the DU

Here, an example of reconstruction procedure is applied in a period of a week in ORCA-DU3:

The v is less than 15 cm/s and ω of DOMs are between 290 and 5 degrees.

Reconstruction example in ORCA for a week period

CONCLUSIONS

· The APS and AHRS in KM3NeT provides the location and the orientation for all DOMs.

· The APS data analysis using the Mechanical Line Fit model is able to obtain the positions of DOMs even in the case of missing data. Moreover, a filtering process can be applied to discard anomalous data values from APS, AHRS or fitting parameters of the model (efficient sea current direction and velocity).

· In this work the analysis of the APS data procedure have applied to reconstruct the locations of piezo-ceramics.

· The final implementation of the Mechanical Line Fit model is still in progress, and will be applied to obtain the location of the center position and the orientation for every DOM. Once all this is being defined, an automatic procedure for the monitoring of the position and orientation of all DOMs in KN3NeT will be implemented.

THANKS FOR YOUR ATTENTION

Dídac D.Tortosa
on behalf of the KM3NeT collaboration

e-mail: didieit@upv.es
PhD student

ECSA-6

KM3NeT

UNIVERSITAT POLITÈCNICA DE VALÈNCIA
CAMPUS DE GANDIA

IGIC