Mega Drought-Will it happen again? Will we be ready?

MCWRA & ACWA Region 3 Joint Program
March 15, 2013

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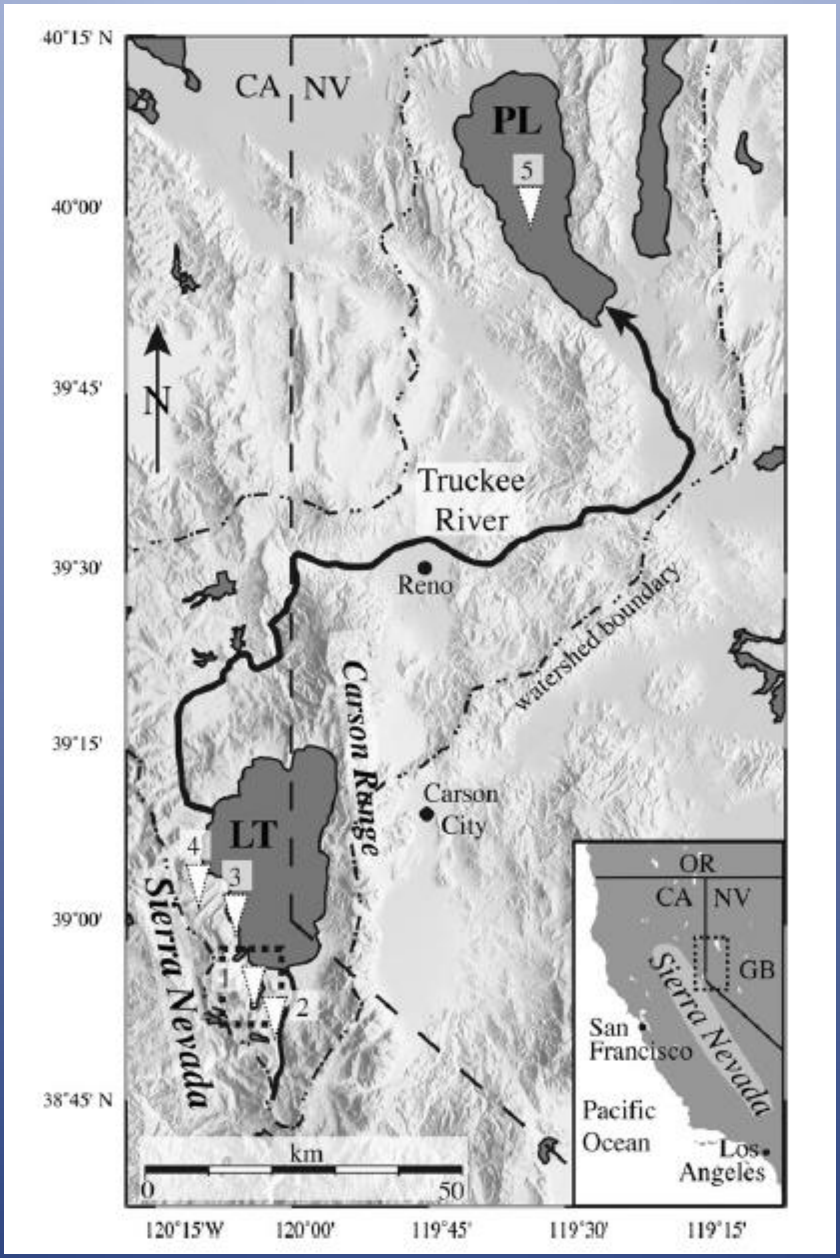
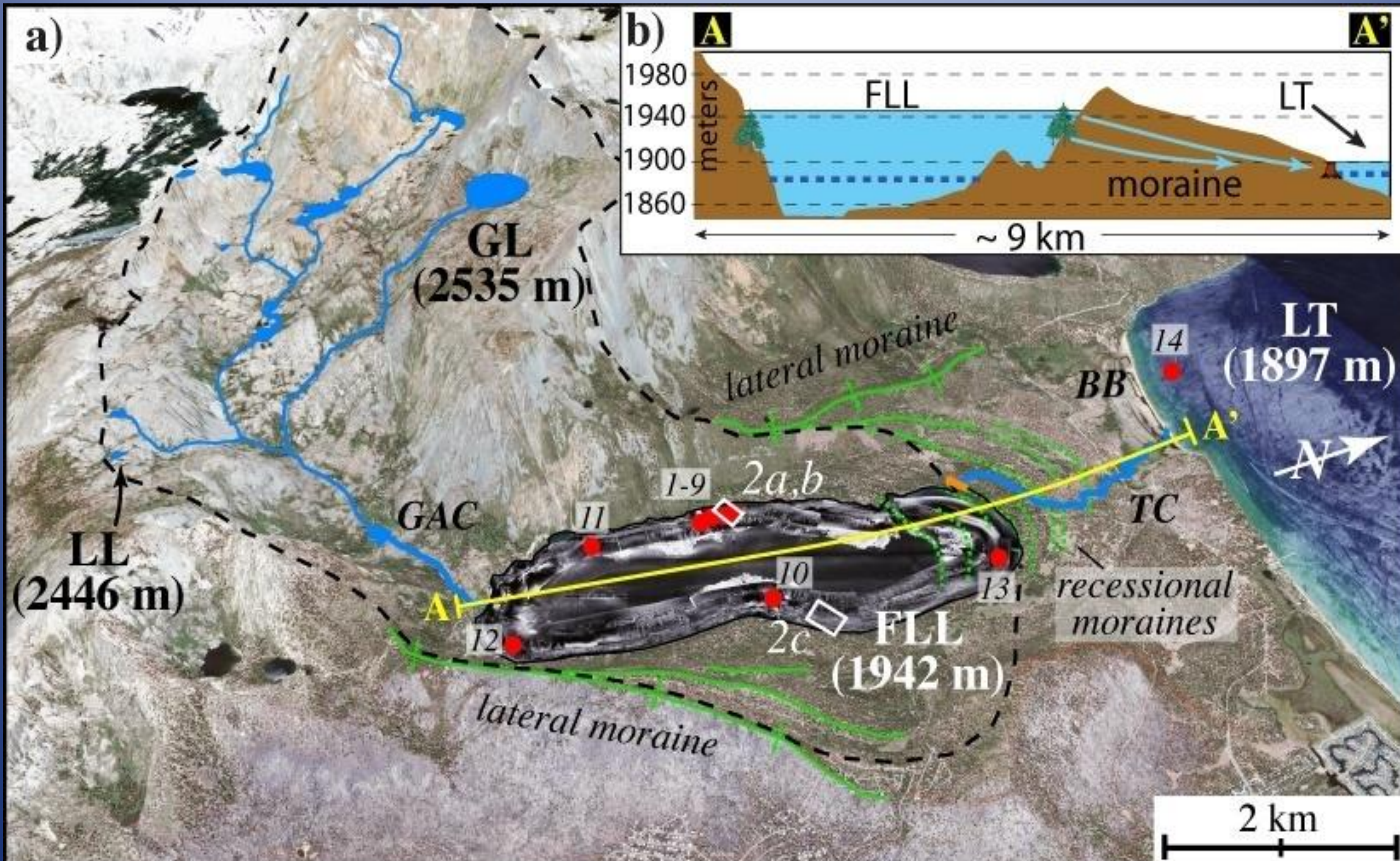
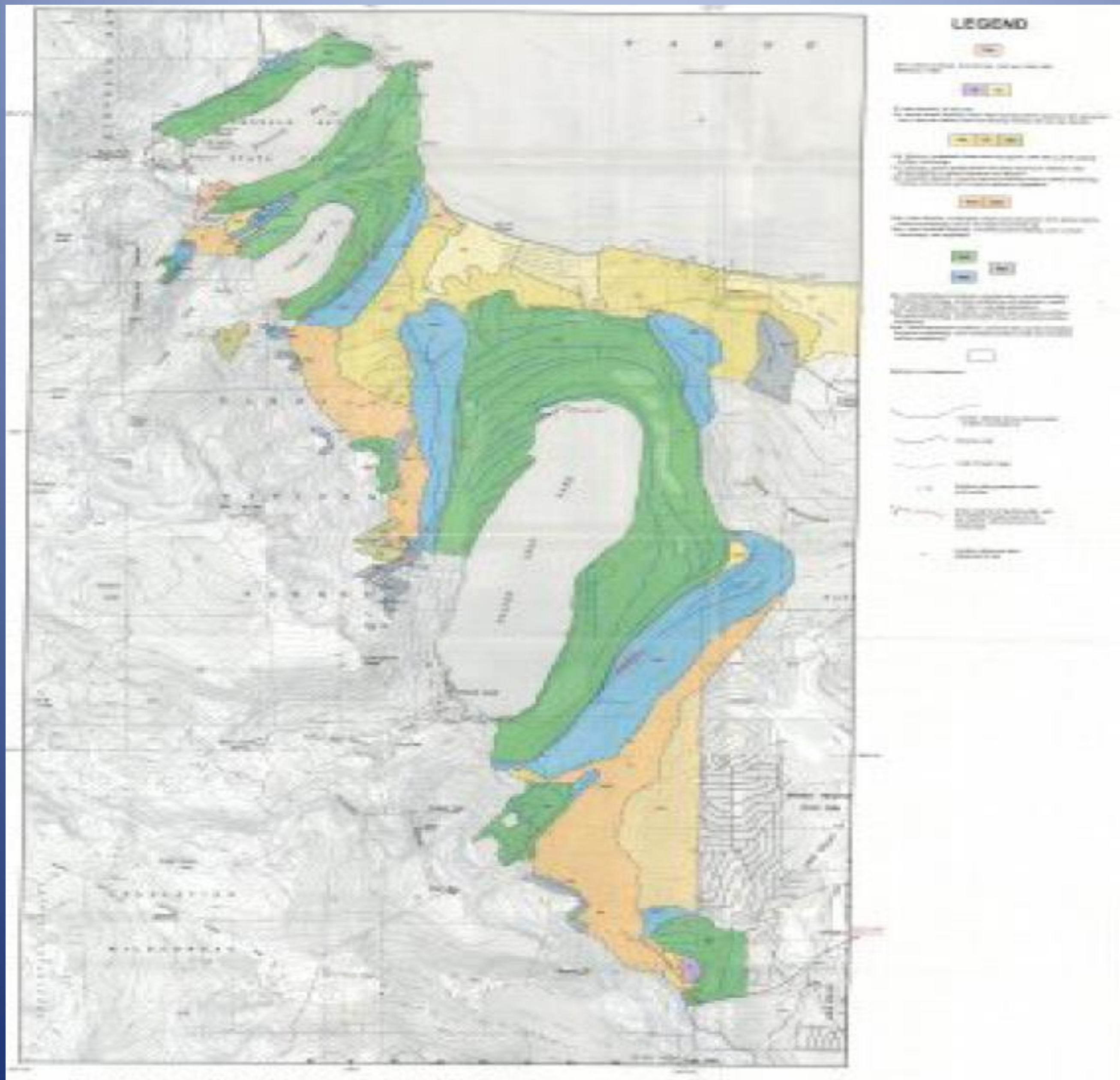
Professor Emeritus
University of Nevada,Reno

Evidence Of Multicentennial Drought in the Lake Tahoe Basin



40°15' N
40°00'
39°45'
39°30'
39°15'
39°00'
38°45' N
120°15'W
120°00'
119°45'
119°30'
119°15'
CA
NV
PL
5
N
Truckee
River
Reno
watershed boundary
Carson Range
Carson
City
LT
4
3
1
2
Sierra Nevada
km
0
50
OR
CA
NV
GB
Sierra Nevada
San
Francisco
Pacific
Ocean
Los
Angeles


a)
b)
A
A'
1980
1940
1900
1860
meters
FLL
LT
moraine
~ 9 km
GL
(2535 m)
lateral moraine
LT
(1897 m)
14
BB
A'
N
1-9
2a,b
11
GAC
TC
LL
(2446 m)
10
13
recessional
moraines
A
12
2c
FLL
(1942 m)
lateral moraine
2 km


LEGEND


Jeep
California
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NV8185KV


HONDA
EU 1000i
INVERTER


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H:116


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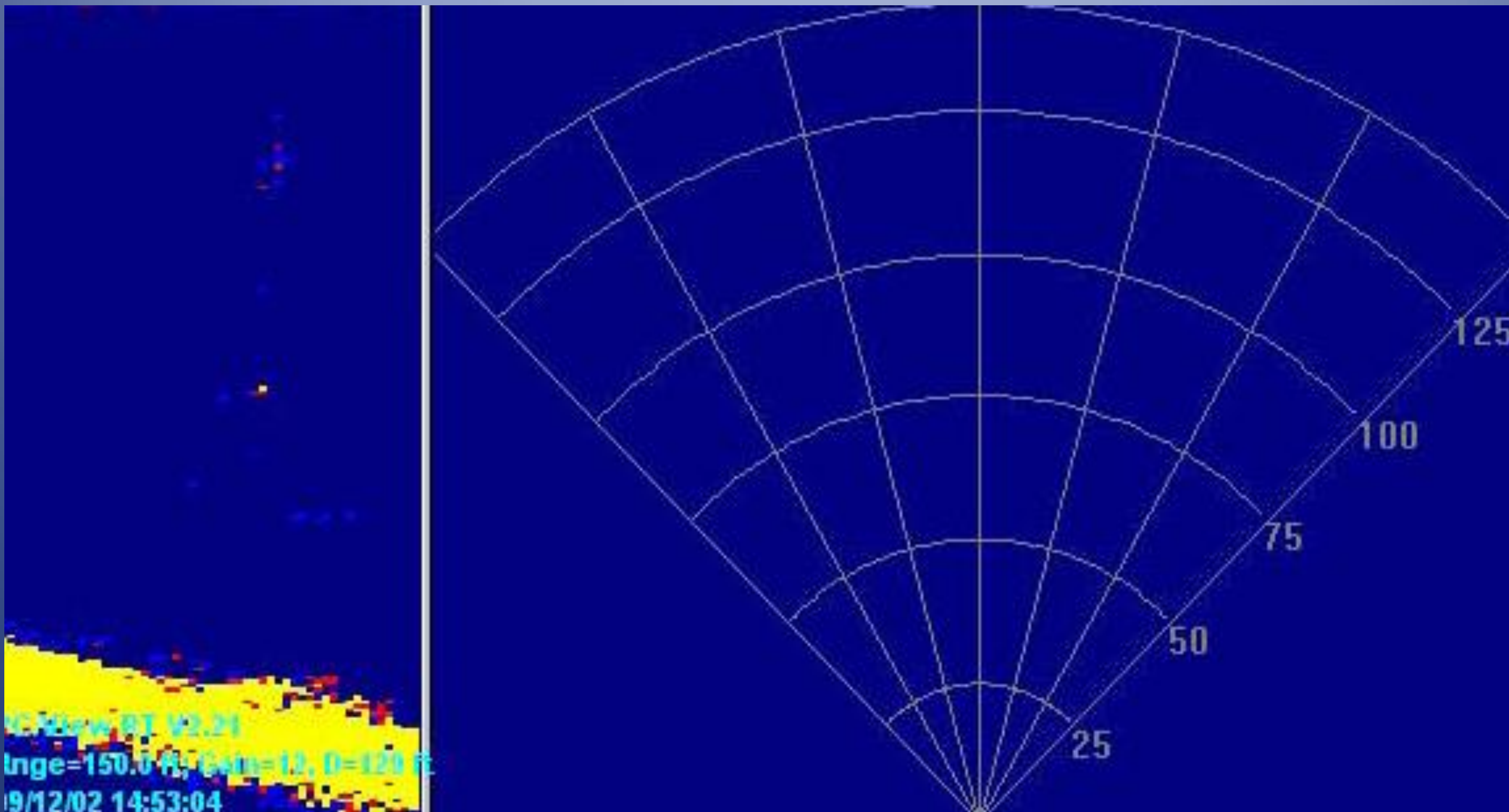
DELL
Inspiron 3500
GLASS ONLY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75
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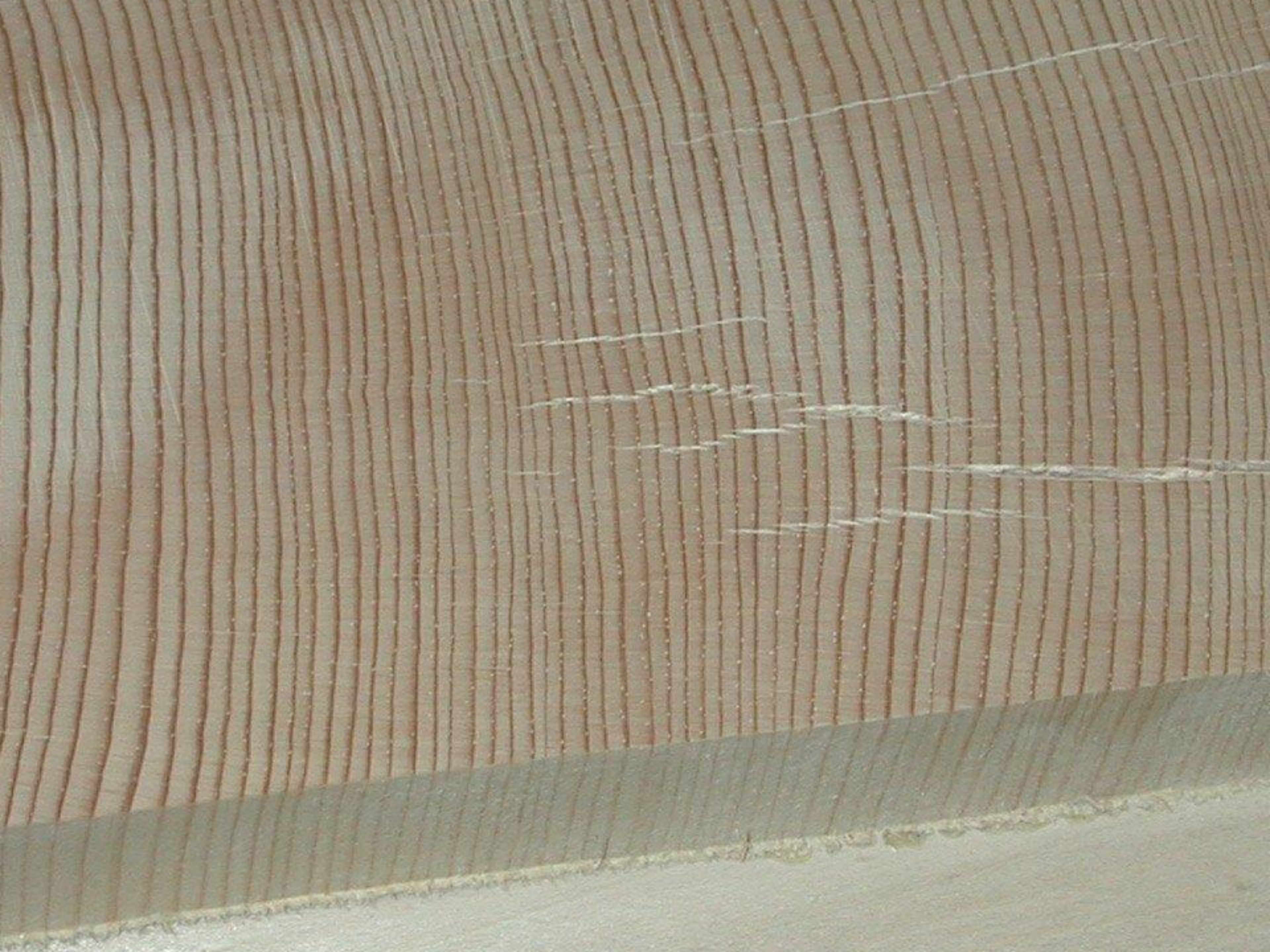
25
9/12/02 14:53:04




3-A

Underwater Dendrochronology of Sierra Nevada Lakes

Franco Biondi, John A. Kleppe, and Scotty Strachan

Abstract

Submerged, apparently rooted trees found in Lake Tahoe, Fallen Leaf Lake, and other Sierra Nevada lakes indicate the possibility of large-magnitude, rapidly-occurring but long lasting changes in lake level. These changes have usually been attributed to extended periods of very dry conditions during the mid and late Holocene, with the most recent mega-droughts happening during Medieval times. Given the relevance of this hypothesis for sustainable water management in the Lake Tahoe Basin and surrounding areas, it is then necessary to answer the question "Are submerged trees indicators of past mega-droughts, or were they transported into the lakes by past slope movements caused by geomorphic or seismic events?" Tree-ring samples collected from the submerged trees, and crossdated against existing and newly developed long chronologies, can provide a clear map of the historic periods when trees now underwater were alive. In 2005, three wood samples were retrieved from submerged trees in Fallen Leaf Lake. For dendrochronological dating, we developed a western juniper (*Juniperus occidentalis*) reference chronology that spans the period from AD 543 to 2003. One underwater sample, i.e. a branch cross section cut from a standing tree, was crossdated with the master chronology for the period AD 1085-1153. This initial result shows that, while it is feasible to date underwater trees, many more wood samples are needed to distinguish between climatic vs. non-climatic origin (and significance) of submerged trees in the Sierra Nevada.

Underwater Wood Samples from Fallen Leaf Lake

The identification of underwater stumps and trees was carried out using an ROV (remotely operated vehicle) that can obtain high resolution color video and retrieve small surface samples using a gripper down to a depth of about 150 m (see picture on the right). This ROV was developed by one of us (J.A. Kleppe), and has been extensively tested in Fallen Leaf Lake, where a total of 13 submerged trees have been located. Some of these trees are over 30 m tall with a circumference > 4 m (Kleppe 2005).

For tree-ring dating, samples were collected by cutting branches from trees standing underwater (see picture below). Two samples contained enough rings (>50) to allow the possibility of dendrochronological dating: these branch cross-sections are shown below, together with their location in the lake.

Fallen Leaf Lake (see map on the left) has a surface area of 5.2 km², is relatively deep and narrow (it fills a glacial valley), and drains into Lake Tahoe. Its watershed covers an area of approximately 42 km². Submerged trees being studied are at a depth of about 36 m below the lake surface.

The ratio of watershed to lake surface area for Fallen Leaf Lake is (42:5) or over 8 times, which in part causes the water level of to rise (fall) quickly during wet (dry) periods. This is in contrast to Lake Tahoe, which has a watershed to lake surface area of only 1.6:1 or slightly over 1½ times.

This section contains a sequence of about 200 rings.

The 3 wood samples have anatomical features of pine species, and show decomposition on the outside.

This section contains a sequence of about 70 rings.

Additional tree-ring samples were obtained by raising a log from the bottom of the lake using a a large floating crane (see pictures below). A section cut from the log at a height of about 5.2 m above root level was used for tree-ring dating. The number of rings on this section varied from 130 to 220.

Lindström, 1990

Lake	Radiocarbon dates (uncalibrated years BP)	Number of trees sampled
Tahoe	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Fallen Leaf	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

Sierra Nevada Submerged Trees

In her seminal work, Susan Lindström (1990) reported the location and radiocarbon dates of trees that appear rooted at the bottom of Lake Tahoe and a few other Sierra Nevada lakes (see pictures and table on the left). Additional evidence for mega-droughts in the Sierra Nevada was uncovered by Stine (1994), including stumps from Walker River (see picture on the right, although it is unclear if these are the same trees mentioned by Stine).

However, the presence of submerged stumps in Sierra Nevada lakes can be explained by a number of non-climatic processes, ranging from geomorphological (sediment accumulation and spill level rise at the lake outlet, stream bed variability, landslides carrying whole slopes into lakes) to tectonic (non-uniform changes in basin elevation) to seismic (earthquake-induced changes), or some combination of these factors.

Rather than attempting a review of the existing paleoclimatic literature, we propose a way to test the climatic vs. non-climatic significance of underwater trees.

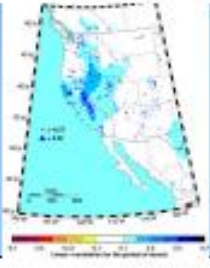
Tree-Ring Dating

For dating purposes, the only local species that could yield a chronology longer than 1000 years was western juniper (*Juniperus occidentalis*). Samples were collected from live and dead trees at three sites around Fallen Leaf Lake (see map). The three sites were at similar elevation (2300-2600 m), with low tree density, and rocky soils (see picture on the right).

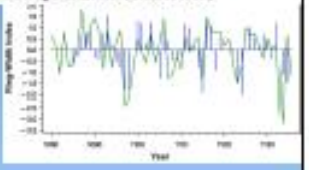
Wood samples were analyzed by two of us (F. Biondi and S. Strachan) using standard dendrochronological methods (see picture on the left). Samples that displayed "ring wedging" (groups of rings not uniformly present around the stem; see picture below) were excluded. The master chronology was formed by a total of 22 series from 16 different trees, and spanned the period AD 543-2003, or 1461 years, with sample depth ≥ 3 series from AD 654.

Overall series intercorrelation for the chronology is 0.532, with a mean series length of 363 years. The longest continuous segment in the chronology is from a log that covers 899 years, from AD 543 to AD 1410. The longest core from a living tree included 682 years, from AD 1322 to 2003. Out of 8648 rings used to build the chronology, only 3 are locally missing, indicating a high level of complacency in the growth patterns (see picture on the right).

From a correlation map with all other tree-ring chronologies available for the western USA (see below), it is clear that the western juniper master chronology is closely related to other Sierra Nevada sites.



Of the three underwater samples, only one could be crossdated with the master chronology. This was the branch cross-section shown in the lower left corner (blue dot in the lake map), which matched the period AD 1085-1154 both visually and numerically (in the plot below, the green line represents the juniper chronology, while the blue readies indicate the branch ring widths; linear correlation is 0.7).



These initial results are proof that it is feasible to obtain calendar dates and continuous ring-width series from submerged trees in the Sierra Nevada. Their climatic vs. non-climatic significance can then be tested using a combination of mapping and dating. By spatially comparing the location, orientation, and time of origin of underwater trees and stumps found in Sierra Nevada lakes, it will be possible to know if they were transported or grew in situ. In the latter case, it will also be possible to determine if they existed because of a local geologic process, or because of a regional climatic anomaly.

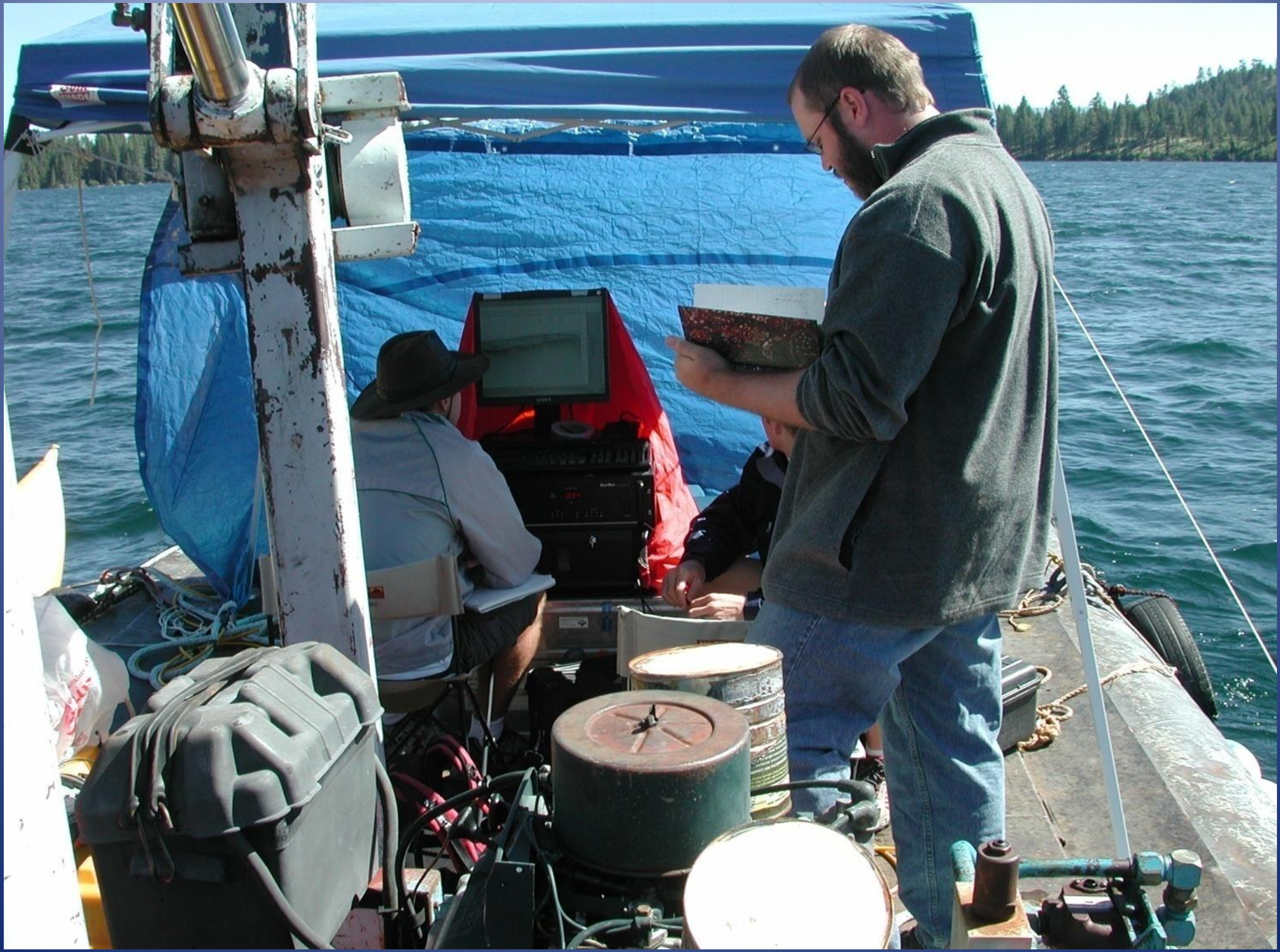
Recent advances in available technology make some of these tasks (such as bathymetry mapping with decimeter resolution) more feasible, while others require additional development (such as a specialized ROV for underwater tree-ring sampling).

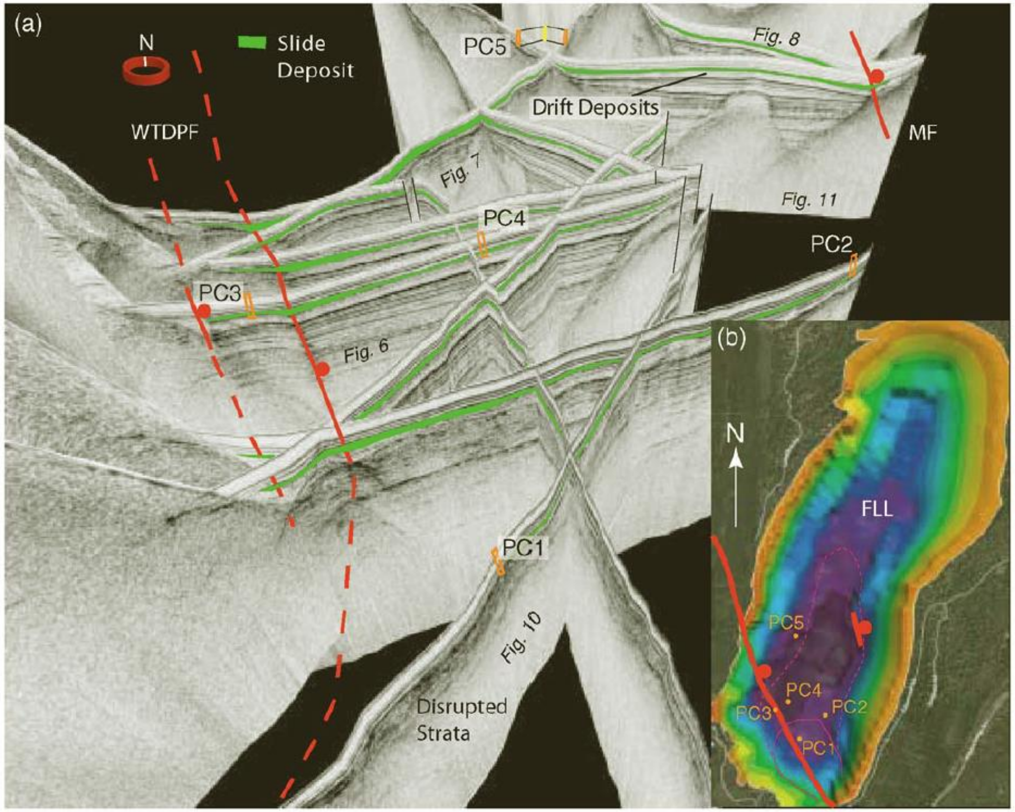
As more and more tree-ring samples are collected, dated, and entered into a master chronology, they will also provide a way to construct a continuous, annually resolved record over several millennia, because some of these submerged trees, according to already conducted radiocarbon analysis, date back to the mid-Holocene (Lindström 1990).

Acknowledgements

F. Biondi and S. Strachan were partially supported by the National Science Foundation (NSF) under Grant ATM CAREER 0132631.


7323 KK




(a)
N
Slide
Deposit
WTDPF
PC5
Fig. 8
Drift Deposits
MF
Fig. 7
Fig. 11
PC4
PC2
PC3
Fig. 6
(b)
N
FLL
PC1
Fig. 10
Disrupted
Strata
PC5
PC4
PC3
PC2
PC1

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New Constraints on Deformation, Slip Rate, and Timing of the Most Recent Earthquake on the West Tahoe–Dollar Point Fault, Lake Tahoe Basin, California

by Daniel S. Brothers, Graham M. Kent, Neal W. Driscoll, Shane B. Smith, Robert Karlin, Jeffrey A. Dingler, Alistair J. Harding, Gordon G. Seitz, and Jeffrey M. Babcock

Abstract High-resolution seismic compressed high intensity Radar pulse (CHIRP) data and piston cores acquired in Fallen Leaf Lake (FLL) and Lake Tahoe provide new paleoseismic constraints on the West Tahoe–Dollar Point fault (WTDPF), the westernmost normal fault in the Lake Tahoe Basin, California. Paleoearthquake records along three sections of the WTDPF are investigated to determine the magnitude and recency of coseismic slip. CHIRP profiles image vertically offset and folded strata along the southern and central sections that record deformation associated with the most recent event (MRE) on the WTDPF. Three faults are imaged beneath FLL, and the maximum vertical offset observed across the primary trace of the WTDPF is ~3.7 m. Coregistered piston cores in FLL recovered sediment and organic material above and below the MRE horizon. Radiocarbon dating of organic material constrained the age of the MRE to be between 3.6 and 4.9 k.y. B.P., with a preferred age of 4.1–4.5 k.y. B.P. In Lake Tahoe near Rubicon Point, approximately 2.0 m of vertical offset is observed across the WTDPF. Based on nearby core data, the timing of this offset occurred between ~3–10 k.y. B.P., which is consistent with the MRE age in FLL. Offset of Tioga-aged glacial deposits provides a long-term record of vertical deformation on the WTDPF since ~13–14 k.y. B.P., yielding a slip rate of 0.4–0.8 mm/yr. In summary, the slip rate and earthquake potential along the WTDPF is comparable to the nearby Genoa fault, making it the most active and potentially hazardous fault in the Lake Tahoe Basin.

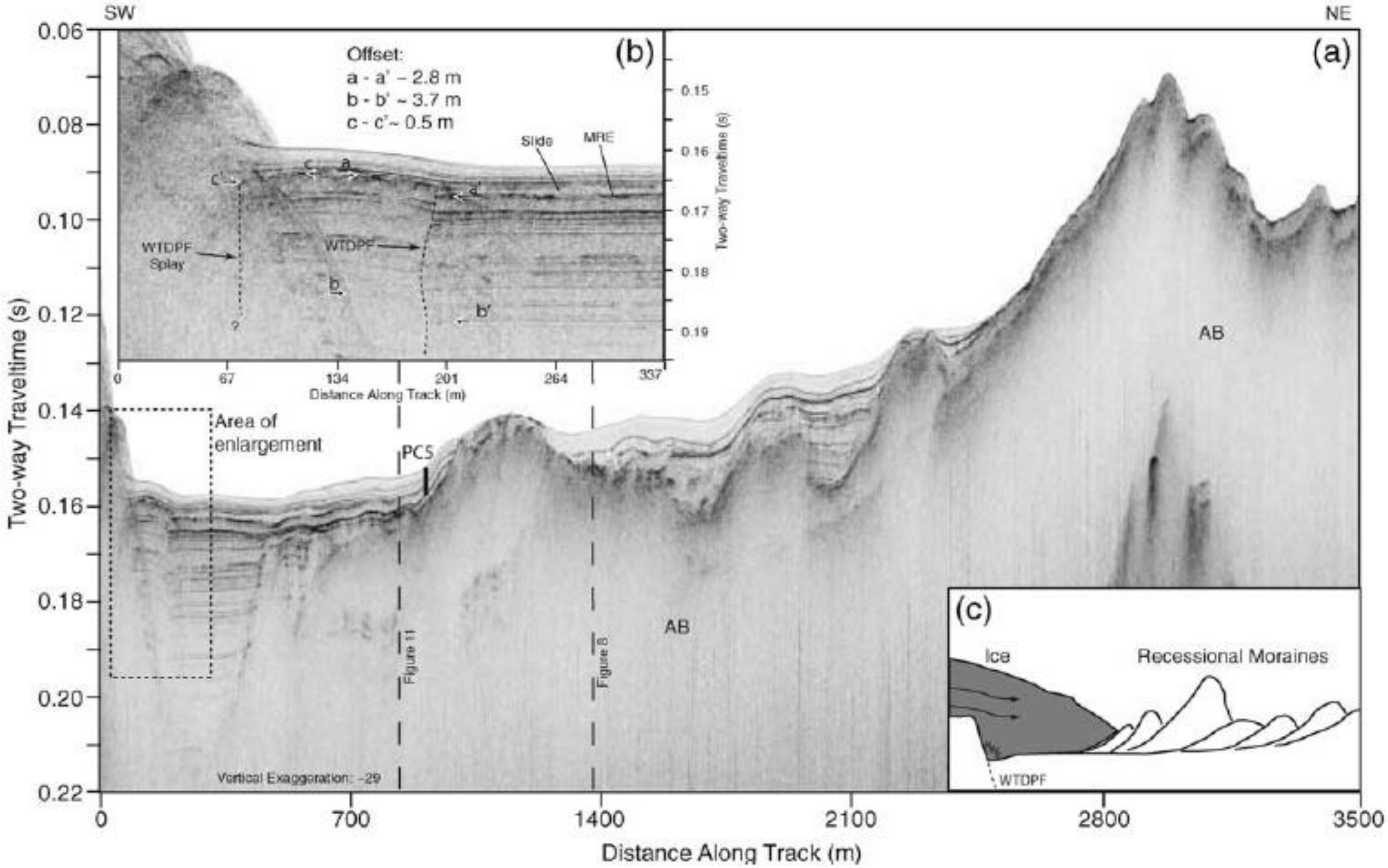

Figure 5. (a) Northeast–southwest tending CHIRP profile spanning over two-thirds of FLL. The WTDPF is seen toward the southern end, adjacent to a steep, fault-parallel escarpment. (b) Enlarged section of the two splays of the WTDPF (dashed box in 5a). Offset across both faults creates anticlinal folding in the sediments. A divergent bed labeled "slide" thickens into the fault and infills accommodation created during the MRE. The slide is an important marker bed that is seen in the seismic stratigraphy and in four of the piston cores (Fig. 4) throughout most of the southern lake. Piercing points (white arrows) on the footwall were selected near the apex of the anticline; beds are assumed to have been deposited approximately horizontal, then were subsequently folded and offset during the MRE. Offset increases with depth from ~2.8 m across the MRE horizon (aa′) to ~3.7 m across horizon bb′ due to increased compaction and dewatering with depth (all travel time to depth conversions assume 1500 m/sec velocity). Piston core PC5 is ~40 m to the west of this profile. (c) Hummocky topography in the acoustic basement (AB) is seen in several profiles. This type of morphology is typical for moraines formed at glacier fronts by temporary still stands or readvancements during an overall glacial retreat. Similar morphology is observed as a series of arcuate recessional moraines between FLL and Lake Tahoe (Saucedo, 2005). The relief toward the southern end of the profile, adjacent to the WTDPF, may be formed by a combination of glacial and tectonic processes, much like a roche moutonée, but glacial plucking may have been facilitated by the location of the fault.


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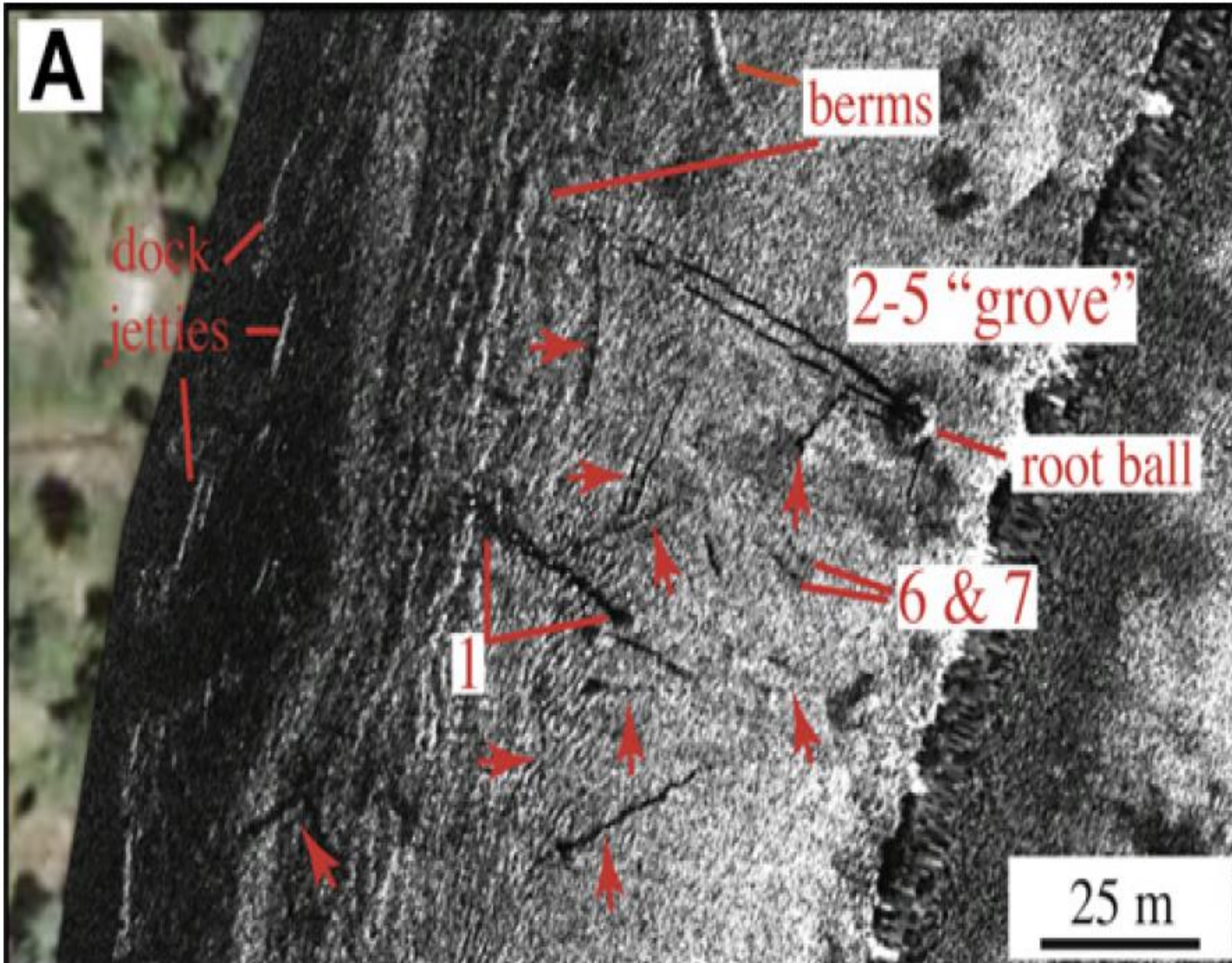
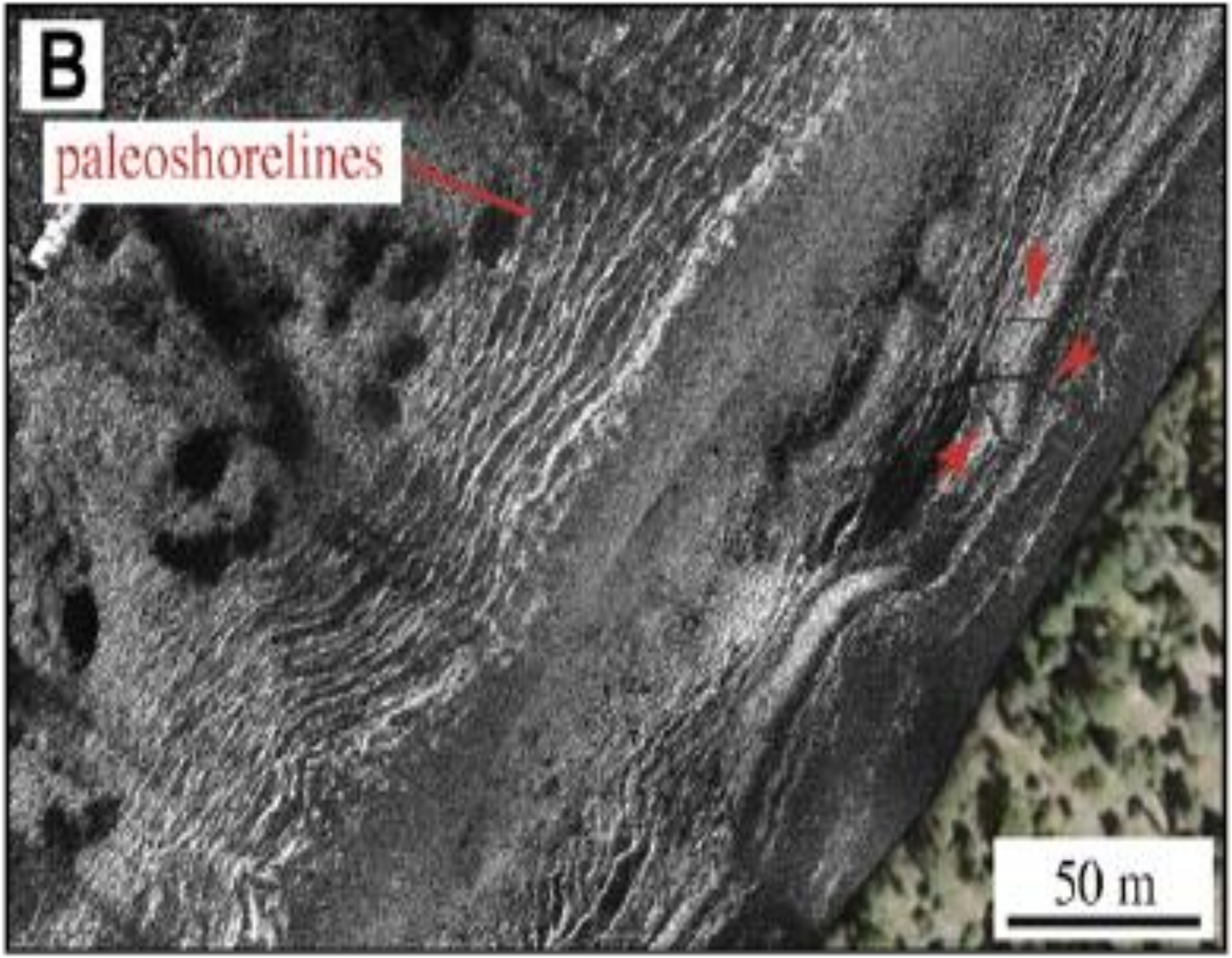
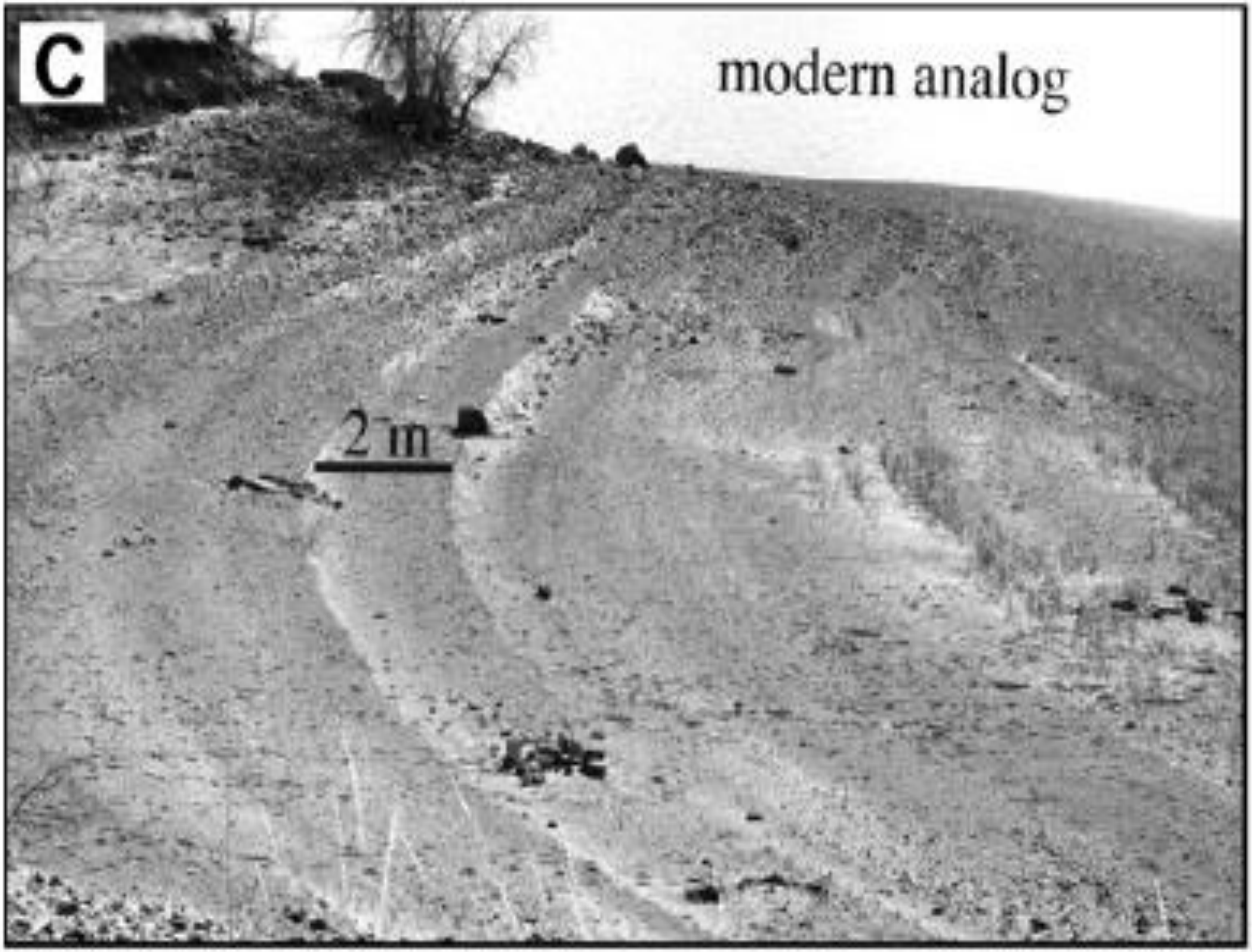
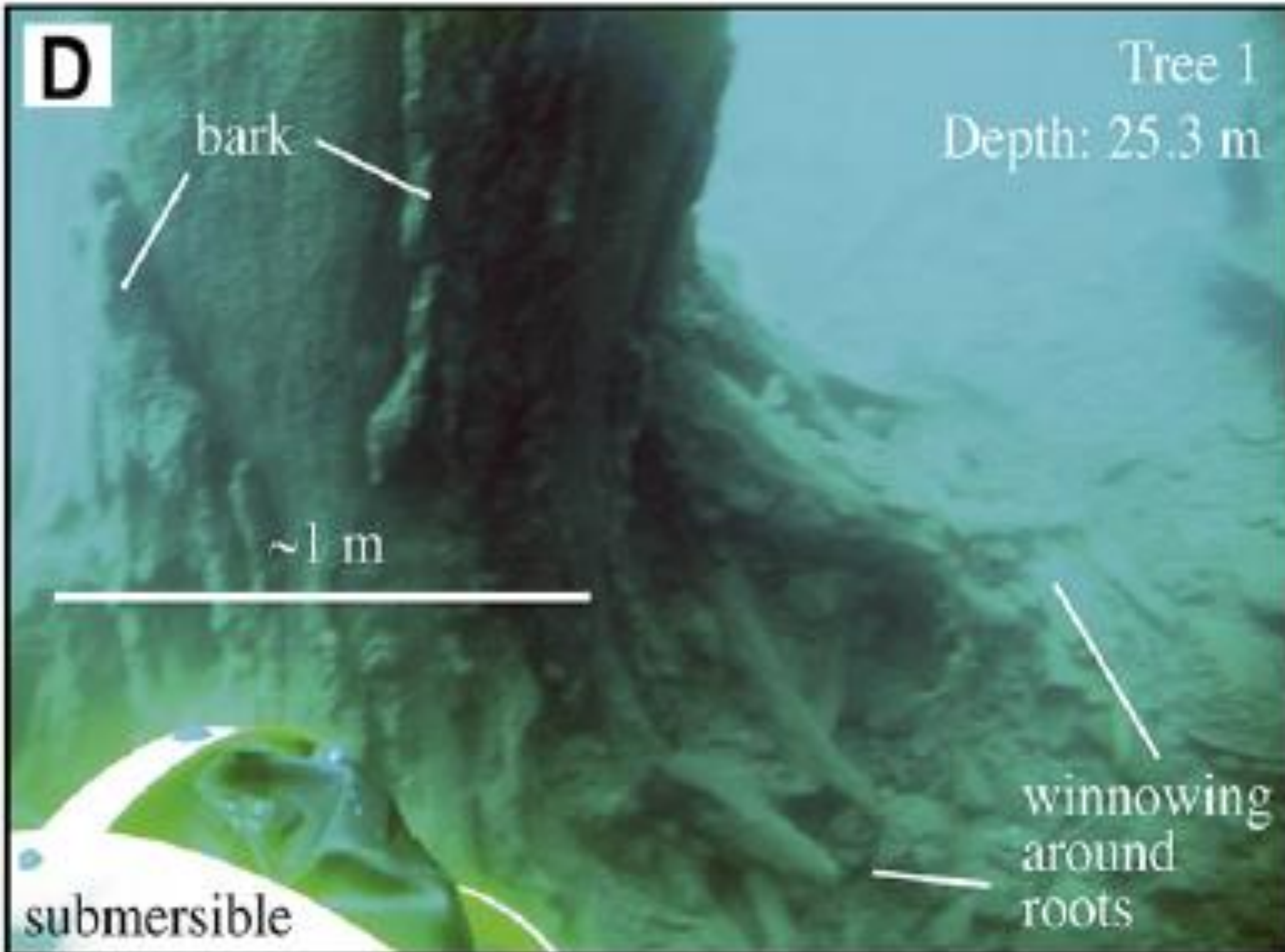
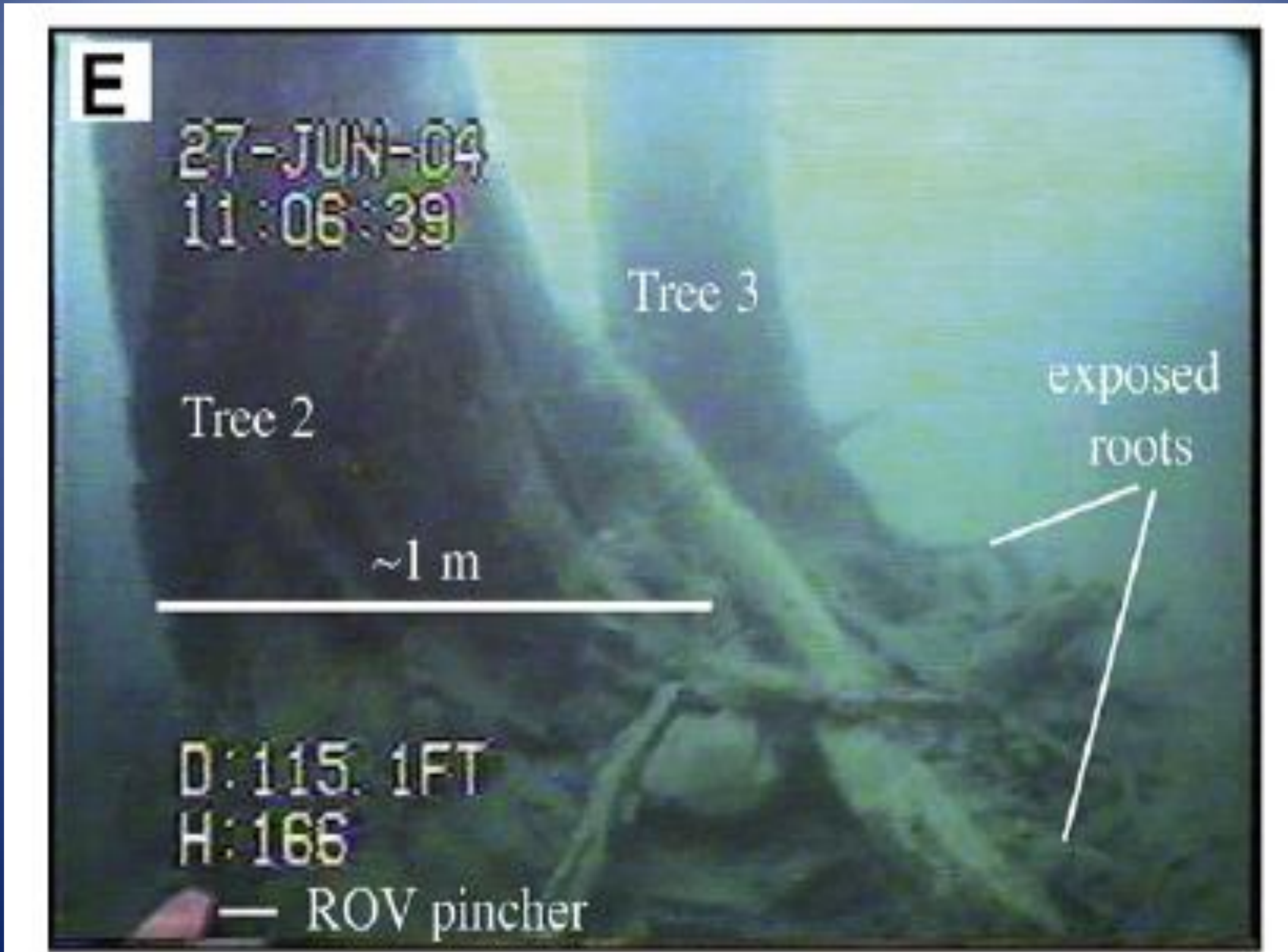

A
berms
dock
jetties
2-5 “grove”
root ball
6 & 7
1
25 m


B
paleoshorelines
50 m


C
modern analog
2 m


D
Tree 1
Depth: 25.3 m
bark
~1 m
winnowing
around
roots
submersible


E
27-JUN-04
11:06:39
Tree 3
exposed
roots
Tree 2
~1 m
D:115. 1FT
H:166
ROV pincher

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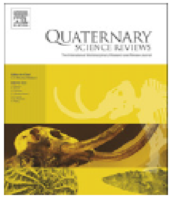
journal homepage: www.elsevier.com/locate/quascirev



Duration and severity of Medieval drought in the Lake Tahoe Basin

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ABSTRACT

Droughts in the western U.S. in the past 200 years are small compared to several megadroughts that occurred during Medieval times. We reconstruct duration and magnitude of extreme droughts in the northern Sierra Nevada from hydroclimatic conditions in Fallen Leaf Lake, California. Stands of submerged trees rooted *in situ* below the lake surface were imaged with sidescan sonar and radiocarbon analysis yields an age estimate of ~1250 AD. Tree-ring records and submerged paleoshoreline geomorphology suggest a Medieval low-stand of Fallen Leaf Lake lasted more than 220 years. Over eighty more trees were found lying on the lake floor at various elevations above the paleoshoreline. Water-balance calculations suggest annual precipitation was less than 60% normal from late 10th century to early 13th century AD. Hence, the lake's shoreline dropped 40–60 m below its modern elevation. Stands of pre-Medieval trees in this lake and in Lake Tahoe suggest the region experienced severe drought at least every 650–1150 years during the mid- and late-Holocene. These observations quantify paleo-precipitation and recurrence of prolonged drought in the northern Sierra Nevada.

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We compute a water balance for the FLL watershed that includes terms for evapotranspiration, evaporation, groundwater flow and change in stage:

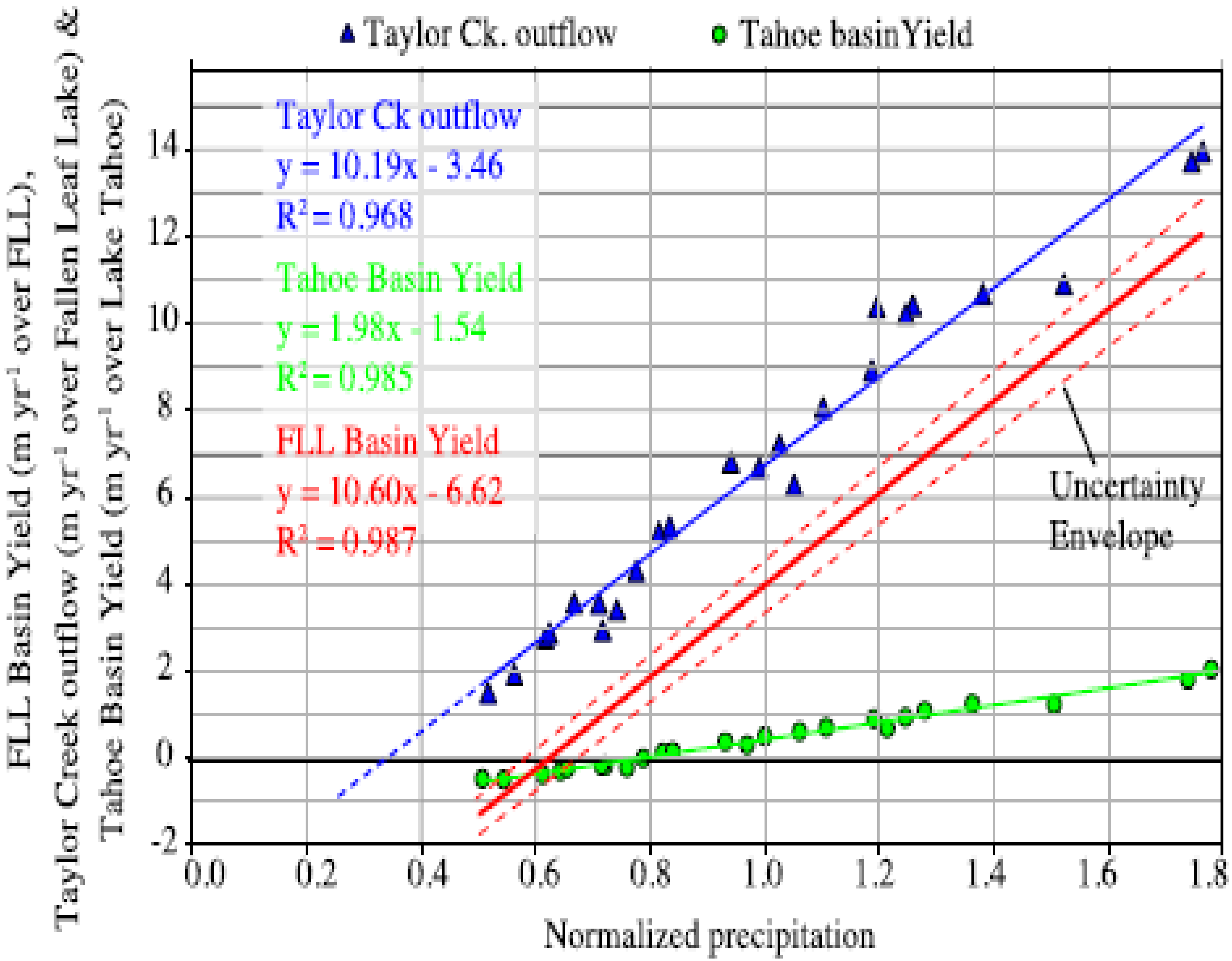
$$P(y) = R_T(y) + GW(y) + \Delta S(y) + E_T(y) + E(y) \quad (1)$$

y = water year over the USGS data period 1969–1992, $P(y)$ = precipitation over watershed (including lake surface), $\Delta S(y)$ = change in stage of FLL, $E_T(y)$ = Evapotranspiration over FLL watershed, $E(y)$ = Evaporation from FLL surface, $R_T(y)$ = Streamflow down Taylor Creek, $GW(y)$ = Net groundwater flow into and out of the lake

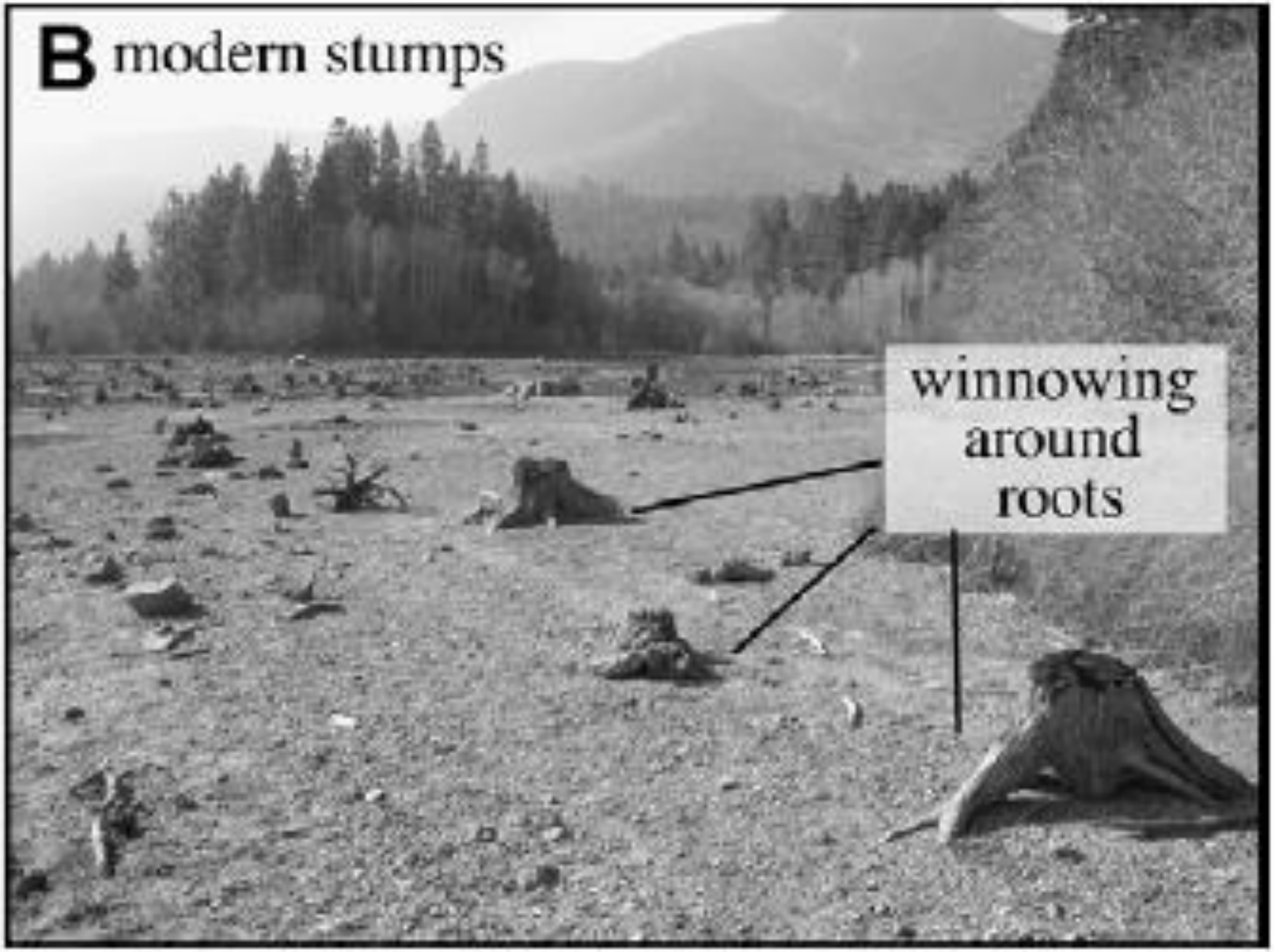
A complete representation of the FLL basin yield (*FLY*) is found by including additional terms:

$$FLY(y) = R_T(y) - \Delta GW(y) + \Delta S(y) \quad (3)$$

$$FLY(y) = 10.19x - 5.86 \quad (4)$$



Taylor Ck. outflow
Tahoe basinYield
Taylor Ck outflow
y = 10.19x - 3.46
R² = 0.968
Tahoe Basin Yield
y = 1.98x - 1.54
R² = 0.985
FLL Basin Yield
y = 10.60x - 6.62
R² = 0.987
Uncertainty Envelope
FLL Basin Yield (m yr⁻¹ over FLL), Taylor Creek outflow (m yr⁻¹ over Fallen Leaf Lake) & Tahoe Basin Yield (m yr⁻¹ over Lake Tahoe)
Normalized precipitation
-2
0
2
4
6
8
10
12
14
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8


B modern stumps
winnowing around roots

09-JUL-10
20:27:10
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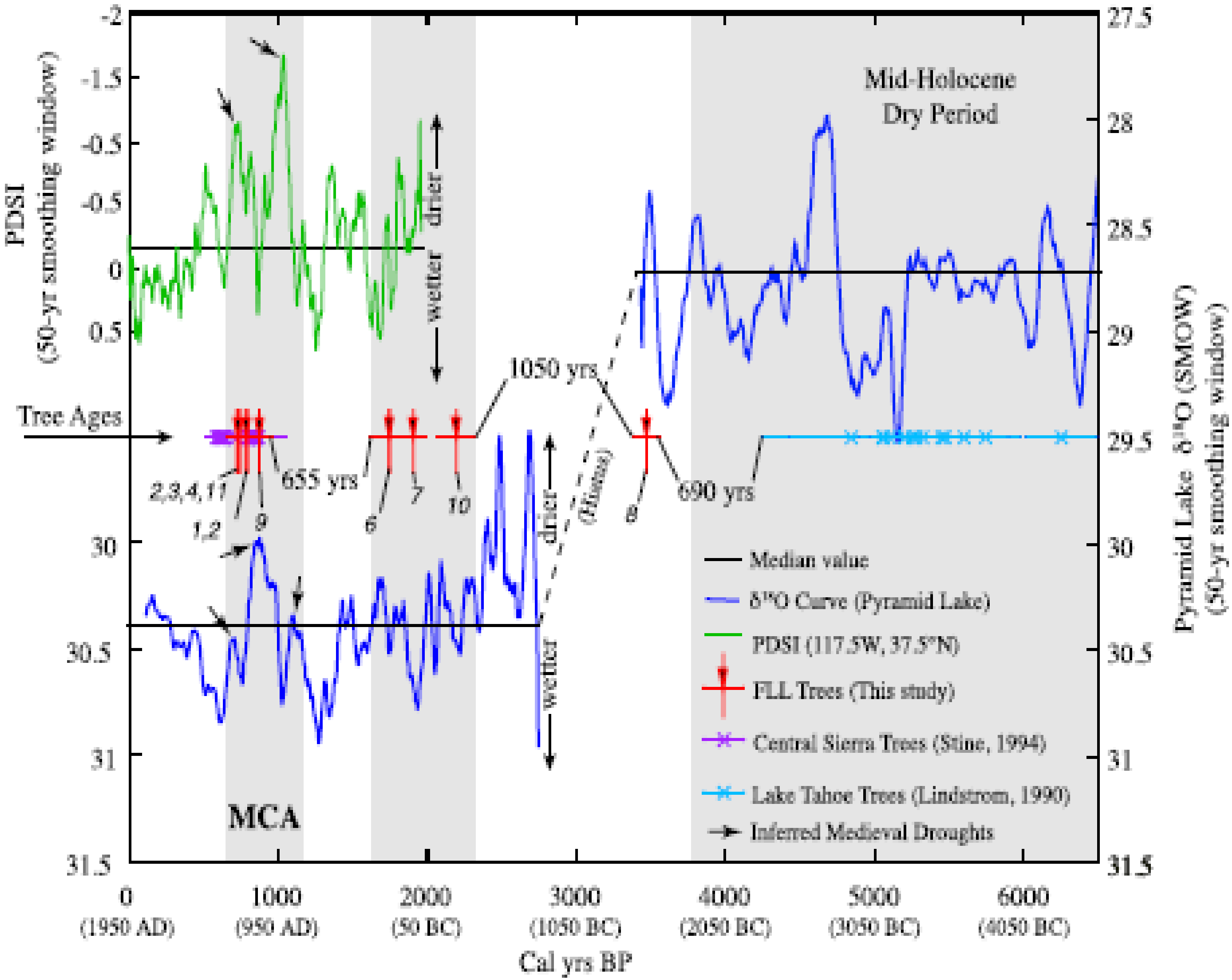
H:021


09-JUL-10
20:11:12
D:027. 7FT
H:101

Mega Drought: Will it happen again?



PDSI
(50-yr smoothing window)
-2
-1.5
-0.5
-0.5
0
0.5
Mid-Holocene
Dry Period
drier
wetter
1050 yrs
Tree Ages
655 yrs
690 yrs
2,3,4,11
1,2
9
6
7
10
8
(Hiatus)
MCA
Median value
δ¹⁸O Curve (Pyramid Lake)
PDSI (117.5W, 37.5°N)
FLL Trees (This study)
Central Sierra Trees (Stine, 1994)
Lake Tahoe Trees (Lindstrom, 1990)
Inferred Medieval Droughts
30
30.5
31
31.5
27.5
28
28.5
29
29.5
Pyramid Lake δ¹⁸O (SMOW)
(50-yr smoothing window)
0
(1950 AD)
1000
(950 AD)
2000
(50 BC)
3000
(1050 BC)
4000
(2050 BC)
5000
(3050 BC)
6000
(4050 BC)
Cal yrs BP

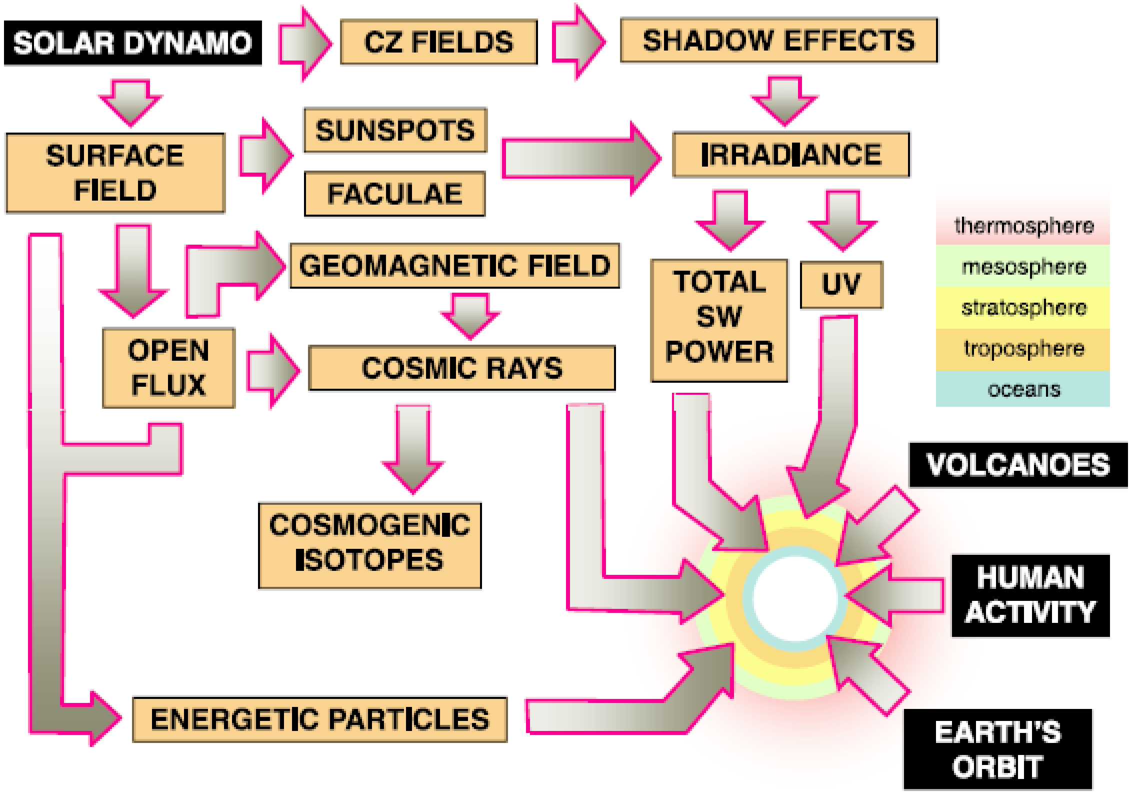
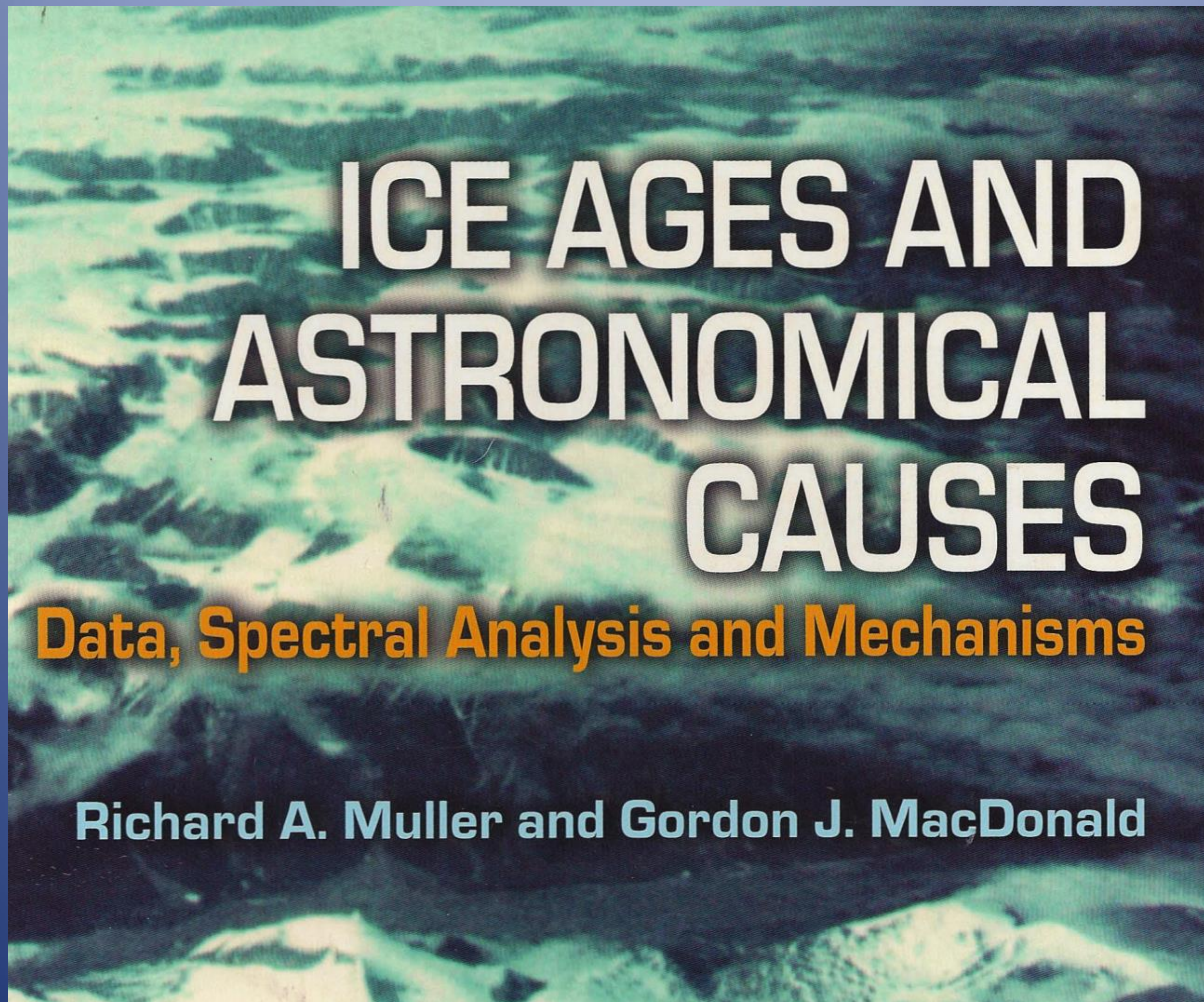
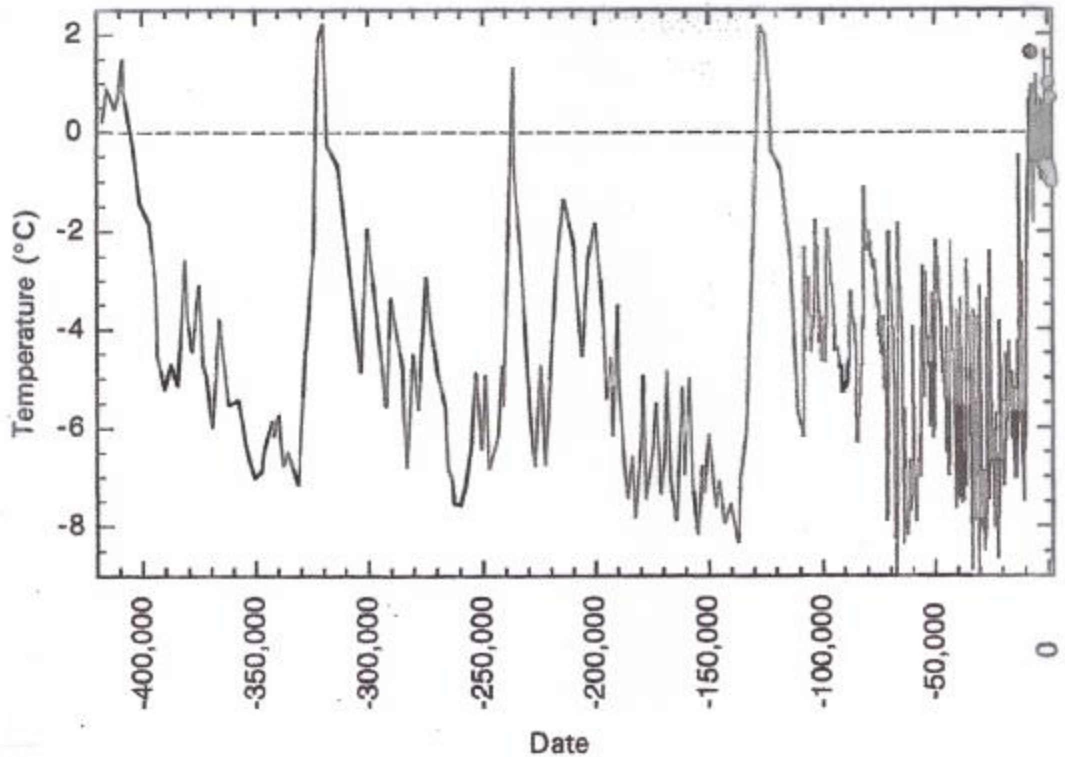
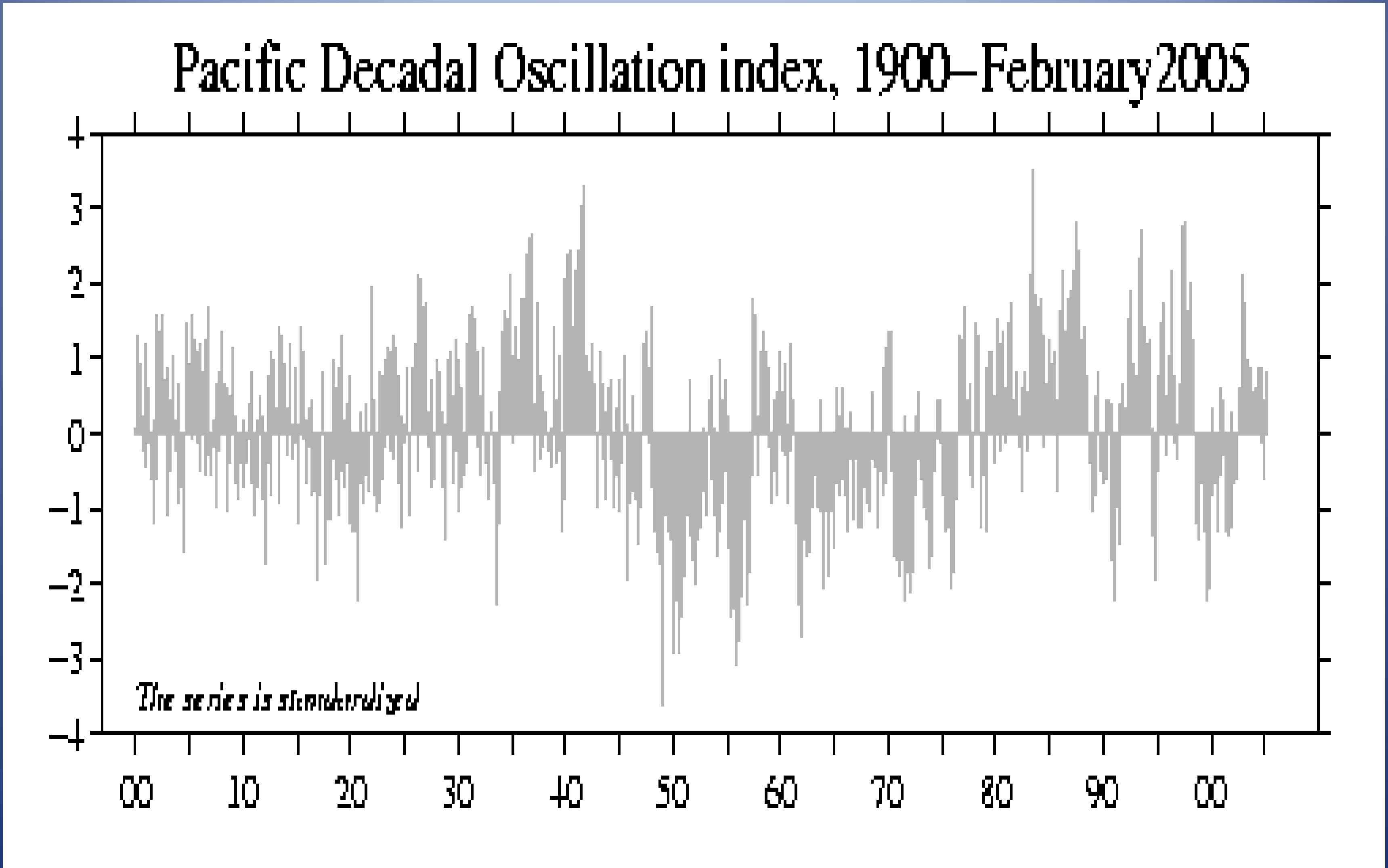


Figure 20. Schematic overview showing various climate forcings of the Earth's atmosphere, with factors that influence the forcing associated with solar variability (irradiance and corpuscular radiation) shown in more detail on the left-hand side, as discussed in section 2.


ICE AGES AND
ASTRONOMICAL
CAUSES
Data, Spectral Analysis and Mechanisms
Richard A. Muller and Gordon J. MacDonald



. Climate for the last 420 kyr, from Vostok ice.


Pacific Decadal Oscillation index, 1900–February2005
4
3
2
1
0
−1
−2
−3
−4
The series is standardized
00
10
20
30
40
50
60
70
80
90
00

SOLAR INFLUENCES ON CLIMATE

L. J. Gray,[1,2] J. Beer,[3] M. Geller,[4] J. D. Haigh,[5] M. Lockwood,[6,7] K. Matthes,[8,9] U. Cubasch,[8] D. Fleitmann,[10,11] G. Harrison,[12] L. Hood,[13] J. Luterbacher,[14] G. A. Meehl,[15] D. Shindell,[16] B. van Geel,[17] and W. White[18]

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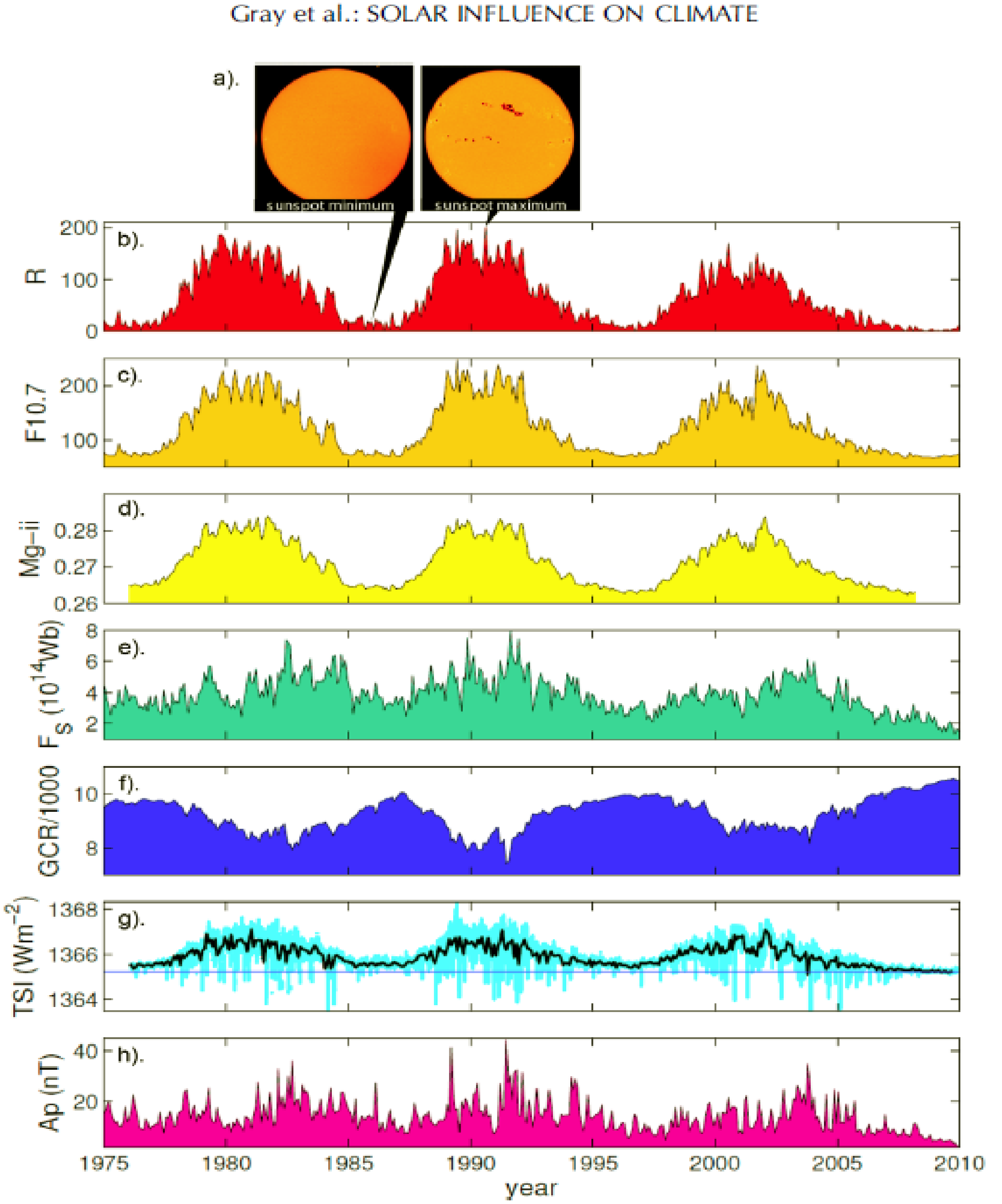
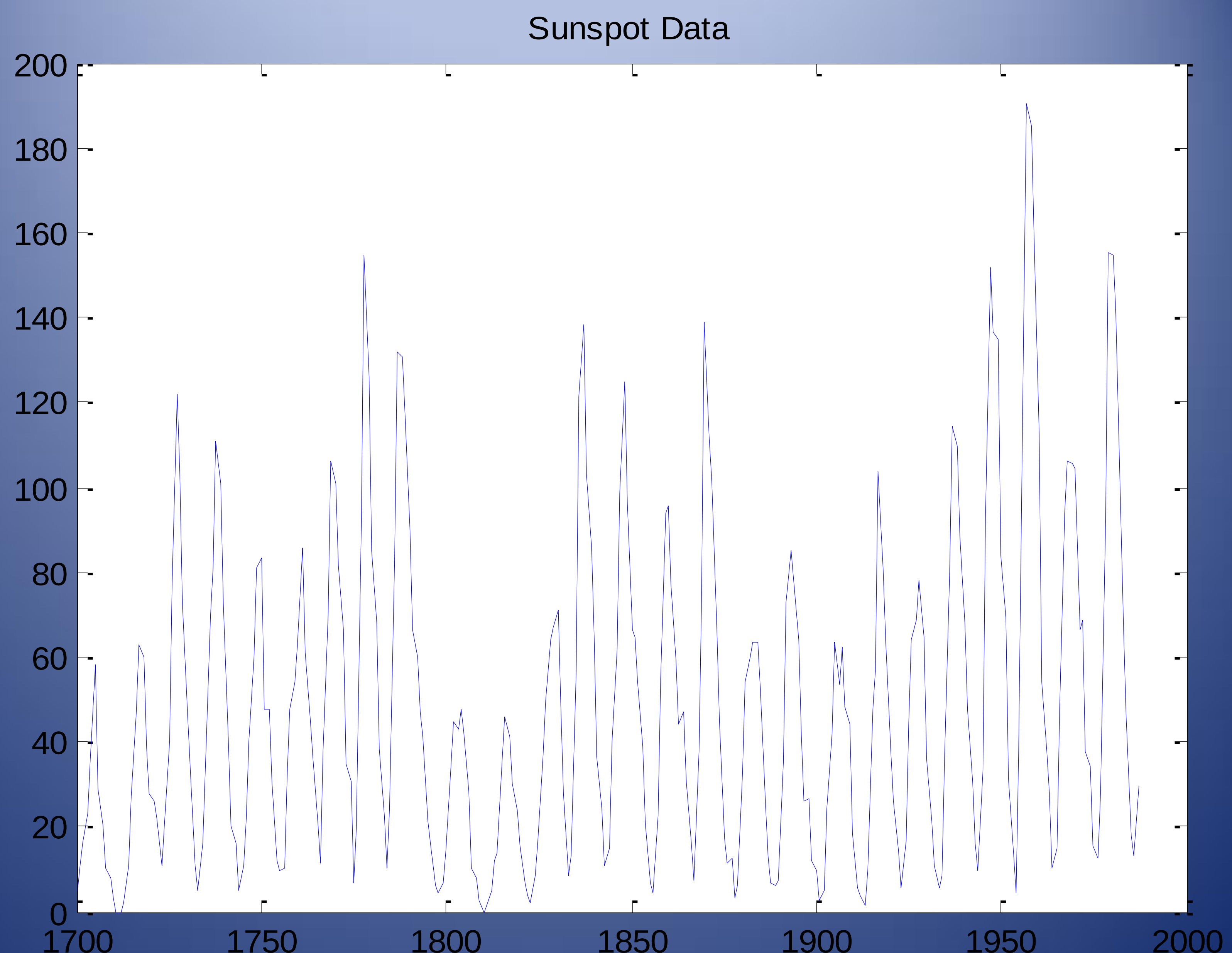
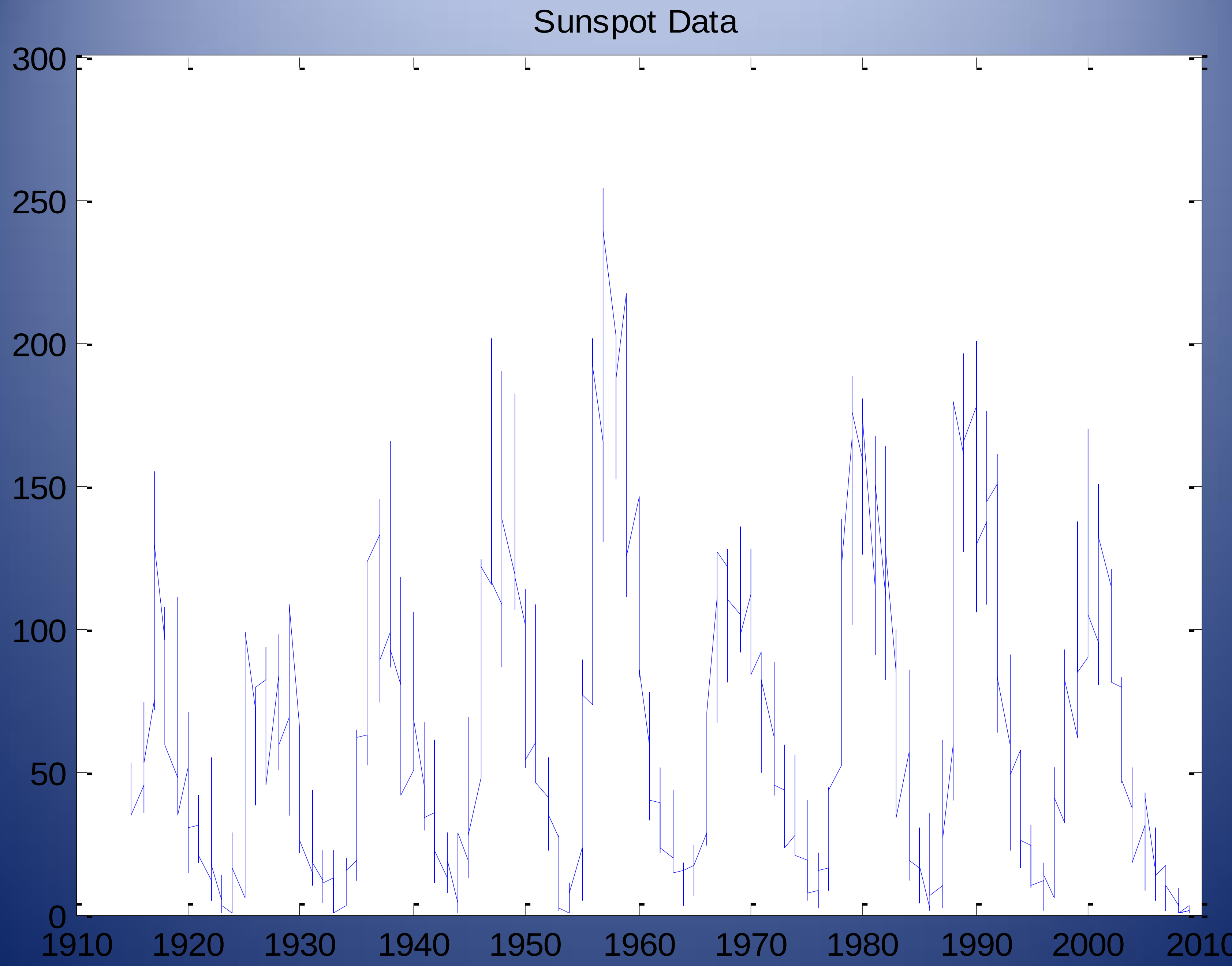
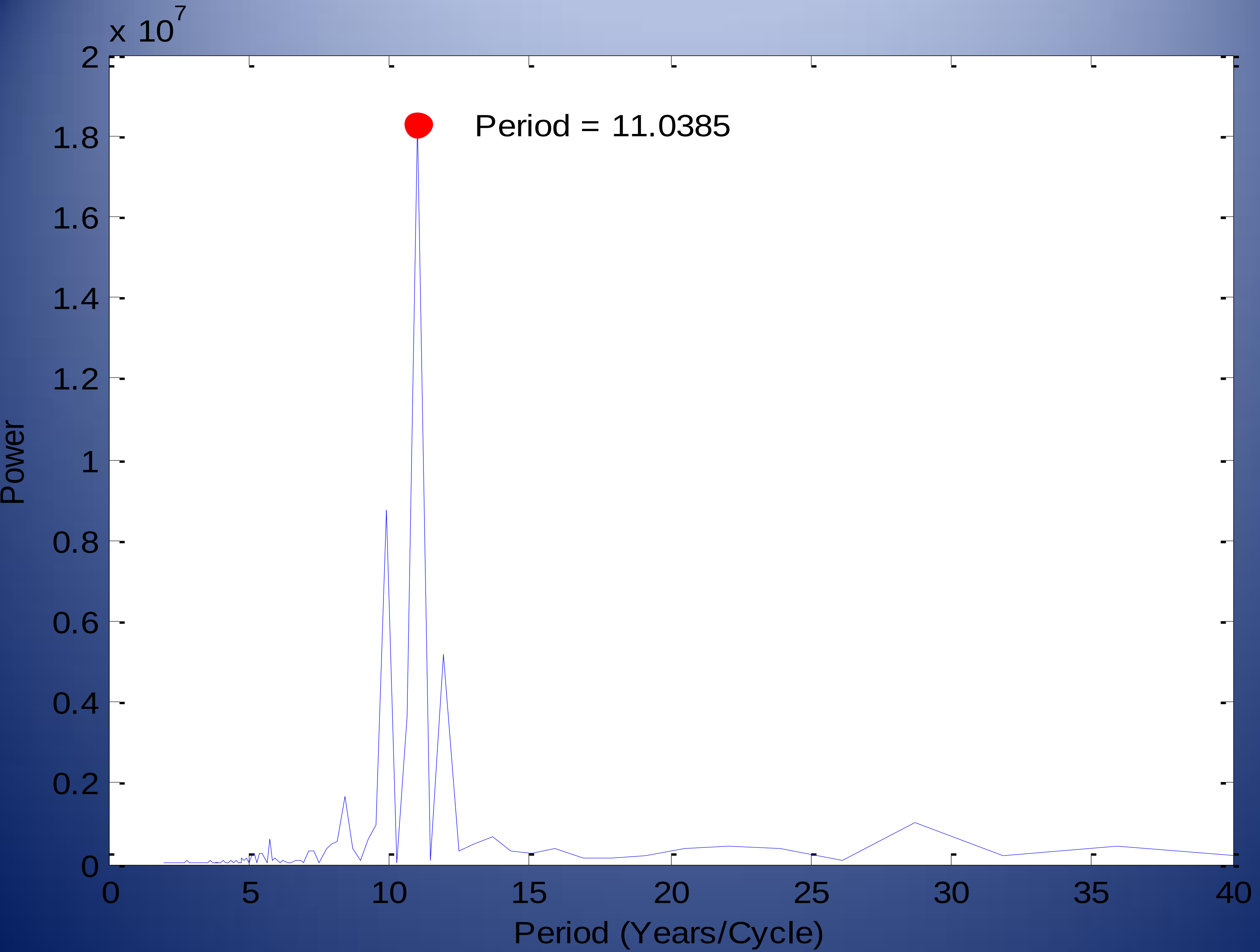
[1] Understanding the influence of solar variability on the Earth's climate requires knowledge of solar variability, solar-terrestrial interactions, and the mechanisms determining the response of the Earth's climate system. We provide a summary of our current understanding in each of these three areas. Observations and mechanisms for the Sun's variability are described, including solar irradiance variations on both decadal and centennial time scales and their relation to galactic cosmic rays. Corresponding observations of variations of the Earth's climate on associated time scales are described, including variations in ozone, temperatures, winds, clouds, precipitation, and regional modes of variability such as the monsoons and the North Atlantic Oscillation. A discussion of the available solar and climate proxies is provided. Mechanisms proposed to explain these climate observations are described, including the effects of variations in solar irradiance and of charged particles. Finally, the contributions of solar variations to recent observations of global climate change are discussed.

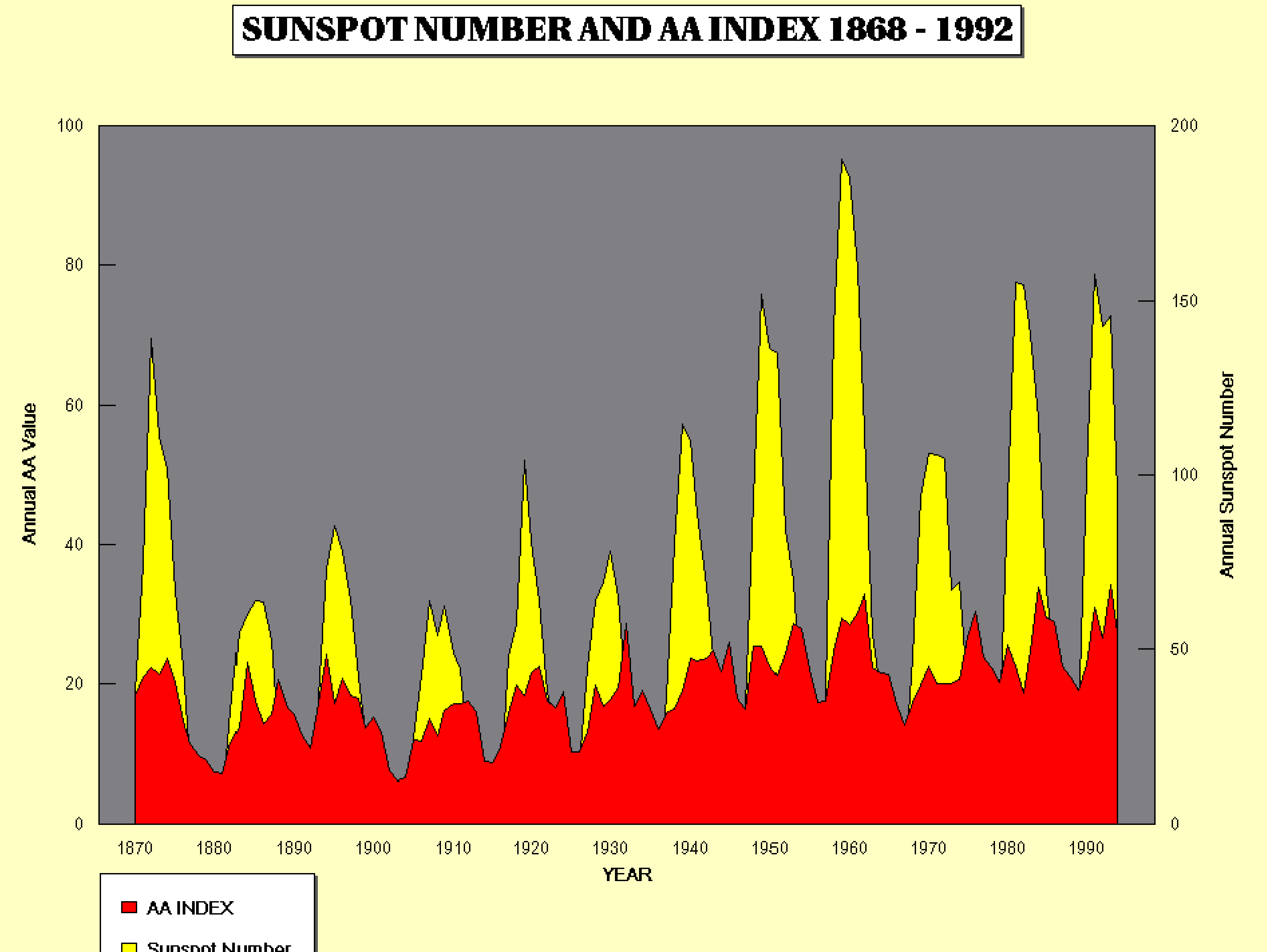
Citation: Gray, L. J., et al. (2010), Solar influences on climate, *Rev. Geophys.*, *48*, RG4001, doi:10.1029/2009RG000282.

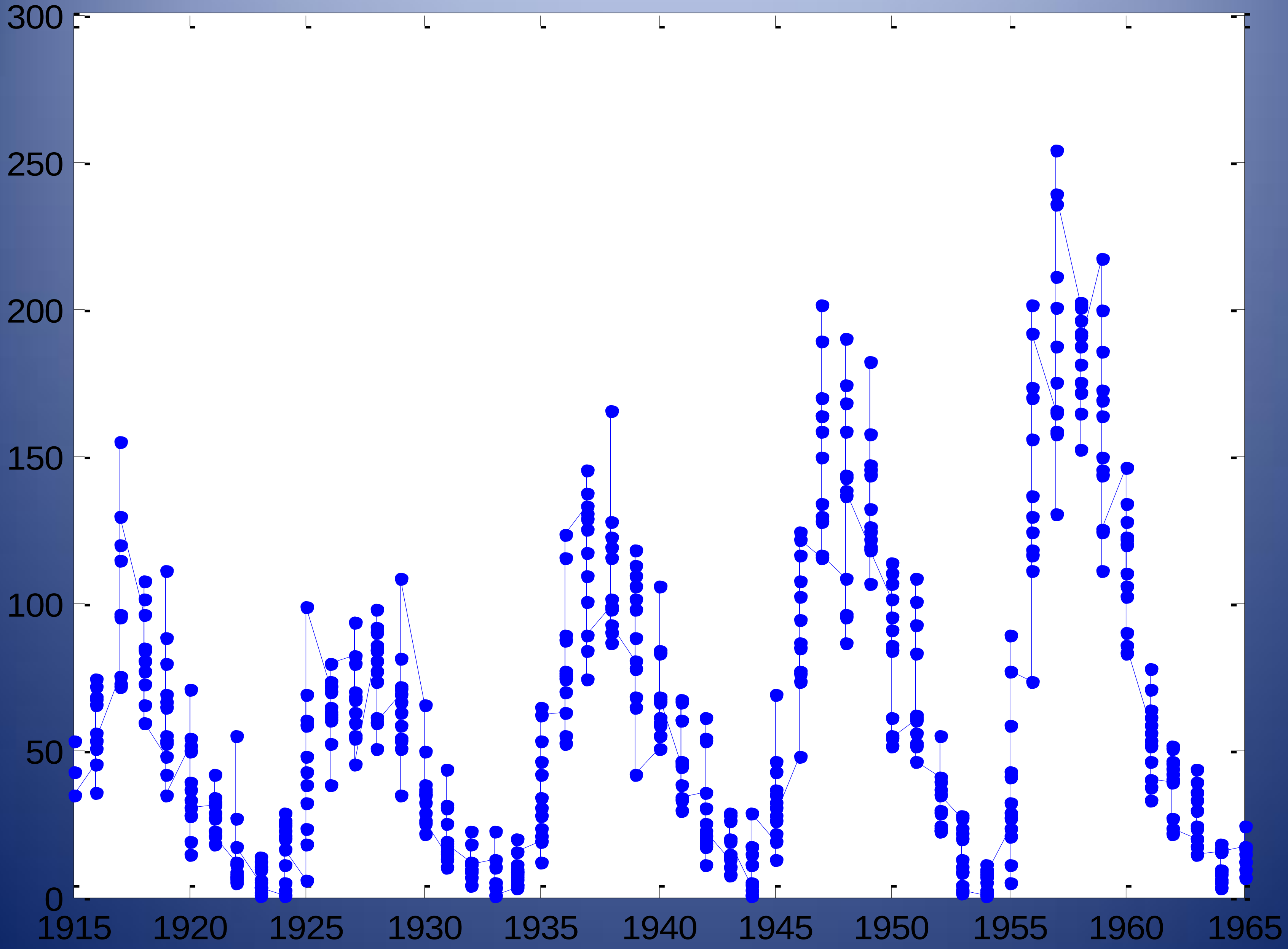

Gray et al.: SOLAR INFLUENCE ON CLIMATE
a).
sunspot minimum
sunspot maximum
b).
R
c).
F10.7
d).
Mg–ii
e).
F_S (10^{14}Wb)
f).
GCR/1000
g).
TSI (Wm^{-2})
h).
Ap (nT)
1975
1980
1985
1990
1995
2000
2005
2010
year


Sunspot Data
200
180
160
140
120
100
80
60
40
20
0
1700
1750
1800
1850
1900
1950
2000

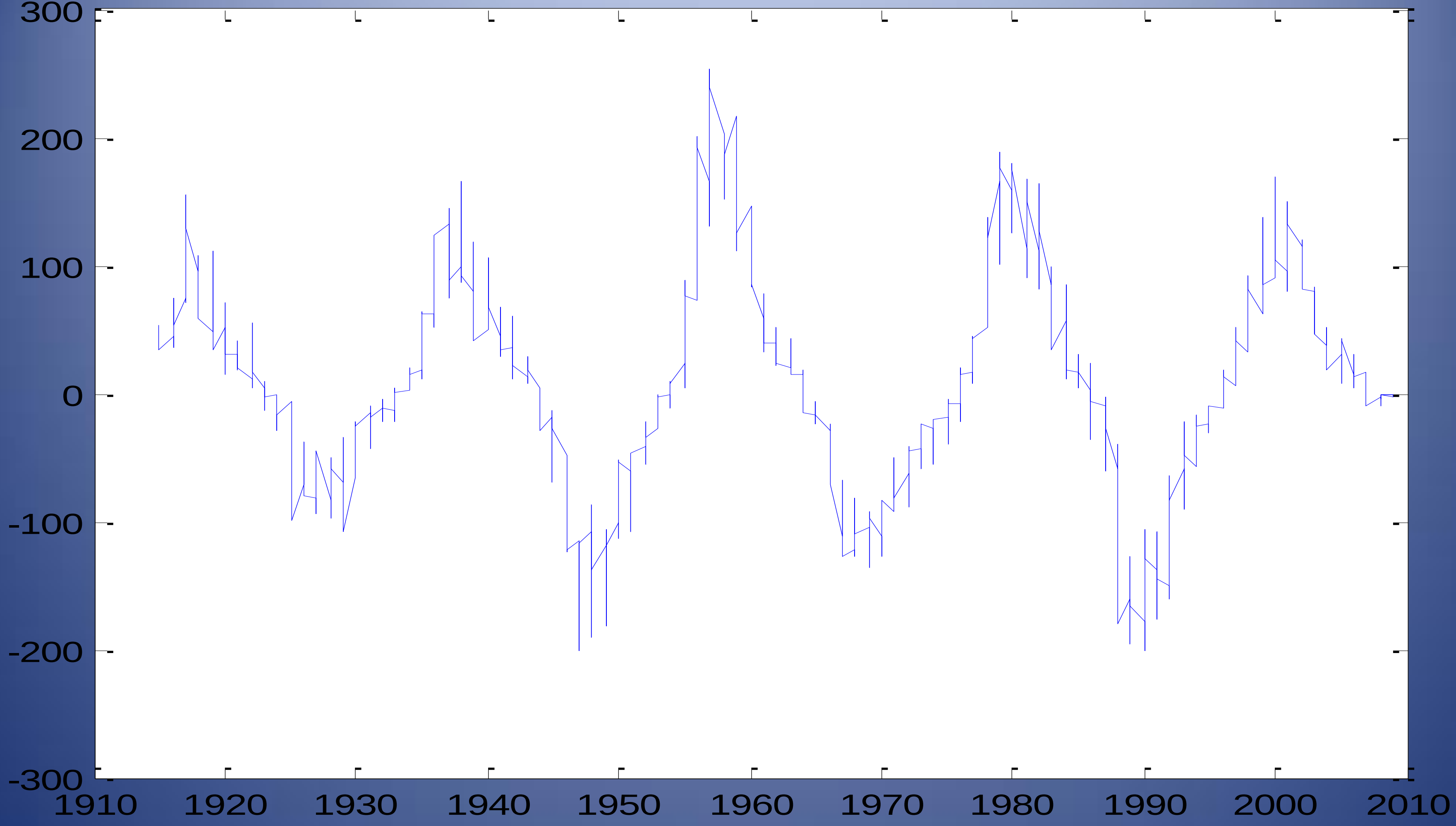

Sunspot Data
300
250
200
150
100
50
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

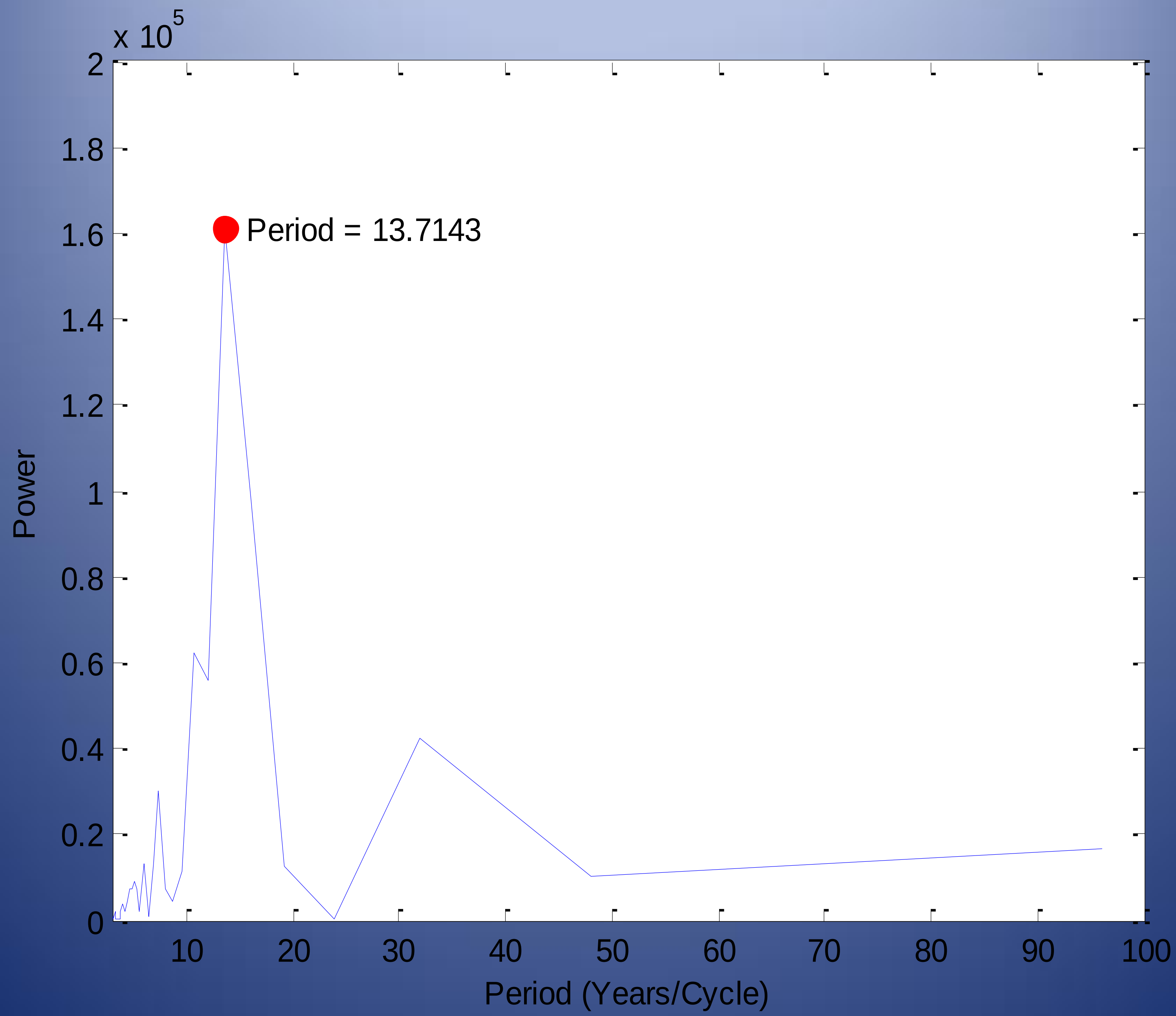

x 10^7
Period = 11.0385
Power
Period (Years/Cycle)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
5
10
15
20
25
30
35
40


SUNSPOT NUMBER AND AA INDEX 1868 - 1992
Annual AA Value
100
80
60
40
20
0
200
150
100
50
0
Annual Sunspot Number
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
YEAR
AA INDEX
Sunspot Number



300
250
200
150
100
50
0
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965


300
200
100
0
-100
-200
-300
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010



x 10^5
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Power
Period = 13.7143
10
20
30
40
50
60
70
80
90
100
Period (Years/Cycle)

Mega Drought: Will it happen again? There appears to be a cycle of about 650 to 1150 years. This will be refined in an upcoming paper in the next several weeks.

The last Mega Drought was between 900 and 1200 AD.

Mega Drought: Will we be ready? It is up to people like you to understand and define the problem(s), to determine the solution(s), to assess the risks, and finally to implement plans to mitigate the Mega Drought(s).

Thank you

Do you have any Questions?