The A. & M. College of Texas

DEPARTMENT OF OCEANOGRAPHY

WIND MIXING CURRENTS

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Technical Report No. 6

John C. Freeman, Jr.

October, 1953

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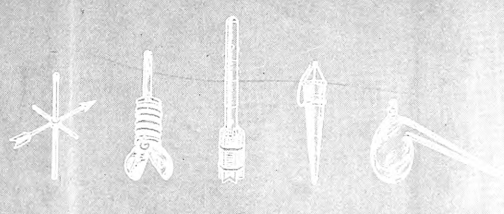

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Project 29

WIND MIXING CURRENTS

(Technical Report No. 6)

Project 29 is a study of the atmospheric influence on the thermal structure of the oceans, sponsored by the Office of Naval Research (Project NR 083-061, Contract N7onr-487, Task Order 3).

October, 1953

Prepared by

JOHN C. FREEMAN, JR.

ABSTRACT

A wind system may create an ocean current by differential mixing in a two layer ocean; such a current may be imposed on other currents due to the wind through effects of stress, piling up of water and mass transport by waves. In one situation studied, such differential mixing produced an average transport of water about ten to twenty percent of the transport due to wind stress.

WIND ACTION ON THE OCEAN

Sverdrup* has summarized the processes through which wind causes currents in the ocean:

a) currents directly driven by wind stress

b) currents indirectly maintained by piling up of stratified water

c) mass transport of water by wind waves.

In addition to these effects on the ocean, wind also causes mixing between the cold thermocline waters and the warm surface layer of the ocean. The following discussion shows that through such mixing action the wind may cause an additional current (in an ocean with a stable density stratification).

It will be assumed that a strong wind mixes more cold water upward into the warm mixed layer than does a weak wind. Observations tend to verify this; for example, in Figure 1 the bathythermograph trace of a ship at 45°N, 45°W for 8 October is contrasted

* The Oceans, 1942, pp. 489-503.

with traces for 28 September and 18 September 1949. For the period 28 September to 8 October (period A) a wind averaging Beaufort $5\frac{1}{2}$ persisted; for the period 18 September to 28 September (period B) the wind averaged Beaufort 4. During period A the mixed layer temperature cooled almost 5° F and deepened about 110 feet, suggesting the upward mixing of a large amount of cold water into the surface layer from below the thermocline. For period B, however, the thermocline depth remained almost constant and the surface layer temperature increased, suggesting little or no mixing across the thermocline.

Consider that a strong wind (and associated mixing across the thermocline) persists in one section of the ocean, while nearby a weaker wind occurs (causing little or no mixing). The colder water in the surface layer under the stronger wind will alter the density distribution in the surface layer. In response to this new density distribution, a current will occur within the upper ocean layers.

EVALUATING THE WIND MIXING CURRENT

Assume that the ocean is a two-layer system with constant densities in the upper and lower layers. Strong winds over a portion of the ocean will then cause mixing across the thermocline (boundary) and a region of relatively cold water to be formed in the surface layer of the ocean. Neglecting the other wind effects, such a horizontal variation in the density distribution of the ocean surface layer will lead to a current.

After initial transient effects have disappeared, such a current will be in geostrophic balance so that

$$u = -\frac{1}{\rho' f}\frac{\partial p}{\partial y} \qquad (1)$$

$$v = \frac{1}{\rho' f}\frac{\partial p}{\partial x} \quad , \qquad (2)$$

where u and v are the ocean velocity components in the x- and y-directions respectively, ρ' represents the ocean density at a given point (x,y) in the surface layer and p represents pressure.

The hydrostatic equation is

$$p\ (z) = p_o + g\rho' z \ , \qquad (3)$$

where p_o is atmospheric pressure at the ocean surface (assumed constant here), g is gravity and z is the depth (measured positive downward). We use this equation to obtain:

$$u = -\frac{gz}{\rho' f}\frac{\partial \rho'}{\partial y} \qquad (4)$$

$$v = \frac{gz}{\rho' f}\frac{\partial \rho'}{\partial x} \ . \qquad (5)$$

This whole process has not affected any pressure below the surface layer. Hence there is no current below the density discontinuity. Thus Margules formulae for the slope of density discontinuities on a rotating earth with (4) and (5) give the relationship:

$$u\ (H) = -\frac{gH}{\rho' f}\frac{\partial H}{\partial y} = -\frac{\gamma}{f}\frac{\partial \rho'}{\partial y} \qquad (6)$$

and

$$v\ (H) = \frac{gH}{\rho' f}\frac{\partial H}{\partial x} = \frac{\gamma}{f}\frac{\partial \rho'}{\partial x} \ , \qquad (7)$$

where $\gamma = g\,\frac{\rho-\rho'}{\rho}$. These expressions assert that the current in the mixed water at the interface is balanced geostrophically by the

slope of the interface. We can show that this slope is a natural result of the mixing process.

For the mixing process assumed here ρ' changes such that

$$\Delta\rho' = \frac{\Delta H}{H}(\rho - \rho') . \qquad (8)$$

Equation (8) tells us that since space changes exist because of mixing

$$\frac{\partial \rho'}{\partial x} = \frac{(\rho - \rho')}{H} \frac{\partial H}{\partial x} . \qquad (9)$$

This is essentially the same as equation (7). Thus the slope of the interface resulting from mixing balances the geostrophic current created by mixing.

Some of the features of such a wind mixing current are shown in Figure 2. The assumptions are made that a steady wind uniform over the region is blowing over the right-hand portion, while a calm exists over the left portion of the figure. These conditions have prevailed for some time so that transient effects are no longer present. The density is constant in the vertical above and below the thermocline transition zone, although it varies in the x-direction. The induced current thus would produce the isobaric pattern shown. A geostrophic current would thus be directed into the figure, and would vary from zero at the top surface to a maximum at the deepest part of the transition zone. Figure 2 differs from Figure 106 in The Oceans (p. 446) in that Figure 2 shows a horizontal variation in density above the transition zone, while there is no such density transition in Figure 3 adapted from The Oceans.

ORDER OF MAGNITUDE OF THE WIND MIXING CURRENT

Since the wind mixing current varies linearly with depth in the model above the total transport of water is

$$T_y = \frac{1}{2} z_H \left(\frac{g z_H}{\rho' f} \frac{\partial \rho'}{\partial x} \right) \qquad (10)$$

$$T_x = -\frac{1}{2} z_H \left(\frac{g z_H}{\rho' f} \frac{\partial \rho'}{\partial y} \right) . \qquad (11)$$

Considering data from which Figures 1 and 4 were taken* over the indicated intervals of time between Stations "C" and "D", assuming one-half the variation at "D" was due to mixing, the average transport due to wind mixing during the 10-day period 28 September to 8 October was 0.4 ft^2/sec. The transport due to wind stress during this period could have been about 27 ft^2/ sec. Hence it would appear that the wind mixing current is small compared to possible wind stress currents. However, taking into account the direction of the wind, the resultant stress transport for this period was 2-5 ft^2/sec. Thus the wind mixing current was ten to twenty percent of the net transport by the wind stress for this 10-day period.

ACKNOWLEDGMENTS

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* Technical Report No. 3, "Summary of North Atlantic Weather Station Data", Project 29 Texas A & M Research Foundation, ONR Contract N7 onr 48703, NR 083-061, September 1952

Meadows Lodge, Virginia, 25-27 May 1953, and by work on Office of Naval Research Contract N7 onr 48703, Project NR 083-061. Messers. C. Sparger and G. Jung, members of the project, made significant contributions to the style and technical detail.

LEGEND

FIGURE 1

The warming during the period 18 September to 28 September occurred when the winds were Beaufort Force 4. Between 28 September and 8 October the column cooled by a large amount and the winds were Beaufort force 5 1/2.

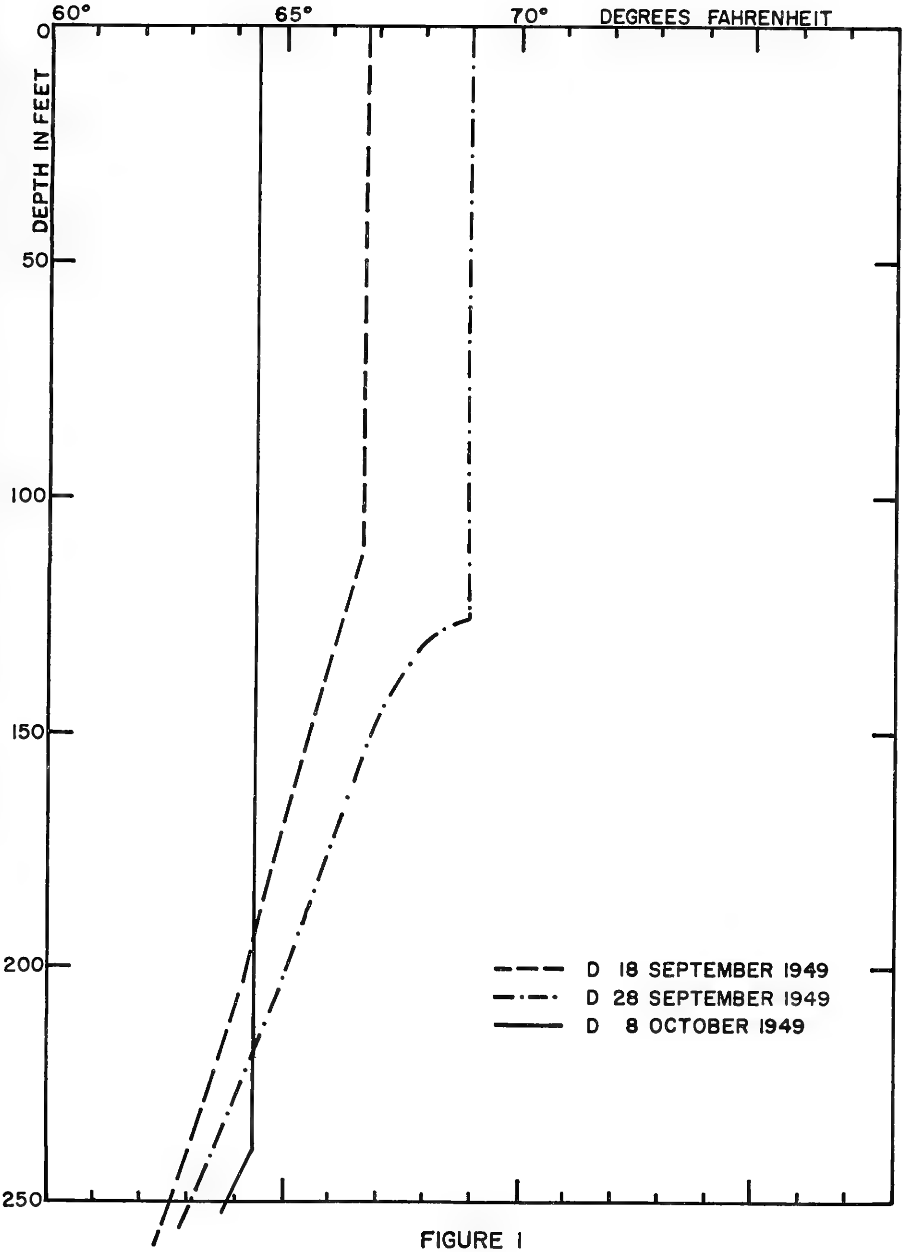
60°
65°
70°
DEGREES FAHRENHEIT
DEPTH IN FEET
0
50
100
150
200
250
D 18 SEPTEMBER 1949
D 28 SEPTEMBER 1949
D 8 OCTOBER 1949

FIGURE 1

LEGEND

FIGURE 2

Variations in the mixing cause horizontal variations in the density which lead to a current that increases with depth. The current at the bottom of the mixed layer must balance the slope of the thermocline if there is no current in the lower layer.

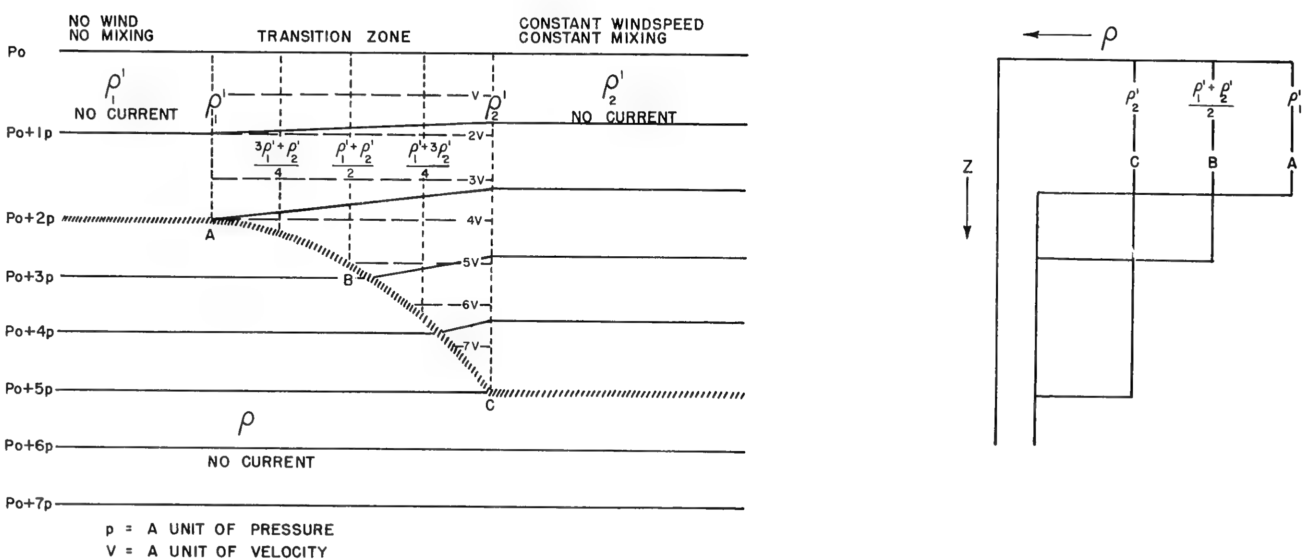
NO WIND
NO MIXING
TRANSITION ZONE
CONSTANT WINDSPEED
CONSTANT MIXING
Po
Po+1p
Po+2p
Po+3p
Po+4p
Po+5p
Po+6p
Po+7p
NO CURRENT
NO CURRENT
NO CURRENT
V
2V
3V
4V
5V
6V
7V
A
B
C
p = A UNIT OF PRESSURE
V = A UNIT OF VELOCITY
Z
A
B
C

FIGURE 2

LEGEND

FIGURE 3

An adaptation of an illustration in Sverdrup "The Oceans" showing a current constant in the horizontal and with depth in a layer of constant density.

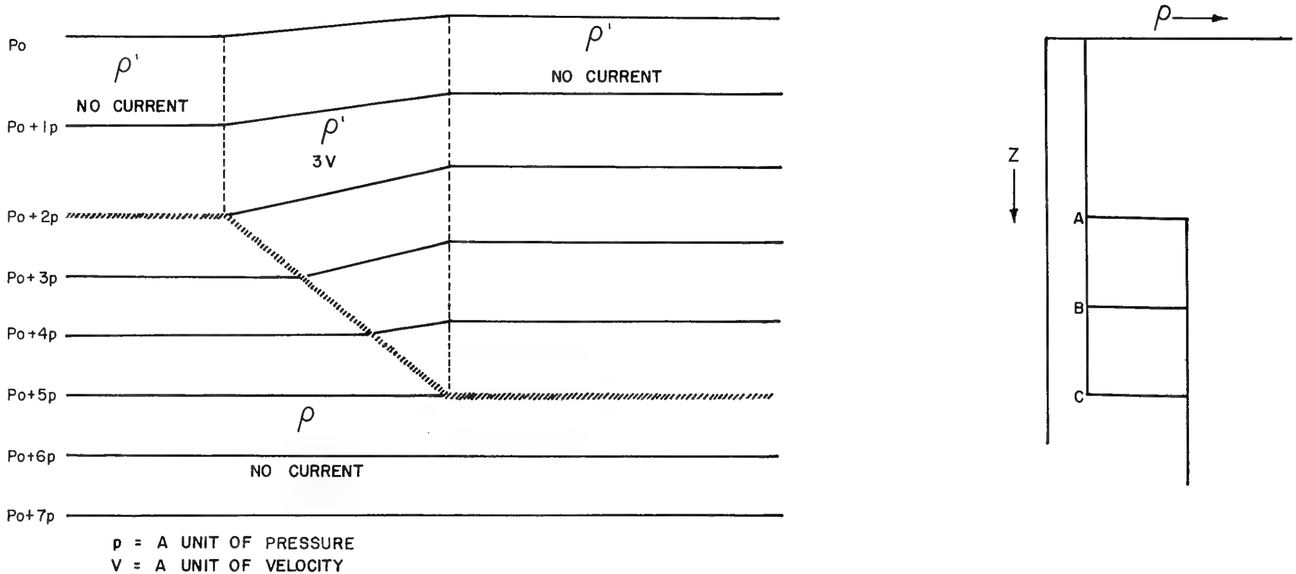
Po
Po + 1p
Po + 2p
Po + 3p
Po + 4p
Po + 5p
Po + 6p
Po + 7p
ρ'
NO CURRENT
ρ'
3V
ρ'
NO CURRENT
ρ
NO CURRENT
p = A UNIT OF PRESSURE
V = A UNIT OF VELOCITY
ρ
Z
A
B
C

FIGURE 3

LEGEND

FIGURE 4

The small amount of mixing at Station "C" is illustrated here. This is to be compared with the large amount of mixing at Station "D" for the same period.

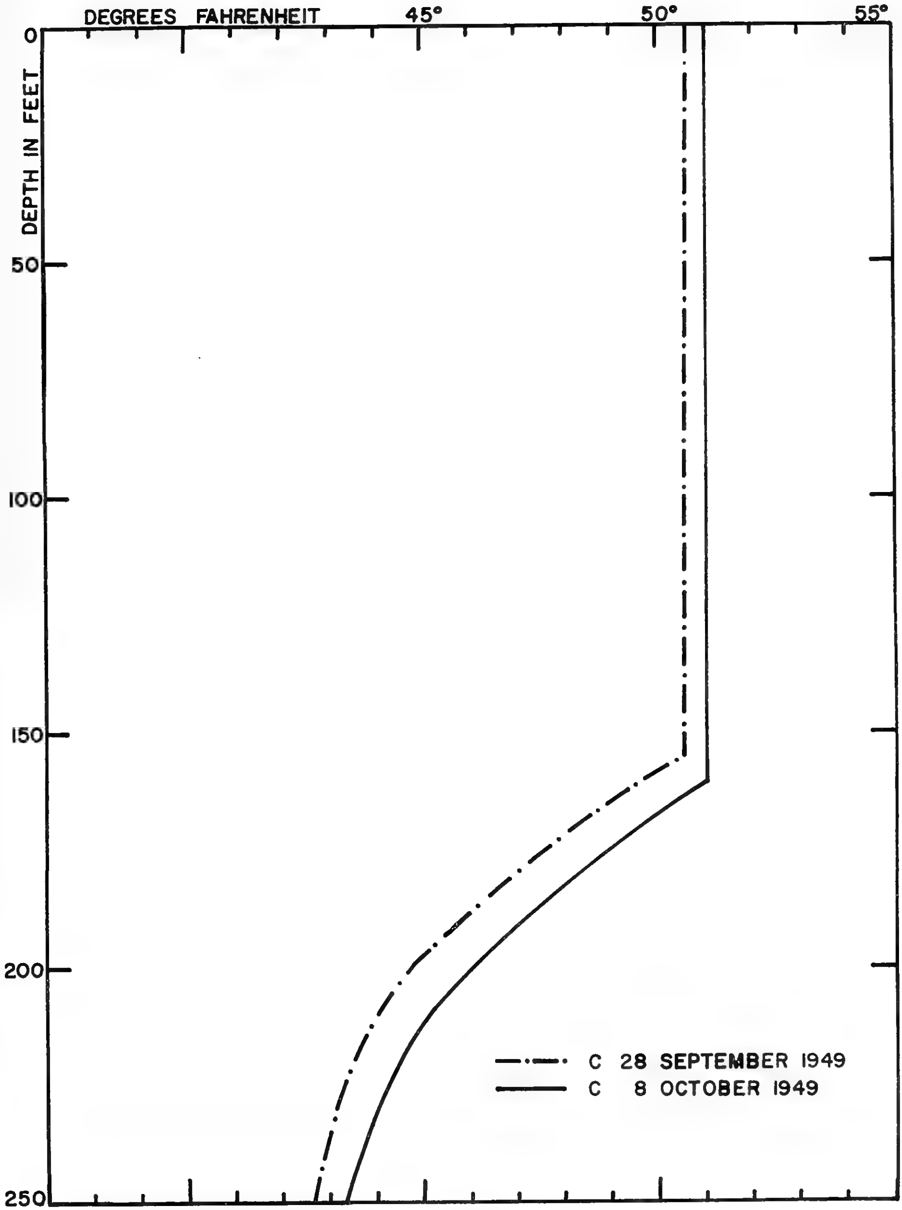
DEGREES FAHRENHEIT
45°
50°
55°
DEPTH IN FEET
0
50
100
150
200
250
C 28 SEPTEMBER 1949
C 8 OCTOBER 1949

FIGURE 4

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