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C     ************************************************************
C
C     ASCE Standardized Reference ET Equation for AgriMet
C     January and February, 2011.  Peter L. Palmer
C     AgriMet Program Manager, US Bureau of Reclamation, Boise, Idaho
C     and Karl Tarbet, Hydromet Program Manager.
C
C     ************************************************************
C
C     Program development from "Penman-Monteith daily (24 hour)
C     Reference Evapotranspiration Equations for Estimating ETo, ETr,
C     and HS ETo with Daily Data" by Snyder, R.L., University of
C     California Davis, and Eching, S., California Department of
C     Water Resources.  January 6, 2002, Revised February 2007.
C     This document describes the implementation of the "ASCE
C     Standardized Reference Evapotranspiration Equation",
C     (ASCE-EWRI, 2004).
C
C     Note: Variable abbreviations in parentheses in the comments
C           below are those used in the reference above.
C
C    ************************************************************
C                         List of Variables
C    ************************************************************
C
C
C    AgriMet Archive Weather Parameter Variables:
C    ----------------------------------------
C
C    Tmaxf     -  Maximum Daily Air Temperature (Fahrenheit)
C    Tminf     -  Minimum Daily Air Temperature (Fahrenheit)
C    Tavgf     -  Average Daily Air Temperature (Fahrenheit)
C    Tdewf     -  Mean Dew Point Temperature (Fahrenheit)
C    Rlangley  -  Observed Solar Radiation  (Langleys/day)
C    WRun      -  Total wind run at 2 meters (miles/day)
C
C
C    AgriMet Station Variables:
C    -------------------------
C
C    Station   -  Four letter station identifier.
C    Elev      -  Station Elevation in meters.
C    Latdeg    -  Station Latitude in degrees (positive for North).
C
C
C    Converted AgriMet Weather Parameter Variables:
C    ----------------------------------------------
C
C    Tmax   (Tx)     -  Maximum Daily Air Temperature (Centigrade).
C    Tmin   (Tn)     -  Minimum Daily Air Temperature (Centigrade).
C    Tavg   (Tm)     -  Mean Daily Air Temperature computed as the mean
C                       of the max and min daily air temperatures (C).
C    Tdew   (Td)     -  Mean Daily Dew Point Temperature (Centigrade).
C    WSavg  (U2)     -  Mean Daily Wind Speed at 2 meters, m/s.
C    Rs     (Rs)     -  Measured solar radiation (MJ/m2/day)
C
C
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C    Humdity/Vapor Pressure Variables:
C    ---------------------------------
C
C    LHvap   (lamda) -  Latent heat of vaporization: 2.45 MJ/kg
C                       Inverse: 0.408 kg/MJ
C    AtmPress (beta) -  Mean atmospheric (barometric) pressure at station
C                       Elevation. Defined by a simple formulation of the
C                       Universal Gas Law.
C    PsyCon  (gamma) -  Psychrometric Constant.  Propotional to the mean
C                       atmospheric pressure: PsyCon=0.000665*AtmPress
C    SVP_Tmax (esTx) -  Saturation Vapor Pressure at the maximum daily
C                       air temperature (Tmax).
C    SVP_Tmin (esTn) -  Saturation Vapor Pressure at the minimum daily
C                       air temperature (Tmin).
C    SVP_Tavg (eo)   -  Saturation Vapor Pressure at the mean daily
C                       air temperature (Tavg).
C    SVP_Tdew (ea)   -  Actual vapor pressure or Saturation Vapor Pressure
C                        at the daily mean dew point temperature (Tdew).
C    SVPslope (delta)-  Slope of the Saturation Vapor Pressure-Temperature
C                       Curve at mean air temperature (Tavg).
C    SVPavg   (es)   -  Mean daily Saturation Vapor Pressure
C    Ar       (Ar)   -  Aerodynamic term for tall canopy reference ET
C    Ao       (Ao)   -  Aerodynamic term for short canopy reference ET
C
C
C    Solar Radiation Variables:
C    --------------------------
C
C    Ra       (Ra)    -  Extraterrestrial Radiation - MJ/m2/day
C    Rs       (Rs)    -  Incoming Solar Radiation - MJ/m2/day
C    Rns      (Rns    -  Net Short Wave Radiation - MJ/m2/day
C    Rnl      (Rnl)   -  Net Long Wave Radiation  - MJ/m2/day
C    Rn       (Rn)    -  Net radiation over grass  - MJ/m2/day
C    Rso      (Rso)   -  Clear Sky Solar Radiation (MJ/m2/day) (Calculated)
C    JDay     (i)     -  Julian Day of the Year (1-366)
C    Gsc      (Gsc)   -  Solar constant = 0.082 MJ/m/minute
C    SBconst  (Sigma) -  Steffan-Boltzman constant = 4.90 x 10e-9
C    Latrad   (Phi)   -  Latitude in radians = (PI*Latdeg)/180
C    EccCorr  (dr)    -  Correction for eccentricity of Earth's orbit around
C                        the sun on julian day of the year:
C                        = 1+.033cos(2PI/365*Jday)
C    SunDec (sm Delta)-  Declination of the sun above the celestial equator
C                        in radians on julian day of the year:
C                        = 0.409sin(2PI/365*Jday-1.39)
C    PI               -  = 3.14159265358979323846
C    SunAngle (Omega) -  Sunrise hour angle in radians
C                        = cos e-1  (-tan Latrad x tan Sundec)
C    Cloudf    (f)    -  A cloudiness function of Rs and Rso
C                        = 1.35(Rs/Rso)-0.35
C    Emis_sky  (eps') -  Apparent net clear sky emissivity
C    Radr      (Rr)   -  Radiation term of ETrs equation for tall canopy.
C    Rado      (Ar)   -  Radiation term of ETos equation for short canopy.
C
C
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C    Date Variables:
C    --------------
C
C    Month            - Month of the Year (1-12)
C    Day              - Day of the Month (1-31)
C    Year             - Year (four digits)
C    JDay             - Julian day of the year
C
C
C    ET Variables:
C    ------------
C
C    ETrs             - ASCE Standardized ET (Tall Crop Reference)
C    ETos             - ASCE Standardized ET (Short Crop Reference)
C
C
       subroutine ETS(*,Station,Month,Day,Year,Tmaxf,Tminf,Tavgf,
     1               Rlangley,WRun,Tdewf,Etrs,ETos)
       Integer Month,Day,Year
       character*12 Station,STN
       Real Elev,Latdeg,Tmaxf,Tminf,Tavgf,Rlangley,WRun,Tdewf
       Real*4 CLDYC(5)

       INTEGER JDay
       REAL Latrad
       REAL Lhvap
       REAL*8 SBconst

       INTEGER*4 IEND(13)
C
C    ***************************************************************
C          Read in AgriMet Weather Station Location Parameters
C          (Data is found in huser2:[agrimet.et]climat.dat)
C
C    Elev (El) -  Station Elevation in meters.
C    Latdeg    -  Station Latitude in degrees (positive for North).
C    Stn       -  Station Identifier read from climat.dat
C
       OPEN(UNIT=76,FILE='HUSER2:[AGRIMET.ET]CLIMAT.DAT',TYPE='OLD',
     1  READONLY,IOSTAT=IOS,recl=86)
       IF(IOS.NE.0) THEN
               WRITE(*,*) '  ERROR OPENING CLIMAT.DAT etos.for:160'
               GO TO 950
       END IF
 30     READ(76,'(A5,3F9.0,F10.0,F9.0,F6.0,F4.0,2F7.0,F5.0,F6.0)',
     2  END=1000,
     3  IOSTAT=ISTAT)STN,CLDYC,CLDYM,ANEMH,ELEV,CSUBT,TSUBX,Latdeg
       IF(ISTAT.NE.0) THEN
               WRITE(*,*) '  ERROR READING CLIMAT.DAT'
               GO TO 925
       END IF
       IF(STN.NE.STATION)GO TO 30

        Write(*,*)'Etos:  Elev=',Elev,' LatDeg= ',LatDeg
C
C
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C     ************************************************************
C
C        Convert AgriMet Tmaxf, Tminf, Tavgf, and Tdewf to degrees C
C
C        Convert AgriMet wind run(Wrun miles/day)to average wind speed m/s.
C        meters per second  = miles per day/24/2.236936
C
C     ************************************************************
C
         Tmax=5.*(Tmaxf-32.)/9.
         Tmin=5.*(Tminf-32.)/9.
         Tavg=5.*(Tavgf-32.)/9.
         Tdew=5.*(Tdewf-32.)/9.
         WSavg=Wrun/24./2.236936
C
C
C     ************************************************************
C        Compute Julian Day of the Year (JDay) (1-366) for
C        subroutine call input date.  Procedure from Appendix A,
C        Table A5, equation A5.1, ASCE Manual 70 Revision, 2011.
C
C     ************************************************************
C
         Jday=Day-32+INT(275*Month/9)+2*INT(3/(Month+1))+
     1   INT(Month/100-(MOD(Year,4)/4)+0.975)
C
C     ************************************************************
C        Limit AgriMet solar radiation (langleys) to less than 800 to
C        prevent extreme ET values due to rollover or bad data.
C
C        Convert AgriMet Solar Radiation(langleys) to MJ/m2/day
C        Note that AgriMet Langleys are computed using the
C        Meteorology 15C Calorie, defined as 4.1855 J/cm2.
C        Therefore, Rs(MJ/m2/day) = .041855 * Rlangley
C        Note that ASCE FAO 56 uses ITcal, defined as
C        4.1868 joules, but we need to use the same conversion here
C        as implemented in the AgriMet database for consistency.
C        The difference is only 0.03%, 100 times less than the
C        accuracy of the Licor pyranometer.
C
C     ************************************************************
C
C
         If(Rlangley.GT.900.0)Rlangley=800.0
         Rs=Rlangley*0.041855
C
C
C     ************************************************************
C        Compute Extraterrestrial Radiation (Ra) using equations
C        From Duffie and Beckman (1980), "Solar engineering of thermal
C        processes". John Wiley and Sons, New York, pp. 1-109.
C
C        Ra= (24*60/PI) * Gsc * EccCorr * (SunAngle * sin Sundec
C             *sin LatRad + cos Latrad *cos Sundec *sin Sunangle)
C
```

```
C       Where:
C
C       Gsc     = Solar constant = 0.082 MJ/m2/minute
C       EccCorr = Correction for eccentricity of Earth's orbit around
C                 the sun on julian day of the year:
C                 = 1+.033cos(2PI/365*Jday)
C       Latrad   = Latitude in radians = (PI*Latdeg)/180
C       SunDec   = Declination of the sun above the celestial equator
C                  in radians on julian day of the year:
C                  = 0.409sin(2PI/365*Jday-1.39)
C       SunAngle = Sunrise hour angle in radians
C                  = arccos(-tan Latrad x tan Sundec)
C
C    ************************************************************
C
          PI=3.14159265358979323846
          Gsc=0.082
          EccCor=1+(0.033*cos(2*PI/365*Jday))
          Latrad=(PI*Latdeg)/180
          SunDec=0.409*sin(2*PI/365*Jday-1.39)
          SunAngle=(acos(-tan(Latrad)*tan(Sundec)))
          Ra= 24*60/PI*Gsc*EccCor*(SunAngle*sin(Sundec)*
     1      sin(LatRad)+cos(Latrad)*cos(Sundec)*sin(Sunangle))
C
C    ************************************************************
C       Compute Net Radiation (Rn) in MJ/m/day using equations
C       from Allen et al. (1994). "An update for the calculation
C       of reference evapotranspiration".  ICIC Bulletin 1994
C       Volume 43 No 2.
C
C       Rso      (Rso)   = Clear sky total global solar radiation at
C                          the earth's surface in MJ/m2/day
C                          = Ra(0.75 + 2.0 x 10e-5  * Elev)
C       Rns      (Rns)   = Net solar radiation over grass as function of
C                          measured solar radiation in MJ/m2/day
C                          = (1-0.23)Rs
C       Cloudf   (f)     = Cloudiness function = 1.35 * Rs/Rs0 - 0.35
C       SVP_Tmax (esTx)  = Saturation Vapor Pressure (kPa) at the
C                          maximum daily air temperature in Centigrade:
C                          = 0.6108 exp (17.27 * Tmax / Tmax + 237.3)
C       SVP_Tmin (esTn)  = Saturation Vapor Pressure (kPa) at the minimum
C                          daily air temperature in Centigrade:
C                          = 0.6108 exp (17.27 * Tmin / Tmin + 237.3)
C       SVP_Tavg (eo)    = Saturation Vapor Pressure (kPa) at the mean
C                          daily air temperature in Centigrade:
C                          = 0.6108 exp (17.27 * Tavg / Tavg + 237.3)
C       SVP_Tdew  (ea)   = Actual vapor pressure or saturation vapor pressure
C                          at the daily mean dew point (Tdew) temperature:
C                          = 0.6108exp(17.27Tdew/Tdew+237.3)
C       SVPavg    (es)   = Mean daily Saturation Vapor Pressure:
C                          = (SVP_Tmax + SVP_Tmin) / 2
C       Emis_sky   (e')  = Apparent net clear sky emissivity
C                          = 0.34 - 0.14 sqrt(SVP_Tdew)
C       SBconst    (o)   = Steffan-Boltzman constant = 4.90 x 10e-9
C       Rnl        (Rnl) = Net long wave radiation in MJ/m2/day
C       Rn         (Rn)  = Net radiation over grass in MJ/m2/day
C                          = Rns + Rnl
```

```
C       Radr       (Rr)  = Radiation term of ETrs equation for tall canopy.
C       Rado       (Ro)  = Radiation term of ETos equation for short canopy.
C
C    ************************************************************
C
        Rso= Ra*(0.75+0.00002*Elev)
        Rns=(1-0.23)*Rs
        Cloudf=(1.35*Rs/Rso)-0.35
        SVP_Tmax=0.6108*exp(17.27*Tmax/(Tmax+237.3))
        SVP_Tmin=0.6108*exp(17.27*Tmin/(Tmin+237.3))
        SVP_Tavg=0.6108*exp(17.27*Tavg/(Tavg+237.3))
        SVP_Tdew=0.6108*exp(17.27*Tdew/(Tdew+237.3))
        SVPavg=(SVP_Tmax+SVP_Tmin)/2
        Emis_sky =0.34-(0.14*sqrt(SVP_Tdew))
        SBconst=4.90/10**9
        Rnl=-
Cloudf*Emis_sky*Sbconst*(((Tmax+273.15))**4+((Tmin+273.15)**4))/2
        Rn=Rns+Rnl
C
C    ************************************************************
C       Compute Mean Atmospheric Pressure as a function of station
C       elevation in meters (Elev).  AtmPress is a simplified
C       formulation of the Universal Gas Law.
C
C                                          5.26
C                           (293-0.0065 Elev)
C       AtmPress (B) = 101.3 (---------------)
C                           (      293      )
C
C
C    ************************************************************
C
        AtmPress = 101.3 * ((((293-0.0065*Elev)/293))**5.26)
C
C    ************************************************************
C       Compute Psychometric Constant (PsyCon)
C       Proportional to the mean atmospheric pressure and latent heat
C       Of vaporization (2.45 MJ/kg).
C
C       Lhvap  (lambda) = 2.45 MJ/kg
C       PsyCon (gamma)  = 0.00163(AtmPress/LHvap)
C    ************************************************************
C
        Lhvap=2.45
        PsyCon=0.00163*(AtmPress/LHvap)
C
C
C    ************************************************************
C       Compute the slope of the Saturation Vapor Pressure Curve
C       at the mean air temperature (Tavg):
C
C       SVPSlope =      4099 * SVP_Tavg
C                  ------------------
C                                2
C                    (Tavg + 237.3)
C
```

```
C     ************************************************************
C
         SVPSlope = (4099*SVP_Tavg)/((Tavg+237.2)**2)
C
C     ************************************************************
C
C        Compute ETrs using the ASCE-EWRI (2004) standardized equation
C        for tall canopy (alfalfa) reference ET.
C
C        Radr = radiation term of the equation for tall canopy.
C        G    = soil heat flux density in MJ/m2/day = 0
C
C                    0.408 SVPslope (Rn - G)
C        Radr = ------------------------------
C               SVPslope + PsyCon(1+0.38 WSavg)
C
C        Ar   = Aerodynamic term of the equation for tall canopy.
C
C             (1600 PsyCon)
C             (-----------) WSavg(SVPavg-SVP_Tdew)
C             ( Tavg +273 )
C        Ar = (-----------------------------------
C                  SVPslope + PsyCon (1+0.38 WSavg)
C
C        ETrs = Radr + Ar
C
C
         G=0.00
         Radr=(0.408*SVPslope*(Rn - G))/(SVPslope+PsyCon*(1+0.38*WSavg))
         Ar=((1600*PsyCon)/(Tavg+273))*WSavg*(SVPavg-SVP_Tdew)/
     1      (SVPslope+PsyCon*(1+0.38*WSavg))
         ETrs=Radr+Ar
C
C
C     ************************************************************
C
C        Compute ETos using the ASCE-EWRI (2004) standardized equation
C        for short canopy (grass) reference ET.
C
C        Rado = radiation term of the equation for short canopy.
C
C        G    = soil heat flux density in MJ/m2/day = 0
C
C                    0.408 SVPslope (Rn - G)
C        Rado = ------------------------------
C               SVPslope + PsyCon(1+0.34 WSavg)
C
C        Ao   = Aerodynamic term of the equation for tall canopy.
C
C             (900  PsyCon)
C             (-----------) WSavg(SVPavg-SVP_Tdew)
C             ( Tavg +273 )
C        Ao = (-----------------------------------
C                  SVPslope + PsyCon (1+0.34 WSavg)
C
C        ETro = Rado + Ao
C
```

```
C
        G=0.00
        Rado=(0.408*SVPslope*(Rn - G))/(SVPslope+PsyCon*(1+0.34*WSavg))
        Ao=((900*PsyCon)/(Tavg+273))*WSavg*(SVPavg-SVP_Tdew)/
     1     (SVPslope+PsyCon*(1+0.34*WSavg))
        ETos=Rado+Ao
C
C
C     ************************************************************
C               Convert ETrs and ETos from mm to inches
C     ************************************************************
C
       ETos=ETos/25.4
       ETrs=ETrs/25.4
C
C     ************************************************************
C                  Printout Variable Names and Values
C     ************************************************************
C
        PRINT *,'Jday',JDay
        PRINT *,'Elev',Elev
        PRINT *,'Latdeg',Latdeg
        PRINT *,'Latrad',Latrad
        PRINT *,'Tmaxf',Tmaxf
        PRINT *,'Tminf',Tminf
        PRINT *,'Tavgf',Tavgf
        PRINT *,'Tdewf',Tdewf
        PRINT *,'Rlangley',Rlangley
        PRINT *,'WRun',WRun
        PRINT *,'Tmax (Tx)',Tmax
        PRINT *,'Tmin (Tn)',Tmin
        PRINT *,'Tavg (Tm)',Tavg
        PRINT *,'Tdew (Td)',Tdew
        PRINT *,'WSavg (U2)',WSavg
        PRINT *,'PI',PI
        PRINT *,'Gsc',Gsc
        PRINT *,'EccCor (dr)',EccCor
        PRINT *,'SunDec (o^)',SunDec
        PRINT *,'SunAngle (Ws)',SunAngle
        PRINT *,'Cloudf (f)',Cloudf
        PRINT *,'Emis_sky (e)',Emis_sky
        PRINT *,'SBconst (sigma)',SBconst
        PRINT *,' '
        PRINT *,'Rs',Rs
        PRINT *,'Ra',Ra
        PRINT *,'Rso',Rso
        PRINT *,'Rns',Rns
        PRINT *,'Rn',Rn
        Print *,'Rnl',Rnl
        PRINT *,' '
        PRINT *,'SVP_Tmax (EsTx)',SVP_Tmax
        PRINT *,'SVP_Tmin (EsTn)',SVP_Tmin
        PRINT *,'SVP_Tavg (Eo)',SVP_Tavg
        PRINT *,'SVP_Tdew (Ea)',SVP_Tdew
        PRINT *,'SVPAvg   (Es)',SVPavg
        PRINT *,'SVPslope (delta)',SVPslope
        PRINT *,'AtmPress (beta)',AtmPress
```

```
        PRINT *,'Lhvap (lamda)',Lhvap
        PRINT *,'PsyCon (gamma)',PsyCon
        PRINT *,'G',G
        PRINT *,'Radr for ETrs (Rr)',Radr
        PRINT *,'Ar for ETrs (Ar)',Ar
        PRINT *,'Rado for ETos (Ro)',Rado
        PRINT *,'Ao for ETos (Ao)',Ao
        PRINT *,'ETrs',ETrs
        PRINT *,'ETos',ETos
C
        CLOSE(UNIT=76,ERR=1002)
C
        RETURN
C
1000    WRITE(6,1001,ERR=925) STATION
1001    FORMAT(' %ETPCOMP-1001-STATION NOT FOUND: ',A)
925     CLOSE(UNIT=76,ERR=950)
950     RETURN 1
C
1002    RETURN
        END
```