PROCEEDINGS OF SCIENCE

Underwater Muon Detection System to Measure Coastal Mixed Layer Depth for Ocean and Climate Studies

M. Akif Korkmaz* **and M. Bilge Demirköz**

Middle East Technical University,
Üniversiteler Mahallesi, Dumlupınar Bulvarı No:1 Çankaya, Ankara, TURKEY

E-mail: akif.korkmaz@cern.ch, demirkoz@metu.edu.tr

After atmospheric muons enter the sea, a decreased muon count is observed at the bottom of water. Muon count is inversely proportional to the density of water which can be measured by counting muons at the bottom. Mixed Layer (ML) in Oceans is defined as the less dense upper region of the water column where turbulent mixing occurs. Mixed Layer Depth (MLD) is the depth of this region and shows diurnal, seasonal fluctuations, and spatial variations. MLD can be estimated by combining bottom muon count measurement with the sea surface temperature, salinity, and altimetry data from earth observing satellites. We proposed a scintillator based underwater muon detection system which can measure average water column density by counting surviving muons at the bottom. Using a Geant4 model, it is shown that combining this density measurement with data from Earth observing satellites enables us to continuously estimate daily mean MLD with an accuracy of 3% for down to 100m depth.

42nd International Conference on High Energy Physics (ICHEP2024)
18-24 July 2024
Prague, Czech Republic

*Speaker

PoS(ICHEP2024)1219

1. Introduction

Atmospheric muons along with other particles are created when cosmic rays interact with the upper atmosphere. These relativistic muons generate a shower which has an angular distribution relative to zenith angle depending on their energy [1]. At the sea level, muon contribution to the cosmic ray flux is the highest for particles with energies above $1GeV$ and obeys $cos^2(\theta)$ distribution around $10GeV$ [1, 2]. Sea level muon flux exhibits 0.1% diurnal and 1% seasonal variation as well as showing a 0.27% per latitude increase from equator to poles [2]. During the coronal mass ejection period, atmospheric muon flux can decrease down to 80% of the mean for 3 to 10 days [3]. Since energy loss of muons depends on density of water, they should have certain energies in order to reach a particular depth of water before decaying [1]. Due to this fact, the number of surviving muons at the bottom of water is inversely proportional to the average density of water above.

In oceans and lakes, due to wind stress, precipitation, and freshwater inputs, there is a layer of water in the upper region which has almost constant density and this layer is named Mixed Layer (ML) and the depth of this layer is called Mixed Layer Depth (MLD) [4]. Variation of MLD is important in order to study chemical mixing rate which affects ocean biology and ecosystem [4, 5]. Mixed layer also acts as a heat reservoir for the atmosphere therefore monitoring MLD is essential for meteorology and climate studies [5]. Current measurements of MLD are mostly done by Conductivity, Temperature and Depth (CTD) sensors which give momentary and localized data [6]. Most MLD definitions are made using the high density difference between ML and bottom layer using this momentary data [4]. It is possible to simplify MLD definition using the average density of water which can be measured by using atmospheric muon shower.

2. Measurement System and Theory

A MLD monitoring system can be made using two muon counters to eliminate temporal variations in the muon flux. A surface muon counter can be placed on the shoreline while the other will be placed at the bottom of the water. Total density of water (σ_T) can be found using the muon count difference (N_μ) between surface and bottom by employing equation (1). Parameters α and β can be found by experiments and modeling studies.

$$\sigma_T = \alpha N_\mu + \beta \tag{1}$$

Assuming MLD is a fraction of total depth (D_T) of water, an equation can be written using the average density of water. This fraction is the ratio of difference of bottom (σ_B) and average (σ_a) density to difference of bottom (σ_B) and surface (σ_S) density as can be seen in equation (2).

$$MLD = D_T \frac{\sigma_B - \sigma_a}{\sigma_B - \sigma_S} \tag{2}$$

Surface density can be acquired from open access satellite observations and a density sensor sensor can be placed next to the bottom muon counter in order to measure bottom density. Finally, corrections to the total depth can be done using altimetry measurements from satellites and average MLD can be calculated for a chosen time window.

3. Validation Studies

In order to determine the validity range of the MLD measurement system, a Geant4 model was prepared. Salty sea water with two density levels was introduced to mimic various MLD and sea level atmospheric muon flux was used. Results show that daily mean MLD can be measured with a 3% accuracy up to $100m$ total depth which corresponds to coastal waters. It is also found that parameter α increases with total depth while order of parameter β remains the same and can be thought as a correction term.

Laboratory work has been carried out to realize the MLD measurement system. A $0.25m^2$ scintillator based muon counter was constructed and left to collect muon flux data. Initial results show an agreement with expected muon flux and time series of daily mean muon flux can catch increased solar activity which results in a Forbush decrease [1, 3]. Next step of the work will be to deploy the system in a coastal water while actively measuring MLD with conventional methods to validate this technique.

4. Conclusion

This study reveals that Mixed Layer Depth (MLD) can be measured in coastal shallow waters with an underwater muon detection system which measures atmospheric muon flux. Proposed detector system can measure average water column density by counting surviving muons at the bottom of water. Combining this density measurement with data from remote sensing technologies enables us to estimate MLD continuously. Using these data, a new approach for calculating MLD has been introduced and shown to be valid by a modeling study. Continuous measurement of MLD can help monitoring the environment for coastal ecosystem and climate studies.

References

[1] S. Cecchini and M. Spurio, *Atmospheric muons: experimental aspects*, *Geoscientific Instrumentation, Methods and Data Systems* **1** (2012) 185.

[2] V. Shutenko, I. Astapov, N. Barbashina, A. Dmitrieva, R. Kokoulin, K. Kompaniets et al., *Long-term variations in the muon flux angular distribution*, *Geomagnetism and Aeronomy* **53** (2013) 571.

[3] I. Braun, J. Engler, J.R. Hörandel and J. Milke, *Forbush decreases and solar events seen in the 10–20 gev energy range by the karlsruhe muon telescope*, *Advances in Space Research* **43** (2009) 480.

[4] R.E. Thomson and W.J. Emery, *Data analysis methods in physical oceanography*, Newnes (2014).

[5] S. Liang and J. Wang, *Advanced remote sensing: terrestrial information extraction and applications*, Academic Press (2019).

[6] S. Xiao, M. Zhang, C. Liu, C. Jiang, X. Wang and F. Yang, *Ctd sensors for ocean investigation including state of art and commercially available*, *Sensors* **23** (2023) 586.

PoS(ICHEP2024)1219