TECHNICAL REPORT

AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION

ALLEN L. BROWN
Applied Oceanography Branch
Division of Oceanography

SEPTEMBER 1954

U. S. NAVY HYDROGRAPHIC OFFICE
WASHINGTON, D. C.

ABSTRACT

Techniques for computing the ice potential as developed by Zubov and Defant are tedious and laborious. In this report these techniques are examined analytically and a simplified rapid method of computation is developed. This new method enables the long-range ice forecaster to limit the detailed analysis of oceanographic data to those locations where ice formation is indicated.

FOREWORD

The increasing importance of defense installations in northern areas has increased greatly the responsibilities of the U. S. Navy in supplying bases in Arctic waters, where sea ice is often an operating obstacle. The Hydrographic Office is charged with the responsibility of developing and testing techniques for observing and forecasting sea ice conditions. Standardized techniques for observing, charting, and reporting sea ice are now in operational use by the Navy, as described in publications issued by the Hydrographic Office. Heretofore, techniques for forecasting the formation, growth, and movement of sea ice have not been published by this Office. This publication describes a method of long-range forecasting of ice formation and growth. Since this technique is still in the developmental stage, the Hydrographic Office welcomes comments as to its operational value.

J. B. COCHRAN
Captain, U. S. Navy
Hydrographer

DISTRIBUTION LIST

CNO (Op-03, 03D3, 31, 316, 32, 33, 332, 04, 05, 533, 55)
BUAER (2)
BUSHIPS (2)
BUDOCKS (2)
ONR (Code 100, 102, 410, 416, 420, 430, 464, 466)
NOL (2)
NEL (2)
NRL (2)
COMOPDEVFOR (2)
COMSTS (2)
CODTMB (2)
AROWA
SUPNAVACAD (2)
NAVWARCOL (2)
NAVPOSTGRADSCOL, Monterey (2)
COMDT COGARD (IIP) (2)
USC&GS (2)
CG USAF (AFOOP)
CGAWS (2)
CGNEAC (2)
USAF CAMBRSCHLAB (2)
USWB (2)
CIA (2)
BEB (2)
SIPRE (2)
ASTIA (2)
ARTRANSCORP
CE (2)
INTLHYDROBU, Monaco (2)
ARCRSCHLAB, COL, Alaska
ARCINSTNA (2)
WHOI (2)
SIO (2)
UNIV WASH (2)
TEXAS A&M (2)
CBI (2)

CONTENTS

FIGURES

TABLES

A. INTRODUCTION

The Zubov-Defant ice potential computation technique, although not difficult, is quite tedious and in essence graphical or tabular. Furthermore, the results of the computation may indicate that ice formation is very improbable. Clearly there is need for a technique that will indicate with considerably less labor both possible ice formation and the quantity of ice. In addition the technique should be placed on a simple analytic basis to eliminate the need for several large-scale density nomographs or bulky tables.

B. DERIVATION OF THE ICE POTENTIAL FOR SALINITY $\geqq 24.70$ ‰

When the salinity of sea water equals or exceeds 24.70 ‰, the maximum density occurs at the temperature of freezing,

$$T_f = -0.0966\ Cl - 0.0000052\ Cl^3, \qquad (1)$$

where

$$Cl = (S - 0.030)/1.805. \qquad (2)$$

It can be shown that the results of thermohaline convection, which are obtained by mixing of infinitesimal layers of sea water from the surface to a depth h, are identical with those obtained when mixing is considered for the entire layer from the surface to h.*

The density of freezing, $\sigma_f(h)$, for a column of mixed water of depth h and with mean salinity $\bar{S}_{0,h}$, where

$$\bar{S}_{0,h} = \frac{1}{h}\int_0^h S(z)\ dz, \qquad (3)$$

is so nearly linear (i.e. the error is less than ± 0.01) that we can express it as

$$\sigma_f(h) = \sigma_t\left[T_f(\bar{S}_{0,h}),\ \bar{S}_{0,h}\right] = 0.8104\ \bar{S}_{0,h} - 0.1600. \qquad (4)$$

When considering a graphic representation of the freezing density (Fig. 1), it is quite apparent that ice must be formed to attain thermohaline mixing of a column of water of depth h, mean salinity $\bar{S}_{0,h}$, and a density at h, $\sigma_h = \sigma_t\left[T(h), S(h)\right]$,

if σ_h is greater than $\sigma_f(h)$.

The graphical equivalent of this statement is that the point $(\bar{S}_{0,h};\ \sigma_h)$

*See Appendix I

plots above the line (.000) in Figure 1 which indicates the density of freezing. In the case of the first point(σ_{h_1}; $\overline{S}_{o,h_1}$) shown in the figure, it is evident that the column of water(o, h_1)can be given a uniform density (σ_{h_1})by temperature changes alone and that no freezing results. However, for the column of water(o, h_2) with coordinates (σ_{h_2}; $\overline{S}_{o,h_2}$) temperature changes alone can take it only to the line of the density of freezing. In order to obtain the uniform density (σ_{h_2}), a change in the mean salinity ($\Delta \overline{S}_{o,h_2}$) is needed.

From the geometry it is clear that

$$\Delta \overline{S}_{o,h} = (\sigma_h - \sigma_f) \tan \alpha_1 ; \tag{5}$$

but

$$\sigma_f = \overline{S}_{o,h} \cot \alpha_1 + b_1 ; \tag{6}$$

therefore,

$$\Delta \overline{S}_{o,h} = (\sigma_h - b_1) \tan \alpha_1 - \overline{S}_{o,h} \tag{7}$$

A mean salinity change of $\Delta \overline{S}_{o,h}$ has (Defant, 1949) an ice equivalent of

$$* \qquad l_i (h) = \frac{h \Delta \overline{S}_{o,h}}{k \left(\frac{\rho_i}{\rho_w}\right) \overline{S}_{o,h}} , \tag{8}$$

where ρ_i / ρ_w (the ratio of the density of ice to that of sea water) is taken to be 0.9, and where k is the proportional part of the salt released from the sea water that is frozen (k averages about 0.85). Equation 8 becomes

$$l_i (h) = h \left(\frac{1}{k}\right) \left[\frac{1}{.9} \left\{ \frac{\sigma_h - b_1}{\overline{S}_{o,h}} \right\} \tan \alpha_1 - \frac{1}{.9} \right] \tag{9}$$

or in numerical units

$$l_i (h) = h \left(\frac{1}{k}\right) \left[\frac{137.11(\sigma_h + 0.1600)}{\overline{S}_{o,h}} - 111.111 \right] , \tag{10}$$

where l_i is expressed in centimeters, h in meters, $\overline{S}_{o,h}$ in o/oo, and σ_h in density units $(\rho - 1) \times 10^3$.

*See Appendix III

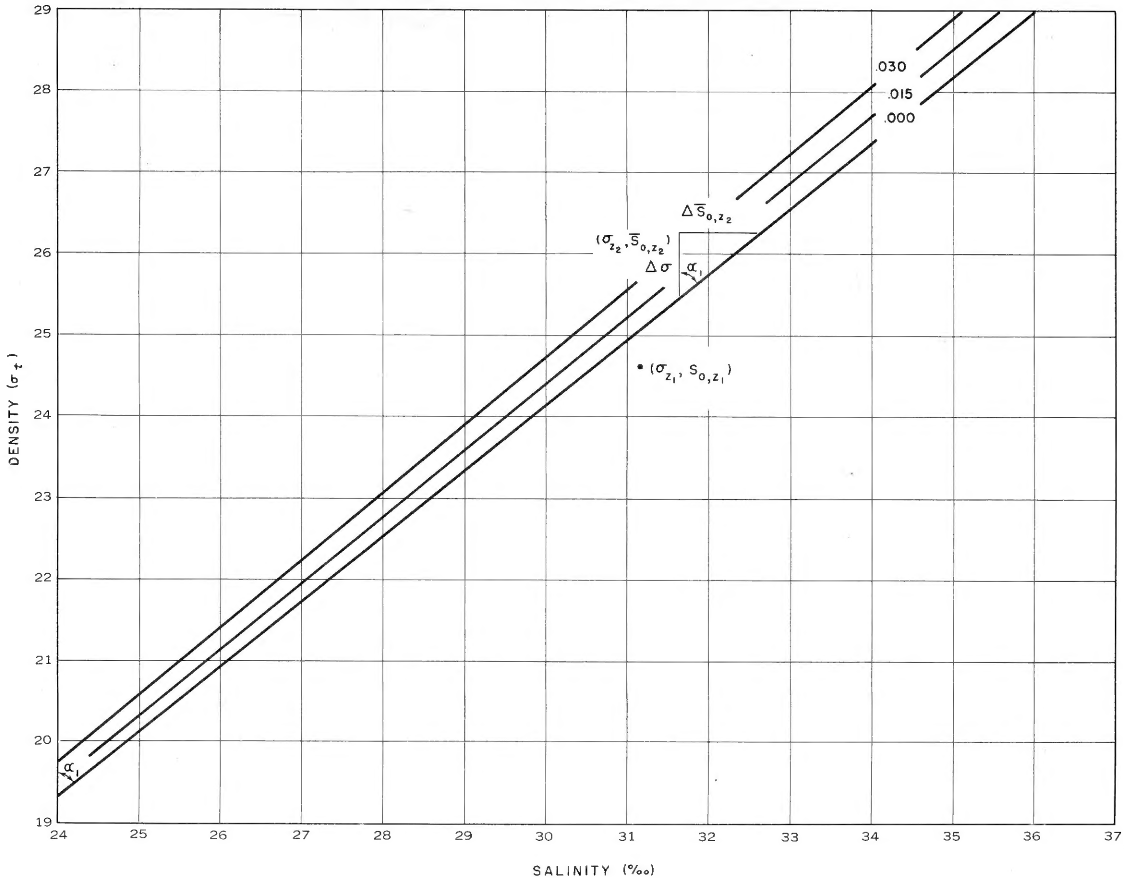

FIGURE 1. ICE DETERMINATION GRAPH FOR S ≥ 24.70‰, K = .85

C. DERIVATION OF THE ICE POTENTIAL FOR SALINITY < 24.70 °/oo

When $S < 24.70$ °/oo, the temperature of maximum density is higher than the freezing temperature, so it is possible for convection to reach a depth, z equal h, under two sets of conditions for some values of $\sigma_t(h)$. The following represent all the mutually exclusive conditions in the water column (o,h) that have a bearing on convection:

$$\sigma_t\ (h) > \sigma_{max}\ (\overline{S}_{o,h}), \tag{11}$$

$$\begin{cases} \sigma_f(\overline{S}_{o,h}) < \sigma_t\ (h) \gtreqless \sigma_{max}\ (\overline{S}_{o,h}) \\ \overline{T}_{o,h} \leq\ T_f\ (\overline{S}_{o,h}), \end{cases} \tag{12}$$

$$\sigma_t\ (h) \gtreqless \sigma_f\ (\overline{S}_{o,h}), \tag{13}$$

$$\begin{cases} \sigma_f\ \ (\overline{S}_{o,h}) < \sigma_t\ (h) \gtreqless \sigma_{max}\ (\overline{S}_{o,h}) \\ \overline{T}_{o,h} > T_{\sigma_m}(\overline{S}_{o,h})\ \ , \text{ and} \end{cases} \tag{14}$$

$$\begin{cases} \sigma_f(\overline{S}_{o,h}) < \sigma_t(h) \gtreqless \sigma_{max}(\overline{S}_{o,h}) \\ T_f(\overline{S}_{o,h}) < \overline{T}_{o,h} \gtreqless T_{\sigma_m}(\overline{S}_{o,h}). \end{cases} \tag{15}$$

Assuming convection to a depth h, equations 11 and 12 imply the formation of ice; 13 and 14 imply that no ice forms, while 15 may fall into either category. An inspection of Table 2 will reveal that for

$$15 \gtreqless S \gtreqless 25\ , \quad \sigma_m(S) - \sigma_f(S) \gtreqless .02;$$
$$10 \gtreqless S < 15\ , \quad \sigma_m(S) - \sigma_f(S) \gtreqless .05; \text{ and}$$
$$3 \gtreqless S < 10\ , \quad \sigma_m(S) - \sigma_f(S) \gtreqless .10.$$

The above tabulation considered in conjunction with an inherent error of ±.02 in $\sigma_t(h)$ and a very probable error of ±.05 in $\bar{S}_o,h$, when determined from a noncontinuous salinity sounding (in depth), means that the end points of the density inequality in 15 may easily be in error by ±.04 and also that the correct value of $\sigma_t(h)$ may actually lie outside the range of the inequality, especially when $15 \gtrless S \gtrless 25$. The likelihood of salinities being lower than 15°/oo is small unless a sounding is taken in an inshore region of intensive fresh-water runoff or unless there is an influx of ice from colder regions which is melting at the site of the sounding. The Zubov-Defant model does not attempt to account for these nonstatic, nonconvective effects upon the water mass. Therefore, under the conditions of (11), (12), and (15), the reference line for possible ice formation is $\sigma_f(S)$ just as for the case of $S \gtrless 24.70$ °/oo. The equation of the new reference line is

$$\sigma_f(S) = 0.8075S - 0.087. \tag{16}$$

Table 2 will reveal that (16) has a maximum error of ±.01, or at most half the experimental error in $\sigma_t(h)$. Maximum density can be represented to the same degree of accuracy by

$$\sigma_m(S) = 0.8029S - 0.030, \tag{17}$$

while the temperature of maximum density (Sverdrup, 1942) is

$$T_m(S) = 4.00°C - 0.2150\ S. \tag{18}$$

From the arguments used in deriving (10), with the additional restriction that

$$\bar{T}_{o,h} \geqq T\left[\sigma_t(h), \bar{S}_{o,h}\right] \tag{19}$$

when

$$\sigma_f(\bar{S}_{o,h}) < \sigma_t(h) \leqq \sigma_m(\bar{S}_{o,h}), \tag{20}$$

it can be concluded that if a column of water (o,h) has coordinates $[\bar{S}_o, h; \sigma_t(h)]$ which plot above the freezing density line (0.000) in Figure 2, i.e., if

$$\sigma_t(h) > 0.8075\ \bar{S}_{o,h} - 0.087, \tag{21}$$

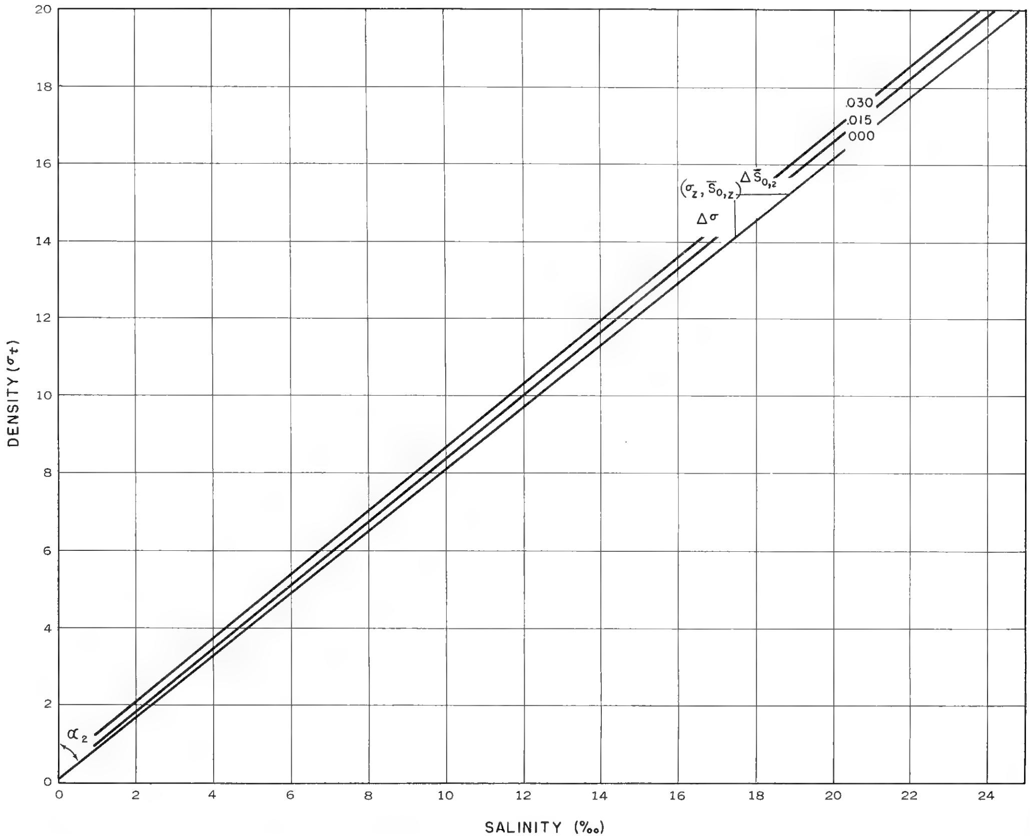

FIGURE 2 ICE DETERMINATION GRAPH FOR $S \leq 24.70$ ‰, K = .85

there is implied in order to achieve convective mixing to a depth h, an ice equivalent

$$* \qquad l_i(h) = h\left[161.88\left\{\frac{\sigma_t(h)+0.087}{\bar{S}_{o,h}}\right\} - 130.72\right] \qquad (22)$$

where the numerical units of h, $\sigma(t)$, $\bar{S}_{o,h}$ and $l_i(h)$ are defined as they were for (10).

D. CONCLUSIONS

This new approach to the ice potential computation technique has several advantages: (a) it is simpler and speedier than the regular method; (b) one can see immediately, by plotting the points $(\sigma h, \bar{S}_{o,h})$ whether freezing or freezing with subsequent melting occurs as a result of thermohaline convection; and (c) it is easy to estimate the depth of mixing for which freezing initially occurs. When the curve, generated by the points $(\sigma h, \bar{S}_{o,h})$, remains parallel to a constant percentage line (constant l_i/h)** or it turns back toward the density of the freezing line, tremendous quantitites of thermal energy are involved for additional increases in the ice thickness. One can decide what depths of mixing are of interest (usually that of the initial freeze and/or that for some specified ice thickness) and compute the associated Q'S (sensible heat losses) alone by the resultant formula proved in APPENDIX I.

* See Appendix III
** For plotting lines of constant l_i/h on either "Ice Determination Graph", the following relation is obvious:

$$\sigma_h = \cot \alpha_j\left[(.9k)(l_i/h)+1\right]\bar{S}_{o,h} + b_j \,. \qquad (23)$$

BIBLIOGRAPHY

DEFANT, A. 1949. "Convection and Ice Potential In the Polar Shelf Seas." Geografiska Annaler, Heft XXXI, pp. 25-35

SVERDRUP, H. A., JOHNSON, M.W., AND FLEMING, R.H. The Oceans, Their Physics, Chemistry, and General Biology. New York: Prentice - Hall, 1942.

ZUBOV, N. N. 1938. Morskie Vody i L'dy (Marine Water and Ice). Moskva Gidrometeoizdat, 453 pp. 1938

APPENDIX I

DERIVATION OF A FORMULA FOR THE SENSIBLE HEAT LOSS $Q_T(h)$ ASSOCIATED WITH CONVECTION TO h AS A RESULT OF ICE FORMATION

Since $l_i(h)$ is in general small in comparison with h, $Q_T(h)$ is very nearly

$$Q_T(h) = \int_0^h c_w(z)\,\rho_w(z)\left\{T(z) - T_f(\bar{S}_{0,h} + \Delta\bar{S}_{0,h})\right\} dz$$

where $c_w(z)$ and $\rho_w(z)$ are respectively the specific heat and density of the sea water at the depth z.

Now the product $c_w(z)\,\rho_w(z)$ is relatively constant for all sea waters and $\Delta\bar{S}_{0,h}$, as a result of the initial assumption, must be small in comparison with $\bar{S}_{0,h}$. Hence, one has

$$Q_T(h) \approx c_w\rho_w\, h\left[\bar{T}_{0,h} - T_f(\bar{S}_{0,h})\right].$$

APPENDIX II

FREEZING TEMPERATURES AND DENSITIES FOR SEA WATER

Tables 1 and 2 demonstrate the linear relationship between salinity and density of freezing and between salinity and maximum density, respectively.

The temperatures of freezing were computed by equation 1. The densities of freezing were determined from the tables in H. O. Pub. No. 615 using salinity and temperature of freezing as the arguments. The maximum densities were obtained by inspecting the same tables for maximum values at the indicated salinity. The temperatures of maximum density are computed by the approximate formula by Sverdrup:

$$T(\sigma_{max}) = 4.00°C. - 0.215\ S.$$

It will be noted in Table 2, that a range of temperatures of maximum density actually satisfies the maximum density value to three decimal places in σ_t. However, the numerical accuracy that has been maintained in Tables 1 and 2 is greater than the optimum accuracy in actual practice.

TABLE 1

TEMPERATURE AND DENSITY OF FREEZING FOR SEA WATER OF HIGHER SALINITIES

Salinity S $^{o}/oo$	Temperature of Freezing $T_f(S)$ (°C)	Density of Freezing $\sigma_t(T_f, S)$	Δ
24	-1.30	19.290	
			808
25	-1.35	20.098	
			808
26	-1.41	20.906	
			809
27	-1.46	21.715	
			809
28	-1.52	22.524	
			809
29	-1.57	23.333	
			810
30	-1.63	24.143	
			810
31	-1.68	24.953	
			811
32	-1.74	25.764	
			812
33	-1.80	26.576	
			812
34	-1.85	27.388	
			814
35	-1.91	28.202	
			813
36	-1.97	29.015	

TABLE 2

FREEZING AND MAXIMUM DENSITIES WITH THE ASSOCIATED TEMPERATURES FOR SEA WATER OF LOWER SALINITIES

Salinity S °/oo	Temperature of Freezing T_f (°C)	Freezing Density σ_f	Δ	Maximum Density σ_{max}	Δ	Temperature of Maximum Density T(σ max)(°C)	Practical Range of T(σ max)(°C)	
0	-0.00	-0.132		0.000		4.00	3.74	4.23
1	-0.06	0.717	849	0.839	839	3.78	3.58	3.94
2	-0.11	1.528	811	1.639	800	3.57	3.28	3.83
3	-0.17	2.337	809	2.439	800	3.36	3.02	3.67
4	-0.22	3.147	810	3.240	801	3.14	3.04	3.23
5	-0.27	3.956	809	4.040	800	2.92	2.75	3.09
6	-0.33	4.764	808	4.840	800	2.71	2.49	2.94
7	-0.38	5.573	807	5.640	800	2.49	2.21	2.79
8	-0.43	6.380	807	6.441	801	2.28	2.27	2.30
9	-0.49	7.188	808	7.241	800	2.06	1.83	2.31
10	-0.54	7.995	807	8.042	801	1.85	1.74	1.98
11	-0.59	8.802	807	8.842	800	1.64	1.30	1.99
12	-0.65	9.609	807	9.644	802	1.42	1.33	1.54
13	-0.70	10.416	807	10.445	801	1.20	0.97	1.45
14	-0.75	11.222	806	11.247	802	0.99	0.83	1.15
15	-0.81	12.029	807	12.049	802	0.78	0.58	0.97
16	-0.86	12.835	806	12.851	802	0.56	0.24	0.87
17	-0.92	13.642	807	13.654	803	0.34	0.04	0.64
18	-0.97	14.448	806	14.458	804	0.13	-0.01	0.26
19	-1.02	15.255	807	15.262	804	-0.08	-0.19	0.00
20	-1.08	16.061	806	16.066	804	-0.30	-0.57	-0.05
21	-1.13	16.868	807	16.871	805	-0.51	-0.80	-0.26
22	-1.19	17.675	807	17.677	806	-0.73	-0.94	-0.56
23	-1.24	18.483	808	18.483	806	-0.94	-1.24	-0.69
24	-1.30	19.290	807	19.290	807	-1.16	-1.47	-0.90
25	-1.35	20.098	808	20.098	808	-1.38	-1.62	-1.18

APPENDIX III

EXACT SOLUTION OF THE ICE POTENTIAL EQUATION

Defant and Zubov have both shown that for the formation of l_i centimeters of ice, when convection has reached a depth of h centimeters, the change in the mean salinity of the column of water (o,h), must be

$$\Delta \overline{S}_{o,h} = \frac{\left(\frac{\rho_i}{\rho_w}\right) l_i}{h - \left(\frac{\rho_i}{\rho_w}\right) l_i} k \overline{S}_{o,h} \quad , \tag{3.1}$$

where k is the proportional part of the salt released from the sea water that is frozen. If l_i is small in comparison with h, a first approximation to l_i, l_o, is

$$l_o = h \frac{\left(\frac{\rho_w}{\rho_i}\right) \Delta \overline{S}_{o,h}}{k \overline{S}_{o,h}} \tag{3.2}$$

Denote

$$r = \left(\frac{\rho_i}{\rho_w}\right)\left(\frac{l_o}{h}\right). \tag{3.3}$$

Then r is an index of the percentage error in the first approximation to l_i. If $r \geqq .05$, then $l_o \sim l_i$ is in error by more than 5% and the exact solution

$$l_i = l_o \left[\frac{1}{1+r}\right] \tag{3.4}$$

should be used.

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5

U. S. Navy Hydrographic Office
AN ANALYTICAL METHOD OF ICE POTENTIAL CALCULATION, by Allen L. Brown, September 1954. 13p., 2 charts, 2 tables. (H. O. TR-5).

The techniques for computing the ice potential developed by Zubov and Defant are analyzed and a simplified, rapid, analytic method of computation is developed.

1. Sea Ice Forecasting
2. Oceanography
3. Meteorology
4. Sea Ice Potential
5. Heat
6. Convection

i. title: An Analytical Method of Ice Potential Calculation

ii. author: Allen L. Brown

iii. H. O. TR-5