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THE LIU, KATSAROS, AND BUSINGER (1979) BULK ATMOSPHERIC FLUX COMPUTATIONAL ITERATION PROGRAM IN FORTRAN AND BASIC

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**Abstract**

The computer program described by Liu, Katsaros, and Businger (1979) for calculating the bulk-derived atmospheric fluxes, stability, and roughness is presented in both FORTRAN and BASIC versions. The results of 12 test calculations are presented to ensure that the program has been properly encoded.
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THE LIU, KATSAROS, AND BUSINGER (1979)
BULK ATMOSPHERIC FLUX COMPUTATIONAL ITERATION
PROGRAM IN FORTRAN AND BASIC

ABSTRACT

The computer program described by Liu, Katsaros, and Businger (1979) for calculating the bulk-derived atmospheric fluxes, stability, and roughness is presented in both FORTRAN and BASIC versions. The results of 12 test calculations are presented to ensure that the program has been properly encoded.

INTRODUCTION

Liu, Katsaros, and Businger (1979) present a model developed for the marine atmospheric surface layer which takes into consideration the interfacial sublayers on both sides of the air-sea interface where molecular constraints on transports are important. Flux-profile relations which are based on the postulation of intermittent renewal of the surface fluid are matched to the logarithmic profiles and compared with both field and laboratory measurements. These relations enable numerical determination of air-sea exchanges of momentum, heat, and water vapor (or bulk transfer coefficients) employing the bulk parameters of mean wind speed, temperature, and humidity at a certain height in the atmospheric surface layer and the water temperature.

With increasing wind speed, the flow goes from smooth to rough and the bulk transfer coefficient for momentum also increases. The increase in roughness is associated with increasing wave height, which in the present model results in sheltering at the wave troughs. Due to the decrease in turbulent transport, the transfer coefficients of heat and water vapor decrease slightly with wind speed after the wind speed exceeds a certain value. The bulk transfer coefficients are also found to decrease with increasing stability. By including the effects of stability and interface conditions in bulk parameterization, the model provides a way to account for physical conditions which are known to affect air-sea exchanges.

A computer program utilizing computational iteration is required in order to solve three simultaneous equations of three unknowns, which are formed from five equations containing twelve dependent variables. Although the original program was written in FORTRAN, the recent proliferation of compact desk-top computers usable in the field has warranted its translation into BASIC.

The program requires seven input parameters:

1. Wind speed \((w)\) in m/s;
2. Air temperature \((T)\) in °C;
3. Specific humidity \((q)\) in kg/kg;
4. Water temperature at the surface \((T_s)\) in °C;
5. Altitude of the wind-speed measurement \((z_w)\) in m;
6. Altitude of the air-temperature measurement \((z_t)\) in m; and
7. Altitude of the humidity measurement \((z_q)\) in m.

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If the humidity is to be inputted in terms of the wet bulb temperature, dew point temperature, or relative humidity, consult the Appendix at the end of this report.

The results are outputted in the form of eight parameters:

1. The friction velocity ($u_\ast$) in m/s;
2. The scaling potential temperature ($\theta_\ast$) in °C;
3. The scaling specific humidity ($q_\ast$) in kg/kg;
4. The roughness length ($z_0$) in m;
5. The Monin-Obukhov stability ($z/L$);
6. The wind-speed-roughness Reynolds number ($R_w$);
7. The temperature-roughness Reynolds number ($R_t$); and
8. The humidity-roughness Reynolds number ($R_h$).

From the outputted information it is possible to compute the momentum flux ($M$) in N/m², the sensible heat flux ($H_s$) in W/m², and the humidity flux ($E$) in kg/(s m²) by

\[
M = -\rho u_\ast^2 \\
H_s = -\rho C_p \theta_\ast u_\ast \\
E = -\rho q_\ast u_\ast
\]

and

\[
H_L = E L_v
\]

where the density of moist air ($\rho$) in kg/m³ and the specific heat of moist air at constant pressure ($C_p$) in J/(kg/K) can be determined by

\[
\rho = \frac{(3.4838 \times 10^{-3}) P}{T_v + 273.16}
\]

and

\[
C_p = 1.004[1 + 0.9(q)] \times 10^3,
\]

where $P$ is the barometric pressure in pascals (if not recorded, assumed to be $1.01325 \times 10^5$ Pascals) and $T_v$ is the virtual potential temperature in °C such that

\[
T_v = [(T + 273.16) \times [1 + (0.608q)]] - 273.16.
\]

By convention, a positive sign is used to indicate an upward flux and a negative sign a downward flux. Because momentum flux is almost always downward (except in a few cases when the water velocity exceeds the wind), the negative momentum flux is traditionally defined as the stress ($\tau$),

\[
\tau \equiv -M.
\]

Additionally, it is frequently convenient from a thermodynamic perspective to represent the humidity flux in terms of the latent heat flux ($H_L$) in W/m² such that

\[
H_L = E L_v
\]

where $L_v$ is the latent heat of vaporization in J/kg,

\[
L_v = 4.1868(597.31 - 0.56525 T) \times 10^3.
\]
THE FORTRAN PROGRAM

00010 PROGRAM LKB79F
00020 COMMON/FIN/U,T,Q,TS,2U,CT,2Q,1D
00030 COMMON/OUT/USR,TSR,QSR,ZO,ZL,RR,RT,RQ
00040 C
00050 C INPUT DATA FROM TTY
00060 C
00070 1000 CONTINUE
00080 USR=0.0
00090 TSR=0.0
00100 QSR=0.0
00110 ZO=0.0
00120 ZL=0.0
00130 RR=0.0
00140 RT=0.0
00150 RQ=0.0
00160 CD=0.0
00170 WRITE (5,1) USR,TSR,QSR,ZO,ZL,RR,RT,RQ
00180 1 FORMAT(' INPUT VALUES ARE:')
00190 WRITE (5,2) USR,TSR,QSR,ZO,ZL,RR,RT,RQ
00200 2 FORMAT(' U=',G13.6,/
00210 A 'TSR=',G3.6,/
00220 B 'QSR=',G3.6,/
00230 C 'ZO=',G13.6,/
00240 D 'ZL=',G13.6,/
00250 E 'RR=',G13.6,/
00260 F 'RT=',G13.6,/
00270 G 'RQ=',G13.6,/
00280 H 'IER=',G13.6)
00290 900 FORMAT(G13.6)
00300 910 FORMAT(' LAST CASE? 0=YE1, 1=NO ',$/
00310 0 END
00320 SUBROUTINE ASL(IER)
00330 C TO EVALUATE SURFACE FLUXES, SURFACE ROUGHNESS, AND STABILITY OF
00340 C THE ATMOSPHERIC SURFACE LAYER FROM BULK PARAMETERS ACCORDING TO
00350 C LIU ET AL. (79) JAS 36 1722-1735
00360 C WRITTEN BY TIM LIU ON 5/8/79
00370 C
00380 C INPUT:
00390 C U WIND SPEED IN M/S
COMMON/PIN/U,T,Q,TS,ZU,ZT,ZQ,ID
COMMON/POUT/USR,TSR,QSR,ZO,ZL,RR,RT,RQ
IER=0
RI=9.61*ZU*(T-TS)/((273.15+T)*U**2)
IF(RI.GT.0.25)IER=-1
VISA=.15E-4
ZL=0.
ZQ=.0005
US=0.
CALL HUMLOW(TS,TS,QS)
DU=U-US
DT=T-TS
DQ=Q-QS
USR=.04*DU
N=0
CONTINUE
N1=0
CONTINUE
U1O=USR*ALOG(10./ZO)/.4
TYPE 8400,ID,U1O,CD
8400 FORMAT ('DRAG',3G13.6)
CALL DRAG(ID,U1O,CD)
TYPE 8400,ID,U1O,CD
C=1./SQRT(CD)
ZON=10./EXP(.4C)
TEST1=ABS((ZON-ZO)/(ZO+1.E-8))
8810 FORMAT ('TEST1,ZON,ZO,C,CD,N1',6G3.6)
IF(TEST1.LT.0.01)GO TO 19
N1=N1+1
IF(N1.GT.50)GO TO 95
ZO=ZON
GO TO 10
95 CONTINUE
19 CONTINUE
FUZ=PSI(1,ZL)
ZTL=ZL*ZT/ZU
ZQL=ZL*ZQ/ZU
PTZ=PSI(2,ZTL)
PQZ=PSI(2,ZQL)
USR=DU*0.4/(ALOG(ZU/ZO)-FUZ)
RR=ZC*USR/VISA
ZSR=ZT*USR/VISA
ZQSR=ZQ*USR/VISA
CALL LKB(RR,RT,1)
1F(RT .NE. -999.)GO TO 21
1R=2
1E=0
WRITE(5,2)RR
RETURN
19 CONTINUE
1210 USR=DU*0.4/(ALOG(ZU/ZO)-FUZ)
1220 RR=ZC*USR/VISA
1230 ZSR=ZT*USR/VISA
1240 ZQSR=ZQ*USR/VISA
1250 CALL LKB(RR,RT,1)
1260 IF(RT .NE. -999.)GO TO 21
1270 IER=2
1280 WRITE(5,2)RR
1290 RETURN
1300 21 CALL LKB(RR,RQ,2)
1310 IF(RT .NE. -999.)GO TO 22
SUBROUTINE DRAG(ID, U, CD)

C TO DETERMINE NEUTRAL DRAG COEFFICIENT CD FROM WIND SPEED
C AT 10 M U IN M/S

C ID=1 KONDO(1975) BIM 9 91-112
C ID=2 SMITH(1980) JPM 10 709-726
C ID=3 LARGE & POND (1981) JPM 11 324-336
C RANGE OF U SPECIFIED ARE: KONDO(.3,50),SMITH(6,22),L&P(4,25)
C WRITTEN BY TIM LIU FOR VAX ON 2/10/82

DIMENSION RAN(5), A(5), B(5), P(5)

DATA A/0., .771, .867, 1.2, 0./
DATA B/1.08, .0898, .0667, 0.025, 0.073/
DATA P/-0.12, 1.2, 1., 1., 1./
K=ID-2

IF(K)100,200,300

100 IF(U.GT.50.)GO TO 131
IF(U.LT.3)GO TO 130

110 IF(U.LE.RAN(I))GO TO 120
I=1

120 CD=(A(I)+B(I)*U**P(I))/1000.
GO TO 99

130 CD=3.E-3
GO TO 99

131 CD=1.25E-3
GO TO 99

132 CD=0.61-0.055*U/1000.
GO TO 99

133 CD=0.45+0.025*U/1000.
GO TO 99

134 CD=1.05

135 CD=1.25E-3
GO TO 99

136 CD=2.2*(ALOG(ZS/RQ)-PZ)
RETURN

SUBROUTINE HUMLOW(T, TW, Q)

C TO EVALUATE SPECIFIC HUMIDITY Q FROM DRY AND WET BULB TEMP
C T AND TW ACCORDING TO LOWE(77) JAM 16 100-103
C WRITTEN BY TIM LIU ON 5/3/79, REVISED FOR VAX ON 2/10/82

DIMENSION A(6)
DATA A/4.436519E-1,1.428946E-2,2.650649E-4,3.031240E-6,
         2.034081E-8,6.136821E-11/
P=1013.25
X=0.
DO 100 I=1,6
   J=7-I
   X=(X+A(J))*TW
100 CONTINUE
ES=6.107800+X
Q=0.622*ES/(P-ES)-4.045E-04*(T-TW)
RETURN
END

SUBROUTINE LKB(RR,RT,IFLAG)
C DETERMINE THE LOWER BOUNDARY VALUE RT OF THE LOGARITHMIC
C PROFILES OF TEMPERATURE (IFLAG=1) OR HUMIDITY (IFLAG=2)
C IN THE ATMOSPHERE FROM ROUGHNESS REYNOLD NUMBER RR BETWEEN
C u AND 1000. OUT OF RANGE RR INDICATED BY RT=-999.
C WRITTEN BY TIM LIU ON 1/22/78, REVISED FOR VAX ON 2/10/82
DIMENSION A(8,2) B(8,2) IN3)
DATA A/0.177,1.376,1.926,1.602,3.661,2.308,1.195,0.904,1.667,19.5,8885,
       0.892,1.808,1.993,1.996,4.994,30.709,1448,682,9885/
DATA B/0.0,0.599,0.599,-0.181,1.475,-2.667,-2.907,-3.935,
       0.0,0.826,-0.528,-0.870,-1.297,-1.845,-2.682,-3.616/
DATA RAN/0.11,0.825,3.0,10.0,30.0,100.0,300.0,1000.0/
I=1
IF (RR.LE.O.,OR.RR.GE.1000.) GO TO 90
10 CONTINUE
IF (HR.LE.RAN(I)) GO TO 20
I=I+1
GO TO 10
20 RT=A(IIFLAG)*RR**B(I,IFLAG)
GO TO 99
90 RT=-999.
RETURN
END

FUNCTION PSI(ID,ZL)
C TO EVALUATE THE STABILITY FUNCTION PSI FOR WIND SPEED (IFLAG=1)
C OR FOR TEMPERATURE AND HUMIDITY PROFILES FROM STABILITY PARAMETER ZL
C SEE LIU ET AL. (1979) JAS 36 1722-1723 FOR DETAILS
C WRITTEN BY TIM LIU ON 9/12/71, REVISED FOR VAX ON 2/10/82
C VON =0.4
IF(ZL),0,20,30
10 CHI=(I.-16.*ZL)**0.25
   IF(ID.EQ.1)GO TO 11
   PSI=2.*ALOG((1.+CHI*CHI)/2.)
   GO TO 99
11 PSI=2.*ALOG((1.+CHI/2.)*ALOG((1.+CHI*CHI)/2.)-2.*ATAN(CHI)
   & +2.*ATAN(1.)
   GO TO 99
20 PSI=0.
GO TO 99
30 PSI=-6.*ALOG(1.+ZL)
99 RETURN
END

SUBROUTINE ZRER(T,Q,USR,TSR,QSR,Z,ZL)
C EVALUATE OBUKHOVS STABILITY PARAMETER Z/L FROM AVERAGE
C TEMPERATURE T IN DEG C, AVERAGE HUMIDITY Q IN GM/GM, HEIGHT Z IN M,
C AND FRICTIONAL VELOCPY,TEMP., HUM. IN MKS UNITS
C SEE LIU ET AL. (1979) JAS 36 1722-1723 FOR DETAILS
C WRITTEN BY TIM LIU ON 10/17/77, REVISED FOR VAX ON 2/10/82
VON=0.4
G=9.81
TA=2/17.16*T
TV=TA*(1.+0.61*Q)
TVSR=TSR*1. +0.61*Q +0.61*QSR
IF (TVSR.EQ.0.) GO TO 10
OB=TV*USR*USR/(G*VON*TVSR)
ZL=Z/0B
GO TO 99
ZL=0.
RETURN
END
THE BASIC PROGRAM

10 REM "LKB79B" PROGRAM 12 OCT 83 T.V. BLANC NRL 4110 DISK #6
20 REM
30 REM THE BULK FLUX COMPUTATIONAL ITERATION PROGRAM OF LIU, KATSAROS &
40 REM BUSINGER (1979) TRANSLATED FROM FORTRAN INTO ELEMENTRY BASIC FOR USE
50 REM ON A HEWLETT-PACKARD MODEL 9845. THIS PROGRAM WAS ADAPTED FROM AN
60 REM ORIGINAL TRANSLATION OF A T WILSON NRL 2820 FOR USE ON A DIGITAL
70 REM EQUIPMENT CORPORATION MODEL DEC-10 COMPUTER.
80 REM
90 REM INPUTS U= Wind Speed (m/s), T= Air Temp (C), Q= Spec. Humid (Kg/Kg),
100 REM T1=Tw= Water Temp (C), Z= Zu= U Altitude (m), Z2-Zt= I Alt. (m)
110 REM Z3=Zq= 0 Alt (m)
120 REM NOTES U SHOULD NOT < 0
130 REM OUTPUTS Ul=Ustr= U* (m/s), T2=Tstr= T* (C), Q1=Qstr= Q* (Kg/Kg),
140 REM Z4=Zq= Rough Length (m), Zb=Z/L= Monin-Obukhov Stability,
150 REM R=Ru= Rough Reynolds No., R2= Rt= T Rough Reynolds No.,
160 REM R3=Rq= Rough Reynolds No.
170 REM
220 DATA 2 2.5 .B .2 .5 .50
230 DATA 0 .0 771.0 867.1 2.0
240 DATA 1 08.0 0858.0 0667.0 025.0 073
250 DATA -0 .15 .10 .1 .1 .1
260 DIM A1(6)
270 DATA 4 435619E-1.1 42946E-2.2 650649E-4
280 DATA 3 031240E-6.2 034081E-8 .6 136021E-11
290 DATA 2 177.1 37.1 026.1 625.4 661.3 490.4 1667 19.5 8BE5
300 DATA 0 292.1 808.1 393.1 956.4 994.30 709.1448 68.2 8BE5
310 DATA 0 .0 4.79 .0 599.1 016.1 -1 475.2 067.2 -907.3 935
320 DATA 0 .0 526.0 0526.0 -0 870.-1 297.1 845.2 682.3 616
330 DATA 0 11.0 225.3 .0 0 0.10 .30 0.100 0.300 .1000 0
340 RESTORE 220
350 FOR I=1 TO 5
360 READ R5(I)
370 NEXT I
380 FOR I=1 TO 5
390 READ A2(I)
400 NEXT I
410 FOR I=1 TO 5
420 READ B2(I)
430 NEXT I
440 FOR I=1 TO 5
450 READ P(I)
460 NEXT I
470 FOR I=1 TO 6
480 READ A1(I)
490 NEXT I
500 FOR J=1 TO 4
510 READ A0(J)
520 NEXT J
530 FOR J=1 TO 2
540 READ A1(J)
550 NEXT J
560 FOR J=1 TO 2
570 READ B1(J)
580 NEXT J
590 FOR J=1 TO 8
600 NEXT I
610 NEXT J
620 FOR I=1 TO 8
630 READ R6(I)
640 NEXT I
650 REM
660 PRINT " "

INPUT DATA: \( U(m/s), T(C), Q(kg/kg), Tw(C), Zu(m), Zt(m), Zq(m) \)

\[ \text{LET } U_1 = 0 \]
\[ \text{LET } T_2 = 0 \]
\[ \text{LET } \rho_1 = 0 \]
\[ \text{LET } Z_4 = 0 \]
\[ \text{LET } Z_6 = 0 \]
\[ \text{LET } R_1 = 0 \]
\[ \text{LET } R_2 = 0 \]
\[ \text{LET } R_3 = 0 \]
\[ \text{INPUT } U, T, Q, Z_1, Z_2, Z_3 \]
\[ \text{PRINT } U, T, Q, Z_1, Z_2, Z_3 \]
\[ \text{REM} \]
\[ \text{CALL SUBROUTINE ASL(IER)} \]
\[ \text{LET } A_9 = I_9 \]
\[ \text{GOSUB 990} \]
\[ \text{LET } I_9 = A_9 \]
\[ \text{REM} \]
\[ \text{PRINT "OUTPUT VALUES ARE:"} \]
\[ \text{PRINT } U^* (m/s) = U_1 \]
\[ \text{PRINT } T^* (C) = T_2 \]
\[ \text{PRINT } \rho^* (kg/kg) = \rho_1 \]
\[ \text{PRINT } Z_{o} (m) = Z_4 \]
\[ \text{PRINT } Z_{L} = Z_6 \]
\[ \text{PRINT } R_{u} = R_1 \]
\[ \text{PRINT } R_{t} = R_2 \]
\[ \text{PRINT } R_{q} = R_3 \]
\[ \text{REM} \]
\[ \text{PRINT "LAST CASE? 0=YES, 1=NO ";} \]
\[ \text{INPUT } I_8 \]
\[ \text{IF } I_8 = 1 \text{ THEN GOTO 660} \]
\[ \text{GOTO 2670} \]
\[ \text{SUBROUTINE ASL(IER)} \]
\[ \text{LET } A_9 = 0 \]
\[ \text{LET } R_4 = 9.81 * Z_1 * (T-T_1)/(C_273.15+T) * U'^2 \]
\[ \text{IF } R_4 > 25 \text{ THEN GOTO 1040} \]
\[ \text{GOTO 1050} \]
\[ \text{LET } A_9 = -1 \]
\[ \text{LET } V_1 = 1.5E-5 \]
\[ \text{LET } I_5 = 0 \]
\[ \text{LET } Z_4 = 0.0005 \]
\[ \text{LET } U_2 = 0 \]
\[ \text{LET } U_3 = 0 \]
\[ \text{LET } H_1 = T_1 \]
\[ \text{LET } H_2 = T_2 \]
\[ \text{LET } H_3 = Q_1 \]
\[ \text{CALL HUMLOW(Tw, Tw, Q, S)} \]
\[ \text{GOSUB 2290} \]
\[ \text{LET } T_1 = H_1 \]
\[ \text{LET } T_1 = H_2 \]
\[ \text{LET } Q_1 = H_3 \]
\[ \text{LET } D_0 = U - U_2 \]
\[ \text{LET } W_2 = T_1 - T_2 \]
\[ \text{LET } W_3 = Q - Q_1 \]
\[ \text{LET } U_1 = 0.4 * D_0 \]
\[ \text{LET } N_3 = 0 \]
\[ \text{CONTINUE} \]
\[ \text{LET } M_1 = 0 \]
\[ \text{LET } U_0 = U_1 * \log(10/Z_4)/.4 \]
\[ \text{LET } D_1 = D_1 \]
\[ \text{LET } D_2 = U_0 \]
\[ \text{LET } D_3 = C_1 \]
\[ \text{GOSUB 2050} \]
\[ \text{CALL DRAG(ID, U_10, CD)} \]
\[ \text{LET } D_1 = D_1 \]
\[ \text{LET } U_0 = D_2 \]
\[ \text{LET } C_1 = D_3 \]
LET C=I/SQR(C1)
LET Z5=10/EXP(4*C)
LET T3=ABS((Z5-Z4)/(Z4+1E-8))
IF T3<.01 THEN GOTO 1410
LET N1=N1+1
IF N1>50 THEN GOTO 2020
LET Z4=Z5
COTO 1240

REM ............. CONTINUE
LET P1=FNP(1,Z6)
LET Z7=Z6*Z2/Z1
LET Z8=Z6*Z3/Z1
LET P2=FNP(2,Z7)
LET P3=FNP(2,Z8)
LET UI=DO*.4/(LOG(Z1/Z4)-PI)
LET RI=Z4*UI/V1
LET Z9=Z2*UI/V1
LET ZO=Z3*UI/V1
GOSUB 2410
REM .................. CALL LKB(Ru,Rt,1)
PRINT "LBK FAILS BECAUSE Ru="R1
RETURN

LET L1=R1
LET L2=R2
LET L3=1
GOSUB 2410
REM .................. SET VALUE OF 2 TO A VARIABLE
LET L1=R1
LET L2=R3
LET L3=2
GOSUB 2410
LET R2=R3
LET L3=2
IF R2<-.999 THEN GOTO 1630
LET A9=2
PRINT "LBK FAILS BECAUSE Ru="R1
RETURN

LET F1=1
LET F2=0
LET F3=U1
LET F4=2
LET F5=Q1
LET F6=Z1
LET F7=Y1
GOSUB 2550
LET T=F1
LET Q=F2
LET U1=F3
LET T2=F4
LET Q1=F5
LET Z1=F6
LET Y1=F7
LET T4=ABS((Z6-Y1)/(Z6+1E-8))
IF T4<.01 THEN GOTO 2000
LET N3=N3+1
IF N3>50 THEN GOTO 2020
LET Z6=Y1
1990 GOTO 1220
2000 REM .......... CONTINUE
2010 GOTO 2040
2020 LET A9=1
2030 PRINT "ASL FAILS TO CONVERGE",N1,N3
2040 RETURN
2050 REM ............... SUBROUTINE DRAG(D1,D2,D3)
2060 REM R5=RAN, A2=A, B2=B IN DRAG
2070 LET K=D1-2
2080 IF K=0 THEN GOTO 2220
2090 IF K>0 THEN GOTO 2240
2100 IF D2>50 THEN GOTO 2200
2110 IF D2<.3 THEN GOTO 2180
2120 LET I=1
2130 IF D2<R5(I) THEN GOTO 2220
2140 LET I=I+1
2150 GOTO 2130
2160 LET D3=(A2(I)+B2(I)*D2-P(I))/1000
2170 GOTO 2280
2180 LET D3=1.5E-3
2190 GOTO 2280
2200 LET D3=3.7E-3
2210 GOTO 2280
2220 LET D3=(.61+.063*D2)/1000
2230 GOTO 2280
2240 IF D2<11 THEN GOTO 2270
2250 LET D3=(.49+.065*D2)/1000
2260 GOTO 2280
2270 LET D3=1.2E-3
2280 RETURN
2290 REM .................. SUBROUTINE HUMLOW(T,TW,Q)
2300 REM A1=A IN HUMLOW
2310 REM A1=A IN HUMLOW
2320 LET P=1013.25
2330 LET X=0
2340 FOR I=1 TO 6
2350 LET J=7-I
2360 LET X=(X+AI(J))*H2
2370 NEXT I
2380 LET E1=6.107800*X
2390 LET H3=.622*E1/(P-E1)-4.045E-4*(H1-H2)
2400 RETURN
2410 REM .................. SUBROUTINE LKB(Ru,Rt,IFLAG)
2420 REM SUBROUTINE LKB(L1,L2,L3)
2430 REM R6=RAN IN LKB
2440 LET I=1
2450 IF LI<0 THEN GOTO 2530
2460 IF LI>=1000 THEN GOTO 2530
2470 REM .......... CONTINUE
2480 IF LI<=R6(I) THEN GOTO 2510
2490 LET I=I+1
2500 GOTO 2470
2510 LET L2=AI(L3)*RI"B(I,L3)
2520 GOTO 2510
2530 LET L2=-999
2540 RETURN
2550 REM .................. SUBROUTINE ZETA (T,G,Ustr,Tstr,Qstr,Z,I/L)
2560 LET U=4
2570 LET G=9.81
2580 LET T5=273.16+F1
2590 LET T6=T5*(1+.61*F2)
2600 LET T7=F4*(1+.61*F2)+.61*T5*F5
2610 IF T7=0 THEN GOTO 2650
2620 LET D1=T6+F3*F3/(G*V*T7)
2630 LET F7=F6/D1
2640 GOTO 2660

11
2650 LET F7=0
2660 RETURN
2670 END
2680 REM
2690 REM FUNCTION PSI(ID, Z/L)
2700 DEF FNP(I7, X5)
2710 REM TEST Z/L FOR ±, 0, +
2720 IF X5=0 THEN GOTO 2800
2730 IF X5>0 THEN GOTO 2820
2740 LET C2=(I-16*X5)^.25
2750 IF I7=1 THEN GOTO 2780
2760 RETURN 2*LOG((I+C2*C2)/2)
2770 GOTO 2830
2780 RETURN 2*LOG((1+C2)/2)+2*ATN(C2)+2*ATN(I)
2790 GOTO 2830
2800 RETURN 0
2810 GOTO 2830
2820 RETURN -6*LOG(1+X5)
2830 FNEND
### TEST CALCULATION RESULTS

To ensure that the programs have been properly copied by the user, the results of 12 test calculations are presented. The outputted results should agree with those indicated below to within ±2 of the fourth significant figure.

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ACKNOWLEDGMENTS

The authors wish to thank Alwiter T. Wilson of NRL's Software Systems Support Branch for her translation of the program. The publication of this report was made possible by a grant from the General Science and Technology Directorate of the Naval Research Laboratory.

REFERENCES

APPENDIX

The specific humidity \((q)\) in kg/kg is calculated by

\[
q = \frac{0.622e}{P - (0.378e)}
\]

where \(P\) is the barometric pressure and \(e\) is the water vapor pressure in pascals. If the humidity is measured by the wet and dry bulb temperatures \((T_{wb}, T)\) in °C then

\[
e = e_s - 6.6 \times 10^{-4} \left[ 1 + (1.15 \times 10^{-3} T_{wb}) \right] P (T - T_{wb})
\]

where \(e_s\) is the saturated vapor pressure in pascals such that

\[
e_s = P a_1^{b_3} \times 10^{a_2 b_4 + a_4 b_5 + a_5 b_6}
\]

where

\[
a_1 = \frac{373.16}{T + 273.16},
\]

\[
a_2 = a_1 - 1,
\]

\[
a_3 = 1 - \frac{1}{a_1},
\]

\[
a_4 = (10^{a_2 b_4}) - 1,
\]

\[
a_5 = (10^{a_2 b_5}) - 1,
\]

and the Goff-Gratch humidity formulation constants are

\[
b_1 = -3.49149, \quad b_4 = -7.90298,
\]

\[
b_2 = 11.344, \quad b_5 = 8.1328 \times 10^{-3},
\]

\[
b_3 = 5.02808, \quad b_6 = -1.3816 \times 10^{-7}.
\]

If the humidity is measured by the dew point temperature \((T_{dp})\) in °C then

\[
e = P a_1^{b_3} \times 10^{a_2 b_4 + a_4 b_5 + a_5 b_6}
\]

where

\[
a_1 = \frac{373.16}{T_{dp} + 273.16}
\]

and \(a_2\) through \(a_5\) are calculated in the same manner as for the saturated vapor pressure. If the relative humidity (RH) in % is measured then

\[
e = \frac{e_s RH}{100}
\]

where the saturated vapor pressure \((e_s)\) is calculated from the air temperature as shown above.