CNWRA
CONTROLLED

COPY 699

Gary Walter Gw 3/15/05

Proj. # 20.006002.252 Gary Walter PE Gw 4/7/06

This notebook describes review of the representation of future climate in the TPA code and consideration of the representation of future climate by DOE as may be used in TSPA

DOE description of future climate. Don't know how it will be represented in TPA, so discussion here is based on conceptualization in "Future Climate Analysis – 10,000 years to 1,000,000 years after present"
MOD-01-001 Rev. 00 dated 3/14/2002
MOL.20020422.0011
downloaded from LSN 12/20/2004

Assumes next 400K years will be like last 400K years based on ~~year~~ Gw 3/15/05 Earth orbital parameters and position

Four climate states
Interglacial (modern) hot, dry
Monsoon hot, increased summer precip.
Intermediate (glacial-transition) cool, wetter
Glacial cold, wet

2

3/15/05

Analog sites corresponding to climate states from above referenced report

Title: Future Climate Analysis—10,000 Years To 1,000,000 Years After Present

Table 6-3. Present-Day Meteorological Stations Selected as Analogs for Climate States*

Climate State	Analog Meteorological Stations	Latitude	Longitude	Elevation/m[1]	MAT ° C	MAP mm/yr
Full Glacial, OIS 6/16—Average upper bound[2]	Lake Yellowstone, WY (485345)	44° 33'	110° 24'	2368	0.0	513
Full Glacial OIS 6/16--Average lower bound[2]	Browning, MT (241202)	48° 34'	113° 01'	1329	4.4	380
	Simpson 6NW, MT (247620)	48° 59'	110° 19'	835	5.0	260
Full Glacial, OIS 2, 4--Average upper bound[2]	Browning, MT (241202)	48° 34'	113° 01'	1329	4.4	380
	Simpson 6NW, MT (247620)	48° 59'	110° 19'	835	5.0	260
Full Glacial, OIS 2, 4--Average lower bound[2]	Elko, WB Airport, NV (262573)	40° 50'	115° 47'	1539	7.7	243
Full Glacial, OIS 8, 10--Average upper bound[2]	Chewelah, WA (451395)	48° 15'	117° 43'	509	7.9	537
Full Glacial, OIS 8, 10--Average lower bound[2]	Rosalia, WA (457180)	47° 14'	117° 22'	732	8.3	455
	St. John, WA (457267)	47° 06'	117° 35'	594	9.1	432
	Spokane, WSO Airport, WA (457938)	47° 38'	117° 32'	719	8.9	409
Intermediate—Average upper bound[2]	Rosalia, WA (457180)	47° 14'	117° 22'	732	8.3	455
	St. John, WA (457267)	47° 06'	117° 35'	594	9.1	432
	Spokane, WSO Airport, WA (457938)	47° 38'	117° 32'	719	8.9	409
Intermediate—Average lower bound[2]	Beowawe, NV (260795)	40° 36'	116° 29'	1433	8.8	217
	Delta, UT (422090)	39° 20'	112° 35'	1408	10.1	201
Monsoon—Average upper bound[2]	Nogales Old Nogales, AZ (025922)	31° 20'	110° 57'	1189	17.1	399
	Hobbs, NM (294026)	32° 42'	103° 08'	1103	16.6	409
Monsoon—Average lower bound[3]	Yucca Mountain regional stations			750-2300	13.4	125
Modern or interglacial climate[3]	Yucca Mountain regional stations			750-2300	13.4	125

*Output DTN: UN0201SPA021SS.007

Data Sources: Western U.S. Climate Historical Summaries. DTN: UN0112SPA021SS.004; USGS 2000b; Thompson et al. 1999, Table 4, p.24.
Note: MAT = mean annual temperature; MAP = mean annual precipitation; OIS = Oxygen isotope stage

[1] Elevations are above mean sea level

[2] Using DTN: UN0112SPA021SS.004, MAT is calculated by averaging average annual maximum and average minimum temperature (in °F) and then converting to °C; MAP is calculated by converting inches to mm.

[3] Thompson et al. 1999.

Gary Walling 3/17/05

Based on its ~~analyt~~ analysis of climate
ar 3/17/05

states for the past 400K yrs, DOE developed a sequence of future climate states for the future 10^6 yrs represented in Table 6-6 of the future climate report. This sequence differs from that used in 10^4 yr simulations, in part because the present climate at YM is interpreted is being in the monsoon transition to glacial climate based on current position in Milankovich cycle. Referring back to table on p. 2, this would place the present MAP at 125 mm/yr as opposed to the 186 to 266 mm/yr represented in Technical Basis ~~Docato~~ Document No. 1 Table 2-3.
ar 3/17/05

According to the TSPA-SR report (TDR-WIS-PA-000001) the 10^6 yr climate sequence was used for long-term simulations. To do this, infiltration estimates were developed ~~fro~~ for the various glacial
ar 3/17/05

climate states listed in Table 6-3, p 2 and used along with the infiltration estimates that had been developed for the modern, monsoon and glacial-transition climate states in the 10^4 yr simulations

4

GW 3/17/05

The infiltration estimates reported for the glacial climates are shown in Table 3.2-6 from the TSPA-SR

Table 3.2-6. Average Net Infiltrations for the Glacial Infiltration Cases

Infiltration Case	Glacial Climate, Stage 8/10	Glacial Climate, Stage 6/16	Glacial Climate, Stage 4
Low infiltration	37 mm/yr	28 mm/yr	17 mm/yr
Medium infiltration	71 mm/yr[a]	71 mm/yr[a]	28 mm/yr[b]
High infiltration	110 mm/yr	110 mm/yr	71 mm/yr

Source: CRWMS M&O 2000 [153002], file OIS16-results2.doc

NOTES: 25.4 mm = 1 in.

[a]Average of high and low cases for glacial climate, stage 6/16

[b]Low case for glacial climate, stage 6/16

GW 7/6/05

From Performance Total System Performance Assessment for Site Recommendations December 2000

The values of MAP and MAT based on analog sites as reported in the future climate reported are tabulated along with MAI estimated in TSPA-SR on p. 5

Gm 3/17/05

State	Code	MAT (degC)	MAP (mm/	MAI (mm/yr)	
Glacial(6/16,upper)	g16_6u	0.0	513	110	
Glacial(6/16,lower)	g16_6l	4.7	320	28	mean
Glacial(2/4,upper)	g4_u	4.7	320	71	mean
Glacial(2/4,lower)	g4_l	7.7	243	17	
Glacial(8/10,upper)	g8_10u	7.9	537	110	
Glacial(8/10,lower)	g8_10l	8.8	432	37	mean
Inter(upper)	imu	8.8	432	37	mean
Inter(lower)	iml	9.5	209	2.2	mean
Monsoon(upper)	mu	16.9	404	20	mean
Monsoon(lower)	ml	13.4	200 ~~125~~ Gm 3/17/05	4.7	mean
Interglacial(modern)	ig	13.4	200 ~~125~~	4.7	mean
"mean" indicates that average of analog site data used					

From "future climate from DOE.xls"

The apparently low MAP estimates for modern and low ~~gla~~ Gm 3/17/05 monsoon were replaced with 200 mm/yr to be more consistent with values used for 10^4 yr. simulations.

6 Gary Mattio 3/18/05

To create a future climate file generally consistent with that used by DOE for the 10^6 yr simulations in the TSPA-SR, I entered the starting times of the climate states listed in Table 6-6 of the Future Climate Analysis into spreadsheet "future climate from DOE.xls" For each climate state, MAP and MAI were assigned based on the analog site records for the upper and lower bounds. Where multiple analog sites for a bound were provided, the average was used. An example listing of the resulting table is shown on p. 5 including the MAI reported in the TSPA-SR.

To convert the climato history in the spreadsheet to a form suitable for TPA, that is, the climato2.dat file, the spreadsheet history is first extracted into a text file containing

col 1	col 2	col 3
start time	MAP	MAT

This file is then processed with a fortran program "make_climato.f90"

Gw 3/18/05

Upper Estimate					Lower Estimate				
Year	State	MAP	MAT	MAI	Year	State	MAP	MAT	MAI
0	ig	200	13.4	4.7	0	ig	200	13.4	4.7
500	imu	432	8.8	37	500	imu	209	9.5	2.2
18500	mu	404	16.9	20	18500	mu	200	13.4	4.7
20000	imu	432	8.8	37	20000	imu	209	9.5	2.2
38000	g8_10u	537	7 9	110	38000	g8_10u	432	8.8	37
49000	imu	432	8.8	37	49000	imu	209	9.5	2.2
65000	ig	200	13.4	4.7	65000	ig	200	13.4	4.7
77000	mu	404	16.9	20	77000	mu	200	13.4	4.7
78500	imu	432	8.8	37	78500	imu	209	9.5	2.2
91500	mu	404	16.9	20	91500	mu	200	13.4	4.7
93000	imu	432	8.8	37	93000	imu	209	9.5	2.2
106000	g8_10u	537	7.9	110	106000	g8_10u	432	8.8	37
120000	imu	432	8.8	37	120000	imu	209	9.5	2.2
137000	ig	200	13.4	4.7	137000	ig	200	13.4	4.7
148000	mu	404	16.9	20	148000	mu	200	13.4	4.7
149500	imu	432	8.8	37	149500	imu	209	9.5	2.2
174000	mu	404	16.9	20	174000	mu	200	13.4	4.7
175500	imu	432	8.8	37	175500	imu	209	9.5	2.2
200000	g16_6u	513	0.0	110	200000	g16_6u	320	4.7	28
213000	imu	432	8.8	37	213000	imu	209	9.5	2.2
229000	ig	200	13.4	4.7	229000	ig	200	13.4	4.7
241000	mu	404	16.9	20	241000	mu	200	13.4	4.7
242500	imu	432	8.8	37	242500	imu	209	9.5	2.2
266000	mu	404	16.9	20	266000	mu	200	13.4	4.7
267500	imu	432	8.8	37	267500	imu	209	9.5	2.2

To create the climato2.dat file, A listing of make_climato.f90 is provided on p.8 Because the input file to make_climato_fits contains only the start date of a climate state, the data are first reprocessed using a fixed interval for the transition between different climate states, such as 500 years. If the difference between the start times

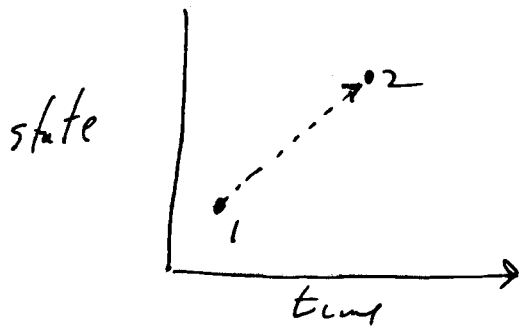
8 Gw 3/18/05

make_climato.f90

```
program make_climato_files
!program to read a climate record and create climato1 and climato2 files
!for TPA
!written by G. Walter

implicit none

integer ,parameter :: ndata = 2000
integer :: ndata_in, ndata_out
integer ,parameter :: io1 = 10, io2 = 20
integer :: i,j,k
character(len=130) :: infile

real, dimension(2000,3) :: in_data
real, dimension(2000,3) :: climato_out
real :: interval, time_1,time_2
real :: time,map,mat
real :: glacial_max_map,glacial_max_mat,map_start,mat_start
write(*,*)'ENTER NAME OF INPUT FILE'
read(*,'(a130)')infile
open(unit=io1,file = infile)
write(*,*)'ENTER THE CLIMATE TRANSITION INTERVAL IN YEARS'
read(*,*)interval
!read the input file into in_data

        ndata_in = 0
        glacial_max_map = 0.
        glacial_max_mat = 1e6
        do i=1,ndata
        read(io1,*,end=100)(in_data(i,j), j=1,3)
        glacial_max_map = max(glacial_max_map,in_data(i,2))
        glacial_max_mat = min(glacial_max_mat,in_data(i,3))
        ndata_in = ndata_in + 1
        end do
100 write(*,*)'READ ',ndata_in,' VALUES'

!loop through the input data and adjust times
        ndata_out = 0
        map_start = in_data(1,2)
        mat_start = in_data(1,3)
        do i=1,ndata_in - 1
        time_1 = in_data(i,1)
        time_2 = in_data(i+1,1)
        ndata_out = ndata_out + 1
        climato_out(ndata_out,1) = time_1
        climato_out(ndata_out,2) = in_data(i,2)
        climato_out(ndata_out,3) = in_data(i,3)
        if((time_2 - time_1) > interval) then
        !the duration of this climate state is greater than interval
        !add a new data entry
                ndata_out = ndata_out + 1
                climato_out(ndata_out,1) = time_2 - interval
                climato_out(ndata_out,2) = in_data(i,2)
                climato_out(ndata_out,3) = in_data(i,3)
        else
                climato_out(ndata_out,1) = time_1
                climato_out(ndata_out,2) = in_data(i,2)
                climato_out(ndata_out,3) = in_data(i,3)
        endif
        enddo
        open(io2,file='climato2.dat')
        do i = 1,ndata_out
        climato_out(i,2) = (climato_out(i,2) - map_start) &
                                /(glacial_max_map - map_start)
        climato_out(i,3) = (climato_out(i,3) - mat_start) &
                                /(glacial_max_mat - mat_start)

        write(io2,'(f8.0,1x,f10.4,1x,f7.4)')(climato_out(i,j),j=1,3)
        enddo
end program
```

Gw 3/18/05

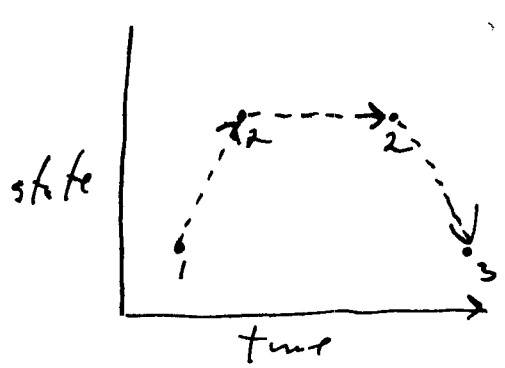
is less than the interval, then the start times are not changed in the climator.dat file, that is, the transitions between the climate states will be treated as a linear transition in the TPA code, as illustrated below



If the difference in start times is more than the interval (Δt), then the start time for the subsequent state is reduced by Δt and the new time value is added to the climator.dat file. This creates a linear transition from state 1 to state 2 over Δt follow by constant values of MAP and ~~MAT~~ MAT over the original

Gw 3/18/05

duration of state as illustrated to the right →



GW 3/18/05

The output from ~~make_dct~~ GW 3/18/05 make_climate is in the form

time MAP_factor MAT_factor

where $$\text{MAP\_factor} = \frac{MAP(t) - MAP(t=0)}{MAP(\text{glacial max}) - MAP(t=0)}$$

$$\text{MAT\_factor} = \frac{MAT(t) - MAT(t=0)}{MAT(\text{glacial max}) - MAT(t=0)}$$

A graph of the resulting output file based on the upper range MAP values is shown as Figure 1 on ~~plate~~ GW 3/18/05 page 11

The resulting values of MAP and MAT are shown in Figure 2 on page 11

RL 9/22/09

Gw 3/18/05

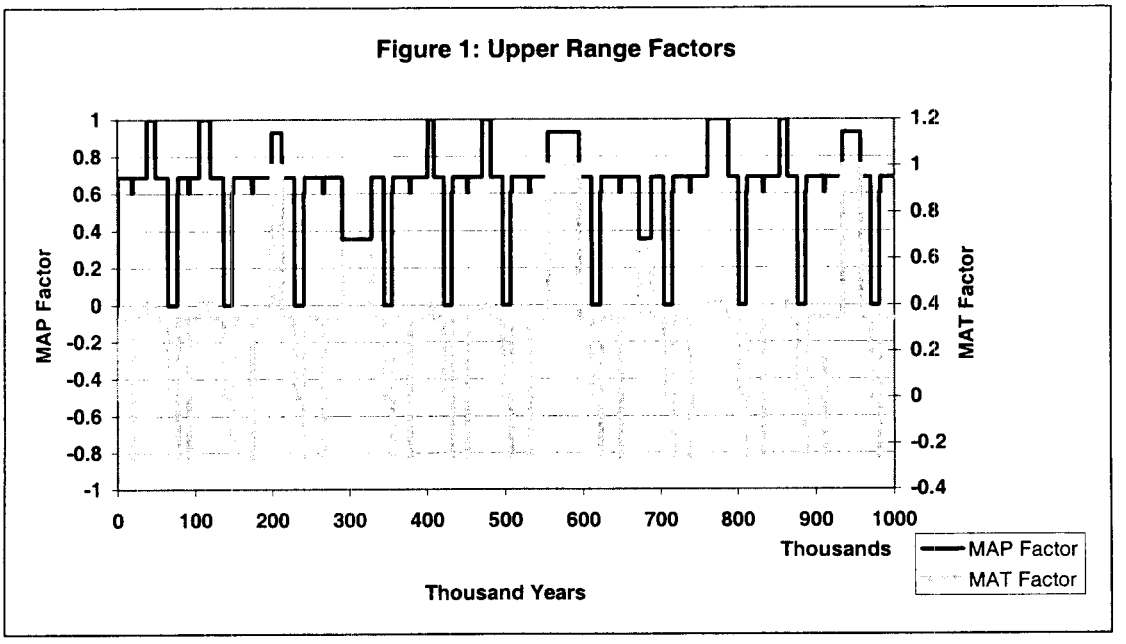


Figure 1: Upper Range Factors
MAP Factor
MAT Factor
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
Thousands
Thousand Years
MAP Factor
MAT Factor

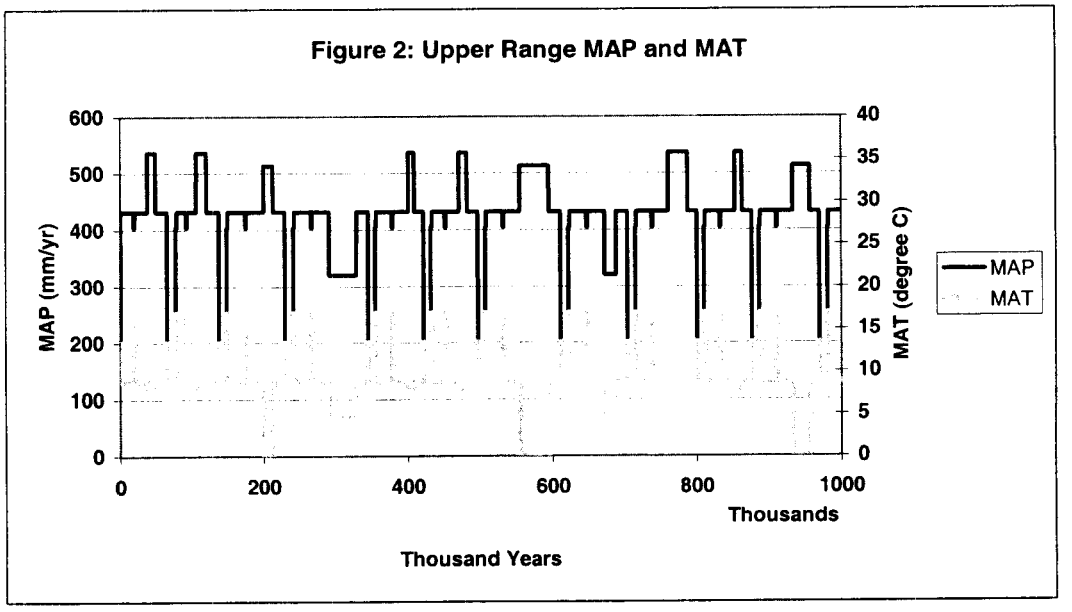


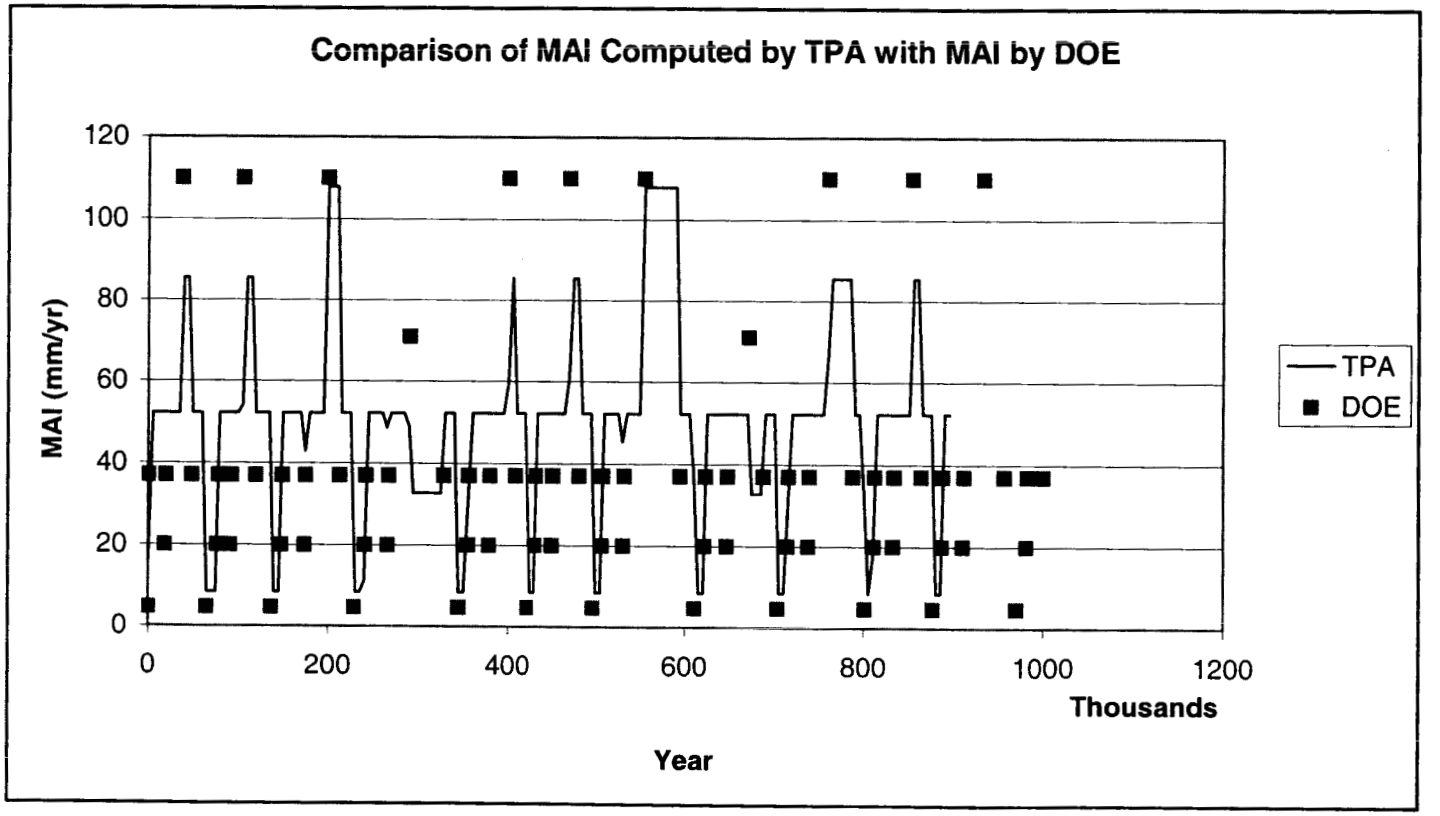
Figure 2: Upper Range MAP and MAT
MAP (mm/yr)
MAT (degree C)
600
500
400
300
200
100
0
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
Thousands
Thousand Years
MAP
MAT

12 Guy Multey 3/24/05

Checked new climato2.dat by running TPA simulation using base case parameters but change ratio of mean annual precip. at glacial maximum to present value to 2.67 to be consistent with precipitation rates used by DOE. A comparison of the MAI computed by TPA to the MAI reported by DOE in TSPA SR is shown on p. 13
The TPA MAI values are generally a bit higher than DOE estimates except during the glacial climates.

Simulation performed with tpa5000/tpa.e

RL 9/22/09



infilper

3/24/05

3/30/05 [illegible]

Made two changes to the climato2.dat file 1) added an initial 500yr time step at present climate to solved problem with tpa time interpolation 2) added detail to the first 10k yrs to be consistent with previous versions of the file.

4/7/05 Gary R Walter

These entries relate to analyzing the propagation of climate and infiltration in the DOE code Goldsim used for TSPA. The following analysis is based on the descriptions of Goldsim and TSPA in the TSPA-SR report MDL-WIS-PA-000002 Rev 00

Goldsim DDL's that are affected by climate or infiltration

DDL	Function	C or I Influence
T2_BINNING	Generates repository release bins based on infiltration	C + I, but I directly
SZ_CONVOLUTE	Generates SZ breakthru curves	C
SEEPDLL	calculates seepage fraction + flux	I

RL 9/22/09

9/08/05 Gary R Walling

The following entries document a fortran program used to compute past and future values of earth orbital parameters that was used to prepare an intermediate milestone report on future climate uncertainty. The program used to perform the calculations is called "orbital.f" It was created by writing a main program that accesses subroutine ORBPAR.f obtained from the NASA website http://aom.giss.nasa.gov/SOLAR/ORBPAR.SUB accessed August 22, 2005

A complete listing is provided on pages 17 through 21. The only change made to the ORBPAR code was to change the function call MOD to Modulo.

To verify the program, the computed eccentricity and precession index C were compared to a table of values for the past 500,000 yrs obtained from ~~http~~ ftp://ftp.ncdc.noaa.gov/pub/data/paleo/insolation/content.91 accessed August 20, 2005 (con't p. 21)

GW 9/8/05

9/8/05

```
      program orbital_parameters
      real*8 start_time, delta_time, end_time, time
      real*8 eccen,obliq,omegvp,precession_index
      character*80 out_file
      write(*,*)'PROGRAM ORBITAL PARAMETERS'
      write(*,*)'enter starting year(positive for AD), increment in years
     $  and end time '
      read(*,*)start_time,delta_time,end_time
      write(*,*)'enter output file name '
      read(*,'(a80)')out_file
      open(unit=10,file=out_file)
      time = start_time
      do i=1,10000
      if(time.le.end_time)then
      call orbpar(time,eccen,obliq,omegvp)
      precession_index = eccen*sin(omegvp)
      Write(10,'(f8.0,1x,f6.4,1x,f6.4)')time,eccen,precession_index
      time = time + delta_time
      else
      go to 100
      endif
      end do
100   write(*,*)'END OF PROGRAM'
      stop
      end


      SUBROUTINE ORBPAR (YEAR, ECCEN,OBLIQ,OMEGVP)
C****
C**** ORBPAR calculates the three orbital parameters as a function of
C**** YEAR.  The source of these calculations is: Andre L. Berger,
C**** 1978, "Long-Term Variations of Daily Insolation and Quaternary
C**** Climatic Changes", JAS, v.35, p.2362.  Also useful is: Andre L.
C**** Berger, May 1978, "A Simple Algorithm to Compute Long Term
C**** Variations of Daily Insolation", published by Institut
C**** D'Astronomie de Geophysique, Universite Catholique de Louvain,
C**** Louvain-la Neuve, No. 18.
C****
C**** Tables and equatunitions refer to the first reference (JAS).  The
C**** corresponding table or equation in the second reference is
C**** enclosed in parentheses.  The coefficients used in this
C**** subroutine are slightly more precise than those used in either
C**** of the references.  The generated orbital parameters are precise
C**** within plus or minus 1000000 years from present.
C****
C**** Input:  YEAR   = years A.D. are positive, B.C. are negative
C**** Output: ECCEN  = eccentricity of orbital ellipse
C****         OBLIQ  = latitude of Tropic of Cancer in radians
C****         OMEGVP = longitude of perihelion =
C****                = spatial angle from vernal equinox to perihelion
C****                  in radians with sun as angle vertex
C****
      IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER (TWOPI=6.283185307179586477d0, PIz180=TWOPI/360.d0)
      REAL*8 TABLE1(3,47),TABLE4(3,19),TABLE5(3,78)
C**** Table 1 (2).  Obliquity relative to mean ecliptic of date: OBLIQD
```

Cen 9/8/05

```
      DATA TABLE1/-2462.2214466d0, 31.609974d0, 251.9025d0,
     2            -857.3232075d0, 32.620504d0, 280.8325d0,
     3            -629.3231835d0, 24.172203d0, 128.3057d0,
     4            -414.2804924d0, 31.983787d0, 292.7252d0,
     5            -311.7632587d0, 44.828336d0,  15.3747d0,
     6             308.9408604d0, 30.973257d0, 263.7951d0,
     7            -162.5533601d0, 43.668246d0, 308.4258d0,
     8            -116.1077911d0, 32.246691d0, 240.0099d0,
     9             101.1189923d0, 30.599444d0, 222.9725d0,
     O             -67.6856209d0, 42.681324d0, 268.7809d0,
     1              24.9079067d0, 43.836462d0, 316.7998d0,
     2              22.5811241d0, 47.439436d0, 319.6024d0,
     3             -21.1648355d0, 63.219948d0, 143.8050d0,
     4             -15.6549876d0, 64.230478d0, 172.7351d0,
     5              15.3936813d0,  1.010530d0,  28.9300d0,
     6              14.6660938d0,  7.437771d0, 123.5968d0,
     7             -11.7273029d0, 55.782177d0,  20.2082d0,
     8              10.2742696d0,   .373813d0,  40.8226d0,
     9               6.4914588d0, 13.218362d0, 123.4722d0,
     O               5.8539148d0, 62.583231d0, 155.6977d0,
     1              -5.4872205d0, 63.593761d0, 184.6277d0,
     2              -5.4290191d0, 76.438310d0, 267.2772d0,
     3               5.1609570d0, 45.815258d0,  55.0196d0,
     4               5.0786314d0,  8.448301d0, 152.5268d0,
     5              -4.0735782d0, 56.792707d0,  49.1382d0,
     6               3.7227167d0, 49.747842d0, 204.6609d0,
     7               3.3971932d0, 12.058272d0,  56.5233d0,
     8              -2.8347004d0, 75.278220d0, 200.3284d0,
     9              -2.6550721d0, 65.241008d0, 201.6651d0,
     O              -2.5717867d0, 64.604291d0, 213.5577d0,
     1              -2.4712188d0,  1.647247d0,  17.0374d0,
     2               2.4625410d0,  7.811584d0, 164.4194d0,
     3               2.2464112d0, 12.207832d0,  94.5422d0,
     4              -2.0755511d0, 63.856665d0, 131.9124d0,
     5              -1.9713669d0, 56.155990d0,  61.0309d0,
     6              -1.8813061d0, 77.448840d0, 296.2073d0,
     7              -1.8468785d0,  6.801054d0, 135.4894d0,
     8               1.8186742d0, 62.209418d0, 114.8750d0,
     9               1.7601888d0, 20.656133d0, 247.0691d0,
     O              -1.5428851d0, 48.344406d0, 256.6114d0,
     1               1.4738838d0, 55.145460d0,  32.1008d0,
     2              -1.4593669d0, 69.000539d0, 143.6804d0,
     3               1.4192259d0, 11.071350d0,  16.8784d0,
     4              -1.1818980d0, 74.291298d0, 160.6835d0,
     5               1.1756474d0, 11.047742d0,  27.5932d0,
     6              -1.1316126d0,  0.636717d0, 348.1074d0,
     7               1.0896928d0, 12.844549d0,  82.6496d0/
C**** Table 4 (1).  Fundamental elements of the ecliptic: ECCEN sin(pi)
      DATA TABLE4/ .01860798d0,  4.207205d0,  28.620089d0,
     2             .01627522d0,  7.346091d0, 193.788772d0,
     3            -.01300660d0, 17.857263d0, 308.307024d0,
     4             .00988829d0, 17.220546d0, 320.199637d0,
     5            -.00336700d0, 16.846733d0, 279.376984d0,
     6             .00333077d0,  5.199079d0,  87.195000d0,
     7            -.00235400d0, 18.231076d0, 349.129677d0,
     8             .00140015d0, 26.216758d0, 128.443387d0,
     9             .00100700d0,  6.359169d0, 154.143880d0,
```

Gw 9/8/05

```
     O              .00085700d0, 16.210016d0, 291.269597d0,
     1              .00064990d0,  3.065181d0, 114.860583d0,
     2              .00059900d0, 16.583829d0, 332.092251d0,
     3              .00037800d0, 18.493980d0, 296.414411d0,
     4             -.00033700d0,  6.190953d0, 145.769910d0,
     5              .00027600d0, 18.867793d0, 337.237063d0,
     6              .00018200d0, 17.425567d0, 152.092288d0,
     7             -.00017400d0,  6.186001d0, 126.839891d0,
     8             -.00012400d0, 18.417441d0, 210.667199d0,
     9              .00001250d0,  0.667863d0,  72.108838d0/
C**** Table 5 (3).  General precession in longitude: psi
      DATA TABLE5/ 7391.0225890d0, 31.609974d0, 251.9025d0,
     2             2555.1526947d0, 32.620504d0, 280.8325d0,
     3             2022.7629188d0, 24.172203d0, 128.3057d0,
     4            -1973.6517951d0,  0.636717d0, 348.1074d0,
     5             1240.2321818d0, 31.983787d0, 292.7252d0,
     6              953.8679112d0,  3.138886d0, 165.1686d0,
     7             -931.7537108d0, 30.973257d0, 263.7951d0,
     8              872.3795383d0, 44.828336d0,  15.3747d0,
     9              606.3544732d0,  0.991874d0,  58.5749d0,
     O             -496.0274038d0,  0.373813d0,  40.8226d0,
     1              456.9608039d0, 43.668246d0, 308.4258d0,
     2              346.9462320d0, 32.246691d0, 240.0099d0,
     3             -305.8412902d0, 30.599444d0, 222.9725d0,
     4              249.6173246d0,  2.147012d0, 106.5937d0,
     5             -199.1027200d0, 10.511172d0, 114.5182d0,
     6              191.0560889d0, 42.681324d0, 268.7809d0,
     7             -175.2936572d0, 13.650058d0, 279.6869d0,
     8              165.9068833d0,  0.986922d0,  39.6448d0,
     9              161.1285917d0,  9.874455d0, 126.4108d0,
     O              139.7878093d0, 13.013341d0, 291.5795d0,
     1             -133.5228399d0,  0.262904d0, 307.2848d0,
     2              117.0673811d0,  0.004952d0,  18.9300d0,
     3              104.6907281d0,  1.142024d0, 273.7596d0,
     4               95.3227476d0, 63.219948d0, 143.8050d0,
     5               86.7824524d0,  0.205021d0, 191.8927d0,
     6               86.0857729d0,  2.151964d0, 125.5237d0,
     7               70.5893698d0, 64.230478d0, 172.7351d0,
     8              -69.9719343d0, 43.836462d0, 316.7998d0,
     9              -62.5817473d0, 47.439436d0, 319.6024d0,
     O               61.5450059d0,  1.384343d0,  69.7526d0,
     1              -57.9364011d0,  7.437771d0, 123.5968d0,
     2               57.1899832d0, 18.829299d0, 217.6432d0,
     3              -57.0236109d0,  9.500642d0,  85.5882d0,
     4              -54.2119253d0,  0.431696d0, 156.2147d0,
     5               53.2834147d0,  1.160090d0,  66.9489d0,
     6               52.1223575d0, 55.782177d0,  20.2082d0,
     7              -49.0059908d0, 12.639528d0, 250.7568d0,
     8              -48.3118757d0,  1.155138d0,  48.0188d0,
     9              -45.4191685d0,  0.168216d0,   8.3739d0,
     O              -42.2357920d0,  1.647247d0,  17.0374d0,
     1              -34.7971099d0, 10.884985d0, 155.3409d0,
     2               34.4623613d0,  5.610937d0,  94.1709d0,
     3              -33.8356643d0, 12.658184d0, 221.1120d0,
     4               33.6689362d0,  1.010530d0,  28.9300d0,
     5              -31.2521586d0,  1.983748d0, 117.1498d0,
     6              -30.8798701d0, 14.023871d0, 320.5095d0,
```

Gw 9/8/05

```
     7              28.4640769d0,  0.560178d0, 262.3602d0,
     8             -27.1960802d0,  1.273434d0, 336.2148d0,
     9              27.0860736d0, 12.021467d0, 233.0046d0,
     0             -26.3437456d0, 62.583231d0, 155.6977d0,
     1              24.7253740d0, 63.593761d0, 184.6277d0,
     2              24.6732126d0, 76.438310d0, 267.2772d0,
     3              24.4272733d0,  4.280910d0,  78.9281d0,
     4              24.0127327d0, 13.218362d0, 123.4722d0,
     5              21.7150294d0, 17.818769d0, 188.7132d0,
     6             -21.5375347d0,  8.359495d0, 180.1364d0,
     7              18.1148363d0, 56.792707d0,  49.1382d0,
     8             -16.9603104d0,  8.448301d0, 152.5268d0,
     9             -16.1765215d0,  1.978796d0,  98.2198d0,
     0              15.5567653d0,  8.863925d0,  97.4808d0,
     1              15.4846529d0,  0.186365d0, 221.5376d0,
     2              15.2150632d0,  8.996212d0, 168.2438d0,
     3              14.5047426d0,  6.771027d0, 161.1199d0,
     4             -14.3873316d0, 45.815258d0,  55.0196d0,
     5              13.1351419d0, 12.002811d0, 262.6495d0,
     6              12.8776311d0, 75.278220d0, 200.3284d0,
     7              11.9867234d0, 65.241008d0, 201.6651d0,
     8              11.9385578d0, 18.870667d0, 294.6547d0,
     9              11.7030822d0, 22.009553d0,  99.8233d0,
     0              11.6018181d0, 64.604291d0, 213.5577d0,
     1             -11.2617293d0, 11.498094d0, 154.1631d0,
     2             -10.4664199d0,  0.578834d0, 232.7153d0,
     3              10.4333970d0,  9.237738d0, 138.3034d0,
     4             -10.2377466d0, 49.747842d0, 204.6609d0,
     5              10.1934446d0,  2.147012d0, 106.5938d0,
     6             -10.1280191d0,  1.196895d0, 250.4676d0,
     7              10.0289441d0,  2.133898d0, 332.3345d0,
     8             -10.0034259d0,  0.173168d0,  27.3039d0/
C****
      YM1950 = YEAR-1950.
C****
C**** Obliquity from Table 1 (2):
C****   OBLIQ# = 23.320556 (degrees)              Equation 5.5 (15)
C****   OBLIQD = OBLIQ# + sum[A cos(ft+delta)]    Equation 1 (5)
C****
      SUMC = 0.
      DO 110 I=1,47
      ARG    = PIz180*(YM1950*TABLE1(2,I)/3600.+TABLE1(3,I))
  110 SUMC   = SUMC + TABLE1(1,I)*COS(ARG)
      OBLIQD = 23.320556d0 + SUMC/3600.
      OBLIQ  = OBLIQD*PIz180
C****
C**** Eccentricity from Table 4 (1):
C****   ECCEN sin(pi) = sum[M sin(gt+beta)]            Equation 4 (1)
C****   ECCEN cos(pi) = sum[M cos(gt+beta)]            Equation 4 (1)
C****   ECCEN = ECCEN sqrt[sin(pi)^2 + cos(pi)^2]
C****
      ESINPI = 0.
      ECOSPI = 0.
      DO 210 I=1,19
      ARG    = PIz180*(YM1950*TABLE4(2,I)/3600.+TABLE4(3,I))
      ESINPI = ESINPI + TABLE4(1,I)*SIN(ARG)
  210 ECOSPI = ECOSPI + TABLE4(1,I)*COS(ARG)
```

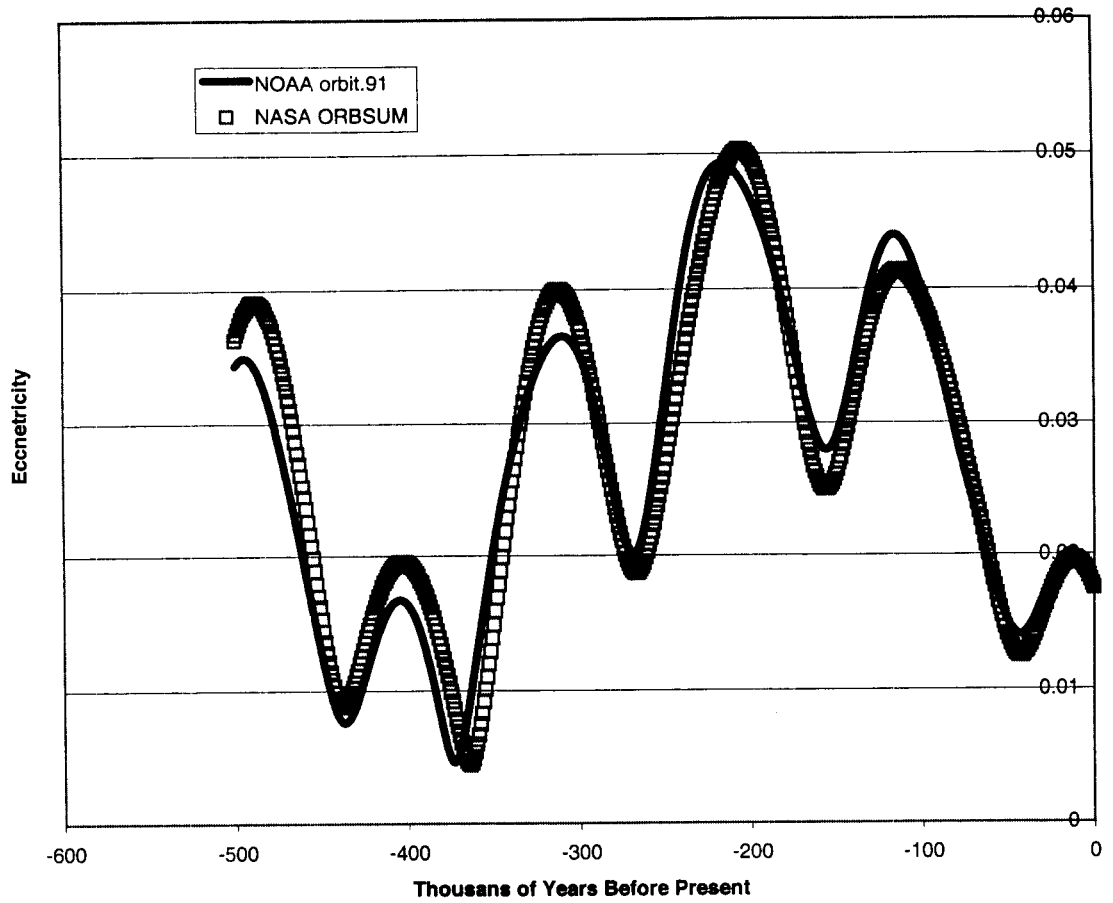
Cw 9/8/05

```
      ECCEN  = SQRT(ESINPI*ESINPI+ECOSPI*ECOSPI)
C****
C**** Perihelion from Equation 4,6,7 (9) and Table 4,5 (1,3):
C****   PSI# = 50.439273 (seconds of degree)          Equation 7.5 (16)
C****   ZETA =  3.392506 (degrees)                    Equation 7.5 (17)
C****   PSI = PSI# t + ZETA + sum[F sin(ft+delta)]    Equation 7 (9)
C****   PIE = atan[ECCEN sin(pi) / ECCEN cos(pi)]
C****   OMEGVP = PIE + PSI + 3.14159                  Equation 6 (4.5)
C****
      PIE    = ATAN2(ESINPI,ECOSPI)
      FSINFD = 0.
      DO 310 I=1,78
      ARG    = PIz180*(YM1950*TABLE5(2,I)/3600.+TABLE5(3,I))
  310 FSINFD = FSINFD + TABLE5(1,I)*SIN(ARG)
      PSI    = PIz180*(3.392506d0+(YM1950*50.439273d0+FSINFD)/3600.)
cgrw      OMEGVP = MODULO (PIE+PSI+.5*TWOPI, TWOPI)
      OMEGVP = MOD(PIE+PSI+.5*TWOPI, TWOPI)
C****
      RETURN
      END
```

The agreement between the computed ~~[illegible]~~ eccentricity and tabulated eccentricity is adequate for the purposes of this study. Although both data are attributed to Berger, the header for SUBPAR indicates the parameters used to compute the orbital parameters have been modified which may explain the lack of exact agreement. See comparison page 22

Cw 9/8/05

Cw ~~9/8/07~~ Cw 9/8/05

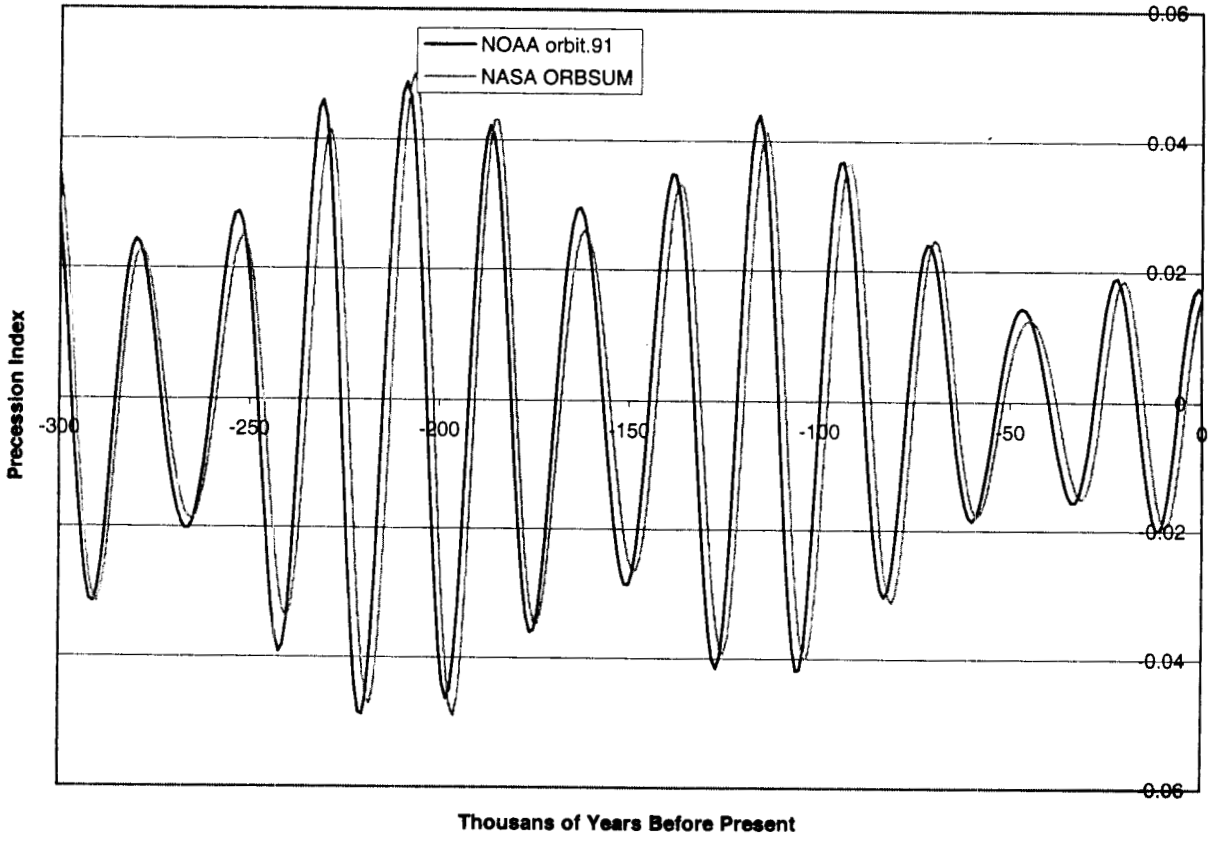


The values of omegavp(ω) produced by ORBPAR appear to be offset by π so that to reproduce the precession index

$$C = e \sin(\omega)$$

with C positive for southern hemisphere maximum insolation, the computed values need to be $C^* = -C$. The resulting relationship between the precession

Lew 9/8/05 ~~5~~ 9/5/05
index computed with 5 ORBPAR and
the tabulated values is shown below.



Because the output from orbital.F
is used primarily ~~fro~~ for graphic purposes,
or 9/8/05

it is considered sufficiently accurate.
The program should be further verified if it
is to be used for more quantitative analyses.

Gary R Walter

9 January 2006 (1/9/06)

The material starting on this page is related to methods for generating sequences of possible future ~~clean~~ climates that can
ar 1/9/06

be used as input to the TPA code to analyze the sensitivity of seepage and ~~doses~~ doce outcomes to uncertainty in
ar 1/9/06

future climate. The goal is to develop a simple mathematical approach for generating a sequence of future climates where the sequence has characteristics, in terms of transitions between interglacial and glacial climates, similar to those observed in the Pleistocene paleoclimate record but contains adjustable parameters that allow multiple realizations of future climates to be generated.

On 1/5/06

Paillard Model

Paillard, D. 1998. The timing of Pleistocene glaciations from a simple multiple-state climate model. Nature. V. 191, 370-381

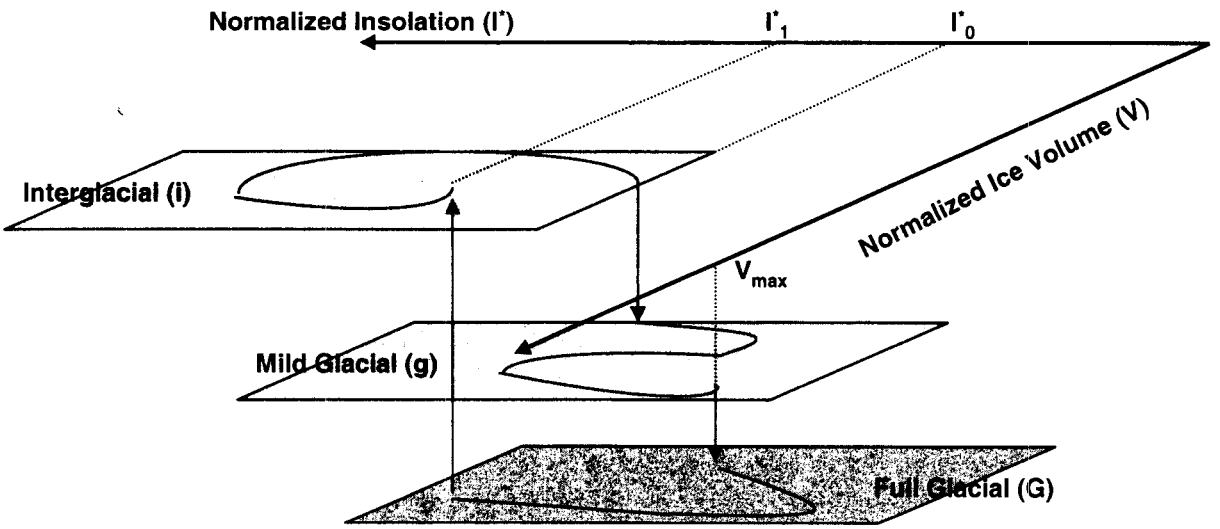
and

Paillard, D. 2001. Glacial Cycles: Toward a New Paradigm. Reviews of Geophysics, V. 39(3), 325-346

Paillard presents a simple model that uses ice volume as an indicate of climate state. His model is driven by variations in insolation due earth orbital mechanics with feedbacks, thresholds, and lags controlling transitions between 3 climate states: i (interglacial), g (mild glacial) and G (full glacial. Paillard's basic concept is illustrated by the figure on p. 26

RL 9/22/09

Gm 11/9/06



Paillard's Model Concept

I^* refers to a normalized value of insolation that will be defined later, as will V which is a normalized global ice volume

Conceptually, the model works as follows. Assuming that the earth starts at some time in the interglacial state, the earth will stay in that state until the insolation decreases to a critical value I_0^* at which time it transitions to the mild glacial state.

Ow 1/9/06

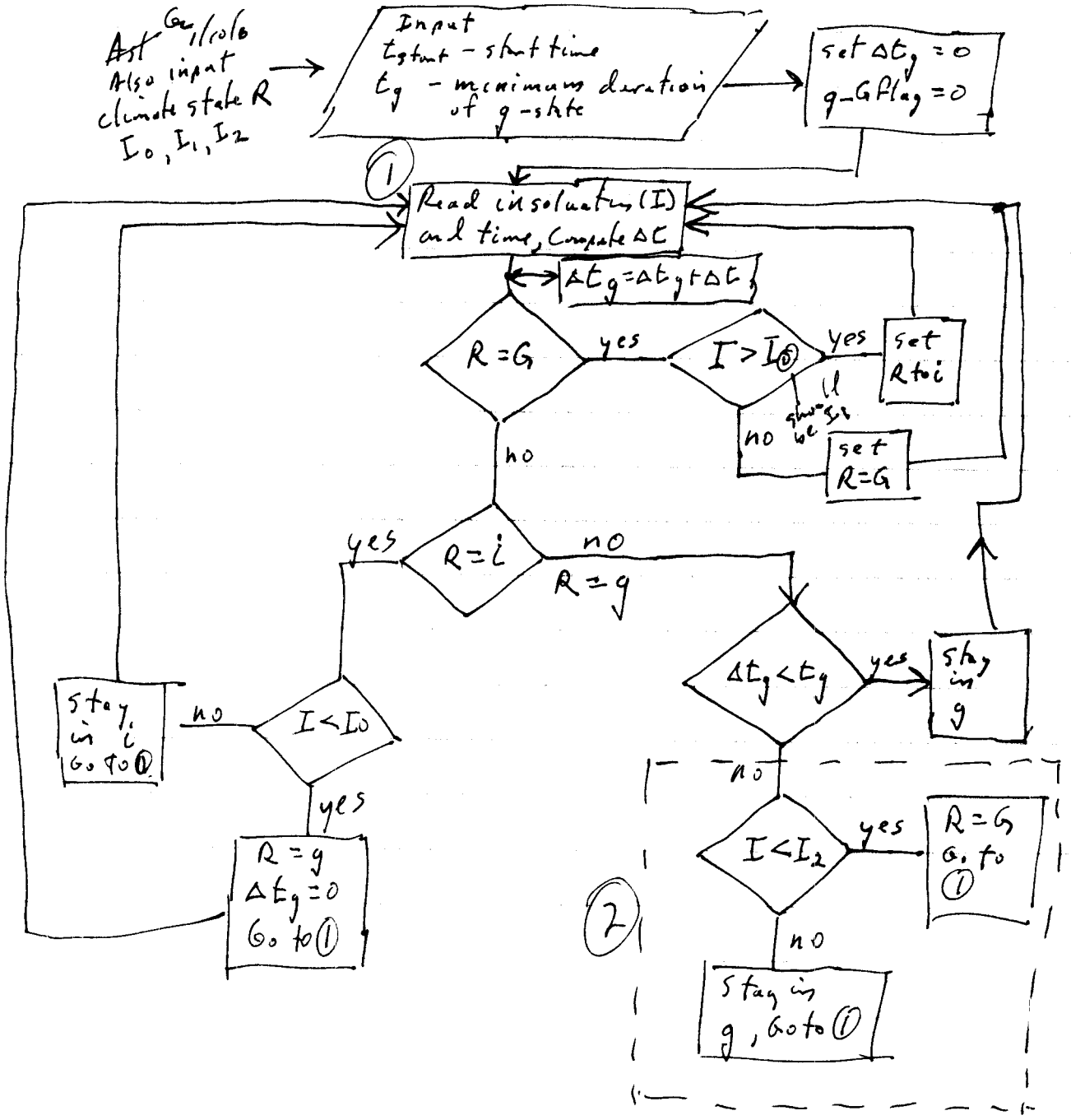
The climate transitions from mild glacial to full glacial when the ice volume increases to V_{max}. The climate transitions from full glacial to interglacial when the insolation increases to I_1^*. The climate transitions are treated as "one-way" and some transitions are forbidden by the rules of the model

The i-G transition is forbidden by defining the G climate state by a minimum ice volume V_{max} as is the G → g transition.

Paillard (1998) describes two implementations of this concept, one leading to a discrete sequence of climates, the other yielding a continuous variation in climate. Both models are deterministic but multiple realizations can be generated by varying parameters such as the insolation triggering levels and time parameters as will be explained later

Gene Lyddatte 1/10/06

Paillard Model 1 (Discrete climate states)
The following flowchart is my interpretation of Paillard's discrete model based on the description in Paillard (1998).



Om 1/10/06

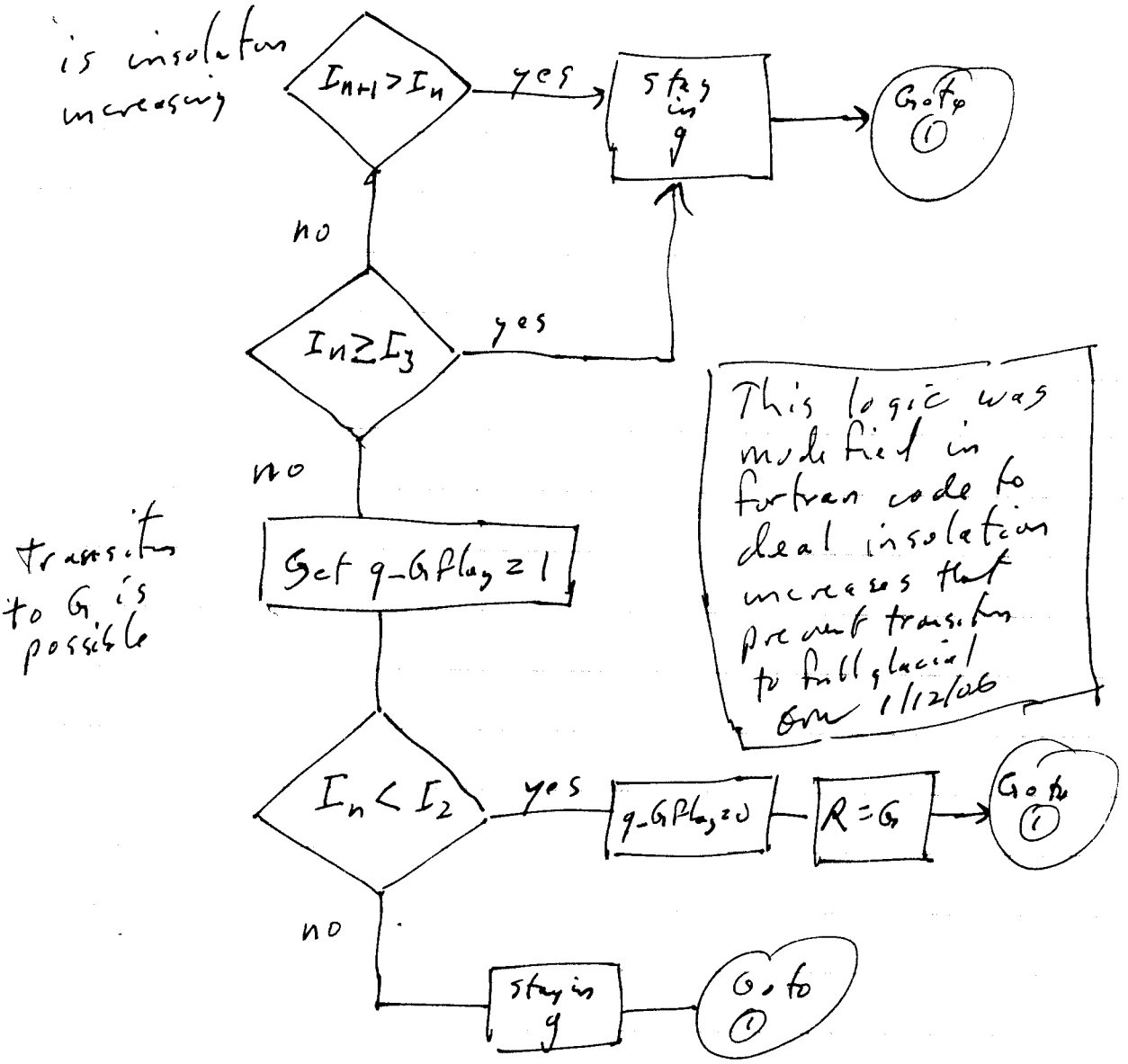
The flow chart on p. 28 does not contain one of the transition rules that Paillard (1998) say is part of his model. This "that the insolation maxima ~~pr~~ Om 1/10/06 preceding the g-G transition must remain below the level i_3. The g-G transition then can occur at the next insolation decrease, when it falls below i_2" (Paillard, 1998) As stated, this rule is unclear. Inspection of Figure 2 in Paillard (1998) indicates that this rule was introduced to prevent early transitions from g to G at multiple times in the paleoclimatic record when insolation was high but isotopic data suggested a mild glacial climate.

Om 1/11/06

The logic for the rules described above is shown in the flow chart on p. 30

1/11/06 OM

Replace logic identified as (2) on page 28 with



1/11/06 CW

Regarding the insolation forcing function in Paillard's model, he states that it is a normalized value for N65° with zero mean and unit variance, but does not ~~definite~~ define it otherwise.
CW 1/11/06

An appropriate formula would be

$$I^* = \frac{I - I_m}{\sigma}$$

where I^* is the normalized insolation
I is the actual insolation
I_m is the mean insolation
σ is the standard deviation of the actual insolation

11/13/06 [illegible]

Paillard's discrete algorithm was implemented in a fortran program called paillard1.exe consisting of the files listed below

```
f90 -c -g -e perm_declare_mod.f90
f90 -c -g -e paillard_1_main.f90
f90 -c -g -e paillard_algorithm1.f90
f90 -c -g -e  paillard_input.f90
```

The code for the algorithm is listed on pages 33 + 34.

The program was tested using normalized insolation for Jul at 65°N (I^*) computed from insolation values obtained from ftp://ftp.ncdc.noaa.gov/pub/data/paleo/insolation/content.91 on 11/13/06 contained in the Excel file noaa_insolation.xls

1/13/06 GW

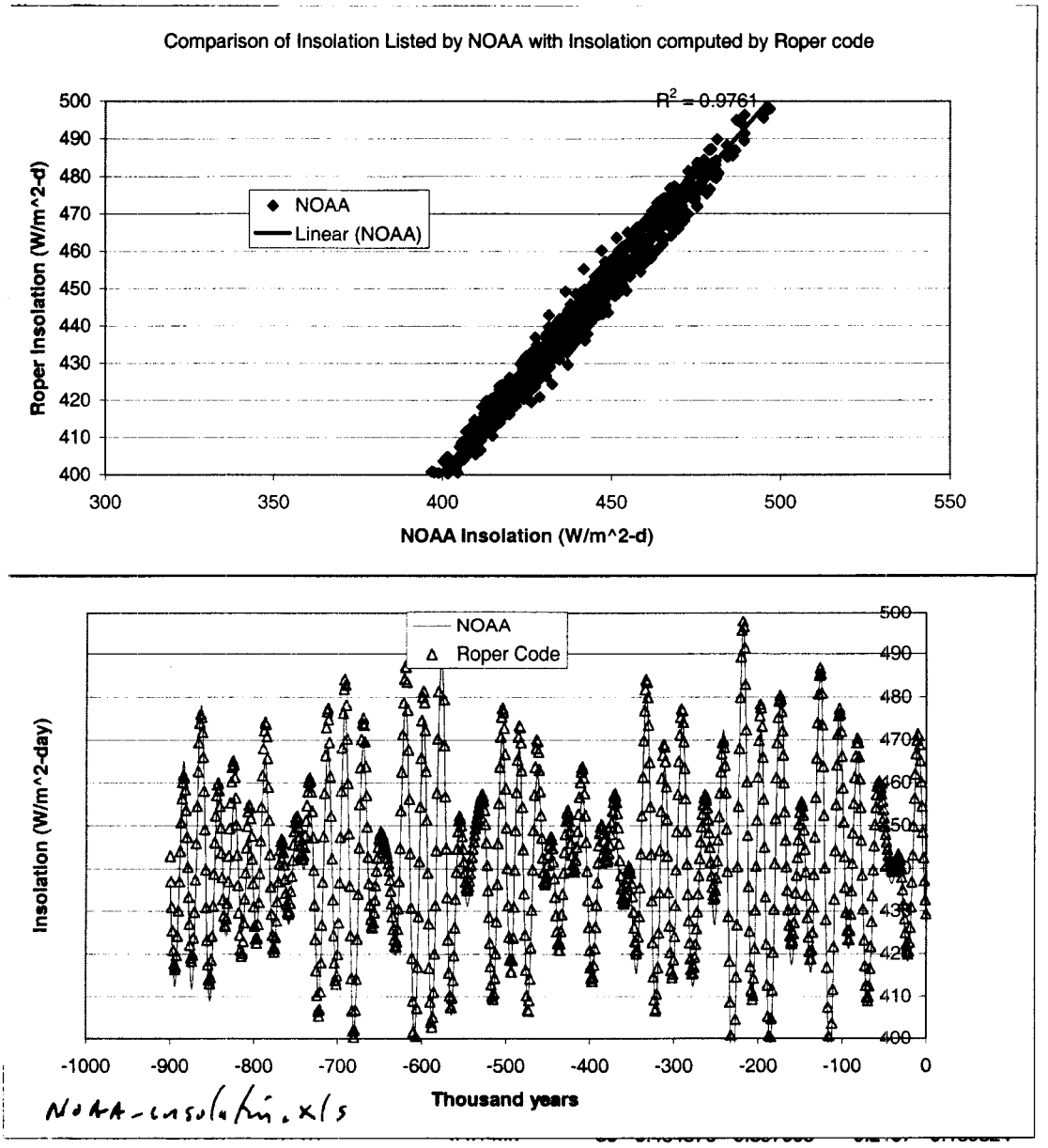
```
subroutine paillard_algorithm(climate_state)
!*********************************************************************
! File Name:        paillard_algorithm.f90
! Pr0ject:            20.06002.01.252
! Purpose:          implements Paillard discrete model
! Language:         fortran90
! Operating System:  Solaris
! Date:             1/11/2006
! Written by:       G. Walter
! History:          original code, 1/11/2006
!*********************************************************************
use sim_controls
implicit none

integer :: climate_state !1 = interglacial, 0 = mild glacial, -1 = full glacial


!insolation_0 - insolation value to triggering interglacial-mild glacial transition
!insolation_1 - insolation value triggering full glacial-interglacial transition
!insolation_2 - insolation value that allows mild glacial-full glacial transition
!insolation_3 - insolation value preventing mild glacial-full glacial transition
!time_g      - minimum duration of mild glacial

if(climate_state .eq. -1) then !if state is full glacial

        if(insolation_array(i_time)%insolation > insolation_1) then
        !switch to interglacial
                climate_state = 1
                return
        else
                return !stay in full glacial
        endif
endif
if(climate_state .eq. 1) then !if state is interglacial

        if(insolation_array(i_time)%insolation < insolation_0) then
        !switch to mild glacial
                climate_state = 0
                delta_tg = 0
                return
        end if
        return
endif
! to get to this point, must have started in mild glacial climate

        delta_tg = delta_tg + delta_t !increment time in mild climate
        !check elapsed time in mild glacial climate
        if(delta_tg < time_g) return

        !it is now possible to transition to full glacial depending of
        !insolation

        !check to see if insolation is increasing
        !if insolation is increasing, need to wait for maximum
        !to determine the next transition
        if(insolation_array(i_time+1)%insolation &
```

1/13/06 Gu

```
> insolation_array(i_time)%insolation) then !insolation is increasing
        insolation_max = -1000

else

!insolation is decreasing
!capture the peak
insolation_max = max(insolation_max,insolation_array(i_time)%insolation)

!if the current value of insolation was > insolation_3,
!stay in mild climate
if(insolation_max >= insolation_3) return
        !the last insolation maximum was less than insolation_3
        g_Gflag =1 !set flag that allows switch to full glacial

        if(insolation_array(i_time)%insolation>=insolation_2) return !stay in mild

        !reset flag
        g_Gflag =0

        !switch to full glacial

        climate_state = -1
endif

return

end subroutine paillard_algorithm
```

For input to the model I used insolation values computed using a program developed by Dr. L. David Roper based on code provided by Berger. Roper's windows executable is Insol MY.exe. A comparison of the insolation values for 65°N July produced by Roper's code to those tabulated by NOAA is shown on p. 35

1/13/06



A comparison of the simulated climate history for the past 800,000 years between that computed using the Roper insolation and the Paillard code developed here and that reported by Paillard (1998) is shown on p 36 along with the input parameters

1/18/06 Jerry McManus

Paillard (1998) also describes a continuous model for ice volume based on the following differential equation

$$\frac{dV}{dt} = (V_R - V)/\tau_R - F/\tau_F$$

where V is the normalized ice volume ~~[illegible]~~ on 1/18/06

t is time

V_R is the reference ice volume for a given climate state (i, g or G)

τ_R is the time constant for the climate state

F is a smoothed, truncated normalized insolation function that will be described later

τ_F is a time constant

The same climate transition rules apply as were used for the discrete model.

1/18/06 On

The forcing term F is not described very well by Paillard. After some numerical experimentation, it appears to be computed as follows

Starting with a "raw" insolation record, compute the mean, I_m, and standard deviation, σ.

Compute normalized insolation, I^*, using

$$I^* = \frac{I - I_m}{\sigma}$$

Filter the normalized insolation using the following function

$$I_T^* = \frac{1}{2}\left(I^* + \sqrt{4a^2 + I^{*2}}\right)$$

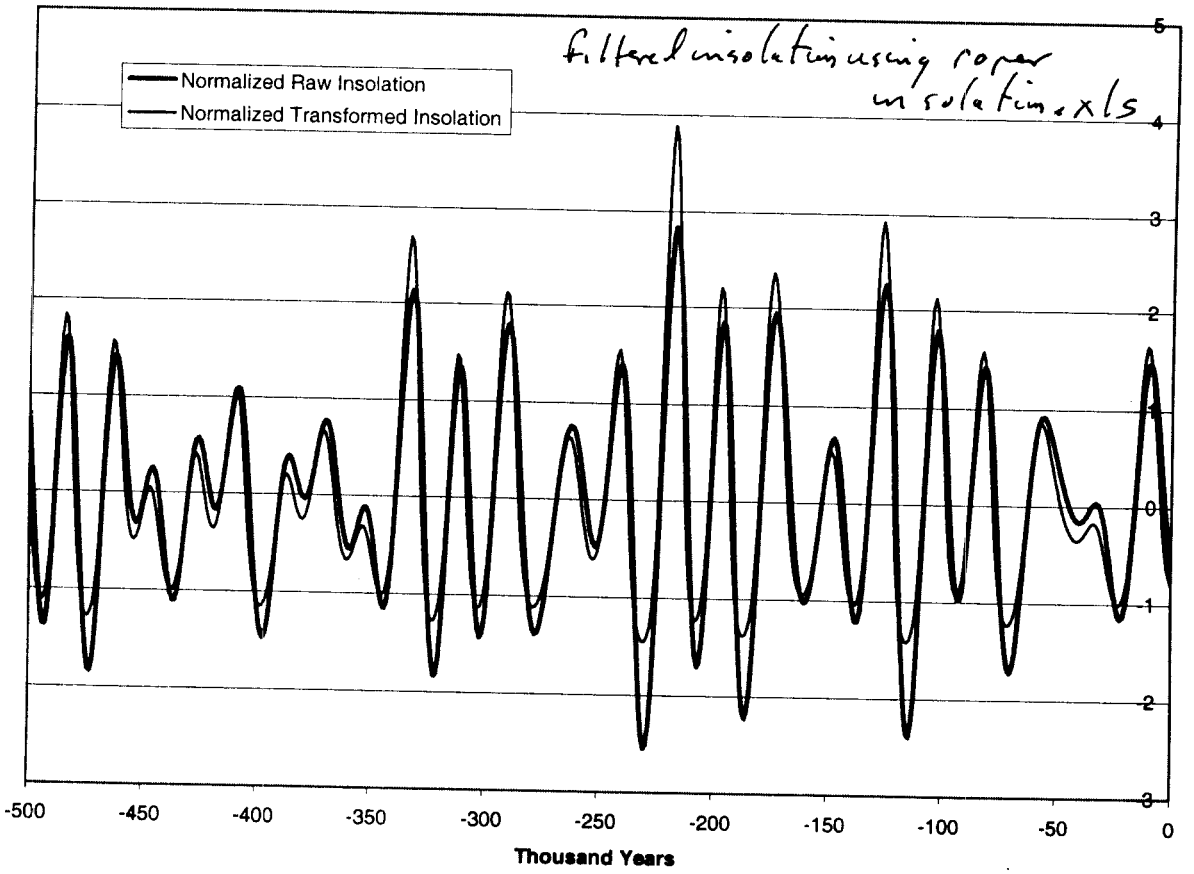
where a can vary from 0 to ∞

Compute the mean, I_m^*, and standard deviation, σ^* of the transformed values the compute F as

$$F = \frac{I_T^* - I_m^*}{\sigma^*}$$

1/10/06 Q

The effect of this filtering algorithm is to reduce negative extremes in the record as illustrated below for a = 1



Roy Walters 2/7/06

I would now like to consider a zero-~~order~~ dimension climate model
Gr 2/7/06

that is more "physics based" than that of Paillard, the model presented by Ghil, M. 1994. Cryothermodynamics: the chaotic dynamics of paleoclimate Physica, V. 77, pp 130-159

Ghil's model consists of 3 coupled ordinary differential equations (ODEs) forced ~~orb~~ orbital changes in
Gr 2/7/06

insolation. The 3 ODEs represent

1. Earth radiation balance with ice-albedo ~~feedbac~~ Gr 2/7/06
2. with ice albedo feedback

2. ice-mass balance with precipitation-temperature feedback
3. isostatic rebound with ice mass feedback

Guy Walters 2/9/06

More complete descriptions of Ghil's modeling approach are contained in Ghil, M. and H. LeTreut. 1981.
A Climate Model with Cryodynamics and Geodynamics. J. Geophysical Research 86 (C6) 5262-5270
and LeTreut, H. and M. Ghil. 1983
Orbital Forcing, Climatic Interactions and Glaciation Cycles.
J. Geophysical Research 88 (C9) 5167-5199

The following descriptions of the models will be based ~~primarily~~ primarily
Gw 2/9/06

on LeTreut + Ghil (1983)

The zonally averaged radiation balance is written in terms of a globally average temperature as

$$c_T \frac{dT}{dt} = Q(t)\{1 - [\gamma(\alpha_0 + \alpha_1 L^* l) + (1-\gamma)\alpha_{oc}(T)\} - K(T - T_0) \qquad (1)$$

Gw 2/9/06

where T is globally averaged temperature of the atmosphere-cryosphere system $[T]$

t is time $[t]$

$Q(t)$ is solar insolation at the top of the atmosphere which may be a function of time

r is the ratio of the surface area of land mass to the total area of the earth

$\alpha_0 + \alpha_1 L^* l$ is the albedo of the land mass adjusted for the albedo of ice cover

$\alpha_{oc}(T)$ is the albedo of the ocean as influence by sea ice

$K(T - T_{K_0})$ is outgoing radiation

Gw 2/9/06

~~where T_K is a reference~~ Gw 2/9/06

T_0 is a reference temperature

2/10/06 [illegible]

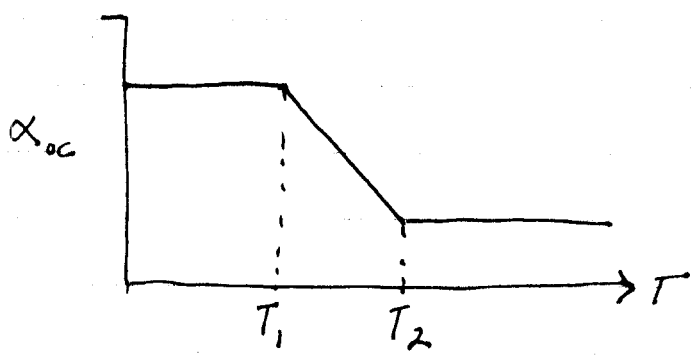
l is the dimensionless extent of the ice sheet defined as L/L^*

L is the latitudinal half-width of the ice sheet (to be explained later)

L^* is a scaling factor

The definition of L^* in LeTreut + Ghil (1983) does not seem to consistent with its use in Ghil + LeTreut (1981)

The oceanic albedo, α_{oc}, is a function temperature as illustrated below



which will be determined by the following algorithm

if $T \leq T_1$, $\alpha_{oc} = \alpha_{max}$

if $T \geq T_2$, $\alpha_{oc} = \alpha_{min}$

else

$$\alpha_{oc} = \alpha_{max} - \left[\frac{\alpha_{max} - \alpha_{min}}{T_2 - T_1}\right][T - T_1]$$

Gary Mullen 2/14/06

To understand the ice sheet dimensions in eq'n (1), need to refer to Källen, E., ~~Crawford~~ C. Crafoord et al
GM 2/14/06

M. Ghil. 1980. Free oscillations in a Climate Model with Ice-Sheet Dynamics. J. Atmospheric Sciences V. 36. pp 2292-2303

GM 2/15/06
After further the review of the model the scaling factor L^* in eq'n (1) does not seem necess and eq'n (1) can be written in dimensional form as

$$c_T \frac{dT}{dt} = Q(t)\left\{1 - [r(\alpha_0 + \alpha_1 L) + (1-r)\alpha_{oc}(T)]\right\} - K(T - T_0) \quad (1B)$$

where c_T is heat capacity of the land-ocean system

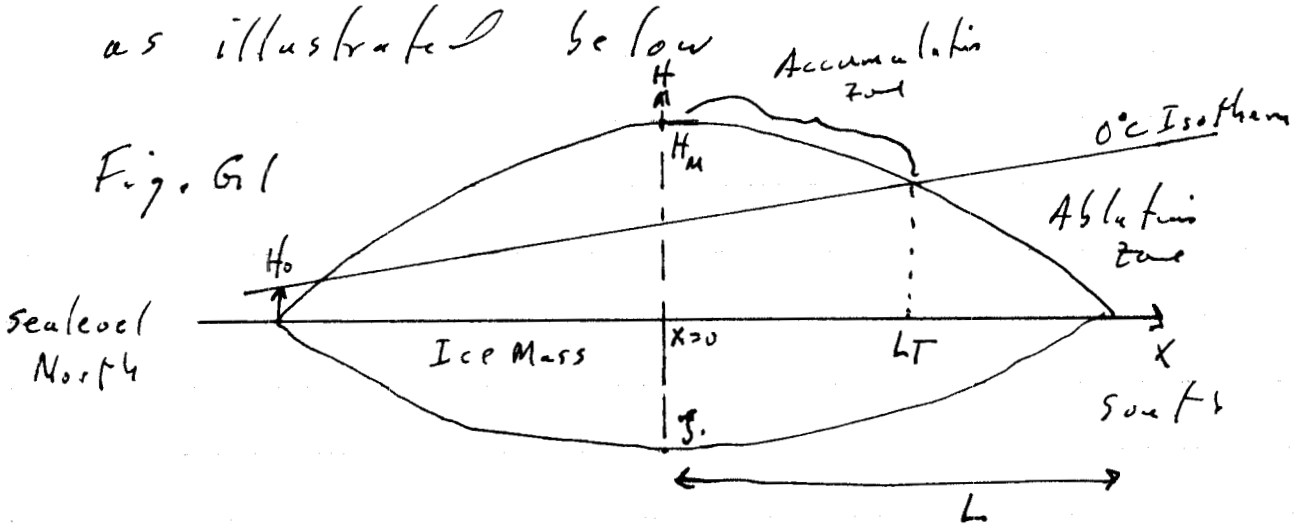
RL 9/22/09

Roy Mellor 2/16/06

Now I'm going to revisit the ice sheet model and, while following the approach of Hollen et al and Ghil et al, start from the basic principles.

First, the ice mass is postulated to be double parabolic in shape based on physical arguments presented in Hollen et al (1979) and Ghil and LeTreut (1981) as illustrated below

Fig. G1



H_M is the maximum height above sealevel
ξ is the maximum depth below sealevel

The ice sheet assumed to have uniform width perpendicular to the cross-section illustrated above so that its volume can be taken as proportional to the area under (and above) the two parabolic curves

Gr 2/16/06

Thus $$V = \frac{4}{3} H_M L + \frac{4}{3} \xi L \qquad (2)$$

where the first term on the RHS of (2) is the volume above sealevel and the second term is the volume below sealevel due to isostatic depression of the continent. V is volume per unit width

The maximum height, H_M, is given by

$$H_M = \lambda^{1/2} L^{1/2}$$

where $\lambda = \tau / \rho g$

with τ being the yield stress of ice (See Kallen et al 1979)
ρ the density of ice
g gravitational acceleration

Gr 2/16/06

The change in ice volume is governed by the mass balance between accumulation of frozen precipitation and ablation south of L_T in Figure G1.

Ow 2/16/06

The mass balance equation is

$$\frac{dV}{dt} = a L_T - a'(L - L_T) \qquad (3)$$

where a is the ~~accumulat~~ accumulation
Ow 2/16/06

rate per unit area $[L/t]$
a' is the ablation rate per unit area $[L/t]$

Substituting (2) into the LHS of (3)

$$\frac{d}{dt}\left[\frac{4}{3} H_M L + \frac{4}{3}\xi L\right] = a L_T - a'(L - L_T)$$

or
Ow 2/16/06

$$\cancel{(a + a')L_T - a' L = \frac{d}{}\left[\frac{4}{3} H_M\right.}$$

$$(a + a')L_T - a' L = \frac{d}{dt}\left[\frac{4}{3}\lambda^{1/2} L^{3/2} + \frac{4}{3}\xi L\right] \quad (4)$$

where H_M was replaced with $\lambda^{1/2} L^{1/2}$
Differentiating the RHS of (4) gives

$$(a + a')L_T - a' L = \frac{4}{3}\lambda^{1/2}\frac{3}{2} L^{1/2}\frac{dL}{dt} + \frac{4}{3}\xi\frac{dL}{dt} + 4/3\, L\frac{d\xi}{dt}$$

2/16/06 Gwr

Rearranging and solving for $\frac{dL}{dt}$ gives

$$-\left[2\lambda^{1/2}L^{1/2} + \frac{4}{3}\xi\right]\frac{dL}{dt} = -(a+a')L_T + a'L + \frac{4}{3}L\frac{d\xi}{dt} \qquad (5)$$

The term L_T can be expressed in terms of L by solving for the intersection of the upper parabolic ice surface with the 0°C isotherm shown in Fig G1

The upper ice surface is given by

$$H(x) = \lambda^{1/2}(L-x)^{1/2} \qquad (6)$$

and the 0°C isotherm by

$$H(x) = H_0 + S(L_T + L) \qquad (7)$$

where H_0 is the height at the northern edge of the ice sheet (see Figure G1)
S is the slope of the isotherm

2/16/06 Gw

Equating (6) and (7) and solving for L_T gives

$$\lambda^{1/2}(L-\underset{\uparrow L_T}{X})^{1/2} = H_0 + S(L_T+L)$$

$$\lambda L - \lambda L_T = H_0^2 + 2H_0 S(L_T+L) + S^2(L_T+L)^2$$

$$\lambda L - \lambda L_T = H_0^2 + 2H_0 S L_T + 2H_0 S L + S^2 L_T^2 + 2S^2 L_T L + S^2 L^2$$

$\boxed{\text{note } \lambda \text{ has units of } L}$

$$0 = S^2 L_T^2 + (2H_0 S + 2S^2 L + \lambda) L_T + (H_0^2 + 2H_0 S L - \lambda L + S^2 L^2) \quad (8)$$

Gw 3/21/06

Eq'n (8) is a quadratic equation which can be solved for L_T using the quadratic formula letting

$$A = S^2; \quad B = (2H_0 S + 2S^2 L + \lambda)$$
$$C = (H_0^2 + 2H_0 S L - \lambda L + S^2 L^2)$$

Gw 3/21/06

$$L_T = (2A)^{-1}\left[-B \pm (B^2 - 4AC)^{1/2}\right] \quad (9)$$

and we want only positive values of L_T

Note: Kallen et al provide an expanded version of (9), but I see no need to do the algebraic manipulation to derive it

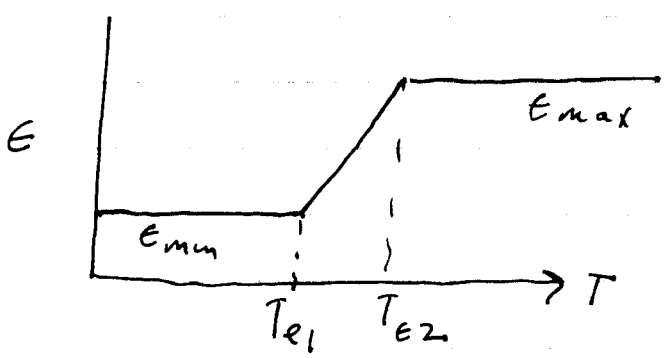
On 2/16/06

Now rearranging eq'n (5)

$$\frac{dL}{dt} = +\left[2\lambda^{1/2}L^{1/2} + \frac{4}{3}\xi\right]^{-1} \cdot \left[a'(\epsilon+1)L_T - a'L - \frac{4}{3}L\frac{d\xi}{dt}\right] \qquad (10)$$

where $\epsilon = a/a'$

a' is assumed to be constant and ϵ is described by a ramp function based on temperature



if $(T < T_{\epsilon 1})$, $\epsilon = \epsilon_{min}$

if $(T > T_{\epsilon 2})$, $\epsilon = \epsilon_{max}$

else

$$\epsilon = \frac{(\epsilon_{max} - \epsilon_{min})}{(T_{\epsilon 2} - T_{\epsilon 1})}(T - T_{\epsilon 1}) + \epsilon_{min}$$

Guy Walters 3/2/06

Now consider the isostatic depression of the lithosphere, ξ, in eq'n (10)

Following Ghil and Le Treut (1981) the lithosphere deflection is given by the following ODE which assumes a doubling parabolic shape for the ice sheet surface and base (Their eq'n (10)

$$\frac{d\xi}{dt} = -D(1-q)\frac{2\xi}{L^2} + Dq^2$$

where $D = \dfrac{\rho_a g H^3}{2\eta}$; $q = \dfrac{\rho_g}{\rho_a}$

ρ_a is density of the asthenosphere
ρ_g is density of ice
η is viscosity (not clearly defined by Ghil and LeTreut but is the viscosity of the aesthenosphere)
H is the undisturbed thickness of the aesthenosphere

3/19/06 [illegible]

A model parameter that has not yet been fully described is H_0, the height of the zero isotherm. Kallen et al represents this value as a function of temperature by (their eq'n 8)

$$h_0 = \beta (T - T_{00})$$

where h_0 is $H_0 / [4/3 \lambda]^{1/2}$
(note that Kallen's λ is $4/3 \lambda$ as defined here)

and β is given by the following function (Kallen eqn 9b)

~~$\beta = 2 s L_{max}$~~ [illegible] 3/19/06

$$\beta = \frac{2s(\alpha_{max} - \alpha_0)}{(T_{00} - T_1)\alpha_1} \qquad [A]$$

where $s = S / [4/3 \lambda]^{1/2}$

T_{00} is the global temperature at which the isotherm would intersect the arctic coastline

3/19/06 GW

Making the appropriate substitutions in [A] simply gives

$$H_0 = 2S \cdot \left[\frac{(\alpha_{max} - \alpha_0)}{(T_{00} - T_1)\alpha_1} \right]$$

3/24/06 Guy Callendar

I developed a simple explicit method for solving the equations of Ghil's model as the Fortran program "explicit_solver.f90". Initial experimentation with the model indicated that it is very sensitive to the choice of parameters and, as noted in the various articles on the modeling approach, has unstable states.
I am going to put this approach aside for a while and focus on the Pailard model as a method for generating possible future climates

3/30/06 Gary Clarke

I am returning now to the Paillard model 2, the continuous model discussed previously on pages 37-39. (changing pens)

The main program and subroutine implementing the Paillard continuous model are listed on pages 55 thru 59

This code implements Paillard's algorithm as described in Paillard (1998) with the exception that the ice volume is constrained to be between 0 and 1. Paillards original algorithm allows it to stray outside these limits which doesn't make physical sense, particularly negative values.

The primary difference between the continuous Paillard model and his discrete model is in the interpretation of the time constants. The discrete model uses only 1 time constant, τ_g, which is the minimum duration of the mild glacial. (continue on p. 59)

3/30/06 GW

paillard_2_main.f90

```
program paillard_2
!This program simulates continuous climate states based on an
!algorithm presented in Paillard, D. 1998. The timing of Pleistocene
!glaciations from a simple multiple-state climate model. Nature 391, pp 378-381
!*********************************************************************
!  File Name:          paillard_model2.f90
!  Project:           20.06002.01.252
!  Purpose:            main input file
!  Language:           fortran90
!  Operating System:   Solaris
!  Date:               1/24/2006
!  Written by:         G. Walter
!  History:            original code, 1/24/2006
! Modified:            3/30/2006 to limit ice volume to 0 to 1
!*********************************************************************
use sim_controls !(perm_declare_mod.f90)
use file_names! (perm_declare_mod.f90)
use io_units ! (perm_declare_mod.f90)
use input_functions !(pailliard_input.f90)
use algorithms
integer :: climate
real :: delta_V !change in ice volume

!read input parameters controlling climate thresholds
!read time period of simulation
!read insolation data file
        call input()

!run the model
        g_Gflag = 0
        delta_tg = 0.
!initialize climate to Full Glacial
        climate = -1
        allocate(climate_array(record_counter))
        climate_array%ice_volume = 1.

!add time stepper
        do i_time = 1,record_counter
        if(insolation_array(i_time)%time >= start_time)then
!       climate_array(i_time)%ice_volume = V_G
        if(insolation_array(i_time)%time > end_time) go to 100
        if(i_time > 1)then
        delta_t = insolation_array(i_time)%time - insolation_array(i_time-1)%time
        else
        delta_t = insolation_array(i_time+1)%time - insolation_array(i_time)%time
        endif
        climate_array(i_time)%time = insolation_array(i_time)%time
        call paillard_algorithm(climate,delta_V) !paillard_algorithm.f90
        !update ice volume
        climate_array(i_time+1)%ice_volume = climate_array(i_time)%ice_volume &
                + delta_V
!the following constraint to keep the ice volume between zero and 1 is not
!part of the standard Paillard model
        climate_array(i_time+1)%ice_volume = max(climate_array(i_time+1)%ice_volume,0.)
```

3/30/06

Page 2 paillard_2_main.f90

```
        climate_array(i_time+1)%ice_volume = min(climate_array(i_time+1)%ice_volume,1.)
        if(climate < 1) then
        !if ice volume > glacial reference volume and not in interglacial state
        ! switch to full glacial climate
                if(climate_array(i_time)%ice_volume > V_G) climate = -1
        endif
        climate_array(i_time)%climate = climate

        write(*,*)climate_array(i_time)%time, &
                insolation_array(i_time)%insolation,climate_array(i_time)%climate, &
                climate_array(i_time)%ice_volume
        write(io_insol_record_out,'(f8.0,1x,f8.4,1x,i3,1x,f8.4)')climate_array(i_time)%time, &
                insolation_array(i_time)%insolation,climate_array(i_time)%climate, &
                climate_array(i_time)%ice_volume
        end if
        end do
100     write(*,*)'END OF SIMULATION'

        end program paillard_2
```

3/30/06 G

paillard-algorithm2.f90

```
module algorithms
contains
subroutine paillard_algorithm(climate_state,delta_V)
!*********************************************************************
!  File Name:          paillard_algorithm.f90
!  Project:           20.06002.01.252
!  Purpose:            implements Paillard continuous model
!  Language:           fortran90
!  Operating System:   Solaris
!  Date:               1/11/2006
!  Written by:         G. Walter
!  History:            original code, 1/11/2006
!*********************************************************************
use sim_controls

implicit none

integer :: climate_state !1 = interglacial, 0 = mild glacial, -1 = full glacial
integer :: c_index
real :: delta_V, ice_func


!insolation_0 - insolation value to triggering interglacial-mild glacial transition
!insolation_1 - insolation value triggering full glacial-interglacial transition
!insolation_2 - insolation value that allows mild glacial-full glacial transition
!insolation_3 - insolation value preventing mild glacial-full glacial transition
!time_g       - minimum duration of mild glacial
!ice volume parameters
!ice volume parameters
!V_i interglacial reference ice volume
!V_mg mild glacial reference ice volum
!V_G full glacial reference ice volume
real, dimension(3) :: V_ref
real :: F !local variable to hold insolation value

!tau(3) interglacial time constant
!tau(2) mild glacial time constant
!tau(1) full glacial time constant
!       real :: tau_F !forcing time constant

V_ref(1) = V_G ; V_ref(2) = V_mg ; V_ref(3) = V_i
       F = insolation_array(i_time)%insolation
if(climate_state .eq. -1) then !if state is full glacial

        if(insolation_array(i_time)%insolation > insolation_1) then
        !switch to interglacial
                climate_state = 1
                c_index = climate_state + 2
                delta_V = ice_func(delta_t,tau(c_index),V_ref(c_index),F,tau_F, &
                        climate_array(i_time)%ice_volume)
```

3/30/06 am

```
                return
        else
                c_index = climate_state + 2
                delta_V = ice_func(delta_t,tau(c_index),V_ref(c_index),F,tau_F, &
                        climate_array(i_time)%ice_volume)
                return !stay in full glacial
        endif
endif
if(climate_state .eq. 1) then !if state is interglacial

        if(insolation_array(i_time)%insolation < insolation_0) then
        !switch to mild glacial
                climate_state = 0
                delta_tg = 0
                c_index = climate_state + 2
                delta_V = ice_func(delta_t,tau(c_index),V_ref(c_index),F,tau_F, &
                        climate_array(i_time)%ice_volume)
                return
        end if
        !stay in interglacial
        c_index = climate_state + 2
        delta_V = ice_func(delta_t,tau(c_index),V_ref(c_index),F,tau_F, &
                        climate_array(i_time)%ice_volume)
        return
endif
! to get to this point, must have started in mild glacial climate

        delta_tg = delta_tg + delta_t !increment time in mild climate
        !check elapased time in mild glacial climate
        if(delta_tg < time_g) then
        !stay in mild glacial
        c_index = climate_state + 2
        delta_V = ice_func(delta_t,tau(c_index),V_ref(c_index),F,tau_F, &
                        climate_array(i_time)%ice_volume)
        return
        endif
        !it is now possible to transition to full glacial depending of
        !insolation

        !check to see if insolation is increasing
        !if insolation is increasing, need to wait for maximum
        !to determine the next transition
        if(insolation_array(i_time+1)%insolation &
                > insolation_array(i_time)%insolation) then !insolation is increasing
                        insolation_max = -1000

                else

                !insolation is decreasing
                !capture the peak
```

3/30/06 Ch

```
            insolation_max = max(insolation_max,insolation_array(i_time)%insolation)

            !if the current value of insolation was > insolation_3,
            !stay in mild climate
            if(insolation_max >= insolation_3) return
                    !the last insolation maximum was less than insolation_3
                    g_Gflag =1 !set flag that allows switch to full glacial

                    if(insolation_array(i_time)%insolation>=insolation_2) return !stay in mild

                    !reset flag
                    g_Gflag =0

                    !switch to full glacial

                    climate_state = -1

            endif
                    c_index = climate_state + 2
                    delta_V = ice_func(delta_t,tau(c_index),V_ref(c_index),F,tau_F, &
                    climate_array(i_time)%ice_volume)
            return
end subroutine paillard_algorithm

end module algorithms
```

The continuous model uses four time constants (see equation page 37)

τ_i is the interglacial time constant that controls ice sheet growth during the interglacial

τ_g is the mild glacial time constant with similar effect

τ_G is the glacial time constant

τ_F modulates the insolation forcing term

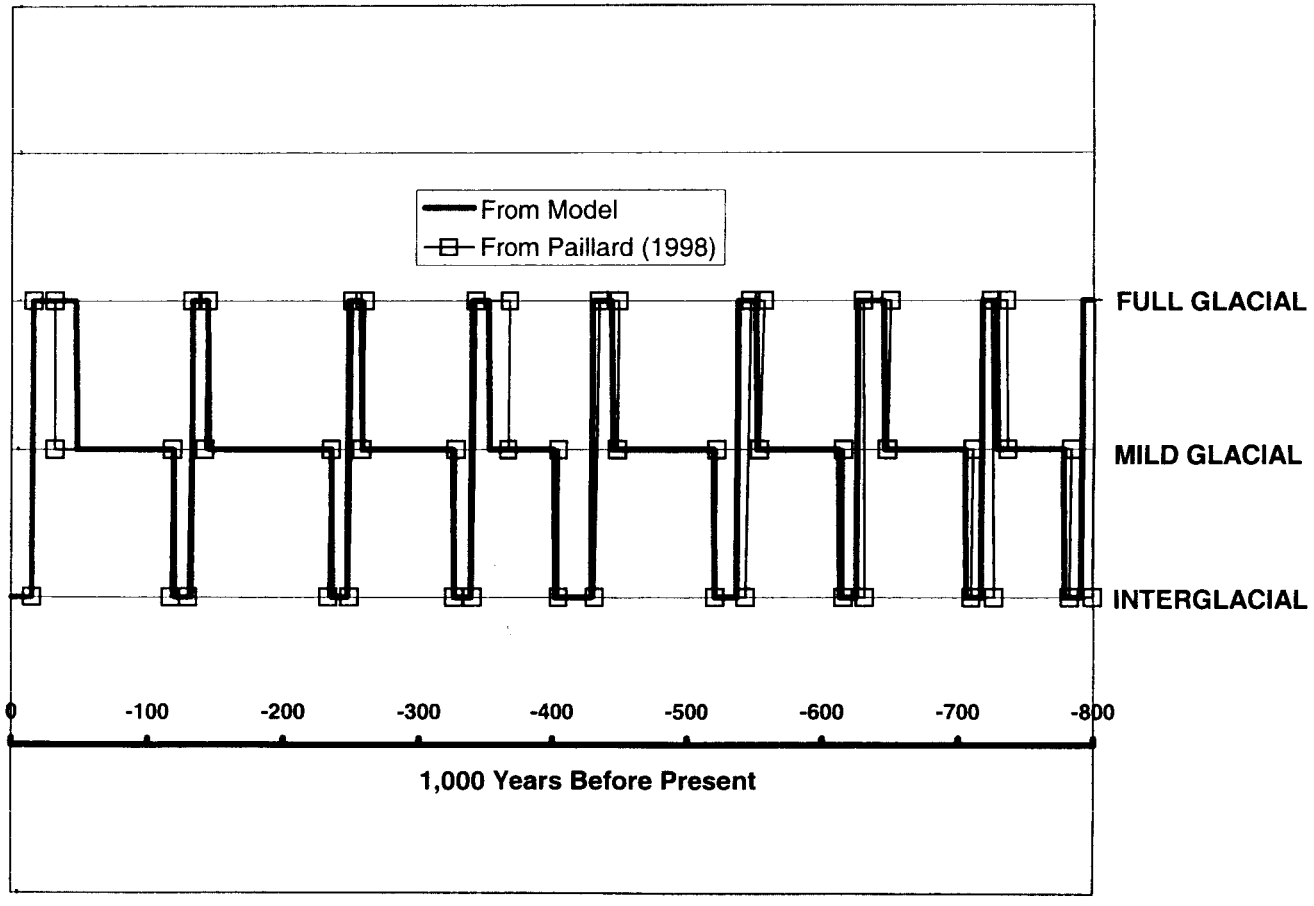
3/30/06 Gr

The fortran model was run using Paillard's nominal values listed below

```
STANDARD PAILLARD PARAMETERS                    input-nominal
!line 1: start time, end time values in insolation record
-800 1000
!line 2: insolation value to triggering interglacial-mild glacial transition
-0.75
!line 3: insolation value triggering full glacial-interglacial transition
0
!line 4: insolation value that allows mild glacial-full glacial transition
0
!line 5: insolation value preventing mild glacial-full glacial transition
1
!line 6: minimum duration of mild glacial
50
!line 7: time constant for interglacial tau(1)
10.
!line 8: time constant for mild glacial tau(2)
50.
!line 9: time constant for full glacial tau(3)
50.
!line 10: time constant for insolation forcing tau_F(4)
25.
```

The simulated climate sequence is compared to that reported by Paillard (1998) from his discrete model on pt 3/30/06 page 61

With a few exceptions, the climate sequences agree. The differences may be due to differences in the insolation records used or to the forcing of the ice volume to be between 0 and 1 in this study



D:\Climate_Infil_ISI\Future Climate\stochastic climate\Report\comparison of paillard model2 and SPECMAP.xls

figure3

3/30/06

3/30/06
~~63~~ ow

The model output for the nominal case is shown in comparison to the SPECMAP O-18 record on page 63. The SPECMAP record was obtained from

SPECMAP Archive # 1: README file

NGDC Data Set # 0997

obtained from:

U.S. Department of Commerce
National Environmental Satellite, Data, and Information Service
National Oceanic and Atmospheric Administration
U.S. National Geophysical Data Center (NGDC)
(http://www.ngdc.noaa.gov/mgg/mggd.html)
& collocated

World Data Center for Marine Geology & Geophysics

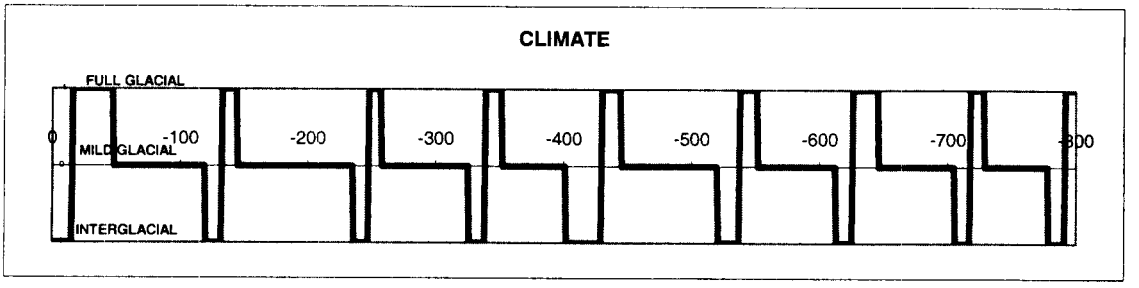
Data also available from WDC Paleoclimatology

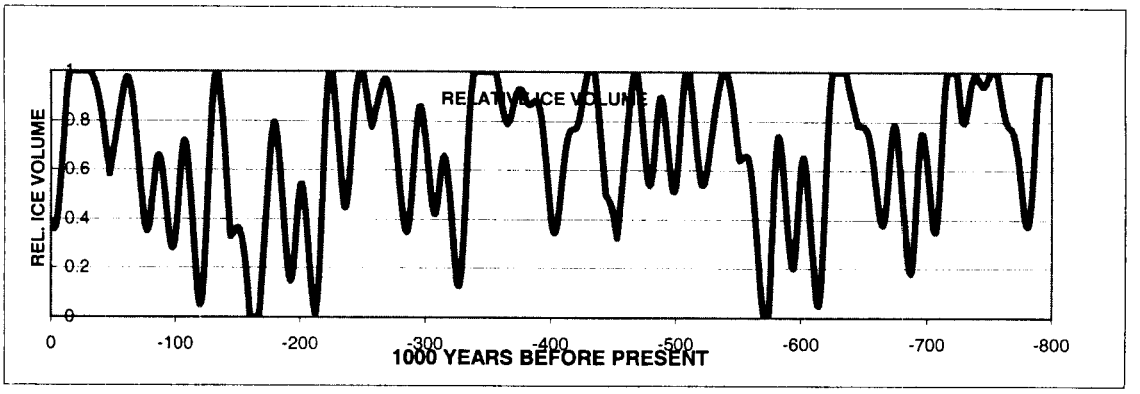
NOTE: PLEASE CITE ORIGINAL REFERENCE WHEN USING THESE DATA

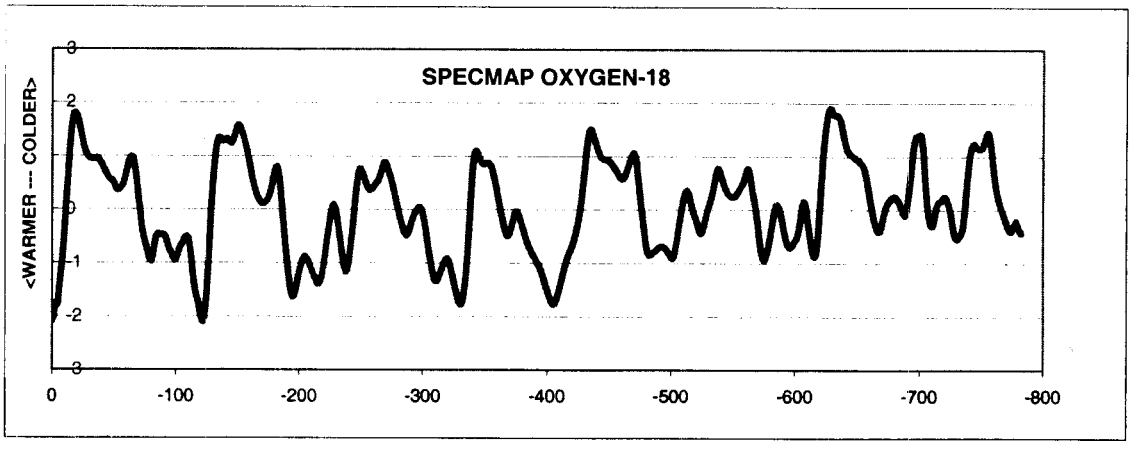
CONTRIBUTORS:	J. Imbrie, A. Duffy, et al , Brown University
NAME OF DATA SET:	SPECMAP Archive #1
LAST UPDATE:	2/90 (Original receipt date by WDC-A MGG)
GEOGRAPHIC REGION:	Global
PERIOD OF RECORD:	0-400,000 YBP
DATA VOLUME:	approximately 1.45 mbytes
MGG IDENTIFIER :	MGG44995001

3/30/06 Gw

D:\Climate_Infil_ISI\Future Climate\stochastic climate\Report\comparison of paillard model2 and SPECMAP.xls







3/31/06 Guy Allen

Review of input/output files for Paillard model

Insolation (raw) generated using insolMY.exe from Roper

Transformed insolation for Paillard model generated from raw insolation in Excel file
"filtered insolation using roper insolation.xls"
Insolation input file for Paillard model is "transformed_insol.txt"
Climates generated using paillard_2.exe

The following simulations were run

Scenario	Input	Output
Paillard Nominal (see p. 60)	input_nominal	climate_nominal.txt
$I_0 = -0.70$, all other nominal, see page 60., line 2	input_point7	climate_point7.txt
$I_0 = -0.80$, all other nominal	input_point8	climate_point8.txt

3/31/06 GR

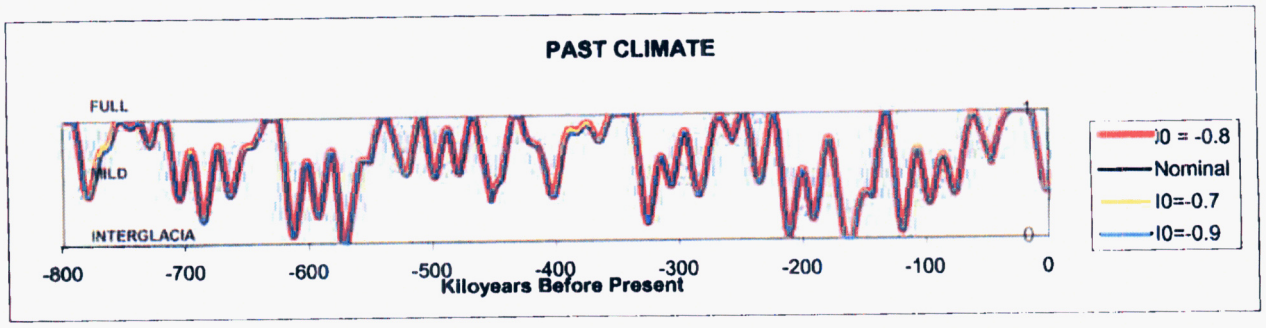
I_0 = 0.90, all other normal input_point9 climate_point9.txt

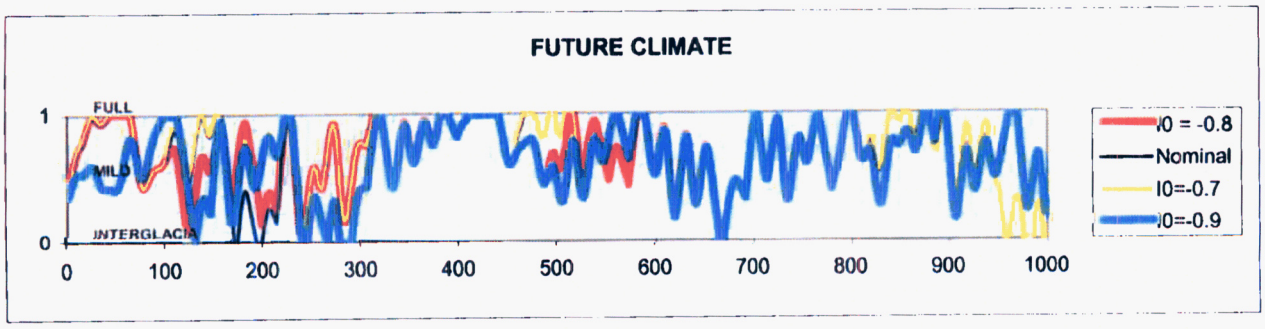
All output was subsequently copied to spreadsheet "comparison of paillard model2 and SPECMAP.xls"

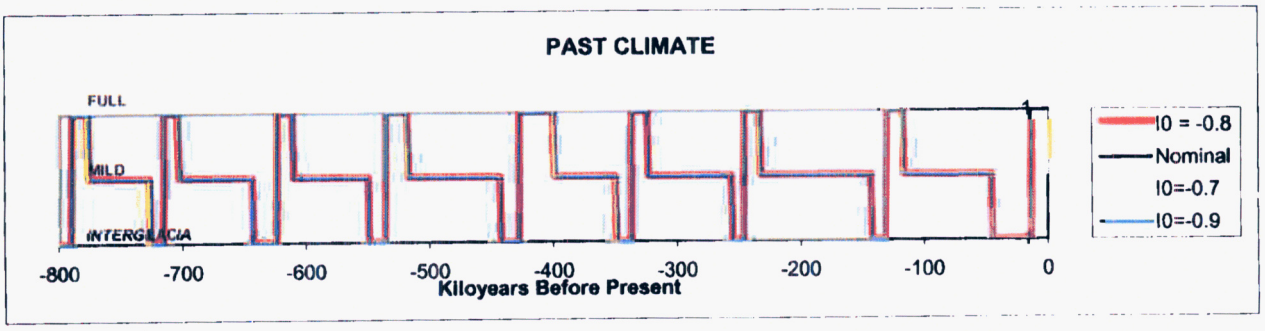
4/3/06 Guy Walters

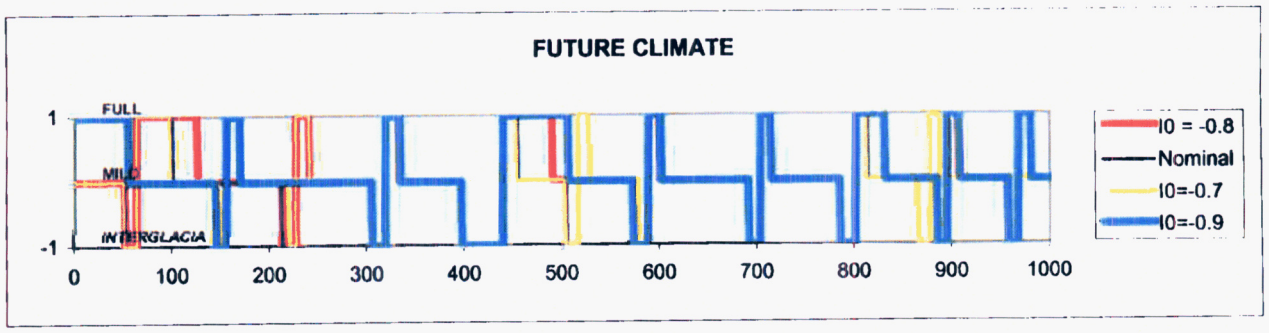
The Paillard model produces output in terms of discrete climate states (glacial = -1, mild glacial = 0, interglacial = +1) and a continuous value of relative ice volume or area ranging from 0 to 1, 1 indicating a large ice sheet. The results of the simulations listed above are shown on page 66. As noted by ~~Paillard~~ GR 4/3/06 Paillard (2001), the value of I_0 has little effect on simulated past climates, either state or ice volume, but does influence future climates.

4/3/06


PAST CLIMATE
FULL
MILD
INTERGLACIA
-800
-700
-600
-500
-400
-300
-200
-100
0
Kiloyears Before Present
I0 = -0.8
Nominal
I0=-0.7
I0=-0.9


FUTURE CLIMATE
1
0
FULL
MILD
INTERGLACIA
0
100
200
300
400
500
600
700
800
900
1000
I0 = -0.8
Nominal
I0=-0.7
I0=-0.9


PAST CLIMATE
FULL
MILD
INTERGLACIA
-800
-700
-600
-500
-400
-300
-200
-100
0
Kiloyears Before Present
I0 = -0.8
Nominal
I0=-0.7
I0=-0.9


FUTURE CLIMATE
1
-1
FULL
MILD
INTERGLACIA
0
100
200
300
400
500
600
700
800
900
1000
I0 = -0.8
Nominal
I0=-0.7
I0=-0.9

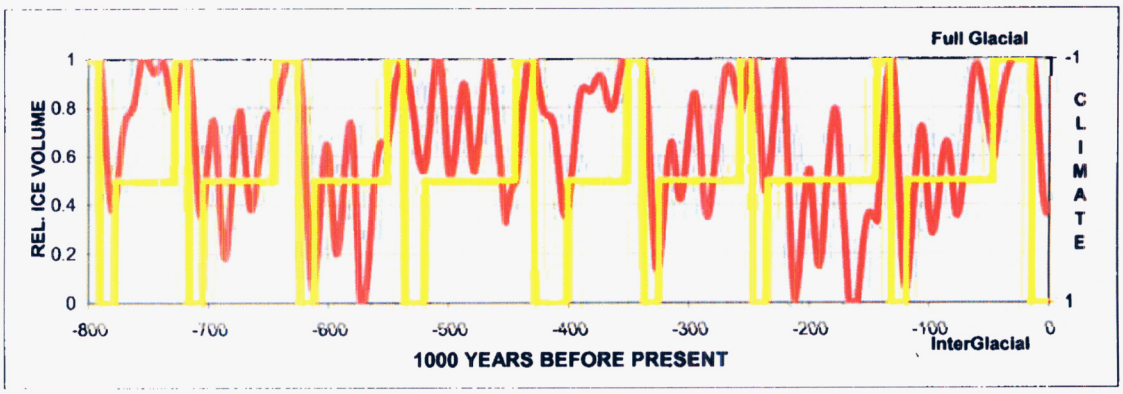
4/3/06 Cont

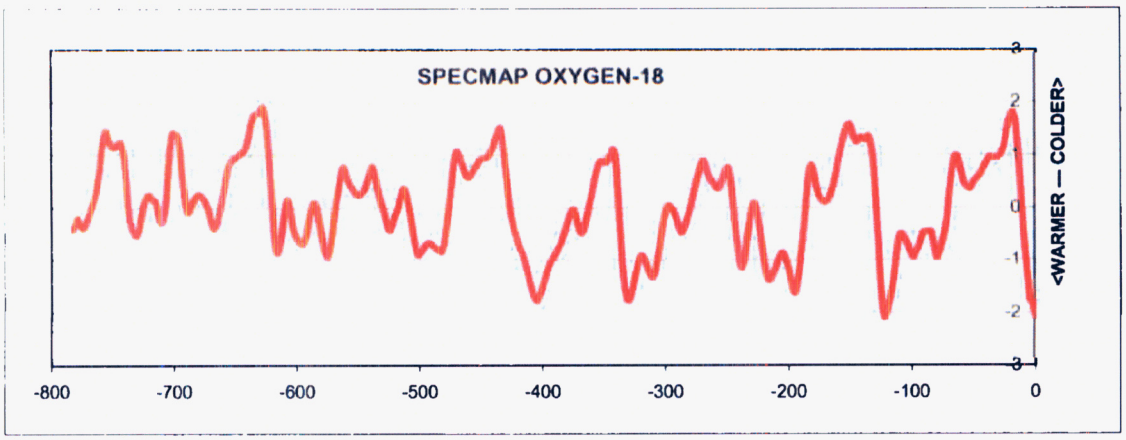
Another important feature of the model output is that the ice volume can vary considerably during a given climate state. Thus, although a full glacial climate generally implies a large ice volume, large ice volumes can occur during mild glacial climates and during portions of interglacial climates. This is a result of the time constants controlling the rate of growth and contraction of the ice sheet. This behavior is illustrated by the past climate graph on p. 68 using the nominal parameters.

Remembering that the purpose of generating possible future climates is to generate possible future sequences of MAP and MAT to be used to estimate infiltration, different sequences of MAP and MAT will result from keying the MAP and MAT to climate state as opposed to ice volume.

4/3/06 GW

D:\Climate_Infil_ISI\Future Climate\stochastic climate\Report\comparison of paillard model2 and SPECMAP.xls





Assuming that the climate near Yucca Mountain is controlled zone atmospheric circulation patters (e.g. Forester et al, 1999, "The Climate and Hydrologic History of Southern Nevada during the Late Quaternary" USGS Open-File Report 98-635

4/3/06 Gr

it is reasonable to that climate will be strongly influenced by the size of the North American ice sheet. Because of the lag in response between the size of the ice sheet and the global climate state, as described by the Paillard model, tying future MAP and MAT to relative ice volume may be more ~~relat~~ realistic than tying them Gr 4/3/06

to climate ~~st~~ 4/3/06 Gr state. In order

to estimate the possible future values of MAP and MAT, values of these parameters were assigned to values of relative ice volume using the following rationale.

1. Based on the Paillard model, the present day value of relative ice volume (V_0) is 0.38. Relative values of MAP and MAT were assigned based on the current values, thus $P_R = P/P(0)$ and $T_R = T/T(0)$ Note that these definitions of P_R and T_R differ from those in the TPA code. $P_R(0) = 1.0$, $T_R(0) = 1.0$

 4/3/06 Cer

2. As ice volume decreases, climate zone to the south of Yucca Mountain are assumed to migrate to the north. During this process, MAT and T_R are assumed to increase but not significantly and P_R was assumed to initially decrease due to further desertification but then to increase due to intrusion of the summer monsoon or more frequent El Nino conditions (see Philander and Fedorov, 2003).

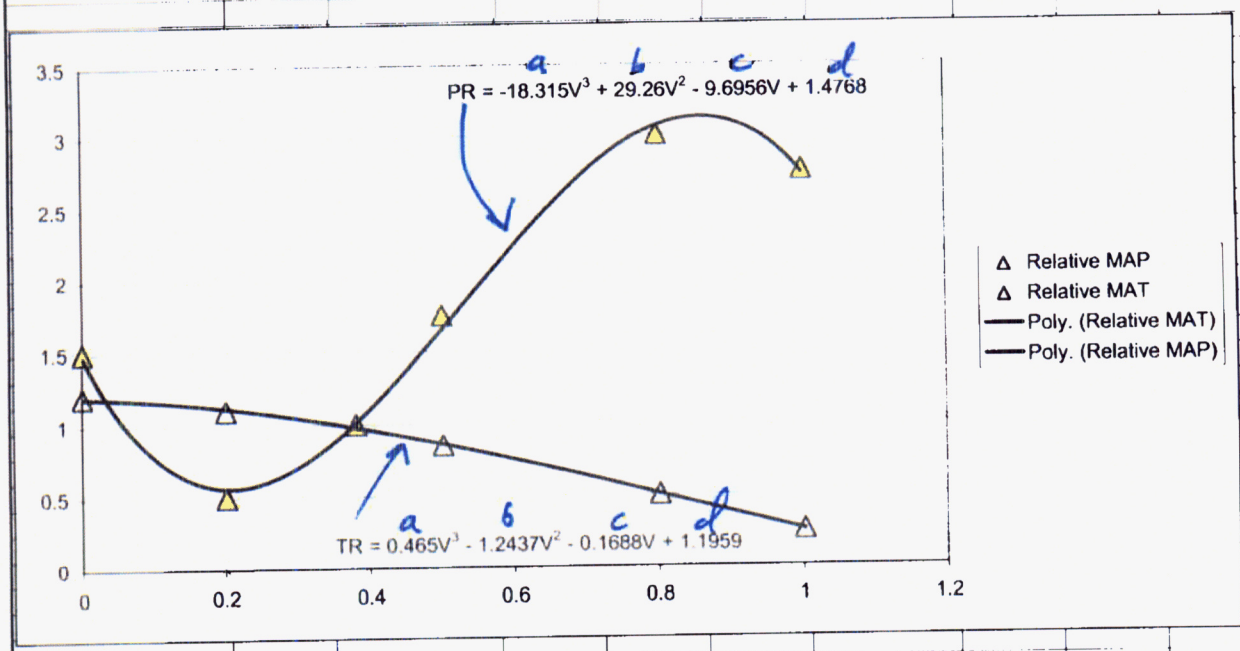
3. When the ice volume increases above present values, P_R increases to a peak value at $V_R = 0.8$ corresponding to a wet glacial period. As the ice sheet expand further, the polar circulation cell dominants leading to a small decrease in P_R. Temperature decreases continuous for $V_R >$ than present

This conceptual model is illustrated on Page 71 along with parameter values used to quantify it.

4/3/06 Gw

D:\Climate_Infil_ISI\Future Climate\stochastic climate\Report\PandTfunctions.xls

Present MAP		150	Present MAT	13.5		
		a	b	c	d	
		-18.3	29.26	-9.6956	1.4768	
Temperature		0.465	-1.2437	-0.1688	1.1959	
Rel. Ice Volume		rel. MAP	MAP	rel MAT	MAT	
	0	1.5	225	1.2	16.2	
	0.2	0.5	75	1.1	14.85	
	0.38	1	150	1	13.5	Interglacial
	0.5	1.75	262.5	0.85	11.475	Mild Glacial
	0.8	3	450	0.5	6.75	Full Glacial
	1	2.75	412.5	0.25	3.375	

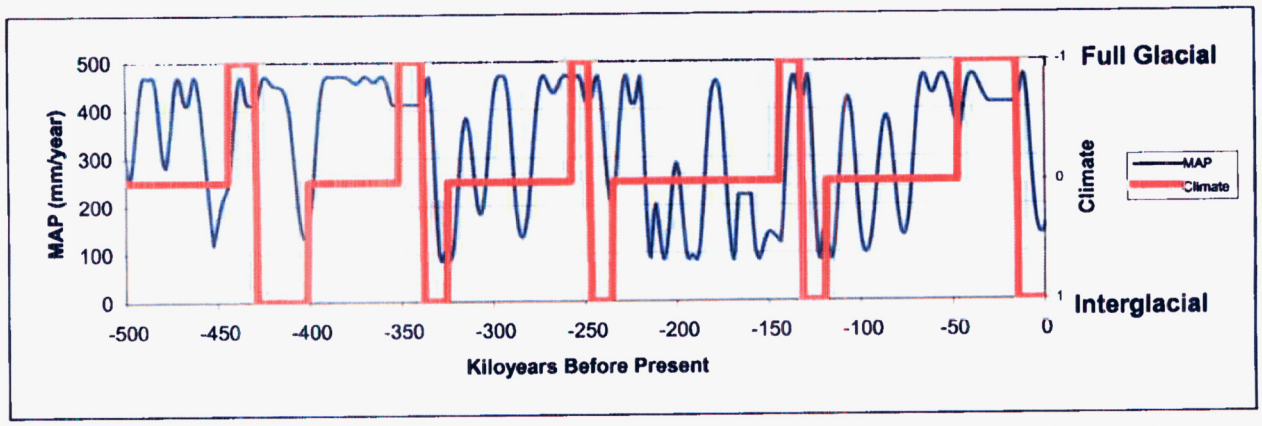


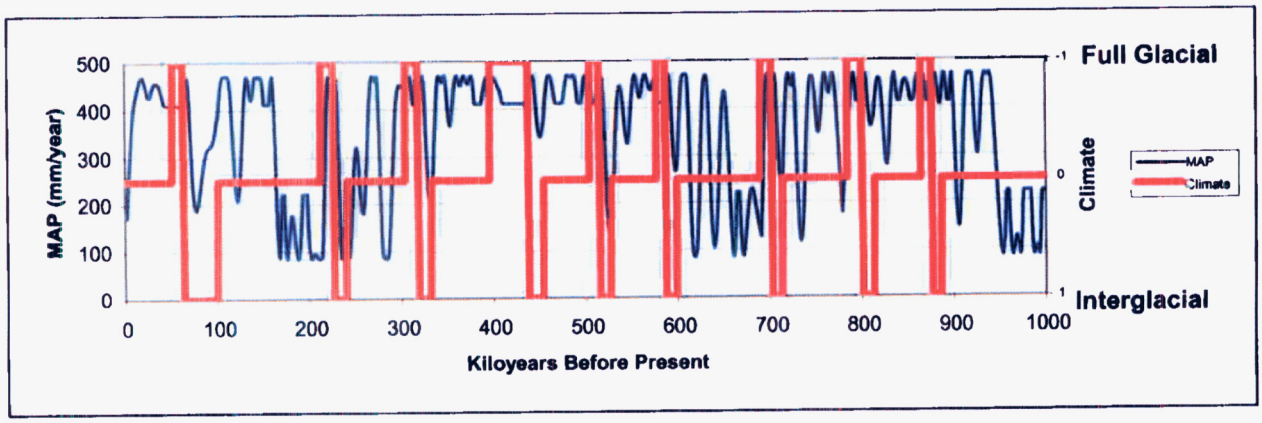
The values for P_R and T_R produce values of MAP and MAT that are generally comparable to those estimated by Sharpe (and BSC). The values for the period -10 kyr to -35 kyr ranged from 410 mm/yr to 470 mm/yr consistent

4/3/06 OR

with estimates by Forester et al based on tree distributions (see Forester et al p.33).
The computed values of MAP and climate for the past 500 kyr and future 1,000 kyr are shown below

D:\Climate_Infil_ISI\Future Climate\stochastic climate\Report\PandTfunctions.xls





4/3/06 GW

The average value of P_R for the past 800 kgr was 2.25 and for T_R was 0.66.
For the future 1,000 kg, $\bar{P}_R = 2.34$ and $\bar{T}_R = 0.63$
(see PandT function.xls)

4/4/06 Greg R Walters

The results of the climate simulations in terms of relative MAP and MAT are summarized using averages over the past, the next 1 million years, and by 100,000 epoch in the future on page 24.

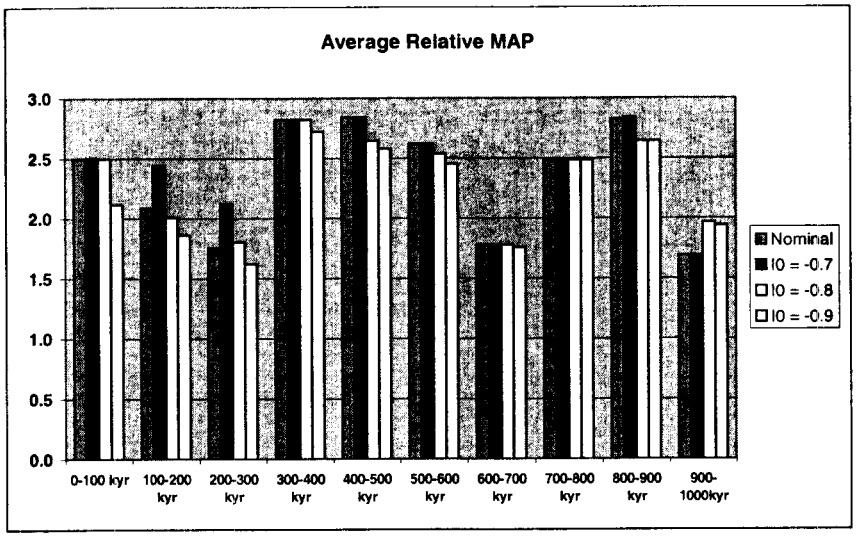
RL 9/21/09

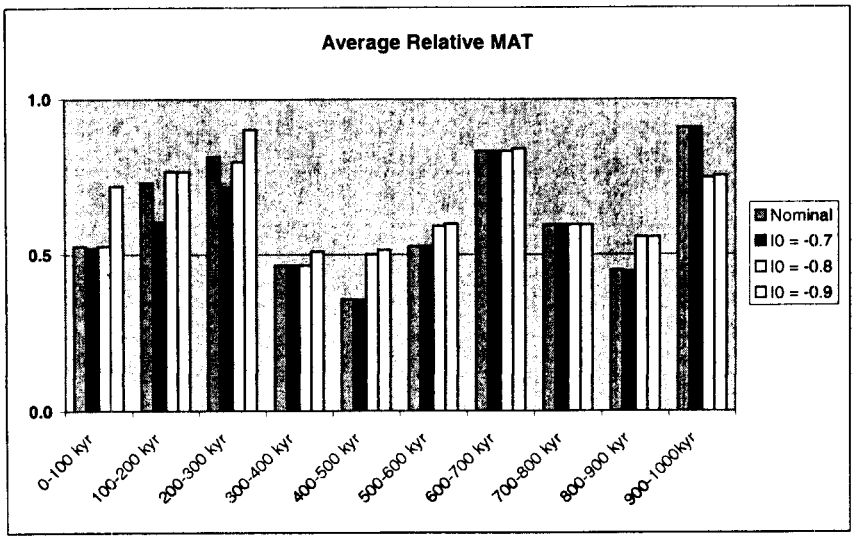
4/4/06 Cm

D:\Climate_Infil_ISI\Future Climate\stochastic climate\Report\PandTfunctions.xls

Parameter Set	Average Past Relative MAP	Average Future Relative MAP	Average Past Relative MAT	Average Future Relative MAT
Nominal	2.24	2.34	0.65	0.62
I0 = -0.7	2.25	2.41	0.65	0.60
I0 = -0.8	2.24	2.32	0.65	0.64
I0 = -0.9	2.23	2.22	0.65	0.67

	Average Relative MAP				Average Relative MAT			
	Nominal	I0 = -0.7	I0 = -0.8	I0 = -0.9	Nominal	I0 = -0.7	I0 = -0.8	I0 = -0.9
0-100 kyr	2.50	2.50	2.50	2.12	0.53	0.52	0.53	0.72
100-200 kyr	2.08	2.44	2.01	1.86	0.73	0.60	0.76	0.77
200-300 kyr	1.75	2.12	1.80	1.62	0.81	0.72	0.80	0.90
300-400 kyr	2.82	2.82	2.82	2.72	0.46	0.46	0.46	0.51
400-500 kyr	2.84	2.84	2.64	2.58	0.36	0.35	0.50	0.51
500-600 kyr	2.62	2.62	2.54	2.45	0.53	0.53	0.59	0.60
600-700 kyr	1.78	1.78	1.78	1.75	0.83	0.83	0.83	0.84
700-800 kyr	2.49	2.49	2.49	2.49	0.59	0.59	0.59	0.59
800-900 kyr	2.82	2.84	2.64	2.64	0.45	0.45	0.56	0.56
900-1000kyr	1.69	1.69	1.97	1.94	0.91	0.91	0.75	0.75





4/20/06 Gary R Walters

The Paillard model was "tuned" to the SPECMAP marine isotope record using the nominal parameters ~~chosen~~ 4/20/06 listed on p. 60. To see how well the SPECMAP climate surrogate compared with the O-18 isotope record for Devils Hole, I obtained the Devils Hole record from U.S.GS Open File Report 97-792 from http://pubs.usgs.gov/of/1997/ofr97-792

4/21/06 Gary R Walters

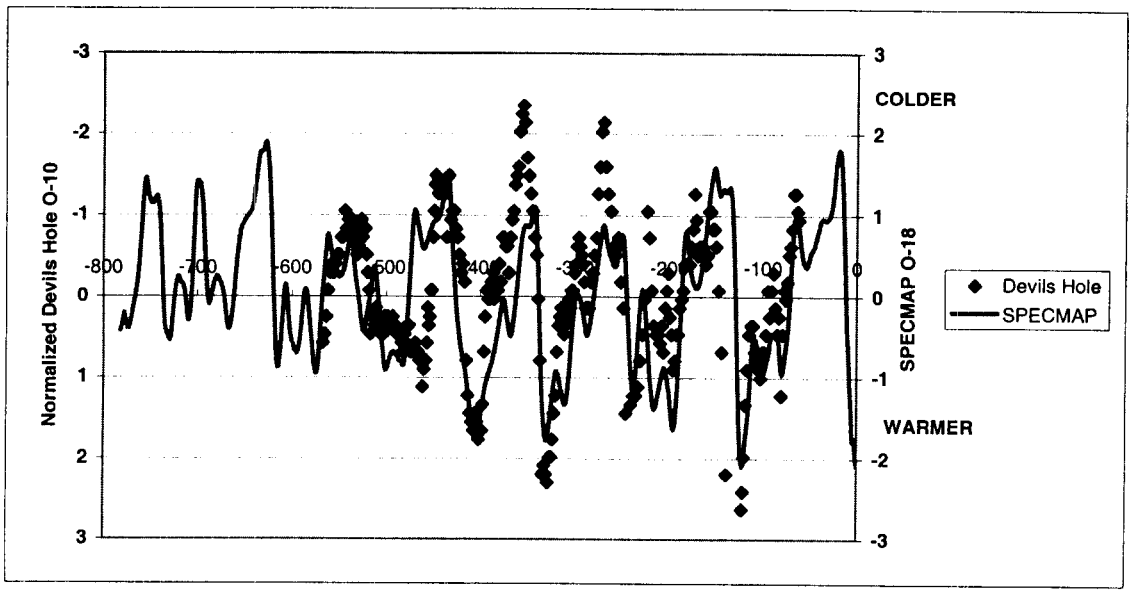
The Devils Hole data obtained from the USGS website are in devils_hole.xls
To compare the Devils Hole data to the SPECMAP record, Devils Hole data were normalized according to the following formula

$$x^* = \frac{x - \bar{x}}{SD}$$

where x^* is the normalized value
x is the raw δO-18 value
$\bar{x}$ is the mean δO-18 value
SD is the standard deviation of δO-18

~~4/28~~ 4/24/06 [illegible]

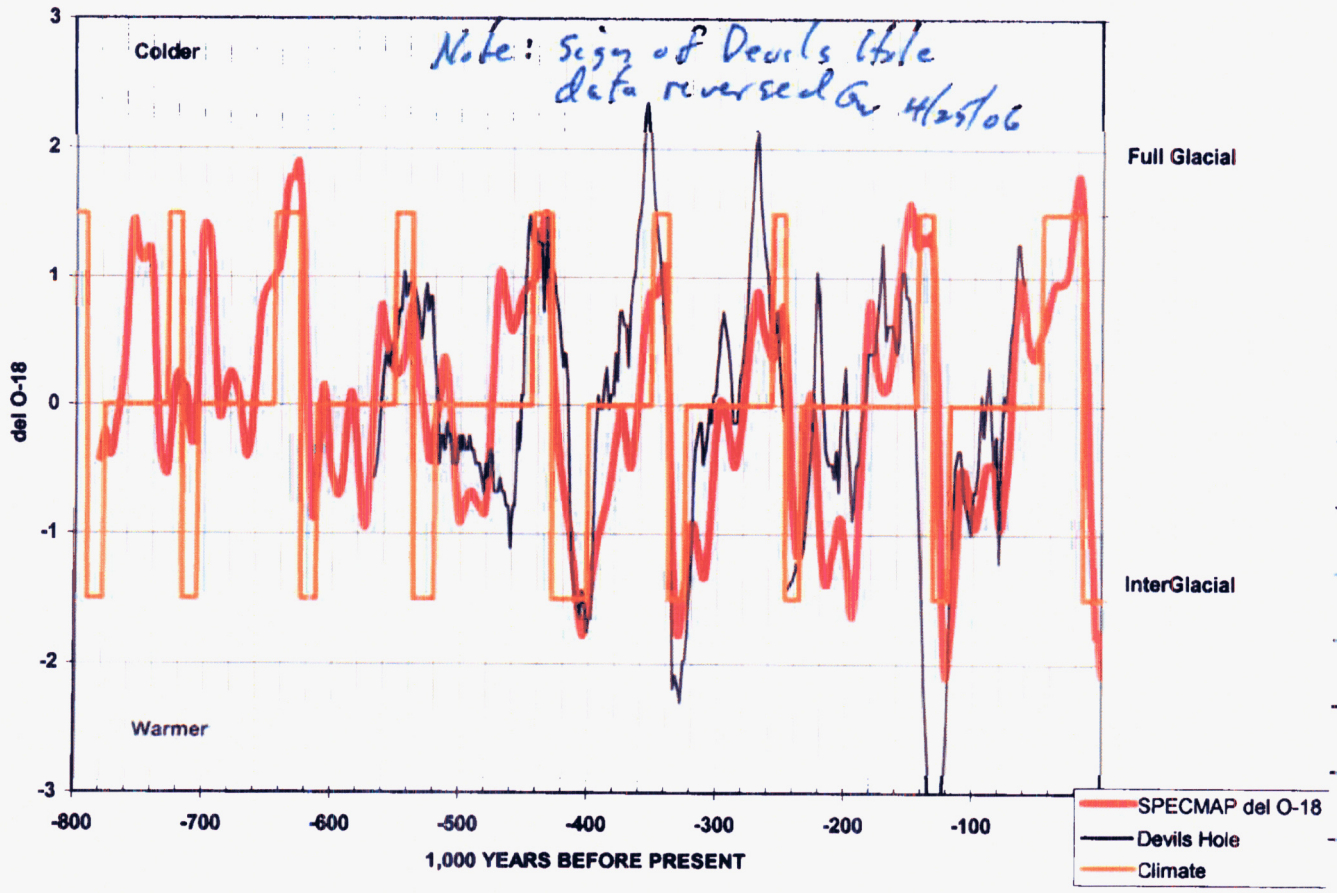
The graph below (from devils hole.xls) is a comparison between the SPECMAP record and the devils hole record. Note that the Devils Hole record is plotted in reverse order to facilitate the comparison.



The agreement between the two records is qualitatively pretty good, although the timing of some of the peaks and valleys disagrees, that is, apparent terminations in glacial stages.

4/25/06 Gary Walter

The graph below shows the correspondence between the SPECMAP record, the Devils Hole record and the discrete climates produced by the Paillard model.



One way to compare the two paleoclimate indicators and the computed climate is by comparing the times at which ~~interglacial~~ Gw 4/25/06 glacial interglacial transitions occur

4/25/06 Gw

since these transitions occur relatively rapidly. Here, the transition is taken as the time when the SPECMAP or Devils Hole data cross zero going from positive to negative (note sign of Devils Hole data is reversed in graph on page 77). These times are tabulated below, all times in kyr BP

SPECMAP	Devils Hole	Paillard Model
130	145	130
245	245	245
340	340	340
425	418	430
530	520	540
620	NA	625

Overall, these transition times agree fairly well.

RL 9/21/09

6/30/06

Revisited the Paillard continuous model algorithm. Paillard allowed normalized ice volume to fall outside the range of zero to one and his algorithm incorporated a rule that caused an immediate transition from the mild to full glacial climate if the computed ice volume was greater than 1 (one). Implementing this rule in my program reduced the correspondence between the simulated climates and the SPECMAP reconstructions. The reason for this discrepancy is not known. Given the relatively good correspondence between the original model output and the SPECMAP and Devil's Hole records, I am ~~do~~ 6/30/06 not going to implement the above mentioned ~~rule~~ 6/30/06 rule.

7/3/06 [signature]

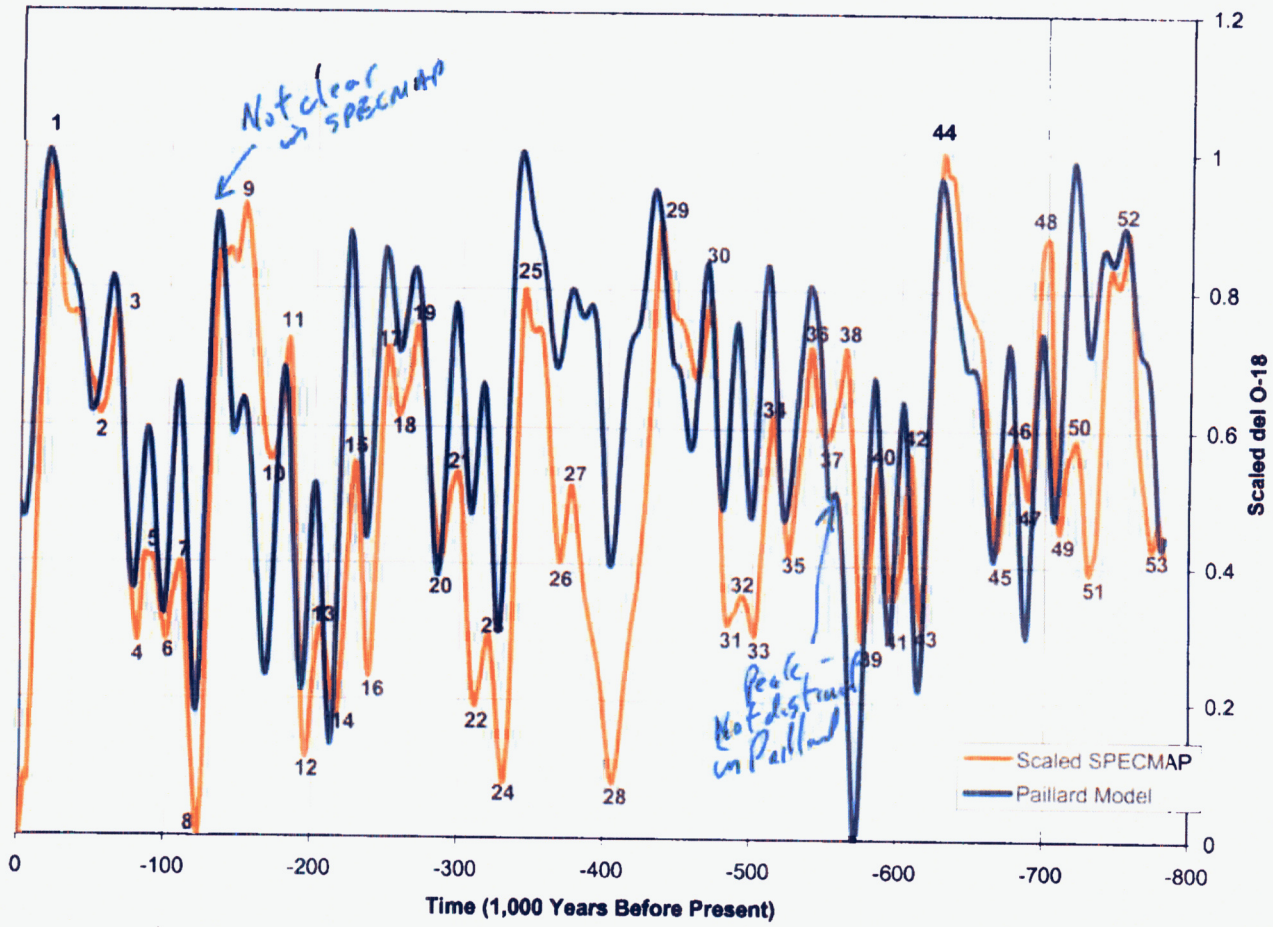
Following on the comment on the program on p. 79, the program was also modified to allow the normalized ice volume to fall outside the range of zero to one.

With these changes, I reran the Paillard model and compared the number of climate transitions, as indicated by peaks and valleys of ice volume, with the peaks and valleys in the SPECMAP record over approximately the last 800 K years. The figure on p. 81 shows the correspondence between the ice volume generated by the Paillard model (scaled to zero to one) and the SPECMAP recorded (scaled to zero to ~~one)~~ one). Each

7/3/06

of the clear SPECMAP peaks and valleys were numbered starting from the present. There are 53 peaks and valleys. 50 of these correspond to peaks and valleys in the Paillard simulation in terms of approximate timing (generally within ± a few thousand years) although the magnitudes do not necessarily match.

~~7/3/0~~ 7/3/06 [signature]



file: detailed_comparison_paillard_specmap_devils_hole.xls

3/13/09 CD

Note book closed

CD

ADDITIONAL INFORMATION FOR SCIENTIFIC NOTEBOOK NO. 699

Document Date:	03/15/2005
Availability:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, Texas 78228
Contact:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, TX 78228-5166 Attn.: Director of Administration 210.522.5054
Data Sensitivity:	■"Non-Sensitive" □ Sensitive □"Non-Sensitive - Copyright" □ Sensitive - Copyright
Date Generated:	09/21/2009
Operating System: (including version number)	Windows
Application Used: (including version number)	
Media Type: (CDs, 3 ½, 5 1/4 disks, etc.)	1 CD
File Types: (.exe, .bat, .zip, etc.)	xls, jpg, txt
Remarks: (computer runs, etc.)	Notebook supplemental material