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LETTER TO THE EDITOR

Comment on "A Large California Flood and Correlative Global Climatic Events 400 Years Ago" (Schimmelmann *et al.,* 1998)

INTRODUCTION

Based on varve studies of deposits in the Santa Barbara Basin (near southern California) Schimmelmann *et al.* (1998) date the evidence for a large flood (a relatively thick, grey layer with abundant terrigenous silty clay) between A.D. 1600 and 1610. The ca. A.D. 1605 grey layer is the thickest identified flood layer in the Santa Barbara Basin sedimentary record of the past millennium. Schimmelmann *et al.* discuss regional and global evidence for rapid and intense cooling about A.D. 1605 and suggest that the large flood in southern California was part of worldwide "teleconnected" climate change.

The authors hypothesize that a cluster of volcanic events was an important factor in the cooling. They acknowledge also that changes in solar irradiance can play a role in climate change. Based on the fact that atmospheric $\Delta^{14}C$ shows a minimum around A.D. 1605, the authors conclude that there was a maximum of solar irradiance before the onset of the Maunder Minimum (A.D. 1650–1715) and argue that "there is no evidence for a direct short-term, predominant role of solar-induced cooling." We do not agree with such an interpretation of the $\Delta^{14}C$ record, as will be discussed below.

THE A.D. 1605 CLIMATE EVENT, SOLAR FORCING, AND THE $\Delta^{14}C$ RECORD

It is well known that the ^{14}C record can be considered as a proxy for the solar radiant output (Stuiver and Braziunas, 1989, 1993, 1998). When solar activity is high, the extended solar magnetic field more effectively shields the Earth from cosmic rays and reduces the production of cosmogenic isotopes such as ^{14}C. In contrast, a low solar activity yields more ^{14}C. Indeed, about A.D. 1605 there was a sharp minimum in the ^{14}C record (Fig. 1). A relatively active sun during the period from ca. A.D. 1520 to 1605 caused declining $\Delta^{14}C$ values, whereas from A.D. 1605 onward, a sharply rising atmospheric ^{14}C level indicates a sudden decline to a lower level of solar activity.

We found evidence for solar forcing as a factor causing abrupt climate change about 850 cal yr B.C. (Kilian *et al.,* 1995; van Geel *et al.,* 1996; van Geel *et al.,* 1998). Climate change occurred when $\Delta^{14}C$ started to rise sharply from about −3‰ ca. 850 B.C. to ca. 20‰ about 760 B.C. (Fig. 1). Based on paleoecological and other evidence, we showed that it was not the maximum in $\Delta^{14}C$ which was indicative for reduced solar activity, but the start of the sharp rise of atmospheric ^{14}C about 850 B.C.

About A.D. 1605, a similar sharp rise in $\Delta^{14}C$ occurred (Stuiver and Braziunas, 1998; Fig. 1). We consider the indications for contemporaneous rapid, intense cooling as published by Schimmelmann *et al.* (1998) to be circumstantial evidence for solar forcing and also as a "climatological parallel" of our 850 B.C. event. We do not deny that volcanic aerosol loadings may have played a role in abrupt climate change ca. A.D. 1605, as suggested by the authors, but it is our opinion that Schimmelmann *et al.* have misinterpreted the radiocarbon evidence and, as a consequence, rejected solar forcing as one of the possible causes of the A.D. 1605 event. In Figure 1 we show (left) the radiocarbon calibration curve for the period 1000 to 500 B.C. and corresponding $\Delta^{14}C$ fluctuations, and (right) the calibration curve and $\Delta^{14}C$ for the period between A.D. 1500 and 1950. The start of the sharp rises of $\Delta^{14}C$ in both cases (ca. 850 B.C. and ca. A.D. 1605) can be interpreted as sudden declines in solar activity.

DISCUSSION

Stuiver and Braziunas (1989) argued that century-scale $\Delta^{14}C$ variations during most of the Holocene are best explained by variations in ^{14}C production rate induced by solar change, but how could a relatively small reduction in solar activity induce the relatively large change in global climate inferred for A.D. 1605 and for 850 B.C.? Answering this question can at present only be speculative, and involves a discussion about reduced solar activity, an increase in the cosmic-ray flux, and rising atmospheric ^{14}C levels.

We discuss here two possible scenarios (which do not exclude each other) explaining how a relatively small reduction of solar radiation and an accompanying increase in cosmic-ray flux may affect the lower stratosphere. The first scenario is based on the notion that a reduction of (ultraviolet) radiation may also lead to a decline in ozone production in the lower stratosphere (Harvey, 1980). This could trigger the inferred climate changes. Haigh (1994, 1996) performed simulations with climate models to study the relation between the 11-yr solar activity cycles, ozone production, and climate change. First, a chemical atmospheric model showed that a 1% increase

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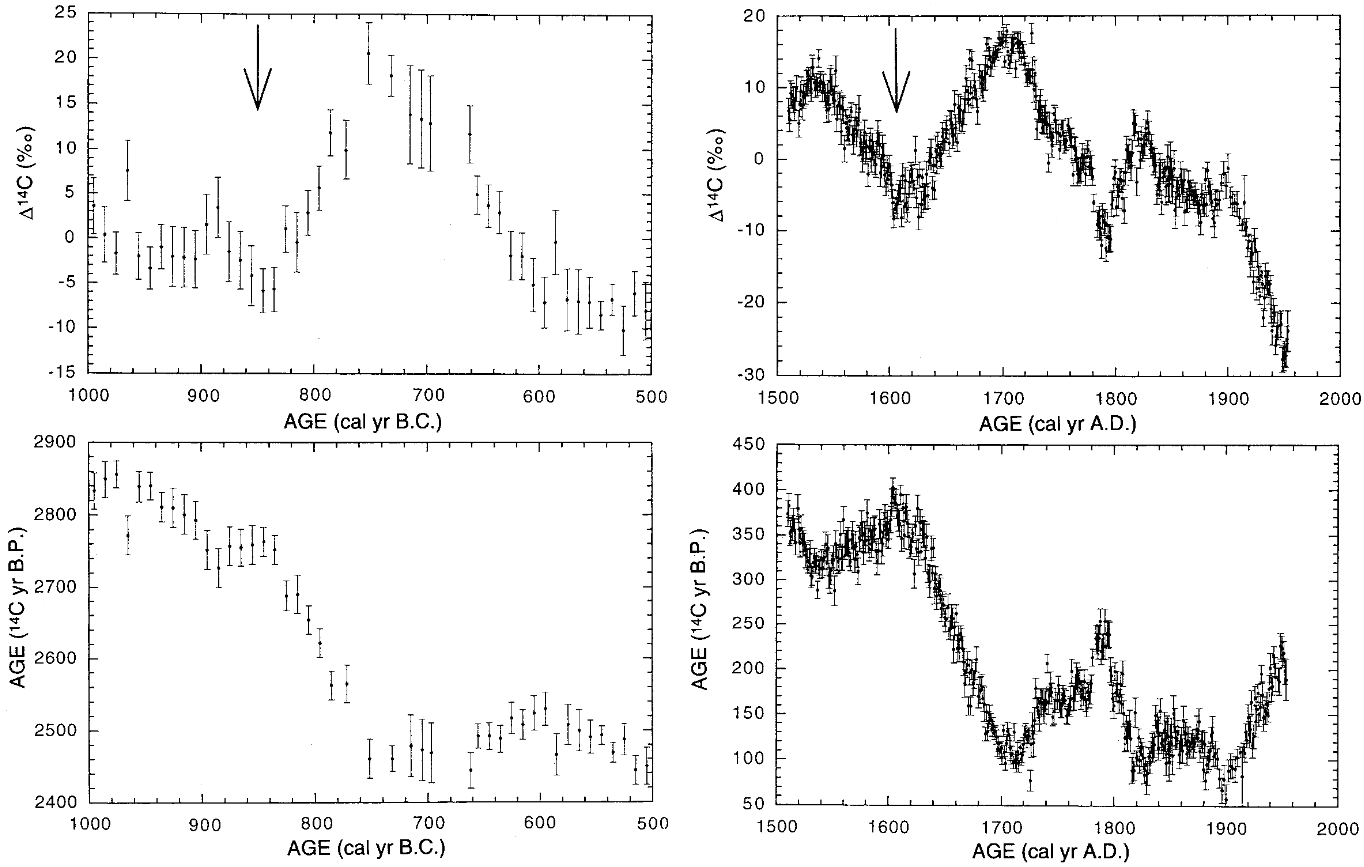

FIG. 1. (left) The radiocarbon calibration curve for the period 1000 to 500 B.C. and corresponding $\Delta^{14}C$ fluctuations. (right) The calibration curve and $\Delta^{14}C$ for the period between A.D. 1500 and 1950. In both cases (850 B.C. and A.D. 1605, respectively) the start of the sharp rise coincides with evidence for abrupt climatic cooling, and we consider this phenomenon as evidence for solar forcing of climate change.

in UV radiation at the maximum of a solar activity cycle generated 1–2% more ozone in the stratosphere (Haigh, 1994). Second, this increase in the stratospheric ozone content was used as input in a climate model experiment (Haigh, 1996). Here, this increase resulted in warming of the lower stratosphere by the absorption of more sunlight. In addition, the stratospheric winds were also strengthened and the tropospheric westerly jet streams were displaced poleward. The position of these jets determines the latitudinal extent of the Hadley Cells and, therefore, the poleward shift of the jets resulted in a similar displacement of the descending parts of the Hadley Cells. This ultimately leads to a poleward relocation of the mid-latitude storm tracks. The opposite effect may have played a role in the discussed climate changes of ca. 850 B.C. and A.D. 1605. The observed strong increases of atmospheric ^{14}C probably were caused by reduced solar activity. Such a reduction also could have resulted in a decrease in the stratospheric ozone content. A decrease of the latitudinal extent of the Hadley Cell circulation and an equatorward relocation of the mid-latitude storm tracks follow (compare Schimmelmann *et al.*, 1998, p. 57, about similar changes in atmospheric circulation).

The second scenario is based on the idea that an increase of the cosmic ray flux may directly lead to an increase in global cloud cover. Ionization by cosmic rays positively affects aerosol formation and cloud nucleation (Pudovkin and Raspopov, 1992; Raspopov *et al.*, 1997; van Geel *et al.*, 1998). Svensmark and Friis-Christensen (1997) found an excellent correlation between the variation in cosmic ray flux and the observed global cloud cover for the most recent solar cycle. An increase in the global cloud cover is believed to cause a cooling of the earth, especially when low-altitude clouds are involved, because more incoming radiation is reflected (Svensmark and Friis-Christensen, 1997). Earlier, Friis-Christensen and Lassen (1991) analyzed for the period 1861–1989 the similarity between the Northern Hemisphere temperature record and the length of the solar cycle (as an indicator of solar activity), and found a close match. Moreover, it is expected that the effect would be most significant at high latitudes, because the shielding effect of the geomagnetic field is larger near the equator.

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Indeed, the correlation between cosmic ray flux and cloud cover increases from the equator toward the poles (Svensmark and Friis-Christensen, 1997).

A direct increase in cloudiness and accompanying cooling would be in agreement with the reconstructed wetter and cooler conditions at middle latitudes about 850 B.C. and A.D. 1605.

CONCLUSION

Schimmelmann *et al.* (1998), although denying solar forcing when explaining climate change (cooling) about A.D. 1605, presented evidence that may indicate solar forcing as an important factor for climate change at the start of the 17th century.

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