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WIND DRIFT OF SEA ICE: A SUPPLEMENT TO THE NAVAL OCEANOGRAPHIC --ETC(U)
SEP 76   D J GERSON, L S SIMPSON
UNCLASSIFIED   N00-RP-8-S   NL

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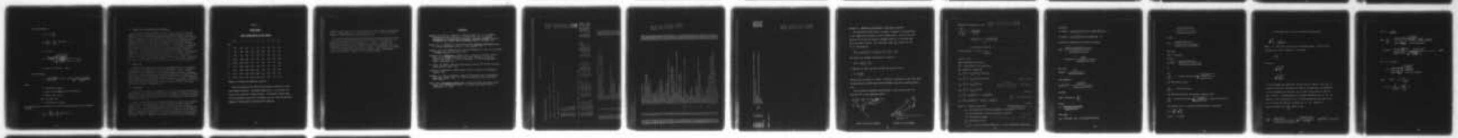

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NAVAL OCEANOGRAPHIC OFFICE REFERENCE PUBLICATION 8 - S

WIND DRIFT OF SEA ICE

A SUPPLEMENT TO THE NAVAL OCEANOGRAPHIC OFFICE NUMERICAL ICE FORECASTING SYSTEM

See 1473
in back

SEPTEMBER 1976

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ABSTRACT

The numerical ice prediction system described in RP 8 has been in use since 1971. Its outputs, however, have been related only to ice growth, not ice drift. An addition to the system now provides an output of daily ice drift at 62 arctic stations. Drift is calculated as a function of wind stress, water stress, and Coriolis force. The computer output is sufficiently accurate for ice drift in the locality of the station whose wind observations were input to the model. However, more recent research indicates that for greater accuracy and for computations of divergence and convergence interaction between floes must be considered.

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NOO RP 8 - S

WIND DRIFT OF SEA ICE

A SUPPLEMENT TO THE NAVAL OCEANOGRAPHIC OFFICE NUMERICAL ICE FORECASTING SYSTEM

DONALD J. GERSON
LLOYD S. SIMPSON

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FOREWORD

Fleet operations in the Arctic are often hindered, and sometimes aborted, by the severity of ice conditions. The Naval Oceanographic Office has pioneered in the development of ice forecasting support designed to permit the Navy to operate effectively at all times in arctic waters. This publication describes an automated program for computing ice drift for selected locations in the Arctic. It supplements a previously existing program for computing and predicting ice thickness for these locations. Ice drift, as well as ice thickness, information is required for mine warfare, submarine surfacings, surface ship transits, and sonobuoy plants.

J. E. AYRES
Captain, USN
Commander

A

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I. INTRODUCTION

Since July 1971 a numerical ice prediction system has been operated by the Naval Oceanographic Office to compute various sea ice characteristics and forecasting aids of importance to arctic operations. Gerson (1975) completely describes the system as of 1975; therefore, it will only be briefly discussed here.

The original outputs of the prediction system include the following:

* present degree-day accumulations
* forecast degree-day accumulations
* daily synoptic temperatures
* temperature trends
* selected sea surface temperatures
* initial freezeup forecasts
* reported snow depths
* ice thickness forecasts

All this information relates to ice formation, growth, thickness, and decay in-situ without consideration of ice drift. Since the knowledge of ice drift is extremely important to the forecaster, its inclusion as part of the daily output was considered desirable. The purpose of this report is to describe this significant update to the ice prediction system, namely the computation of wind drift of ice at each of the 62 stations in the present network. An example of a typical output listing is shown in figure 1.

II. DATA

The data are the same as used for the basic system, and are fully described in Gerson (1975). A slight revision in the heading is discussed in U. S. Department of Commerce (1973). The data base remains the entire world's synoptic weather observations collected by the National Oceanic and Atmospheric Administration, but observations for each day now are on one tape rather than two and are processed on its IBM 360/195 computer.

III. METHOD

A. Mean Wind Speed and Direction

The wind drift is derived entirely from values of synoptic wind speed and direction as reported by the network stations. The four (or fewer if reports are missing) daily synoptic wind observations are vectorially averaged to produce a mean wind speed. The equations used are as follows:

```
                    WIND SPEED (KTS) AND DIRECTION (DEG)
                   AND WIND DRIFT OF ICE FOR SEP  8, 1976

STATION     00Z           06Z           12Z           18Z          MEAN          DRIFT
  NO      SPD   DIR     SPD   DIR     SPD   DIR     SPD   DIR     SPD   DIR     SPD   DIR

 21504    8.0   200    12.0   140     8.0   110      .0   360     5.8   148     .21   171

 21647   16.0    90    16.0   110    18.0   140    18.0   140    15.9   122     .58   142

 21824   12.0   160    12.0   160     4.0   270     4.0   200     6.6   175     .24   197

 21965   16.0    70    12.0    50    10.0    50    12.0    50    12.3    56     .45    78

 21982   14.0   340    20.0   360    10.0   290    22.0   340    15.3   340     .56     0

 25173   12.0   320    16.0   320    14.0   290    20.0   320    15.1   314     .56   334

 25399   14.0   200     4.0   200    12.0   360    18.0   360     3.6   336     .13     2

 25594   10.0   200    10.0    20    14.0    50      .0   360     3.5    50     .13    76

 70026   10.0   160    10.0    90     8.0    70    10.0    60     7.4    94     .27   116

 70086   10.0    80    10.0   130     7.0   110    12.0    90     9.2   102     .34   123

 70133    4.0    90    99.0   990    17.0   360    16.0   320    10.0   349     .27    10

 70200    7.0   320     9.0   300     6.0   350     8.0    10     6.6   334     .24   356

 70218   99.0   990    99.0   990    99.0   990    99.0   990    99.0   990    9.90   990

 70273   11.0   300     6.0   130     6.0    90     4.0   360     1.4    11     .05    47

 70308   20.0   330    99.0   990    20.0   290    99.0   990    18.8   311     .70   330

 70316   21.0   340    22.0   310    18.0   310    99.0   990    19.7   321     .74   340

 70326    4.0   280      .0   360     3.0   280     4.0   250     2.7   269     .10   297

 70350   10.0   120    14.0    40     9.0   330     9.0   290     4.3    16     .16    40

 72815    7.0   280    12.0   210    12.0   220     5.0   330     6.8   239     .26   261

 72816   12.0   360    13.0   340    11.0   320    10.0   310    10.9   335     .41   355
```

Figure 1.
Sample output of wind velocity and ice drift

$$I = \frac{1}{k} \sum_{i=1}^{k} V_i \sin D_i \quad ,$$

$$J = \frac{1}{k} \sum_{i=1}^{k} V_i \cos D_i \quad ,$$

$$\bar{D} = \arctan (I/J) \quad ,$$

$$\bar{V} = (I^2 + J^2)^{\frac{1}{2}} \quad ;$$

where

k = number of observations (1-4) during the day,

D_i = wind direction at time i,

V_i = wind speed at time i,

$\bar{D}$ = mean wind direction for the day, and

$\bar{V}$ = mean wind speed for the day.

The computer program accounts for the quadrant in these computations. This subroutine is listed in appendix A, and a flow chart is shown in figure 2.

B. Drift Computation

The method used for ice drift computation is that of Shuleikin (1953). This method has been used by Wittmann and MacDowell (1964) to produce a set of curves for manual computation of ice drift. In order to obtain a daily output for 62 stations, however, an automated method is necessary. The equations as presented by Shuleikin do not immediately lend themselves to computer programming, and considerable transformation was required. A complete derivation of the equations used in the computer program is given in appendix B. The equations used are as follows:

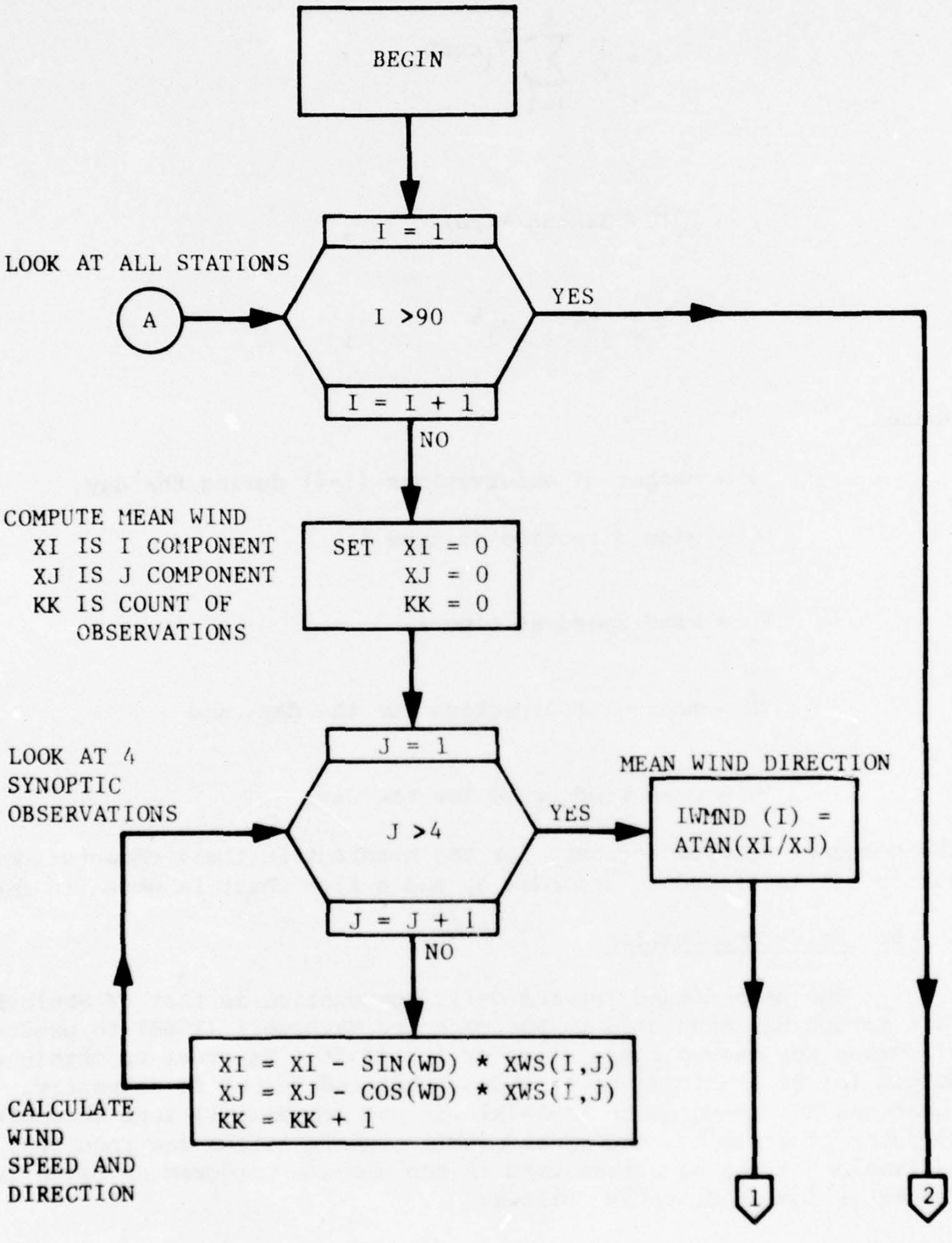


Figure 2.
Flow chart of ice drift subroutine

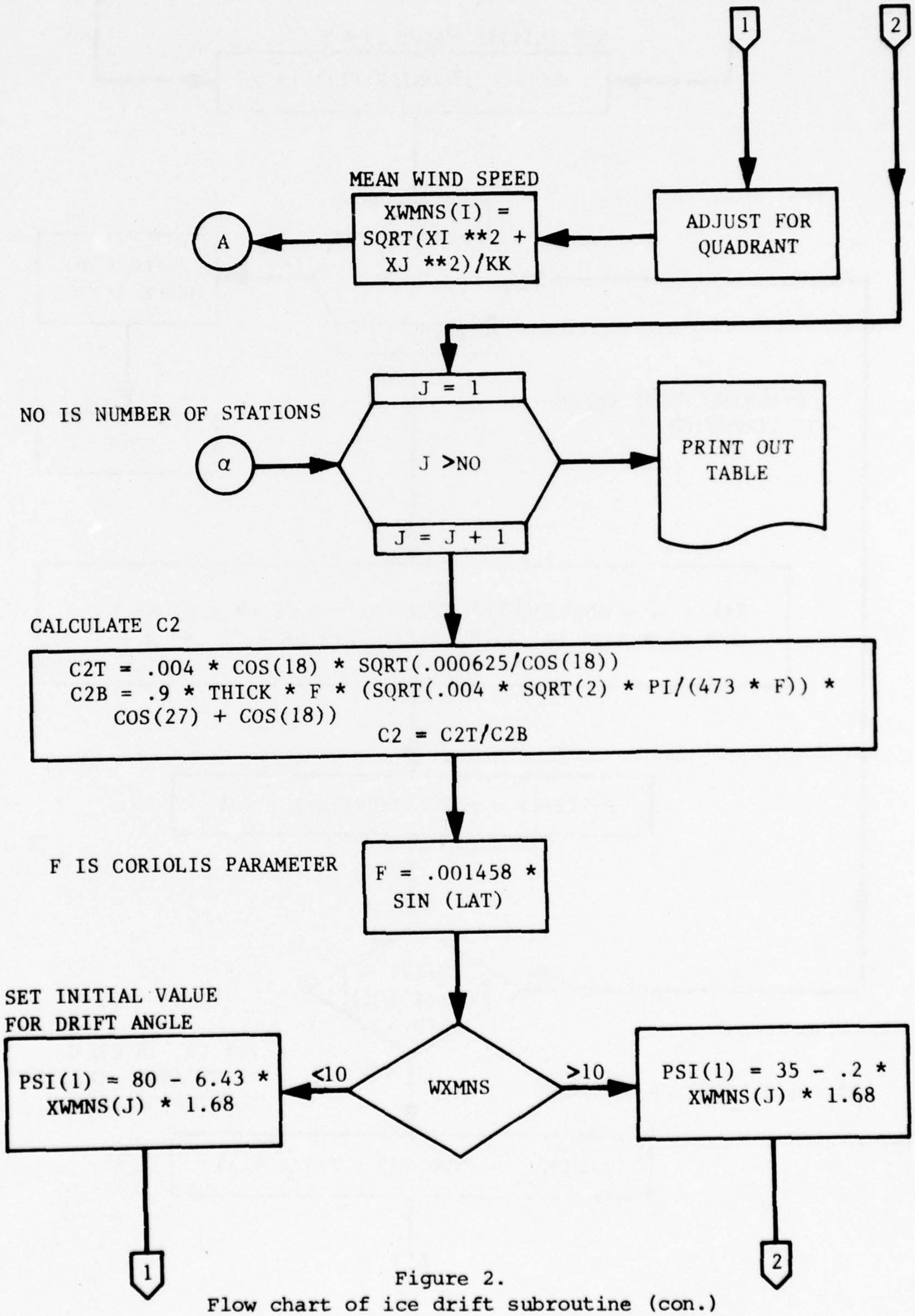


Figure 2.
Flow chart of ice drift subroutine (con.)

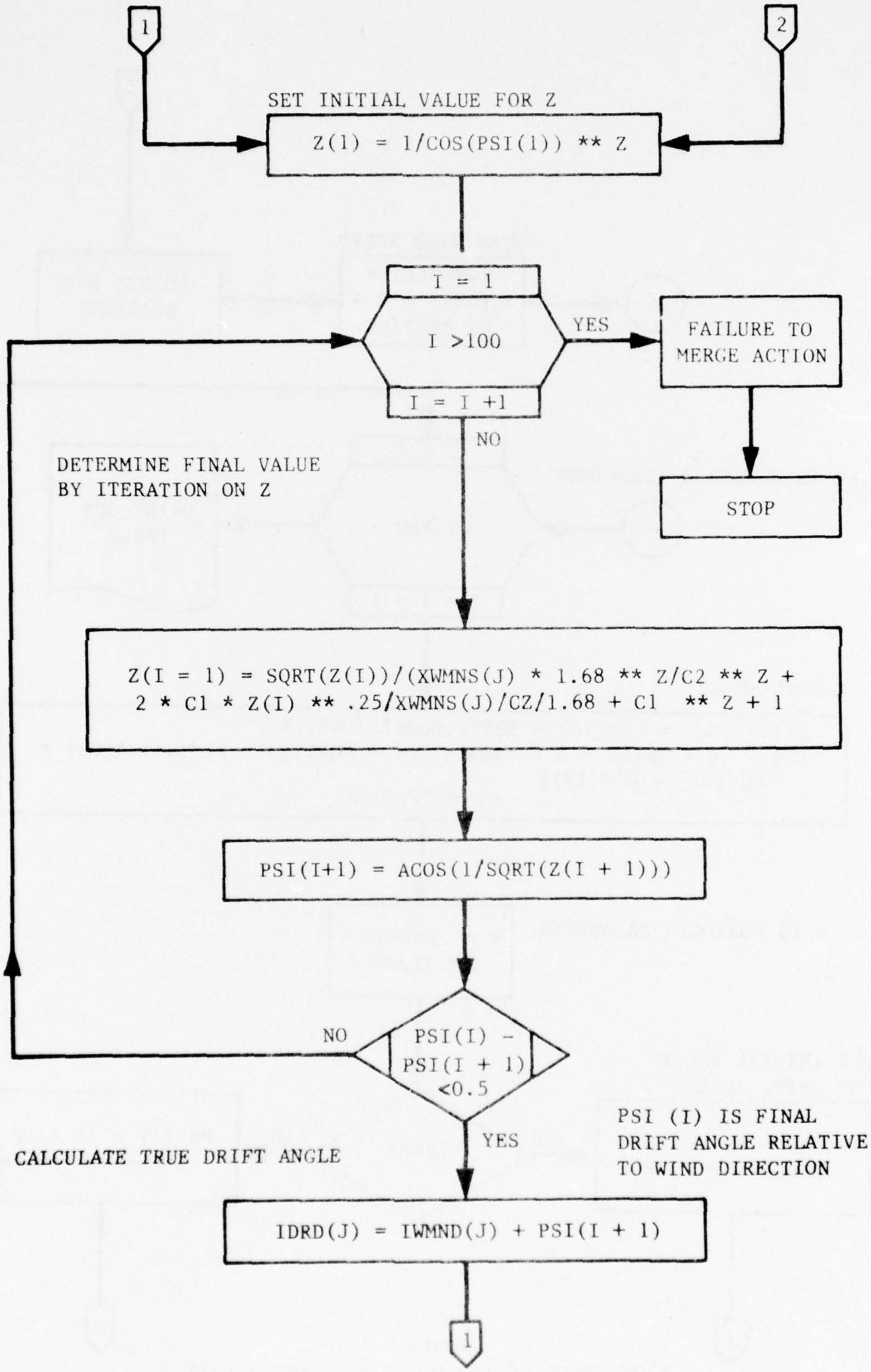
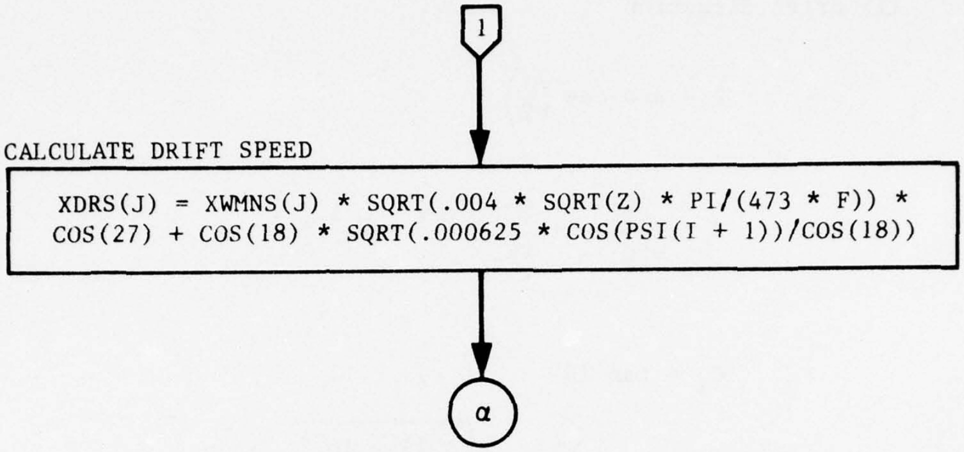


Figure 2.
Flow chart of ice drift subroutine (con.)



```
XDRS(J) = XWMNS(J) * SQRT(.004 * SQRT(Z) * PI/(473 * F)) *
COS(27) + COS(18) * SQRT(.000625 * COS(PSI(I + 1))/COS(18))
```

Figure 2.
Flow chart of ice drift subroutine (con.)

(1) drift direction

$$\psi = \text{arc cos}\left(\frac{1}{Z}\right) \quad ,$$

$$Z = \frac{Z^{\frac{1}{2}}}{V^2 C_2^{\ 2}} + \frac{2C_1}{VC_2} \quad Z^{\frac{1}{4}} + C_1^{\ 2} + 1 \quad ,$$

$$C_1 = \tan 18^\circ \quad ,$$

$$C_2 = \frac{.004\cos 18^\circ \sqrt{\frac{6.25 \times 10^{-4}}{\cos 18^\circ}}}{0.9fI\left[\sqrt{\frac{.004\sqrt{2\pi}}{473f}} \cos 27^\circ + \cos 18^\circ\right]} \quad ,$$

$$f = 1.458 \times 10^{-4}\sin(\text{lat}) \quad ; \text{ and}$$

(2) drift speed

$$u = V\left[\sqrt{\frac{.004\sqrt{2\pi}}{473f}} \cos 27^\circ + \cos 18^\circ\right]\sqrt{\frac{6.25 \times 10^{-4}\cos\psi}{\cos 18^\circ}} \quad ;$$

where

V = wind speed (ft/sec),

ψ = drift to the right of the wind direction

u = drift speed (ft/sec)

lat = latitude, and

I = ice thickness (inches)

The equation for Z is required to be in an iterative form, thus it is used as follows:

$$Z_{n+1} = \frac{Z_n^{\frac{1}{2}}}{V^2 C_2^{\ 2}} + \frac{2C_1}{VC_2} \quad Z_n^{\ \frac{1}{4}} + C_1^{\ 2} + 1$$

IV. VARIATION FOR CONCENTRATION AND ROUGHNESS

The Shuleikin equations assume a single ice floe and do not consider surface roughness. An empirical table of wind factors (Zubov, 1945) was compiled by P.A. Gordienko from many observations of ice drift in the Soviet Arctic. Comparison of this table with the output of the Shuleikin equations shows a match at 0.5 oktas and 4 tenths extent of ridging and hummocking. A factor table (table 1) was then constructed for use in correcting the computer output to the applicable concentration and roughness. Instructions for using the table are given beneath the table. As an example, suppose we have a mean wind speed and direction of 9.2 kn and 102 deg, which produce an ice drift and direction of .34 kn and 123 deg (see station 70086 in figure 1). If the concentration were 0.5 oktas and the extent of ridging and hummocking 4 tenths, then, referring to table 1, the ice drift speed would remain .34 kn since the multiplicative factor is 1. If, however, the concentration was 6 oktas and the ridging 3 tenths, the ice drift speed would be .10 kn since the multiplicative factor is .3. In either case, the drift direction remains 123 deg, since this table only relates to drift speed.

V. CONCLUSIONS

The methods described above have been programmed and are now operational on the UNIVAC 1108 computer at the Naval Oceanographic Office. Ice drift information is now regularly produced, together with the other products described in the Introduction. The outputs have been evaluated by comparing them first with the manual computation method of Wittmann and MacDowell (1964) and second with manual calculations accomplished with the original equations. These comparisons have proved the computer program to be reliable. Evaluation with actual observed drift conditions has not been accomplished, but since the curves from Wittmann and MacDowell have been used successfully for years, the computer output is assumed accurate.

VI. DISCUSSION

As previously stated, this computation of ice drift is based on Shuleikin's work of 1953. This model was chosen since it had been used manually for years and had been found to give accurate results. In addition, it was most easily adapted to estimating wind drift from station observations that were available in the existing system.

A basic problem exists with the Shuleikin model in that it only considers the motion of a single floe as it results from wind and water stress and Coriolis force. No consideration is given to the effect of interaction between floes. In the program herein described, the effects of concentration and ridging are considered empirically but are not input to the theoretical model. Considerable research has been done since Shuleikin's work. Many of the recent papers are published in the extensive AIDJEX series (University of Washington, 1972-). Campbell and Rasmussen (1972) begin with an excellent

Table 1

FACTOR TABLE

TOTAL CONCENTRATION OF ICE (OKTAS)

E*	0.5	1	2	3	4	5	6	7.0	7.5
1	.26	.24	.20	.17	.13	.10	.09	.07	.07
2	.51	.47	.40	.34	.28	.22	.18	.15	.12
3	.75	.71	.63	.55	.47	.39	.30	.22	.19
4	1.00	.96	.84	.72	.62	.51	.39	.29	.24
5	1.26	1.19	1.06	.92	.79	.65	.52	.38	.31
6	1.51	1.43	1.26	1.10	.94	.80	.63	.46	.38
7	1.75	1.66	1.47	1.29	1.10	.92	.73	.55	.46
8	2.01	1.90	1.69	1.49	1.28	1.07	.85	.64	.53
9	2.26	2.13	1.90	1.64	1.40	1.17	.94	.71	.60

*Extent of ridging and hummocking (tenths)

Table of multiplicative factors for estimating speed of ice drift from computer printout. The drift speeds given in the printout are true for 0.5 oktas and 4 tenths ridging. To determine correct speed enter concentration and extent of ridging into this table and multiply computer's drift speed by the factor thus obtained.

summary of ice dynamics up to 1972 and proceed to give a model that considers ice as a viscous material. Rothrock (1975) considers sea ice as a plastic material. Additional papers are expected shortly.

Ice drift estimates, computed by the model discussed in sections III and IV of this paper, are sufficiently accurate for use in the locality of the station whose wind reports are used in the calculation. They are not sufficiently accurate for the calculation of areas of convergence and divergence or for interpolation between stations or extrapolation into areas lacking wind observations. To add these features to the system in the future, it will be necessary to implement one of the more sophisticated models, requiring more specific inputs not now readily available.

REFERENCES

Campbell, W.J. and L.A. Rasmussen, A numerical model for sea ice dynamics incorporating three alternative ice constitutive laws, in Sea Ice: Proceedings of an International Conference, Reykjavik, Iceland, edited by T. Karlsson, pp. 176-187, National Research Council, Reykjavik, 1972.

Gerson, D.J., A numerical ice forecasting system, Reference Publication No. 8, U.S. Naval Oceanographic Office, v. 138, December 1975.

Rothrock, D.A., The energetics of the plastic deformation of pack ice by ridging, J. Geophys Res., 80, 4514-4519, 1975.

Shuleikin, V.V. Fizika moria, izdamie tret'e. (Physics of the Sea, 3rd Ed.) Press of the Academy of Sciences of the USSR, Moscow, 1953. par 16, Drift of Ice Fields, p. 113-129, translation, U.S. Naval Oceanographic Office, Washington, D.C.

U.S. Dept. of Commerce, National Meteorological Center, NMC 360/195 Data Sets, Office Note 85, August 1973.

University of Washington, AIDJEX Bulletin Series, University of Washington, Seattle, 1972-

Wittmann, W.I. and G.P. MacDowell, Manual of short-term sea ice forecasting, Spec. Pub. SP-82, 142pp., U.S. Naval Oceanographic Office, Washington, D.C., 1964.

Zubov, N.N., L'dy Arktiki (Arctic Ice), Northern Sea Route Directorate Press, Moscow 1945, Translation, 491 pp., U.S. Naval Oceanographic Office, Washington, D.C., 1963.

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APPENDIX A. SUBROUTINE LISTING

```
@FOR,S A.WDCALCS,A.WDCALCR
FOR 0DE3-09/07/76-15.54:17 (1,)

   SUBROUTINE WDCALC    ENTRY POINT 001045

   STORAGE USED: CODE(1) 001121; DATA(0) 000567; BLANK COMMON(2) 000000

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003    SIN
    0004    COS
    0005    ATAN
    0006    SQRT
    0007    TAN
    0010    XPRR
    0011    ACOS
    0012    NWDU$
    0013    NI02$
    0014    NI01$
    0015    NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000253 10L       0000     000347 1000F     0000     000354 1010F     0000     000423 1020F     0001     000070 105G
    0001     000570 110L      0000     000336 1100F     0001     000074 113G      0001     000560 120L      0001     000341 151G
    0001     000471 175G      0001     000137 20L       0001     000660 226G      0001     000762 247G      0001     000770 254G
    0001     000644 90L       0000 R 000322 C1        0000 R 000323 C18       0000 R 000331 C2        0000 R 000330 C28
    0000 R 000327 C21       0000 R 000324 C27       0000 R 000317 DEG       0000 R 000325 F         0000 I 000310 I
    0000 I 000320 IDEG      0000     000471 INJPS     0000 I 000335 IPAGE     0000 I 000314 J         0000 I 000332 JDRD
    0000 I 000333 JJ        0000 I 000334 JK        0000 I 000313 KK        0000 R 000321 PI        0000 R 000144 PSI
    0000 R 000326 THICK     0000 R 000315 WD        0000 R 000311 XI        0000 R 000312 XJ        0000 R 000316 XWMND
    0000 R 000000 Z


00101      1.            SUBROUTINE WDCALC(IWD,XWS,XWMNS,IWMND,XDRS,IDRD,N,NO,MO,                 000070
00101      2.           1MONTH,IDATE,IYEAR,JTHICK,ALAT)                                          000070
00103      3.            DIMENSION IWD(90,4),XWS(90,4),XWMNS(90),IWMND(90),XDRS(90),IDRD          000070
00103      4.           1(90),N(90),MO(12),JTHICK(90),ALAT(90),Z(100),PSI(100)                     000070
00104      5.            DO 10 I=1,90                                                             000070
00107      6.            XI=0.                                                                    000070
00110      7.            XJ=0.                                                                    000070
00111      8.            KK=0                                                                     000071
00112      9.            DO 20 J=1,4                                                              000074
00115     10.            IF(IWD(I,J).GT.500.OR.XWS(I,J).GT.90.)GO TO 20                           000074
00117     11.            WD=3.141592654*(IWD(I,J))/180                                            000111
00120     12.            XI=XI-SIN(WD)*XWS(I,J)                                                   000117
00121     13.            XJ=XJ-COS(WD)*XWS(I,J)                                                   000125
00122     14.            KK=KK+1                                                                  000133
00123     15.      20    CONTINUE                                                                 000141
00125     16.            IF(KK.EQ.0)GO TO 10                                                      000141
00127     17.            XWMND=ATAN(XI/XJ)                                                        000143
```

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```
00130            DEG=XWMND*180/3.141592654                                         000162
00131            IDEG=DEG+.5                                                       000155
00132            IF(IDEG.LT.0)IDEG=360+IDEG                                        000165
00134            IF(XI.LT.0.AND.XJ.GE.0)IDEG=IDEG-180                              000173
00136            IF(XI.GE.0.AND.XJ.GE.0)IDEG=IDEG+180                              000212
00140            IWMND(I)=MOD(IDEG ,360)                                           000231
00141            XWMNS(I)=SQRT(XI**2+XJ**2)/KK                                     000235
00142      10    CONTINUE                                                          000257
00144            PI=3.141592654                                                    000257
00145            C1=TAN(.1*PI)                                                     000261
00146            C18=COS(.1*PI)                                                    000267
00147            C27=COS(27/180*PI)                                                000273
00150            DO 90 J=1,NO                                                      000341
00153            IF(XWMNS(J).LT.0.5)GO TO 120                                      000345
00155            IF(XWMNS(J).GT.98.)GO TO 90                                       000351
00157            F=.0001458*SIN(PI*ALAT(J)/180)                                    000355
00160            THICK=JTHICK(J)                                                   000366
00161            THICK=THICK/12.                                                   000371
00162            IF(THICK.LT.0.5)THICK=0.5                                         000374
00164            C2T=.004*C18*SQRT( .000625/C18)                                   000402
00165            C2B=.9*THICK*F*(SQRT(.004*SQRT(2)*PI/(473.*F))*C27+C18)           000404
00166            C2=C2T/C2B                                                        000423
00167            IF(XWMNS(J).LT.10)PSI(1)=60-6.43*XWMNS(J)*1.68                    000426
00171            IF(XWMNS(J).GE.10)PSI(1)=35-.2*XWMNS(J)*1.68                      000437
00173            Z(1)=1/COS(PSI(1)*PI/180.)**2                                     000453
00174            DO 100 I=1,100                                                    000471
00177            Z(I+1)=SQRT(Z(I))/(XWMNS(J)*1.68)**2/C2**2+2*C1*Z(I)**.25/XWMNS(J) 000471
00177           1 /C2/1.68+C1**2+1                                                 000471
00200            PSI(I+1)=ACOS(1/SQRT(Z(I+1)))*180/PI                              000517
00201            IF(ABS(PSI(I)-PSI(I+1)).LT.0.5)GO TO 110                          000535
00203      100   CONTINUE                                                          000544
00205            WRITE(6,1100)N(J)                                                 000544
00210      1100  FORMAT(10X,'DRIFT FOR STATION ',A5,' FAILS TO CONVERGE')          000552
00211            XDRS(J)=99.9                                                      000552
00212            IDRD(J)=999                                                       000554
00213            GO TO 90                                                          000556
00214      120   JDRD=90+IWMND(J)                                                  000560
00215            IDRD(J)=MOD(JDRD,360)                                             000562
00216            XDRS(J)=0.                                                        000565
00217            GO TO 90                                                          000566
00220      110   JDRD=IWMND(J)+(PSI(I+1)+.5)                                       000570
00221            IDRD(J)=MOD(JDRD,360)                                             000604
00222            XDRS(J)=XWMNS(J)*(SQRT(.004*SQRT(2)*PI/(473*F))*C27+C18)          000610
00222           1*SQRT(.000625*COS(PSI(I+1)*PI/180)/C18)                           000610
00223      90    CONTINUE                                                          000660
00225            DO 30 JJ=1,NO,20                                                  000660
00230            JK=JJ+19                                                          000707
00231            IPAGE=JK/20                                                       000712
00232            WRITE(6,1000)IPAGE                                                000715
00235      1000  FORMAT(1H1/103X,'PAGE NO ',I1)                                    000723
00236            WRITE(6,1010)MO(MONTH),IDATE,IYEAR                                000723
00243      1010  FORMAT(1H0////37X,'WIND SPEED (KTS) AND DIRECTION (DEG)'/         000733
00243           136X,'AND WIND DRIFT OF ICE FOR',A5,I2,', 19',I2,////10X,          000733
00243           2'STATION',7X,'002',11X,'062',11X,'122',11X,'182',11X,'MEAN',9X,   000733
00243           3'DRIFT',/12X,'NO',3X,6(5X,'SPD   DIR'))                           000733
00244            IF(JK.GT.NO)JK=NO                                                 000733
00246            DO 30 J=JJ,JK                                                     000741
```

```
00251     75*            WRITE(6,1020)N(J),(XWS(J,I),IWD(J,I),I=1,4),XWMNS(J),                    000762
00251     76*           1IWMND(J),XDRS(J),IDRD(J)                                                   000762
00265     77*      30    CONTINUE                                                                   001013
00270     78*    1020    FORMAT(1H0,10X,A5,1X,5(4X,F4.1,3X,I3),4X,F4.2,3X,I3)                       001013
00271     79*            RETURN                                                                     001013
00272     80*            END                                                                        001120
END FOR

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APPENDIX B. THEORETICAL DEVELOPMENT OF WIND DRIFT EQUATIONS

The frictional stress between two media is assumed to be proportional to the square of the relative velocity between them. Let $\vec{V}_a$ be the wind velocity, $\vec{V}_i$ be the ice velocity, assumed to move in +x direction and $\vec{V}_w$ be the water velocity. The frictional stress ($\vec{T}_a$) between air and ice is then given by:

$$|\vec{T}_a| = k_a\rho_a|\vec{V}_a-\vec{V}_i|^2 = k_a\rho_a|\vec{V}_a|^2 \text{ since } |\vec{V}_a| >> |\vec{V}_i|$$

The stress (T_i) between ice and water is given by:

$$|\vec{T}_i| = k_w\rho_w|\vec{V}_i - \vec{V}_w|^2$$

In addition to these two forces we have the Coriolis force:

$$\vec{C} = f(\vec{V}_i x \vec{k})$$

acting on the ice where $f = 2\omega\sin\theta$. The motion is assumed to take place under the equilibrium of these three forces therefore they must vectorially add to zero.

We now choose a coordinate system whose X - axis coincides with the direction of V_i thus producing figure 3.

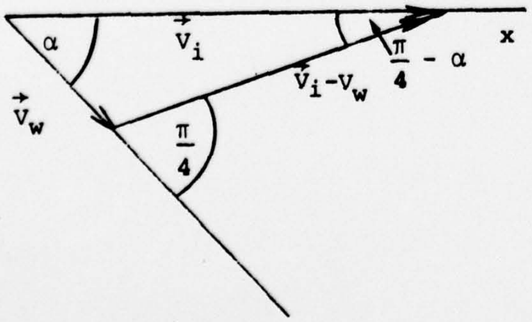

Figure 3a Velocity diagram

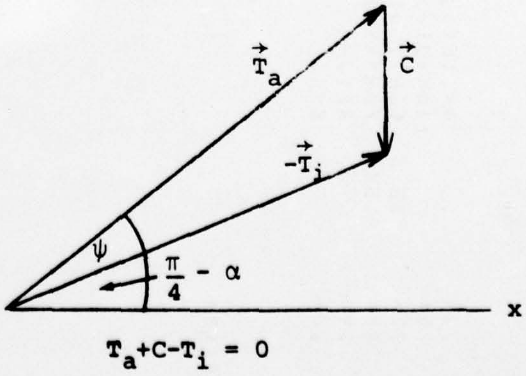

Figure 3b Force diagram

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Referring to figure 3a we see:

$$\frac{|\vec{V}_w|}{|\vec{V}_i-\vec{V}_w|} = \frac{\sin(\pi/4-\alpha)}{\sin(\alpha)}$$

$$= \frac{\sin(\pi/4)\cos(\alpha)-\sin(\alpha)\cos(\pi/4)}{\sin(\alpha)}$$

$$= \sin(\pi/4)\cot(\alpha)-\cos(\pi/4) = \zeta$$

$$\cot(\alpha)-\cot(\pi/4) = \cos(\alpha)-1 = \frac{\zeta}{\sin(\pi/4)}$$

$$\cot(\alpha) = 1+ 2\zeta$$

again from figure 3a we have:

$$|\vec{V}_i| = |\vec{V}_w|\cos(\alpha)+|\vec{V}_i -\vec{V}_w|\cos(\pi/4-\alpha)$$

Now referring to figure 3b:

$$T_{ix} = \vec{T}_i\cdot\vec{i} = k_w\rho_w|\vec{V}_i-\vec{V}_w|^2\cos(\pi/4-\alpha)$$

$$T_{iy} = \vec{T}_i\cdot\vec{j} = k_w\rho_w|\vec{V}_i-\vec{V}_w|^2\sin(\pi/4-\alpha)$$

$$T_{ax} = \vec{T}_v\cdot\vec{i} = k_a\rho_a|\vec{V}_a|^2\cos\Psi$$

$$T_{ay} = \vec{T}_v\cdot\vec{j} = k_a\rho_a|V_a|^2\sin\Psi$$

$$C_x = \vec{C}\cdot\vec{i} = -mf(\vec{k}x\vec{V}_i)\cdot i = 0=-mf(\vec{V}_i x\vec{k})\cdot\vec{i}$$

$$C_y = \vec{C}\cdot\vec{J} =-mf(\vec{k}x\vec{V}_i)\cdot\vec{j} = -mf|\vec{V}_i| = f(\vec{V}_i x\vec{k})\cdot\vec{j}$$

where: m = mass per unit area

k_w = the coefficient of friction between ice and water

k_a = the coefficient of friction between air and ice

ρ_w = the density of water

ρ_a = the density of air

$\vec{i}, \vec{j}, \vec{k}$, = the unit vectors along the x, y, and z directions respectively therefore:

$$\Sigma Y \text{ forces} = -k_w\rho_w|\vec{V}_i-\vec{V}_w|^2\sin(\pi/4-\alpha)-mf|\vec{V}_i|+|\vec{T}_v|\sin\Psi = 0$$

$$\Sigma X \text{ forces} = -k_w\rho_w|\vec{V}_i-\vec{V}_w|^2\cos(\pi/4-\alpha)|\vec{T}_v|\cos\Psi = 0$$

Solving for sinΨ and cosΨ and taking the ratio:

$$\tan\Psi = \frac{mf|\vec{V}_i|+k_w\rho_w|\vec{V}_i-\vec{V}_w|^2\sin(\pi/4-\alpha)}{k_w\rho_w|\vec{V}_i-\vec{V}_w|^2\cos(\pi/4-\alpha)}$$

$$= \tan(\pi/4-\alpha)+\frac{mf|\vec{V}_i|}{k_w\rho_w|\vec{V}_{\bar{i}}\vec{V}_w|^2\cos(\pi/4-\alpha)}$$

Now since:

$$|\vec{V}_i-\vec{V}_w| = \frac{|\vec{V}_i|}{\zeta\cos(\alpha)+\cos(\pi/4-\alpha)}$$

and therefore:

$$k_w\rho_w|\vec{V}_i-\vec{V}_w|^2 = \frac{k_w\rho_w|\vec{V}_i|^2}{[\zeta\cos(\alpha)+\cos(\pi/4-\alpha)]^2}$$

we have:

$$\tan\Psi = \tan(\pi/4-\alpha)+\frac{B}{|\vec{V}_i|}$$

where:

$$B = \frac{mf[\zeta\cos\alpha+\cos(\pi/4-\alpha)]^2}{k_w\rho_w\cos(\pi/4-\alpha)}$$

Now since:

$$T_{vx} = |\vec{T}_v|\cos\Psi = T_{ix} = k_w\rho_w|\vec{V}_i-\vec{V}_w|^2\cos(\pi/4-\alpha)$$

$$= \frac{k_w \rho_w |V_i|^2 \cos(\pi/4-\alpha)}{[\zeta \cos(\alpha)+\cos(\pi/4-\alpha)]^2}$$

we get:

$$|\vec{T}_v| = \frac{k_w \rho_w |\vec{V}_i|^2 \cos(\pi/4-\alpha)}{[\zeta \cos(\alpha)+\cos(\pi/4-\alpha)]^2 \cos\Psi}$$

Now since:

$$|\vec{T}_v| = k_a \rho_a |\vec{V}_a|^2$$

we get:

$$k_a \rho_a |\vec{V}_a| = \frac{k_w \rho_w |\vec{V}_i|^2 \cos(\pi/4-\alpha)}{[\zeta \cos(\alpha)+\cos(\pi/4-\alpha)]^2 \cos\Psi}$$

or:

$$\frac{|\vec{V}_i|}{|\vec{V}_a|} = [\zeta \cos(\alpha)+\cos(\pi/4-\alpha)] \sqrt{\frac{k_a \rho_a \cos(\Psi)}{k_w \rho_w \cos(\pi/4-\alpha)}}$$

Now from above we have:

$$\frac{B}{|\vec{V}_i|} = \tan(\Psi)-\tan(\pi/4-\alpha)$$

and multiplying this by the previous equation we get:

$$\frac{B}{|\vec{V}_a|} = [\zeta \cos(\alpha)+\cos(\pi/4-\alpha)] \sqrt{\frac{k_a \rho_a \cos\Psi}{k_w \rho_w \cos(\pi/4-\alpha)}} \; [\tan(\Psi)-\tan(\pi/4-\alpha)]$$

The equation for ζ is derived from Ekman theory, as follows:

$$V_w = \frac{k_w \gamma^2}{\sqrt{f}} \sqrt{\frac{\rho_w}{\mu}}$$

where: $\gamma = |\vec{V}_i - \vec{V}_w|$

μ = the coefficient of viscosity between ice and water

$$\sqrt{\frac{\rho_w}{\mu}} = \frac{\pi}{N|\vec{V}_w|\sqrt{f}}$$

Where: $N = D/|\vec{V}_i|$ and is the depth of frictional mixing. This has been evaluated as N = 473, (Shuleikin). Now since:

$$\zeta = \frac{|\vec{V}_i|}{\gamma}$$

we derive:

$$\zeta = \sqrt{\frac{\pi k_w \sqrt{2}}{Nf}}$$

$$= \sqrt{\frac{\pi k_w \sqrt{2}}{473f}}$$

It can be assumed with sufficient accuracy that the density of air (ρ_a) is $1.25\text{x}10^{-3}$ gm per cm^3, the density of water is 1 gm per cm^3, the coefficient of friction between ice and water (k_w) is $4\text{x}10^{-3}$ and between air and ice (k_a) is $2\text{x}10^{-3}$. From observations it has been determined that $\alpha = 27°$. In addition, since the density of ice is .9 and the mass per unit area of ice (m) is the density times the thickness (L), m = .9L. Therefore: from the equation for $\frac{B}{|\vec{V}_a|}$ above, we get:

$$\frac{1}{|\vec{V}_a|} = \frac{\rho_w k_w \cos(18°)}{.9Lf[\zeta\cos(27°)+\cos(18°)]}\sqrt{\frac{6.25\text{x}10^{-4}\cos(\Psi)}{\cos(18°)}}\left[\sqrt{\sec^2(\Psi)-1} - \tan(18°)\right]$$

let: $$Z = \frac{1}{\cos^2(\Psi)}$$

then $$\frac{1}{|\vec{V}_a|} = \frac{.004\cos(18^\circ)\frac{1}{Z^{1/4}}\sqrt{\frac{6.25\text{x}10^{4}}{\cos 18^\circ}}\left[\sqrt{Z-1} - \tan 18^\circ\right]}{.9Lf\left[\frac{.004 \quad 2\pi}{473f} \quad \cos(27^\circ)+\cos(18^\circ)\right]}$$

$$\tan(18^\circ) = \frac{Z^{1/4}.9Lf\left[\frac{.004 \quad 2\pi}{473f} \quad \cos 27^\circ+\cos 18^\circ\right]}{|\vec{V}_a|\left[.004\cos 18^\circ \sqrt{\frac{6.25\text{x}10^{-4}}{\cos 18^\circ}}\right]} = \sqrt{Z-1}$$

let: $$C_1 = \tan(18^\circ)$$

$$C_2 = \frac{.004\cos(18^\circ)\sqrt{\frac{6.25\text{x}10^{-4}}{\cos(18^\circ)}}}{.9Lf\left[\frac{.004 \quad 2\pi}{473f} \quad \cos(27^\circ)+\cos(18^\circ)\right]}$$

then: $$\sqrt{Z-1} = C_1 + \frac{Z^{1/4}}{C_2|\vec{V}_a|}$$

$$Z = C_1{}^2 + \frac{Z^{1/2}}{C_2{}^2|\vec{V}_a|^2} + \frac{2C_1Z^{1/4}}{C_2|\vec{V}_a|} + 1$$

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The numerical ice prediction system described in RP 8 has been in use since 1971. Its outputs, however, have been related only to ice growth, not ice drift. An addition to the system now provides an output of daily ice drift at 62 arctic stations. Drift is calculated as a function of wind stress, water stress, and Coriolis force. The computer output is sufficiently accurate for ice drift in the locality of the station whose wind observations were input to the model. However, more recent research indicates that for

20. greater accuracy and for computations of divergence and convergence interaction between floes must be considered.

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p. 16	figure	3a	change	$\vec{V}_i-V_w$	to	$\vec{V}_i-\vec{V}_w$
p. 17	line	5	"	$\cos(\alpha)-1$	to	$\cot(\alpha)-1$
"	"	6	"	$1+2\zeta$	to	$1+\sqrt{2}\zeta$
"	"	12	"	$\vec{T}_v$	to	$\vec{T}_a$
"	"	13	"	$\vec{T}_v$	to	$\vec{T}_a$
p. 18	"	2	"	$\lvert\vec{T}_v\rvert$	to	$\lvert\vec{T}_a\rvert$
"	"	3	"	$\cos(\pi/4-\alpha)\lvert\vec{T}_v\rvert$	to	$\cos(\pi/4-\alpha)+\lvert\vec{T}_a\rvert$
"	"	16	"	T_{vx}	to	T_{ax}
"	"	"	"	$\lvert\vec{T}_v\rvert$	to	$\lvert\vec{T}_a\rvert$
p. 19	"	3	"	$\lvert\vec{T}_v\rvert$	to	$\lvert\vec{T}_a\rvert$
"	"	5	"	$\lvert\vec{T}_v\rvert$	to	$\lvert\vec{T}_a\rvert$
p. 21	"	2	"	$\sqrt{\frac{6.25\mathrm{X}10^{4}}{\cos 18^\circ}}$	to	$\sqrt{\frac{6.25\mathrm{X}10^{-4}}{\cos 18^\circ}}$
"	"	3	"	$\tan(18^\circ)=$	to	$\tan(18^\circ)+$
"	"	"	"	$\sqrt{\frac{6.25+10^{=4}}{\cos 18^\circ}}$	to	$\sqrt{\frac{6.25+10^{-4}}{\cos 18^\circ}}$