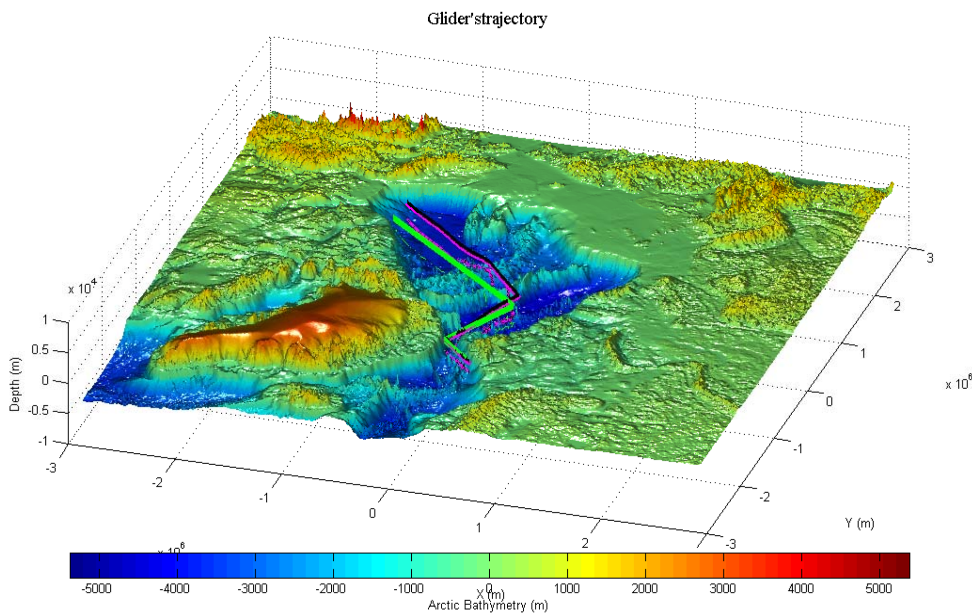
MREA10, Lerici, Italy, October 18-22, 2010

Terrain Navigation for Underwater Autonomous Gliders



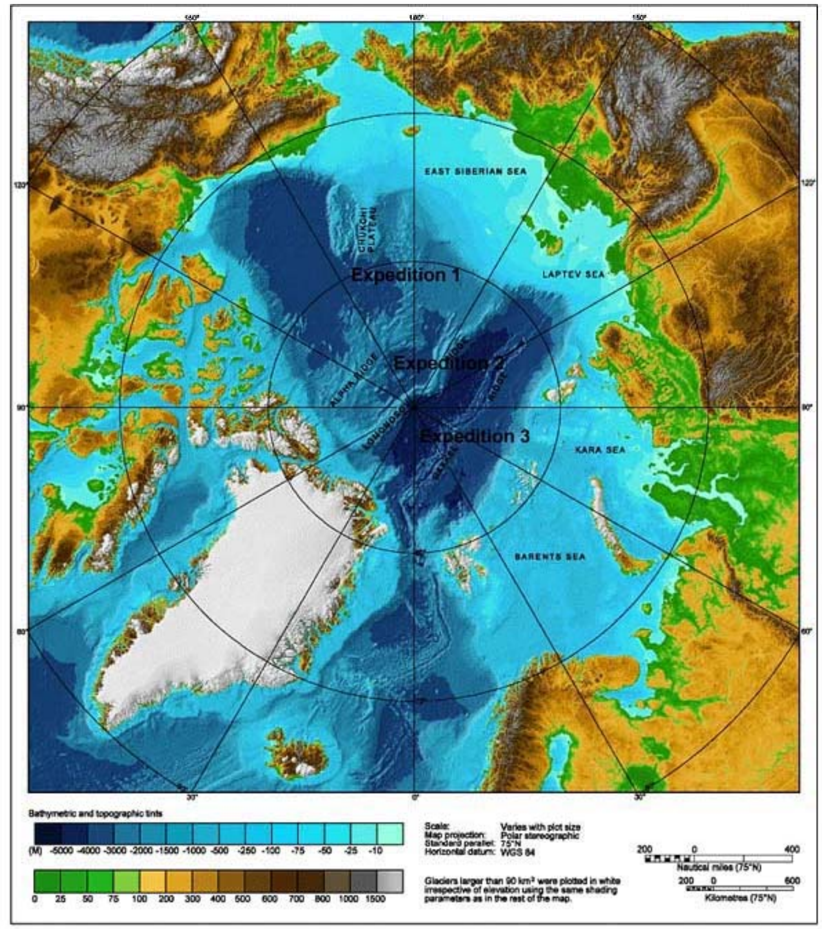
Julien Lagadec, Daniele Cecchi,

Michel Rixen, Raffaele Grasso

PARTNERING FOR MARITIME INNOVATION

Outline

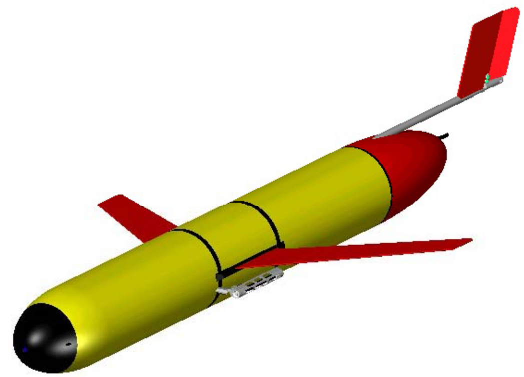
1. Introduction
2. Underwater navigation
3. Terrain Based Navigation
4. Particle Filter
5. Energy Budget
6. Simulations
7. Conclusions
8. Perspectives



Source: IBCAO

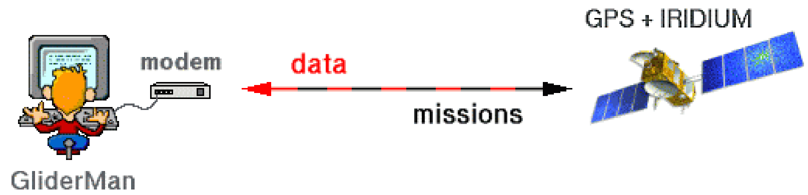
Introduction: Gliders

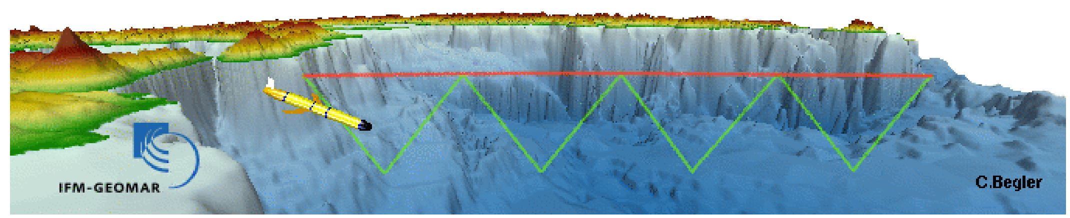
- *Gliders are unique in the AUV world*

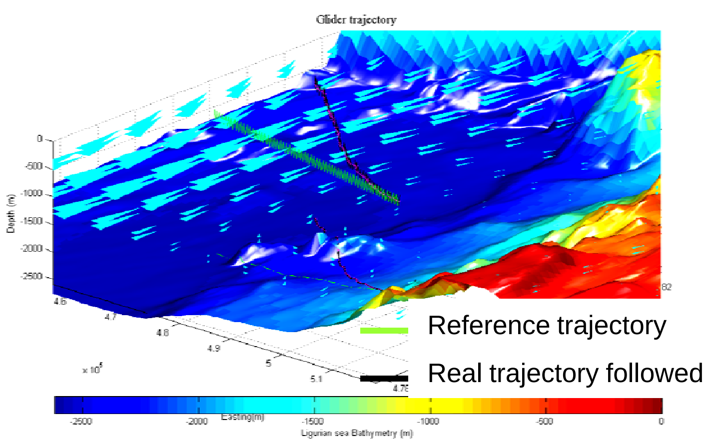


"Gliders require no propeller and operate in a vertical saw tooth trajectory which ensures a high resolution in data sampling"

(source: Slocum glider manual)







- Varying vehicle buoyancy creates the forward propulsion

- Challenge of underwater positioning
  - ⇒ Sea currents influence

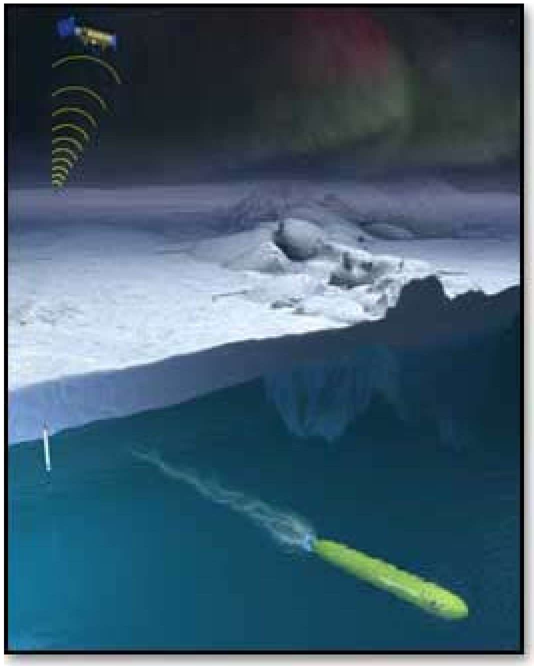
Introduction: Objectives of the project

- "Can we use a terrain navigation approach for a long range under ice mission in the Arctic Ocean?"

Effective localization and navigation is critical to successful AUV mission

Under ice - Long range mission

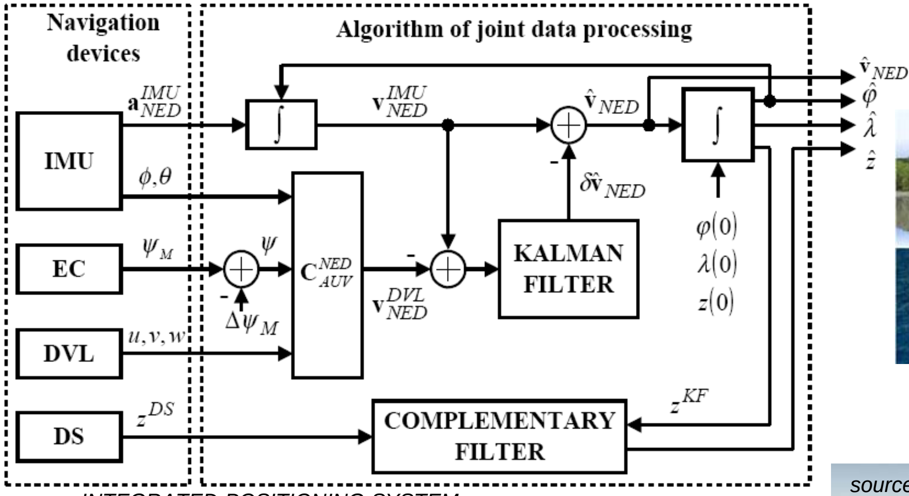
- GPS fix unlikely
- Drift of position estimate
- Growing navigation uncertainty
- Limited energy budget



The ALTEX AUV (Atlantic Layer Tracking Experiment)

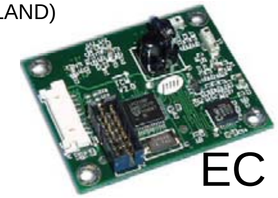
2. Underwater navigation

- Internal Navigation
- External Navigation



source: *INTEGRATED POSITIONING SYSTEM FOR AUV* (Piotr KANIEWSKI, Military University of Technology, Warsaw, POLAND)

IMU



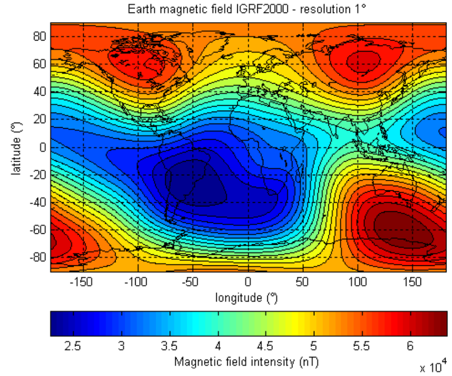
EC

DS

DVL

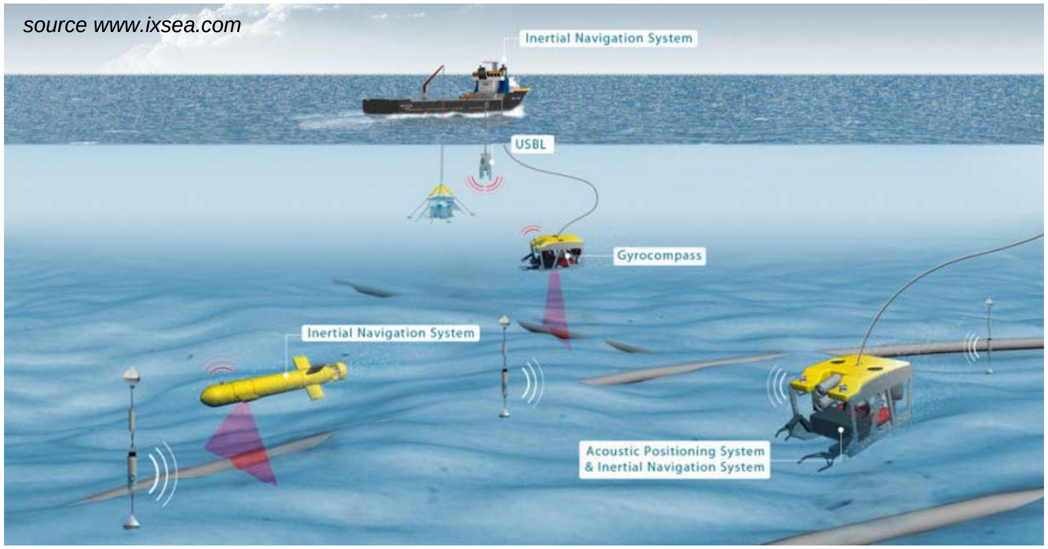
source: www.geo-marine-tech.com

Ultra short baseline

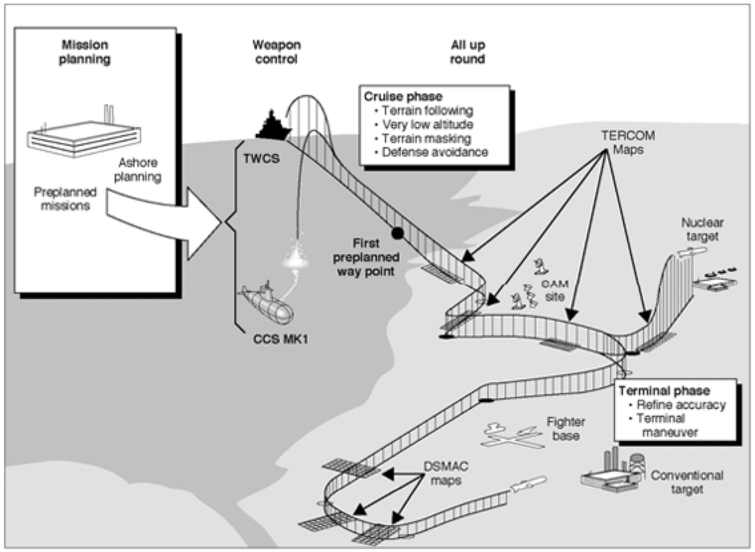


Earth's magnetic field

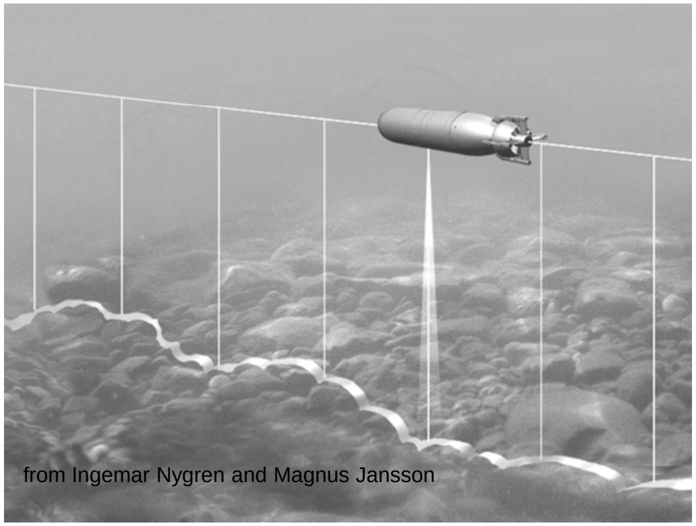
source www.ixsea.com

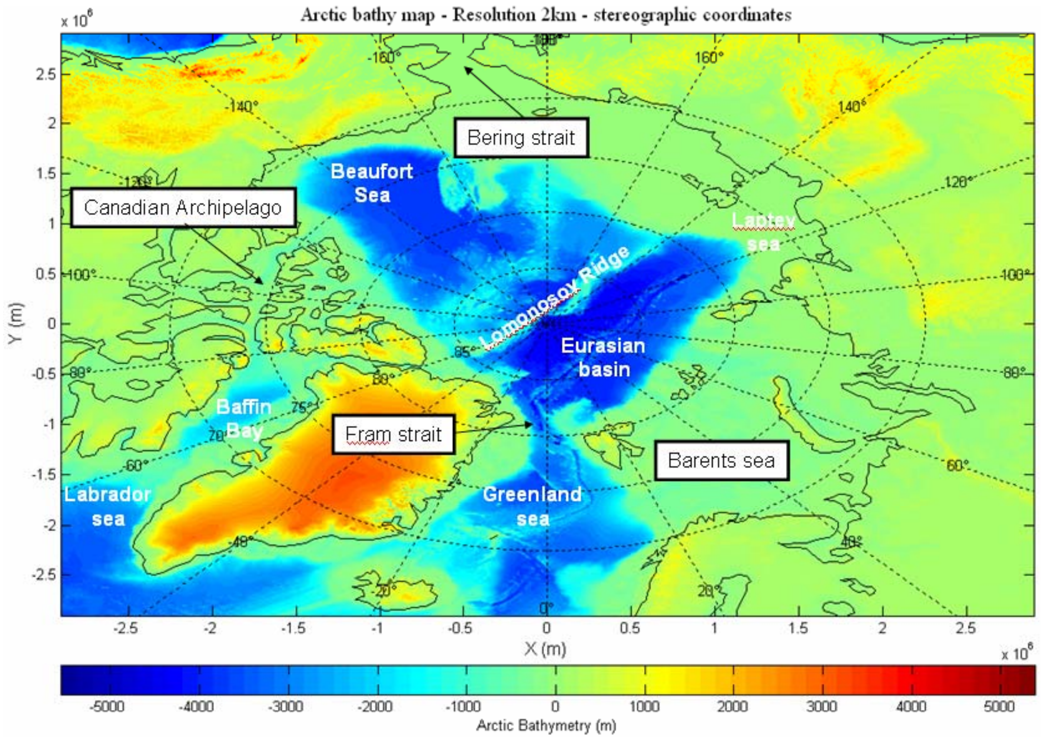


3. Terrain Based Navigation: Principle



- Developed in 1958 to bound the error drift of cruise missile inertial navigation system





- Totally autonomous process
- Oceans seafloor represents a strong source of information

4. TBN – Particle Filter: principle

Bathymetric observation

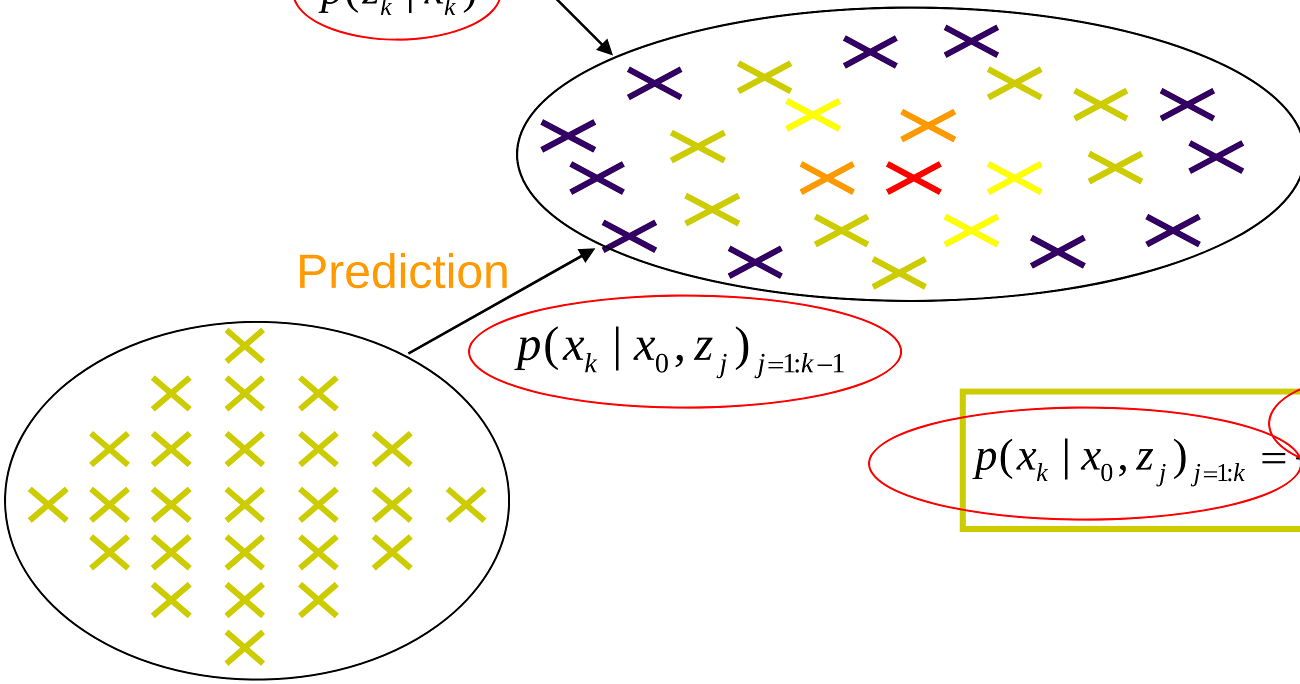
$p(z_k \mid x_k)$

Update

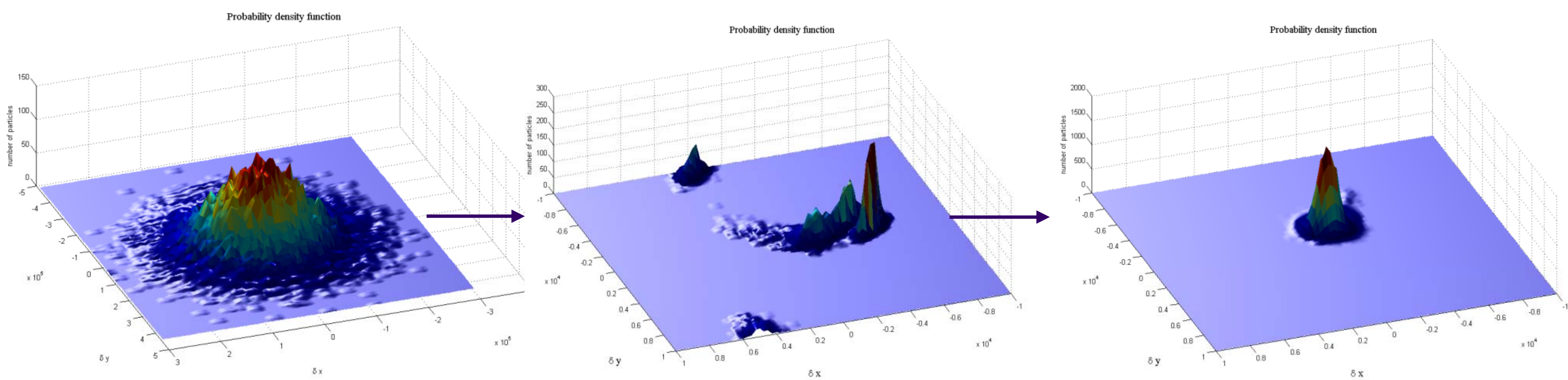
$p(x_k \mid x_0, z_j)_{j=1:k}$

Prediction

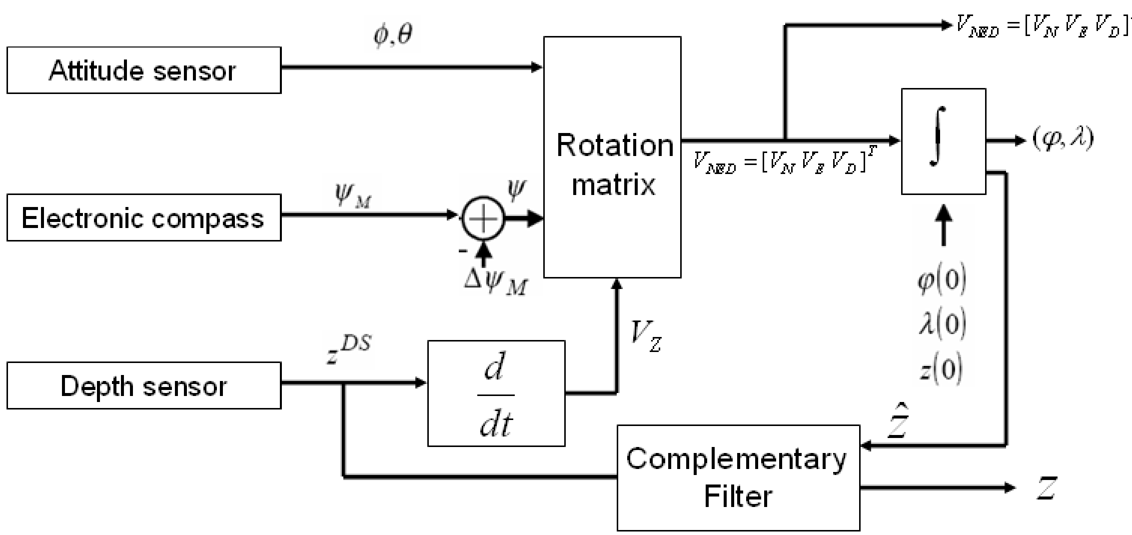
$p(x_k \mid x_0, z_j)_{j=1:k-1}$



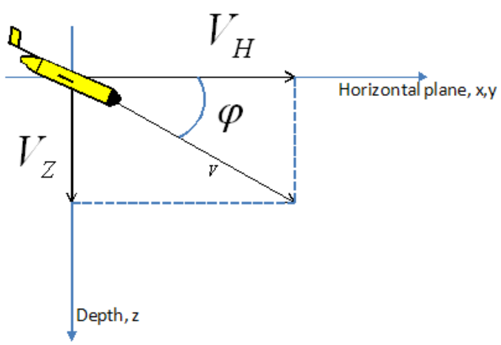
$$p(x_k \mid x_0, z_j)_{j=1:k} = \frac{p(z_k \mid x_k)\, p(x_k \mid x_0, z_j)_{j=1:k-1}}{p(z_k \mid x_0, z_j)_{j=1:k-1}}$$

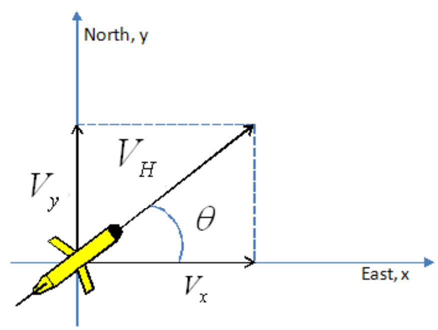


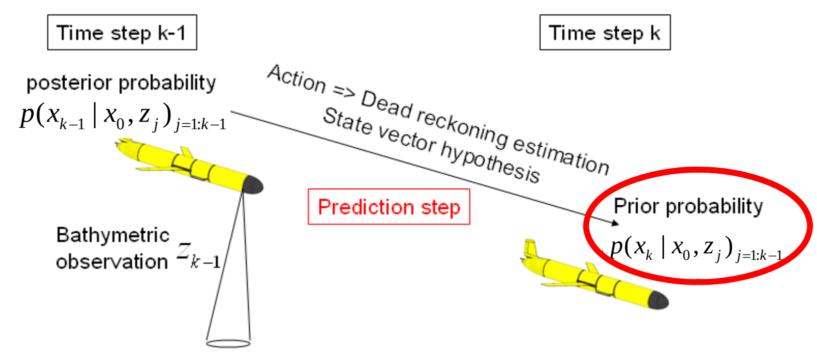
4. TBN – Particle Filter: Prediction Step



- projection forward in time using a kinematics model





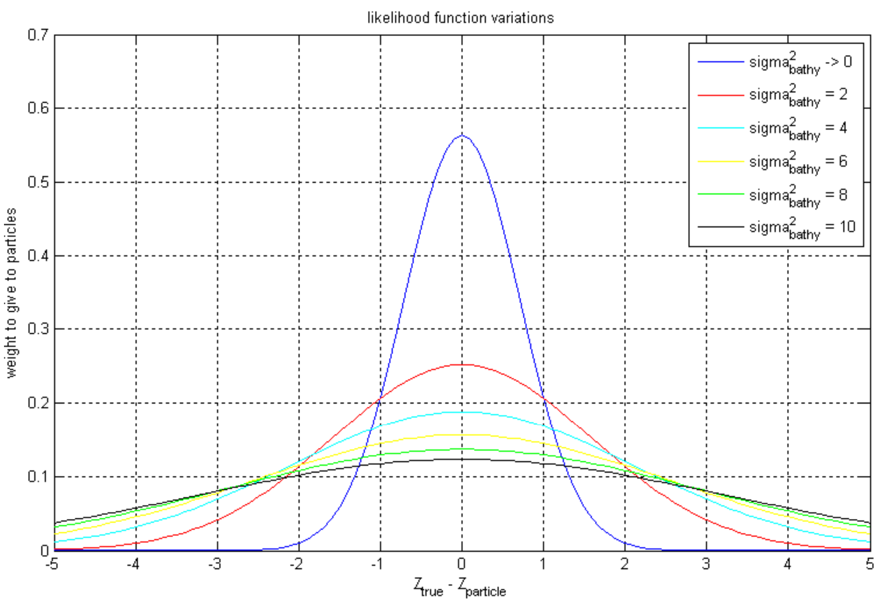


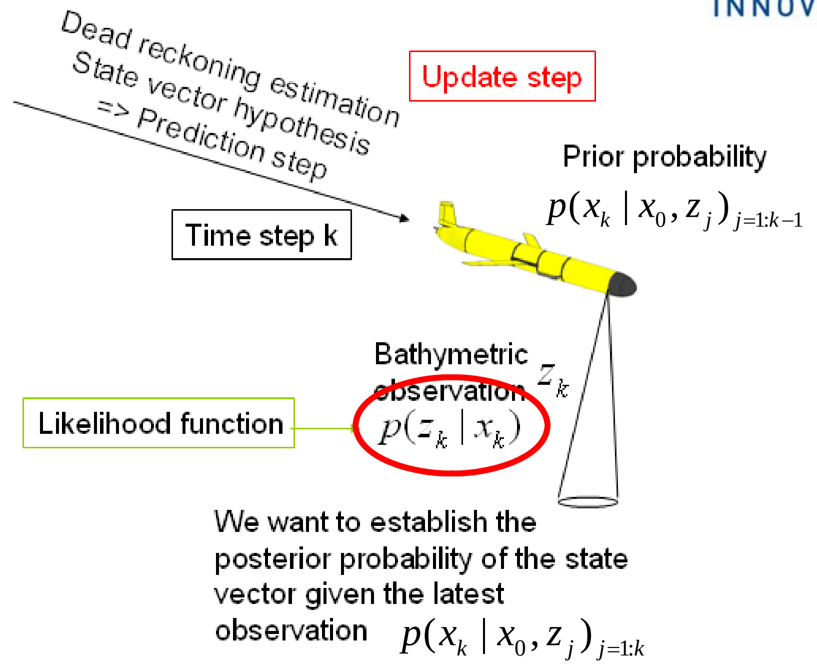
$p(x_k \mid x_0, z_j)_{j=1:k}$ →

$$\begin{pmatrix} x \\ \dot{x} \\ y \\ \dot{y} \end{pmatrix}_{k+1} = \begin{pmatrix} 1 & \Delta T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \Delta T \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ \dot{x}+u \\ y \\ \dot{y}+v \end{pmatrix}_k + \begin{pmatrix} 0 \\ \Delta V_x \\ 0 \\ \Delta V_y \end{pmatrix} + chol(w_k^2 \cdot \begin{pmatrix} \Delta T^2 & \Delta T & 0 & 0 \\ \Delta T & 1 & 0 & 0 \\ 0 & 0 & \Delta T^2 & \Delta T \\ 0 & 0 & \Delta T & 1 \end{pmatrix})$$

4. TBN – Particle Filter: Update Step

- Update the weight of each particle given the likelihood between:
  - the bathymetric measurement
  - depth seen by each particle



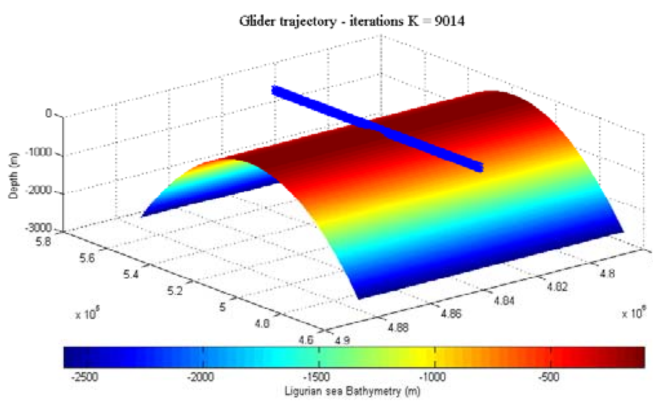


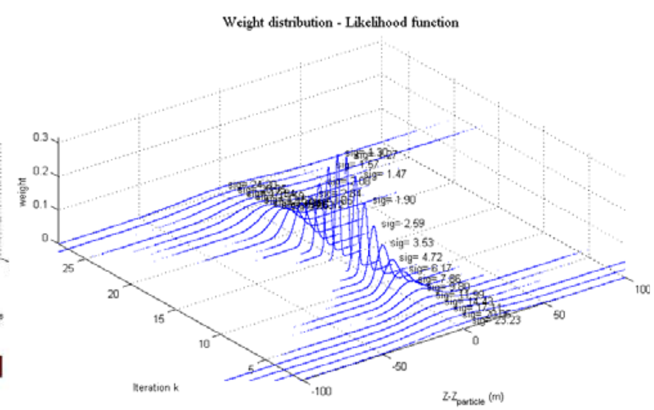
- Likelihood function

$$p(z_k \mid x_k) = \frac{1}{\sqrt{2\pi}.\sigma_{bathy}}.e^{\frac{-[z_k - h(x_k)]^2}{2.\sigma^2_{bathy}}}$$

- International Hydrographic organization (IHO) – S44 order 2

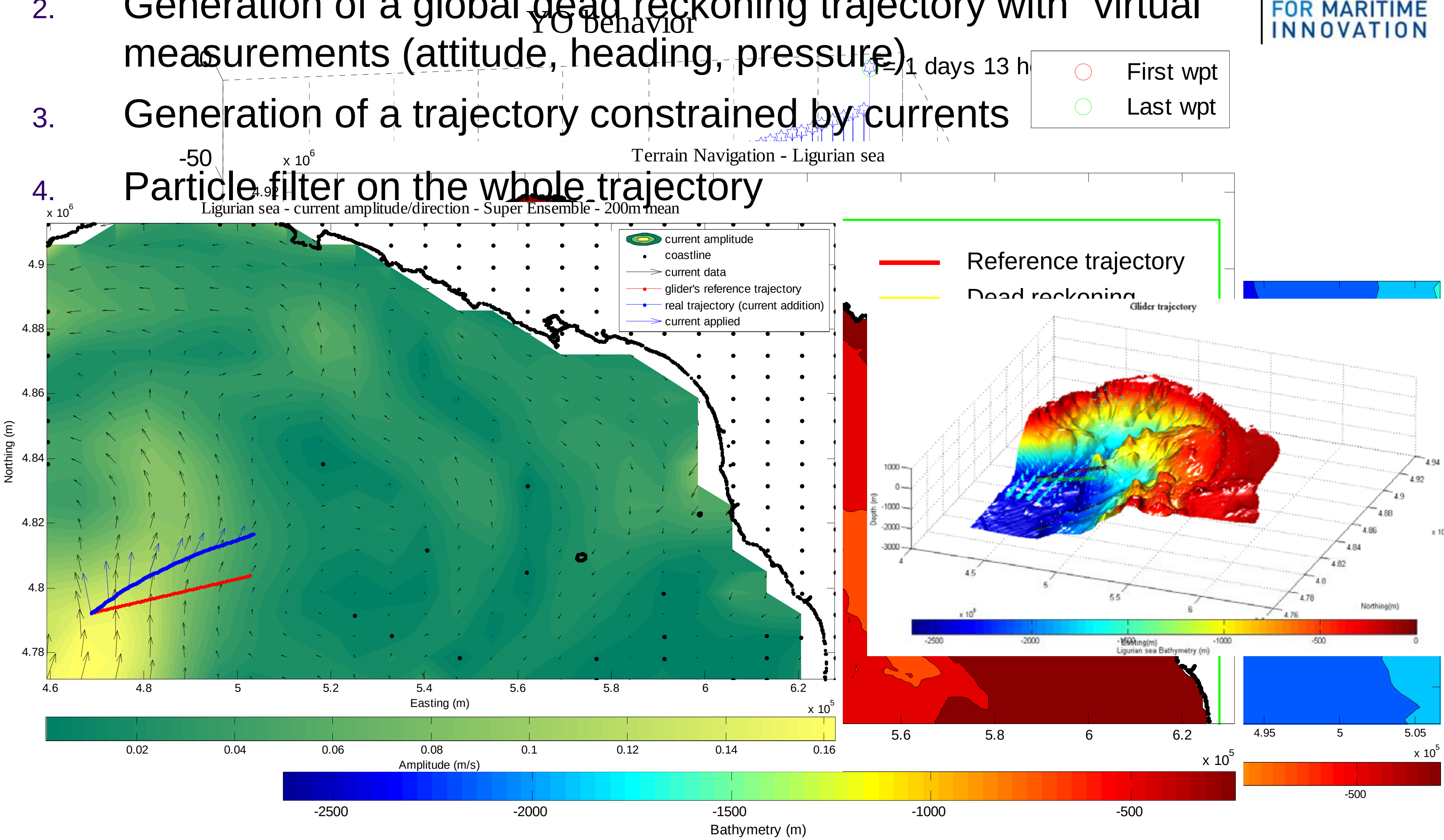
$$\sigma_{bathyTVU} = \frac{1}{2}\sqrt{1^2 + (0.023z)^2}$$





4. TBN – Particle Filter: Simulation principle

1. Generation of a reference trajectory
2. Generation of a global dead reckoning trajectory with “virtual” measurements (attitude, heading, pressure)
3. Generation of a trajectory constrained by currents
4. Particle filter on the whole trajectory



5. Energy Budget

- Mission endurance depends highly on the capacity and usage of batteries
- Tradeoff decisions between
  - energy consumption
  - Sensing
  - data processing
  - communication activities

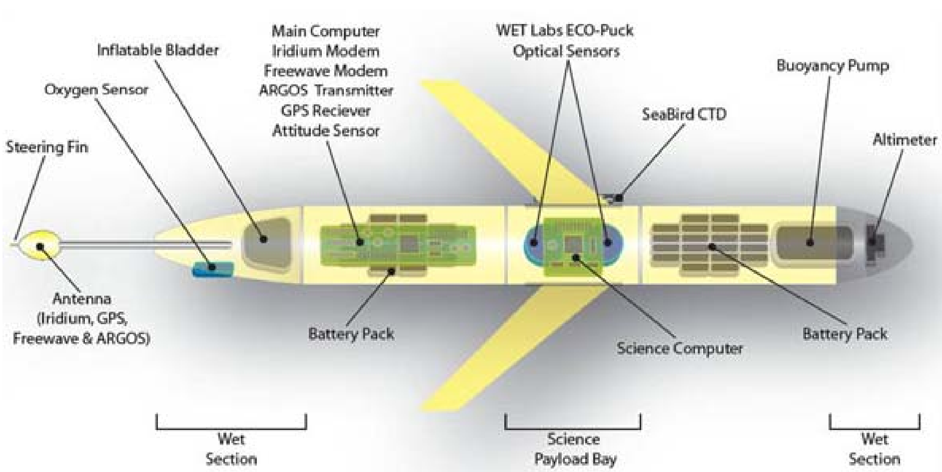
Buoyancy pump

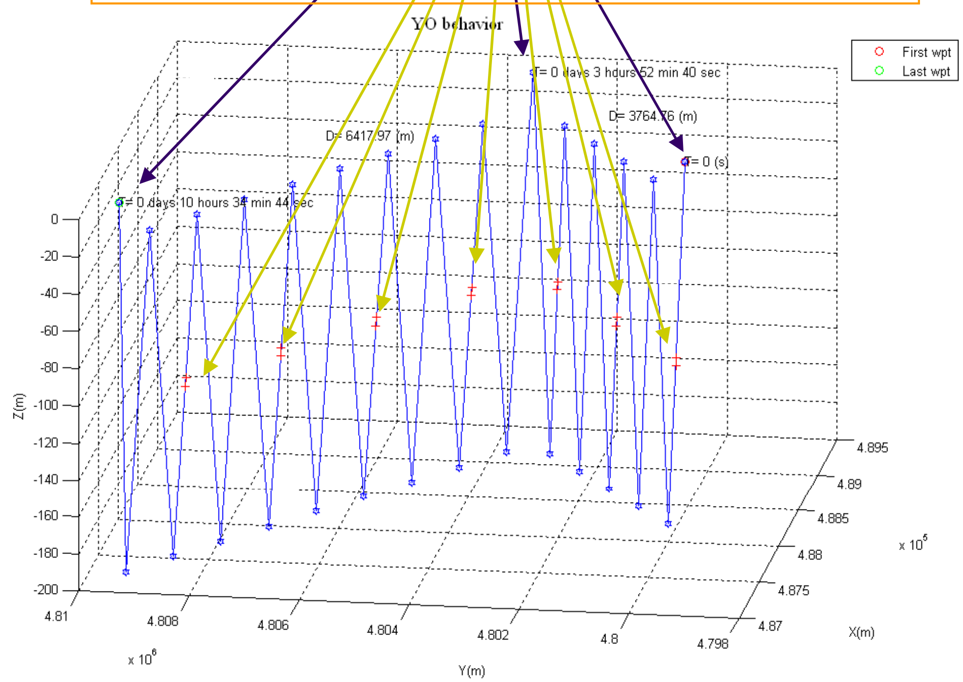
Gliders components:

Surface behavior: GPS, irridium

Pinging policy: pulse emission + data processing

- Controller
- Attitude sensor
- Pressure sensor
- Science sensors



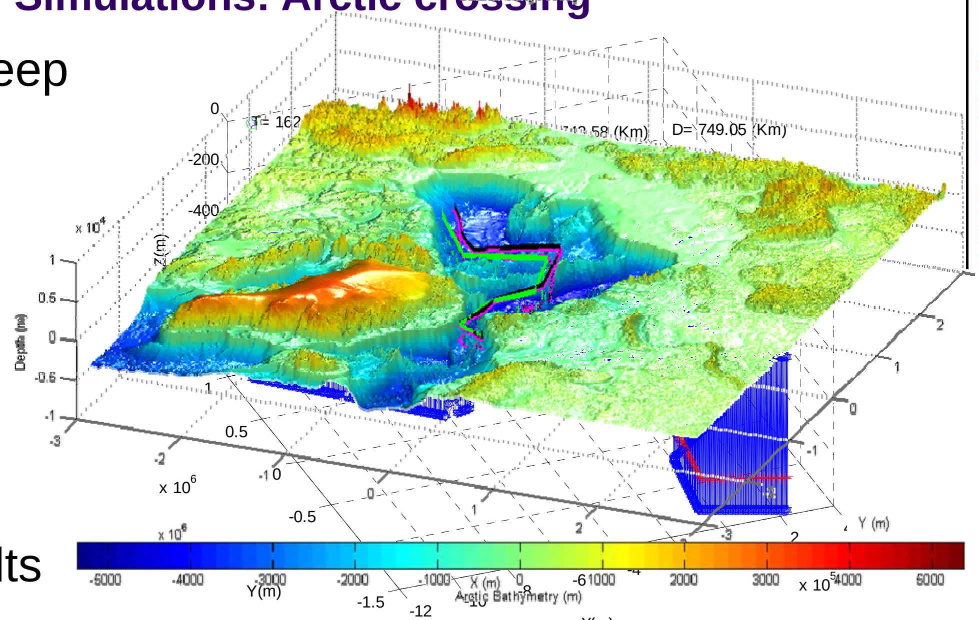


6. Simulations: Arctic crossing

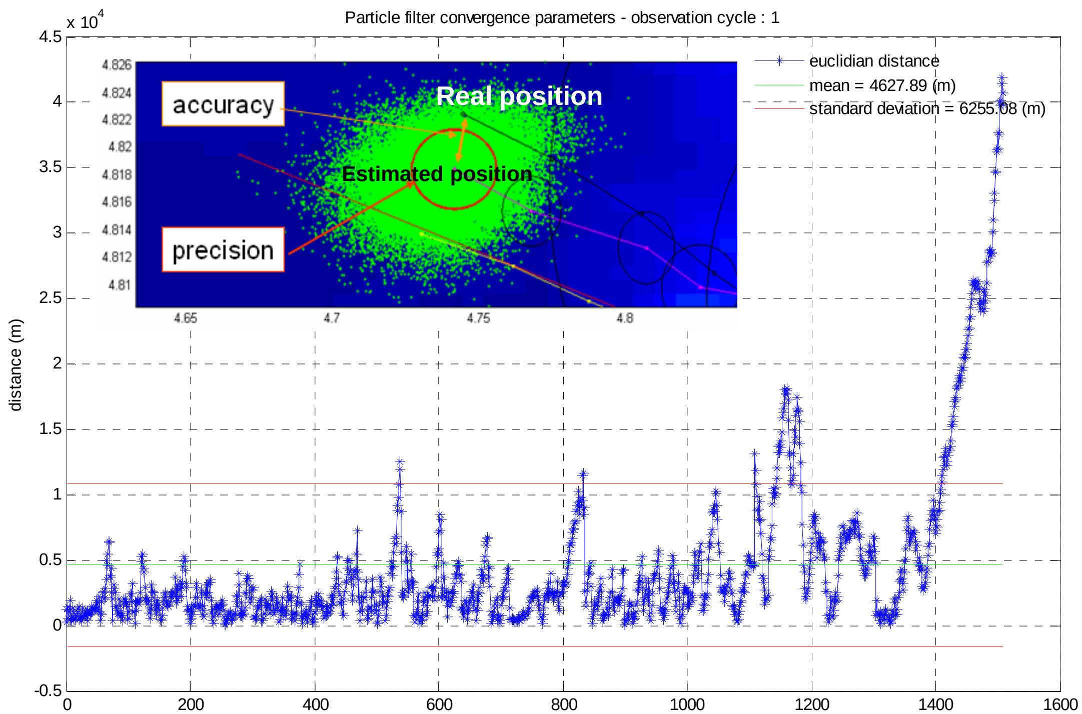
- Arctic crossing: Slocum deep glider (1000m)

Mission specifications:
- 7 waypoints
- pitch angle: 26 degrees
- diving target depth: 1000m (when possible)
- climbing target depth: 400m
-1 pings per dive / every dive

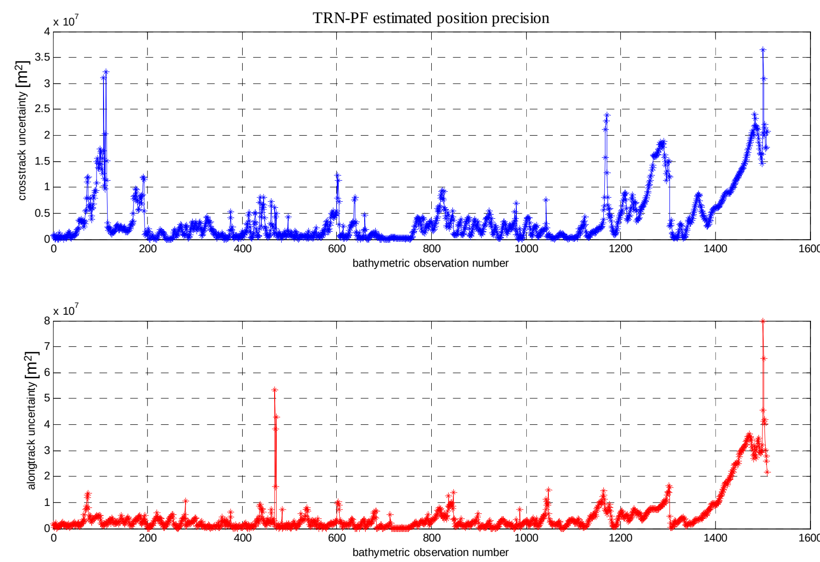
~ 165 days of submerged mission under the ice



- Particle filter accuracy results



- Particle filter precision results

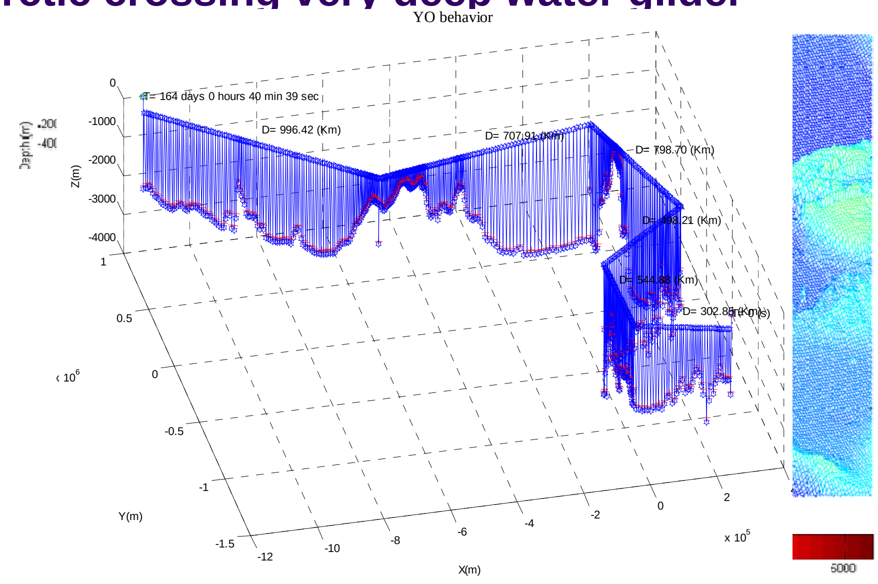


6. Simulations: Arctic crossing very deep water glider

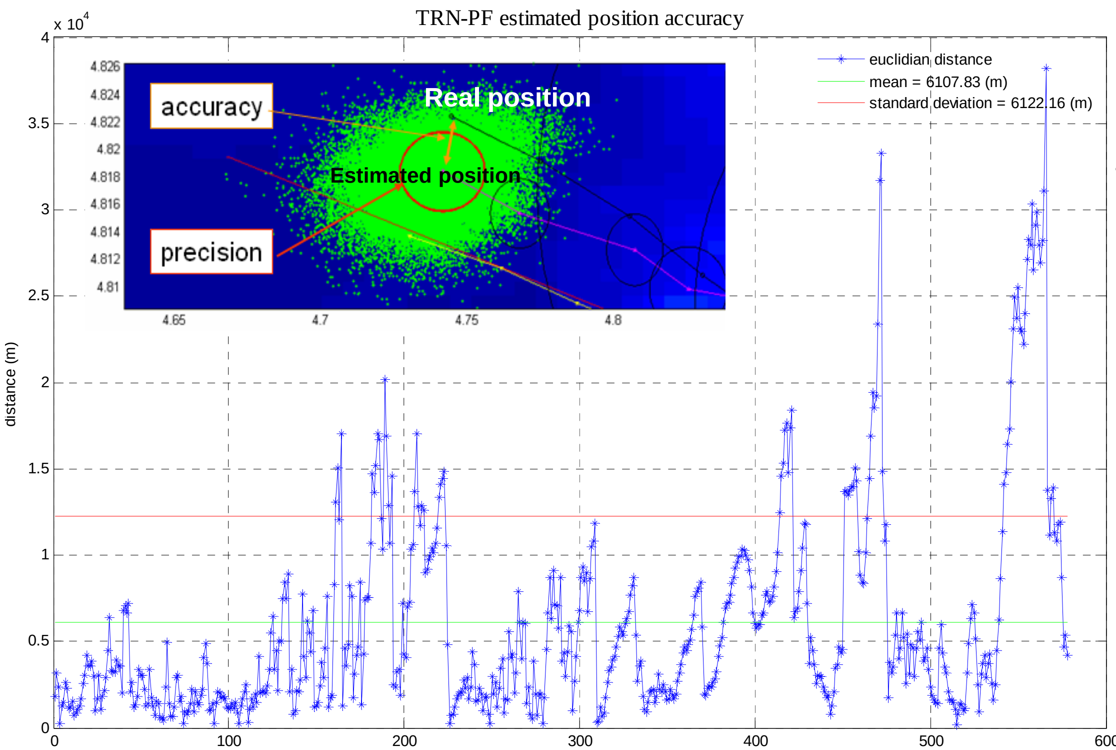
- Arctic crossing: very deep water glider (4000m)

Mission specifications:
- 7 waypoints
- pitch angle: 26 degrees
- diving target depth: 4000m (when possible)
- climbing target depth: 400m
-1 pings per dive / every dive

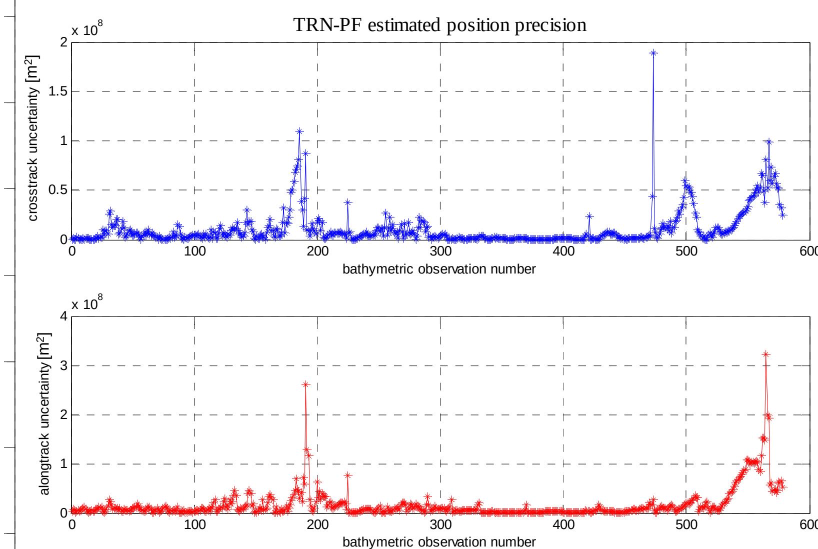
~ 165 days of submerged mission under the ice



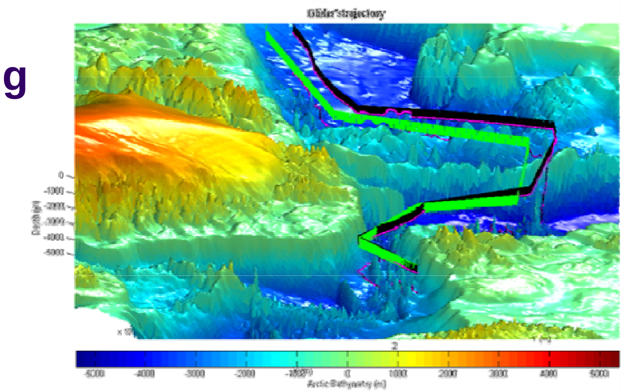
- Particle filter accuracy results



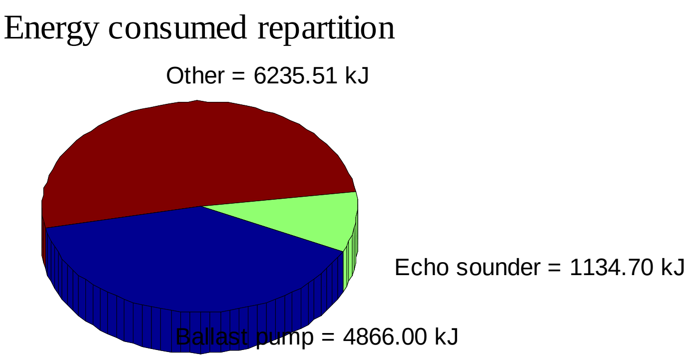
- Particle filter precision results

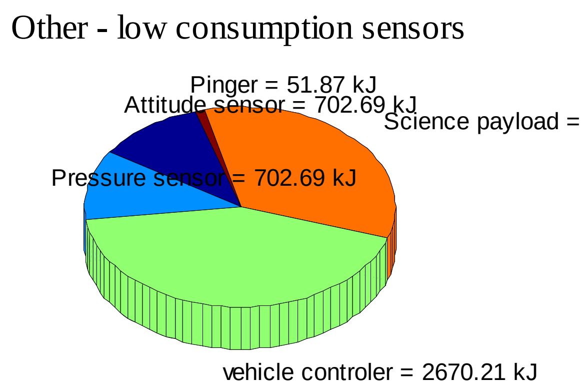


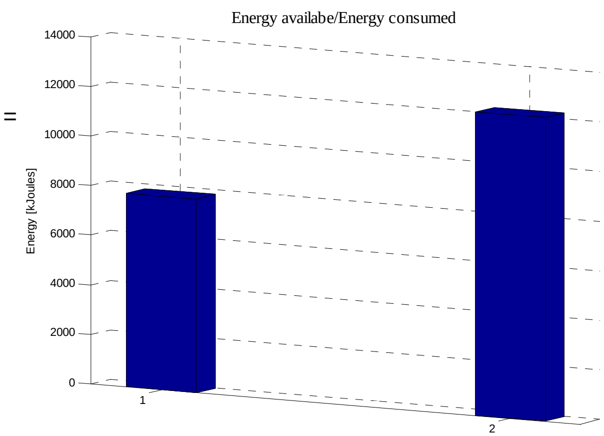
6. Simulations: Arctic crossing Energy consumed



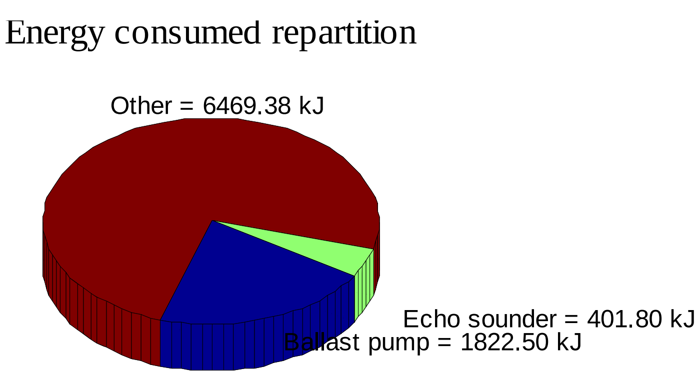
- Slocum glider (1000m)

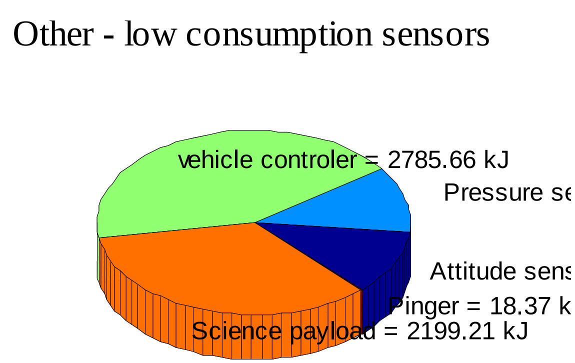


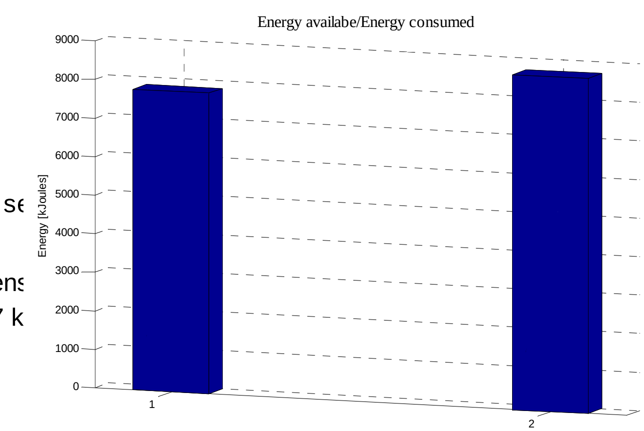




- Very deep water glider (4000m)





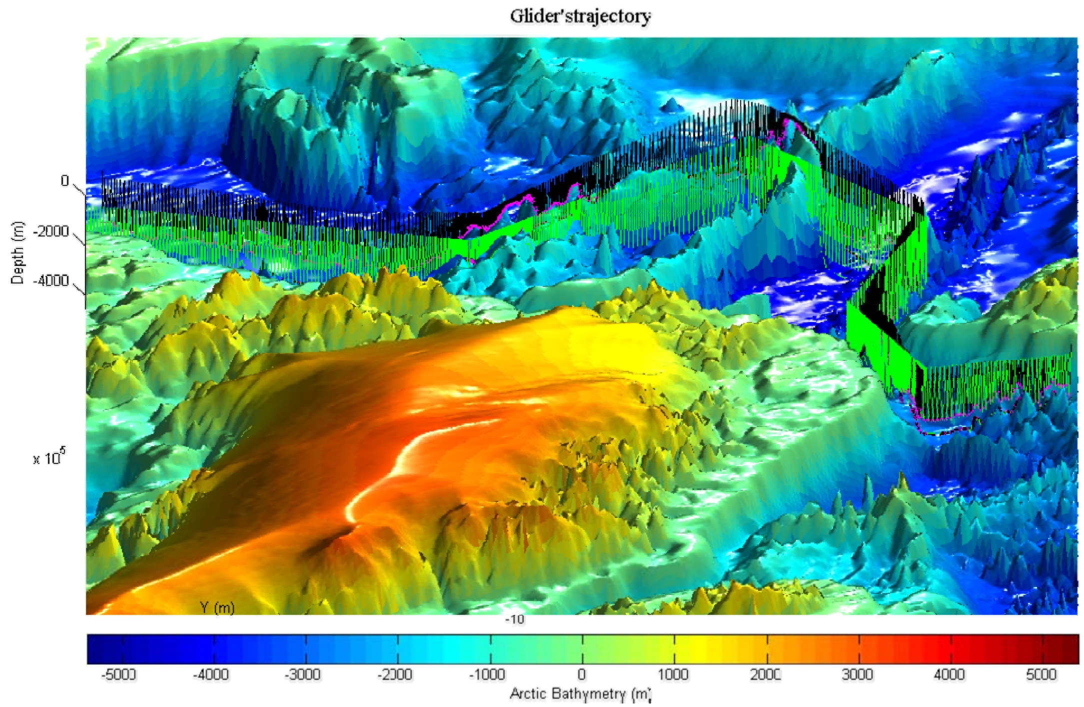


Conclusion

- "Can we use a terrain navigation algorithm for a long range under ice mission in the Arctic Ocean?"

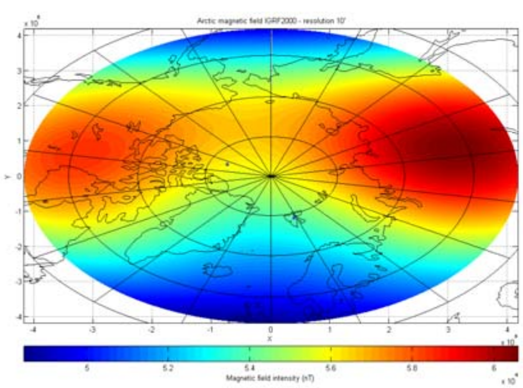
  - Simulation results show that the TBN principle using a particle filter seems to be a perfect tradeoff to meet:

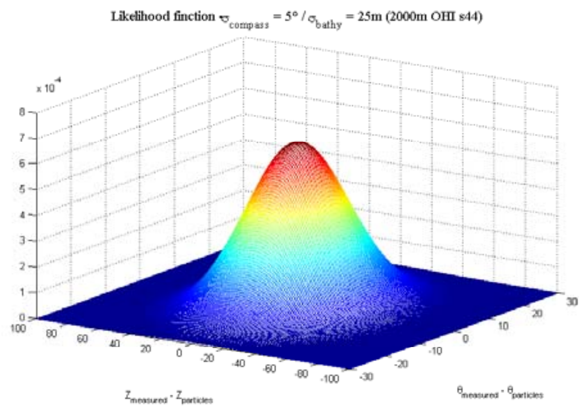
    1. Accurate navigation
    2. Limited endurance
    3. Low cost technology



Perspectives

- Implementation of a 3D dynamic model
- Develop the energy budget study: processing energy consumption

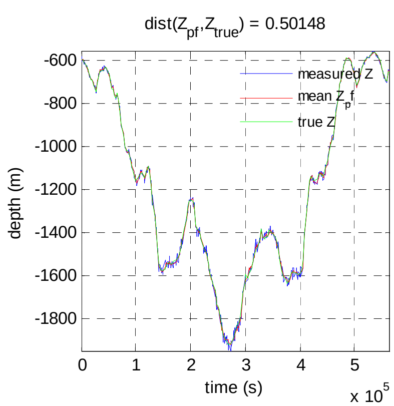


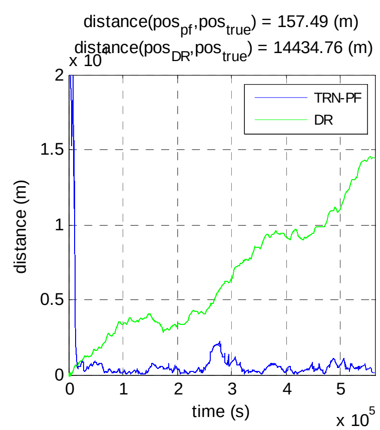


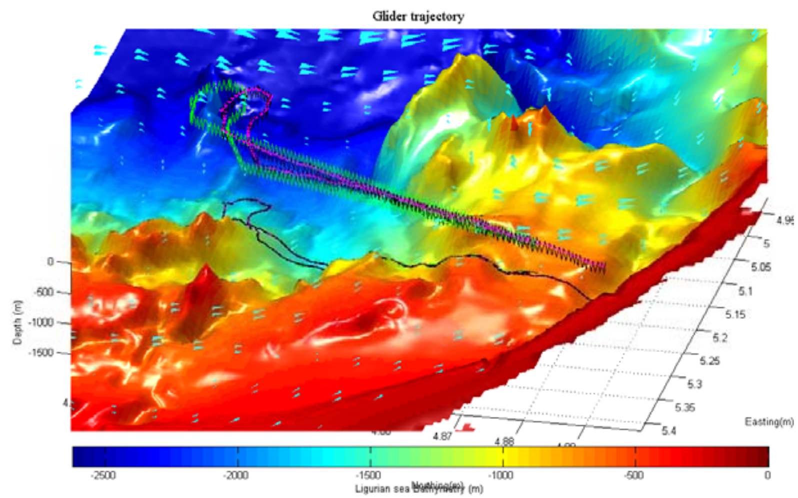
- Incorporate data from magnetometer in the navigation process (update step)

$$like = \frac{1}{\sqrt{2\pi}.\sigma_{bathy}}.e^{\frac{-(Z-Zi)^2}{2.\sigma^2_{bathy}}}\frac{1}{\sqrt{2\pi}.\sigma_{compass}}.e^{\frac{-(\theta-\theta i)^2}{2.\sigma^2_{compass}}}$$

- Test the Terrain Based Navigation in Ligurian Sea







Thank you!!