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SOME EMPIRICAL RELATIONS BETWEEN SEASONAL[1] VALUES OF $(E-P)$ AND SURFACE SALINITIES OVER THE NORTH ATLANTIC[1]

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In the absence of horizontal flow, the surface salinity of any part of the ocean is mainly determined by three processes: Decrease of salinity by precipitation P, increase of salinity by evaporation E, and change of salinity by vertical mixing. Where $(E-P)$ is a positive quantity, the effect on the vertical distribution of salinity is as if salt were being diffused into the volume through the sea surface and, when $(E-P)$ is a negative quantity, the effect is as if salt were being diffused outward through the sea surface. In general, it is to be expected that regions of large $(E-P)$ will be regions of high surface salinities and regions of small or negative $(E-P)$ will be regions of low salinities. Therefore, where the horizontal transport term is small, a quantitative relationship between $(E-P)$ and surface salinity might be expected.

Wüst (1936) has found that the average annual surface salinities can be related to the average annual latitudinal values of $(E-P)$ quite accurately by a simple empirical expression of the form:

$$S_o = K(E-P) + S_k, \qquad (1)$$

where S_o is surface salinity, K is a constant, S_k is a constant salinity and $(E-P)$ is given in cm/year. He finds it necessary, however, to assign different values for K and S_k for different oceans. His formulae do not apply near the coasts where the horizontal transport term tends to be large and where the effects of runoff from land surfaces may be important. They also do not apply near the Equator.

On the basis of previously derived seasonal evaporation and precipitation data for the oceans (Jacobs, 1948), it has been possible to obtain seasonal $(E-P)$ values for the North Atlantic and North Pacific. It is considered of interest to determine whether or not a simple empirical relation can be found between the seasonal salinities and the seasonal quantities of $(E-P)$, similar to the relations found by Wüst, when we consider mean annual values. Unfortunately, seasonal salinity data are not available for the Pacific, while $(E-P)$ values are not available

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[1] Contributions from the Scripps Institution of Oceanography, New Series, No. 400.

for the South Atlantic because computations of evaporation have not been possible for the latter region. Since the region must be one within which the transport of surface waters is at a minimum, the choice of areas left for analysis is limited.

An examination of current charts for the oceans (U. S. Hydrographic Office, 1945) indicates that the only completely suitable area is the one in the North Atlantic bounded by the 20th and 30th parallels and the 60° W and 20° W meridians. This section excludes the coastal areas with their pronounced N–S surface currents and is yet of sufficiently large lateral extent to minimize the effects of E–W flow.[2]

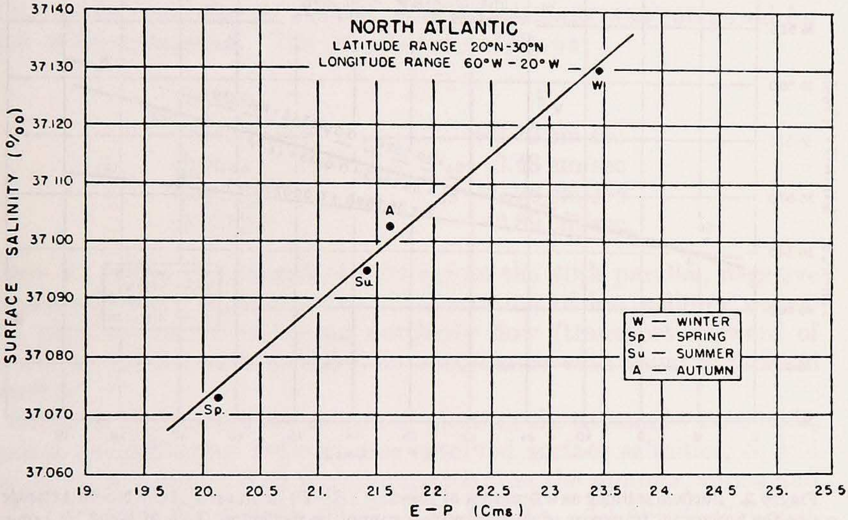


Figure 1. **Surface salinity as a function of seasonal ($E-P$) in an area of the North Atlantic where the transport of surface waters is at a minimum (Lat. 20°–30°N; Long. 60°–20° W).**

The results of plotting the seasonal salinity values against the seasonal ($E-P$) values for this area are given in Fig 1. An almost perfect straight line relationship is shown such that the surface salinities can be given very accurately by the formula:

$$S_o = 0.0171\ (E - P) + 36.730 \pm 0.003\ (°/_{oo}). \qquad (2)$$

The range of salinities computed through its use differs from the observed range of salinities by less than 10%.

[2] The seasonal salinity values have been scaled from charts given by Böhnecke (1936).

Having obtained good results in the one area of the North Atlantic where the transport of surface waters is at a minimum such that the effect of advection on the surface salinity would be small, it was decided to test at least one other area even though a considerable advective effect might be expected. The area chosen for this examination is the one immediately to the north of the previous area, *i. e.*, the area bounded by the 30th and 40th parallels and by the 20th and 60th meridians.

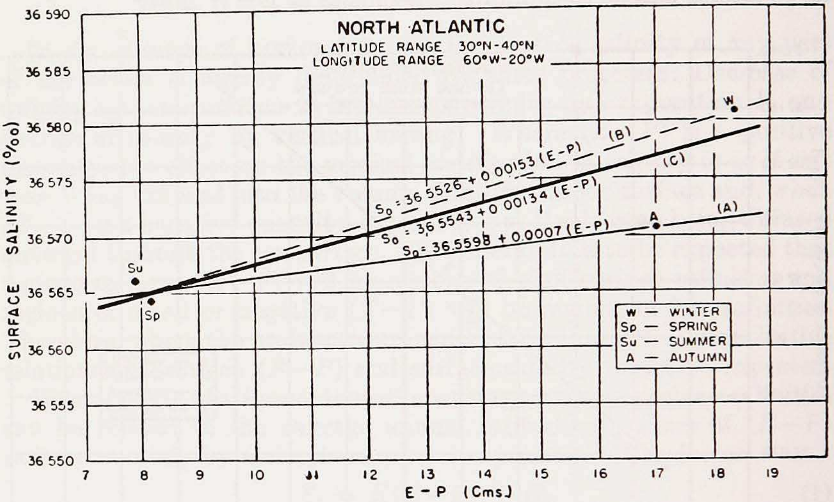


Figure 2. Surface salinity as a function of seasonal ($E - P$) in an area of the North Atlantic where the horizontal transport of surface waters cannot be neglected (Lat. 30°–40° N; Long. 60°–20° W).

The results of plotting the seasonal values of ($E - P$) against the seasonal salinities for this area are given in Fig. 2. Unfortunately, the seasonal ($E - P$) values and seasonal salinities for spring and summer are so nearly identical that, for practical purposes, they both constitute a single point. The winter and autumn points, on the other hand, are so widely dispersed that no reasonable curve can be drawn that would serve to connect all points. However, as first steps in analysis, it is possible to assume that the summer, spring and autumn values are correct and that high salinity water is being advected into the area during winter (curve *A* in Fig. 2) or that the summer, spring and winter values are correct and that low salinity water is being advected into the area during autumn (curve *B* in Fig. 2).

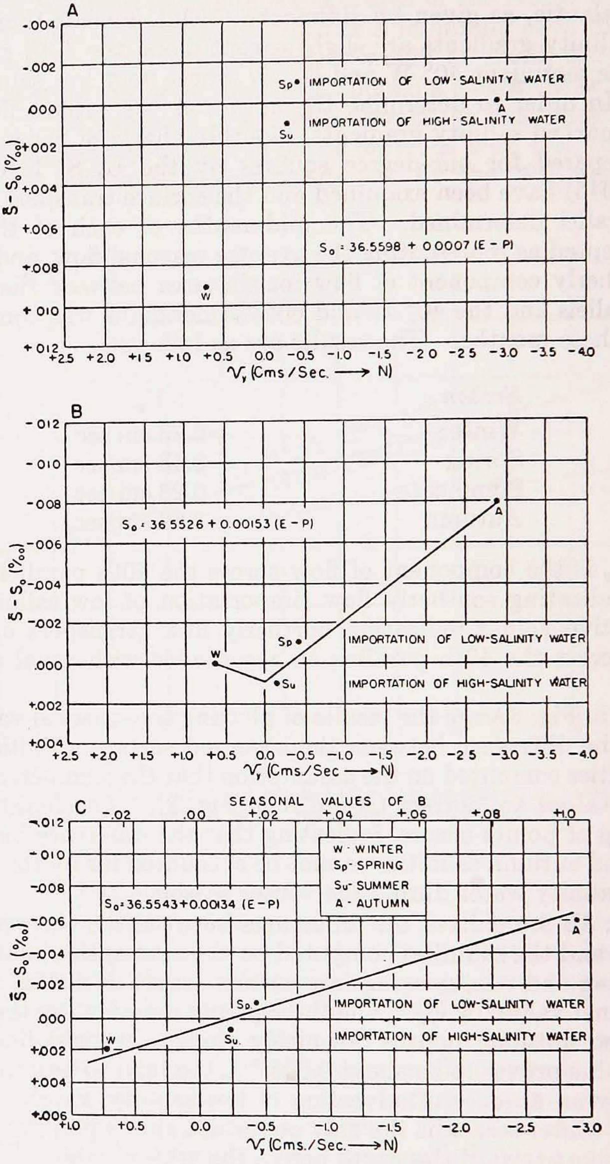
An examination of the salinity distribution over this portion of the North Atlantic, as given by Böhnecke (1936), reveals that the horizontal salinity gradients are slight except along the 40th parallel between the meridians 40° W and 60° W where very low salinity water exists. In order to determine the nature of the surface flow in this area of marked salinity gradients, monthly charts of the surface currents prepared for one-degree squares by the U. S. Hydrographic Office (1945) have been examined and the surface transport across the 40th parallel determined. The midmonths of each of the seasons were accepted as representing the average seasonal flow, and the average northerly component of flow for the area between the 39th and 41st parallels and the 40° W and 60° W meridians was computed for each of these months. The results are as follows:

Season	V_y
Winter	+0.73 cm sec
Spring	−0.43 cm/sec
Summer	−0.26 cm/sec
Autumn	−2.89 cm/sec,

where V_y is the component of flow across the 40th parallel, negative values indicating southerly flow (importation of low salinity water) and positive values indicating northerly flow (transport outward of waters across the 40th parallel) in accordance with usual notational practice.

Given in Fig. 3A are the results of plotting the seasonal values of V_y against the difference between the observed surface salinities, S, and the salinities computed on the assumption that the summer, spring and autumn values are correct (curve A in Fig. 2). An almost complete scattering of points occurs, indicating that the difference between the winter and autumn salinities cannot be accounted for by the advection of high salinity water during the winter season.

In Fig. 3B are plotted the differences between the observed surface salinities and the salinities computed on the assumption that the summer, spring and winter values are correct (curve B in Fig. 2) against the seasonal values of V_y. The three points representing the summer, spring and autumn months fall nicely along a straight line, but the winter value proves to be about 0.003 $^{\circ}/_{oo}$ too high to be accounted for merely by an absence of advection of low salinity water. However, since the winter season is the only one which shows positive values for V_y (transport toward the north across the 40th parallel), it is reasonable to construct the curve as shown in Fig. 3B by simply connecting the points by two straight lines which intersect at a common point


A
$\bar{S} - S_0$ (‰)
-.004
-.002
.000
+.002
+.004
+.006
+.008
+.010
+.012
Sp
IMPORTATION OF LOW-SALINITY WATER
A
IMPORTATION OF HIGH-SALINITY WATER
Su
$S_0 = 36.5598 + 0.0007 (E - P)$
W
+2.5 +2.0 +1.5 +1.0 +0.5 0.0 -0.5 -1.0 -1.5 -2.0 -2.5 -3.0 -3.5 -4.0
V_y (Cms/Sec. ⟶ N)
B
-.012
-.010
-.008
-.006
-.004
-.002
.000
+.002
+.004
$\bar{S} - S_0$ (‰)
$S_0 = 36.5526 + 0.00153 (E - P)$
A
Sp
W
Su
IMPORTATION OF LOW-SALINITY WATER
IMPORTATION OF HIGH-SALINITY WATER
+2.5 +2.0 +1.5 +1.0 +0.5 0.0 -0.5 -1.0 -1.5 -2.0 -2.5 -3.0 -3.5 -4.0
V_y (Cms./Sec ⟶ N)
C
SEASONAL VALUES OF B
-.02 .00 +.02 +.04 +.06 +.08 +1.0
-.012
-.010
-.008
-.006
-.004
-.002
.000
+.002
+.004
+.006
$\bar{S} - S_0$ (‰)
W - WINTER
Sp - SPRING
Su - SUMMER
A - AUTUMN
$S_0 = 36.5543 + 0.00134 (E - P)$
A
Sp
Su
W
IMPORTATION OF LOW-SALINITY WATER
IMPORTATION OF HIGH-SALINITY WATER
+1.0 +0.5 0.0 -0.5 -1.0 -1.5 -2.0 -2.5 -3.0
V_y (Cms./Sec. ⟶ N)

(Figure 3)

along the line where $V_y = 0$ and to make no assumptions regarding the nature of the surface transport of salinity during the winter season.

However, since there is northerly transport of surface waters across the 40th parallel only during the winter season, and considering the fact that, except along the 40th parallel, the salinities of surrounding areas tend to be slightly higher than within the region under consideration, it is more reasonable to assume that water of higher salinity is being advected into the region during winter, the amount advected being proportional also to V_y. On the basis of this assumption the curve *C* in Fig. 2 has been constructed. As shown by Fig. 3C, V_y plotted against the differences between the observed seasonal salinities and the salinities computed on the basis of curve *C* indicate an almost perfect straight-line relationship.

Curve *C* in Fig. 2 can be represented by the following formula:

$$S_o = 0.00134\,(E - P) + 36.5543 \qquad (^\circ/_{oo}), \qquad (3)$$

while the curve in Fig. 3C can be represented by the expressions:

$$\bar{S} - S_o = 0.00246 V_y + 0.00071 \qquad (^\circ/_{oo}) \qquad (4)$$

or

$$V_y = 406.25(\bar{S} - S_o) - 0.2875 \qquad (\text{cm/sec}). \qquad (5)$$

Combining expressions (3) and (4), a simple empirical formula is obtained which allows the surface salinity to be computed with exceptional accuracy. In this case,

$$S_o = 0.00134(E - P) + 0.00246 V_y + 36.555 \pm 0.001 \ (^\circ/_{oo}), \qquad (6)$$

where V_y is in cm/sec.

Because of the paucity of subsurface current and salinity data in these regions and because of the complicated nature of the vertical and lateral mixing processes which are involved, it does not appear profitable at this time to attempt to determine, on the basis of theoretical considerations, the significance of the salinity and $(E - P)$ relationships which have been illustrated.

Figure 3. Difference between the computed (S_o) and observed ($\bar{S}$) salinities for the area in the North Atlantic Lat. 30° to 40° N and Long. 60° to 20° W as a function of the transport of surface waters across the 40th parallel between the meridians 60° W and 40° W.

A. The relationship with the northerly component of surface flow, V_y, assuming the relation between $\bar{S}$ and $(E-P)$ as given by curve (*A*) in Fig. 2.

B. The relationship with V_y, assuming the relation between $\bar{S}$ and $(E-P)$ as given by curve (*B*) in Fig. 2.

C. The relationship with V_y, assuming the relation between $\bar{S}$ and $(E-P)$ as given by curve (*C*) in Fig. 2.

The values for the ratio, *b*, between volume of water advected and total volume of water within the mixing layer (assuming V_y constant with depth throughout the mixing layer) are entered along the top margin of graph.

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