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FINE THERMOHALINE STRUCTURE OF THE COLOMBIAN PACIFIC OCEAN

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ABSTRACT

The present document shows strata classification of the Colombian Pacific Ocean – COLUMBIAN PACIFIC OCEAN, done by first time according its fine thermohaline structure, based on temperature and salinity fields analysis. Layers, where different mechanisms of fine structure predominate, were determined and everywhere in the area a stable stratification was observed, although conditions for not stability as a result of the double diffusion were present.

Key Words**:** fine thermohaline structure, small-scale thermohaline structure, stability of the ocean, stratified ocean, salt finger stratification, differential-diffusion convection, and step structure

RESUMEN

El presente documento muestra la clasificación de las capas de la Cuenca del Pacífico Colombiano (CPC), hecha por primera vez de acuerdo con su estructura termohalina fina, basada en el análisis de los campos de temperatura y salinidad. Las capas fueron determinadas con predominancia de diferentes mecanismos de estructura fina y se observó que en toda la región existe una estratificación estable, aunque se encontraron condiciones de inestabilidad como resultado de una doble difusión.

Palabras clave**:** estructura termohalina fina, estructura termohalina de baja escala, estabilidad en el océano, estratificación oceánica, estratificación de salinidad, convención de difusión diferencial, paso de estructura**.**

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INTRODUCTION

On a fine structure scale, the profiles of hydrophysical fields show alternated sections with small and high gradient properties, the first one called quasi-homogeneous layers and the second one by layers. Inside temperature (T) and salinity (S) profiles, sections with inverted properties distributions are frequently encountered.

The fine structure is understood as a model of physical fields represented by a set of layers instead of homogeneous properties in strata ranging from 0.1 to 1 m, divided by even more thin layers with sharp gradients of temperature and salinity. The vertical gradients are 10 to 100 times higher and more, exceeding corresponding average gradients values (Karlin, 1988).

The fine stratification of water layer is testified by numerous measurements, done in different regions of the ocean with low-inertia sounding equipment, in particular CTD- probes. Contrasting profiles obtained by standard hydrological instruments, these profiles contain many structural details, reproduced by repeated soundings and, therefore, which live long. The frequently curves of vertical distribution T and S take the form of correct steps or variables on the sign of deviations from the average profiles. There are fine-structure heterogeneities in the seasonal and main thermoclines on big depths and even in the upper quasi-homogeneous layer of the ocean (Karlin et al., 1988). Fedorov showed (Fedorov, 1976) that below the upper quasi-homogeneous layer, a fine structure is formed in the majority of cases against the hydrostatic stability background on the vertical distribution density.

On these conditions, two mechanism of fine structure formation are possible. The first one requires kinetic energy from an external source, used to increase the potential energy in the liquid layer. The mechanisms present are shift instability of currents, internal waves, etc. The second mechanisms do not require external energy sources. There, the structurization occurs by liberation of accessible potential energy, dissipated later as heat. The mechanism presents instability due to differential-diffusion convection or dual diffusion (Zhubas and Ozmidov, 1984, Ozmidov, 1983).

In shift instability of currents and internal waves, turbulence and elements of fine structure of hydrophysical fields arise under action of strong hydrodynamical instability in zones with high vertical gradients of speed current, like located areas observed as separate turbulent spots (Benilov, 1985, Maderich and Nikishev, 1986). Turbulent mixing regions are outlined on the vertical profiles of hydrophysical fields as the fine structure elements. The mixture process in the turbulent volume decreases temperature and salinity gradients inside it, being critical on its boundaries.

Spots formation due developed turbulence may also occur because instability or breaking of internal waves (Fedorov, 1976, Fedorov, 1991, Konyaev and Sabinin, 1992). This mechanism is observed when the Richardson´s number achieve a value below some critical value, being the probability of formation of spots of turbulence at instability higher than at breaking of internal waves (Ohotnikov and Panteleis, 1985). The sizes of vertical instable areas of internal waves vary from decimeters to meters.

The differential-diffusion instability is due to diffusion of two or more components of hydrodynamic system at different speeds. Such instability forms a fine structure of temperature and salinity fields in water with a wide circulation at the ocean. Because differences in the molecular thermal conductivity coefficients and salt diffusion in the system, the convective instability appears, producing intensive mixing and forming quasi-homogeneous layer divided by layers with sharp gradients properties (Turner, 1985).

A special attention is paid to the mechanism of differential-diffusion instability, it allows accelerated heat and salts transfers without energy from external sources (Karlin et. al, 1988, Fedorov et. al, 1986, Karlin, 1988). This mechanism is observed, when temperature and salinity gradients produce opposite contributions to the vertical density gradient. Here, the potential energy associated to vertical stratification is used, contributing to destabilize the density gradient. Liberation of instability energy is due to differences in coefficients of molecular exchange of heat and salts. Differential-diffusion instability is manifested in the regime of salt fingers and layered or diffuse convection.

METHODOLOGY

Initial natural data

The calculation of stability of layers in waters of Colombian Pacific Ocean (Villegas, 2001) was made according to the fields of temperature and salinity, obtained in the scientific expedition during May 2000 (Otero y Pineda, 2000). The vertical distribution of water stability and the

Vaisala-Brunt's frequency (Villegas, 2002b, Karlin and Villegas, 2003) were made based on the example of 3 hydrometeorological stations obtained in this expedition: 14, 49 and 111 (Figure 1).

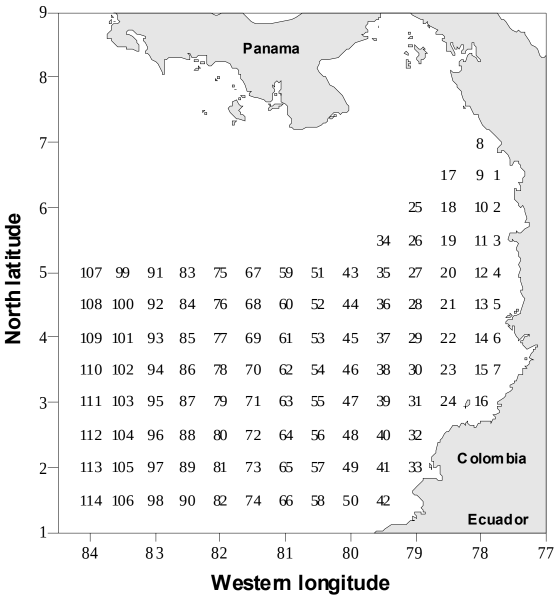

Figure 1. Hydrometeorological stations on the Colombian Pacific Ocean.

These stations, covering the 3 more interesting zones: coastal zone-station 14 (at 4°N/78°W), open sea-station 111 (at 3°N/84°W) and zone of mixing waters-station 49 (at 2°N/80°W), were selected on basis to the quasi-homogeneous zones on this study region (Villegas, 2002a).

Diagnostic of possible fine structure activity in the ocean

The temperature (E_t) and salinity (E_s) components of stability (E) are widely applied in the solution of different problems, including the typification of thermohaline conditions for stratification, diagnosing possible forms of mixing and processes of structurization, including the scales of fine structure (Karlin et al, 1988; Malinin, 1998).

Diagnostics of possible fine structure activity in the ocean is carried out usually along background TS-profiles with the aid of some parameters and criteria. One of them relates temperature and salinity components of stability, and also density relationship R_p (Karlin et al, 1988; Filimonov, 1990, Fedorov and Pereskokov, 1991). Based on these parameters and criteria, the diagnostics of possible fine-structure activity in Colombian Pacific Ocean is represented below.

According to data obtained on Colombian Pacific ocean during May 2000 (Otero and Pineda, 2000), and the help of the Hesselberg Sverdrup's criterion (1) ([Malinin, 1998; Valerianova and Zhukov, 1974; Kamenkovich and Monin, 1978), stability is calculated and contributions of temperature and salinity are located into general stability Colombian Pacific ocean (Villegas, 2001).

$$E = \frac{\partial \rho}{\partial S}\frac{dS}{dz} + \frac{\partial \rho}{\partial T}\frac{dT}{dz} + \frac{\partial \rho}{\partial T}\frac{dT_A}{dz} \qquad (1)$$

With: $\frac{\partial \rho}{\partial S}$ as density variation with a change in the salinity, kg/m^3‰;

$\frac{dS}{dz}$ as vertical gradient of salinity, ‰/m;

$\frac{\partial \rho}{\partial T}$ as density gradient with change in temperature, kg/m^3°Cm;

$\frac{dT}{dz}$ Is the vertical gradient of temperature, °C/m;

$\frac{dT_A}{dz}$ as vertical gradient of adiabatic temperature, °C/m;

The temperature and salinity stability components, and the density relationship R_p (2) (Karlin et al., 1988, Malinin, 1998, Fedorov, 1991) have been used for carrying out of diagnostics of possible fine structure activity at ocean on background T-S profiles.

$$R_\rho = \frac{\left(\alpha \frac{d\theta}{dz}\right)}{\left(\beta \frac{dS}{dz}\right)} \approx -\frac{E_T}{E_S} \qquad (2)$$

With $\frac{d\theta}{dz}$ as vertical gradient of potential temperature, °C/m;

$\frac{dS}{dz}$ as vertical gradient of salinity, ‰/m;

E_T as temperature component of stability, kg/m^4;

E_S as salinity component of stability, kg/m^4.

On the same data is calculated Vaisala-Brunt's frequency (Villegas, 2002b) according to the formula (Malinin, 1998, Konyaev and Sabinin, 1992, Kamenkovich and Monin, 1978; Valerianova and Zhukov, 1974):

$$N = \sqrt{\frac{g}{\rho}\frac{d\rho}{dz}} \quad (3)$$

Where $\frac{d\rho}{dz}$ is the vertical gradient of density.

RESULTS

The stability of layers in waters Colombian Pacific Ocean N, according to temperature and salinity data of May 2000 expedition (Villegas, 2001), showed a vertical distribution of stability and the Vaisala-Brunt's frequency with a jump in the range 10 - 75 m. See station 14 (figures 2 and 3); station 49 (figures 4 and 5) and station 111 (figures 6 and 7) (Villegas, 2002b; Karlin and Villegas, 2003).

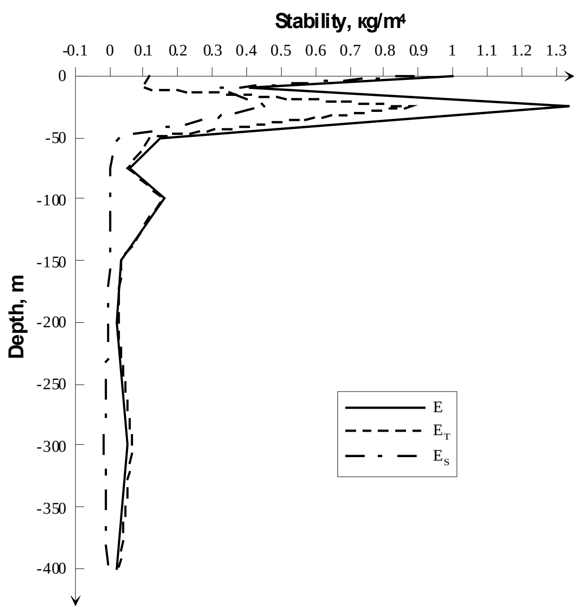

Figure 2. Vertical distribution of stability on Colombian Pacific Ocean. May 2000, station 14

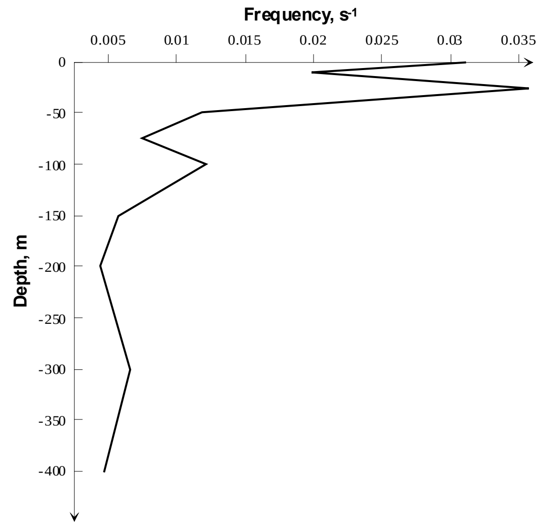

Figure 3. Vertical distribution of Vaisala-Brunt's frequency on Colombian Pacific Ocean. May 2000, station 14

Besides that, Colombian Pacific Ocean has a positive stability on all vertical and prevalence of temperature stability above salinity stability. The hydrological stations near the coast showed that, in a superficial layer, the stability in salinity prevailed over temperature stability. The contribution of salinity to stability decreases with removal from the coast.

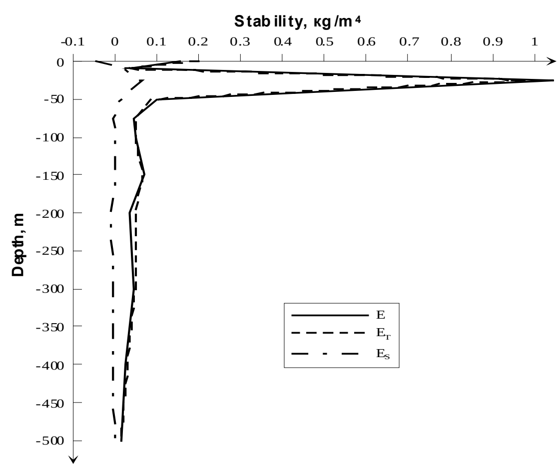

Figure 4. Vertical distribution of stability on Colombian Pacific Ocean. May 2000, station 49.

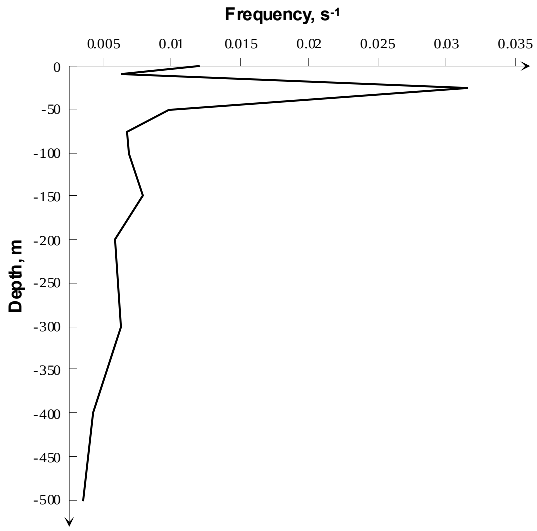

Figure 5. Vertical distribution of Vaisala-Brunt’s frequency on Colombian Pacific Ocean. May 2000, station 49.

Vertical distribution Vaisala-Brunt’s frequency has similar behavior with vertical distribution of stability. Vaisala-Brunt’s frequency has values from 0.0025 to 0.036 s^{-1} which decrease with removal from coast. The greatest values took place in the center section of the coast, and minimum in the southeastern region Colombian Pacific Ocean.

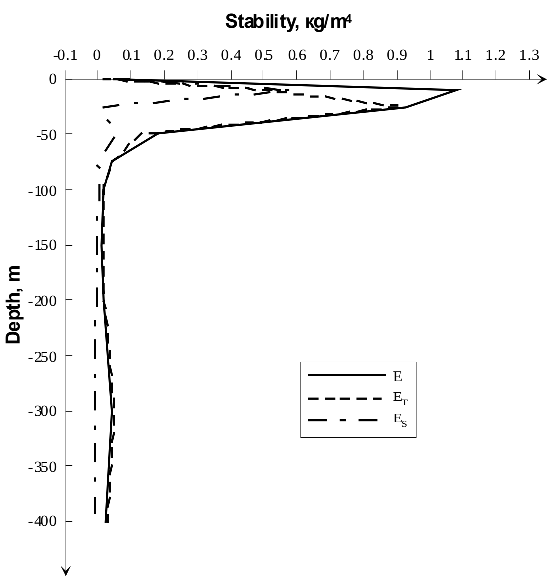

Figure 6. Vertical distribution of stability on Colombian Pacific Ocean. May 2000, station 111

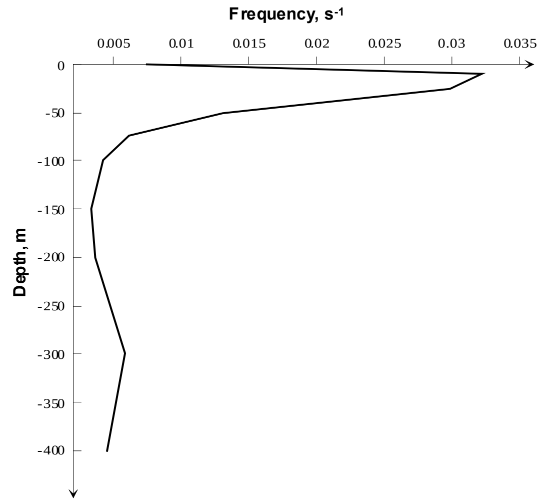

Figure 7. Vertical distribution of Vaisala-Brunt’s frequency on Colombian Pacific Ocean. May 2000, station 111

In 100 - 150 and 75 - 100 m layers, the greatest values of stability were located on the north along the coast and in the region from 78 to 80° W and from 5 to 7° N.

In the 50 - 75 m layer an absolute stability on the north and southwest Colombian Pacific Ocean is observed, while minimum values were observed around the Gorgona Island and southeast Colombian Pacific Ocean.

The layer 25-50 m shows absolute stability. The minimal values were located on the northeast and southwest Colombian Pacific Ocean.

In the 10-25 m layer negative values of stability are observed Colombian Pacific Ocean .

In general, in Colombian Pacific Ocean area stable stratification is observed, but there are conditions for not stability as result of double diffusion (Villegas, 2002b; Villegas, 2003). Table 1 shows the results of conducting diagnostics of the possible fine structure activity in Colombian Pacific Ocean by the example of stations located on all researched area, with the help of vertical distribution of temperature and salinity, combinations of the contributions E_T and E_S to the general stability, and also criterion R_ρ. In the given table four types of stratification are submitted as follows:

- Full, or absolute stability (AS): $\Delta T < 0$, $\Delta S > 0$, $E_T > 0$, $E_S > 0$, $R_\rho < 0$;
- Salt fingers type (SF): $\Delta T < 0$, $\Delta S < 0$, $E_T > 0$, $E_S < 0$, $R_\rho > 0$;

- Type of layered convection (LC): $\Delta T > 0$, $\Delta S > 0$, $E_T < 0$, $E_S > 0$, $R_\rho > 0$;

- Absolute instability (AI): $\Delta T > 0$, $\Delta S < 0$, $E_T < 0$, $E_S < 0$, $R_\rho < 0$.

It is evident from Table 1 that in Colombian Pacific Ocean predominates the complete stability upper 150 m layer. Below 200 m the salt the salt finger stratification is observed. In the layer 0-10 m only at separate stations 17, 42 and 114 absolute instability takes place. The type of salt finger stratification is at stations 49, 81 and 107, and the type of layered convection at the station 1. In the open Colombian Pacific Ocean, in all layers, the alternation by stratification of the type PU and SP is evident. Mixing here is irregular, i.e., in the form of spots, which forms steps in the TS-profiles.

TABLE 1. - TYPES OF STABILITY STRATIFICATION OF LAYERS ON COLUMBIAN PACIFIC OCEAN. MAY 2000

Layers, m	Numbers of station and type of stability														
	1	5	14	17	29	33	42	43	47	49	79	81	107	111	114
0-10	LC	AS	AS	AI	AS	LC	AI	AS	AS	SF	AS	SF	SF	AS	AI
10-25	AS	LC	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS
25-50	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	SF	SF	AS	AS	SF
50-75	AS	AS	AS	SF	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS
75-100	AS	AS	AS	AS	AS	SF	SF	AS	SF	SF	SF	SF	AS	SF	AS
100-150	AS	AS	AS	AS	AS	AS	AS	AS	SF	AS	AS	SF	SF	AS	SF
150-200	AS	SF	AS	SF	SF	SF	AS	SF	SF	AS	SF	AS	SF	SF	AS
200-300	SF	SF	SF	AS	SF	SF	SF	SF	SF	SF	SF	SF	SF	SF	SF
300-400	–	SF	SF	SF	SF	SF	SF	SF	SF	SF	–	SF	SF	SF	SF
400-500	–	SF	SF	–	–	SF	AS	SF	–	SF	–	AS	SF	SF	SF
500-600	–	–	–	–	–	–	–	–	–	SF	–	–	SF	–	SF

CONCLUSIONS

Layers with predominance of different mechanisms of fine structure were determined. In Columbian Pacific Ocean, over the 150 meter layer, the total stability stratification predominates.
Below 200 m the salt fingers type stratification and the diffusion instability were observed on the southwest of Columbian Pacific Ocean.
In the vertical line on the open Columbian Pacific Ocean the alternation of the total stability stratification type and the salt fingers stratification type were observed. The other remaining regions have stable stratification.
In general, in Columbian Pacific Ocean everywhere stable stratification is observed, but there are conditions for not stability as a result of the double diffusion.

REFERENCES

Benilov A.Y. (1985) About the turbulent mechanism of formation to fine structure in the ocean //. IZV AS USSR. Serie. FAO. -. - T.21, No. 9. p. 973-981.

Fedorov K.N. Fine thermohaline structure of waters. - L.: Gidrometeoizdat. - 1976. - 184 p.

Fedorov K.N., and. Pereskokov, A.I. (1991) Typification of the thermohaline conditions of stratification in the world ocean: Physical oceanology. - L.: Gidrometeoizdat. p. 127-135.

Fedorov K.N., Pack V.T. et al. (1986) Analysis of convective steps in the sea temperature inversion// IZV. AS USSR. Serie. FAO. T.22, No. 9 p. 969-978.

Fedorov, I.N. (1991) Chosen transactions on physical oceanology- l.: Gidrometeoizdat, p 309.

Filimonov, AG. (1990) Typification of fine thermohaline structure in two hydrological sections in the subtropical part of the northeastern Atlantic. Hydrology of the Southern Ocean and North Atlantic// Sb.nauch.tr. L.: Publ. lgmi, p. 145-149.

Kamenkovich, V.M., and Monin, (1978) A.S. Physics of ocean. Vol. 1 Hydrophysics of the ocean/USSR. - M.: Science, p 456. (ser. oceanology).

Karlin L.N., Kluykov Y.Y. and Kutko, (1988) V.P. Small-scale structure of hydrophysical fields on the upper layer of ocean. - M.: Gidrometeoizdat,. - 164 p.

Karlin, L.N. and Villegas, N.L. (2003) Isolation of layers in the Columbian Pacific Ocean (Colombian Pacific Ocean) with different fine structure mechanisms of formation// Materials of academic council session of on 27 - 28 January Part.II. Sections of oceanology, ecology and physics. - St. Petersburg: RSHU, C 26-28.

Karlin, L.N. (1988) Processes of formation and interaction of the different-scale vertical thermohaline structure on the upper layer ocean and their numerical simulation. Thesis to the competition of the scientific degree of Dr. of phys. and math. l.: LGMI p. 289.

Konyaev, K.V. and Sabinin, K.D. (1992) Waves inside the ocean. - St. Petersburg: Gidrometeoizdat, p 272.

Maderich, V.S. and Nikishev, V.I. (1986) The diffusion-viscous stage of spreading variable spots in the stratified liquid// IZV. AS USSR. Serie. FAO. T. 22, No. 6. p 656-658.

Malinin, V.N. (1998) General oceanology, part of 1 physical processes. St. Petersburg: Publ. RSHU, p 342.

Ohotnikov, I.N. and Panteleis, N.A. (1985) The shearing instability of internal waves and vertical exchange in the ocean// Sea hydrophysical periodical. No. 3. p 13-20.

Otero L., y Pineda R. (2000) Cruceros oceanográficos Pacífico XXXII ERFEN XXX y Pacífico XXXIII ERFEN XXXI 2000: Reporte Final.– Tumaco.: CCCP,.–200 p.

Ozmidov R.V. (1983) Small-scale turbulence and the fine structure of hydrophysical fields on in the ocean// oceanology. 23, Ed. 4. p. 533-537.

Turner, J.S. (1985) Convection in multicomponent systems//Natur Wissenschaften. 72, No. 2. – p. 70–75.

Valerianova, N.A. and Zhukov, L.A. (1974) Practical works of general oceanology. - L.: Publ. LGMI.

Villegas, N. (2001) Estructura vertical de las aguas en el Océano Pacífico Colombiano: Informe Final.– Tumaco.: Centr. Contr. Cont. Pac.

Villegas, N.L. (2002a) Definition of uniform zones in the surface water of the Columbian Pacific Ocean// Materials of academic council session of on 30 - 31 January. St. Petersburg: RSHU,. – pp. 126-128. (a).

Villegas N. (2002 b)Estabilidad de las aguas en el Océano Pacífico Colombiano en mayo del 2000. Boletín Científico CCCP.– Tumaco.: Centr. Contr. Cont. pp. 1-11

Villegas N.L. Laws governing the formation of the thermodynamic structure of the Columbian Pacific Ocean. Thesis to the competition of the scientific degree of Dr. of phys. and math..: RSHU. - 2003. - 189 p.

Zhubas, V.M. and Ozmidov, R.V. (1984) Stepped structures form of oceanological thermocline and the mechanisms of their generation// oceanology. 2a. ed., pp. 197-204.