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C
C ASCE Standardized Reference ET Equation for AgriMet
C January and February, 2011. Peter L. Palmer
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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 Echling, 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.
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C *****
C List of Variables
C *****

C AgriMet Archive Weather Parameter Variables:
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 AgriMet Station Variables:
C -----

C Station - Four letter station identifier.
C Elev - Station Elevation in meters.
C Latdeg - Station Latitude in degrees (positive for North).
C

C Converted AgriMet Weather Parameter Variables:
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 Humidity/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. Proportional 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

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C Solar Radiation Variables:

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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 = 4.90×10^{-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 = $1+.033\cos(2PI/365*Jday)$
C SunDec (sm Delta)- Declination of the sun above the celestial equator
C in radians on julian day of the year:
C = $0.409\sin(2PI/365*Jday-1.39)$
C PI - = 3.14159265358979323846
C SunAngle (Omega) - Sunrise hour angle in radians
C = $\cos e-1 (-\tan Latrad \times \tan Sundec)$
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.

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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
C   subroutine ETS(*,Station,Month,Day,Year,Tmaxf,Tminf,Tavgf,
1      Rlanglely,WRun,Tdewf,Etrs,ETos)
C     Integer Month,Day,Year
C     character*12 Station,STN
C     Real Elev,Latdeg,Tmaxf,Tminf,Tavgf,Rlanglely,WRun,Tdewf
C     Real*4 CLDYC(5)
C
C     INTEGER JDay
C     REAL Latrad
C     REAL Lhvap
C     REAL*8 SBconst
C
C     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
C     OPEN(UNIT=76,FILE='HUSER2:[AGRIMET.ET]CLIMAT.DAT',TYPE='OLD',
1     READONLY,IOSTAT=IOS,recl=86)
C     IF(IOS.NE.0) THEN
C         WRITE(*,*) ' ERROR OPENING CLIMAT.DAT etos.for:160'
C         GO TO 950
C     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
C     IF(ISTAT.NE.0) THEN
C         WRITE(*,*) ' ERROR READING CLIMAT.DAT'
C         GO TO 925
C     END IF
C     IF(STN.NE.STATION)GO TO 30
C
C     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
C Tmax=5.*(Tmaxf-32.)/9.
C Tmin=5.*(Tminf-32.)/9.
C Tavg=5.*(Tavgf-32.)/9.
C Tdew=5.*(Tdewf-32.)/9.
C 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
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
C Rs=Rlangley*0.041855
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

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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
C      PI=3.14159265358979323846
C      Gsc=0.082
C      EccCor=1+(0.033*cos(2*PI/365*Jday))
C      Latrad=(PI*Latdeg)/180
C      SunDec=0.409*sin(2*PI/365*Jday-1.39)
C      SunAngle=(acos(-tan(Latrad)*tan(Sundec)))
C      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

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C Radr (Rr) = Radiation term of ETrs equation for tall canopy.
 C Rado (Ro) = Radiation term of ETos equation for short canopy.

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 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.

$$\text{AtmPress (B)} = 101.3 \left(\frac{293 - 0.0065 \text{ Elev}}{293} \right)^{5.26}$$

C
 C *****

$$\text{AtmPress} = 101.3 * (((293-0.0065*Elev)/293))^{5.26}$$

C
 C *****
 C Compute Psychrometric Constant (PsyCon)
 C Proportional to the mean atmospheric pressure and latent heat
 C Of vaporization (2.45 MJ/kg).

C Lhvap (lambda) = 2.45 MJ/kg
 C PsyCon (gamma) = 0.00163(AtmPress/LHvap)
 C *****

$$\text{Lhvap}=2.45$$

$$\text{PsyCon}=0.00163*(\text{AtmPress}/\text{LHvap})$$

C
 C *****

C Compute the slope of the Saturation Vapor Pressure Curve
 C at the mean air temperature (Tavg):

$$\text{SVPSlope} = \frac{4099 * \text{SVP_Tavg}}{(\text{Tavg} + 237.3)^2}$$

C

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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
C      Radr=(0.408*SVPSlope*(Rn - G))/(SVPSlope+PsyCon*(1+0.38*WSavg))
C      Ar=((1600*PsyCon)/(Tavg+273))*WSavg*(SVPavg-SVP_Tdew)/
1      (SVPSlope+PsyCon*(1+0.38*WSavg))
C      ETrs=Radr+Ar
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

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```
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
```