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Correlation Between Atmosphere's Low-Pressure Systems and Ocean Surface Gravity Waves Formation: Geneses and Predictability

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Abstract

Some portions of the ocean surface put a troposphere column placed above them in ideal temperature and humidity training atmosphere's low-pressure system and primary gravity waves that accompany them. This is similar to pilots that put their plane in the ideal conditions for the atmosphere to suck it and allow a successful launch. To study the behavior of rogue waves triggered by the tornadoes, cyclones or hurricanes in terms of their space and time evolution, that is, their motion and also in terms of mechanical transformations that these systems may suffer in their dealings with other systems, we use the effectiveness of Mbanes' fluid dynamic balance model which provides relevant knowledge on the vertical profile of winds triggered by the atmosphere's low-pressure system. Result shows that: i) the rogue waves are generated on the free surface of deep-water by constructive filamentation or interference of atmosphere's low-pressure system and ii) the nonlinear evolution of the occurrence probability of freak wave predicted increases with the number of wave train and steepness parameter.

Keywords

Atmosphere's Low-Pressure System, Mbanes' Fluid Dynamic Balance Model, Rogue Wave, Predictability

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1. Introduction

The study of rogue waves fascinates today a great deal of interest from scientific community, especially in nonlinear sciences. These phenomena appear and disappear in the ocean while letting very visible traces (destruction the ships, the oil platforms and the inshore structures) contrary to the testimonies of sailors [1-5]. Observations of the rogue waves that appear unusually on the surface oceans and numerous pictures on the extent of the damages caused by these monsters by their attacks require a development of the nonlinear theory of off-balance systems in the specific case of strong agitations constantly seen on the free surface in the deep-water. Previously, the descriptions of the rogue waves have been considered like a part of the marine folklore during a long period. Indeed, these waves were considered as a myth than a phenomenon being a matter for the physics. However, the physics of processes responsible for the formation (or origin) and propagation of these phenomena as well as their prediction is not completely understood. In spite of many recent works [6-8], many features of the waves remain unspecified. In fact, the general problem of predicting the future of sea state is classic and the available results are mainly based on linear theory. This cannot obtain details of the ocean wave field deterministic necessary for understanding the formation and prediction of extreme events such as a rogue wave. Indeed, gravity waves on the surface of the oceans are nonlinear waves, and while a linear theory can often be

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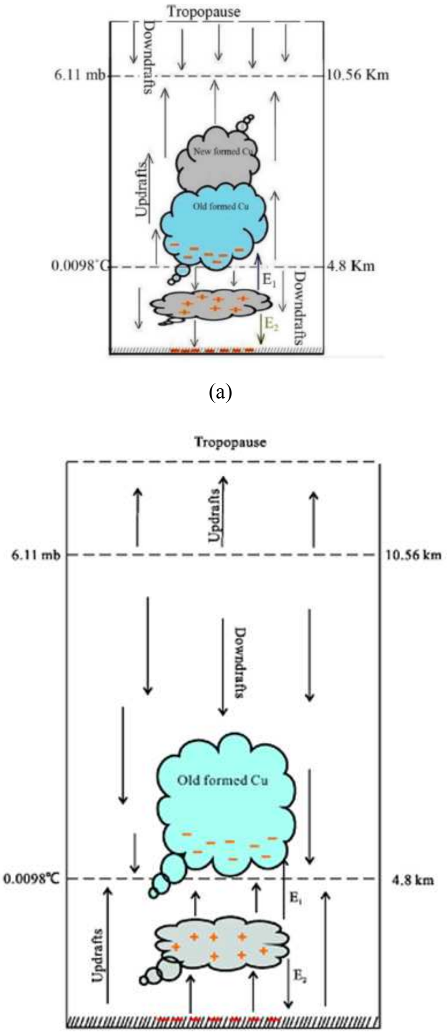
obtained, many phenomena cannot be described in this context. Thus, when the amplitude of the waves increases, phenomena of energy transfer, fluid structure interaction or submersion height may be poorly, if at all, predicted by linear models. Reason for which in this manuscript, the nonlinear theory of the atmosphere - ocean interactions is demonstrated the use of numerical and analytical analysis that characterize the role of forcing in the processes of the rogue wave formation by an atmosphere's low-pressure system. It is precisely in this case, the materialization of action triggers reaction physics' principle and then of a manifestation (among many others) of the irrefutable of atmosphere-oceans coupling. The rogue waves births' constraints are mainly the need for both consistent water (i.e.: extensive-deep rivers) and potential velocity flow domain [9]. The work presented in this paper is structured as follows: In section 2, we present the method by giving the basic kinematics and thermodynamics of Atmosphere's low-pressure systems, the kinematic constraints associated with births of tornadoes' (or cyclones') rogue waves and materialization of the interaction between the atmosphere's low-pressure systems and the gravity waves. In section 3, we present the results and discussion that give the formation of tornadoes' (or cyclones') rogue waves and the predictability of surface rogue waves ocean. In section 4, some conclusions are given.

2. Method

2.1. Basic Kinematics and Thermodynamics of Atmosphere's Low-Pressure Systems

Atmosphere's low-pressure systems are triggered by passive deep convection generated by a (hot or cold) source located at the surface of the earth (Figure 1) with geostrophic winds (Figure 2) inside troposphere moister and warmer columns [10-11]. They can also electrify the troposphere column in which it is formed [12].



(a)

b)

Figure 1. Atmosphere's low-pressure systems are triggered by passive deep convection generated by a (hot or cold) source located: a) Atmosphere's low-pressure systems are triggered by passive deep convection generated by a cold source located at the summit of the troposphere b) Atmosphere's low-pressure systems are triggered by passive deep convection generated by a hot source located at the surface of the earth.

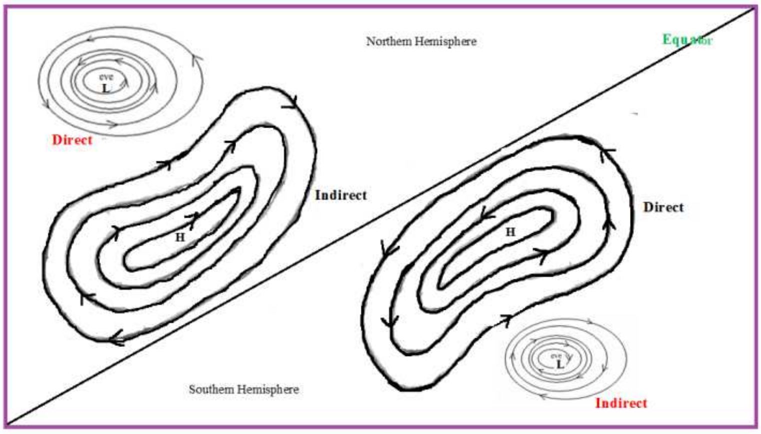


Figure 2. Streamlines of geostrophic winds triggered by Atmosphere's low-pressure systems around their low-pressure groove. L and H designate respectively Low- and High-pressure system. Rotative of the Atmosphere's low-pressure systems (L) and contra-rotative of the Atmosphere's high-pressure systems (H) in the northern hemisphere. The situation is reversed in the southern hemisphere.

2.2. Kinematics' Constraints Associated with Births of Tornadoes' (or Cyclones') Rogue Waves

The general fluid continuity equation is given by:

$$\frac{\partial\rho}{\partial t}+\frac{\partial\rho u}{\partial x}+\frac{\partial\rho v}{\partial y}+\frac{\partial\rho w}{\partial z}=0 \qquad (1)$$

This leads to the continuity equation for an incompressible fluid

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (2)$$

The kinematic boundary conditions

$$\vec{V}.\vec{n}=0\text{, at z = -H and z = }\eta(x,y,t) \qquad (3)$$

Where $\vec{n}$ is the unit vector normal to the boundary surfaces and $\eta(x,y,t)$ is the sea surface elevation. Hence:

$$\left(u,v;w-\frac{\partial\eta}{\partial t}\right).\left(-\frac{\partial\eta}{\partial x},\frac{\partial\eta}{\partial y},1\right)=0\text{ , z}=\eta$$

$$\Rightarrow w=\frac{\partial\eta}{\partial t}+u\frac{\partial\eta}{\partial x}+v\frac{\partial\eta}{\partial y} \qquad (4)$$

Equation of motion in natural coordinates

$$\frac{\partial\vec{V}}{\partial t}+(\vec{V}.\vec{\nabla})\vec{V}=\nu((\vec{\nabla}.\vec{\nabla})\vec{V})-\frac{1}{\rho}\vec{\nabla}P+\vec{g} \qquad (5)$$

For an inviscid fluid, equation (5) is simplify to

$$\frac{\partial\vec{V}}{\partial t}+(\vec{V}.\vec{\nabla})\vec{V}=-\frac{1}{\rho}\vec{\nabla}P+\vec{g} \qquad (6)$$

When the flow is irrotational, one can write

$$\vec{\nabla}.\vec{V}=0 \qquad (7)$$

The related velocity potential is so given by

$$\vec{V}=(u,v,w)=\left(\frac{\partial\phi}{\partial x},\frac{\partial\phi}{\partial y},\frac{\partial\phi}{\partial z}\right)=\vec{\nabla}\phi \qquad (8)$$

The continuity equation in regard to irrotational flow

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}=\Delta\phi=0 \qquad (9)$$

The kinematic boundary condition at the bottom of irrotational flow

$$\vec{\nabla}\phi.\vec{n}=0\text{, at z = -H} \qquad (10)$$

The kinematic boundary condition at the surface of the same flow

$$\frac{\partial\phi}{\partial z}=\frac{\partial\eta}{\partial t}+\nabla_{\perp}\phi.\nabla_{\perp}\eta\text{, at z = }\eta \qquad (11)$$

2.3. Materialization of the Interaction Between the Atmosphere's Low-Pressure Systems and the Gravity Waves

Integrating equation (6) with respect to (x,y,z), leads to Bernoulli equation. Arbitrary functions of integration $C_1(y,z,t)$, $C_2(x,z,t)$, $C_3(x,y,t)$ must be the same function C(t), which can be absorbed by the velocity potential, yielding exactly the same flow

$$\frac{\partial\varphi}{\partial t}+\frac{1}{2}(\vec{\nabla}_Z\varphi)^2+g\eta=-\frac{1}{\rho}(P_{AS}(x,y,t)-P_0)\text{, at z = }\eta \qquad (12)$$

Where: ρ is the density of liquid water; P_{AS} the Sea-level dynamic pressure and P_0 the Sea-level static pressure.

Due to the smallest-vertical extend of oceans with regard to earth's radius, we can consider $\vec{g}$ constant throughout it: $\vec{g}=(0,0,-g)$ making the gravitational force conservative and able to derive from a potential energy throughout the ocean. We can also neglect the surface tension.

When atmosphere's low-pressure systems cross the ocean: *the atmosphere low boundary decreasing pressures field above the ocean replaces* P_{AS} *in eq. (12).*

And then, taking ϕ *constant and equal to 0 at z=*η*, gives formula (13) which describes the geometry of ocean's surface waves [9]:*

$$\eta\ (x,y,T_S,t)=-\frac{1}{\rho(T_S)\,g}(P_{AS}-P_0) \qquad (13)$$

Where

T_s is the sea surface temperature,

P_{AS} is the sea-level decreasing pressure below atmosphere's low-pressure systems,

P_0 is the sea-level static pressure (P_0 = 1013 millibars).

According to formula (13): The height of waves depends mainly on low pressure deepest. i.e., (P_{AS} -P_0) → - ∞.

3. Results and Discussion

3.1. Formation of Tornadoes' (or Cyclones') Rogue Waves

Earth's ecosystem is considerably modified by adverse effects of climate change and this irreversible process reveals human beans vulnerability vis-à-vis of phenomenon like rogue waves; landslides; coastal cities floods, etc. Such a fast development of extreme states of sea can be explained by the interaction between the atmospheres' low pressure generated by the turbulence and the state of sea and have some repercussions on the oil activities, the ships and the inshore structures. On Figure 3, one can see the profile of rogue wave occurs by the atmosphere's low-pressure systems. The resulting wave reveals that interferences or filamentations are mainly constructive in the case of sea-surface carrier waves whose directions of propagation are nearly parallel (see Figure 3). Taking into account the relation 13, the formation of rogue waves can be predicted using meteorological data. Indeed, the deepest of impacts on sea level pressure depends on many weather's parameters.

Figure 3. Rogue wave occurs by the Atmosphere's low-pressure systems.

3.2. Predictability of Surface Rogue Waves Ocean

Figure 4 illustrate Exceedance probability of maximum wave height as a function of the number of wave train N and steepness parameter. On Figure 4, it can predict the distribution of the height for big amplitude that agitates in a narrow strip, weakly nonlinear of the wave field. Figure 5 describe the occurrence probability of freak wave as a function of the number of waves train N and steepness parameter. The occurrence probability of a freak wave predicted in percentage (%) are listed in Table 1. According to this table, the nonlinear evolution of the occurrence probability of freak wave predicted increases with the number of wave train N and steepness parameter. All these simulations give an indication of the predictability of surface rogue waves ocean. Figure 6 illustrate Ratio of freak wave occurrence predicted of rogue wave as function of the number of wave train. It decreases with the number of wave train.

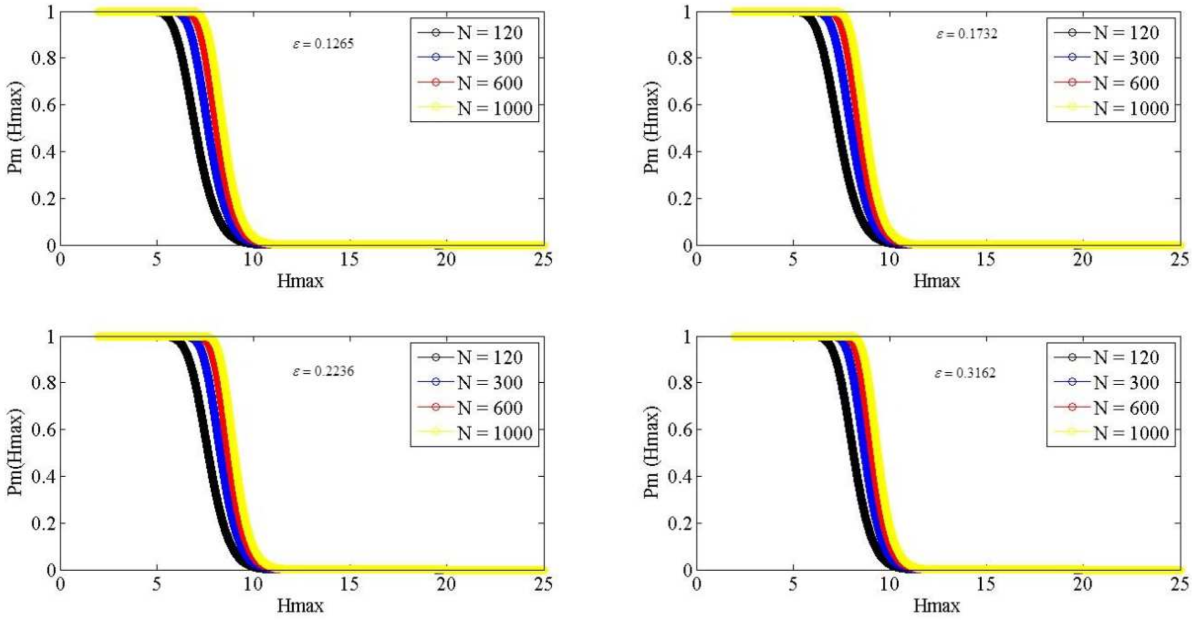


Figure 4. Exceedance probability of maximum wave height as a function of the number of wave train and steepness parameter.

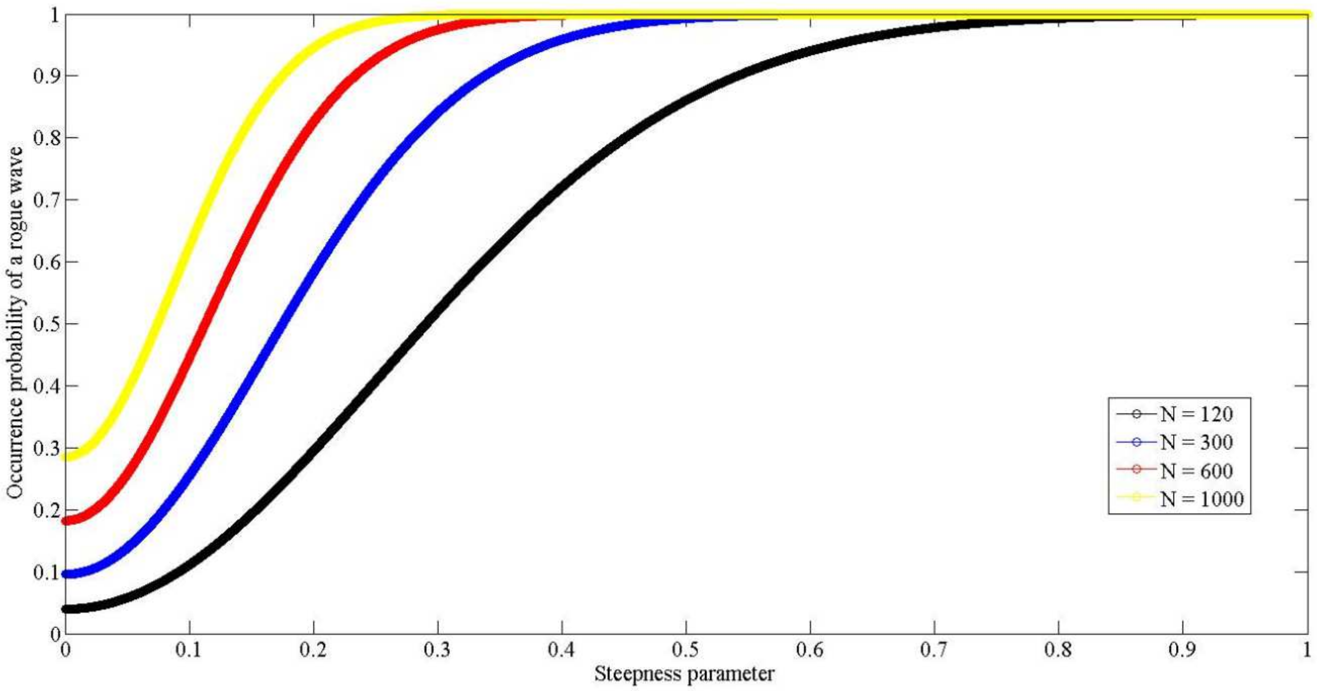


Figure 5. Occurrence probability of freak wave as a function of the number of waves train N and steepness parameter.

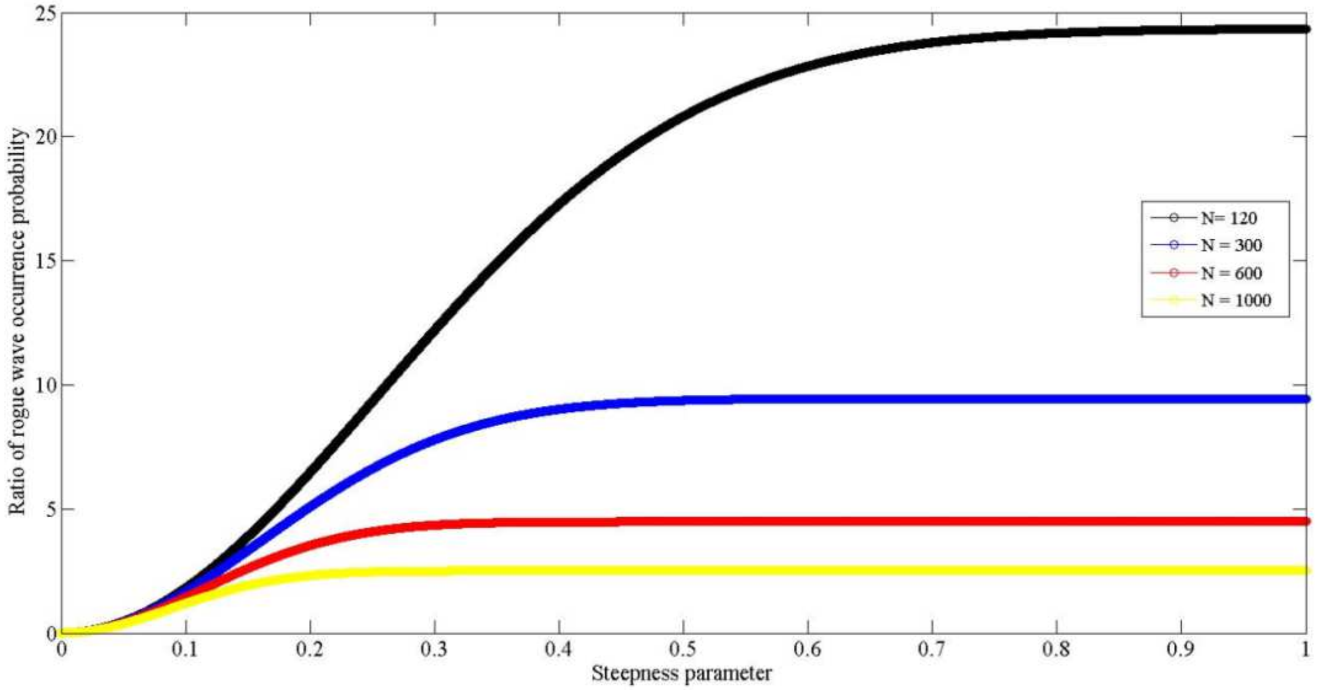


Figure 6. Ratio of freak wave occurrence predicted.

Table 1. Occurrence probability of a freak wave predicted in percentage (%) as a function of the number of waves train N and steepness parameter.

Steepness parameter Number of waves train	0.00	0.05	0.10	0.15	0.20
120	4	6	10	18	28
300	10	14	24	39	55
600	18	25	43	62	79
1000	28	40	59	78	91

4. Conclusion

The main goal of this study is to demonstrate the correlation between the atmosphere's low-pressure system and the ocean surface gravity waves formation. It is crucial for the analysis and interpretation of field data. Indeed, knowledge of meteorological parameters permit to predict the formation of these, when it is crossed by an atmosphere's low-pressure system. Euler-Lagrange and Navier-Stokes equations have provided evidence that waves may form on the surface of water as a reaction to impacts of sea-level decreasing pressures of the atmosphere lower boundary. The deep-water model based on the Navier-Stokes equations coupled with assumptions derived from advance data bases on rogue waves describes well the properties of the generated freak waves by the atmosphere's low-pressure system. The rogue waves births' constraints are mainly the need for availability of both consistent water (i.e.: extensive-deep rivers) and potential velocity flow. They illustrate the permanent and unstable regimes of the formation of this phenomenon and focus the waves in the process of their predictions.

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References

[1] Atock A. N. S., Daïka A., Mbané B. C., (2014) Extended (G'/G) Method Applied to the Modified Non-Linear Schrodinger Equation in the Case of Ocean Rogue Waves. *Open Journal of Marine Science*, 4, 246-256. http://dx.doi.org/10.4236/ojms.2014.44023

[2] Daïka A., Nkoa T. N., Mbané B. C., (2014) Application of Stationary Phase Method to Wind Stress and Breaking Impacts on Ocean Relatively High Waves. *Open Journal of Marine Sciences*, 4, 18-24. http://dx.doi.org/10.4236/ojms.2014.41003.

[3] Dysthe K., Krogstad H. E., Muller P., (2008) Oceanic rogue waves. *Annu Rev Fluid Mech 40*: 287-310.

[4] Kharif C., Pelinovsky E., Slunyaev A., (2009) Rogue Waves in the Ocean. Advances in Geophysical and Environmental Mechanics and Mathematics, DOI 10.1007/978-3-540-88419-4 3, Springer-Verlag Berlin Heidelberg 2009.

[5] White B. S., Fomberg B., (1998) On the Chance of Freak Waves at Sea. *Journal of Fluid Mechanics*, 355, 113-138. http://dx.doi.org/10.1017/S0022112097007751

[6] Chabchoub A., Hoffmann N., Akhmediev N., (2011) Rogue wave observation in a water wave tank. *Physical Review Letters*, 106 (20), 204502.

[7] Daïka A., Mbané B. C., (2020) Nonlinear Evolution of Gravity Waves on the Surface Deep-water Under the Action of Viscosity and Surfactant. *American Journal of Geophysics, Geochemistry and Geosystems*, 6 (2), 50-57

[8] Wu C. H., Yao A, 2004. Laboratory Measurements of Limiting Freak Waves on Current. *Journal of Geophysical Research*, 109, 1-18. http://dx.doi.org/10.1029/2004JC002612.

[9] Daïka A, Mbané B. C., (2015) Relationship between Sea Surface Single Carrier Waves and Decreasing Pressures of Atmosphere Lower Boundary. *Open Journal of Marine Science*, 5, 45-54. http://dx.doi.org/10.4236/ojms.2015.51005.

[10] Daïka A., Messanga E. H., Ngabireng M. C., Mbané B. C., (2012) Application of Benjamin-Feir Equations to Tornadoes' Rogue Waves Modulational Instability In oceans. *International Journal of Physical Sciences*, 7 (46), 6053-6061.

[11] Mbané B. C., (2015) Earth's Atmosphere Dynamic Balance Meteorology. Scientific Research Publishing Inc., 110 p

[12] Mbané B. C., (2016) Identification and Interpretation of Earth's Atmosphere Dynamics' and Thermodynamics' Similarities between Rogue Waves and Oceans' Surface Geostrophic Wind. *Open Journal of Marine Science*, 6, 238-246. http://dx.doi.org/10.4236/ojms.2016.62019