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Raindrop effects on the Mixed-Layer in the Sea

Yağmur Damlasının Denizde Karışım Tabakasına Etkisi

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Abstract

This paper reports on an investigation how far raindrops with free fall terminal velocity can penetrate the mixed layer of the sea water. This issue is studied by preparing an experiment set for the different radii that raindrops have. How far the raindrops can move in the mixed layer is found to depend on their kinetic energy. The data obtained from the results of the experiment are compared with the data obtained from the proposed relation. Knowledge of the penetration depth of the raindrops is important to determine the changes in ocean heat and salt content.

Keywords: mixed-layer, raindrops, kinetic energy, terminal velocity

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Introduction

At their interface, the atmosphere and sea exchange heat and momentum. Also, the atmosphere supplies fresh water to the sea, and the latter yields moisture to the atmosphere (Karaca,1996). Also the differences of the heat structure of both conditions enable them to constantly interact heat with each other. The distribution of salt in the sea surface depends closely on the moisturizing and rain. When air-sea interaction is thought all these events occur in the mixed layer. The mixed layer is formed by density fluctuations as well as by mechanical stirring, and evaporation is perhaps the most important buoyancy driving mechanism. Evaporation affects both the temperature and the salinity to increase the density of the surface water, giving it a tendency to sink convectively (Hasse, 1986). Rain decreases the saltiness of the surface water. It changes the sea surface heat content. If the characteristics of the rain drops are known (speed, kinetic energy, radius) then their penetration depth can be calculated. The magnitude of the kinetic energy in the rain drop determines its penetration depth and this depends on the mass and speed of the raindrop. Both are the functions of the radius of the rain drop. The changes that occur in the mixed layer depend on the penetration depth. When the penetration depth is known more information can be obtained about the structure of the surface layer.

Materials and Method

Terminal Velocity of Raindrops

Bodies that fall freely in the atmosphere which is a fluid environment meet a friction that causes them to fall with a lesser velocity than they would have with a velocity that increases by gravity. Sometimes the friction force equalizes with the gravity force and the compounds of forces that have effect on them become zero. Once they reach this equalization they keep up with their velocity thus their velocity becomes stable. This stable velocity is called free fall terminal velocity (FFTV).

Raindrops have a free fall terminal velocity with this effect. The terminal velocity that the raindrops have depending on their sizes is important for the effect on the mixed layer of the sea surface and the penetration depth. Considering raindrops as spherical drops make it easier to make calculations. The values that World Meteorological Organization (WMO) give for the free fall terminal velocity of the rain drops are as follows (Hirgion, 1978).

Table 1. FFTV for raindrop.

r (cm)	V_0 (cm/s)	r (cm)	V_0 (cm/s)	r (cm)	V_0 (cm/s)
0.005	27	0.10	649	0.22	898
0.01	72	0.12	727	0.24	907
0.02	162	0.14	782	0.26	912
0.04	327	0.16	826	0.28	916
0.06	464	0.18	860	0.29	917
0.08	565	0.20	883	-	-

(Barla,1991) , (Gunn and Kinzer,1949) and (Beard, 1985) have given various relations for the free fall terminal velocity of the raindrops. The relationship offered by Barla (1991) is used here.

$$V_0 = 927.74(0.0184^{B}) \qquad (cm.s^{-1}) \tag{1}$$

In this case $B = (3.9\times10^{-9})^{r}$ and is limited to $r \geq 0.3$ (cm) and it stays stable in the value of $V_0 = 928$ ($cm.s^{-1}$).

We can find the kinetic energy of the raindrops that have a radius by using (1). Therefore, as observed in the Fig.1 the kinetic energy of the raindrops increases as the radius increases and becomes more effective in the water.

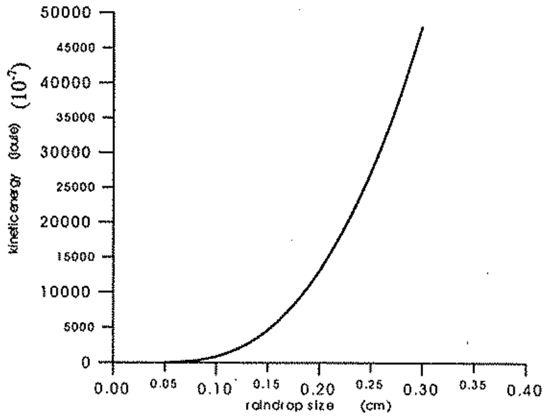

Figure 1. Shows the distribution of the kinetic energy depending on the radius of the raindrop.

Raindrop Spectrum in Rain

It is known that raindrops do not have the same radius. When the spectrums of the raindrops are considered in this experiment the distribution of the raindrops as measured by a distrometer device and the distribution of the raindrops as measured by the MPS (Malvern Particle Size) method are shown in Figure.2. According to the distrometer device an average size of the radius of a raindrop is 0.5 *mm* (Löffler-Mang, Beheng, Gysi, Karlsruhe, 1996). The radius of the smallest raindrop is 0.25 *mm* and the radius of the largest raindrop is 0.95 *mm*. The distribution of the raindrops according to the magnitude of their radii are as follows: drops with small radius form % 15, drops with average radius form % 60 and drops with large radius form % 25 of the rain.

As it is described above, the penetration depth of the raindrop in the sea depends on the raindrops with larger radii. Therefore the turbulence that is caused in the mixed layer of the sea by the effect of the raindrops are determined by the ones that have larger radii.

The layer which the raindrops effect are formed with a turbulence diffusion. The bottom side of this layer stays in the molecular diffusion size..

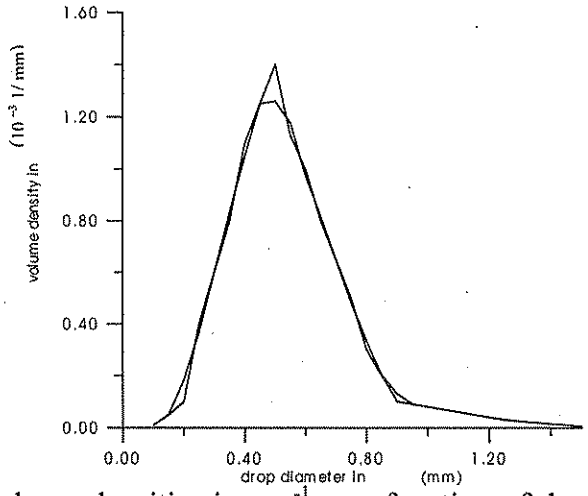

Fig 2. Volume densities in mm^{-1} as a function of drop diameter for MPS solid lines.

Experiment

The purpose of this experiment was to measure how deep L_{exp} raindrops with different radii could reach in water that had sea water characteristics. The raindrops and sea water used for this experiment carried the same characteristics. The radii of raindrops that are used in the experiment are calculated from their masses (m). The experiment was done several times by dropping a distance that they could reach limit velocity for each raindrop which had a radius of r. Raindrops were coloured for several purposes. First reason for doing that is to differ raindrops from the water into which they fell. Second reason is to determine the depth of its impact in to water. Last one is to understand the diffusion level (depth) in the water. The volume of the experimental drop is evaluated according to the distance between the point the drop starts to fall and the point it falls and its velocity. In other words it is evaluated according to the kinetic energy which is calculated by these data. The problem of a raindrop fall on different surface was investigated (Rein, 1993; Rein, 1996). The velocity of the raindrops as they reached the surface is stated as V_0. Their velocity becomes V_1 and decrease. The pictures were taken after the entrance of the raindrop into water up to $V_1 = 0$ and the time which the raindrop was diffused. The impact depth of raindrops were measured experimentally. The kinetic energy of the raindrop that has the velocity V_0 changes as it gets into the water. The amount of change in the kinetic energy of the raindrop is given in the (2) relation.

Table 2. L_{exp} values that are obtained from the experiment according to the radii.

r (cm)	0.005	0.017	0.055	0.080	0.105	0.130	0.155	0.180	0.205	0.230
L_{exp}	0.00	0.00	1.00	2.00	3.50	5.00	7.00	9.00	10.5	13.0

The measurements of the depths L_{exp} of the raindrops that have a radius r are given in Table 2. These values are later on compared with the theoretical values.

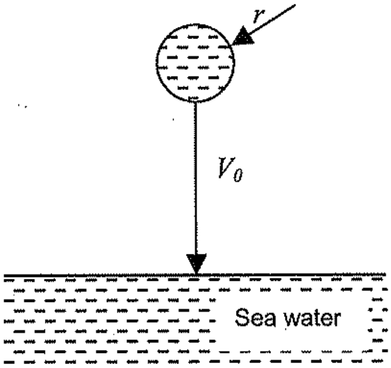

Fig 3. (a)

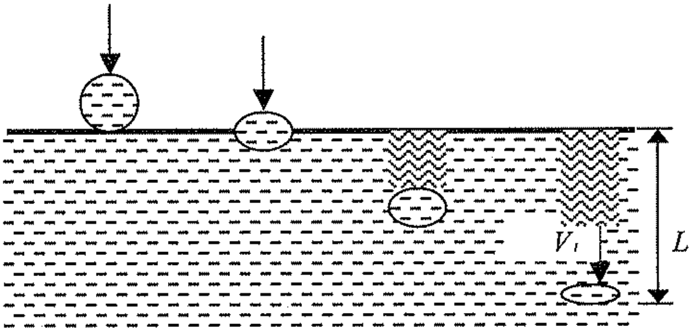

Fig 3. (b)

Figure 3. (a) (b) Raindrop fall to sea water.

Let a drop of radius r, has a terminal velocity $V_0 = V_0(r)$ above the sea surface and $V_1 = V_1(r)$ under the surface (see. Fig.3 a,b) A change of a kinetic energy of the drop is,

$$\Delta E = m\left(\frac{V_0^2}{2} - \frac{V_1^2}{2}\right) \tag{2}$$

Where m is the mass of drop

$$m = \frac{4}{3}\pi\rho\, r^3 \qquad (\rho \approx 1g\ .cm^3\ \text{- density of sea water})$$

The energy ΔE is used up to a work against the surface tension force F, which is determined by

$$F = 2\pi r\sigma$$

Where σ=74 ($g\ cm^{-1}s^{-1}$) is a surface tension coefficient. Thus we can write.

$$\Delta E = F.2r$$

$$\frac{m}{2}\left(V_0^{\ 2} - V_1^{\ 2}\right) = 2\pi r\sigma .2r$$

$$V_1 = \sqrt{V_0^{\ 2} - 6\frac{\sigma}{\rho r}}$$

(3)

The velocity V_1 which is calculated on (3) using V_0 from (1) is given in Table 3.

Table 3. V_1 values that are calculated from the V_0 values according to the selected radius.

r (cm)	0.005	0.017	0.055	0.080	0.105	0.130	0.155	0.180	0.205	0.230
V_0 (cm/s)	95.2	155	391	544	668	758	819	859	885	901
V_1 (cm/s)	0.00	0.00	380	539	665	755	817	858	884	900

It is reasonable to assume that a mixing length L (cm) depends on initial velocity V_1 ($cm.s^{-1}$), drop mass m (g) and turbulent velocity coefficient η ($g\ cm^{-1}s^{-1}$).

Only L the following combination of quantities V_1, m and η gives dimensions in *cm*. Therefore,

$$L \sim m^{\frac{1}{2}} V_1^{\frac{1}{2}} \eta^{-\frac{1}{2}}$$

or

$$L = K.\sqrt{\frac{m.V_1}{\eta}}$$

Where K is a no-dimension coefficient. Note that the value of η changes in interval from 1 to 1000 ($g\ cm^{-1}\ s^{-1}$).The volume of the water diffuses in a homogeneous way in the cup (it does not change from point to point) and the smallest value of η is taken. The experiences have shown that the stable value of K can be taken as equal to 2.

If taken into account, V_1 from (3) for L is obtained (4).

$$L = \sqrt{\frac{4}{3}\frac{\pi\rho r^3}{\eta}.(V_0^2 - 6\frac{\sigma}{\rho r})} \tag{4}$$

A table L=$L(r)$ different drop radius r is given in Table 4.

Table 4. the calculated L values according to selected radius

r (cm)	0.005	0.017	0.055	0.080	0.105	0.130	0.155	0.180	0.205	0.230
L (*cm*)	0.00	0.00	1.03	2.15	3.59	5.27	7.14	9.15	11.3	13.5

Calculated L values given in Table.4 agree with measured values L_{exp} shown in Table 2. When a real raindrop is considered, the thickness of an average mixed layer L can be found by the relation stated below.

$$< L >= \frac{1}{r_{\min} - r_{\max}} \int_{r_{\min}}^{r_{\max}} w(r)L(r)dr \quad (5)$$

There, *w*(*r*) is a drop size distribution function (5).

Conclusion

It has been observed that the values that are obtained after the experiment and the values that are obtained from the theoretical relationship have results, which are quite similar to each other. Especially when the radius of the raindrop reaches a maximum, the values become close to each other as well. When the size distribution of the raindrop is considered it is seen that large raindrops effected the heat, saltiness and volume of the sea water in the mixed layer. The small drops can not pass the surface tension and the ones which can pass that have a small volume. It has been observed that large raindrops had an effect in the mixed layer of the sea water. The raindrops which are effective in the mixture level have radius higher than 0.5 *mm* (r>0.5*mm*). These raindrops form approximately %80 –85 of the rain itself. Because of being different from sea water, features of the raindrops effect air – sea interaction.

Özet

Bu çalışmada, yağmur damlalarının serbest düşme durumunda deniz yüzeyindeki karışım tabakası içinde ne kadar ilerleyeceği incelenmiştir. Bu durum, yağmur damlalarının sahip olabileceği farklı yarıçaplar için bir deney seti hazırlanarak ayrı ayrı yapılmıştır. Damlaların deniz suyuna girmeden önceki ve girdikten sonraki kinetik enerjilerinin miktarlarının bilinmesiyle, karışım tabakası içinde alabileceği yol miktarı bir bağıntı ile verilmeye çalışılmıştır. Deney sonucu elde edilen değerlerle, bağıntıdan elde edilen değerler karşılaştırılmıştır. Yağmur damlasının karışım derinliğinin bilinmesi sıcaklık ve tuzluluğun değişiminin belirlenmesi için önemlidir.

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