A Vintage 2009 Assessment of the Sun-Climate Connection in Paleoclimate Records

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Main Topics Covered

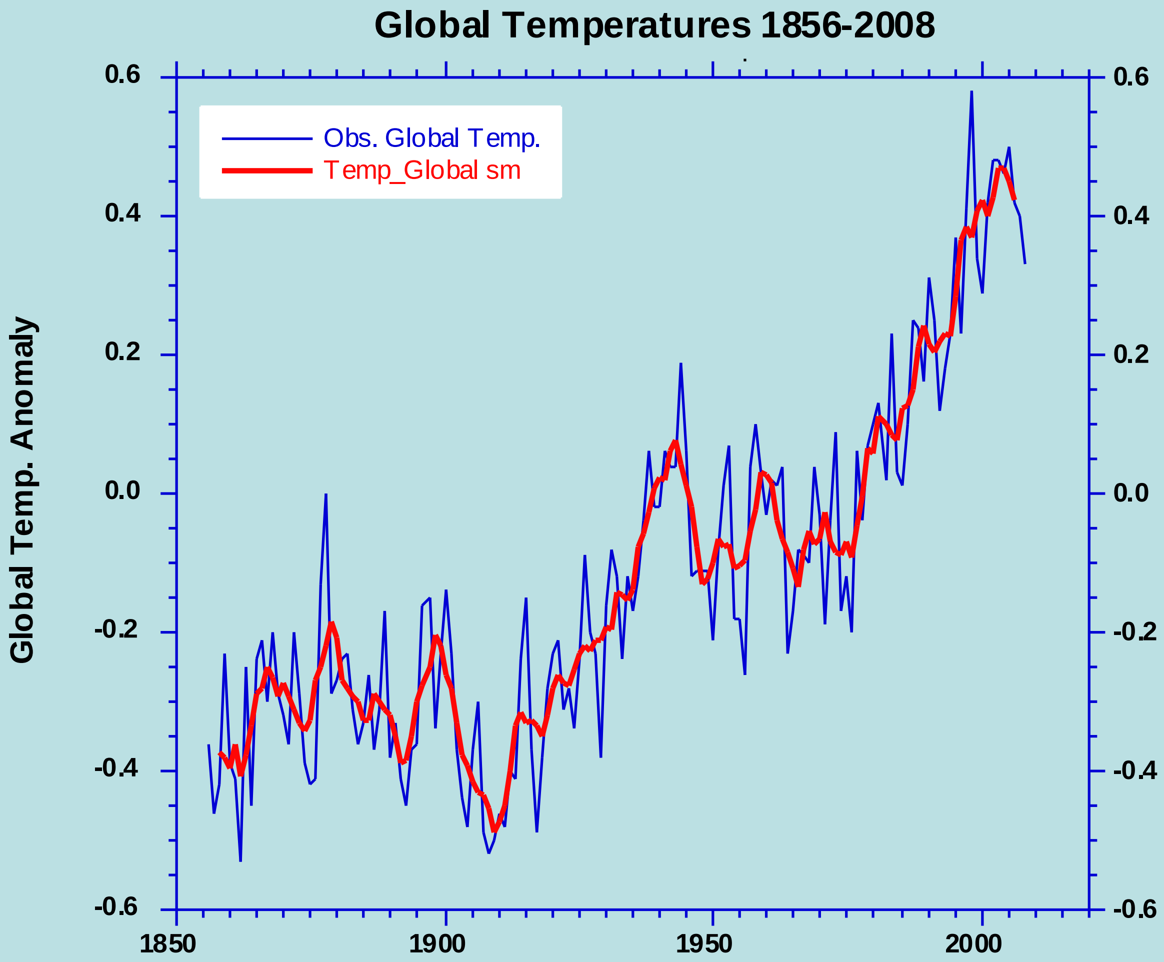
role of the Sun in:

- 20th c. warming
- Little Ice Age
- Centennial-Millennial scale climate change

Overarching Goal:

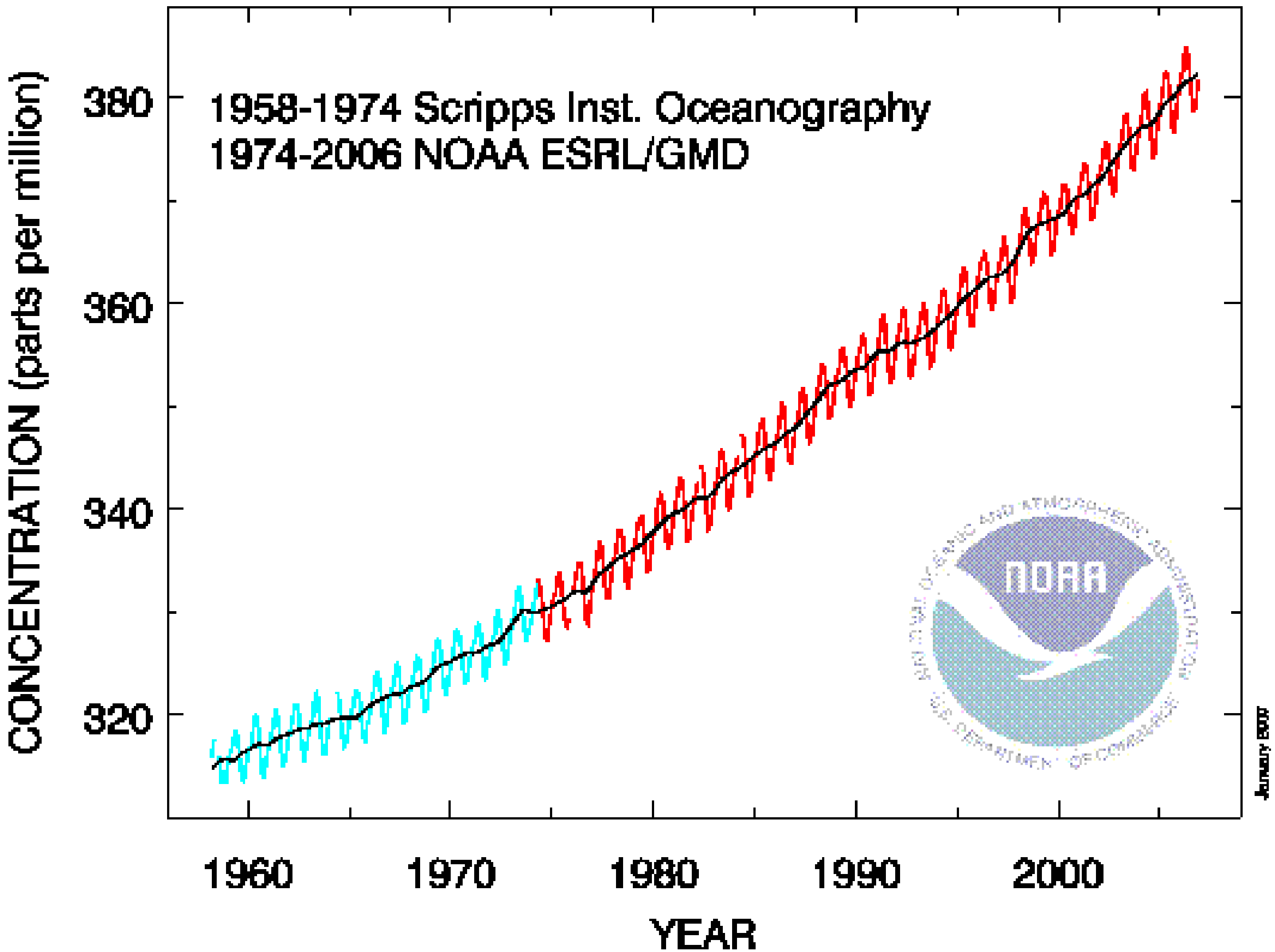
to temper "irrational exuberance" about the role of solar variability in past climate change

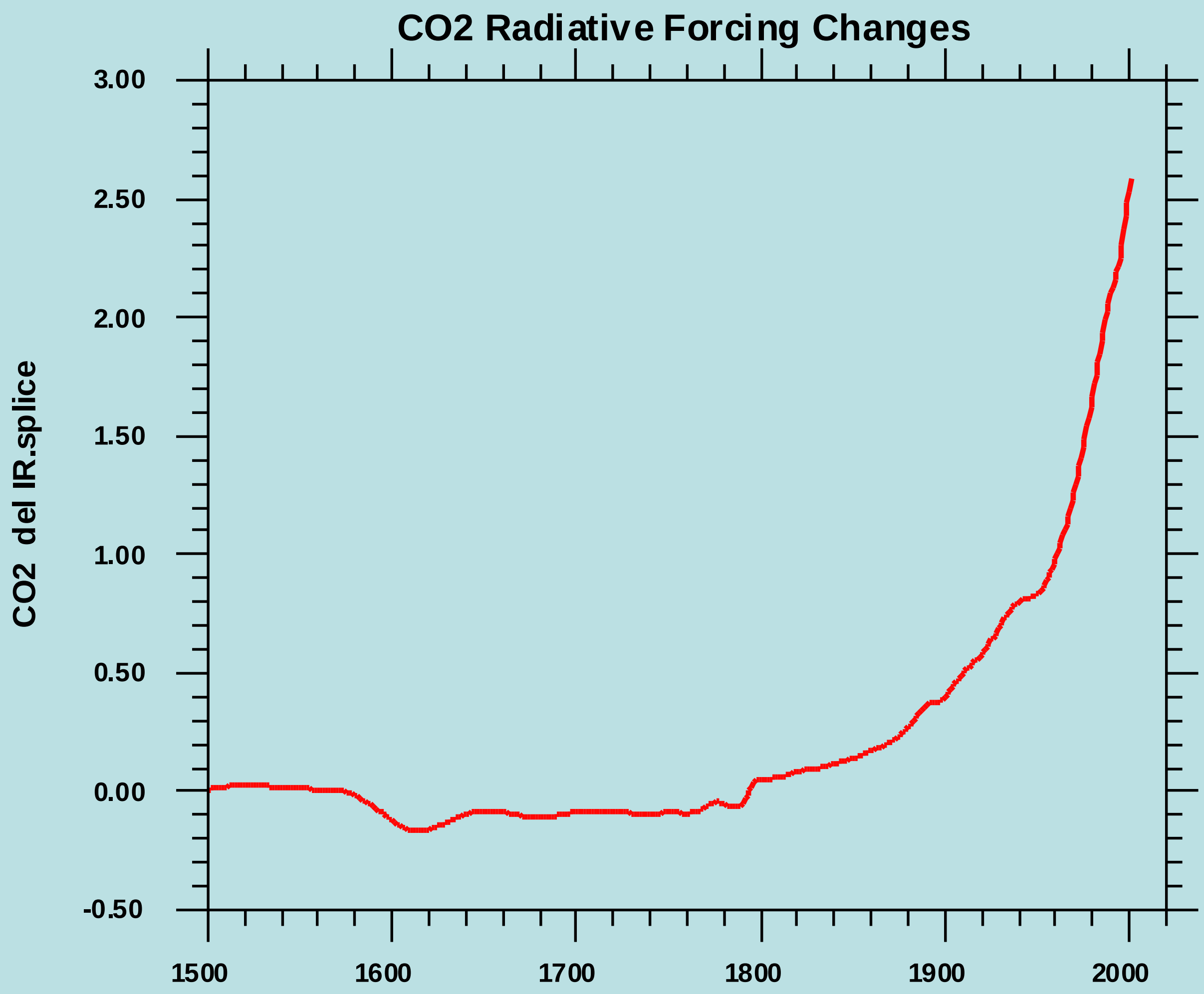
In the beginning…...

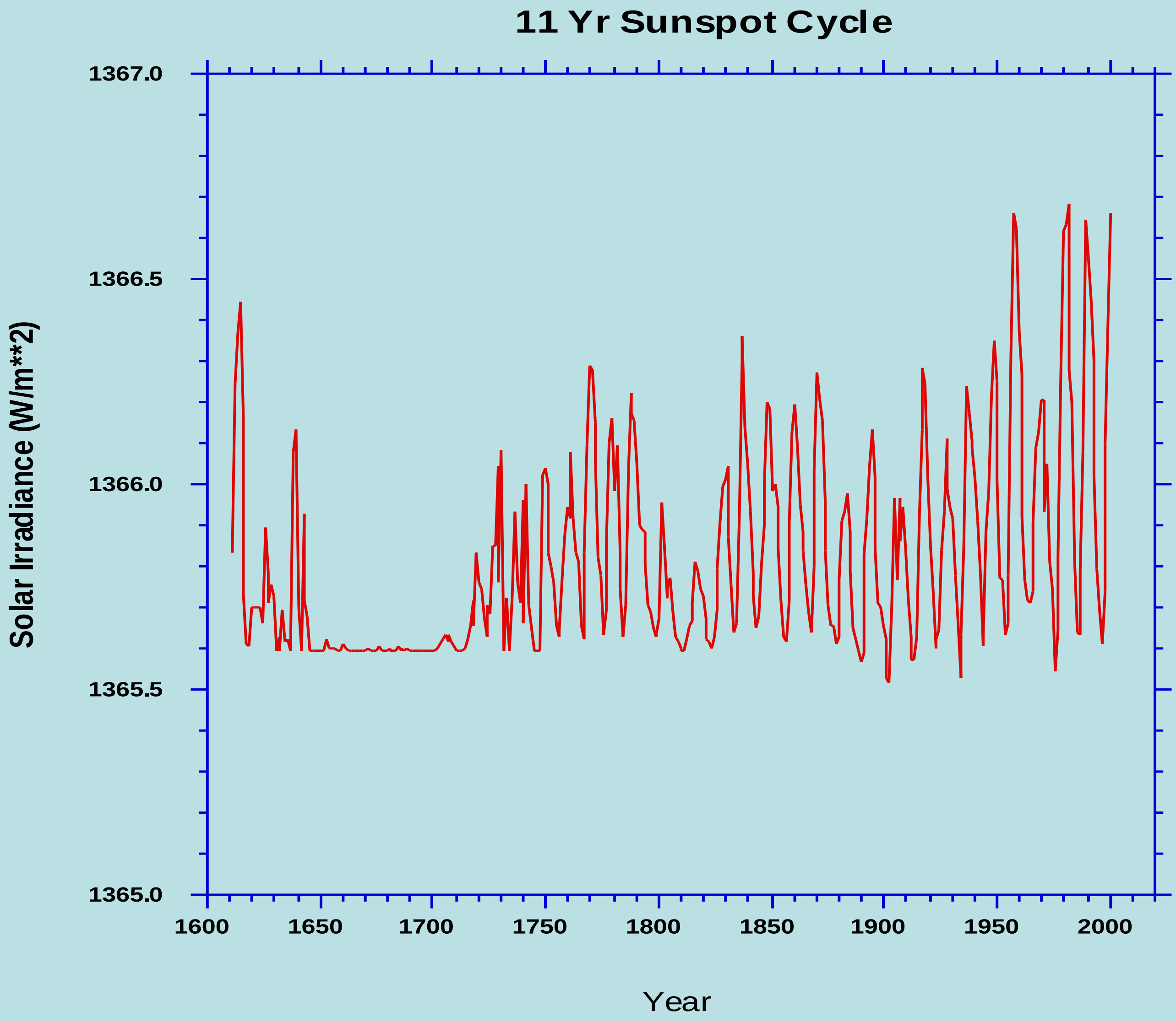


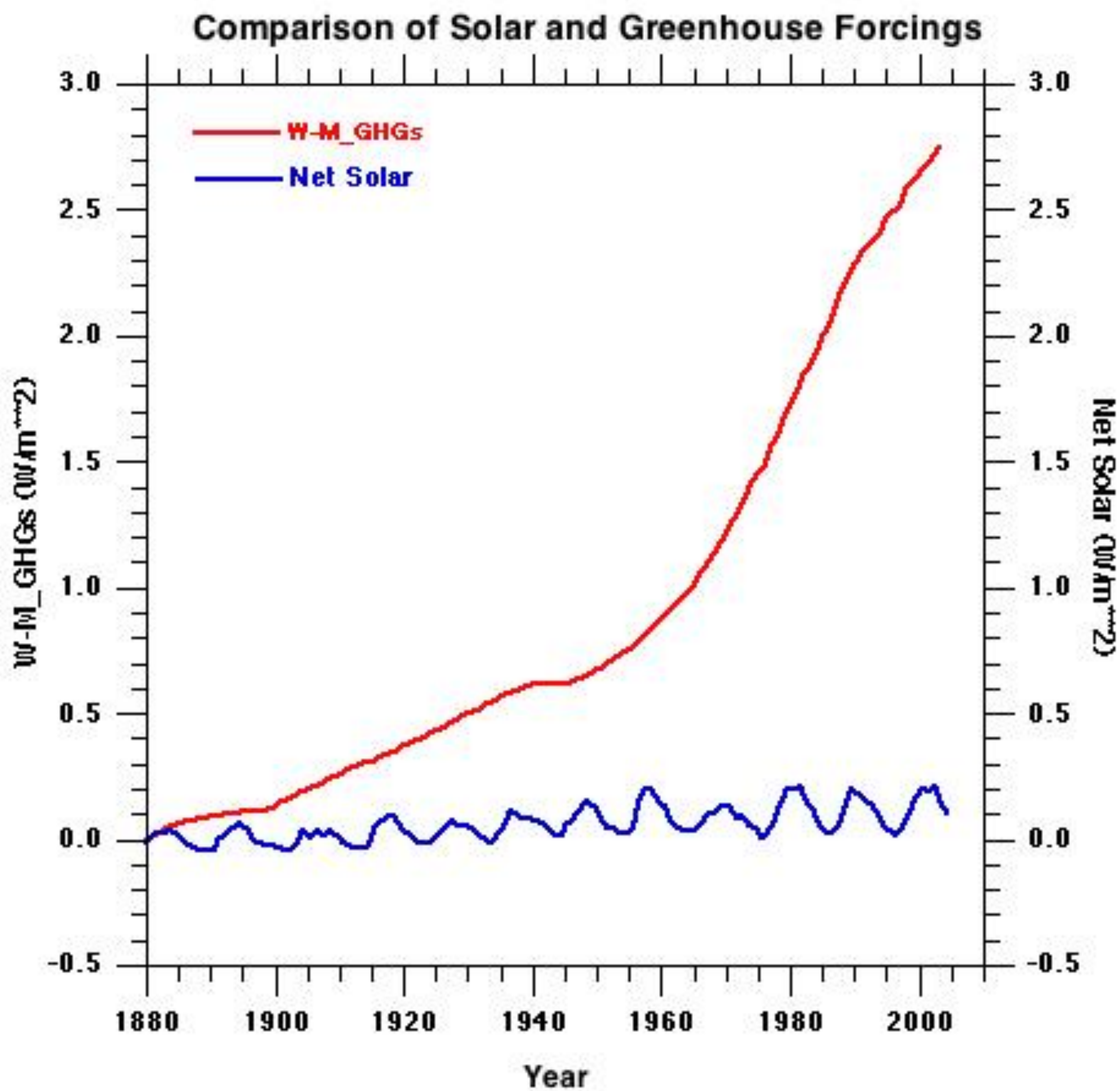
Global Temperatures 1856-2008
Obs. Global Temp.
Temp_Global sm
Global Temp. Anomaly
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1850
1900
1950
2000

Atmospheric CO_2 at Mauna Loa Observatory




CO2 Radiative Forcing Changes
CO2 del IR.splice
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
1500
1600
1700
1800
1900
2000


11 Yr Sunspot Cycle
Solar Irradiance (W/m**2)
1367.0
1366.5
1366.0
1365.5
1365.0
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year


Comparison of Solar and Greenhouse Forcings
W-M_GHGs
Net Solar
W-M_GHGs (W/m**2)
Net Solar (W/m**2)
Year
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
1880
1900
1920
1940
1960
1980
2000

Poor Man's Climate Model

$$\Delta T_{eq} = \lambda \, [(1 - \alpha) \, \Delta Q]$$

where

ΔT_{eq} = change in equilibrium global temperature

λ = climate feedback factor (~ 0.4 - 1.2 $Wm^{-2}/°C$)

α = average Earth albedo (~ 0.3)

ΔQ = change in average global radiative solar forcing
($L_o/4 = Q = 340 \, Wm^{-2}$)

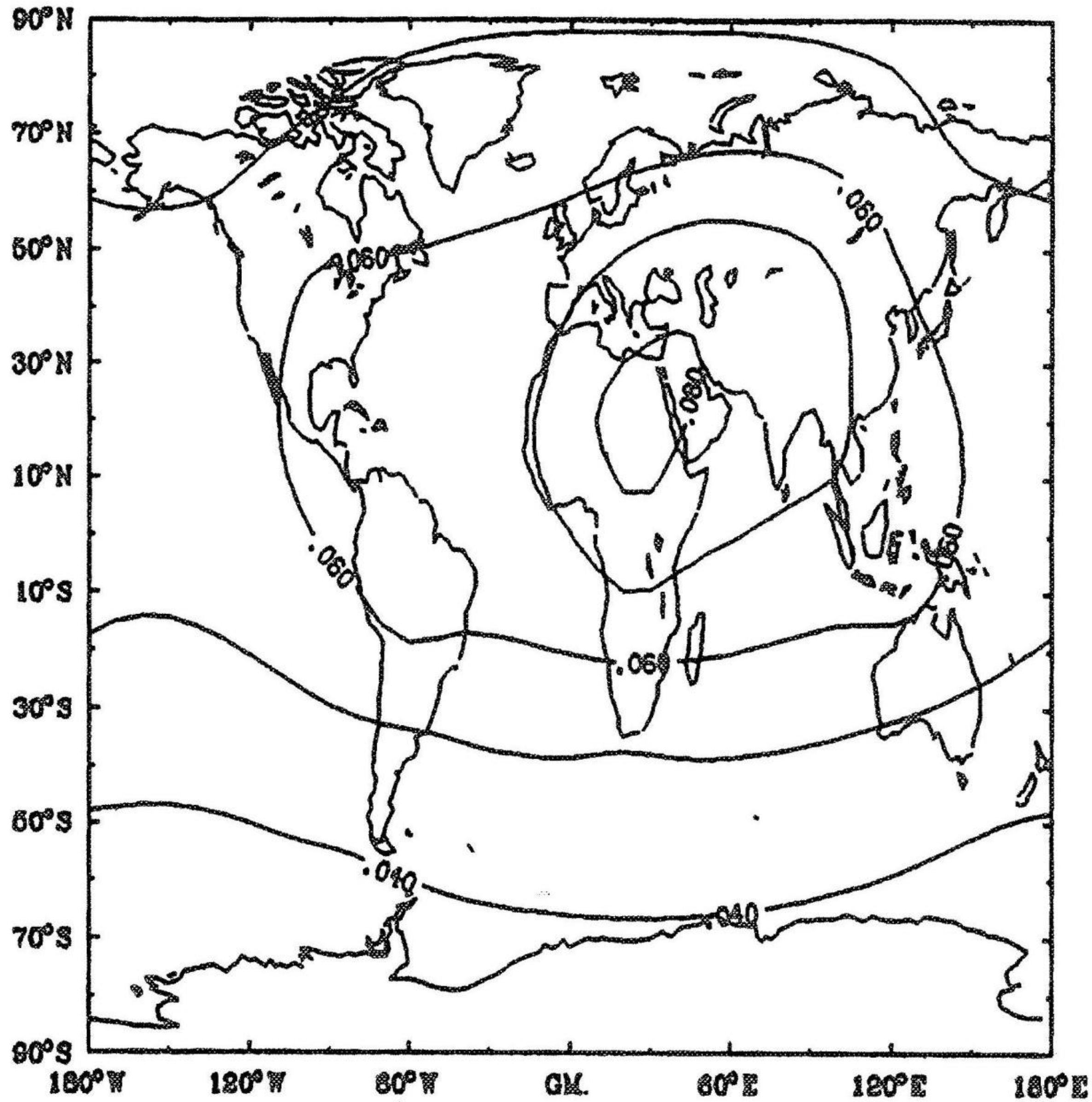
Example 1 – if 1% ΔQ ~ 3.4 Wm^{-2}

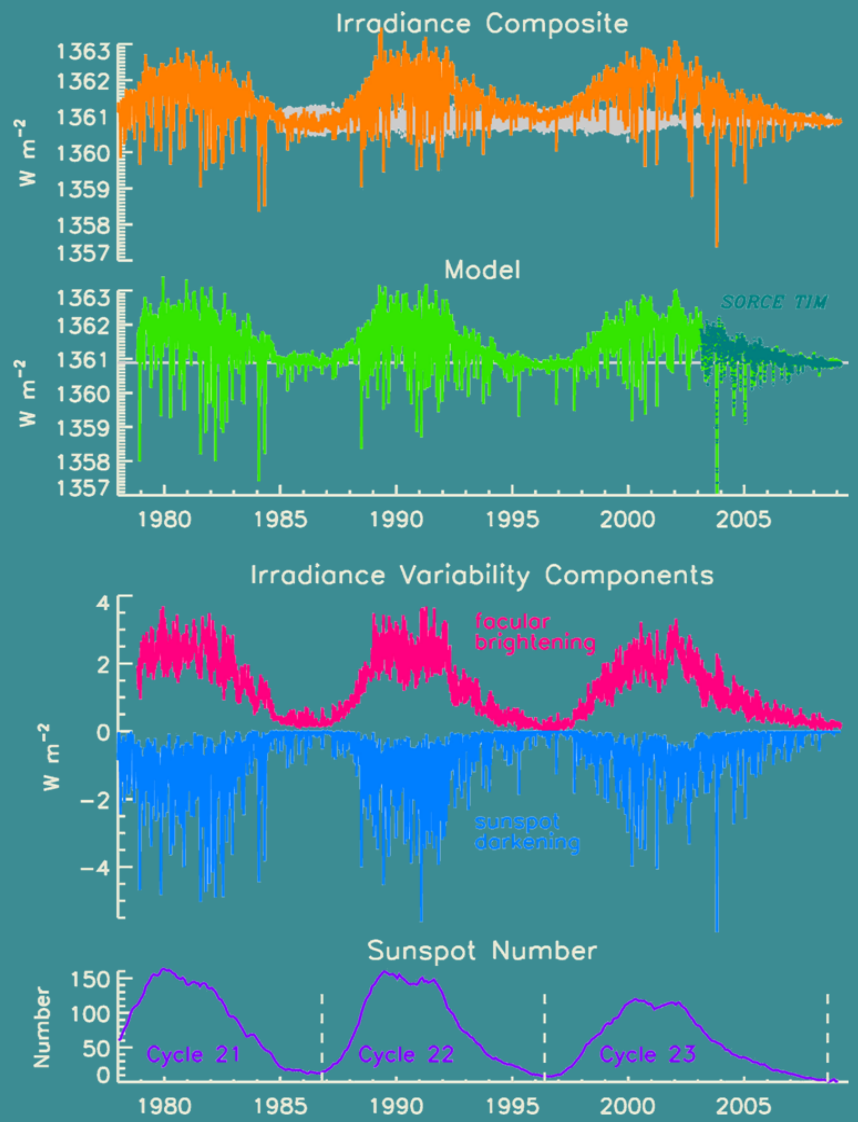
then ΔT_{eq} ~ 1.0 – 2.9°C (0.1-0.3°C for 11 year ΔQ – *max*)

Example 2 – if RF change from doubling of CO_2 is 3.7 Wm^{-2},

then ΔT_{eq} ~ 1.5 – 4.5°C (best guess λ yields 2.5-3.0°C)
(*note* – albedo effect of changing IR *forcing* effectively zero)

AMPLITUDE OF ML-MODEL RESPONSE TO 11-YR FORCING





Irradiance Composite
1363
1362
1361
1360
1359
1358
1357
W m^-2
Model
SORCE TIM
1980
1985
1990
1995
2000
2005
Irradiance Variability Components
4
2
0
−2
−4
facular brightening
sunspot darkening
Sunspot Number
150
100
50
0
Number
Cycle 21
Cycle 22
Cycle 23

“Transient Response (f) ” to Solar Forcing (ie, $f\lambda$)

(Poor Man’s Time-Dependent Climate Model)

example 1, Texas, high noon, summer solstice

~1360 W/m² in low cloud state, 0 at night

equilibrium response ~1300°C

observed ~15°C, therefore f_{max} ~ 1/200 (max over large land areas)

11 year cycle f ~ ½

annual cycle f_{max} ~ 1/10

(e.g, orbital forcing changes over the last 10,000 years yield 40 W/m², with about 4°C summer warming over central Asia)

10 day transient response should be between 1/200 to 1/10 of f_{max}

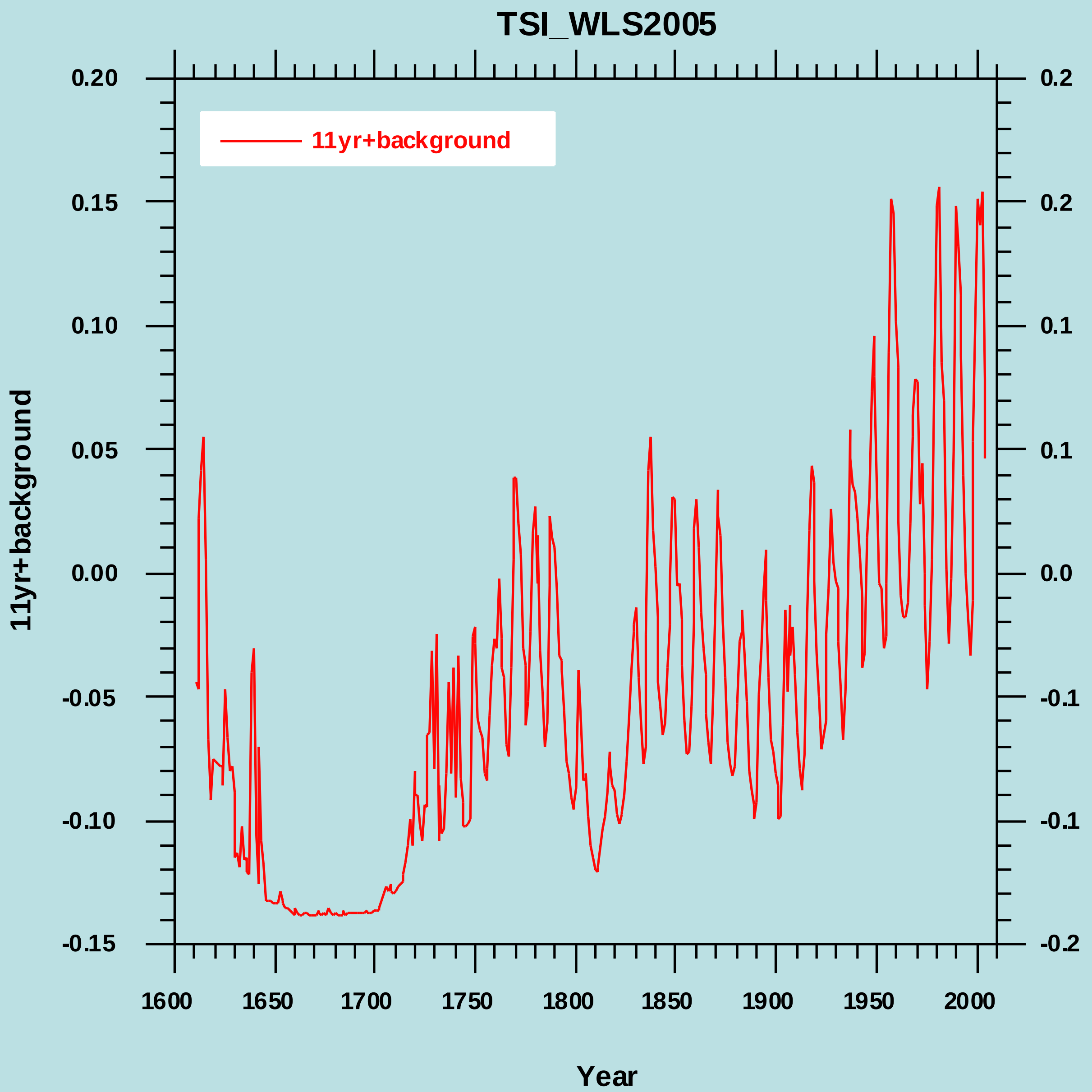
example 2, large sunspot, lifetime ~10 days, ΔL_o~ 2 W/m² (Dq = 0.5 W/m²)

and that f_{max} = 1/100

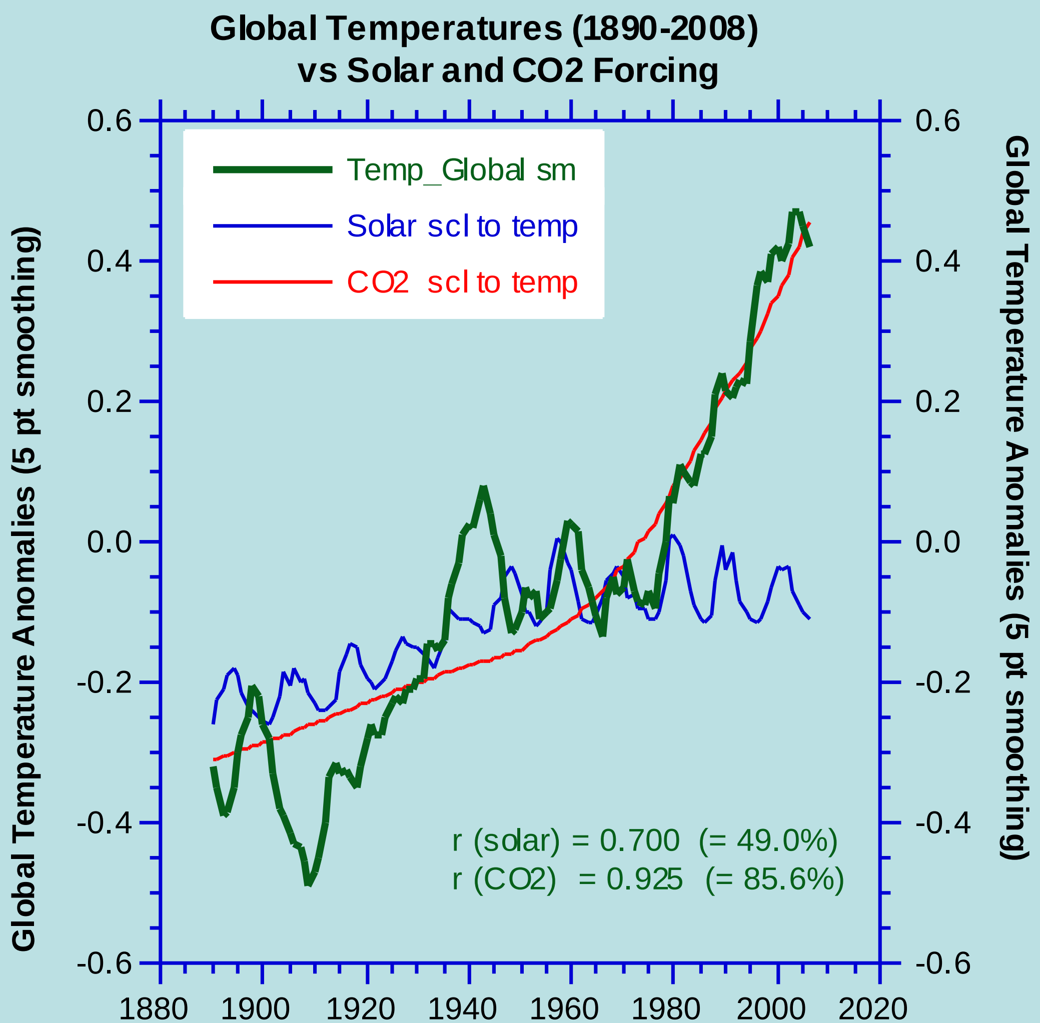
if so ΔT_{max} ~ 0.5/100 = 0.005 --- undetectable by 1-2 orders of magnitude

nevertheless, should realistic solar irradiance changes in forcing ?

why not?

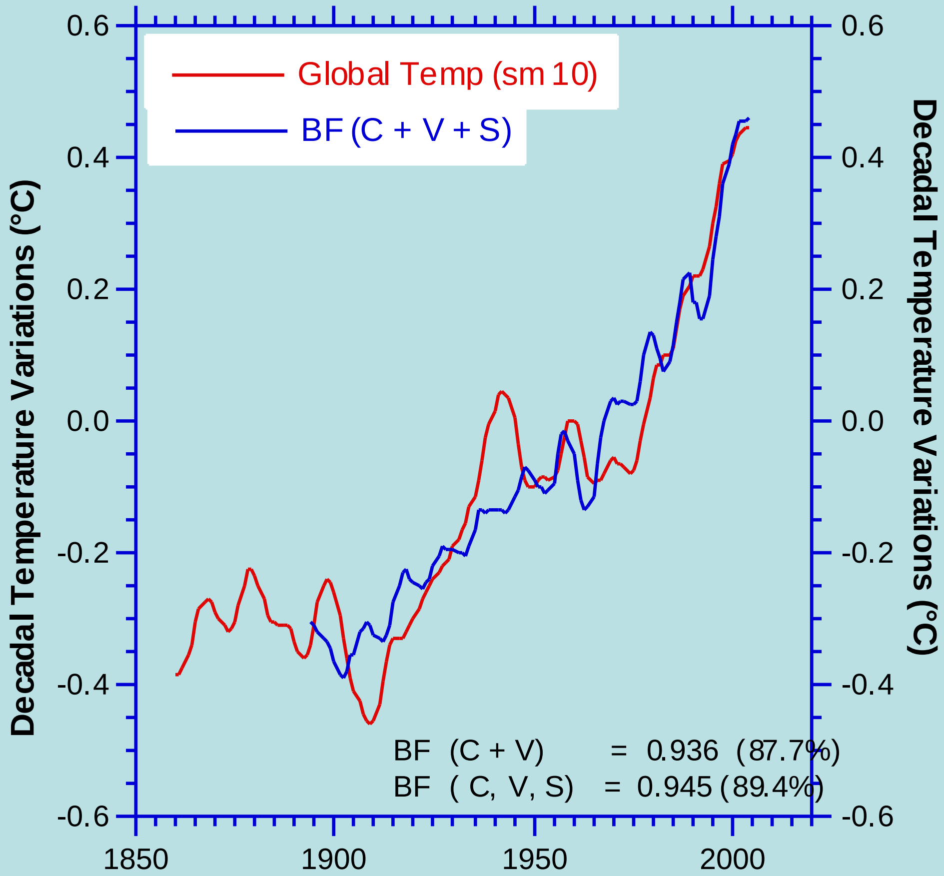


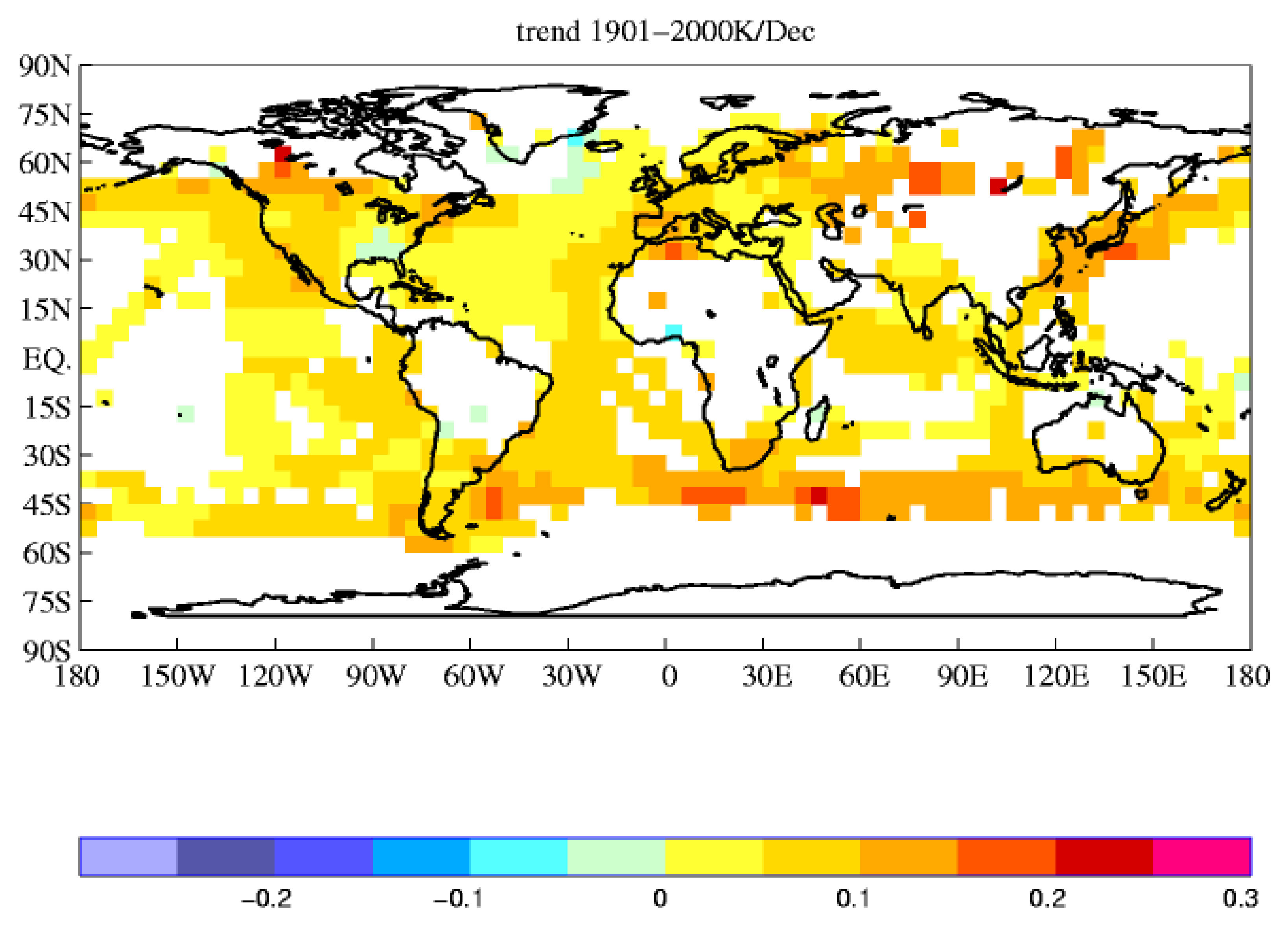
TSI_WLS2005
11yr+background
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
0.2
0.2
0.1
0.1
0.0
-0.1
-0.1
-0.2
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year



Crowley - Fig 2

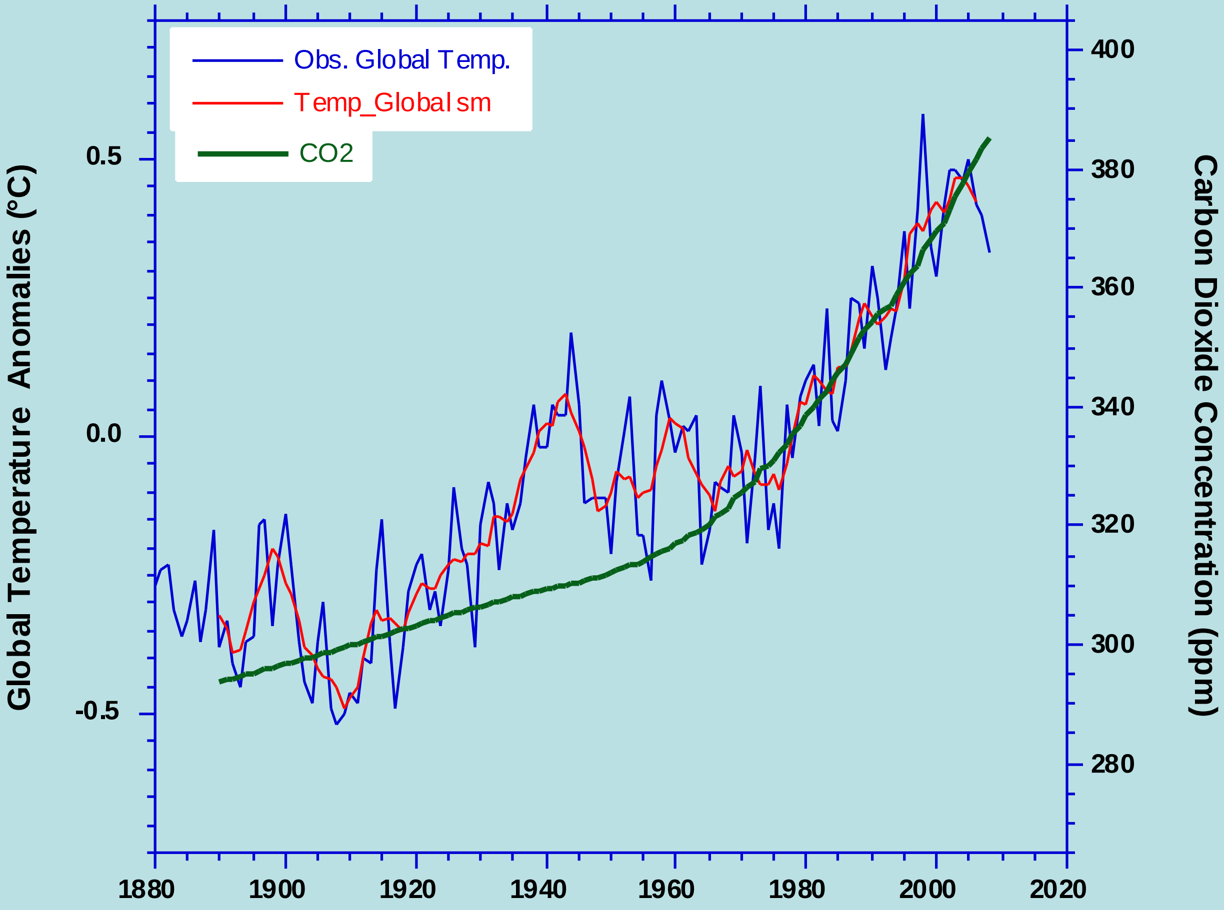
Best Fit to Global Temperature





trend 1901–2000K/Dec
90N
75N
60N
45N
30N
15N
EQ.
15S
30S
45S
60S
75S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
–0.2
–0.1
0
0.1
0.2
0.3

Carbon Dioxide vs Global Temperature (1890-2008)



Conclusions of IPCC Chapter 9 AR4 (Hegerl, Zwiers et al) about solar forcing in the 20th century

Greenhouse gas forcing has very likely caused most of the observed global warming over the last 50 yrs

Based on distinguishing time-space pattern of warming between solar and ghg forcing.

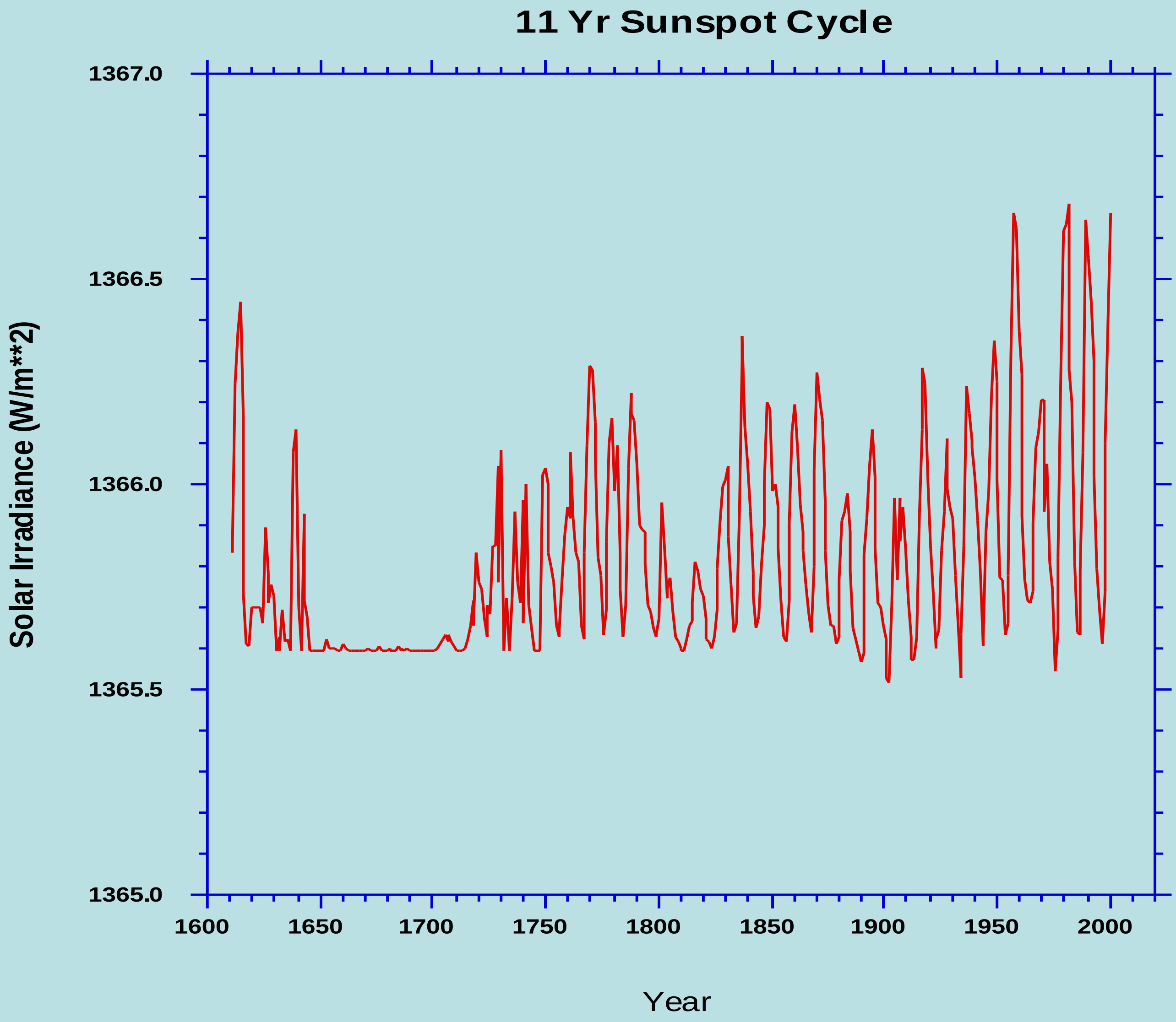
However, the response to solar forcing could be underestimated by climate models

Early 20th century warming may have a solar contribution, results vary between studies.

Other contributors: early greenhouse gas signal or internal variability with warming pattern centered around North Atlantic

Melting on Greenland Ice Sheet

R. Braithwaite, Science
12 July 2002



11 Yr Sunspot Cycle
1367.0
1366.5
1366.0
1365.5
1365.0
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year
Solar Irradiance (W/m**2)

St. Anselm – Archbishop of Canterbury (1033-1109), philosopher and theologian

one role of theology involves "faith seeking understanding"

St. Anselm – Archbishop of Canterbury
(1033-1109), philosopher and theologian

one role of theology involves "faith seeking understanding"

Tom Crowley: "also solar scientists?"

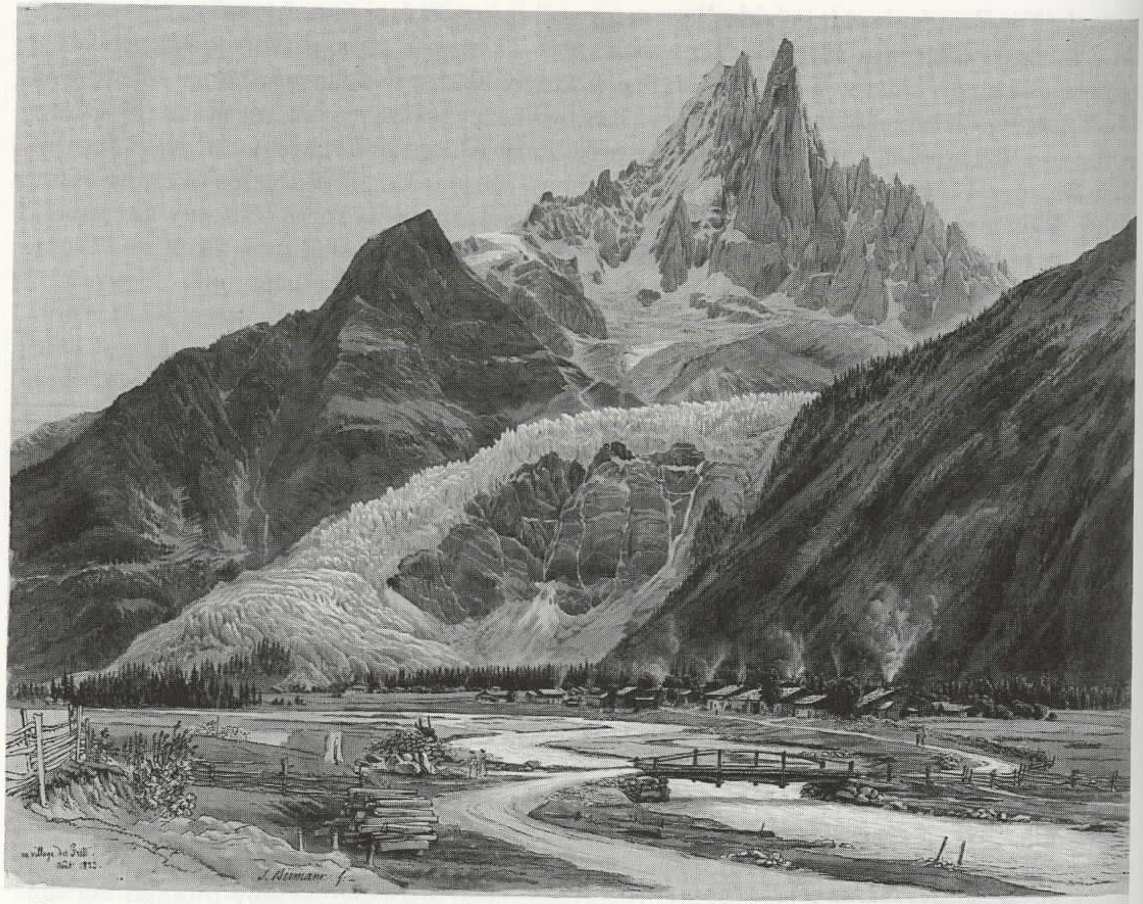
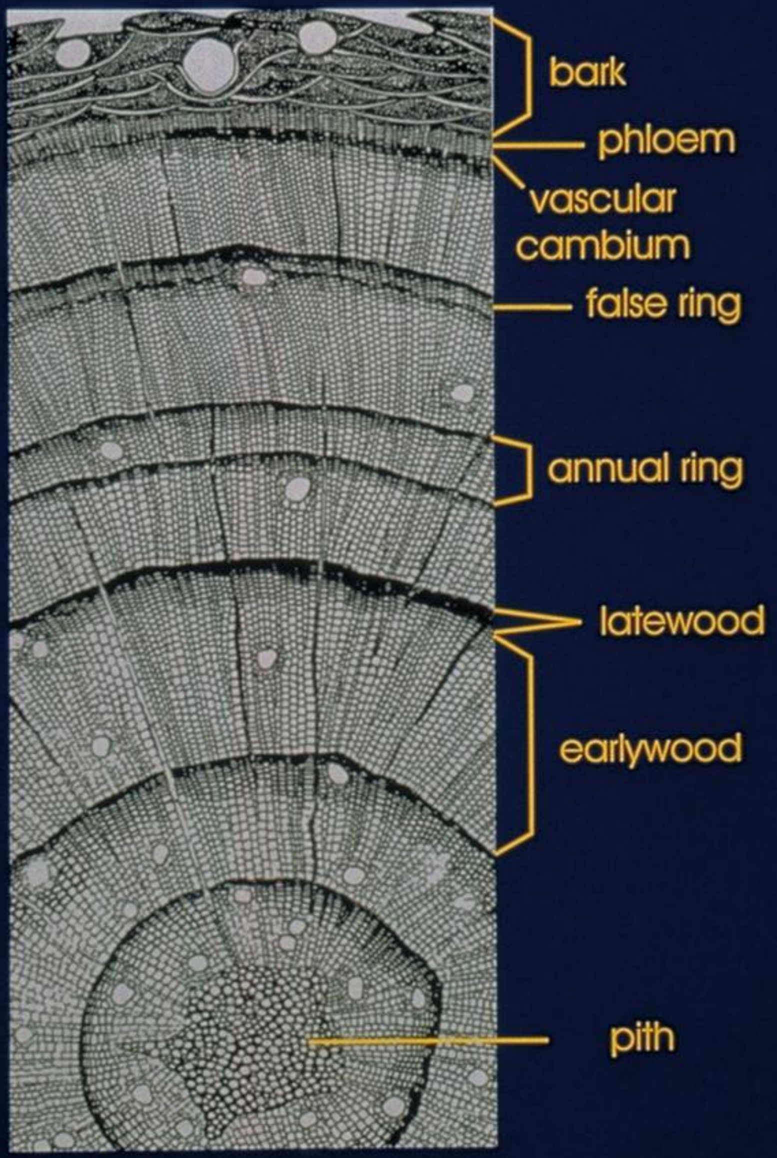
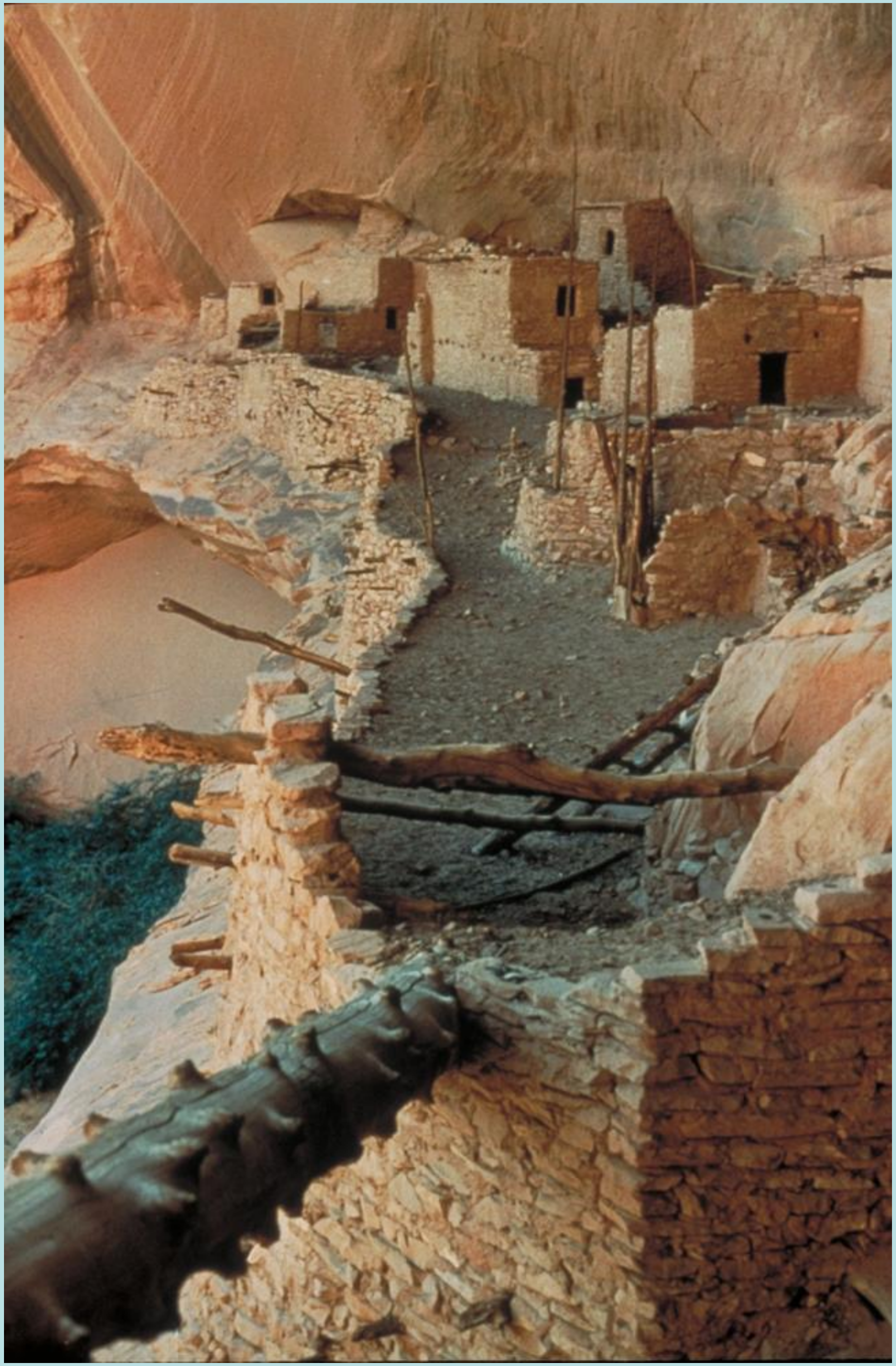


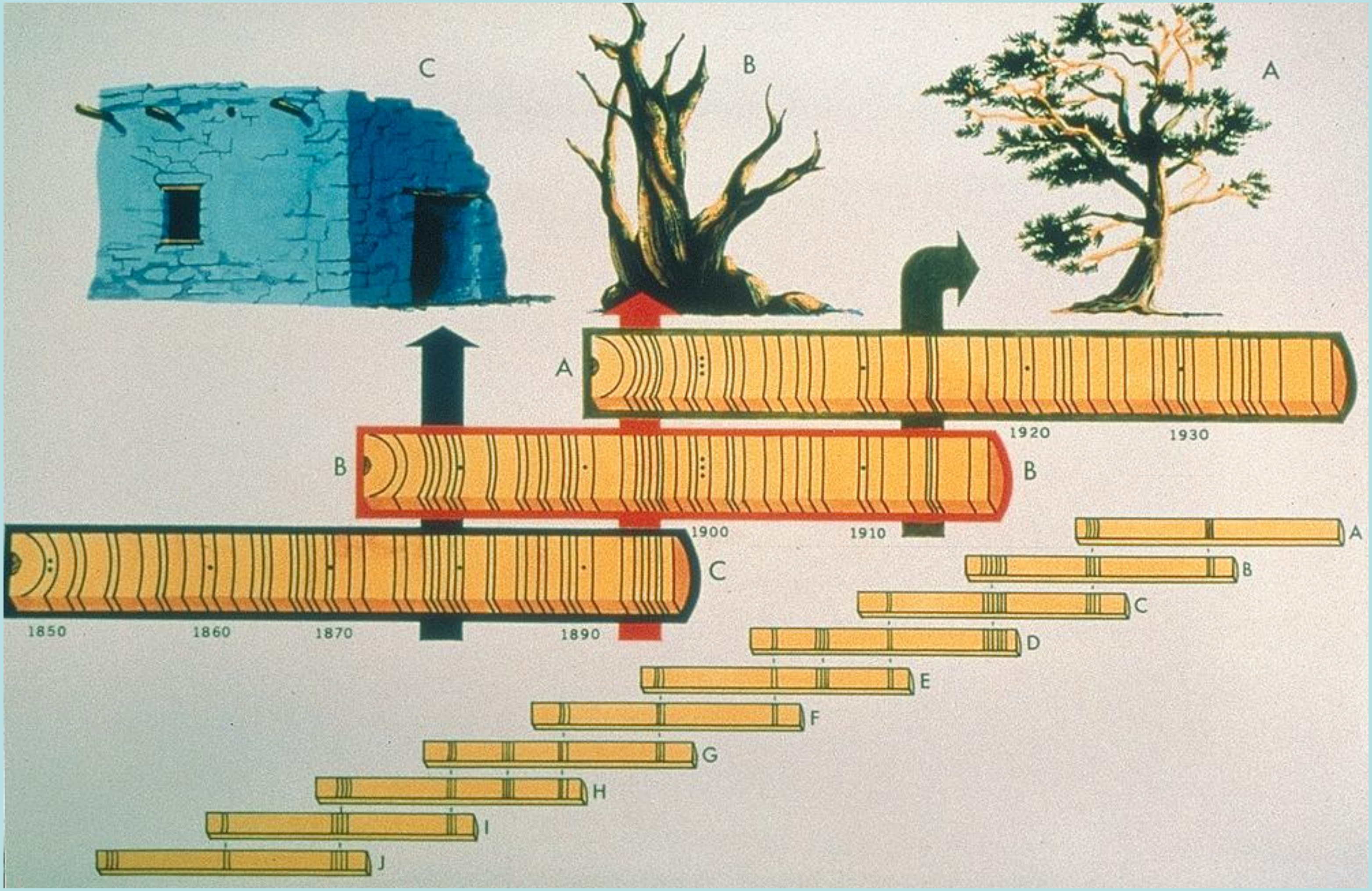
Plate 4.1 The Mer de Glace reached out on to the floor of the Arve valley in 1823 when it was painted by Samuel Birmann. (*Au village des Prats*, Öffentliche Kunstsammlung Basel, Kupferstich-kabinett, Inv. Bi. 30. 125)


DALE MACKENZIE BROWN

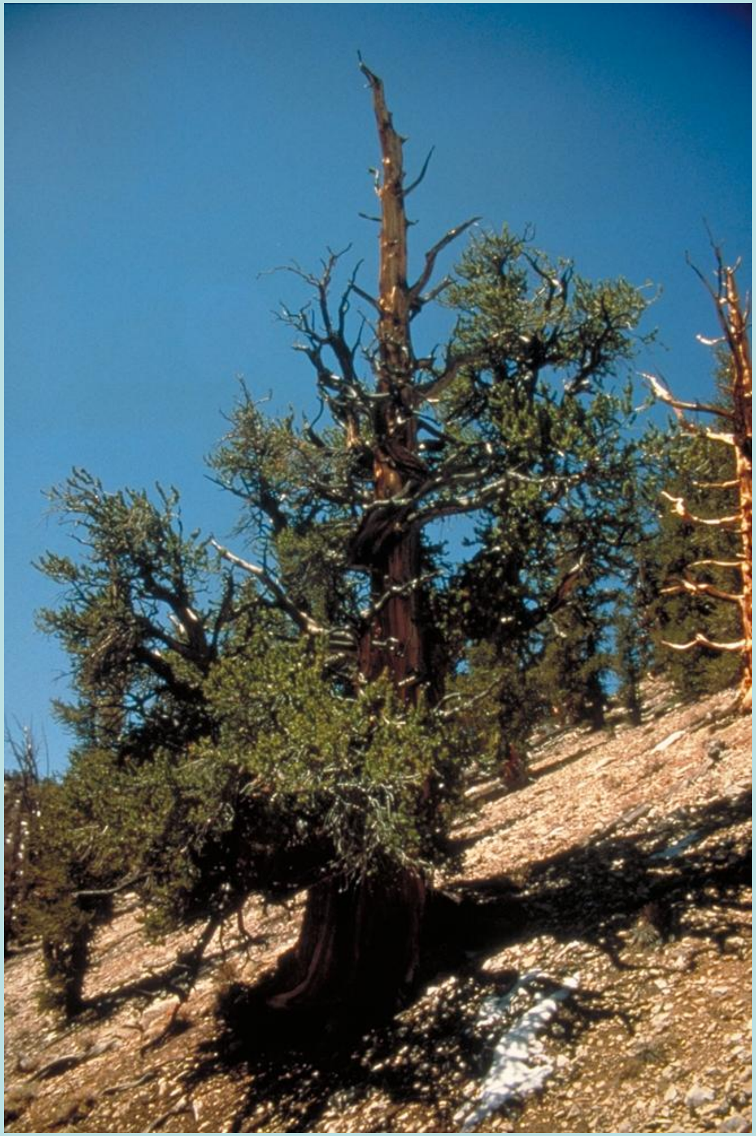
CROSS SECTION of a CONIFER

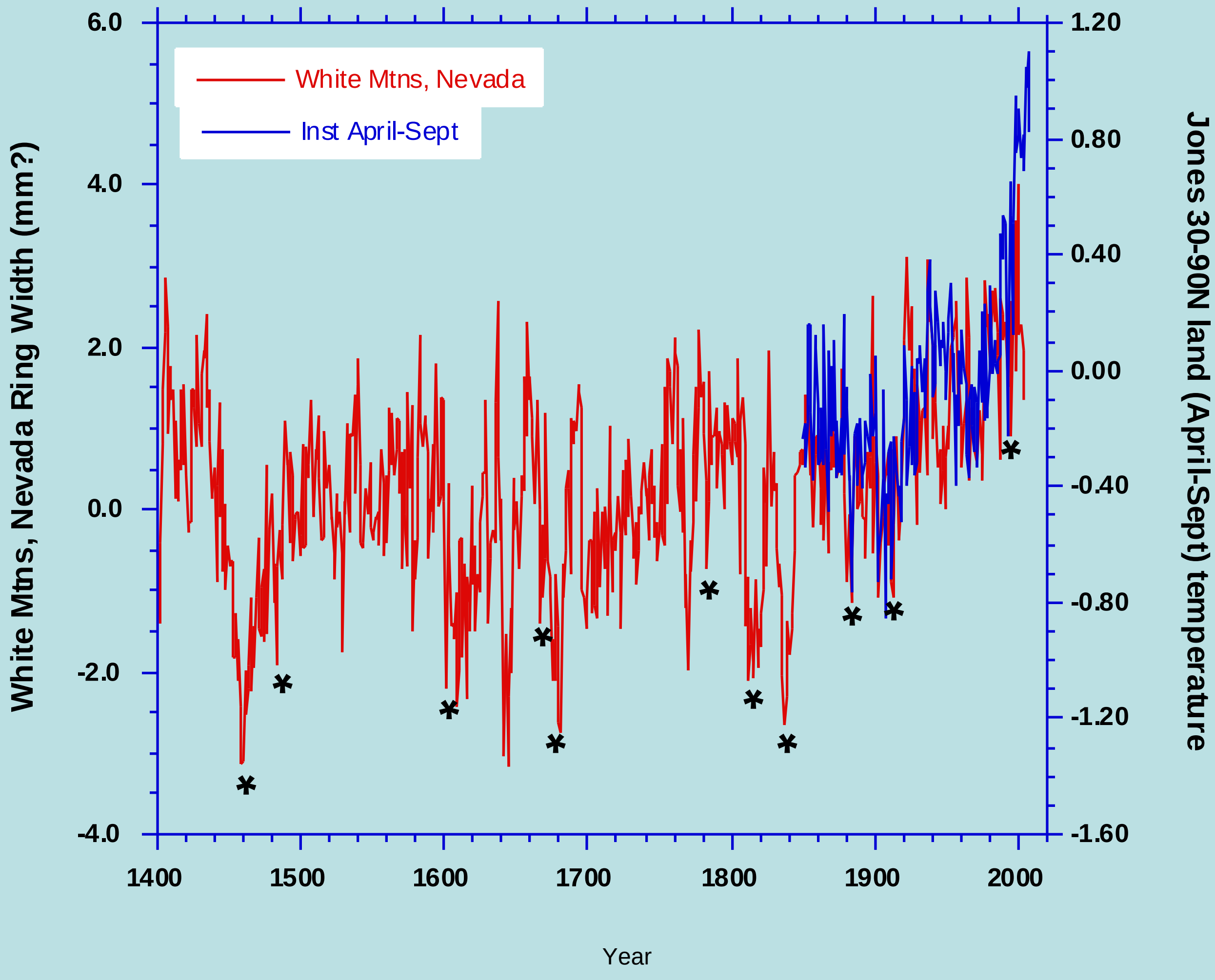


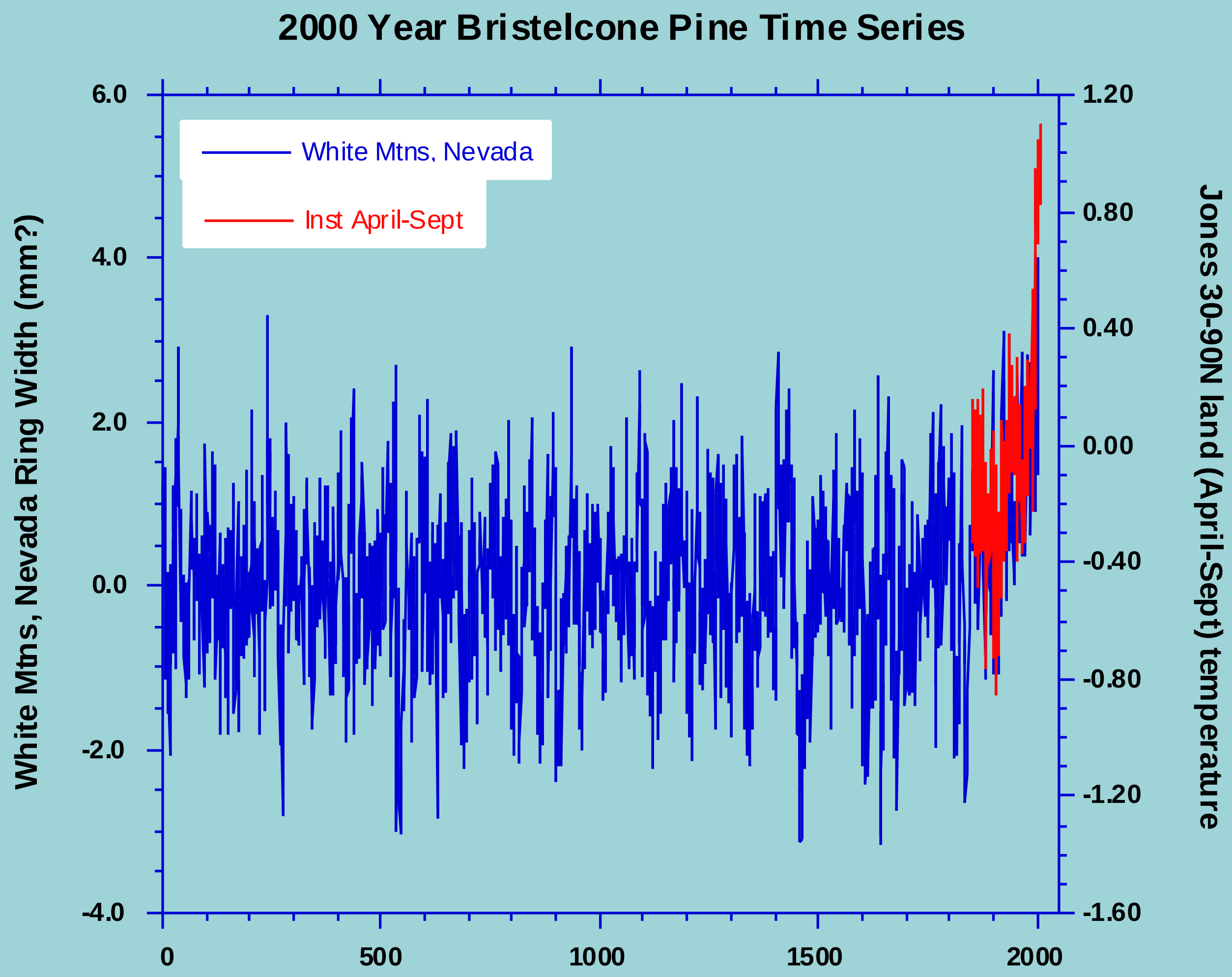




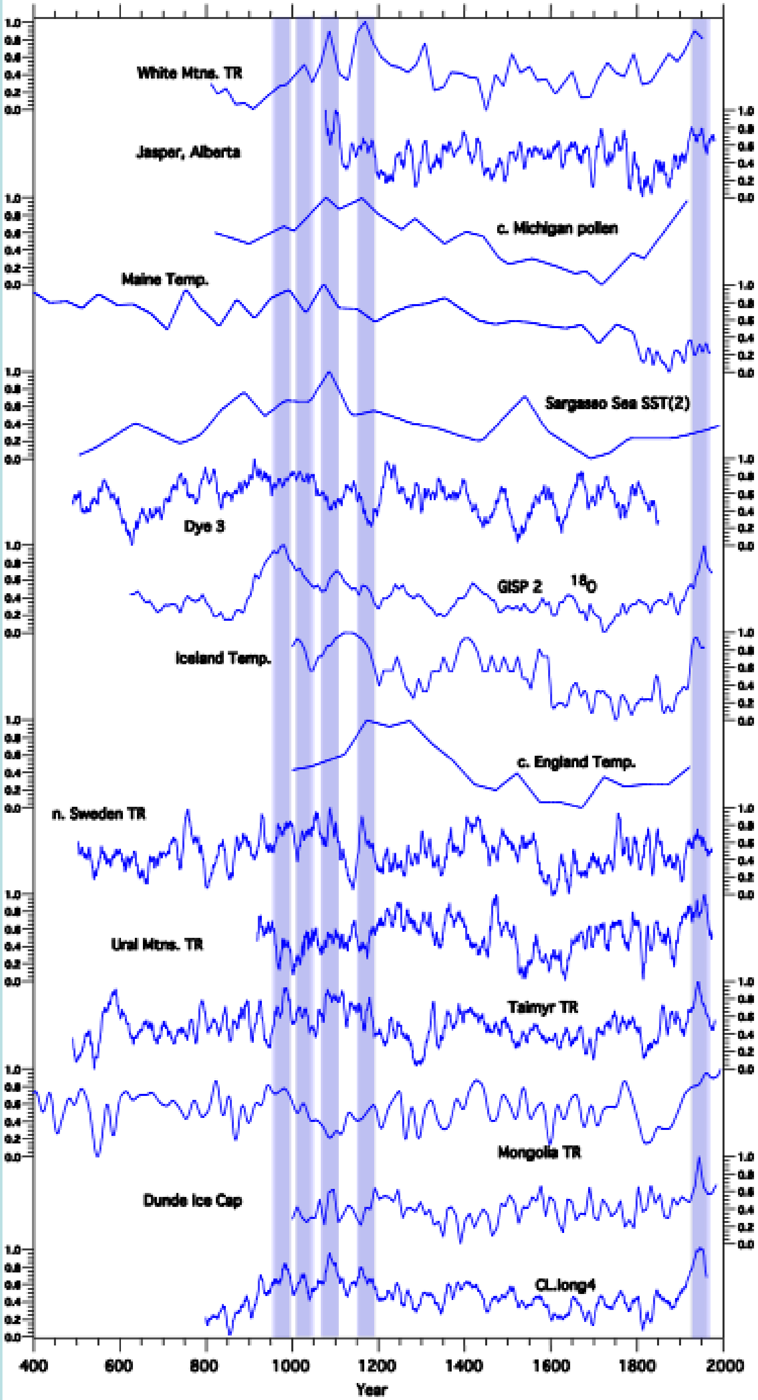
C
B
A
A
B
B
C
1850
1860
1870
1890
1900
1910
1920
1930
A
B
C
D
E
F
G
H
I
J

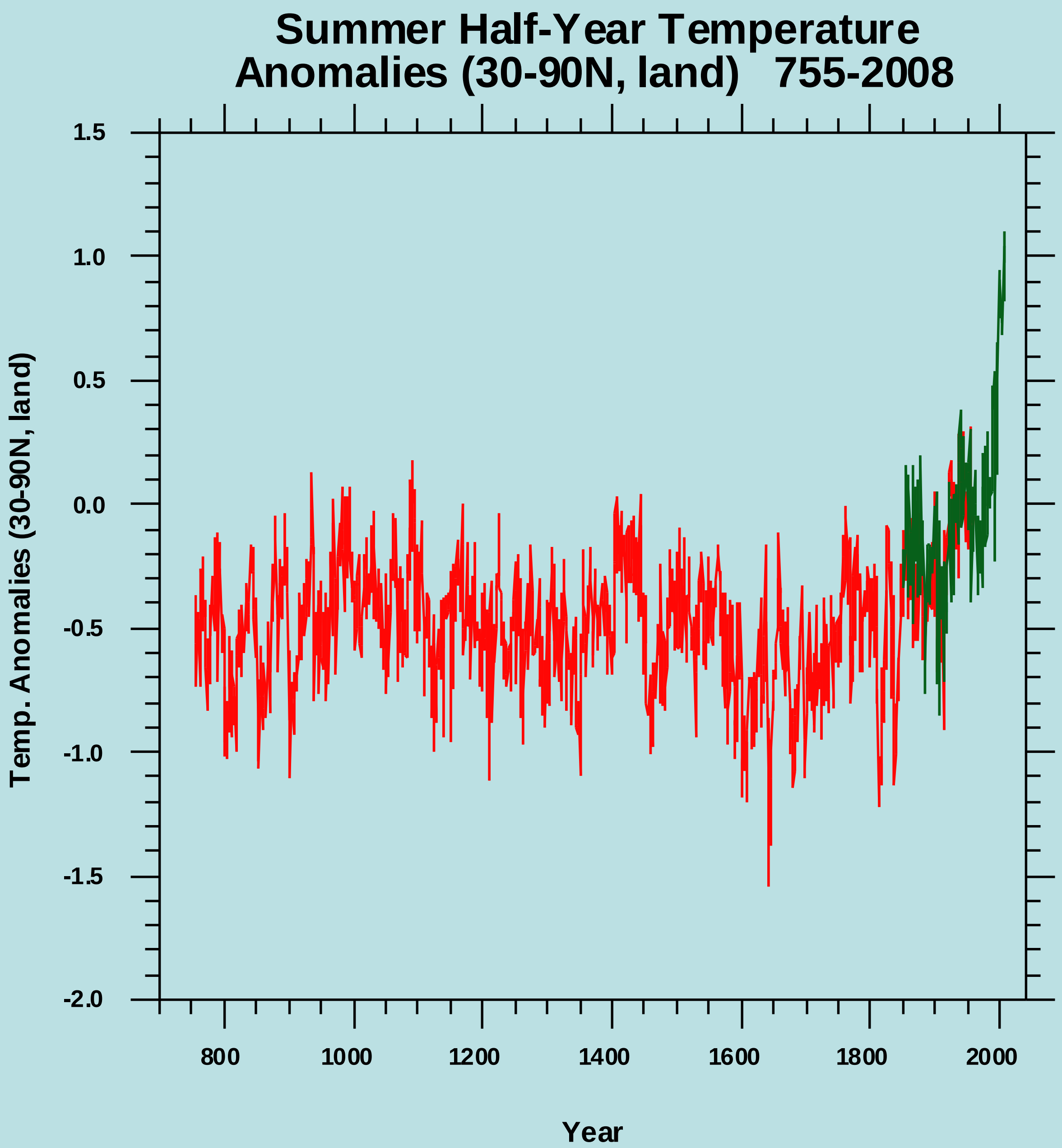



White Mtns, Nevada
Inst April-Sept
White Mtns, Nevada Ring Width (mm?)
Jones 30-90N land (April-Sept) temperature
Year
6.0
4.0
2.0
0.0
-2.0
-4.0
1.20
0.80
0.40
0.00
-0.40
-0.80
-1.20
-1.60
1400
1500
1600
1700
1800
1900
2000


2000 Year Bristelcone Pine Time Series
White Mtns, Nevada
Inst April-Sept
White Mtns, Nevada Ring Width (mm?)
Jones 30-90N land (April-Sept) temperature
6.0
4.0
2.0
0.0
-2.0
-4.0
1.20
0.80
0.40
0.00
-0.40
-0.80
-1.20
-1.60
0
500
1000
1500
2000

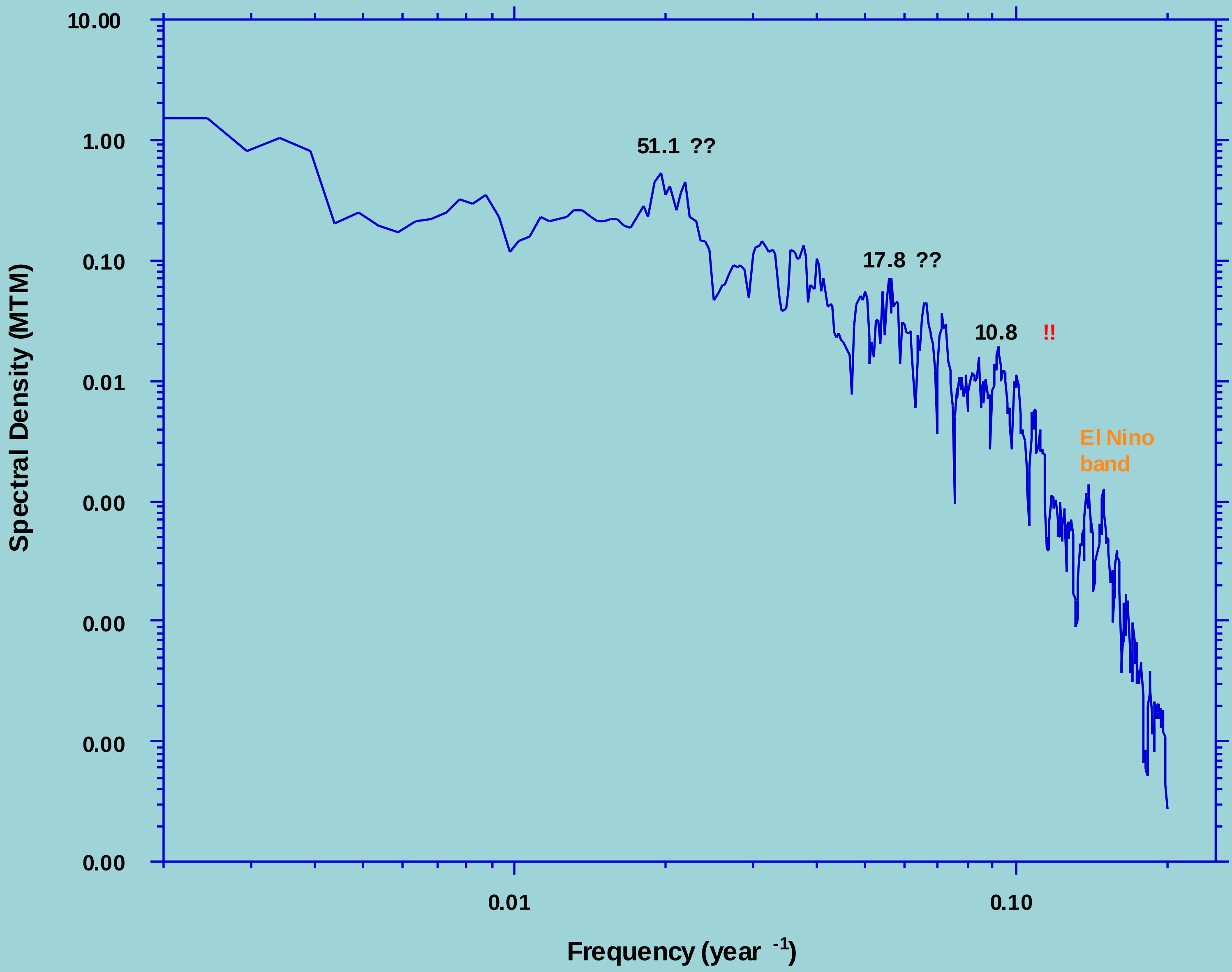
MEDIEVAL WARM PERIOD COMPARISONS

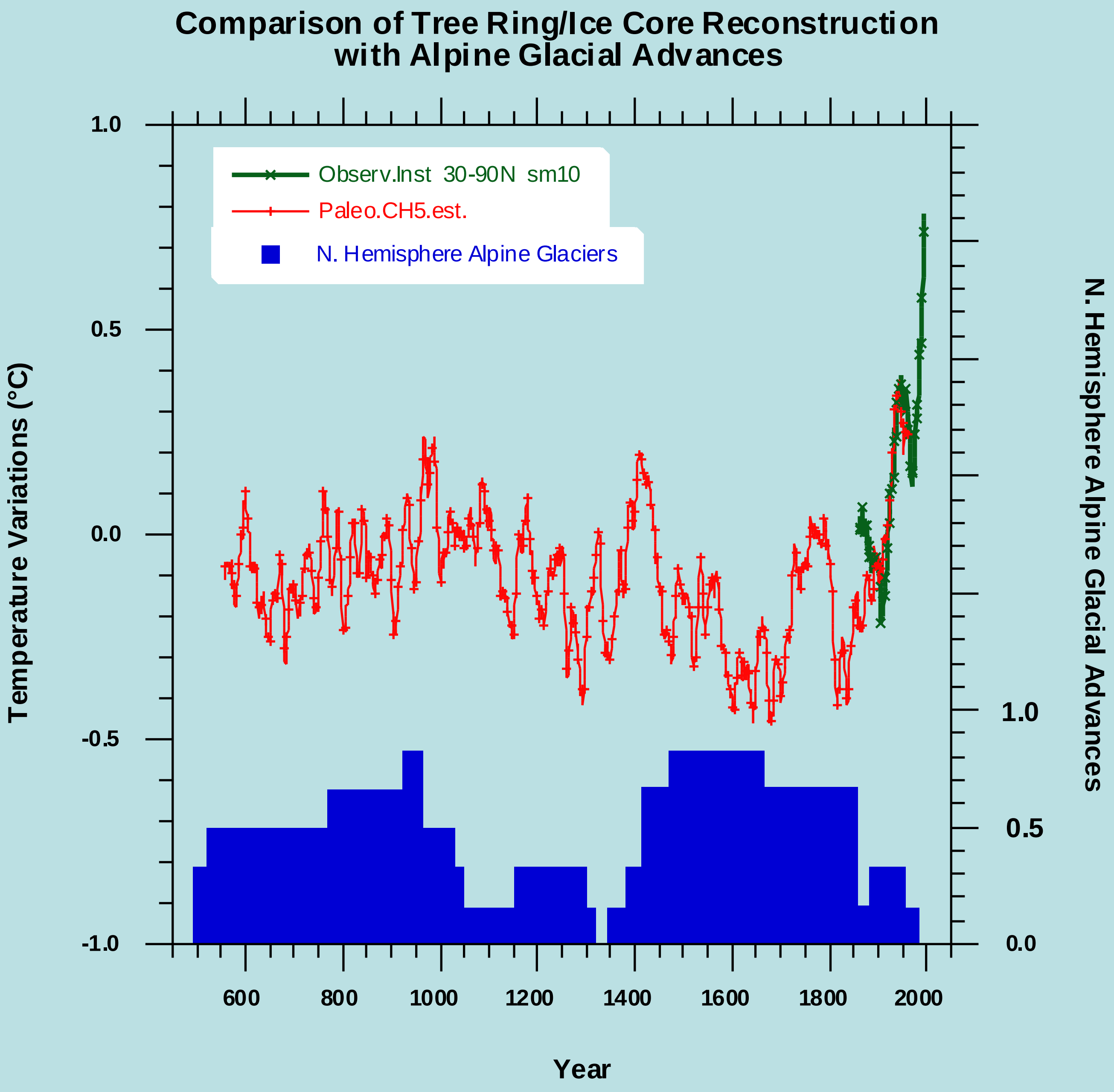




Summer Half-Year Temperature
Anomalies (30-90N, land) 755-2008
Temp. Anomalies (30-90N, land)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
800
1000
1200
1400
1600
1800
2000
Year

MTM Spectrum of 1000 Year Tree Ring Time Series (755-1800)



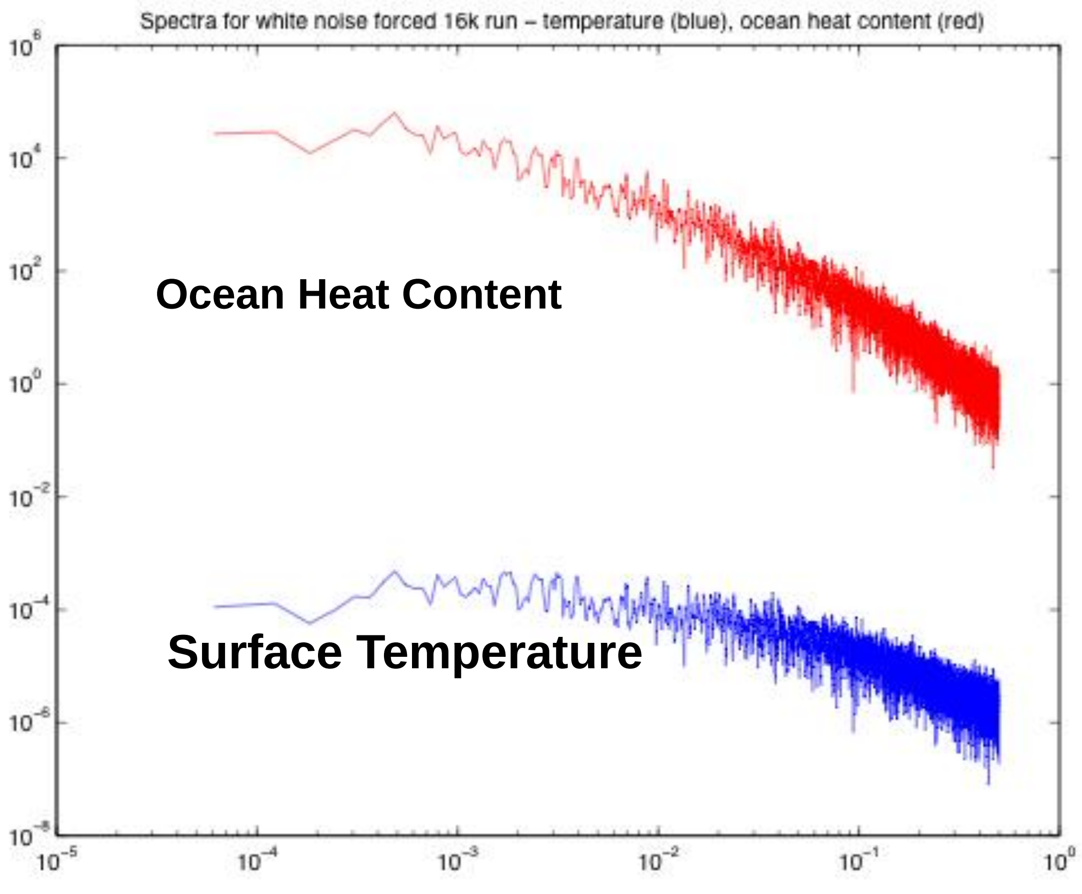

Comparison of Tree Ring/Ice Core Reconstruction
with Alpine Glacial Advances
Observ.Inst 30-90N sm10
Paleo.CH5.est.
N. Hemisphere Alpine Glaciers
1.0
0.5
0.0
-0.5
-1.0
Temperature Variations (°C)
600
800
1000
1200
1400
1600
1800
2000
Year
1.0
0.5
0.0
N. Hemisphere Alpine Glacial Advances

Causes?

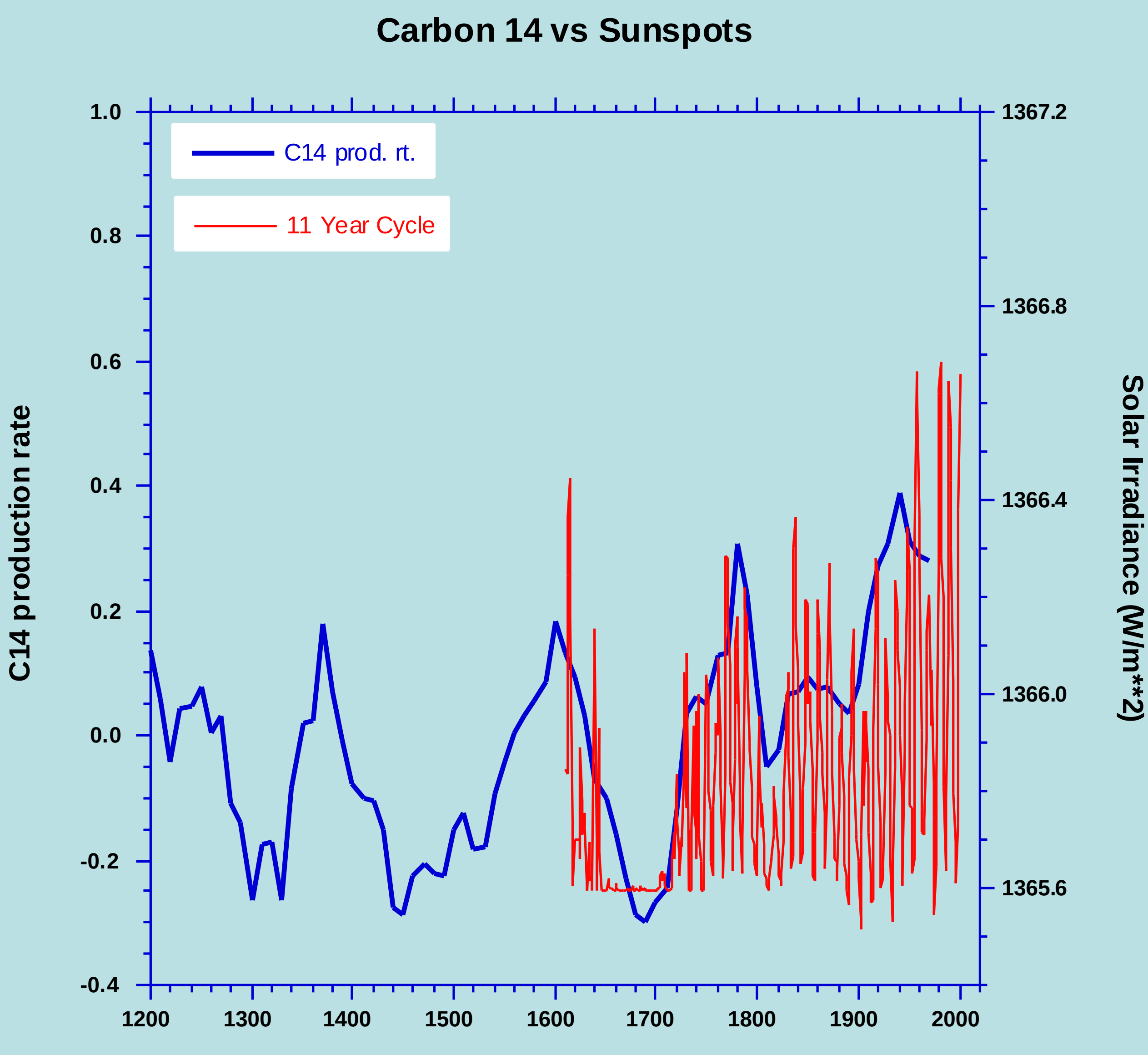
- natural variability, chaos?
- “natural forcing” – sun, volcanism?
- carbon dioxide?

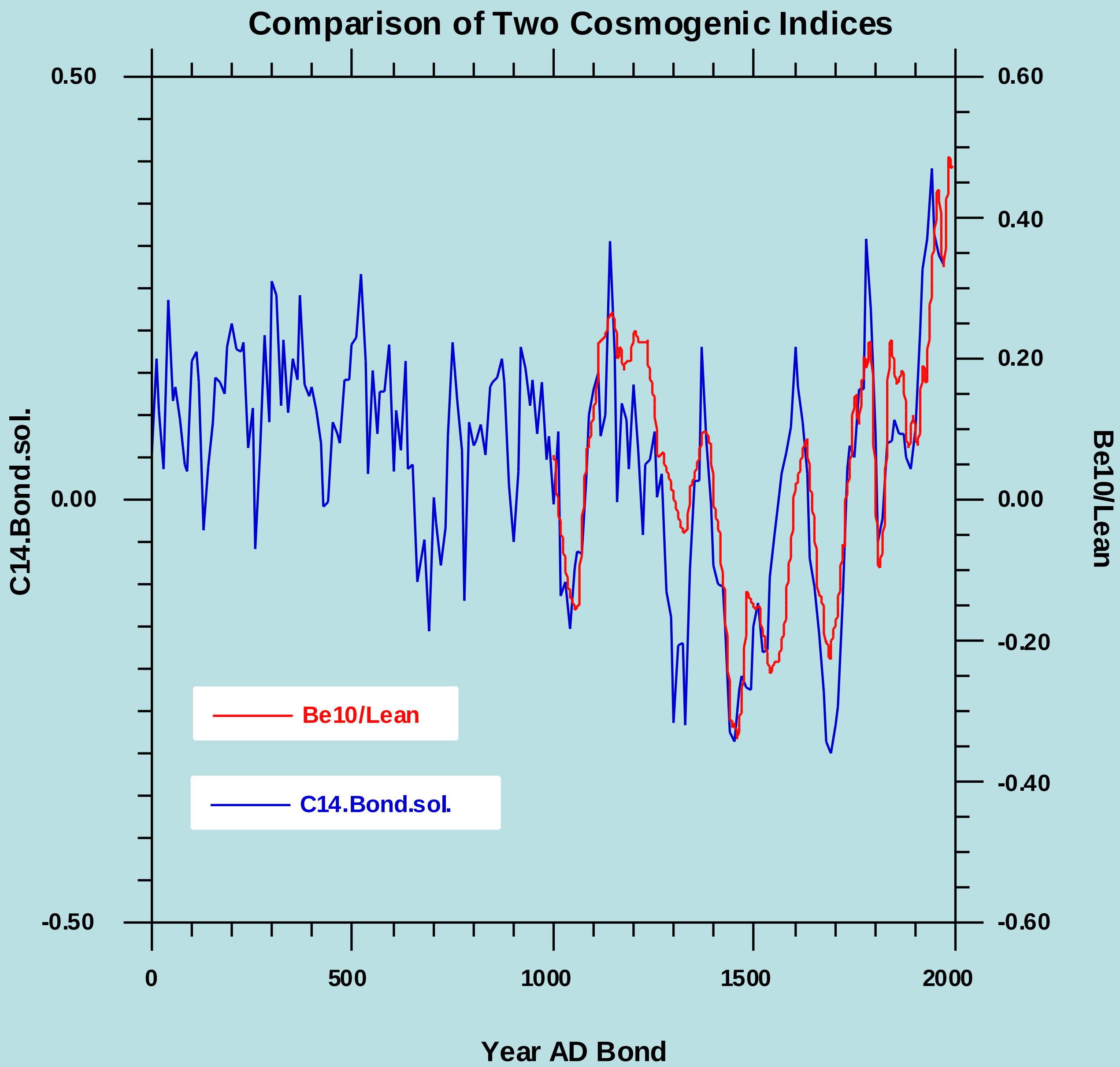

The
CHAOS
Cafe
McDonald's

White Noise Forcing (10 day time step) of 15,000 Year Energy Balance Model Run

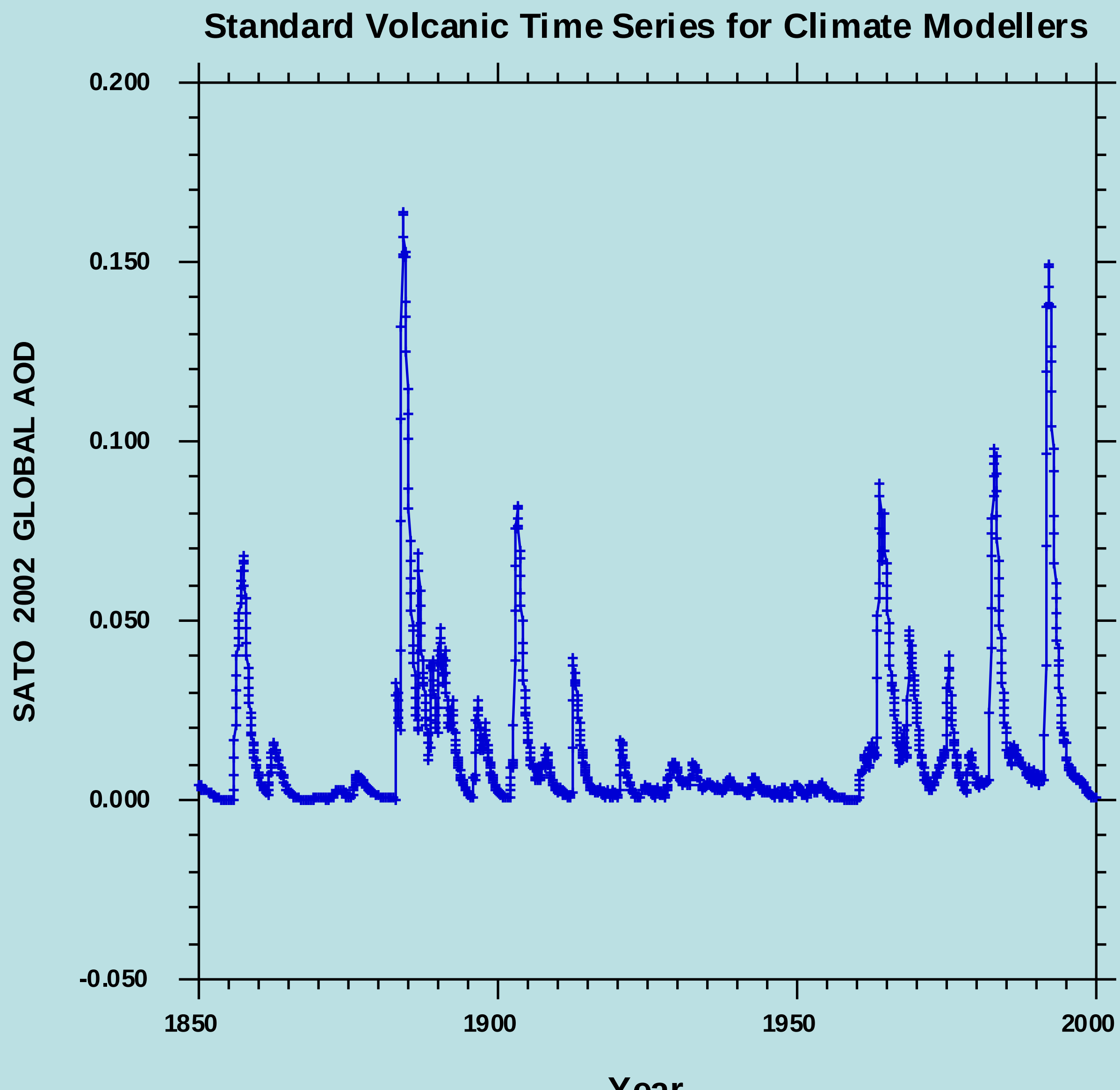


Frequency


Carbon 14 vs Sunspots
C14 prod. rt.
11 Year Cycle
C14 production rate
Solar Irradiance (W/m**2)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
1367.2
1366.8
1366.4
1366.0
1365.6
1200
1300
1400
1500
1600
1700
1800
1900
2000


Comparison of Two Cosmogenic Indices
0.50
0.00
-0.50
C14.Bond.sol.
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
Be10/Lean
Be10/Lean
C14.Bond.sol.
0
500
1000
1500
2000
Year AD Bond

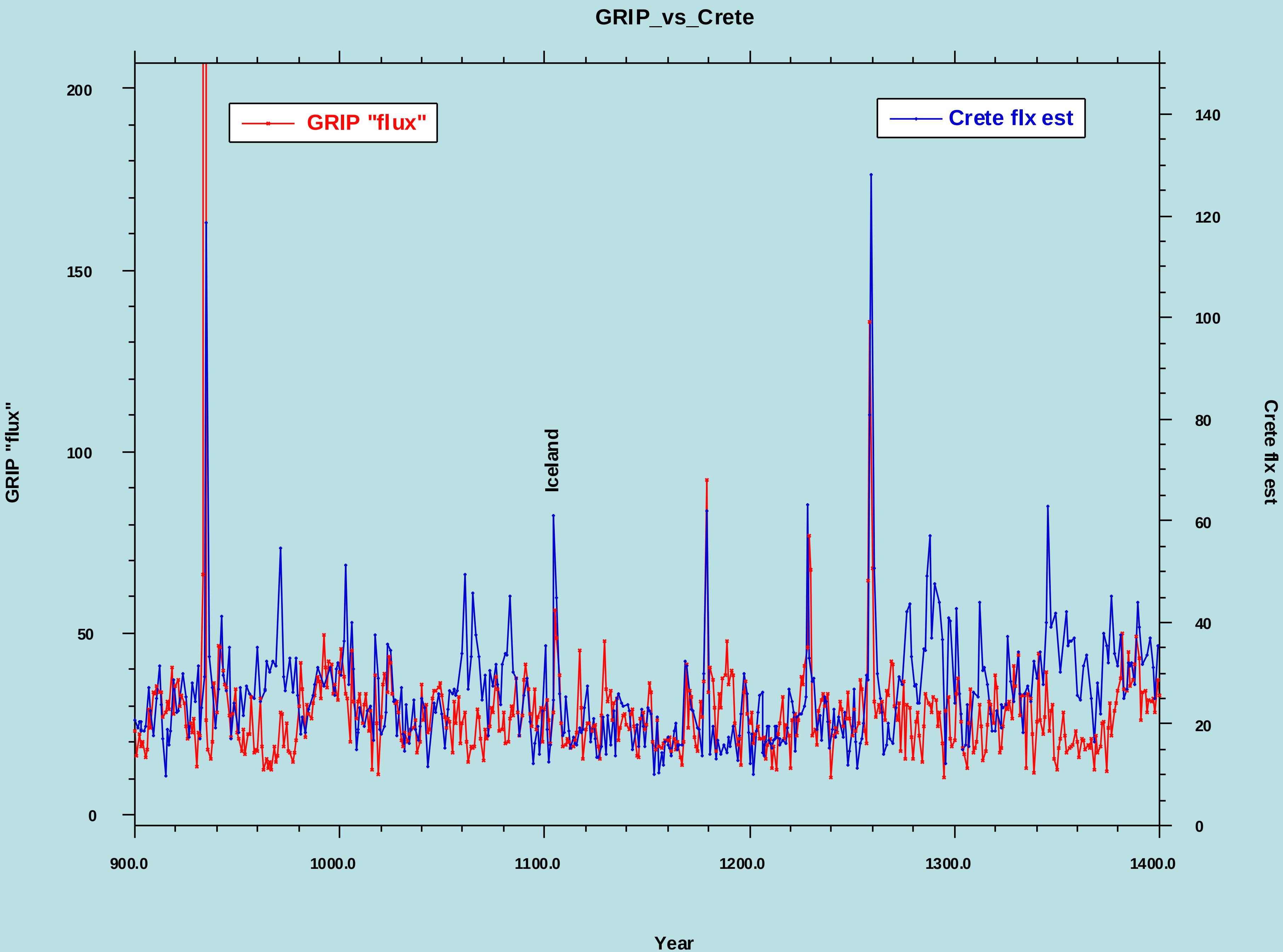
Tambora Volcano



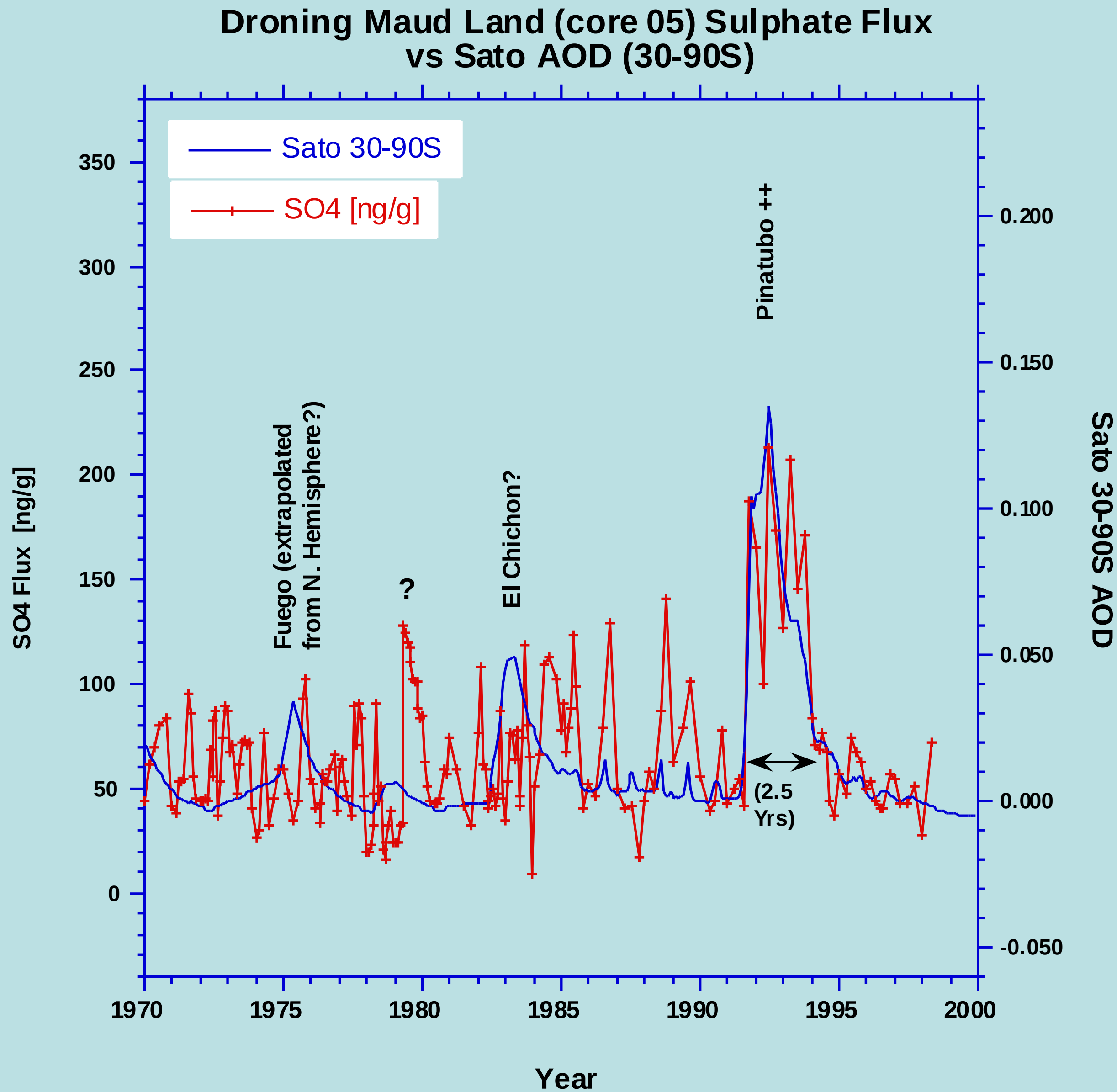
Standard Volcanic Time Series for Climate Modellers
SATO 2002 GLOBAL AOD
0.200
0.150
0.100
0.050
0.000
-0.050
1850
1900
1950
2000
Year

Extruding a core

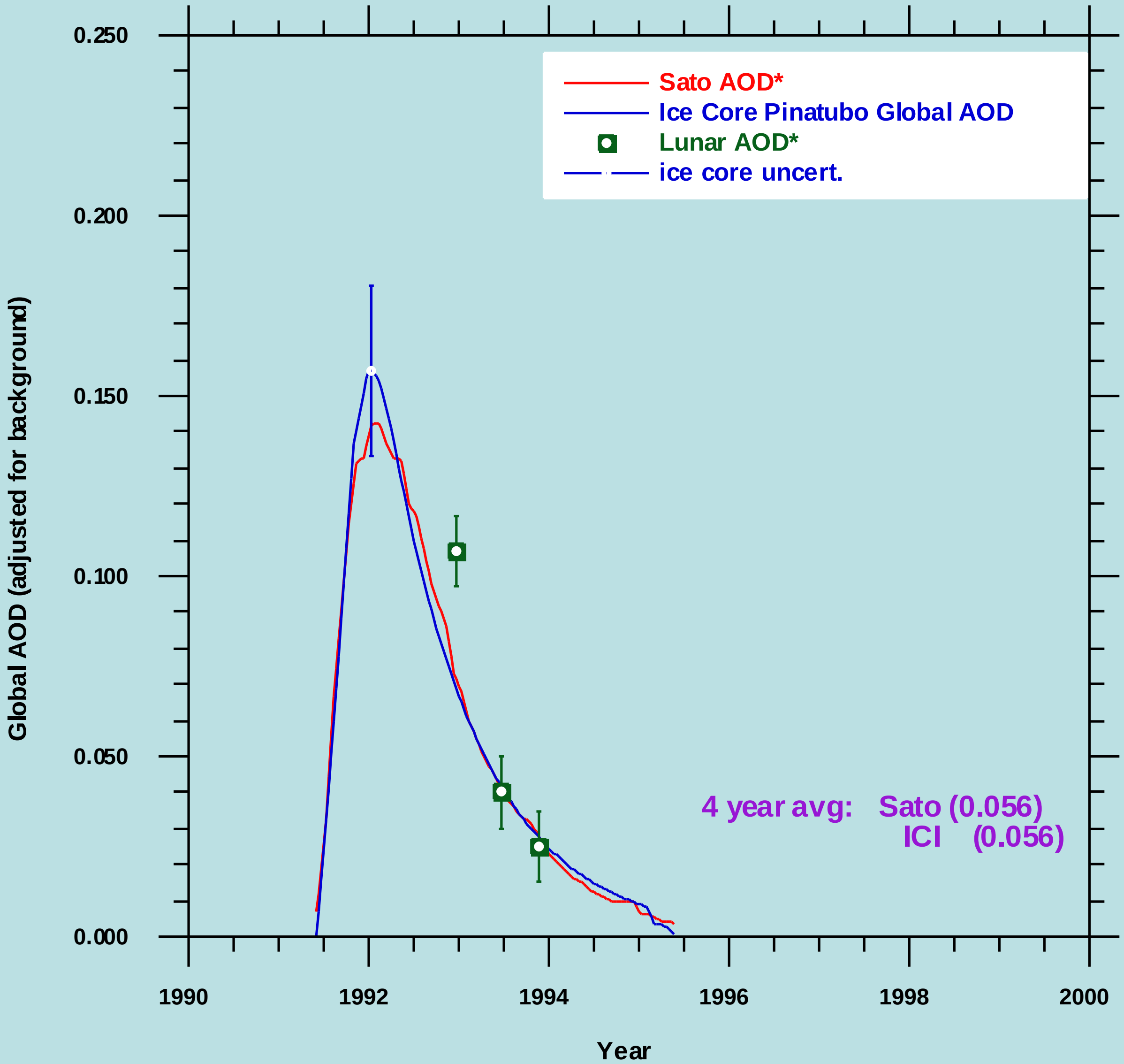
Geoffrey Hargreaves, Curator
USGS/National Ice Core Laboratory



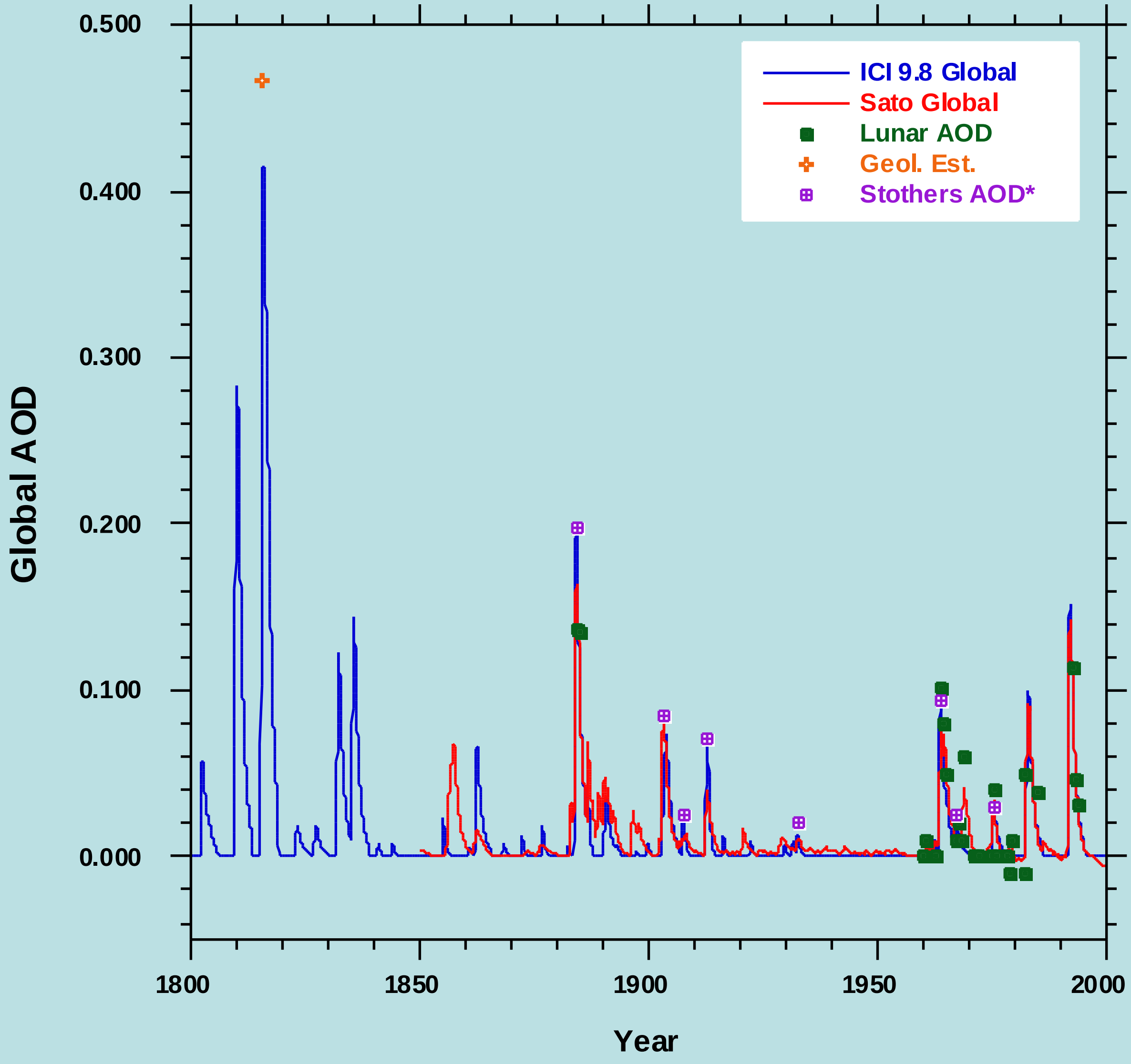
GRIP_vs_Crete
GRIP "flux"
Crete flx est
Iceland
200
150
100
50
0
140
120
100
80
60
40
20
0
900.0
1000.0
1100.0
1200.0
1300.0
1400.0
Year
GRIP "flux"
Crete flx est

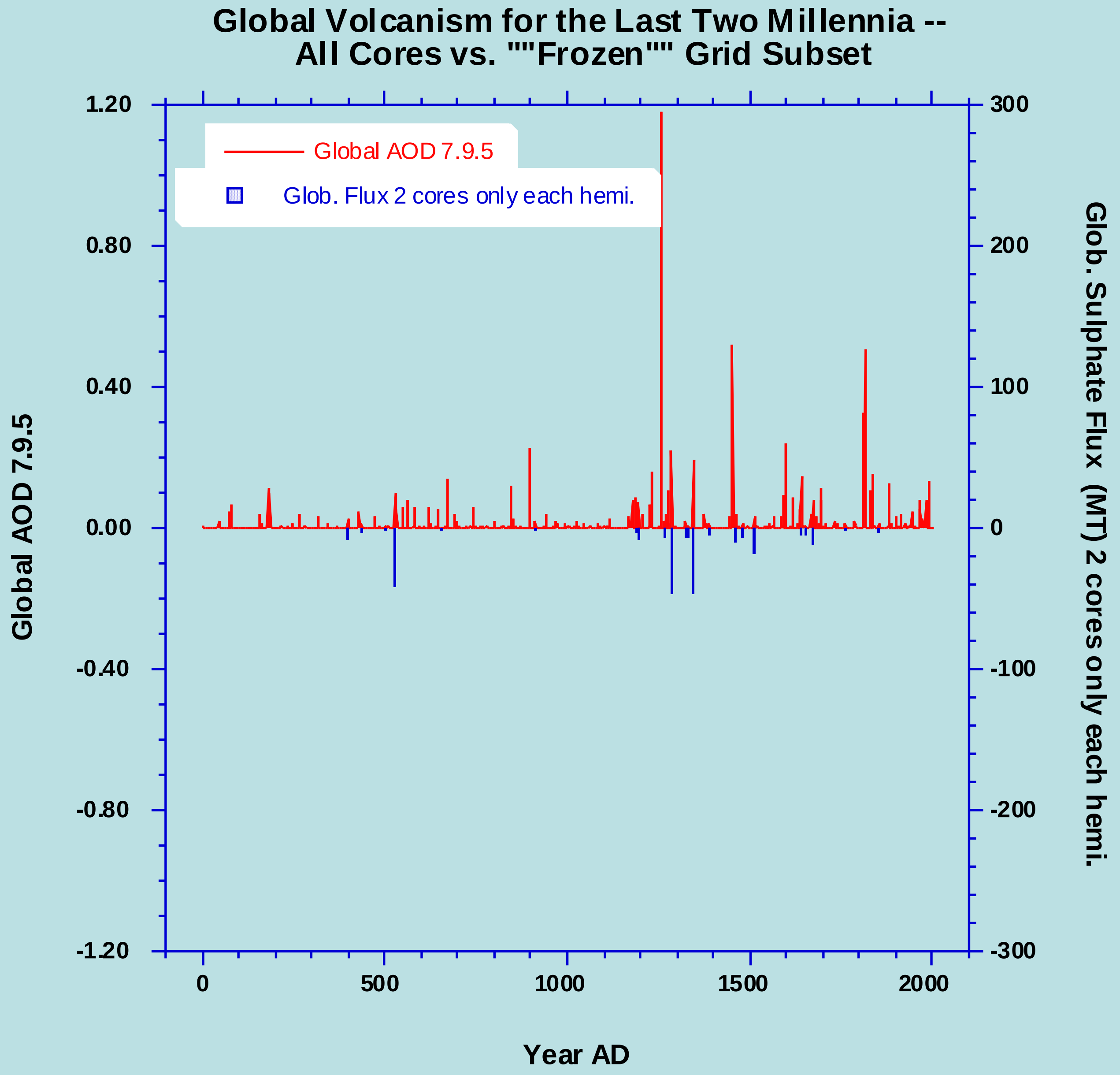

Droning Maud Land (core 05) Sulphate Flux
vs Sato AOD (30-90S)
Sato 30-90S
SO4 [ng/g]
Fuego (extrapolated
from N. Hemisphere?)
?
El Chichon?
Pinatubo ++
(2.5
Yrs)
SO4 Flux [ng/g]
Sato 30-90S AOD
Year
0
50
100
150
200
250
300
350
-0.050
0.000
0.050
0.100
0.150
0.200
1970
1975
1980
1985
1990
1995
2000

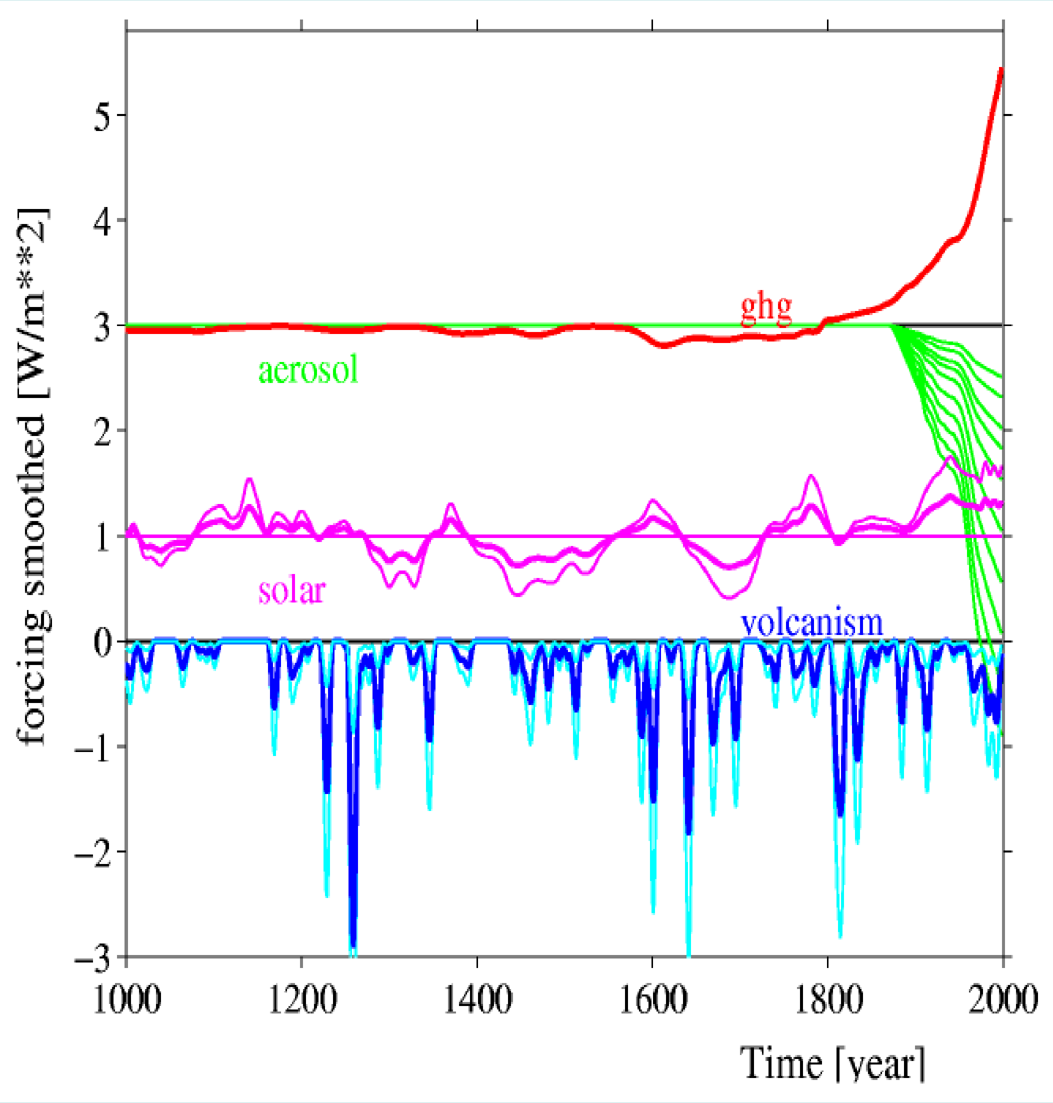
Calibration of Ice Core Sulphate Signal



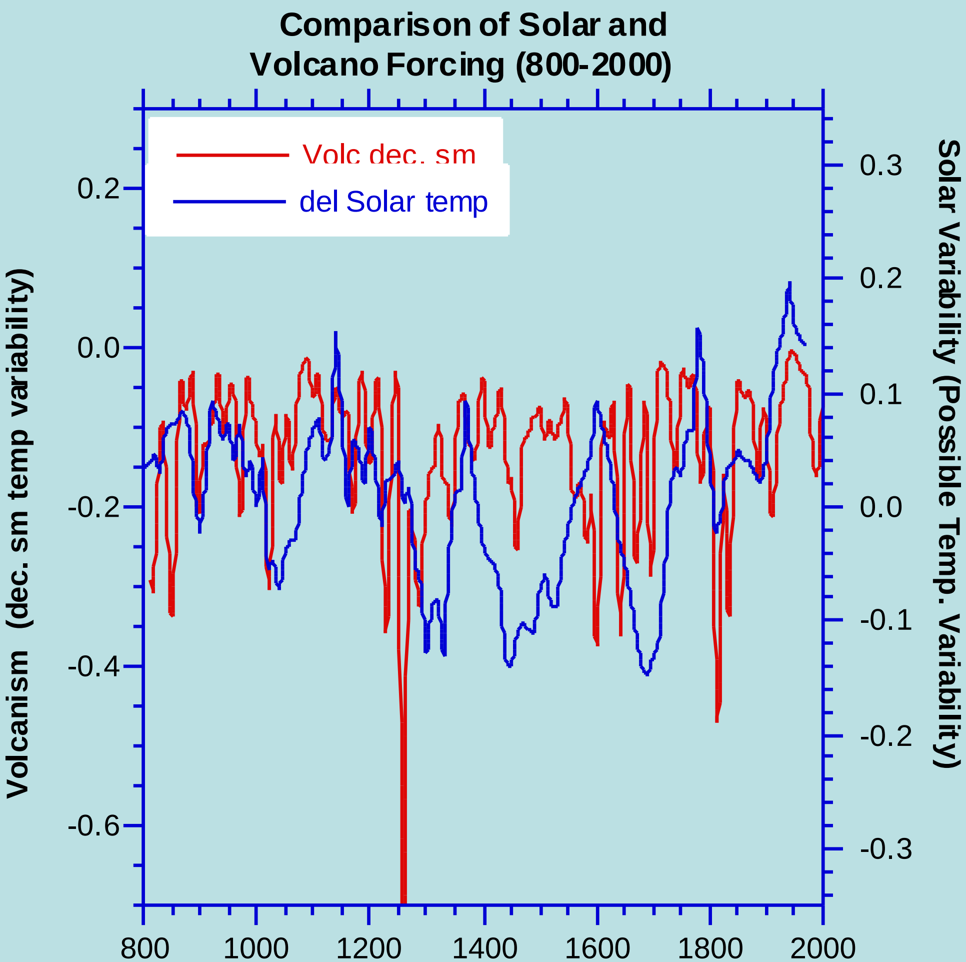
Calibration and Validation of New Volcanism Ice Core Index (ICI) Version 9.8



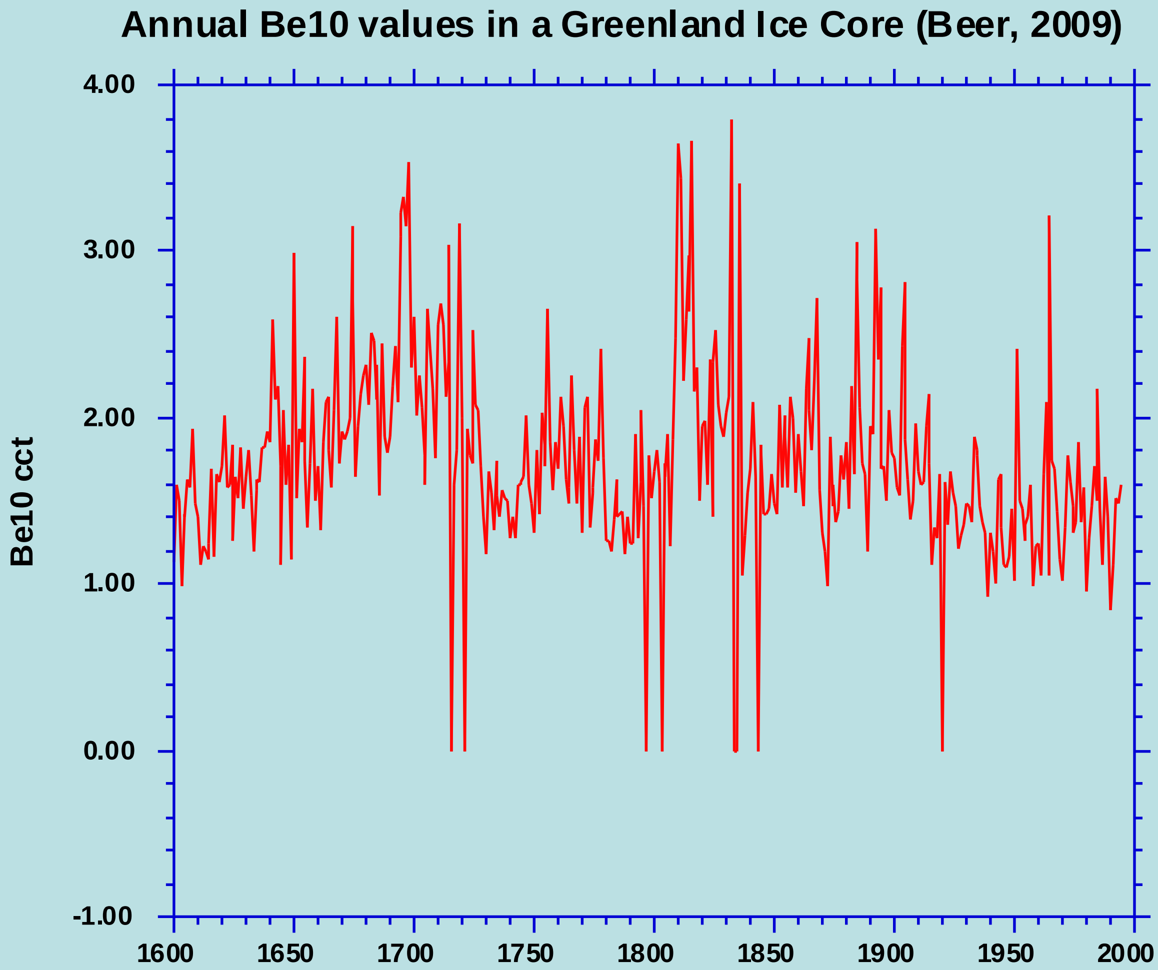

Global Volcanism for the Last Two Millennia --
All Cores vs. ""Frozen"" Grid Subset
Global AOD 7.9.5
Glob. Flux 2 cores only each hemi.
Global AOD 7.9.5
Glob. Sulphate Flux (MT) 2 cores only each hemi.
Year AD
1.20
0.80
0.40
0.00
-0.40
-0.80
-1.20
300
200
100
0
-100
-200
-300
0
500
1000
1500
2000



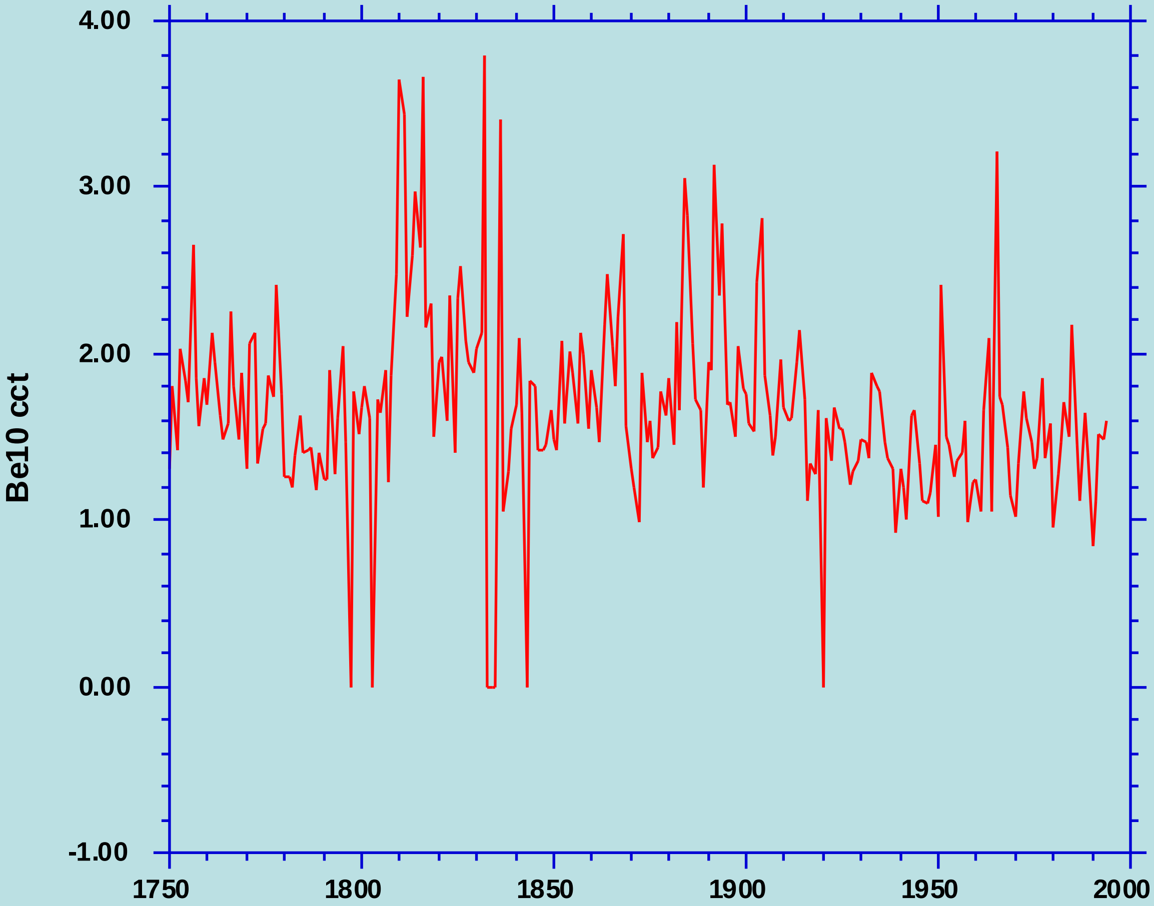
ghg
aerosol
solar
volcanism
forcing smoothed [W/m**2]
5
4
3
2
1
0
−1
−2
−3
1000
1200
1400
1600
1800
2000
Time [year]

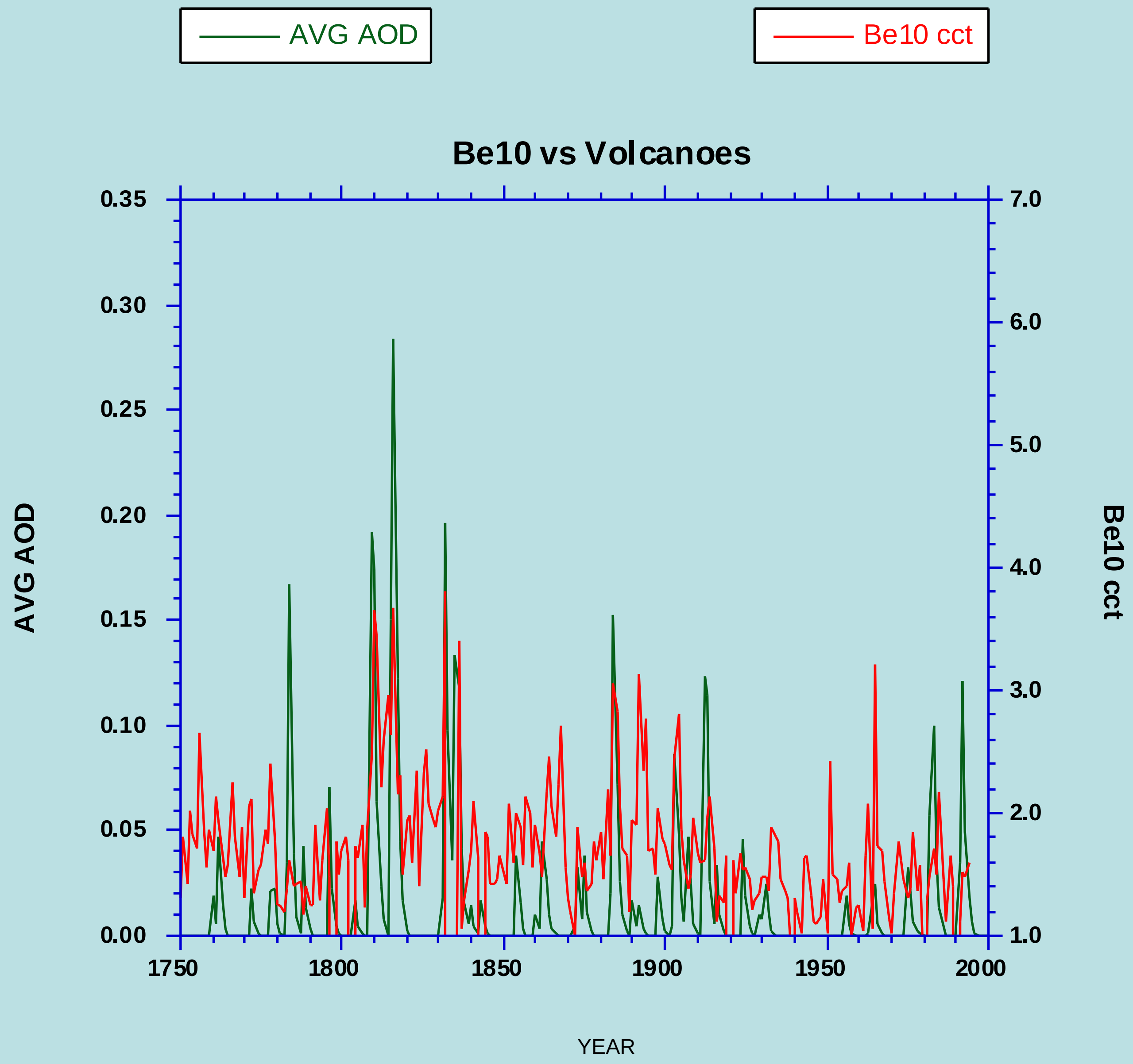


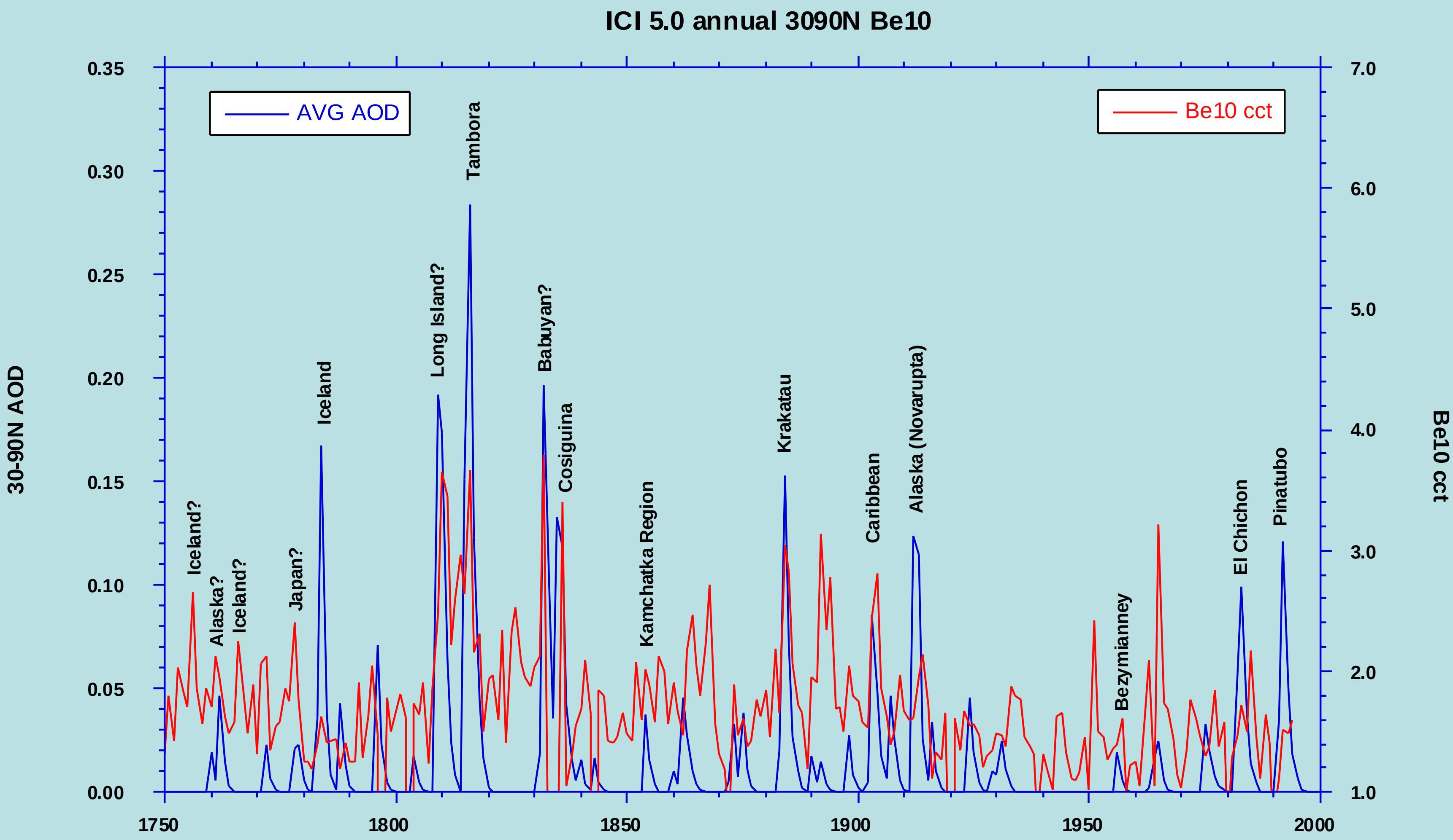
Crowley - Fig 6


Annual Be10 values in a Greenland Ice Core (Beer, 2009)
Be10 cct
4.00
3.00
2.00
1.00
0.00
-1.00
1600
1650
1700
1750
1800
1850
1900
1950
2000

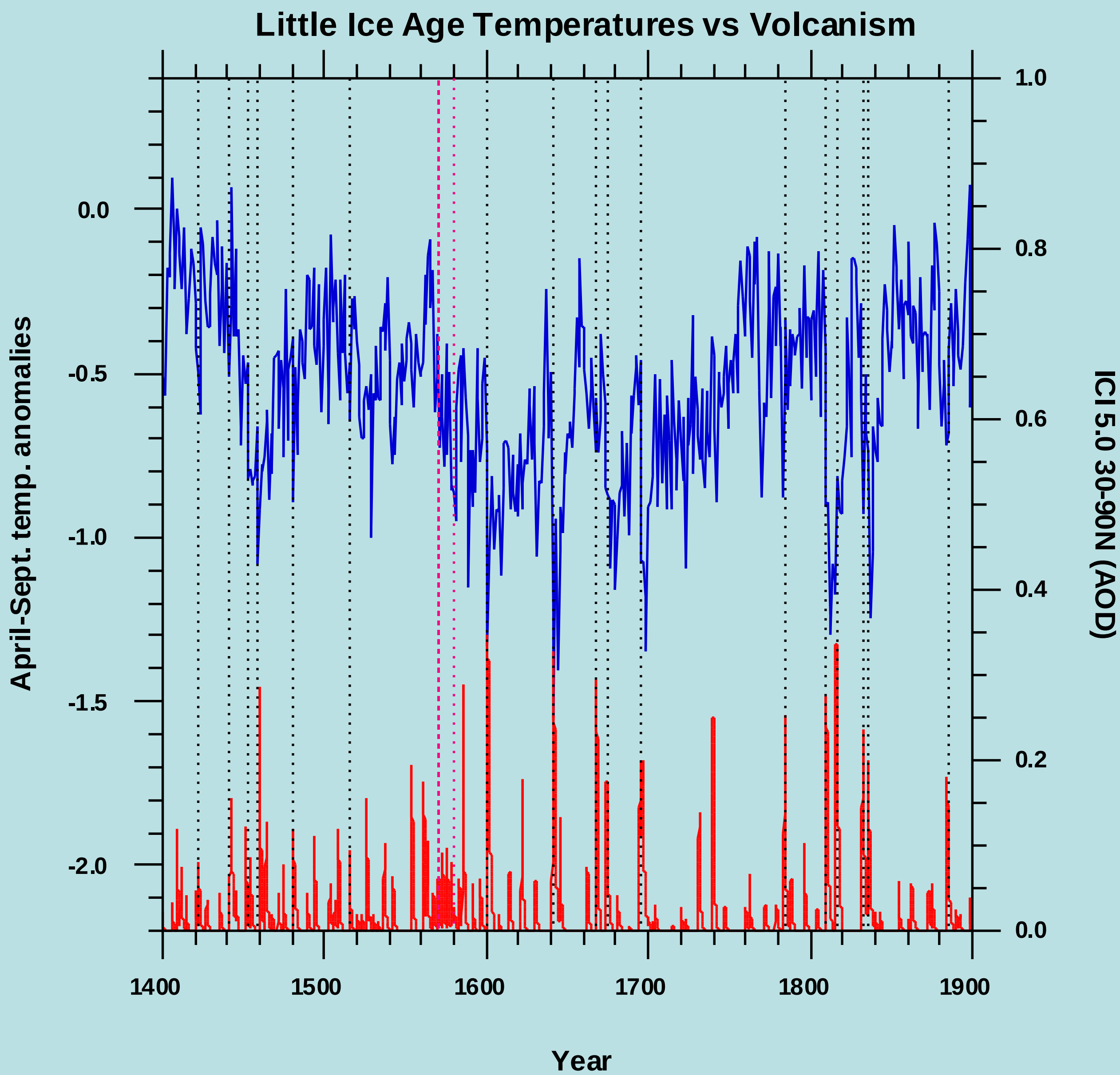
Annual Be10 values in a Greenland Ice Core (Beer, 2009)

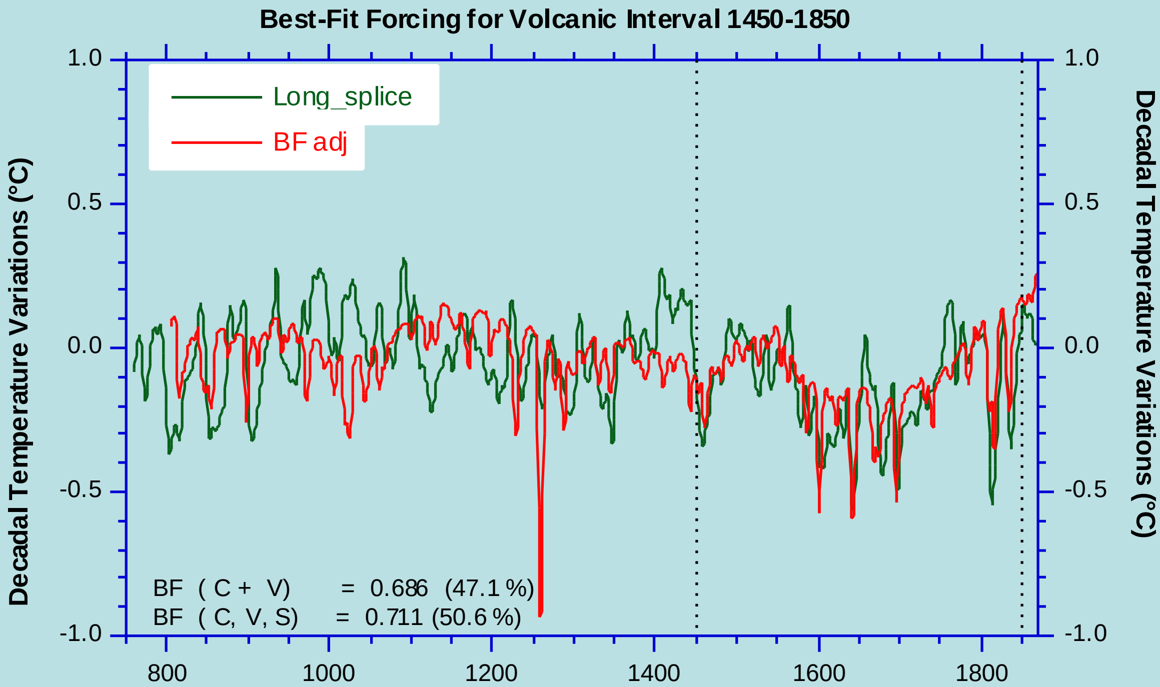



AVG AOD
Be10 cct
Be10 vs Volcanoes
AVG AOD
Be10 cct
YEAR
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
7.0
6.0
5.0
4.0
3.0
2.0
1.0
1750
1800
1850
1900
1950
2000

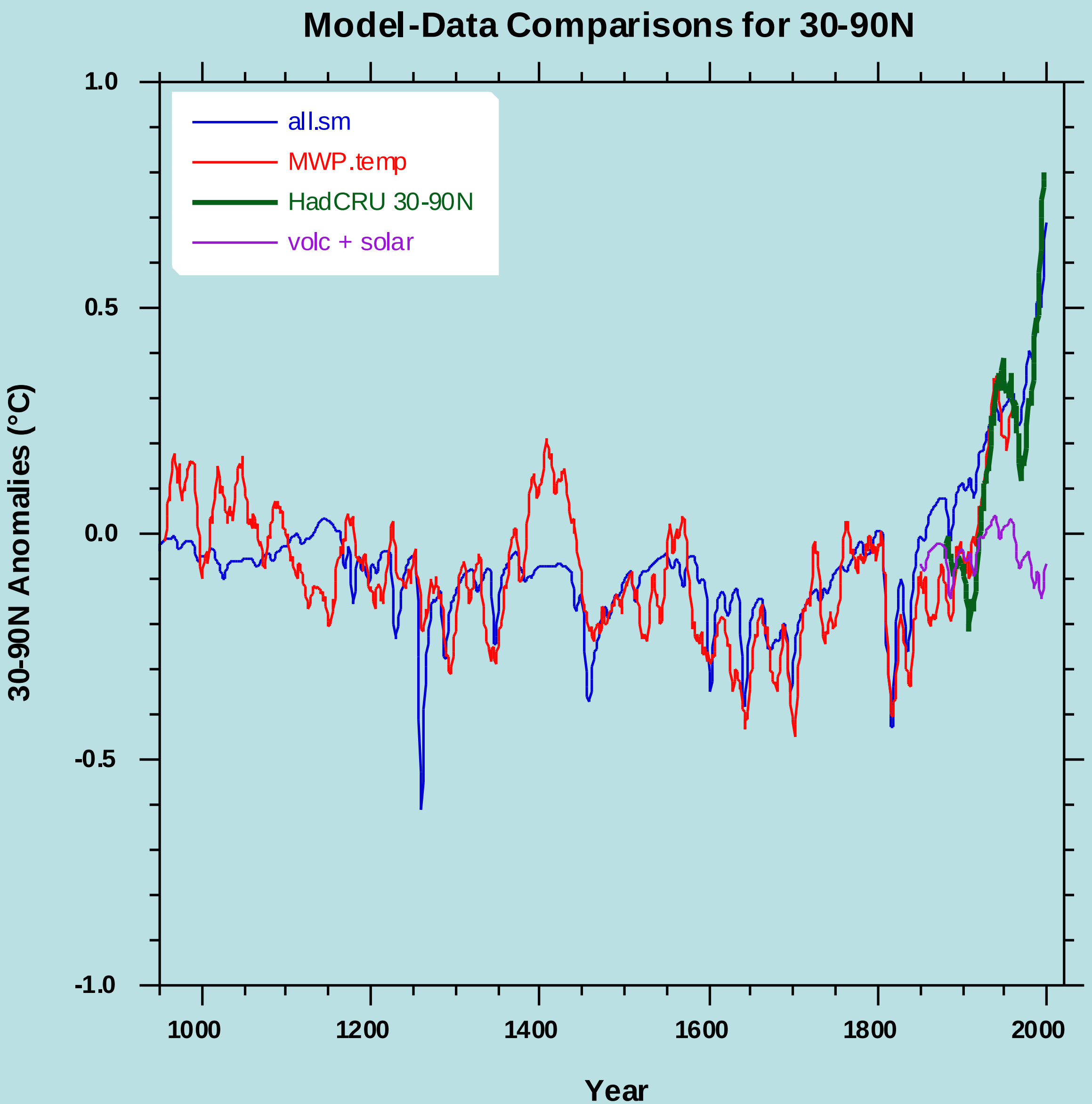


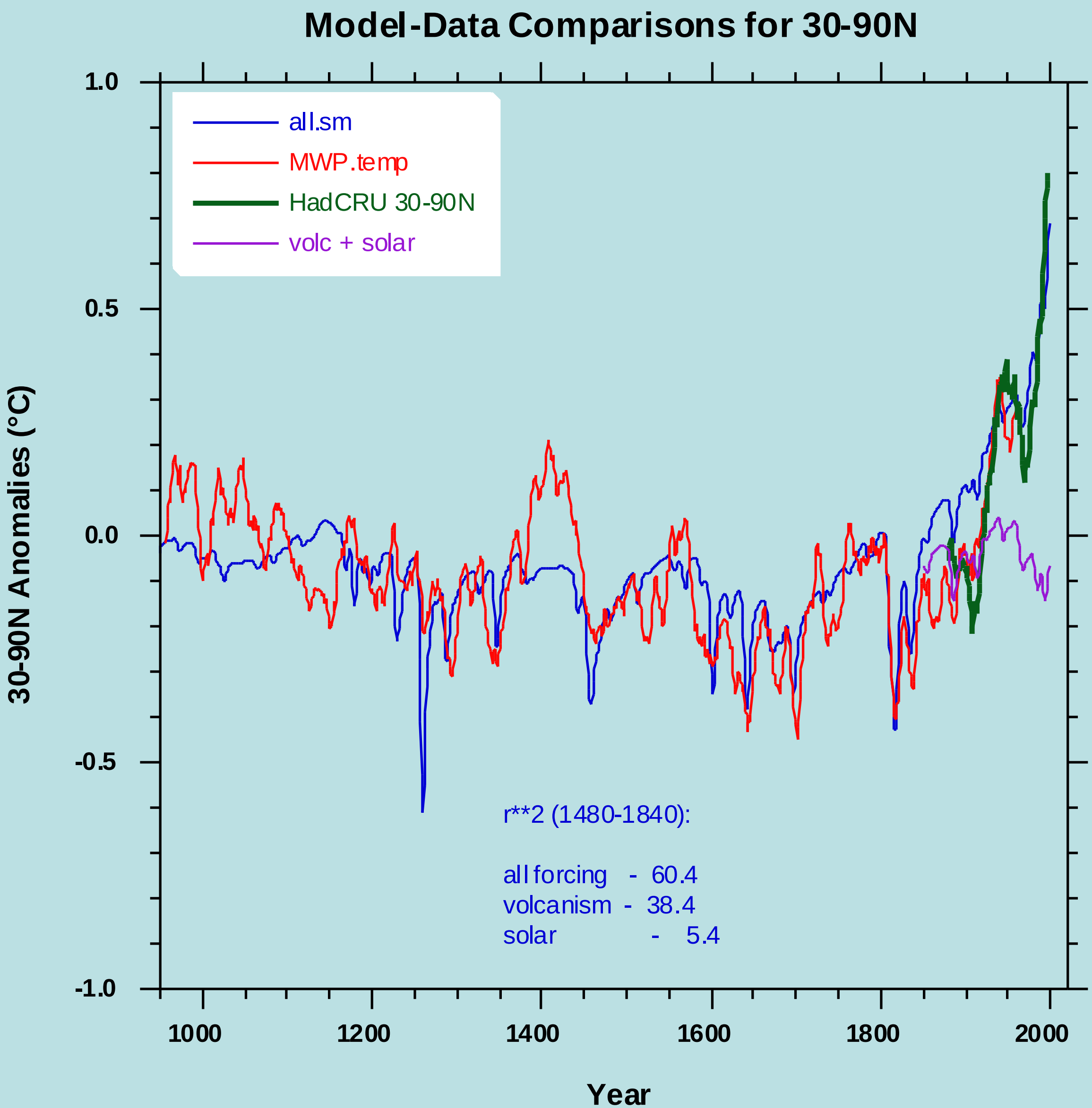
ICI 5.0 annual 3090N Be10
AVG AOD
Be10 cct
30-90N AOD
Be10 cct
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
7.0
6.0
5.0
4.0
3.0
2.0
1.0
1750
1800
1850
1900
1950
2000
Iceland?
Alaska?
Iceland?
Japan?
Iceland
Long Island?
Tambora
Babuyan?
Cosiguina
Kamchatka Region
Krakatau
Caribbean
Alaska (Novarupta)
Bezymianney
El Chichon
Pinatubo


Little Ice Age Temperatures vs Volcanism
April-Sept. temp. anomalies
0.0
-0.5
-1.0
-1.5
-2.0
1.0
0.8
0.6
0.4
0.2
0.0
ICI 5.0 30-90N (AOD)
1400
1500
1600
1700
1800
1900
Year

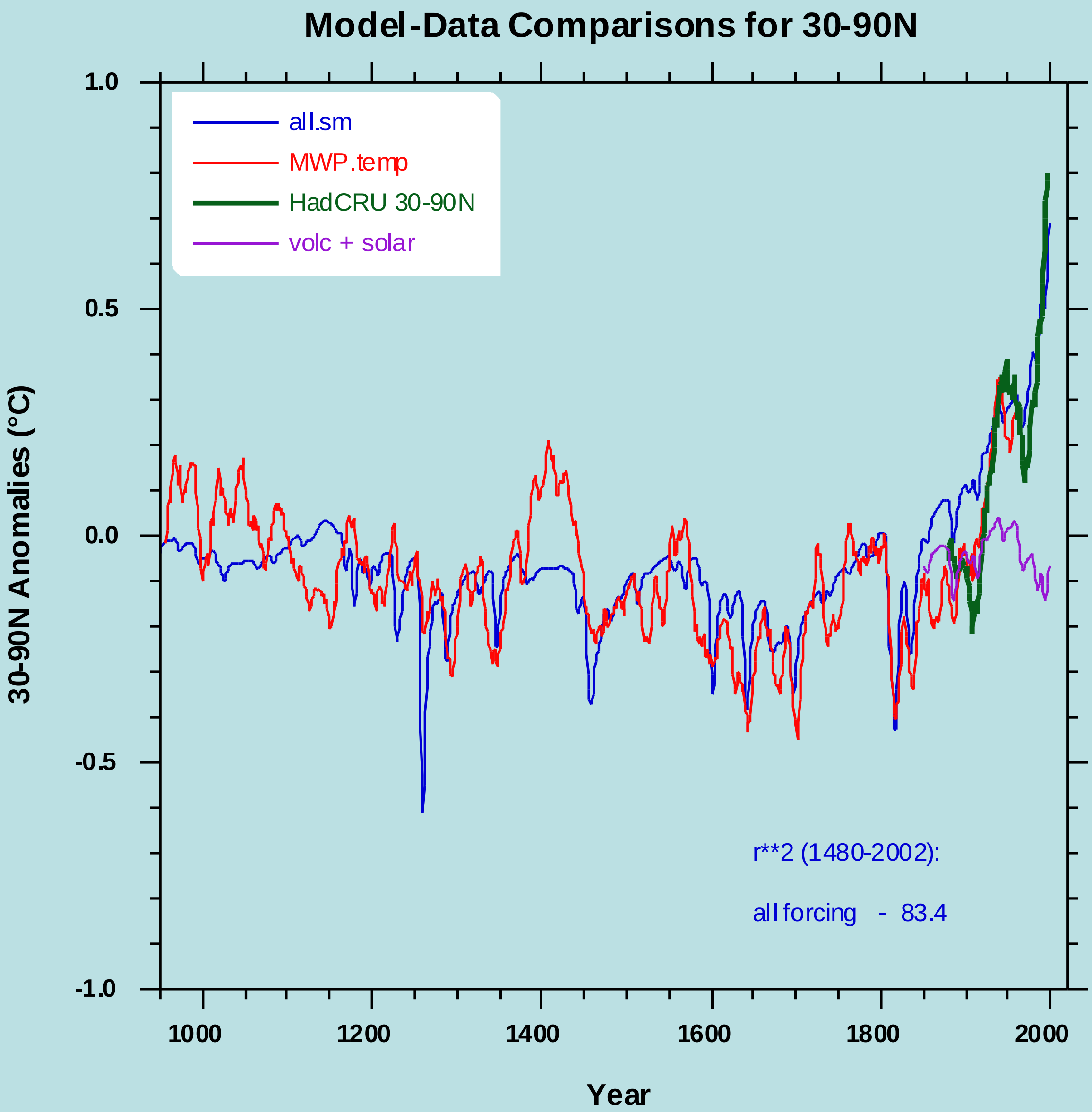


Crowley - Fig 8


Model-Data Comparisons for 30-90N
all.sm
MWP.temp
HadCRU 30-90N
volc + solar
1.0
0.5
0.0
-0.5
-1.0
30-90N Anomalies (°C)
1000
1200
1400
1600
1800
2000
Year



Model-Data Comparisons for 30-90N
all.sm
MWP.temp
HadCRU 30-90N
volc + solar
r**2 (1480-1840):
all forcing - 60.4
volcanism - 38.4
solar - 5.4
1.0
0.5
0.0
-0.5
-1.0
30-90N Anomalies (°C)
1000
1200
1400
1600
1800
2000
Year

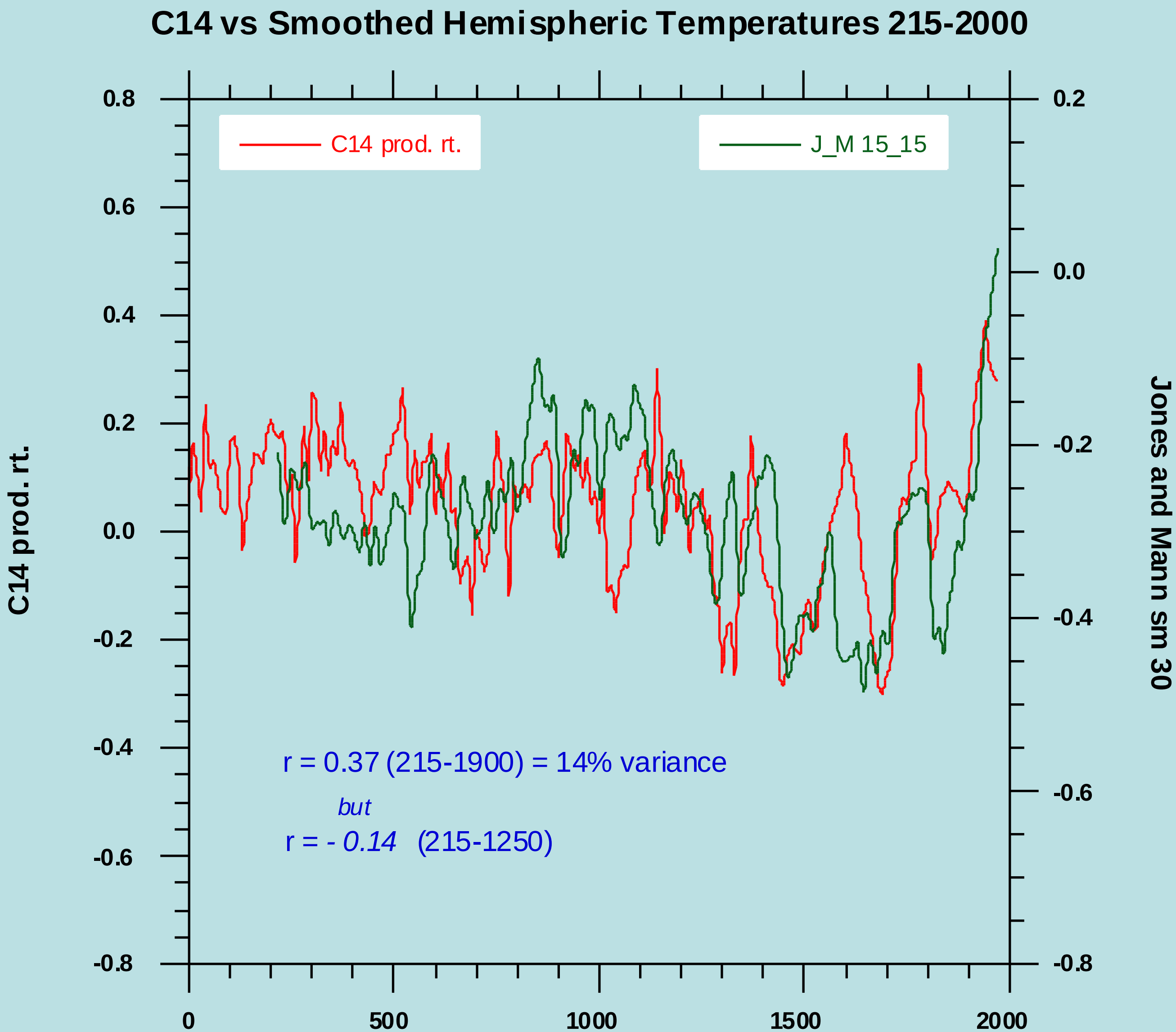


Model-Data Comparisons for 30-90N
all.sm
MWP.temp
HadCRU 30-90N
volc + solar
r**2 (1480-2002):
all forcing - 83.4
30-90N Anomalies (°C)
1.0
0.5
0.0
-0.5
-1.0
1000
1200
1400
1600
1800
2000
Year

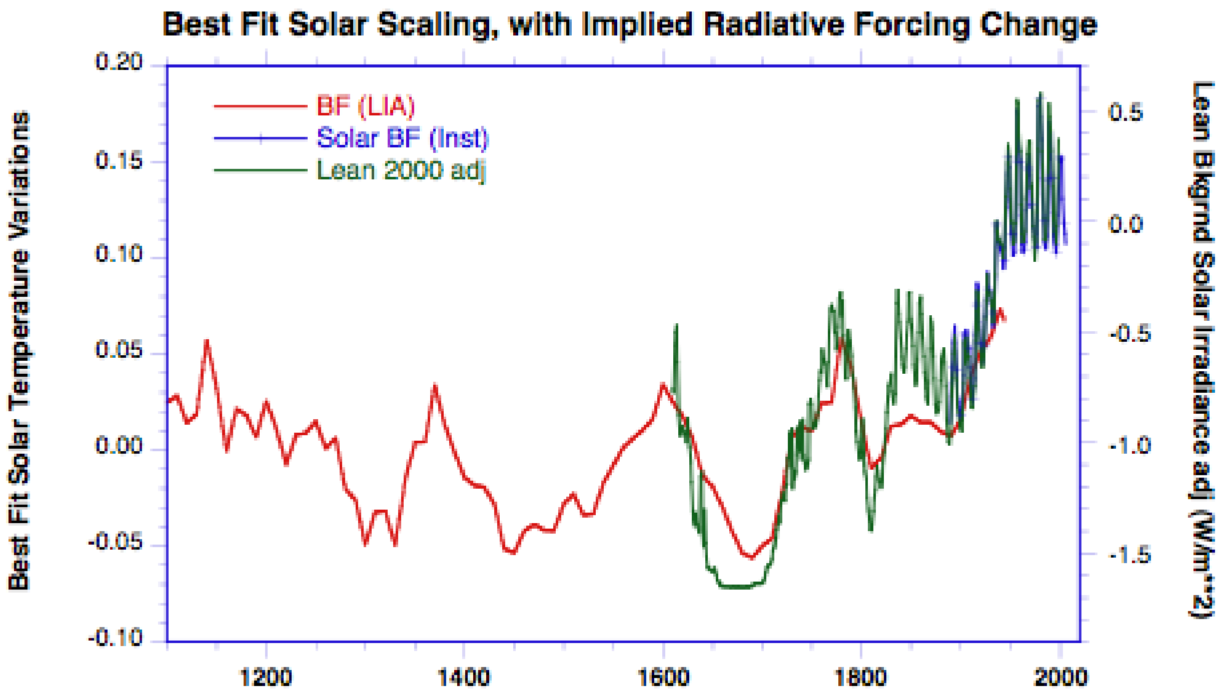
Detection of forced change in records of last millennium

record	Briffa	CH-blend	Mann	Esper	Moberg
period	**1402-1940**	**1270-1960**	**1400-1980**	**1270-1960**	**1270-1925**
volc	Yes	Yes	Yes	Yes	Yes
solar	No	No (Yes 1100on)	No **(Yes periods)**	No	Yes
Ghg+ aer	Yes	Yes	Yes	Yes	Not robust
Res std	0.09 57%	0.09 70%	0.07 49%	0.15 70%	0.11 61%

Hegerl et al., J Climate 2007

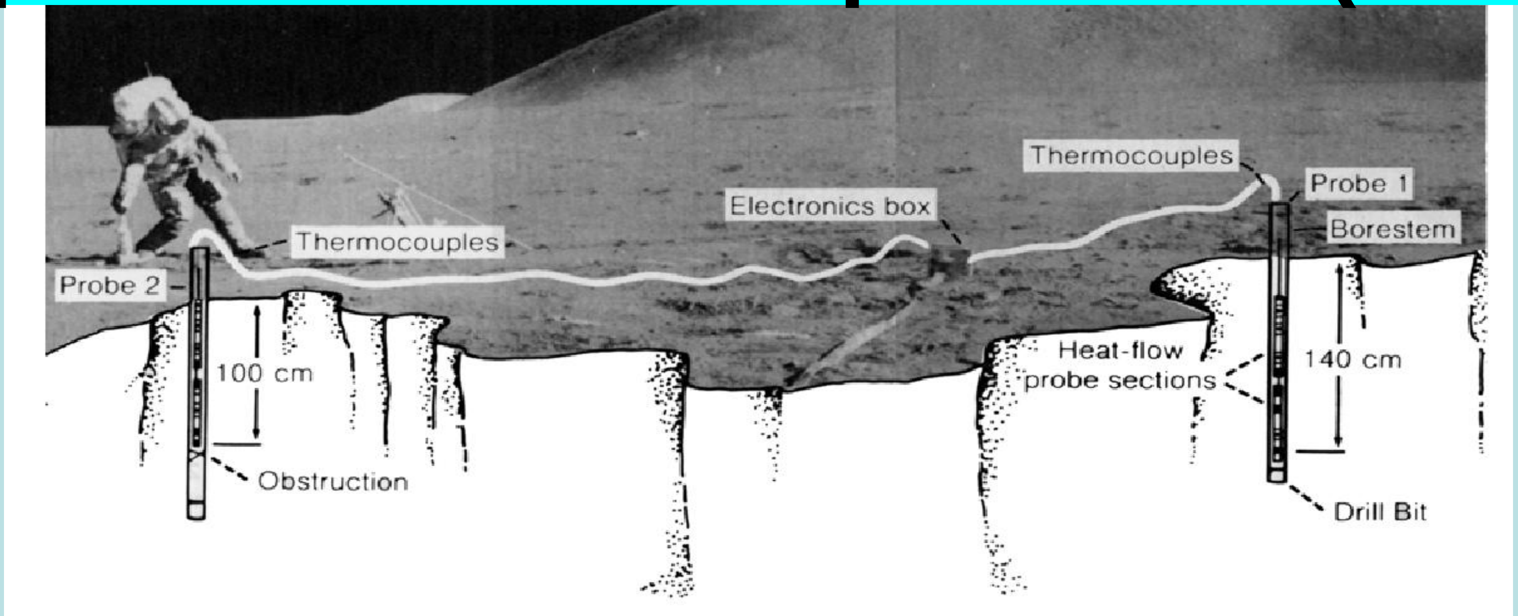


C14 vs Smoothed Hemispheric Temperatures 215-2000
C14 prod. rt.
J_M 15_15
r = 0.37 (215-1900) = 14% variance
but
r = - *0.14* (215-1250)
C14 prod. rt.
Jones and Mann sm 30
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0
500
1000
1500
2000



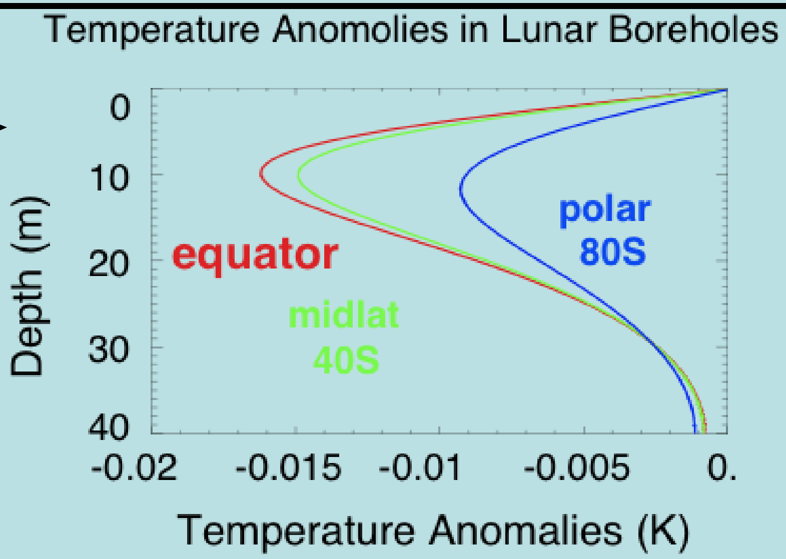
Crowley_Fig 11

Apollo Heat Flow Experiments (HFEs)



Heat Flow Experiments (HFEs) from Apollo 15 & 17 show very small thermal diffusivity of lunar regolith $\approx 10^{-8} m^2/s$, 100 X smaller than that of Earth's crust.

Temperature anomalies as response to two scenarios of reconstructed TSI at the equator, mid-latitude and near south pole.



“Hope springs eternal in the human breast” **Alexander Pope**

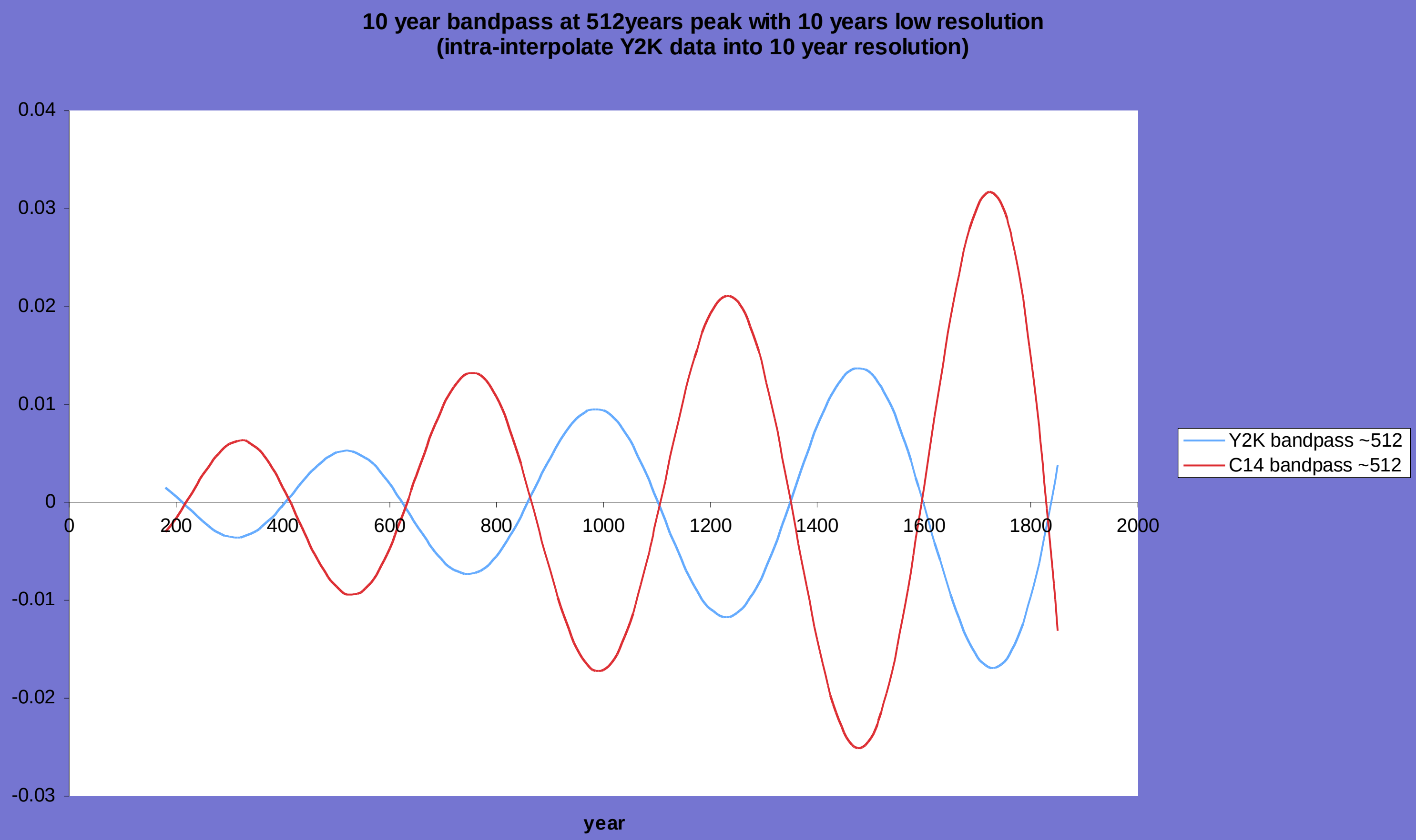
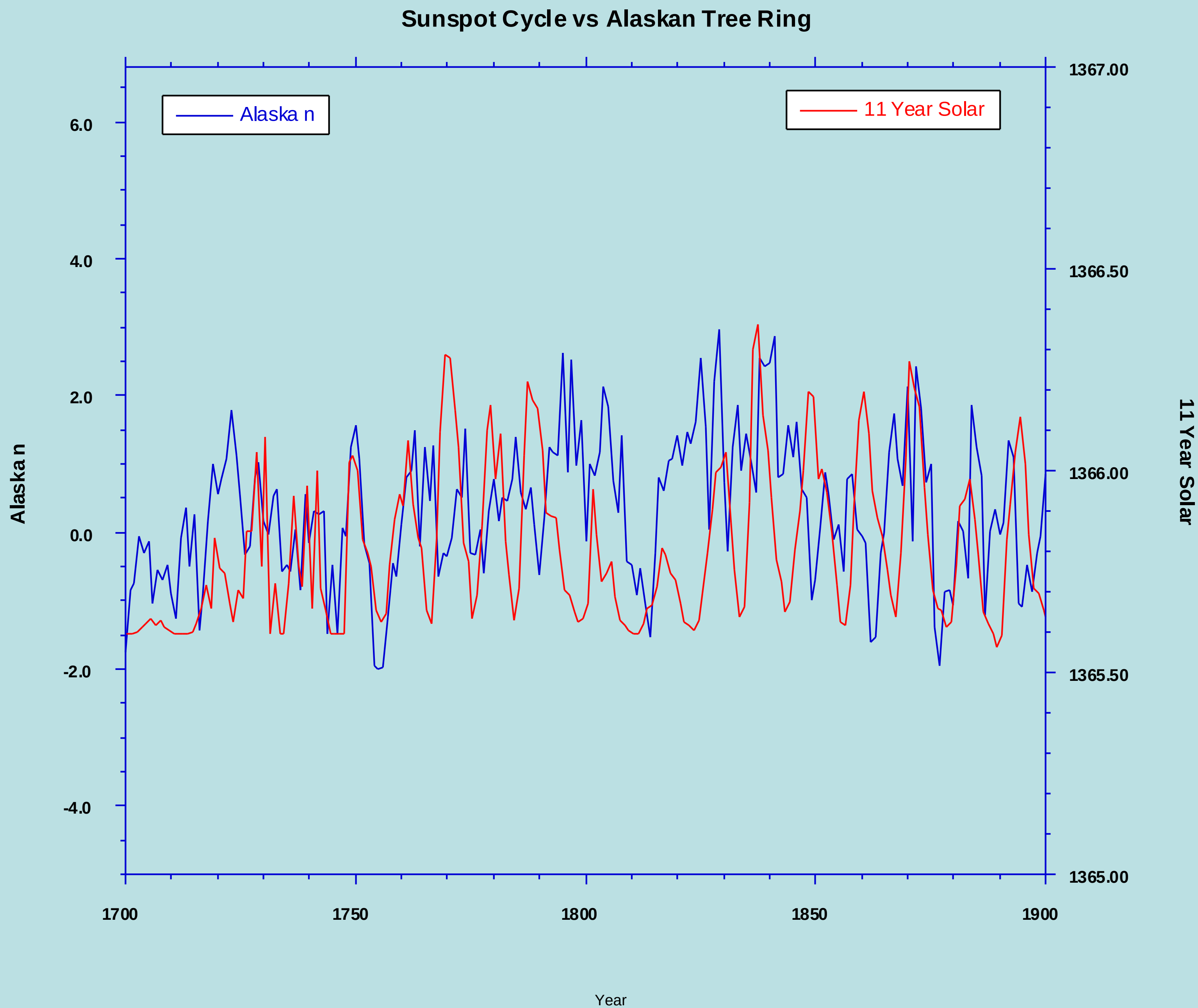
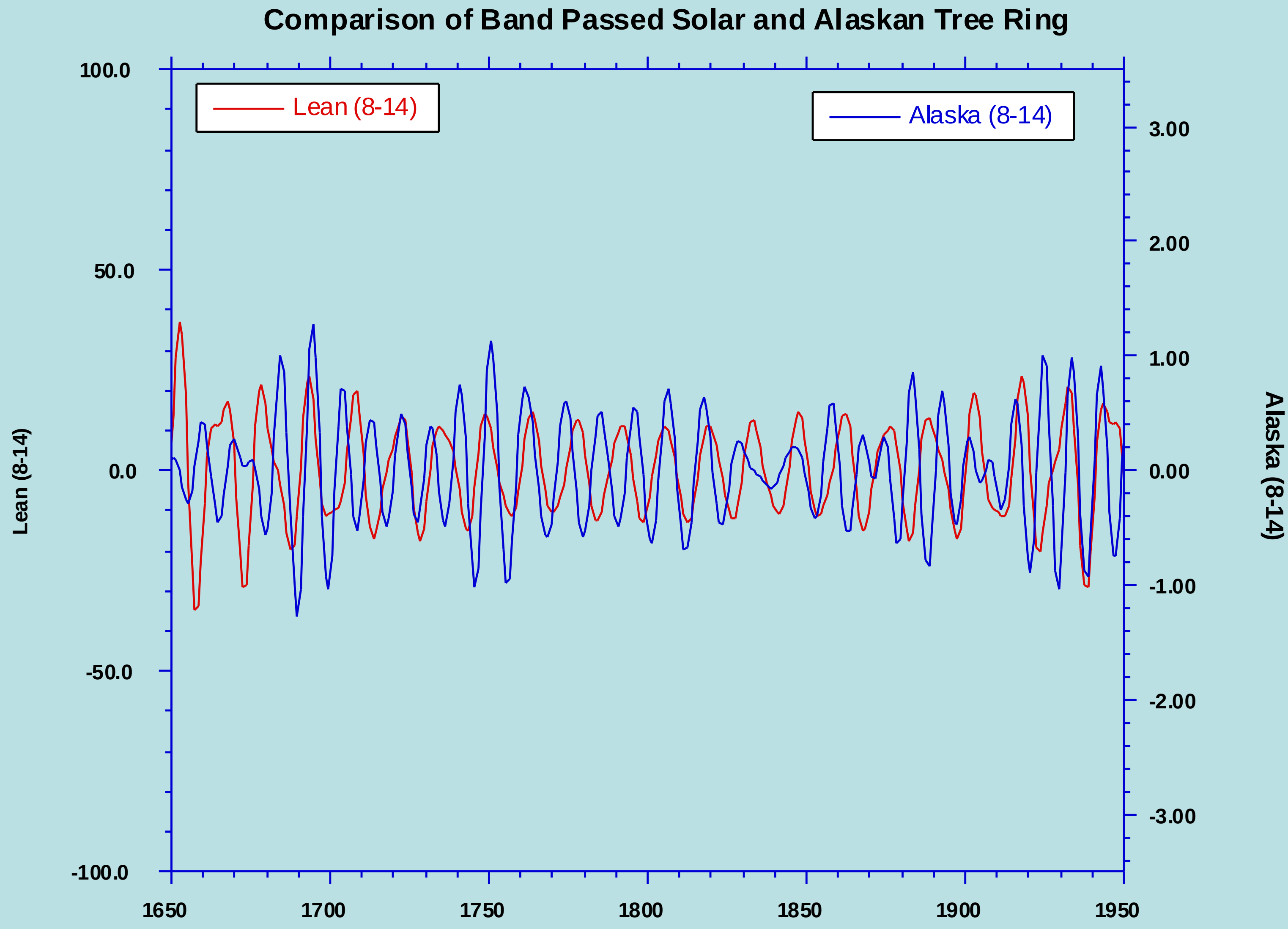

10 year bandpass at 512years peak with 10 years low resolution
(intra-interpolate Y2K data into 10 year resolution)
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
0
200
400
600
800
1000
1200
1400
1600
1800
2000
year
Y2K bandpass ~512
C14 bandpass ~512

TABLE 1. Correlations between solar spectra in climate records.

Period	~420	~200	~120	~187	~56	r	r_{max}	
Glaciers	x		**X**	**X**		–0.11	0.15	(330)
Sierra TR			**X**		**X***	–0.10	0.22	(70)
China TR		**X***	x	x	x	–0.54	–0.54	(0)
Grn O18	**X**		**X**		**X***	–0.01	0.39	(45)
Peru O18			x	x	**X**	0.05	0.08	(15)
Spole O18		**X***	x	x	x	0.37	0.42	(–20)

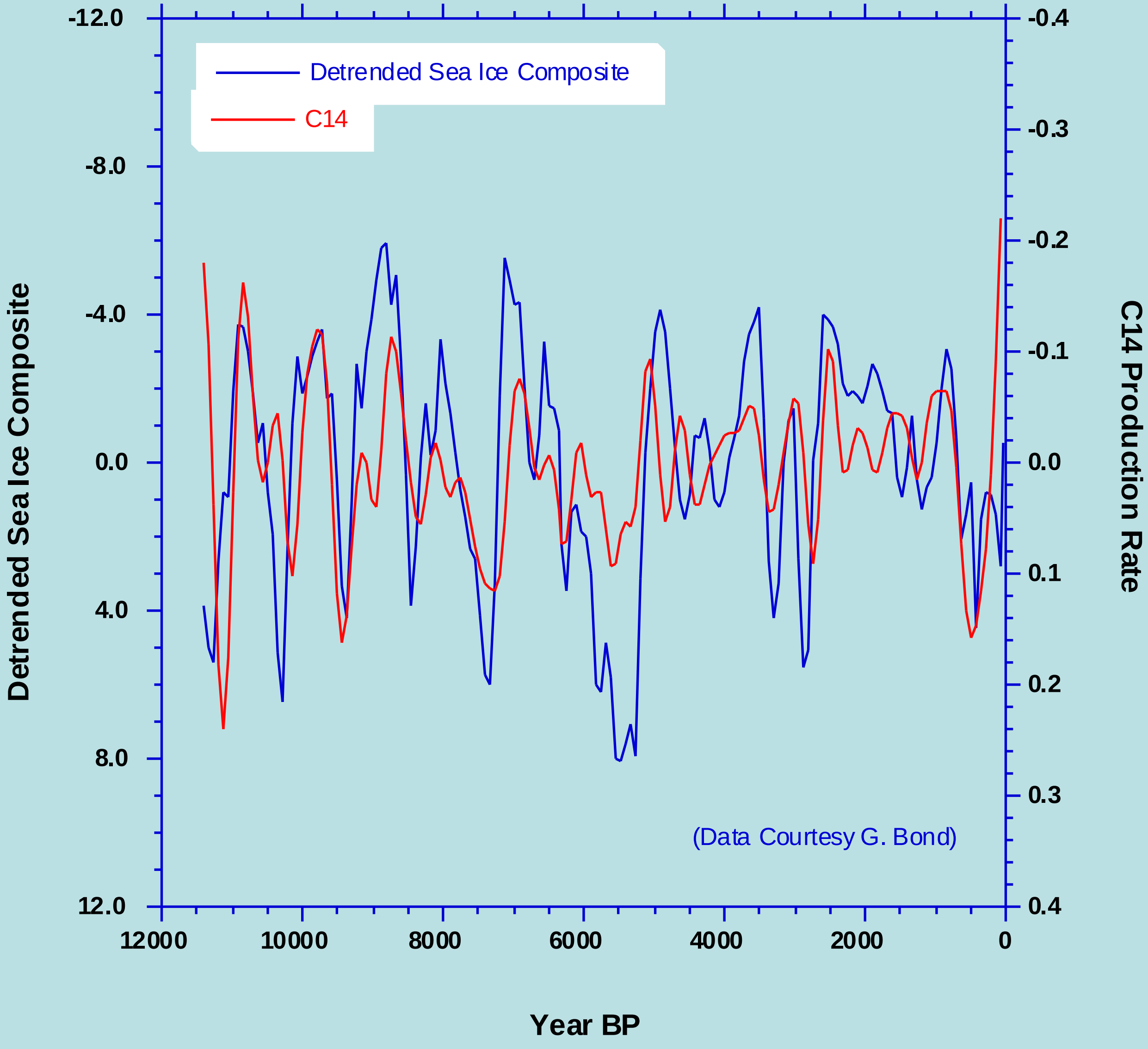


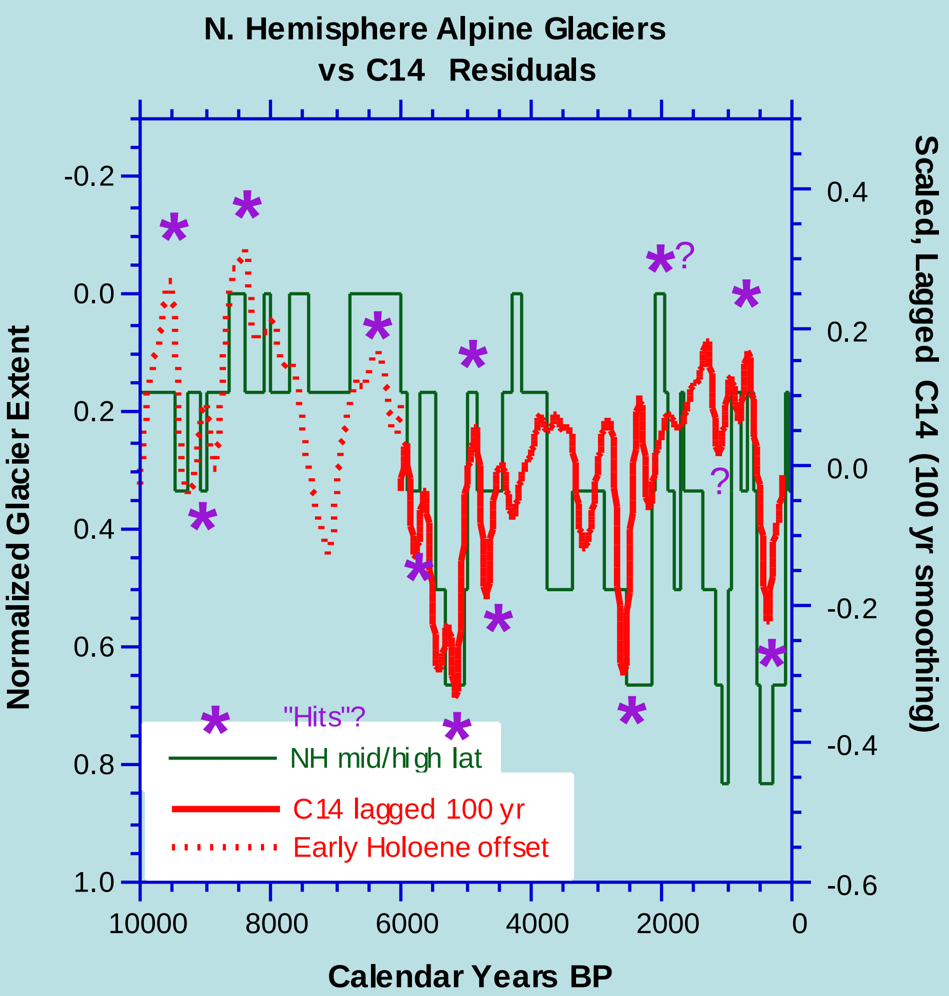
Sunspot Cycle vs Alaskan Tree Ring
Alaska n
11 Year Solar
6.0
4.0
2.0
0.0
-2.0
-4.0
1367.00
1366.50
1366.00
1365.50
1365.00
1700
1750
1800
1850
1900
Year



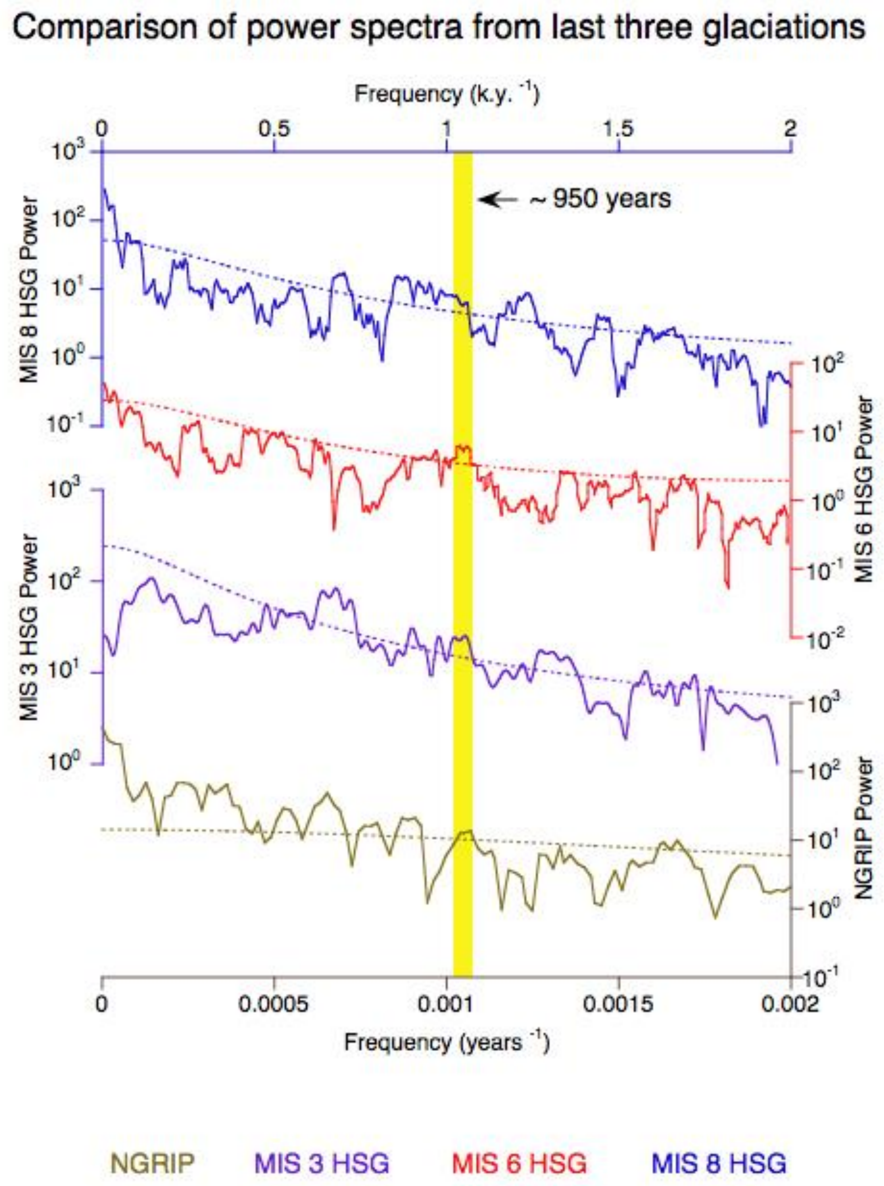
Comparison of Band Passed Solar and Alaskan Tree Ring
Lean (8-14)
Alaska (8-14)
100.0
50.0
0.0
-50.0
-100.0
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
1650
1700
1750
1800
1850
1900
1950
Lean (8-14)
Alaska (8-14)

Solar Forcing vs N. Atlantic Sea Ice





Crowley Fig 10



Source: Steven Obrochta, U. of Tokyo

Main Conclusion:

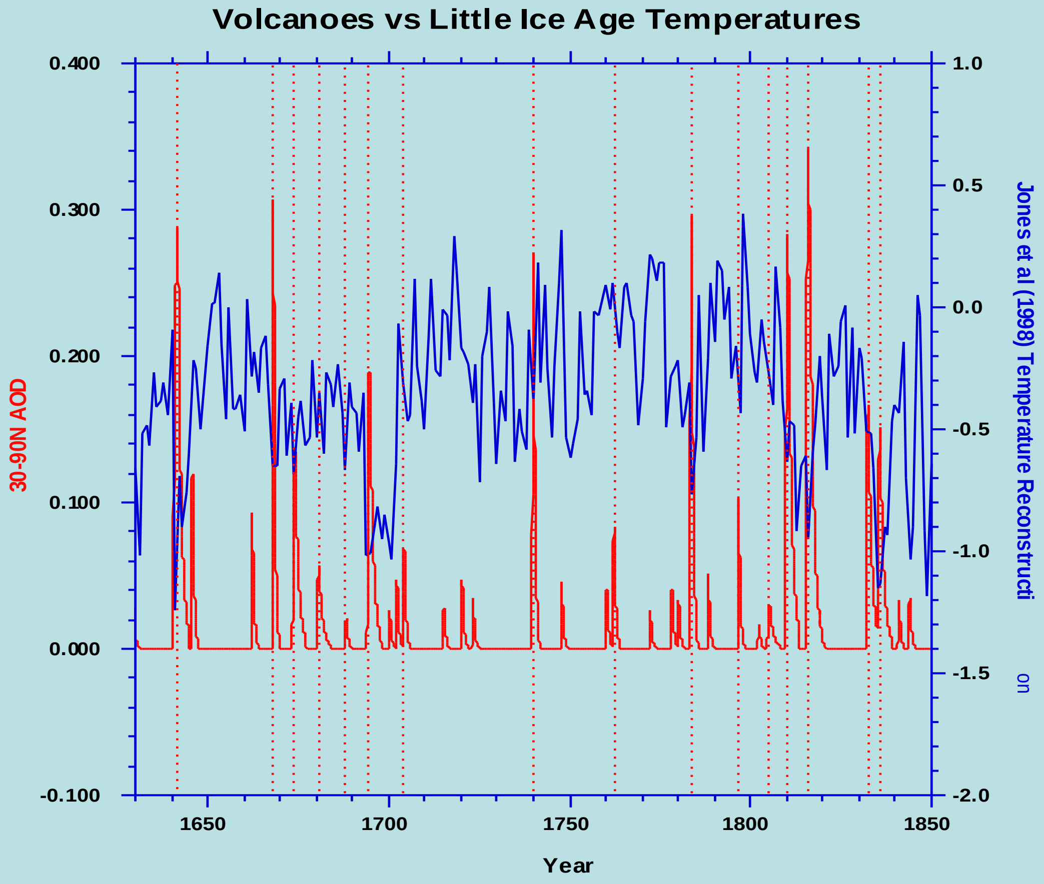
Solar Imprint on Climate – Overstated
For Little Ice Age but sometimes detected on longer time scales in composite records and in *some* local records

present but not necessarily dominant

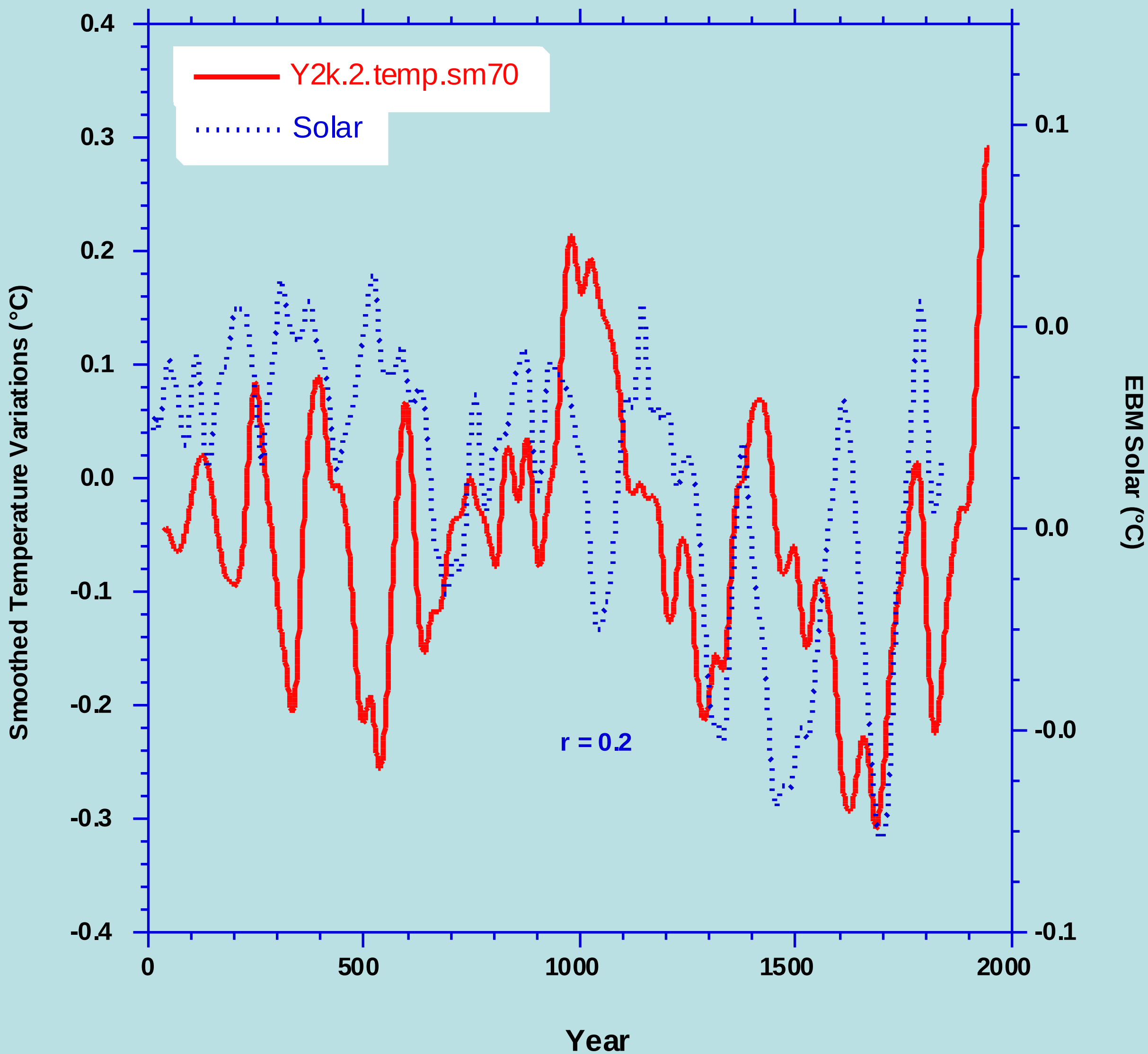
TABLE 1. Correlations between solar spectra in climate records.

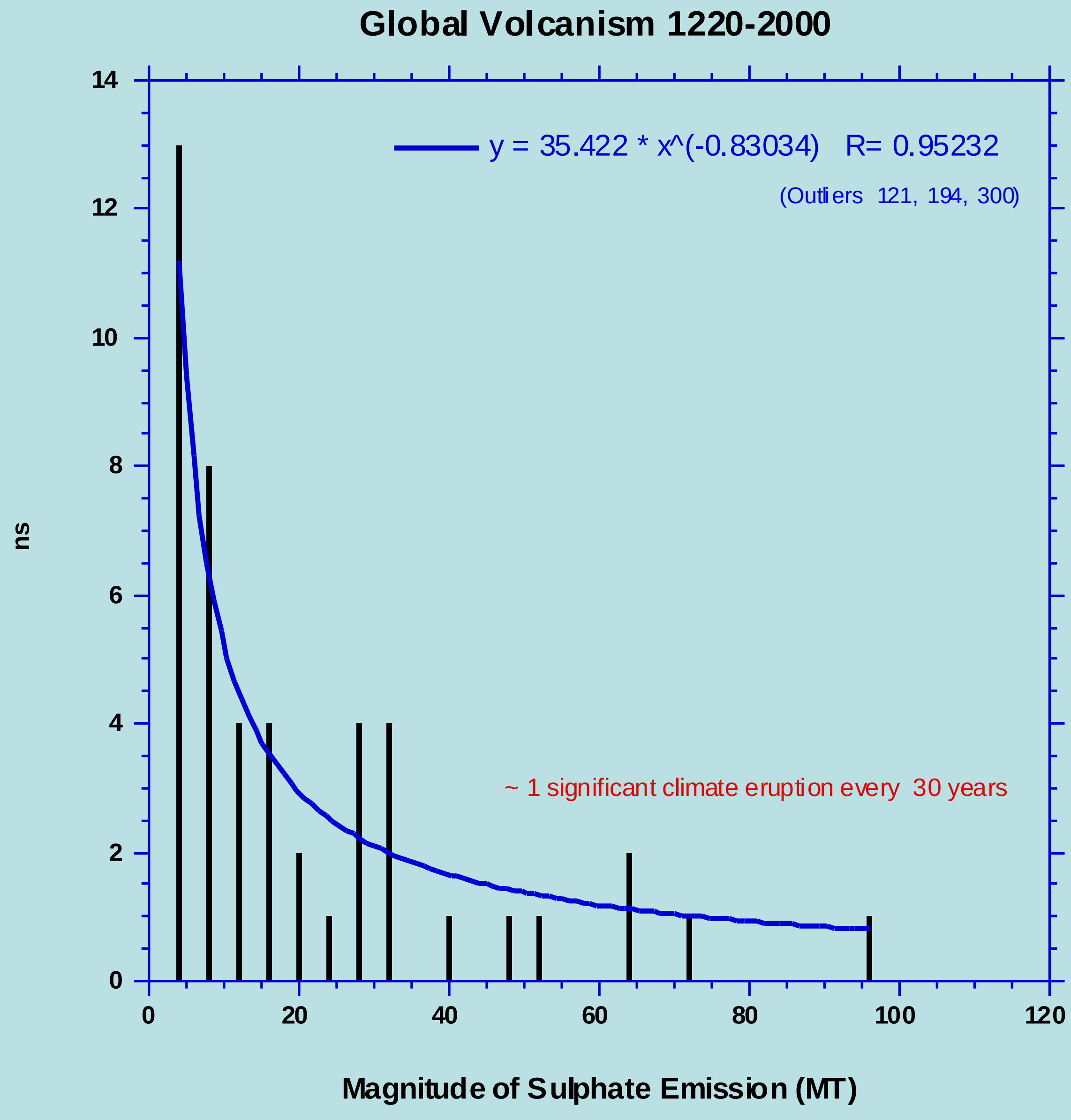
Period	~420	~200	~120	~187	~56	r	r_{max}	
Glaciers	x		**X**	**X**		–0.11	0.15	(330)
Sierra TR			**X**		**X***	–0.10	0.22	(70)
China TR		**X***	x	x	x	–0.54	–0.54	(0)
Grn O18	**X**		**X**		**X***	–0.01	0.39	(45)
Peru O18			x	x	**X**	0.05	0.08	(15)
Spole O18		**X***	x	x	x	0.37	0.42	(–20)

Volcanoes vs temperature

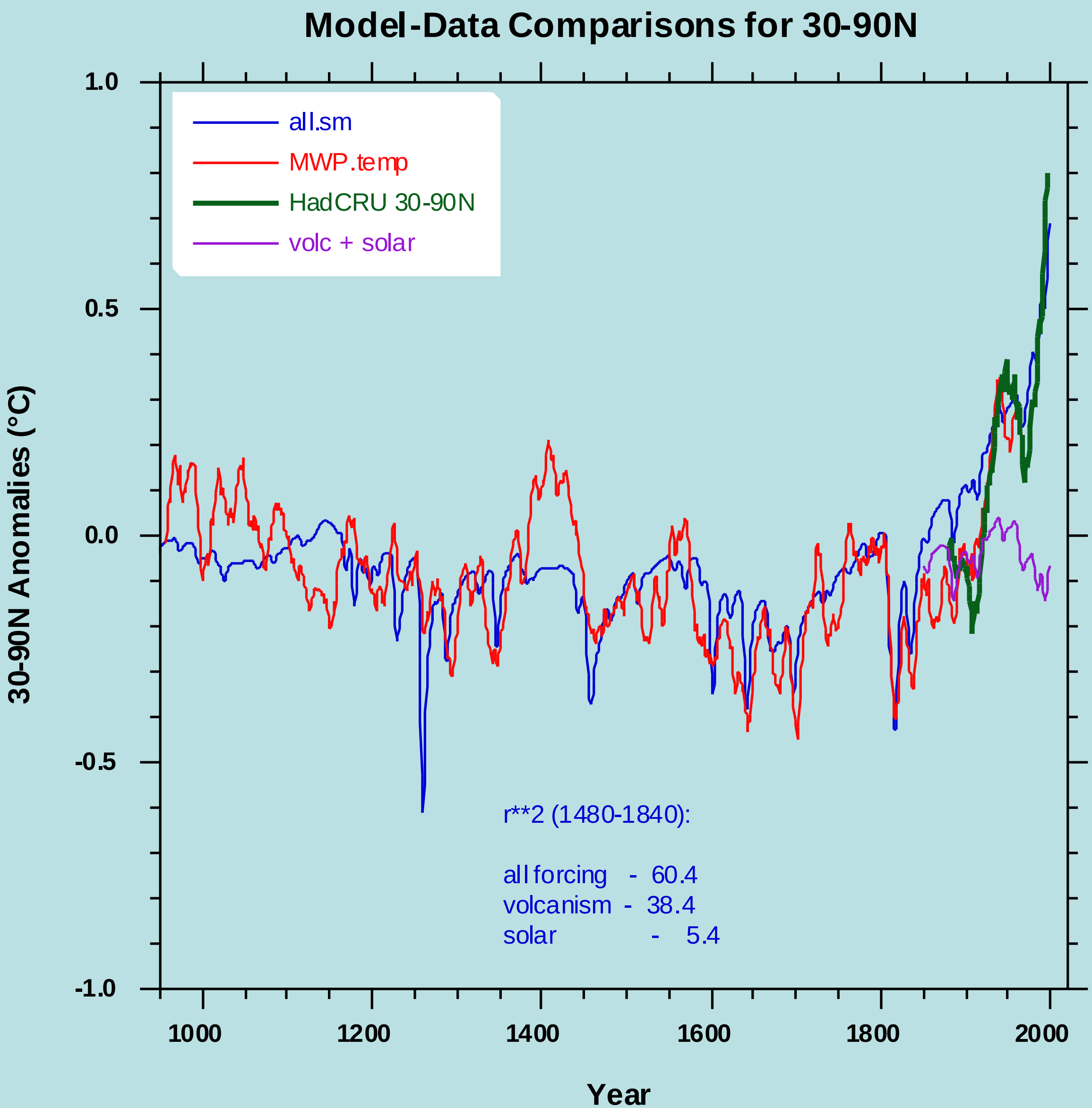


Is Solar Significant?

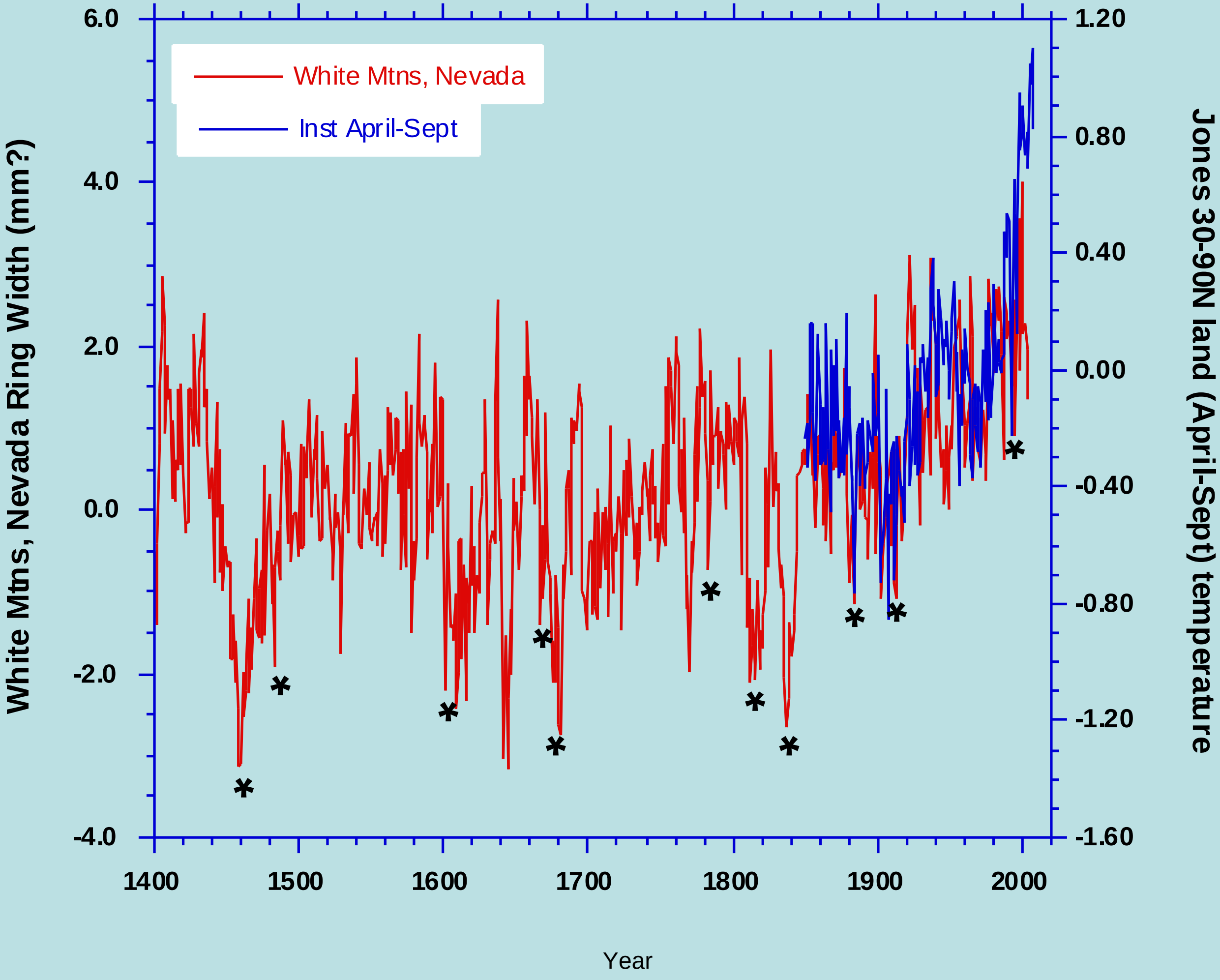




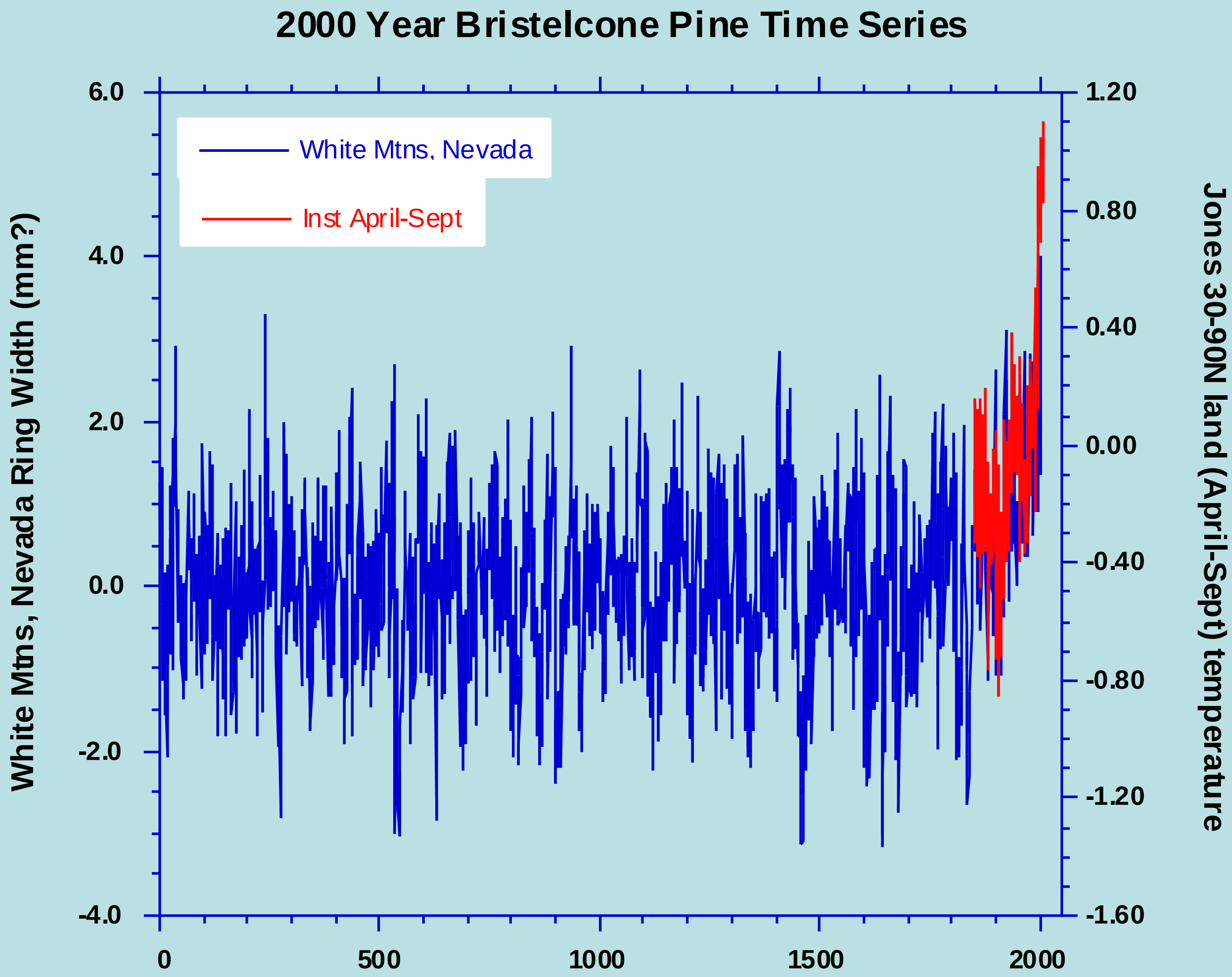
Global Volcanism 1220-2000
y = 35.422 * x^(-0.83034) R= 0.95232
(Outliers 121, 194, 300)
~ 1 significant climate eruption every 30 years
ns
Magnitude of Sulphate Emission (MT)
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120

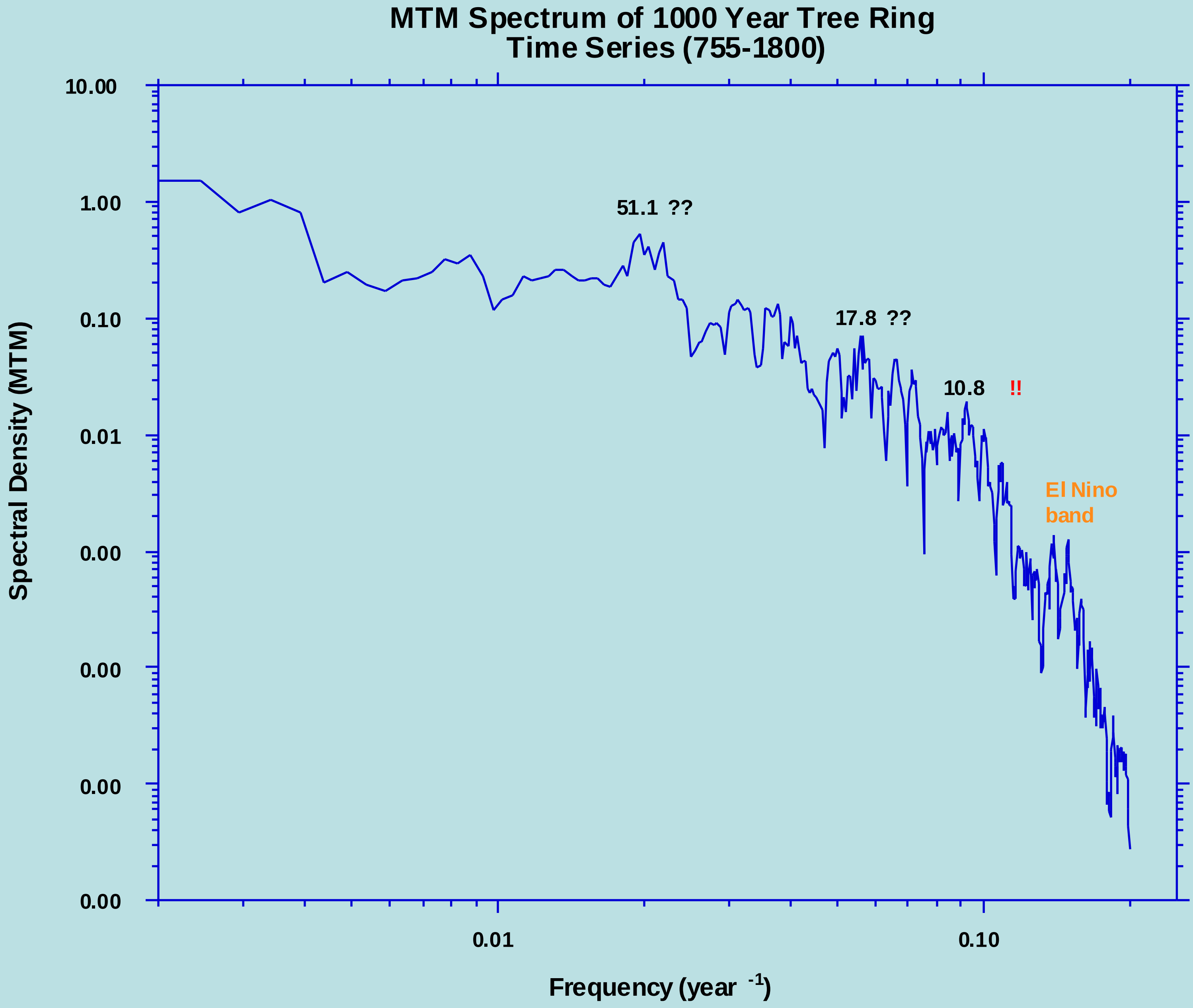


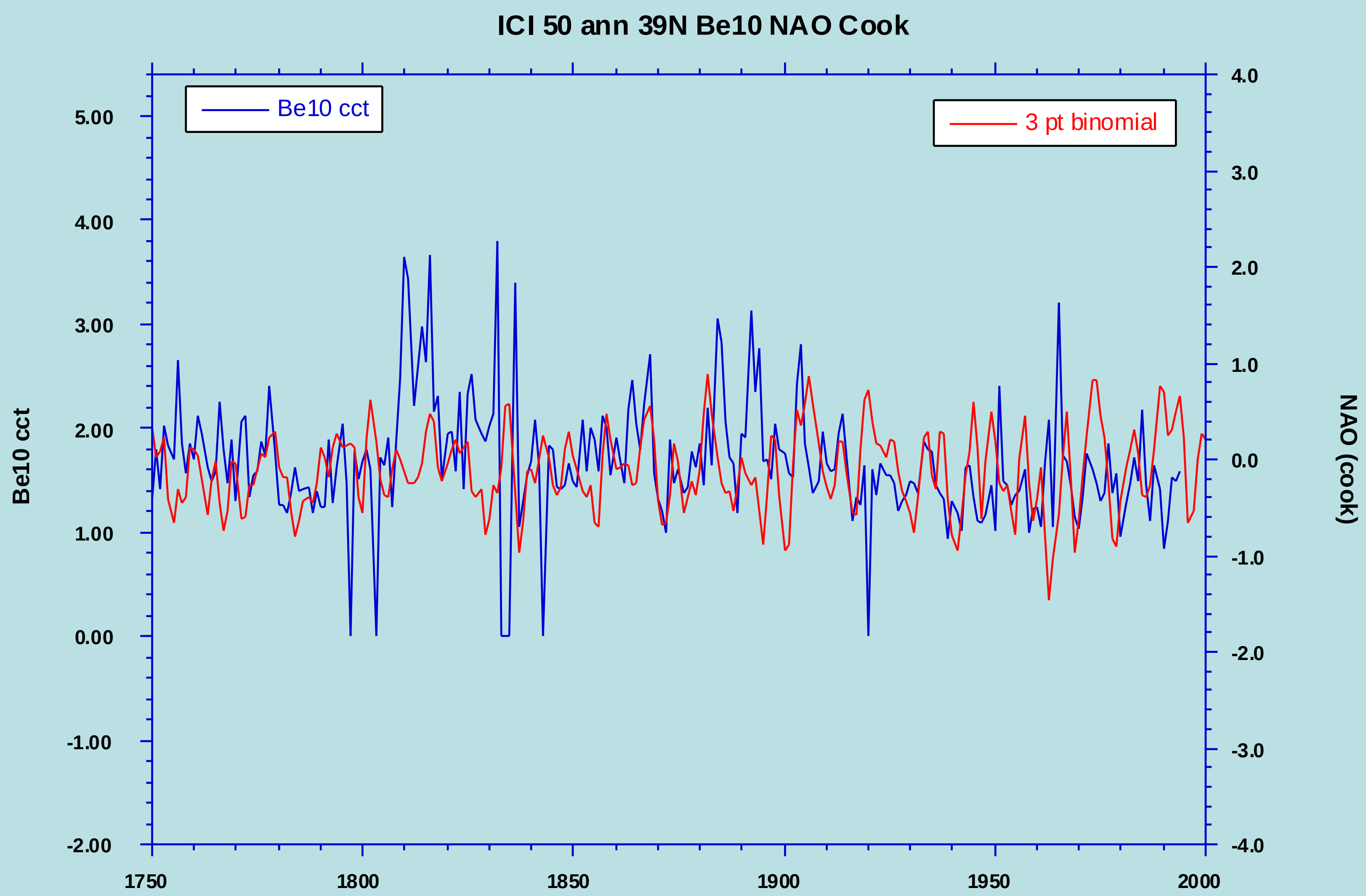
Model-Data Comparisons for 30-90N
all.sm
MWP.temp
HadCRU 30-90N
volc + solar
r**2 (1480-1840):
all forcing - 60.4
volcanism - 38.4
solar - 5.4
30-90N Anomalies (°C)
1.0
0.5
0.0
-0.5
-1.0
1000
1200
1400
1600
1800
2000
Year

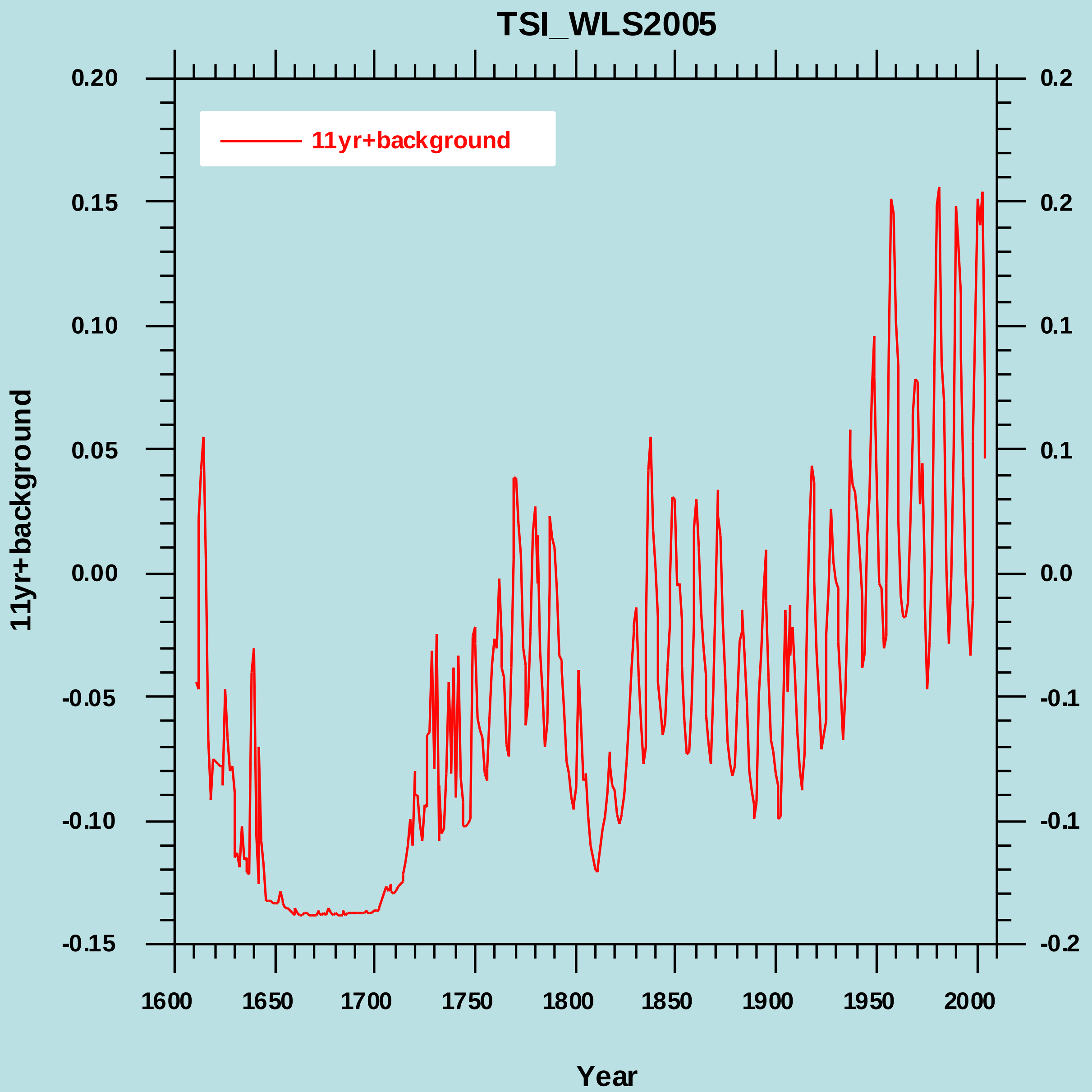


White Mtns, Nevada
Inst April-Sept
White Mtns, Nevada Ring Width (mm?)
Jones 30-90N land (April-Sept) temperature
6.0
4.0
2.0
0.0
-2.0
-4.0
1.20
0.80
0.40
0.00
-0.40
-0.80
-1.20
-1.60
1400
1500
1600
1700
1800
1900
2000
Year


2000 Year Bristelcone Pine Time Series
White Mtns, Nevada
Inst April-Sept
White Mtns, Nevada Ring Width (mm?)
Jones 30-90N land (April-Sept) temperature
6.0
4.0
2.0
0.0
-2.0
-4.0
1.20
0.80
0.40
0.00
-0.40
-0.80
-1.20
-1.60
0
500
1000
1500
2000


MTM Spectrum of 1000 Year Tree Ring
Time Series (755-1800)
10.00
1.00
0.10
0.01
0.00
0.00
0.00
0.00
Spectral Density (MTM)
0.01
0.10
Frequency (year -1)
51.1 ??
17.8 ??
10.8
!!
El Nino
band


ICI 50 ann 39N Be10 NAO Cook
Be10 cct
3 pt binomial
Be10 cct
NAO (cook)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
1750
1800
1850
1900
1950
2000



TSI_WLS2005
11yr+background
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
0.2
0.2
0.1
0.1
0.0
-0.1
-0.1
-0.2
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year
11yr+background

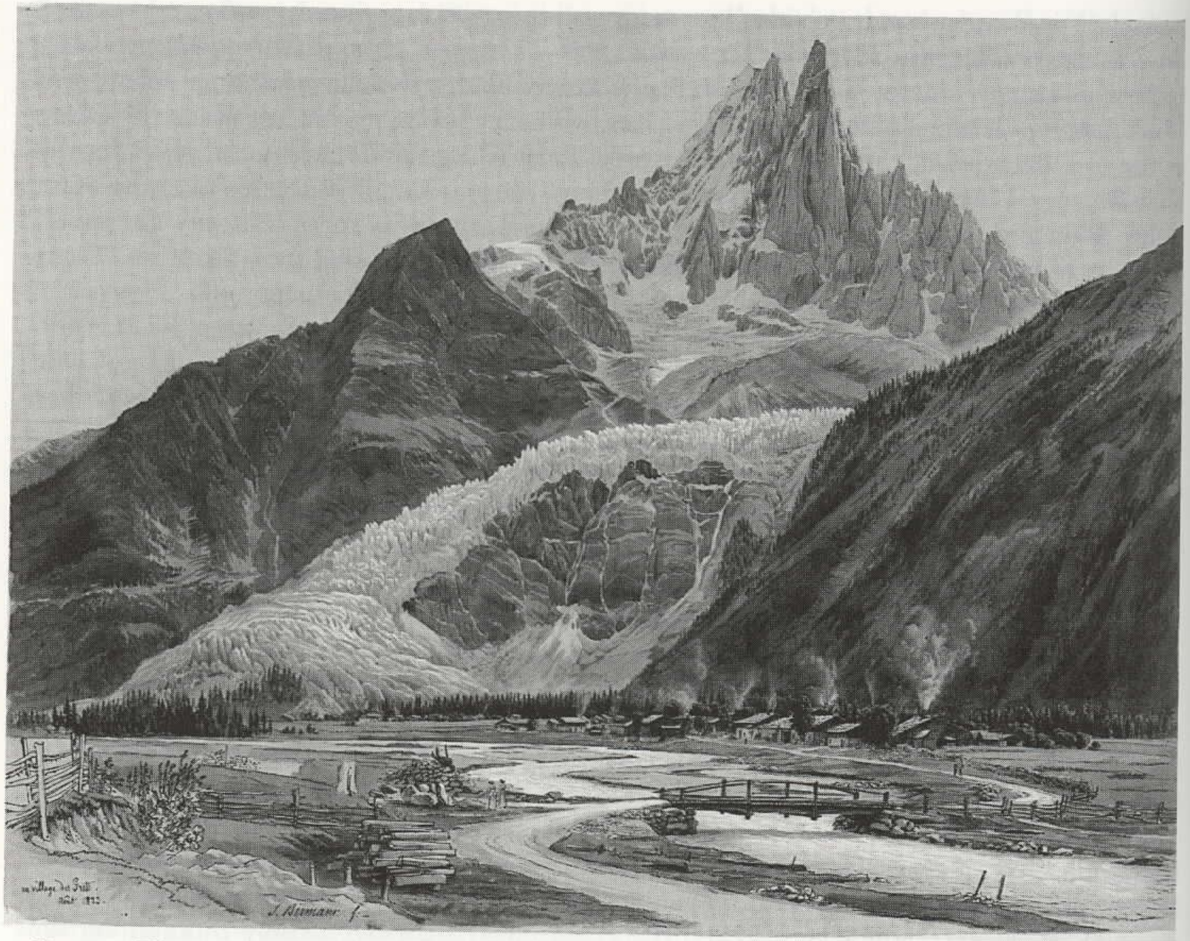
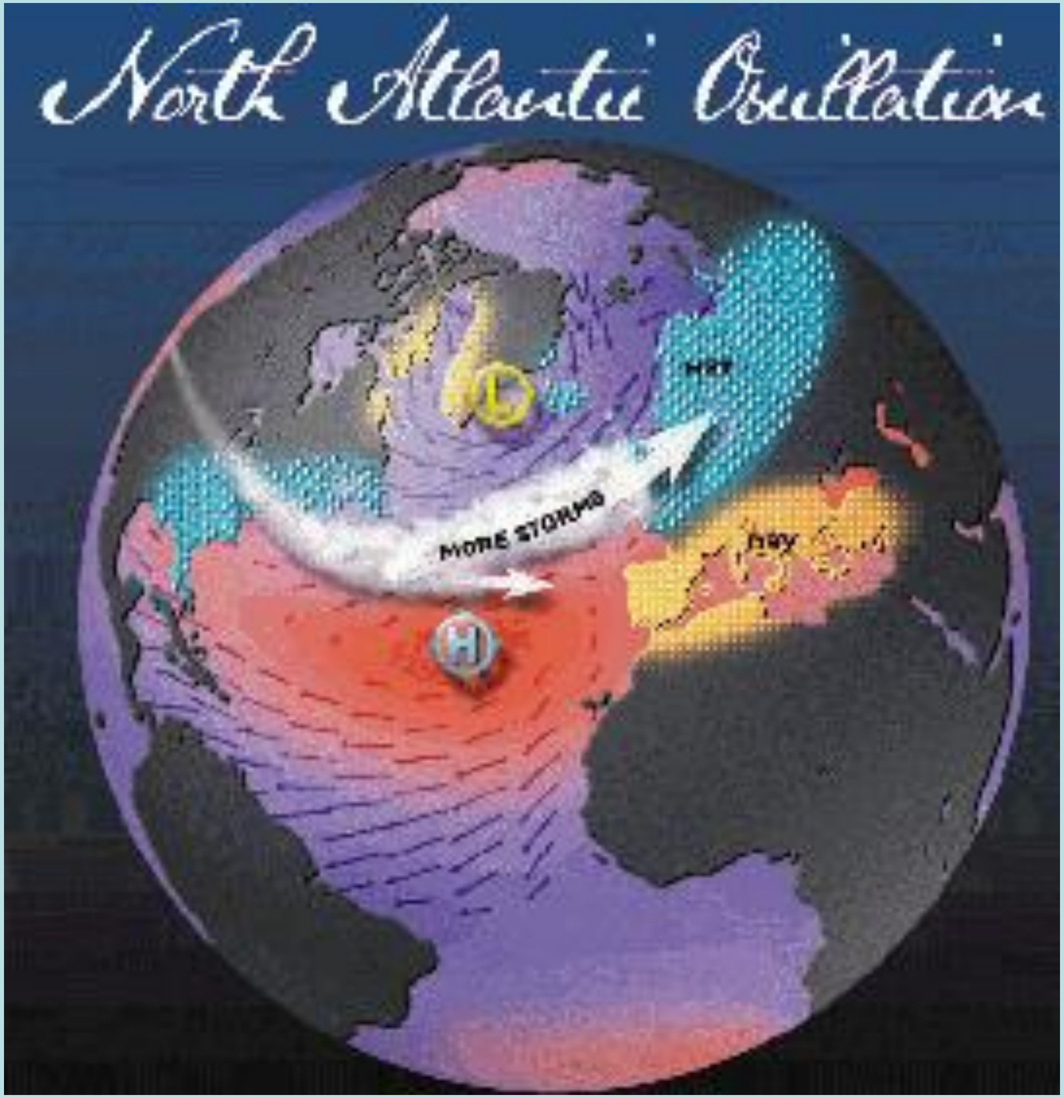
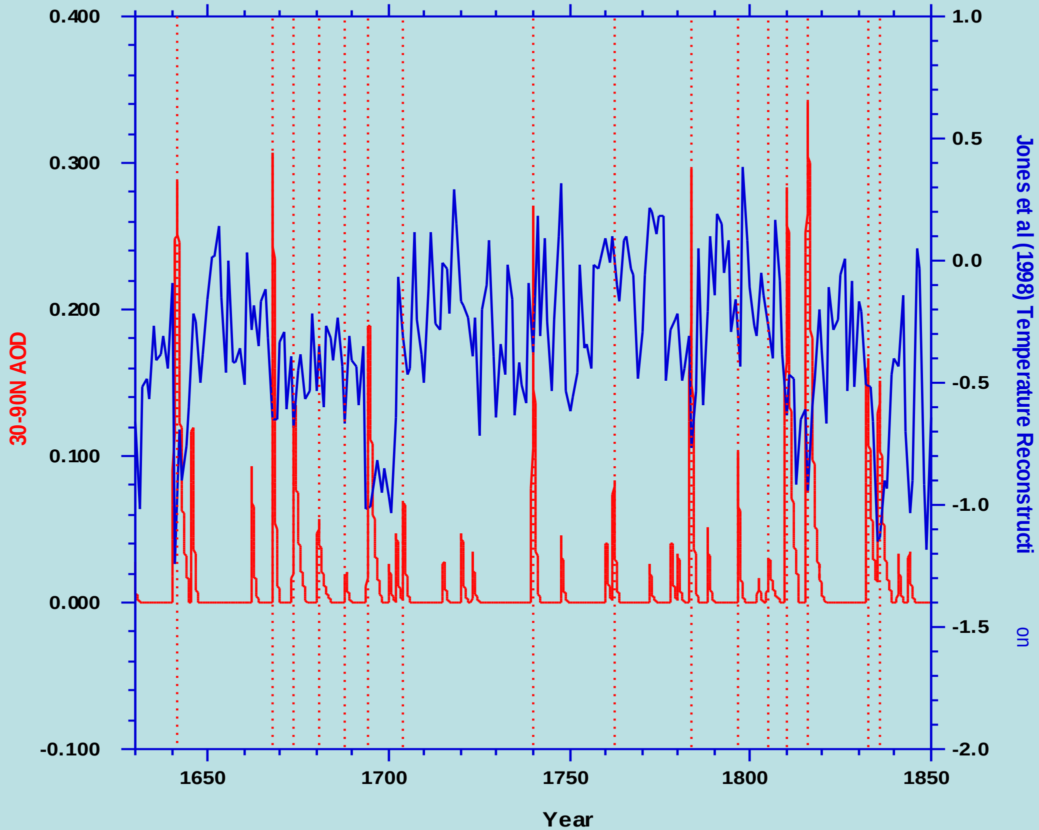
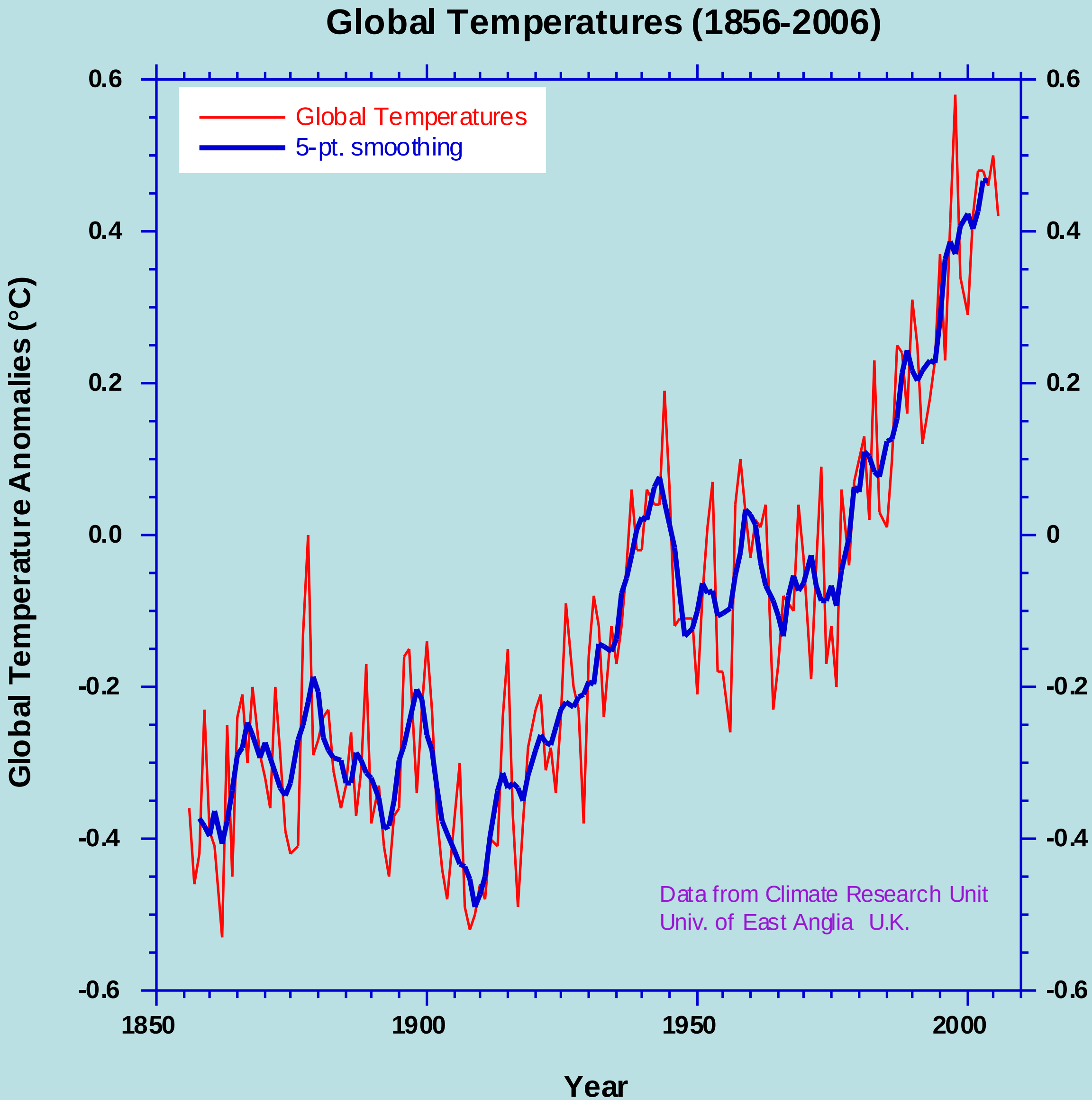


Plate 4.1 The Mer de Glace reached out on to the floor of the Arve valley in 1823 when it was painted by Samuel Birmann. (*Au village des Prats*, Öffentliche Kunstsammlung Basel, Kupferstichkabinett, Inv. Bi. 30. 125)


North Atlantic Oscillation
L
MORE STORMS
Dry
H

Volcanoes vs Little Ice Age Temperatures




Global Temperatures (1856-2006)
Global Temperatures
5-pt. smoothing
Data from Climate Research Unit
Univ. of East Anglia U.K.
Global Temperature Anomalies (°C)
Year
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1850
1900
1950
2000