

## THE MAUNDER MINIMUM: AN INTERLABORATORY COMPARISON OF $\Delta^{14}\text{C}$ FROM AD 1688 TO AD 1710

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**ABSTRACT.** Measurements on same-age tree-ring samples from proximal Ural Mountain trees by the Ioffe Institute research group and at the University of Arizona demonstrate a variance corresponding to a standard deviation of  $\pm 5.1\text{‰}$  for Ioffe compared to  $\pm 2.1\text{‰}$  for Tucson. There is also a calibration difference of  $4.3 \pm 1.2 \text{‰}$ . Comparison of the same years measured in Seattle on wood from the Pacific Northwest shows an offset of  $2.2 \pm 0.5 \text{‰}$ . This is not a calibration error, but rather is expected from the well-documented evidence for divergence and upwelling of  $^{14}\text{C}$ -depleted  $\text{CO}_2$  along the west coast of North America.

### INTRODUCTION

Professor Grant Kocharov, head of the Astrophysics Section of the Ioffe Institute in St Petersburg, Russia, realized early the importance of radiocarbon research in obtaining information concerning paleosolar physics. Consequently, he encouraged and helped support the dendrochronological research of Professor Bitvinskas in Lithuania and a  $^{14}\text{C}$  laboratory in Georgia. His research group also built a  $^{14}\text{C}$  laboratory at the Ioffe Physical Technical Institute in Leningrad. Unfortunately, because they were isolated from the mainstream of  $^{14}\text{C}$  geophysics research in the West, they were unable to participate in workshops and intercalibration studies that helped workers in the United States and Europe achieve the high precision and accuracy required in paleosolar physics research. Accordingly, Professor Kocharov supplied us with tree-ring samples from the relatively flat  $^{14}\text{C}$  maximum resulting from the Maunder Minimum of solar activity (AD 1688–1710) for an intercomparison. The tree-ring samples from the Ural Mountains were dendrochronologically dated by Dr T T Bitvinskas of the Institute of Botany in Kaunas, Lithuania and they are the same samples measured for  $\Delta^{14}\text{C}$  by Kocharov's research group (Galli *et al.* 1987).

### RESULTS AND EVALUATION

$\Delta^{14}\text{C}$  values measured in the Laboratory of Isotope Geochemistry, the University of Arizona, are presented in Table 1 and plotted in Figure 1 along with the measurements published in Galli *et al.* (1987) and data determined at the University of Washington, Seattle, on single-year Douglas-fir tree rings (Stuiver and Braziunas 1993). Table 2 presents an intercomparison of these measurements.

We ascribe the  $2.2 \pm 0.5 \text{‰}$  offset between Tucson and Seattle to the west coast regional effect due to upwelling and atmospheric exchange of  $^{14}\text{C}$ -depleted oceanic  $\text{CO}_2$  at the divergent margin produced by the Ekman spiral (Kennett 1982; Damon *et al.* 1989; McCormac *et al.* 1995; Damon 1995; Southon and Baumgartner 1996; Stuiver and Braziunas 1998). No significant calibration offset is apparent between the Tucson and Seattle laboratories (Kalin *et al.* 1995; Damon *et al.* 1998). The  $4.3 \pm 1.2 \text{‰}$  offset between Ioffe and Tucson does reveal a calibration offset. The difference between the variance for both the Seattle and Tucson results ( $\sigma_m^2 - \sigma_p^2$ ) yields a standard deviation ( $\sigma_s$ ) of  $1\text{‰}$ . This  $1\text{‰}$   $\sigma_s$  is an approximation of the real variance of the signal independent of the measurement error; it may be compared to the estimate of an average amplitude of the approximately 11-yr cycle of  $1.40 \pm 0.16\text{‰}$  for the period of time from AD 1510 to AD 1945 (Stuiver and Braziunas 1993). For the 22 yr at the flat minimum preceding the Maunder Minimum from AD 1619 to AD 1640, we obtained a variance of 3.24 yielding a  $\sigma_s$  of about  $1.8\text{‰}$  from the Stuiver and Bra-

Table 1 Results of  $\Delta^{14}\text{C}$  measurements on dendrochronologically dated tree rings from AD 1688 to 1710

Year	$\Delta^{14}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)
1688	$16.1 \pm 1.9$	-22.7
1690	$14.4 \pm 1.9$	-22.2
1691	$16.9 \pm 1.9$	-22.5
1692	$15.6 \pm 1.8$	-22.2
1693	$16.7 \pm 1.8$	-21.9
1694	$15.9 \pm 1.8$	-22.2
1695	$14.0 \pm 1.7$	-22.1
1696	$18.6 \pm 1.8$	-22.1
1697	$16.8 \pm 1.8$	-22.5
1698	$15.1 \pm 1.8$	-22.2
1699	$19.9 \pm 2.0$	-22.7
1701	$19.8 \pm 1.7$	-22.7
1702	$18.7 \pm 1.8$	-22.3
1703	$16.9 \pm 1.7$	-23.0
1704	$20.4 \pm 1.8$	-22.8
1705	$17.0 \pm 2.0$	-21.8
1706	$20.0 \pm 1.7$	-22.0
1707	$19.4 \pm 2.1$	-22.2
1708	$18.3 \pm 1.8$	-22.3
1710	$13.8 \pm 1.8$	-21.8

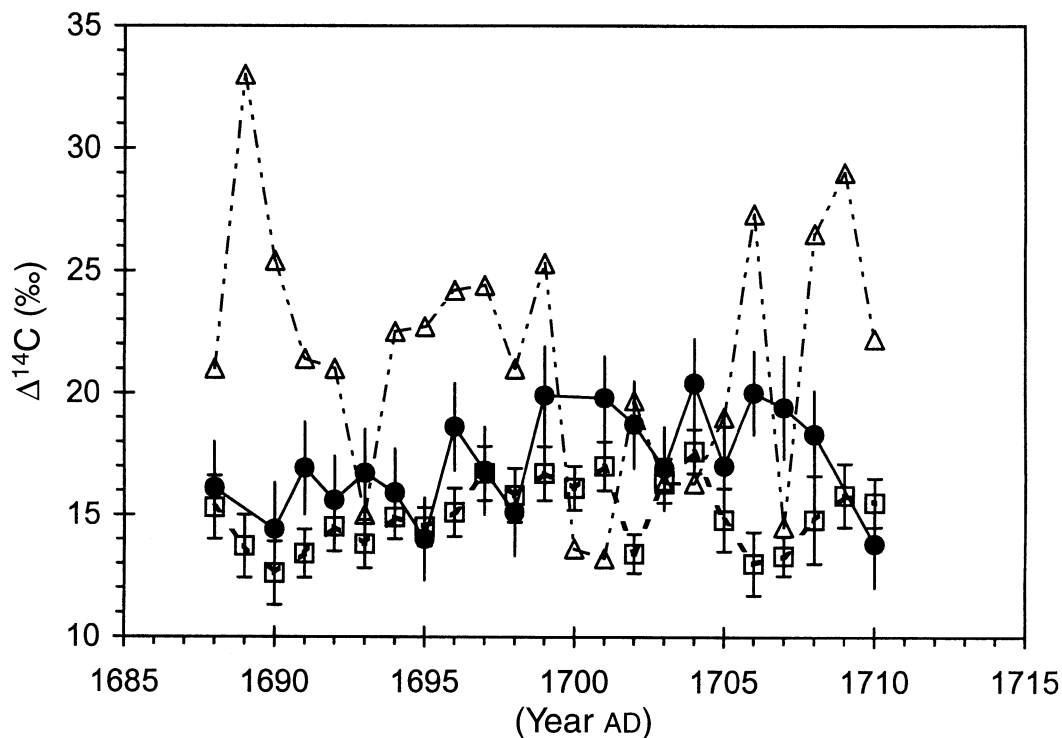


Figure 1 The results of  $\Delta^{14}\text{C}$  measurements in tree-rings of 1688–1700 AD according to the present work (●); Stuiver and Braziunas (1993) (□); Galli et al. (1987) (△).

Table 2 Intercomparison of measurements on single-year tree rings for the interval AD 1688–1710

	Ioffe (1) (‰)	Tucson (2) (‰)	Seattle (3) (‰)
$\bar{\chi}$	21.5	17.2	15.0
$\sigma_m$	5.1	2.1	1.4
$\sigma_p$	?	1.8	1.1

$\bar{\chi}$  = mean value;  $\sigma_m$  = measured;  $\sigma_p$  = average Poisson counting precision  
(1) Galli *et al* 1987; (2) this paper; (3) Stuiver and Braziunas 1993

ziunas (1993) data. The lower  $\sigma_s$  during the Maunder Minimum is compatible with the presence of the 22-yr cycle and suppression of the 11-yr cycle (Peristykh and Damon 1998) as suggested by Vasiliev and Kocharov (1983).

## CONCLUSION

$\Delta^{14}\text{C}$  measurements on same-age samples measured under the direction of Professor Kocharov and also measured at the University of Arizona demonstrate a greater variance for the Ioffe Institute results, corresponding to a standard deviation of  $\pm 5.1\%$  ( $\sigma_m$ ) compared to the Tucson results of  $\pm 2.1\%$  ( $\sigma_m$ ). Konstantinov *et al.* (1997) also concluded, in explaining the differences in data series, that the experimental errors of the Soviet data are much greater than  $\pm 3\%$ . The Tucson–Ioffe calibration offset is  $4.3 \pm 1.2 \bar{\sigma} \%$ . We ascribe an offset between Tucson measurements and Seattle measurements of  $2.2 \pm 0.5 \bar{\sigma} \%$  to divergence and upwelling of  $^{14}\text{C}$ -depleted  $\text{CO}_2$  along the west coast of North America. This divergence is caused by the wind-driven Ekman Transport and ocean currents diverted by coriolis force that result in the Ekman Spiral and west coast divergence and upwelling. The high-precision results from Seattle and Tucson also demonstrate a flat  $\Delta^{14}\text{C}$  maximum corresponding to the Maunder Minimum, with variance and standard deviation around  $\pm 1\%$ .

## ACKNOWLEDGMENTS

We greatly appreciate Professor Grant Kocharov of the Ioffe Institute in St Petersburg for making available the Ural Mountain tree rings that made this study possible. This work was supported by NSF Grant ATM-9520135 and the state of Arizona.

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