Variations of atmospheric ^{14}C and the climate in Yayoi period

太陽活動は弥生時代の気候にどう影響したのか？

Mineo Imamura

The talk aims at obtaining some hints of the Sun's influence on climate in history and hopefully in the future through the correlation between ^{14}C records in tree-rings and the climatic proxy data in East Asia.

Sunspots have been depicted in history as early as more than 2000 years ago.

Wall Painting Depicting Sun and Moon (Fragment), Han Dynasty, 1c.BC-1c.AD: from “The Birth of Chinese Civilization”, Tokyo National Museum, p.128, 2010.

1. ^{14}C production rate in the earth's atmosphere as an indicator of past solar activity

Column density:
per 1 cm^2

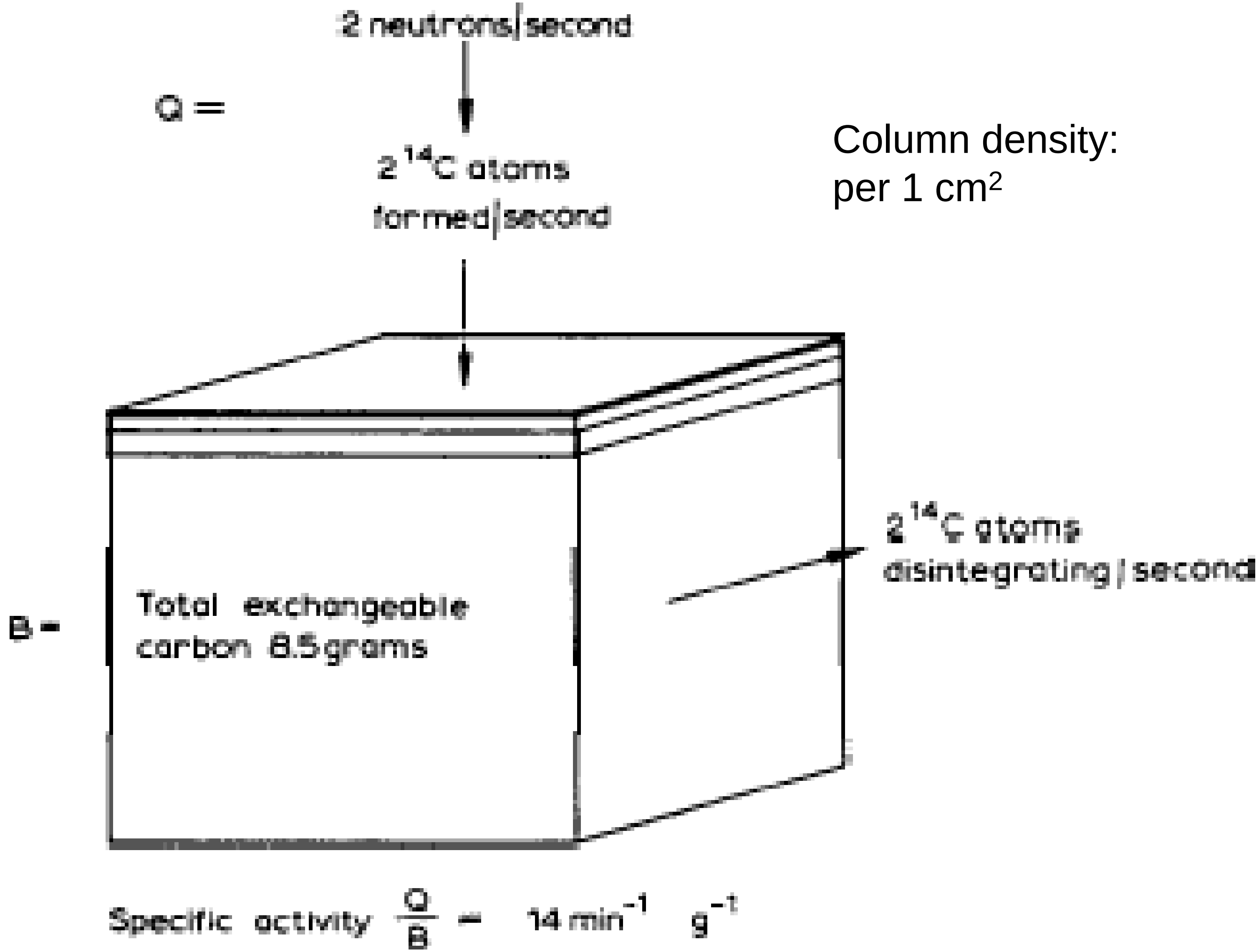


Fig. 1. Radiocarbon genesis and mixing.

(From W F Libby, Nobel lecture, 1960)

^{14}C production rates, $P(^{14}C)$

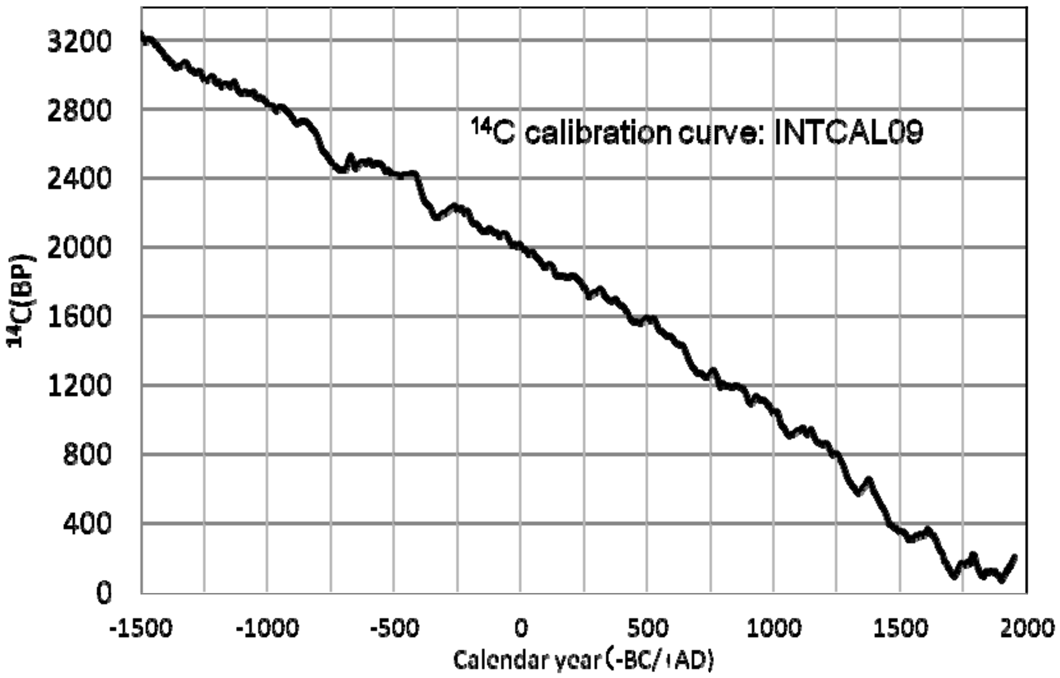
^{14}C in the atmosphere has its origin mostly in marine ^{14}C. It goes back to the ocean.

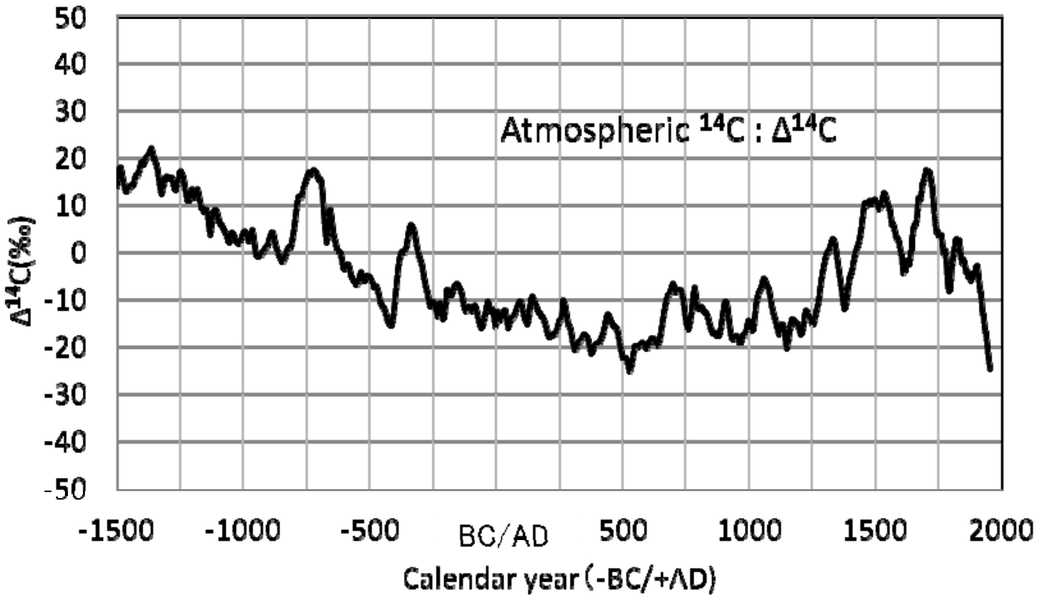
During the residence time (τ) of atmospheric carbon, neutron-induced ^{14}C is accumulated in the atmosphere, so that

$$\Delta(^{14}C/^{12}C)_{atm} - \Delta(^{14}C/^{12}C)_{marine} = P(^{14}C) \cdot \tau(co_2)/m_{12,atm}$$

$$+ \text{(decay corr. terms)}$$

$P(^{14}C)$ can be calculated using INTCAL datasets under assumption of constant τ and *m*.





INTCAL radiocarbon calibration datasets (calibration curve)

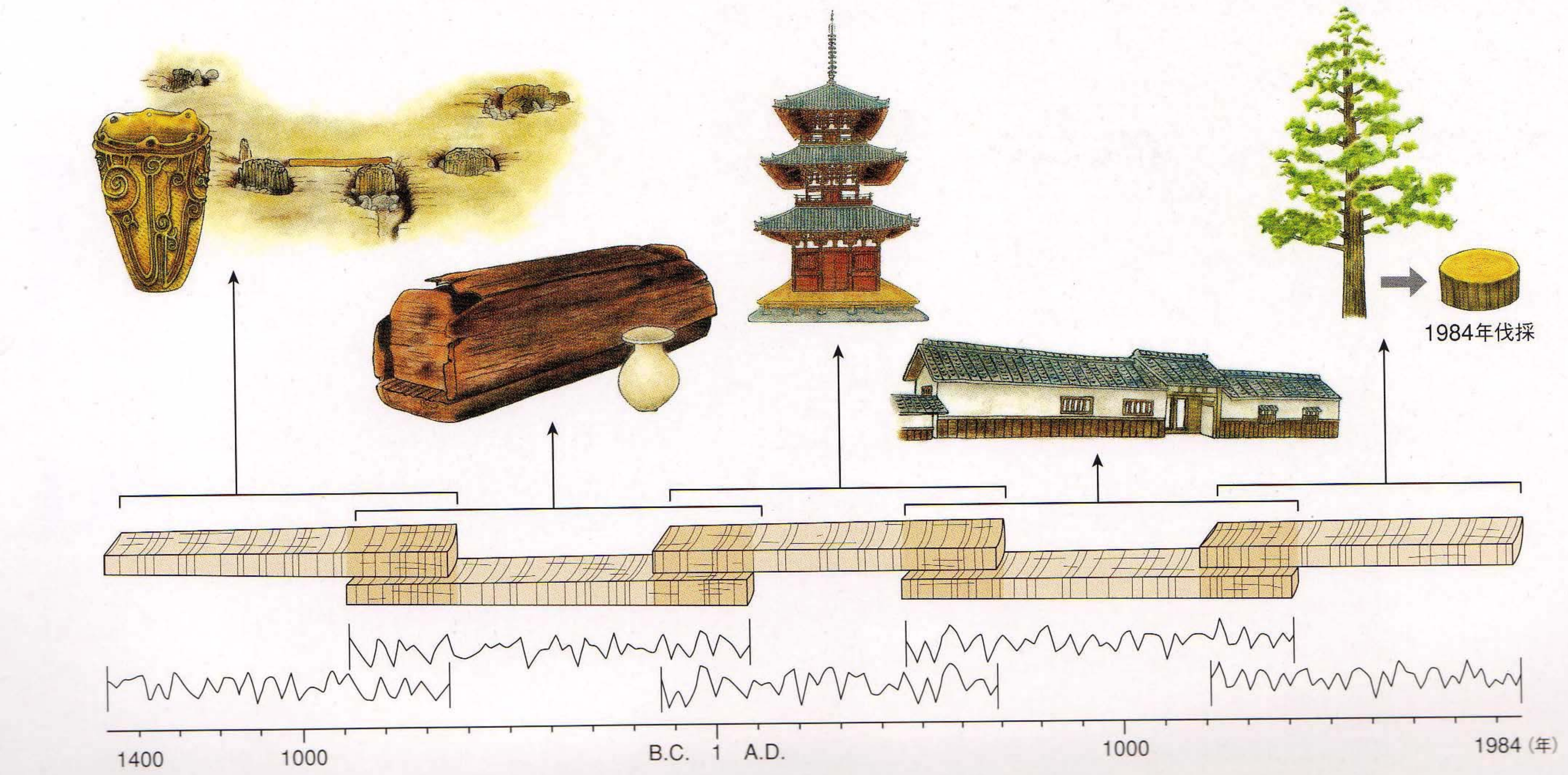
Given for ^{14}C dates and $\Delta^{14}C$

Also given for marine ^{14}C (modeled)

Obtained from tree-rings ^{14}C dates

Evaluated by 10-years mean

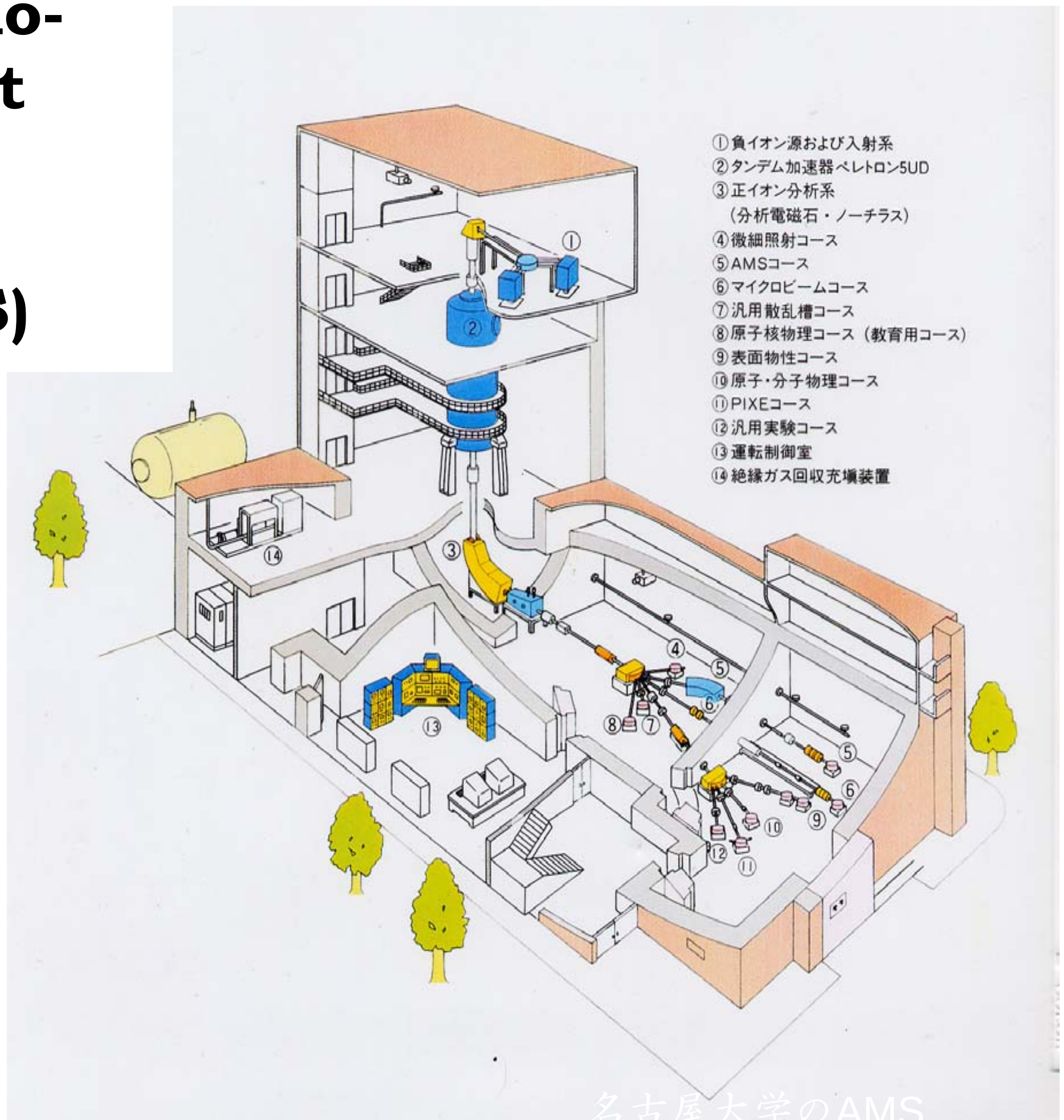
- **In the ^{14}C calibration curve, calendar ages of annual tree-rings are obtained by dendrochronology.**
- **Patterns of treering width are used to connect historical and archaeological tree-rings. (back to ~12400 cal BP for INTCAL09)**



「弥生はいつから？！」(国立歴史民俗博物館) p.14, 2007より: 図は光谷拓実作成.

^{14}C has been measured traditionally by radio-metric method, but currently by accelerator mass spectrometry (AMS)

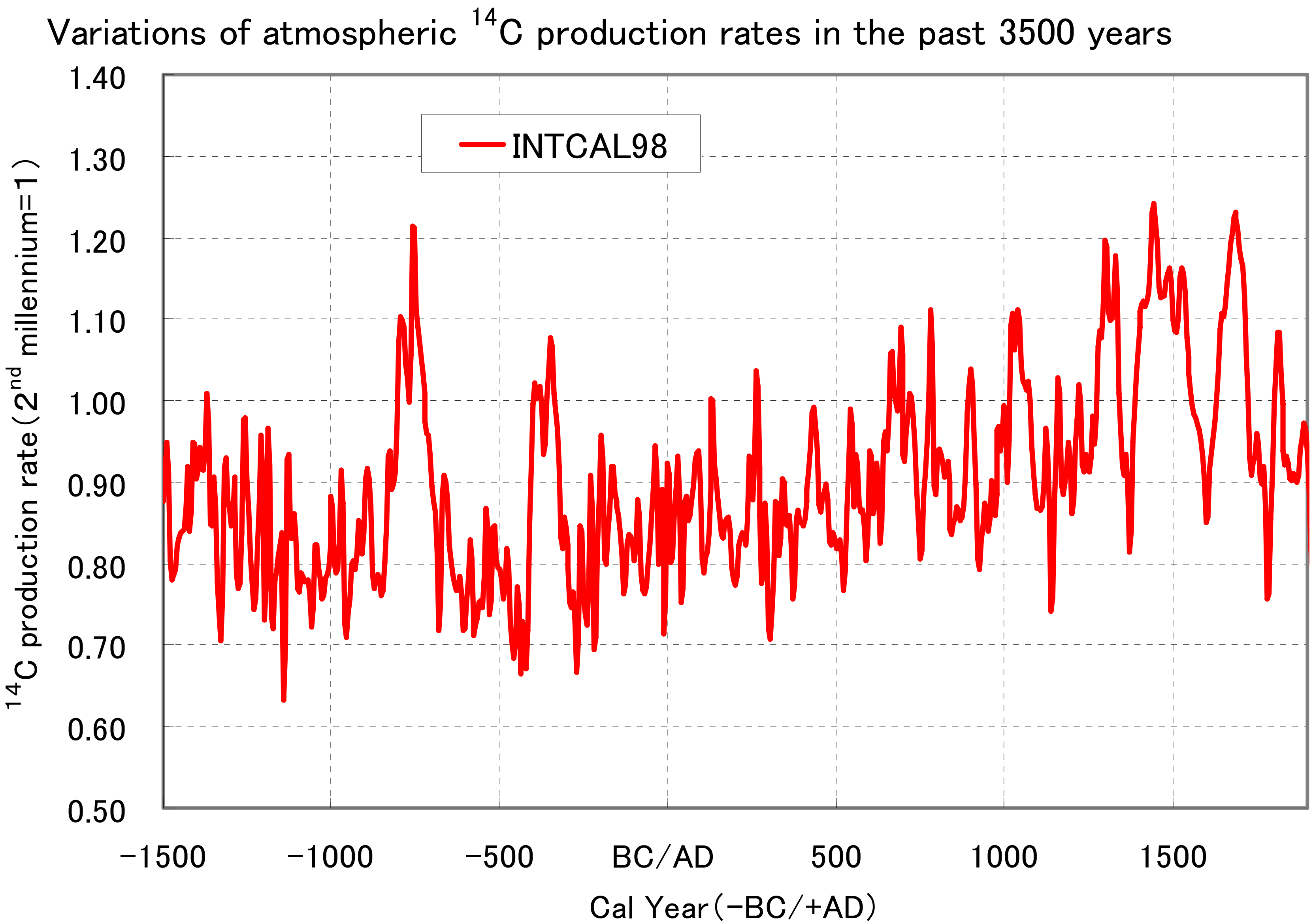
Nagoya U.



U. Of Tokyo

Compact AMS（NEC, USA）

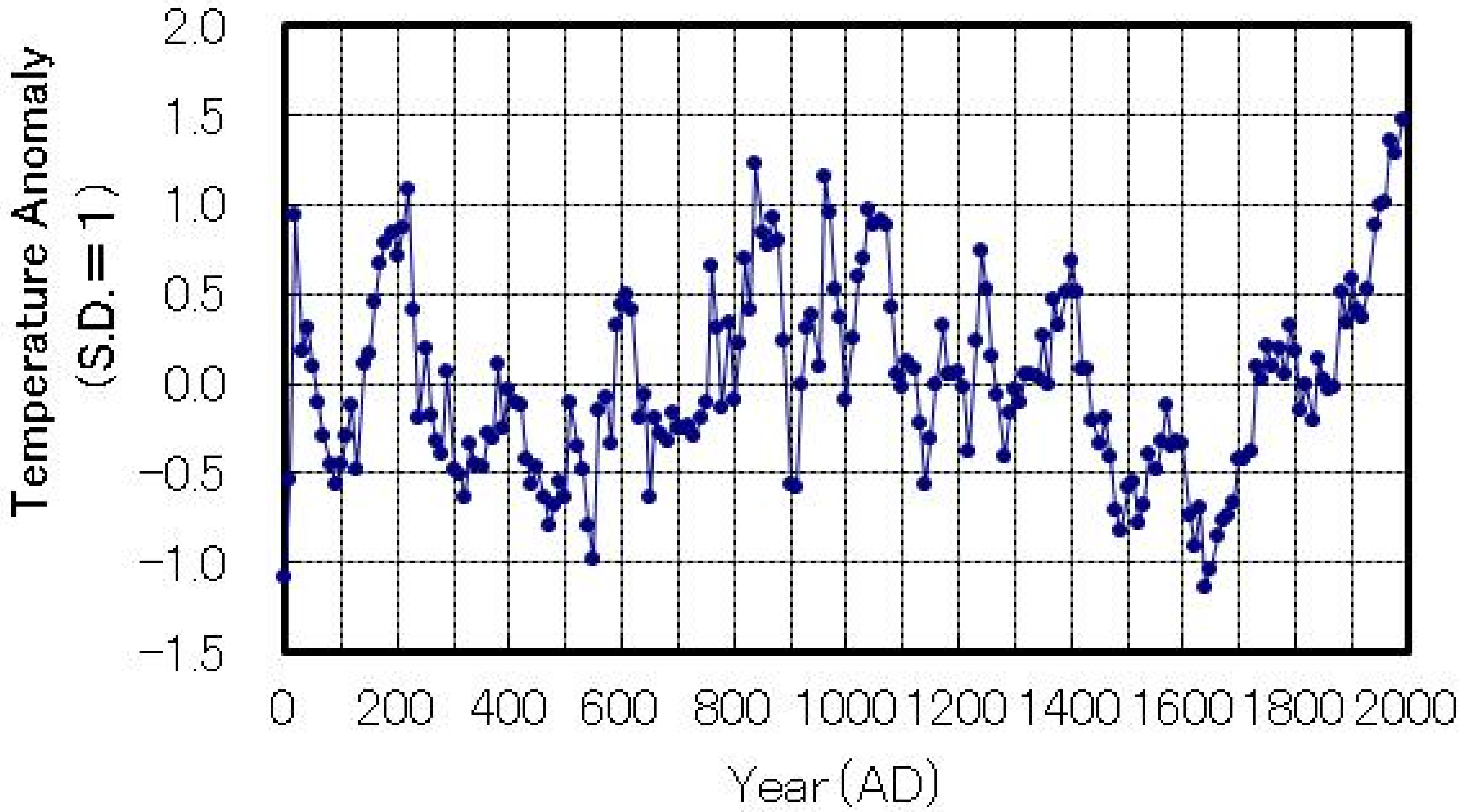
$P(^{14}C) = f\,(\text{solar activity}) + f\,(\text{earth's dipole moment})$

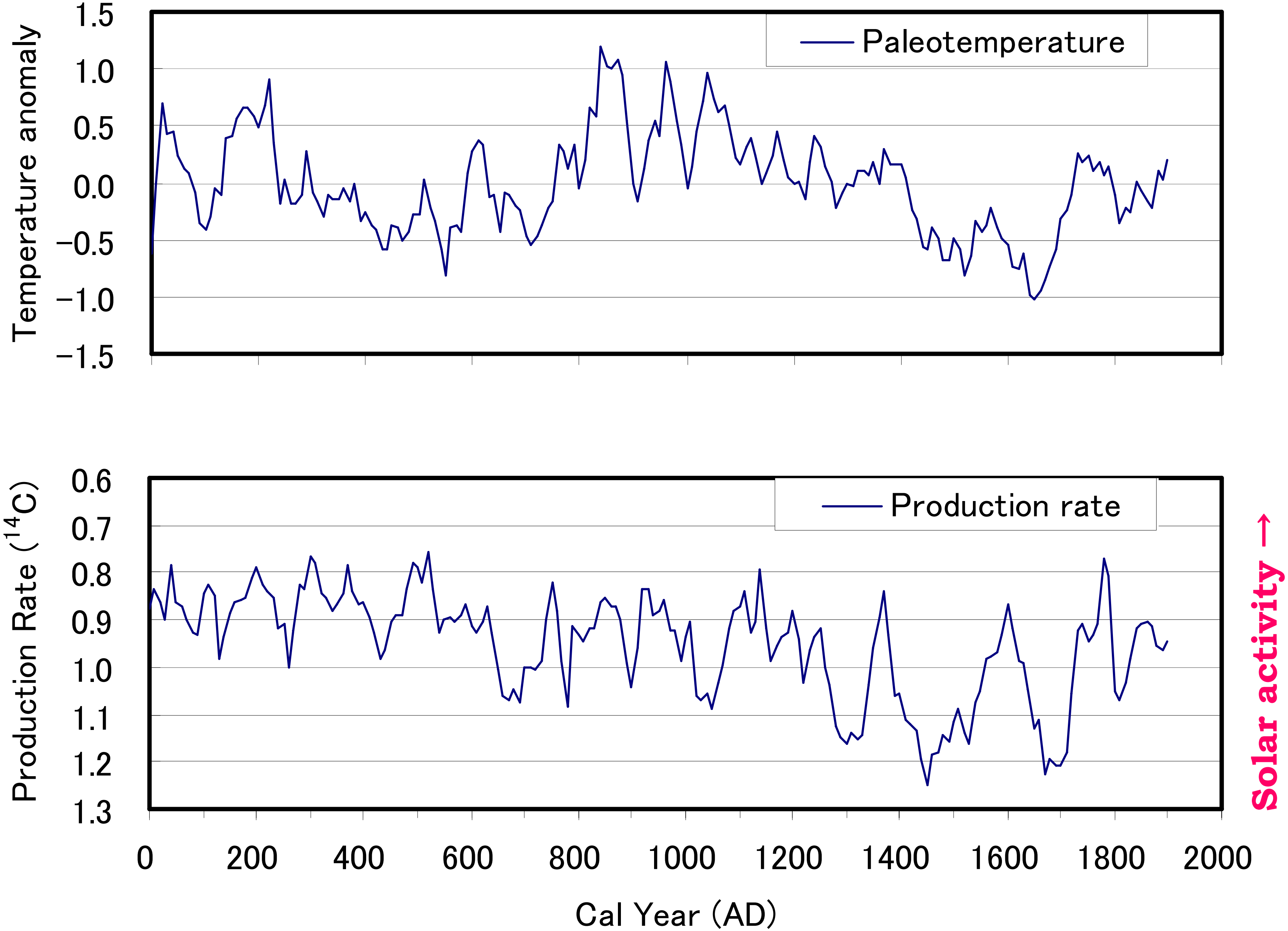


2. Correlations between past climate proxies (East Asia) and ^{14}C production rates

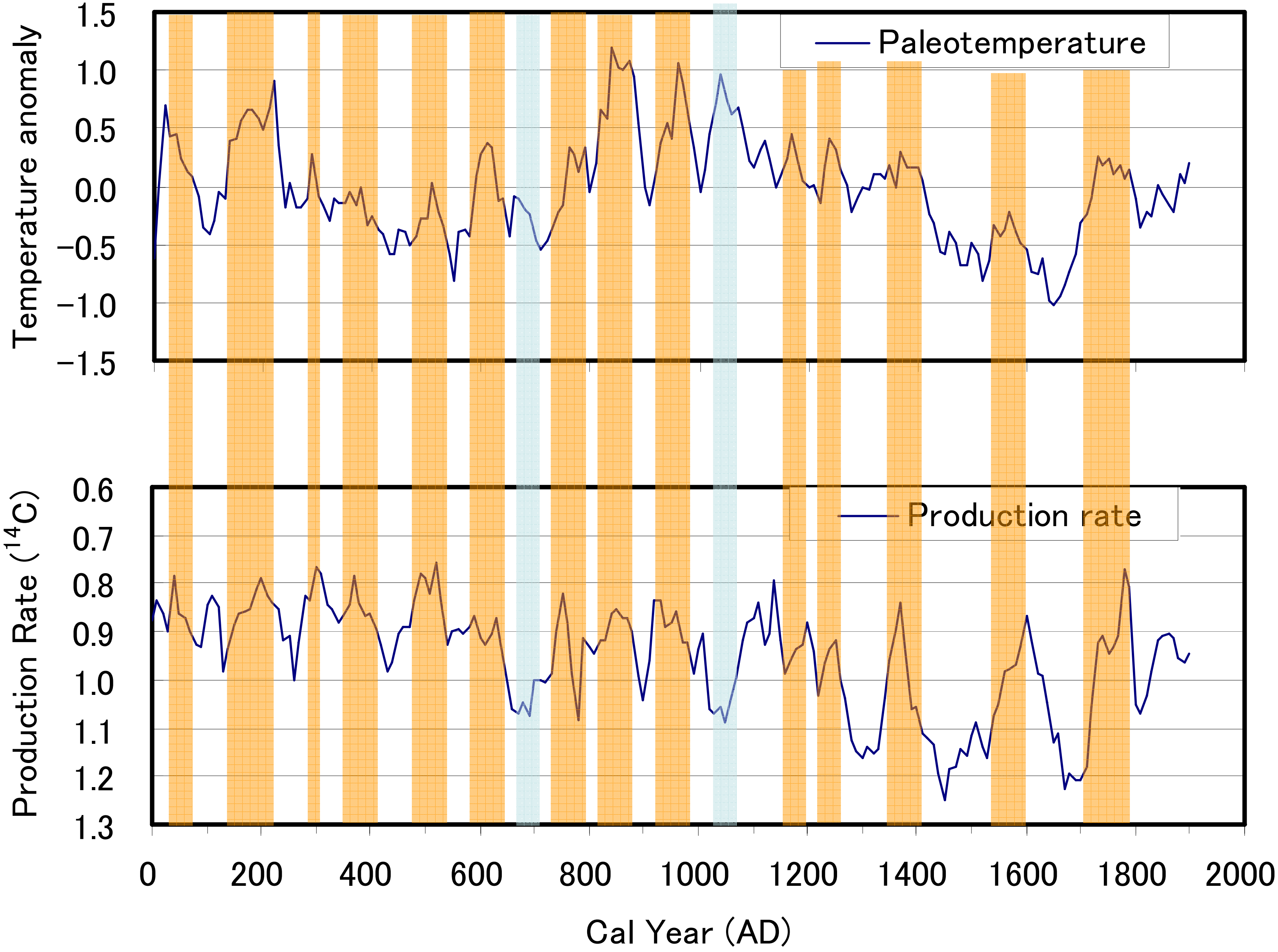
Summer temperature proxies in East Asia

("H-res" data from Bao Yang et al. GRL, GL014485, 2002)

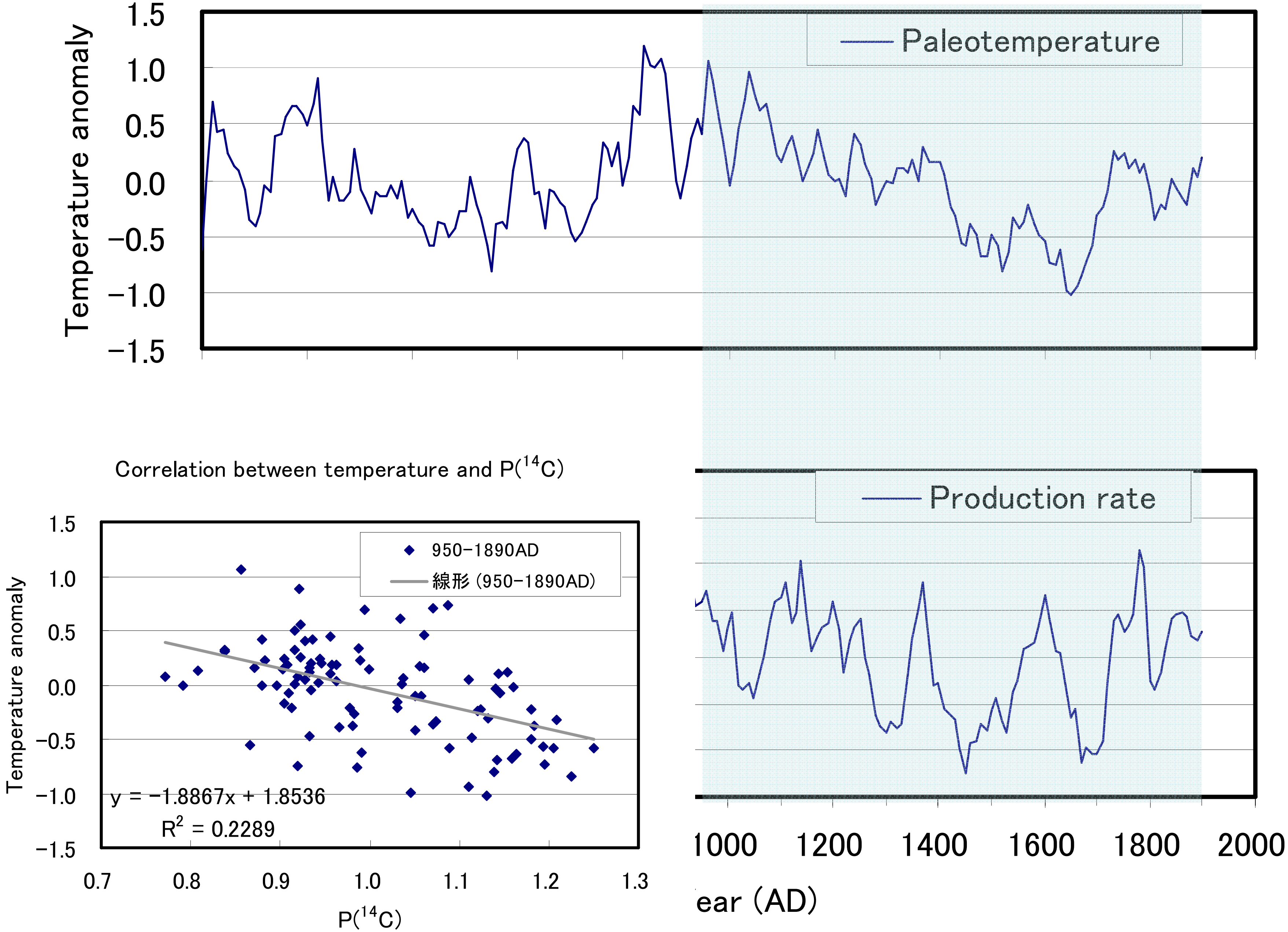




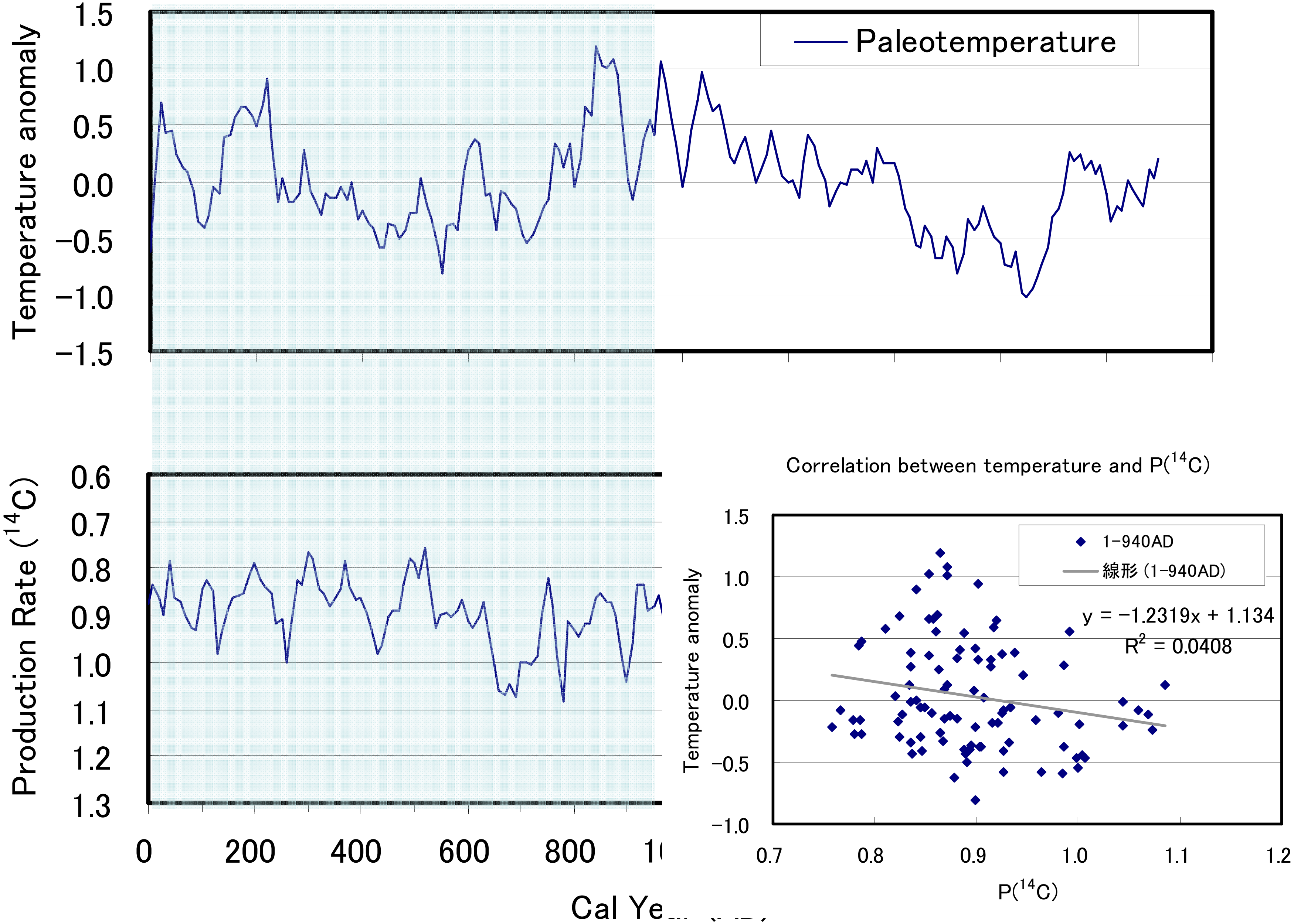
Paleotemperature
Temperature anomaly
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Production rate
Production Rate (14C)
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Cal Year (AD)
Solar activity →



Temperature anomaly
Paleotemperature
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Production Rate (14C)
Production rate
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Cal Year (AD)

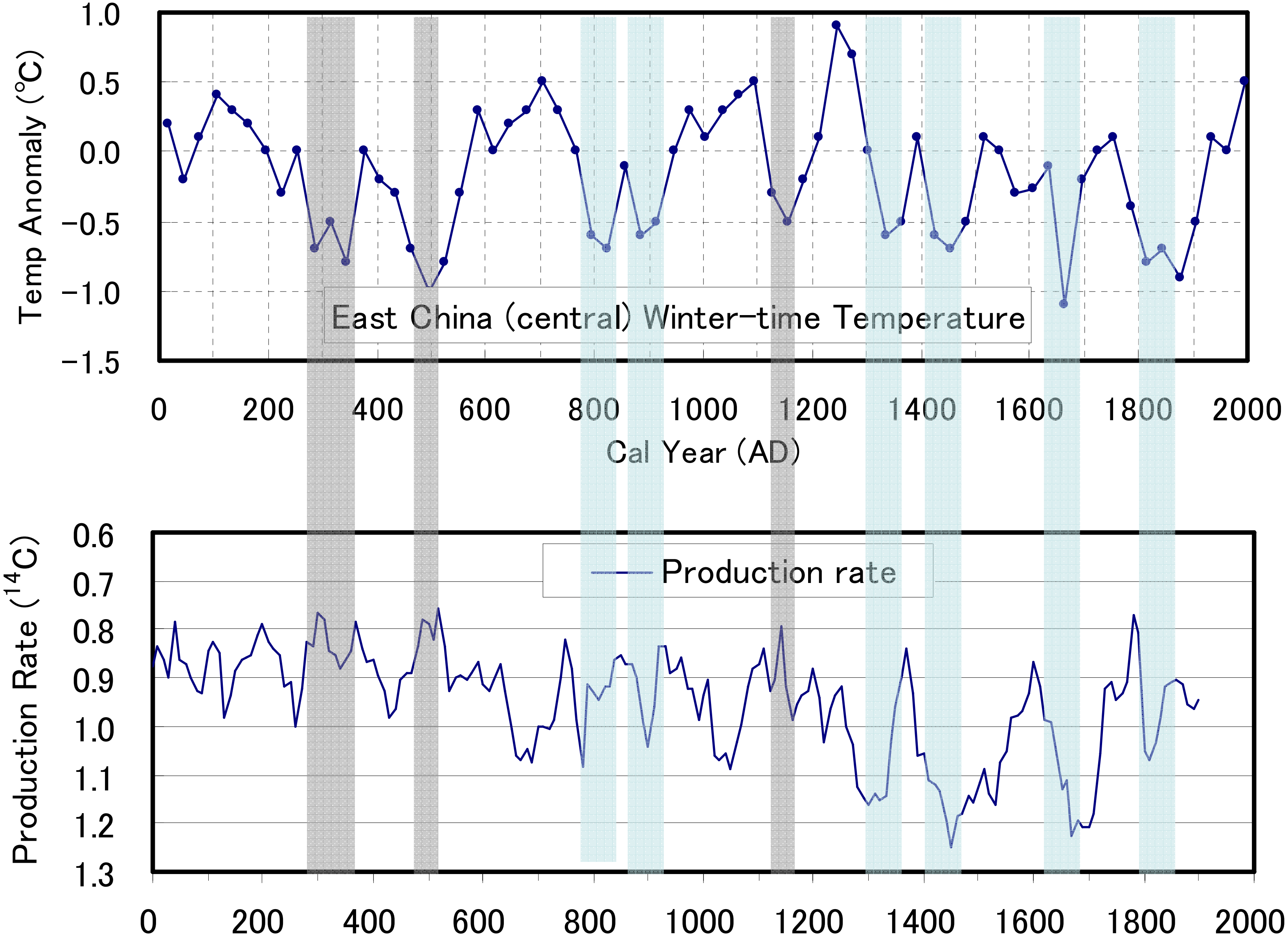


Paleotemperature
Temperature anomaly
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Correlation between temperature and P(14C)
950-1890AD
線形 (950-1890AD)
y = −1.8867x + 1.8536
R2 = 0.2289
0.7
0.8
0.9
1.0
1.1
1.2
1.3
P(14C)
Production rate
1000
1200
1400
1600
1800
2000
ear (AD)



Paleotemperature
Temperature anomaly
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Production Rate (14C)
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
0
200
400
600
800
Cal Ye
Correlation between temperature and P(14C)
1-940AD
線形 (1-940AD)
y = −1.2319x + 1.134
R2 = 0.0408
0.7
0.8
0.9
1.0
1.1
1.2
P(14C)

Winter-time Temperature(Q. Ge et al., Holocene13, 933, 2003)



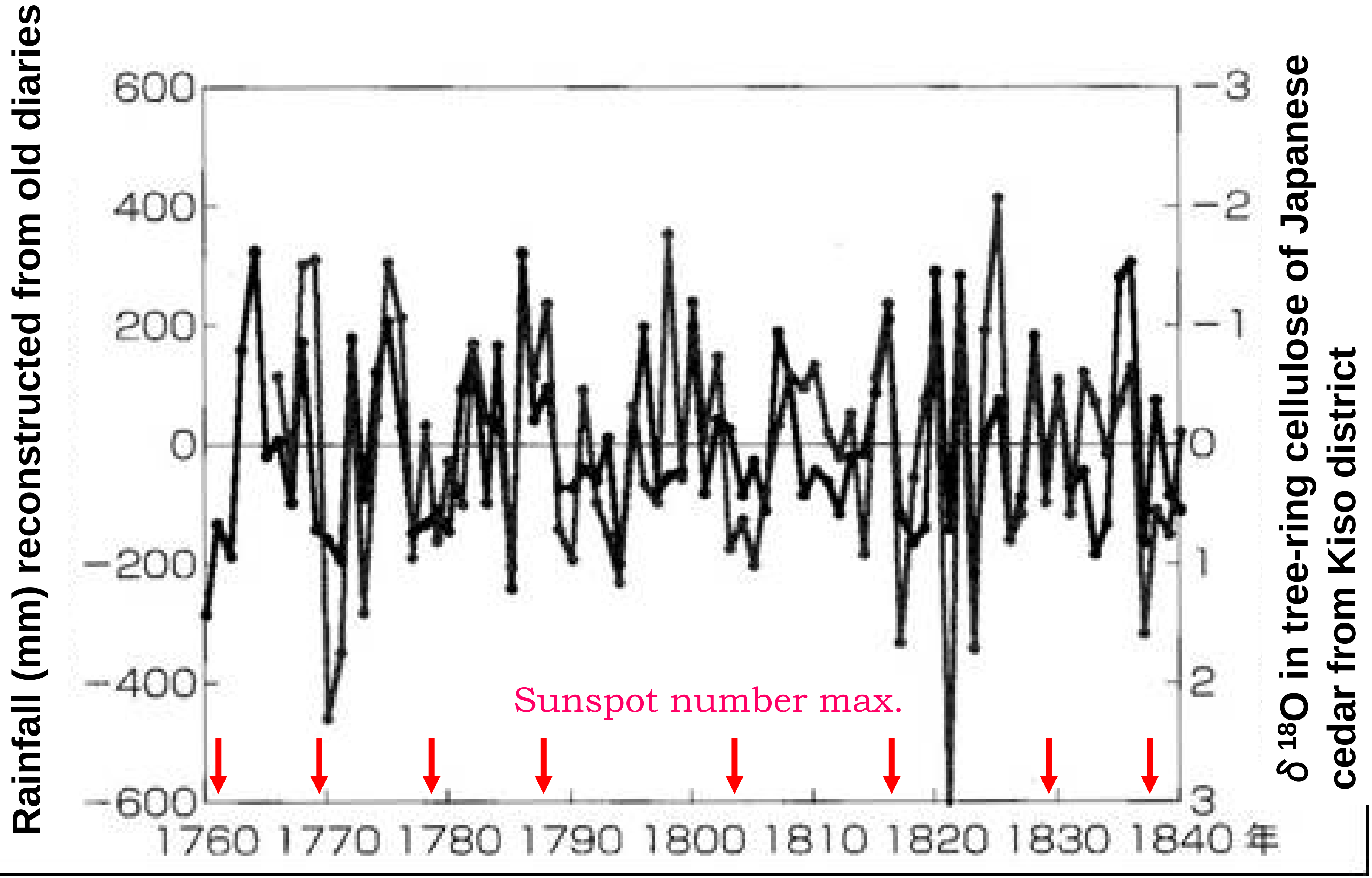
Correlation is weak !

We observe that

- **The periods of high summer temperature records in East Asia for the last 2000years coincide with the high solar activity periods, showing that the sun played a significant role in the East Asian summer climate.**
- **There are a few exceptional periods (2/16) when high summer temperature prevailed in the low solar activity periods. (It is noted that these exceptions have taken place in phases of strong East Asian Monsoon estimated from stalagmite data.)**

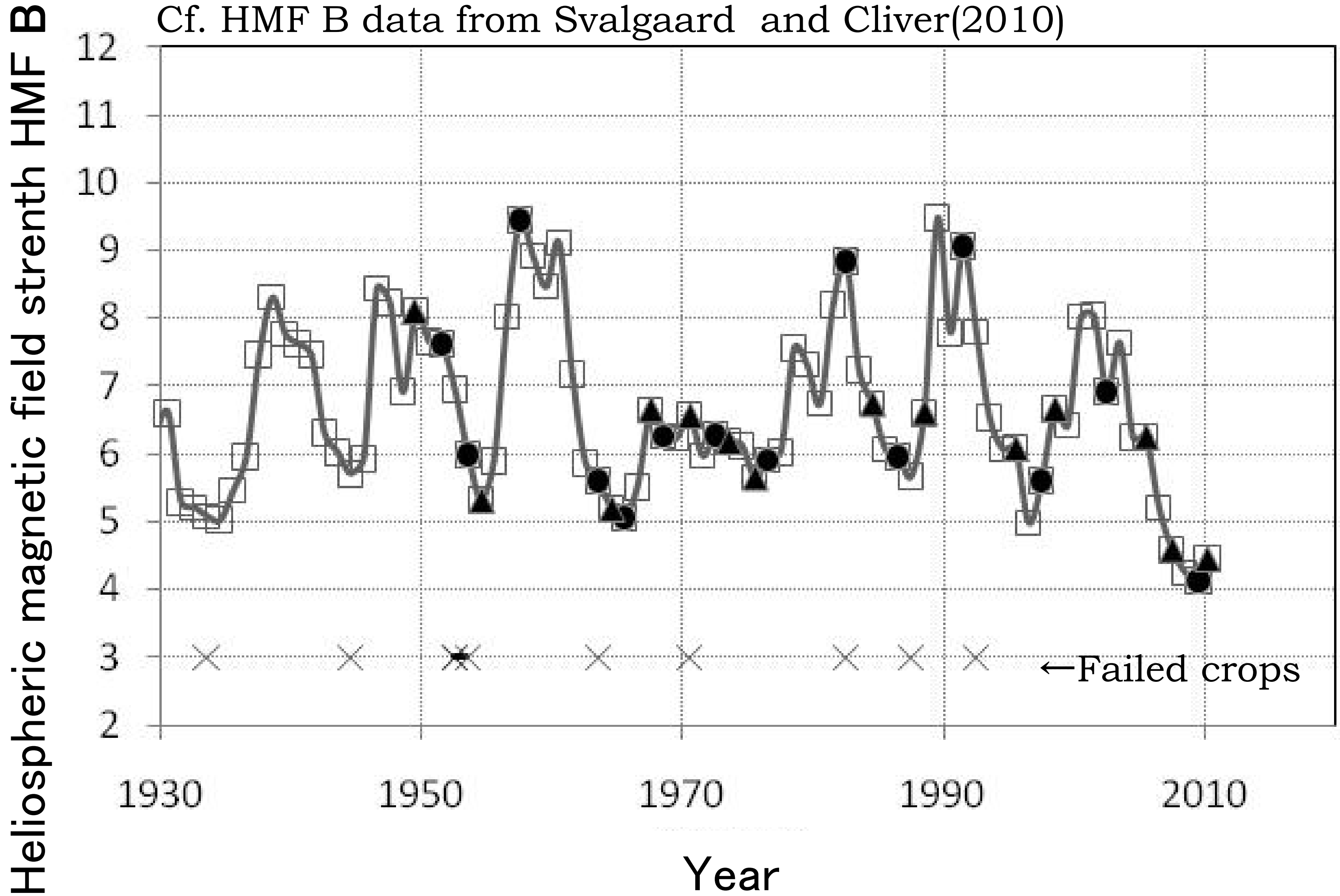
3. Sun-climate correlations in shorter timescale

Rainfall/Humidity in late 18th c. to early 19th c. in Kinki & Tokai districts, Japan (from T. Nakatuka,2010)



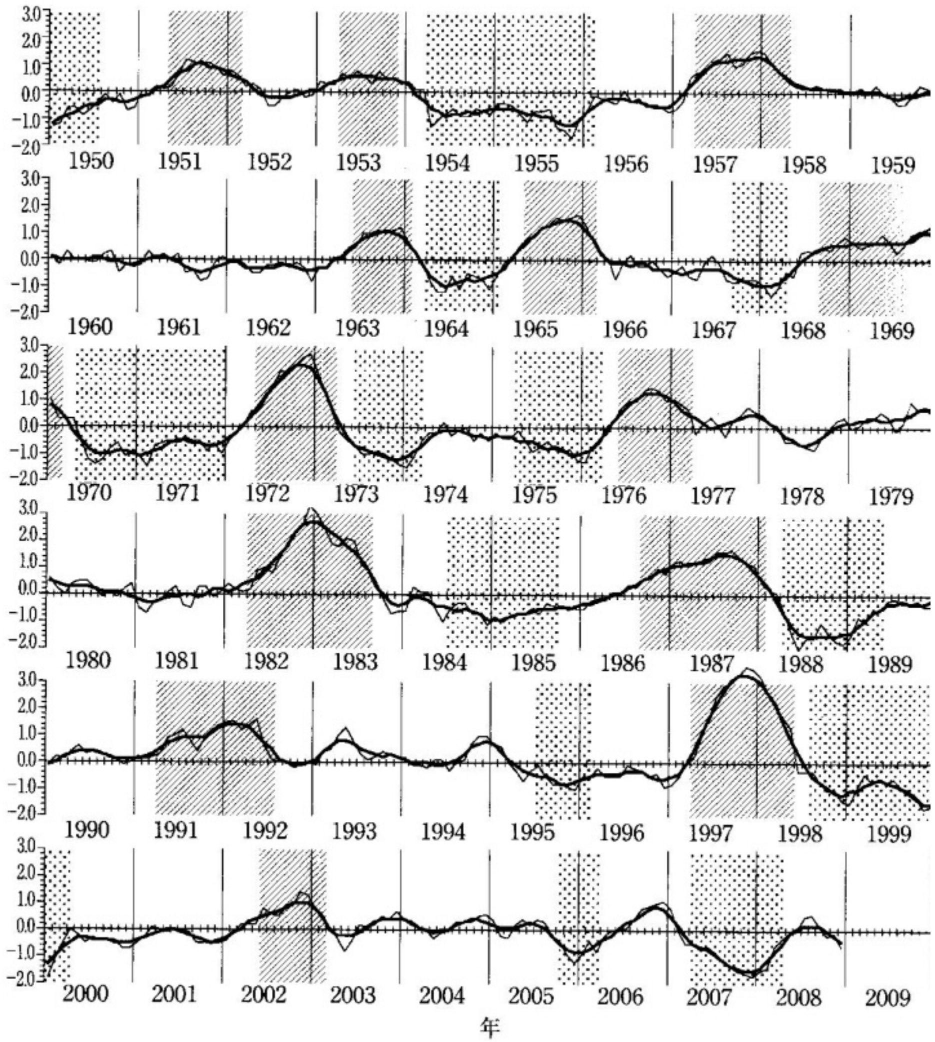
EL Nino (■) and La Nina (▲) tend to occur in low solar magnetic activity

Cf. HMF B data from Svalgaard and Cliver(2010)



El Nino and La Nina (from 気象庁資料(理科年表,2010))

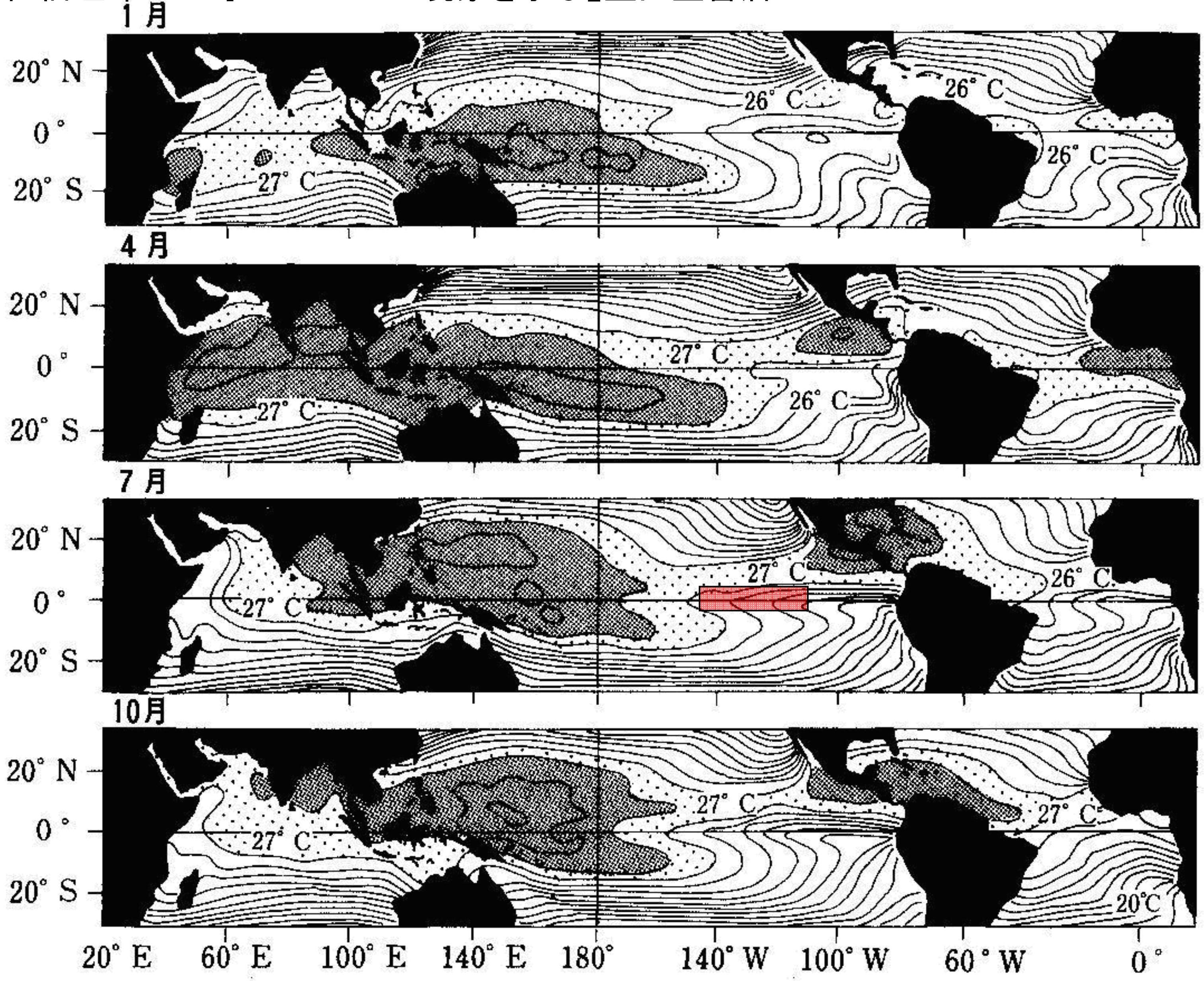
エルニーニョ監視海域の海面水温の基準値（その年の前年までの過去 30 年の平均値）との差（℃）



細い線は毎月の値，太い曲線は 5ヵ月移動平均値を示し，斜線の陰影はエルニーニョの発生期間を，点の陰影はラニーニャ現象の発生期間を表す．

Sea Surface Temperature (SST) distribution(Nino.3 area in red)

from 佐伯理郎2001『エルニーニョ現象を学ぶ』盛山堂書店



Summer temperature (July~August) during El Nino

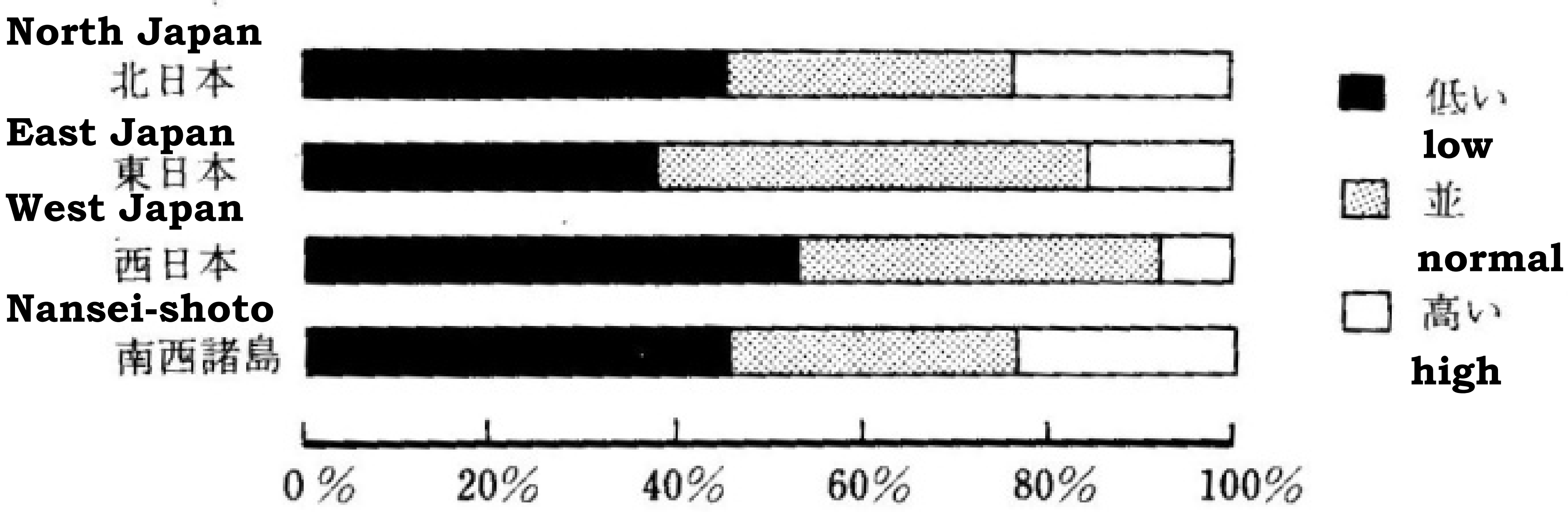


図 7.9 エルニーニョ現象発生中の夏の気温（6～8月平均気温）
「早い，平年並，遅い」の3階級で表示。（気象庁，1994）

from 佐伯理郎2001『エルニーニョ現象を学ぶ』盛山堂書店

Ending of Rainy Season (Baiu) during El Nino

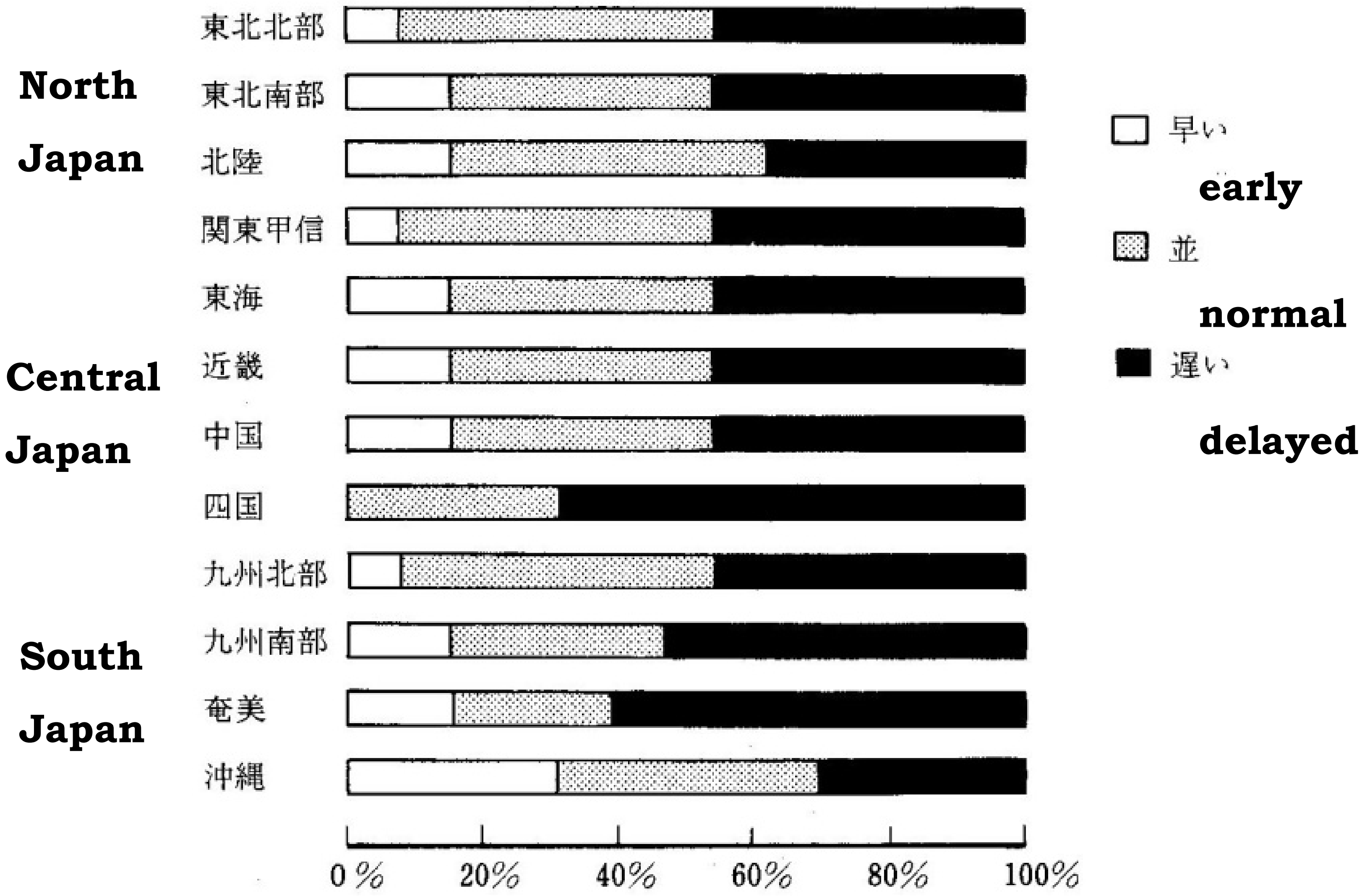


図 7.8　エルニーニョ現象発生中の梅雨明け
「早い，平年並，遅い」の 3 階級で表示（気象庁，1994）

from 佐伯理郎2001『エルニーニョ現象を学ぶ』盛山堂書店

4. East Asian summer monsoon as demonstrated by regional offsets*

* atmospheric ^{14}C difference from northern hemispheric ^{14}C, IntCal09

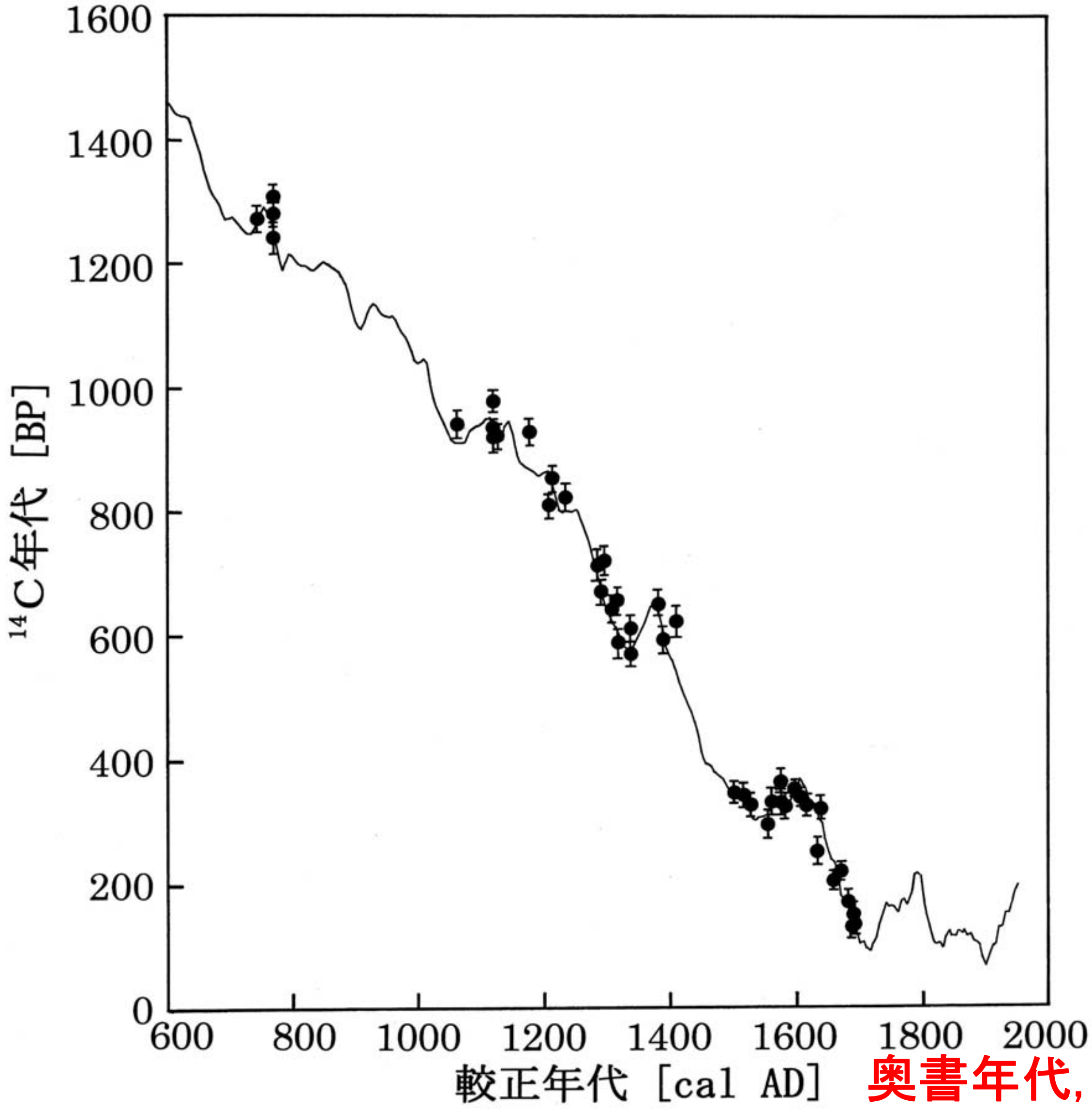
^{14}C dates in northern hemisphere

. Atmospheric ^{14}C in summer (tree growing season) is generally assumed to be constant throughout the mid-lattude, i.e. $\Delta^{14}C \sim 1$ permil.

. Basic assumption for radiocarbon dating.

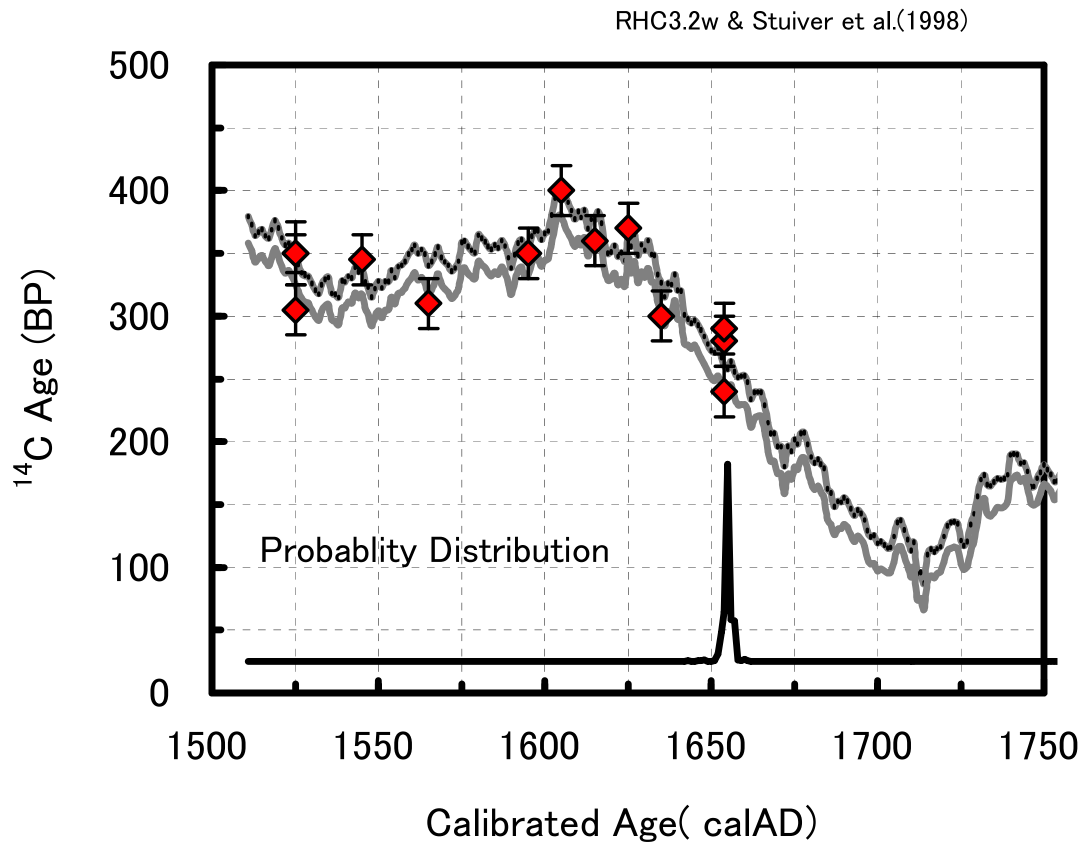
Historical documents (papers) in Japan have given concordant ^{14}C dates with those expected from the description/sign

(by courtesy of Dr. H. Oda)



^{14}C wiggle-matching of 9 single-year tree rings from Miki family house, Tokusima

三木家(Regional effect= 10 14C-years)

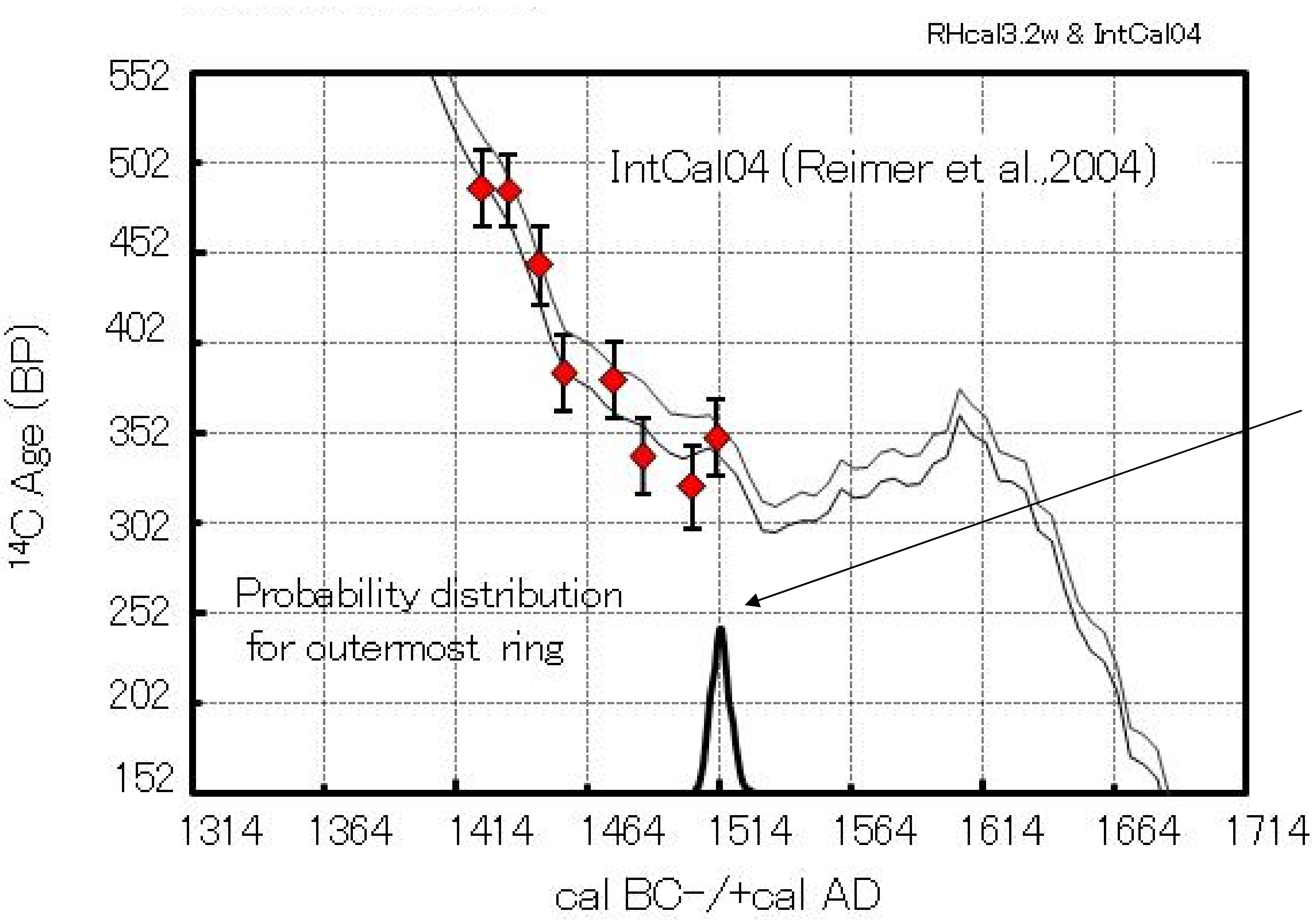


Results

t_{peak}	=		1655	cal AD		
						95.4% cf
1651	cal AD	～	1657	cal AD	(	97.1%)

Wiggle matching of 8 single-year samples from a Korean statue to the IntCal04 calibration curve

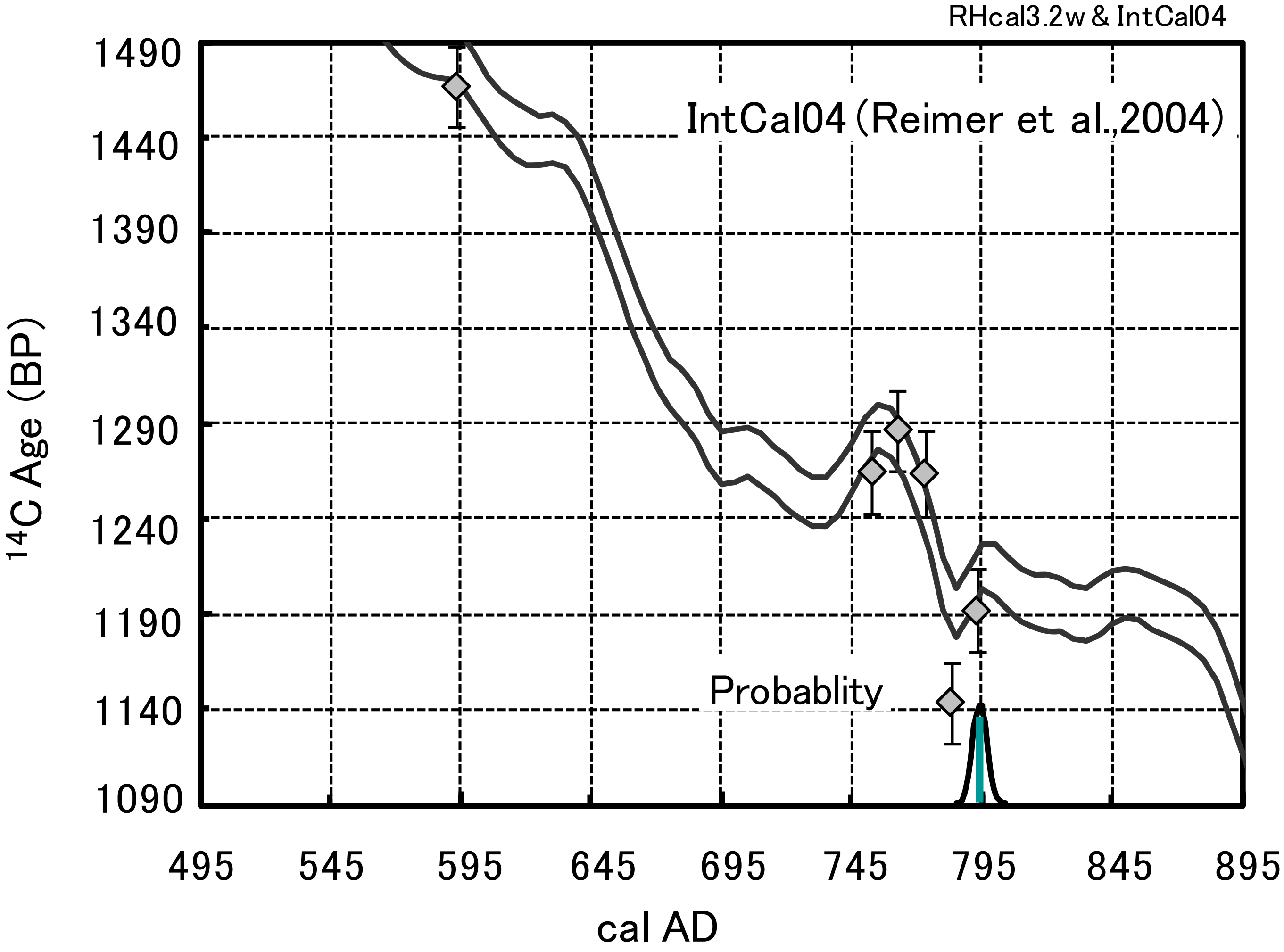
(Y. Kim et al., 2012)



Dendrodate

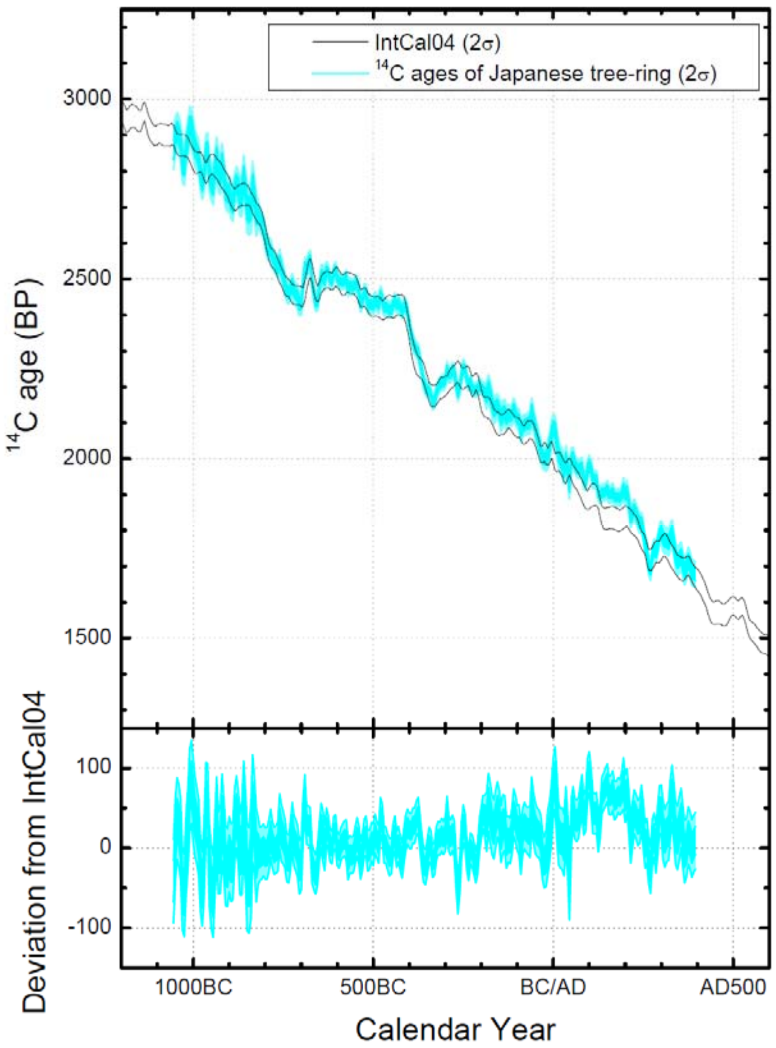
1517AD

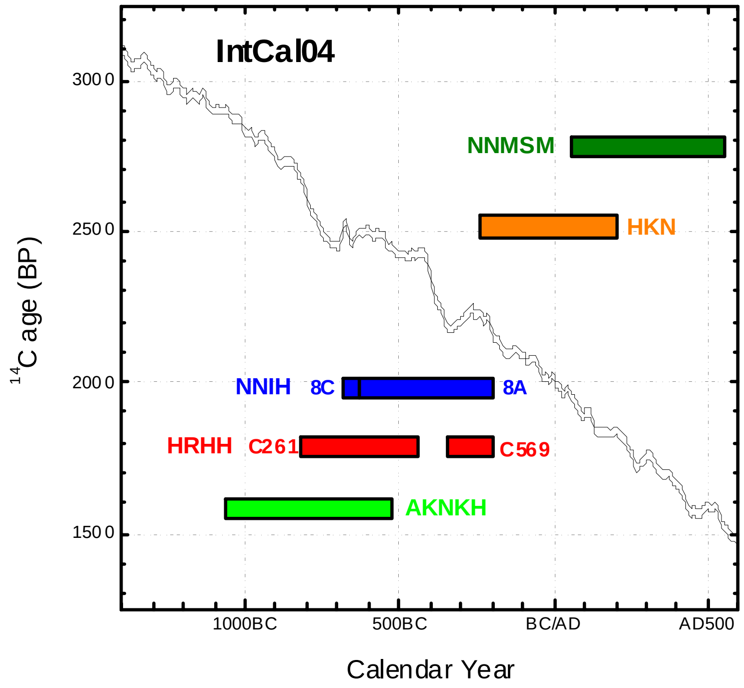
^{14}C wiggle matching of 6 five-year treerings from Horyuji temple, Nara (法隆寺,NRHRJ-E)



^{14}C wiggle-match date is shown in relative probability for the outermost ring.
Data points given for the most probable date

^{14}C dates of Japanese treerings are generally consistent with INTCAL datasets





(from H. Ozaki et al., 2009 Radiocarbon Conference, Hawaii)

However, significant deviations from INTCAL are observed ranging up to ~70 ^{14}C-years

- **Deviation in 1st~2nd century was first suggested (M.Sakamoto et al.,2003) using decadal sample of Japanese cedars for 240BC~AD900.**

- **It was confirmed in measurements with improved precision (+/-20~30 ^{14}C-years) for Japanese cedars and cypresses (5-years treering) for 1060BC~AD400. (H.Ozaki et al. 2009, 20th Raiocarbon conference)**

240BC~AD400

Sources of INTCAL datasets for 240BC~AD400
from Stuiver and Pearson (Radiocarbon 28, 1986)

Lab code	Species	Locality	Dendro ages used
RC	Sequoia	Sequoia Natl Park,CA (36.5N, 118.5W)	AD265-AD935 (decadal)
SC	Sequoia	Sequoia Natl Park,CA (36.5N, 118.5W)	145BC-AD265 (decadal)
BK	Oak	Southern Germany	495BC-AD45

Japanese tree-rings for 240BC~AD400

Spl Code AMS Lab	Species	Locality	Dendro ages used
HKN Paleo Lab	Japanese cedar	Hakone, Kanagawa Central Honshu Is.	240 BC – AD 200 (5-years)
NNMSM Paleo Lab	Japanese cypress	Minami-shinano, Nagano Central Hoshu Is.	153BC – 400AD (5-years)

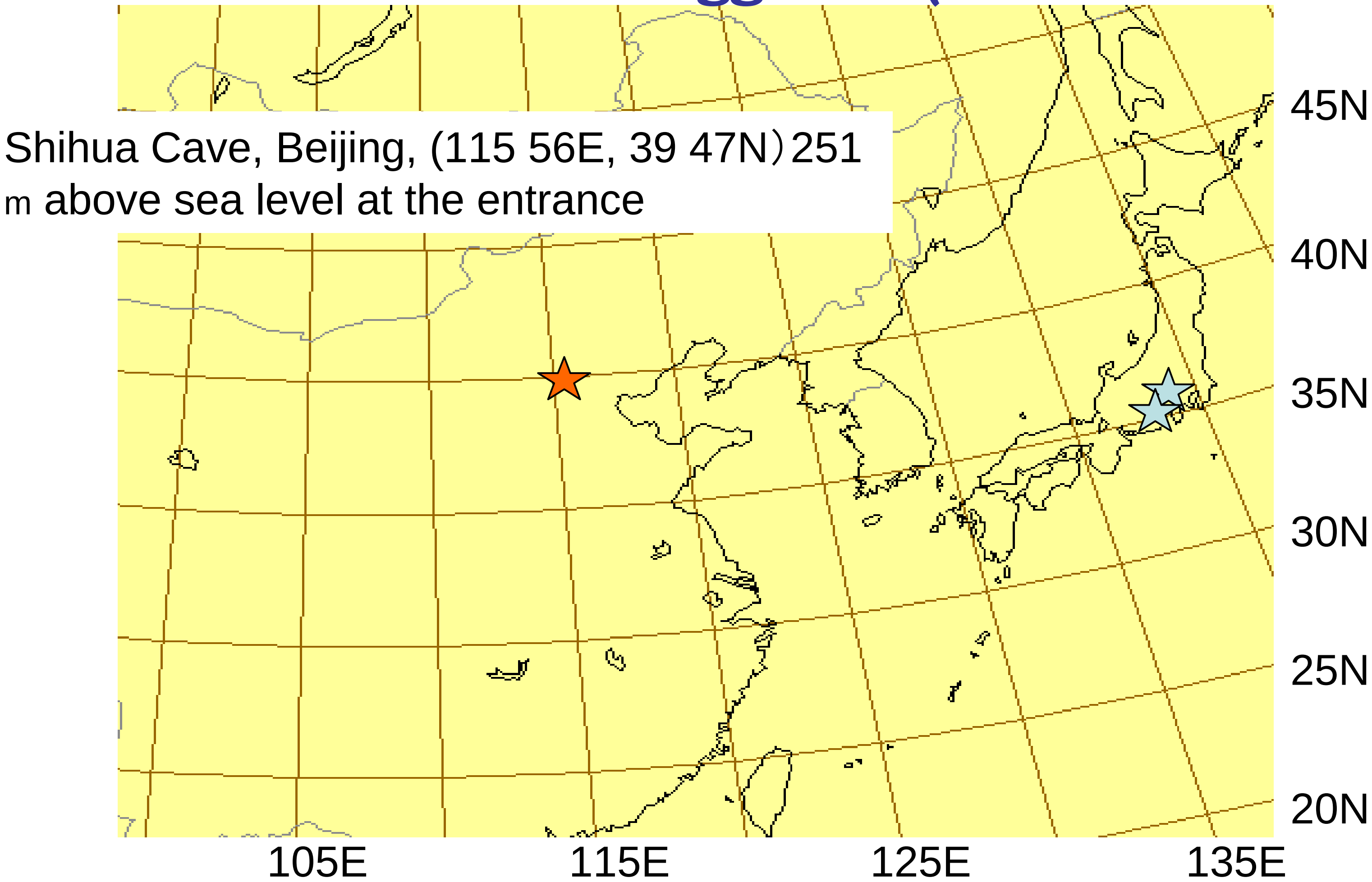
We find

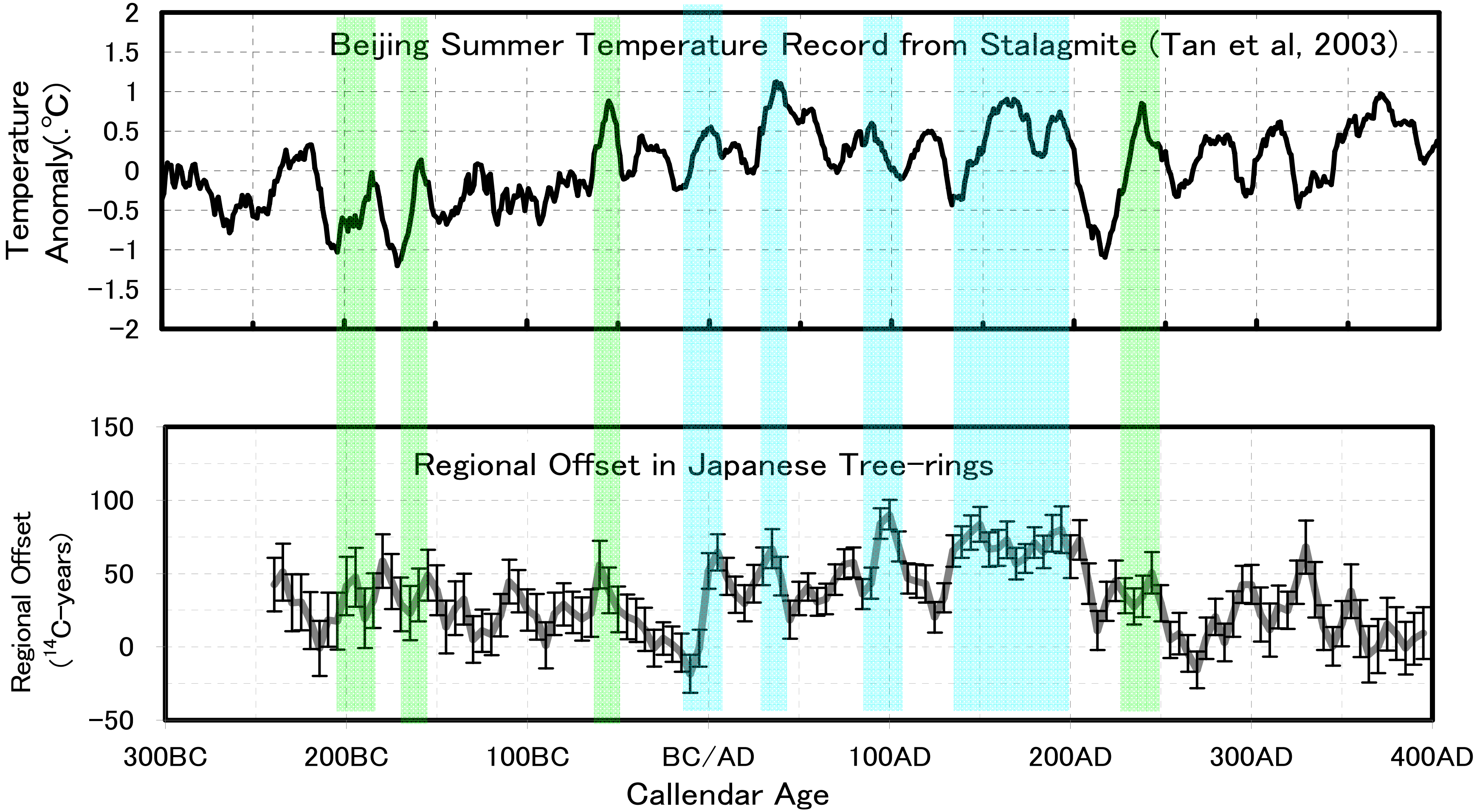
- **General correlations of wiggles between Beijing warm time climate proxies and ^{14}C offsets in the Japanese tree-rings for the periods between 240BC and 400AD.**

- **Large offsets take place when temperature is substantially high, particularly in the periods of 1~200AD.**

> Tan et al.(2003) reported a 2650-years paleo-temperature reconstruction from stalagmite lamina thickness in Shihua Cave, Beijing : GRL 30, 1617-1620.

> Effect of rainfall was suggested(F.Ban et al.2008).

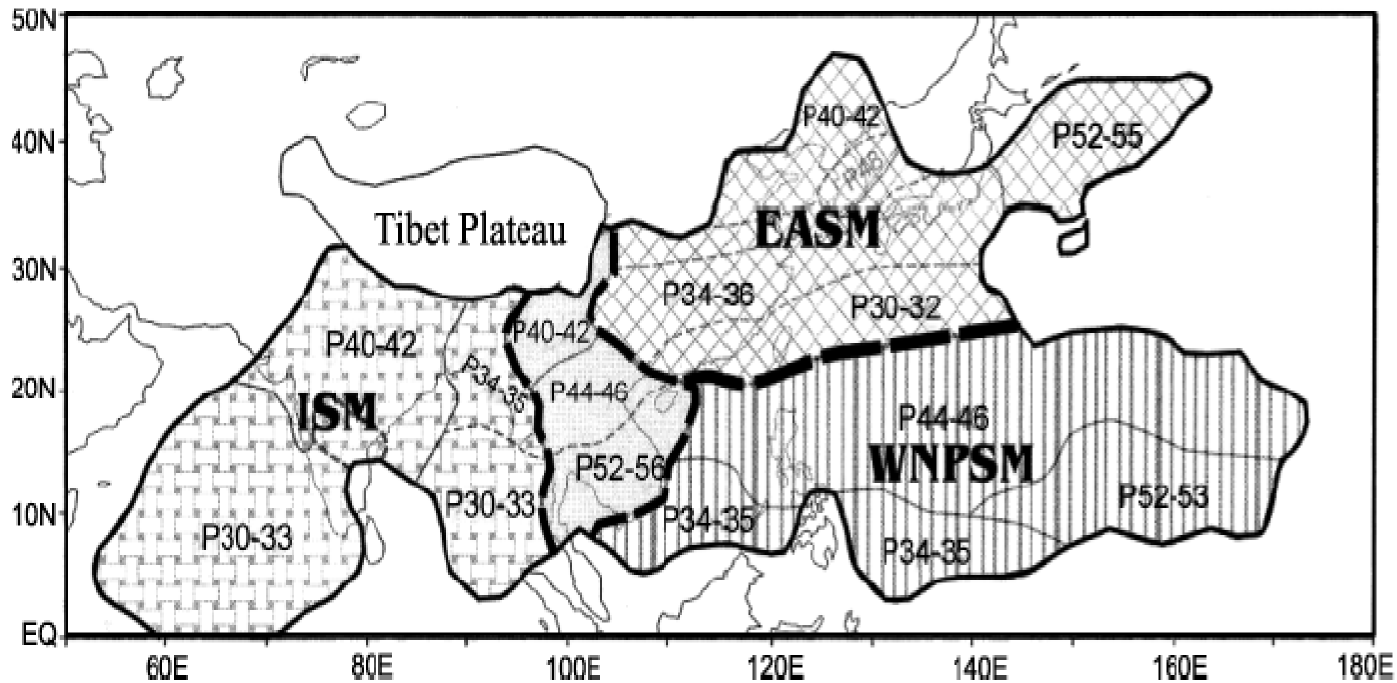




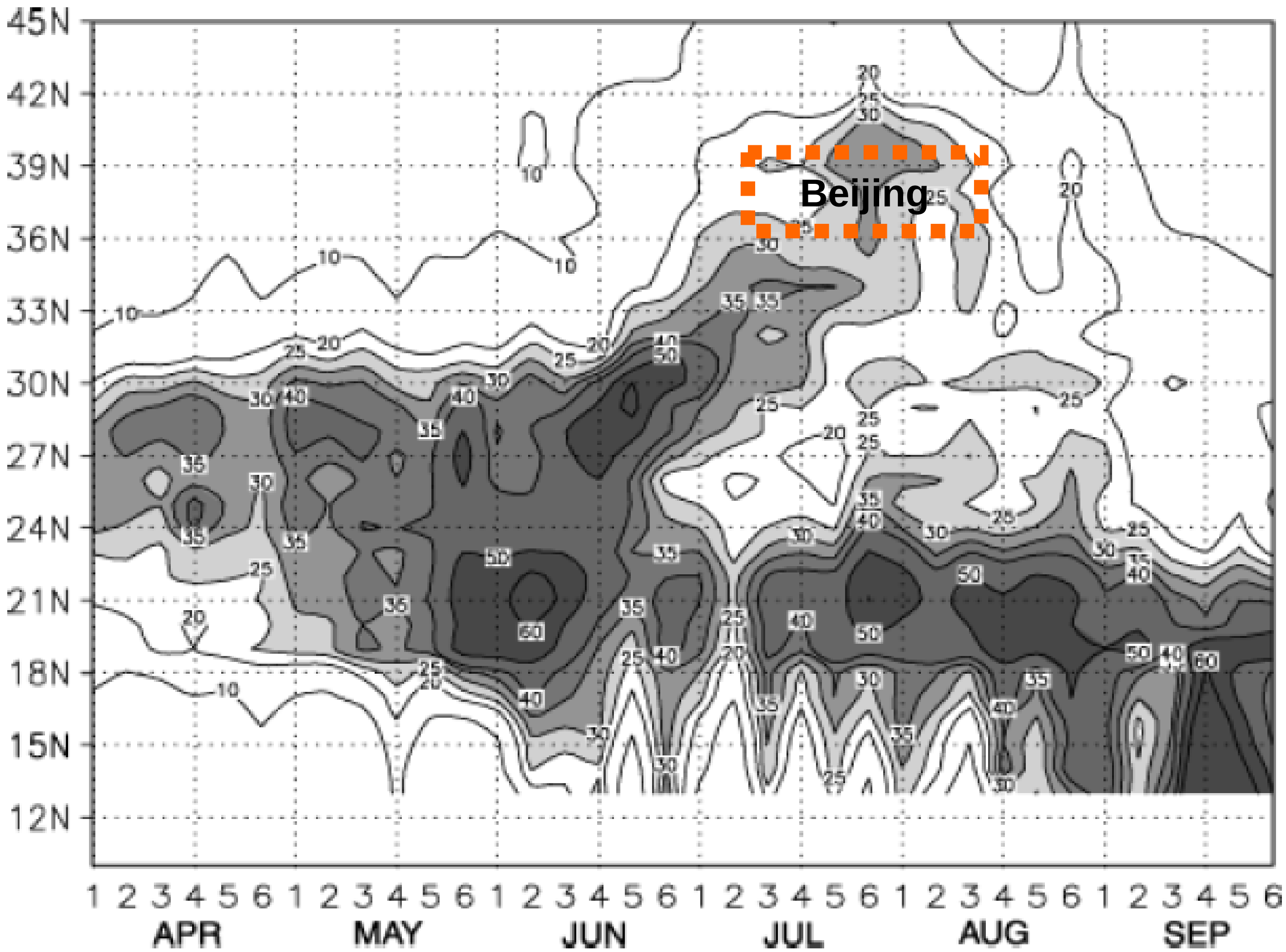
Beijing summer temperature/precipitation proxy records (Tan et al.2003, upper) compared with the regional offsets measured for Japanese cedars and cypress **(Both data are given in 10-years running averages).**.Age uncertainty for the proxy records : ±5-years

- **Synchronous behavior of time series for Beijing warm time climate proxies and ^{14}C offsets in the Japanese tree-rings strongly suggests the effect of Eat Asian summer monsoon.**

East Asian Summer Monsoon (EASM) is a subdivision of Asian Summer Monsoon

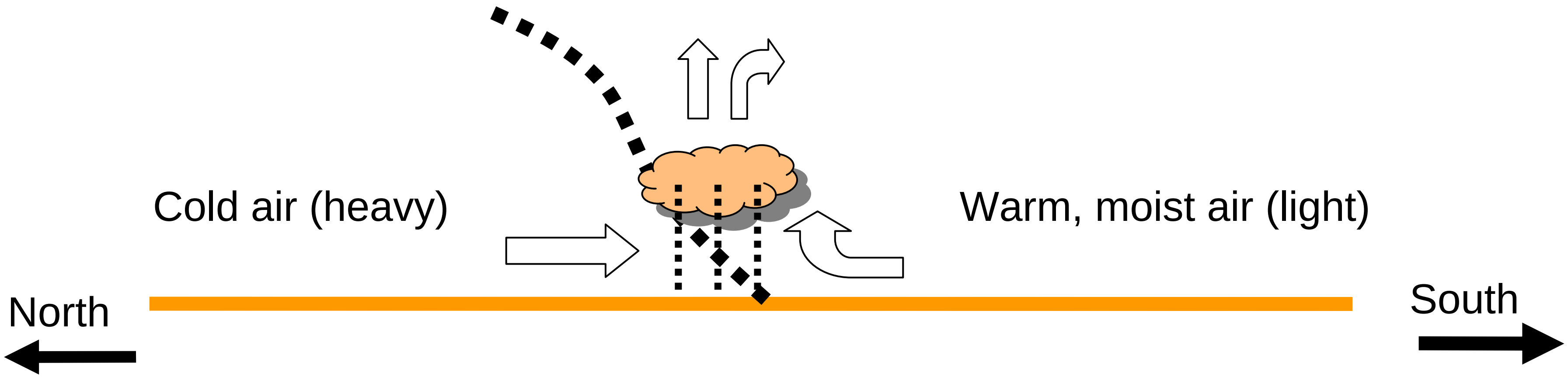


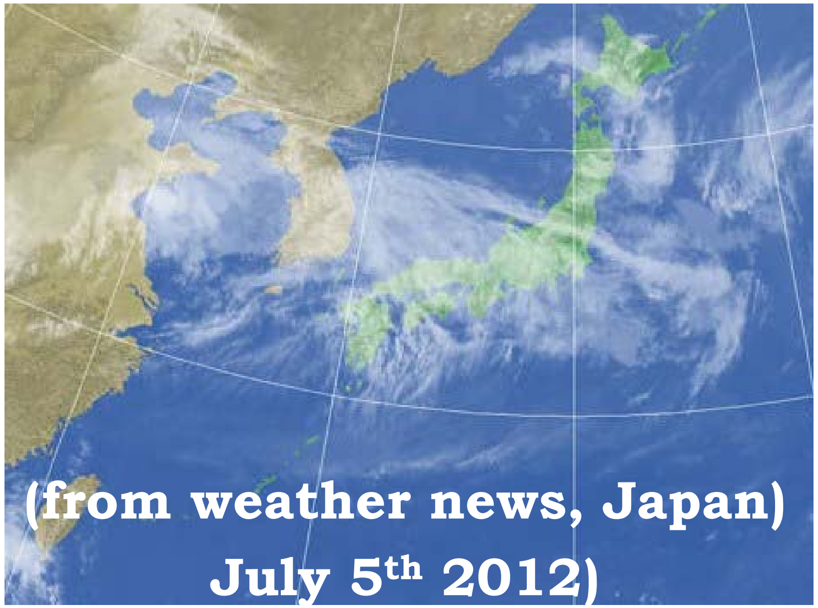
EASM is seasonal wind (May~August) in East Asia region mainly caused by the temperature (pressure) difference between Tibet plateau and Indian and western North Pacific Ocean. From Yuhui and Chang (2005).



Latitude-time section of 5-day **mean rainfall over eastern China (110-120E)** averaged for 1961-1990. Heavy rainfall regions are shaded (uni:mm). From Fig.7 of Yuhui and Chang (2005).

Rain belt (Baiu/Meiyu) formed by East Asian summer monsoon





(from weather news, Japan)
July 5th 2012)

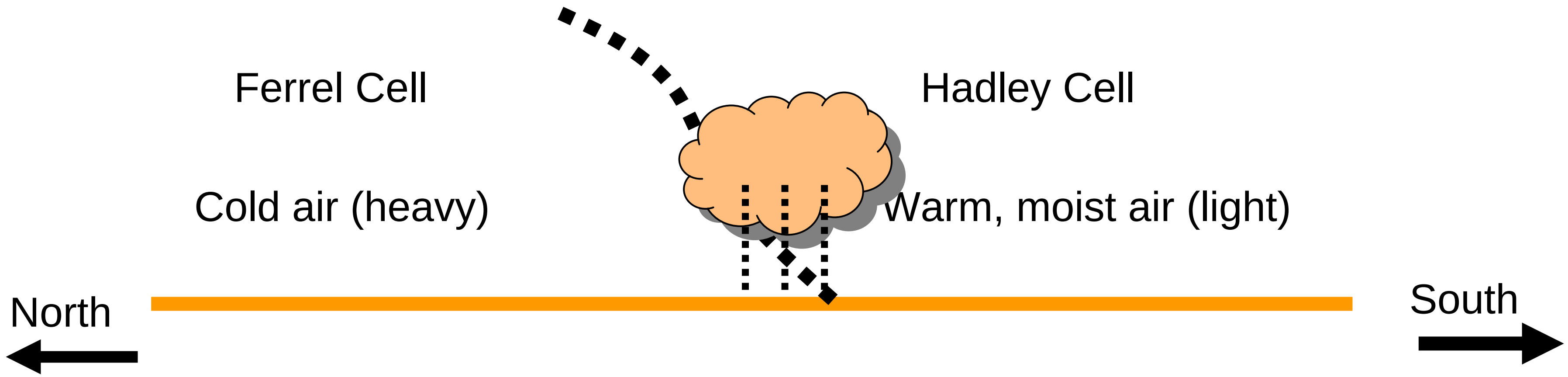
EASA front (Rain belt)

Average rainy season (1951-2011)

Okinawa (26N)	**May 9 - June 23**
South Kyushu (~31N)	**May 3! - July 14**
Central Japan (~35 N)	**June 8 - July 21**
North Japan (~39 N)	**June 14 - July 28**

2000 yr ago

How early did it started ? How far did it move ?



5. Climates in the Yayoi period and the role of solar activity

Yayoi period/Yayoi culture

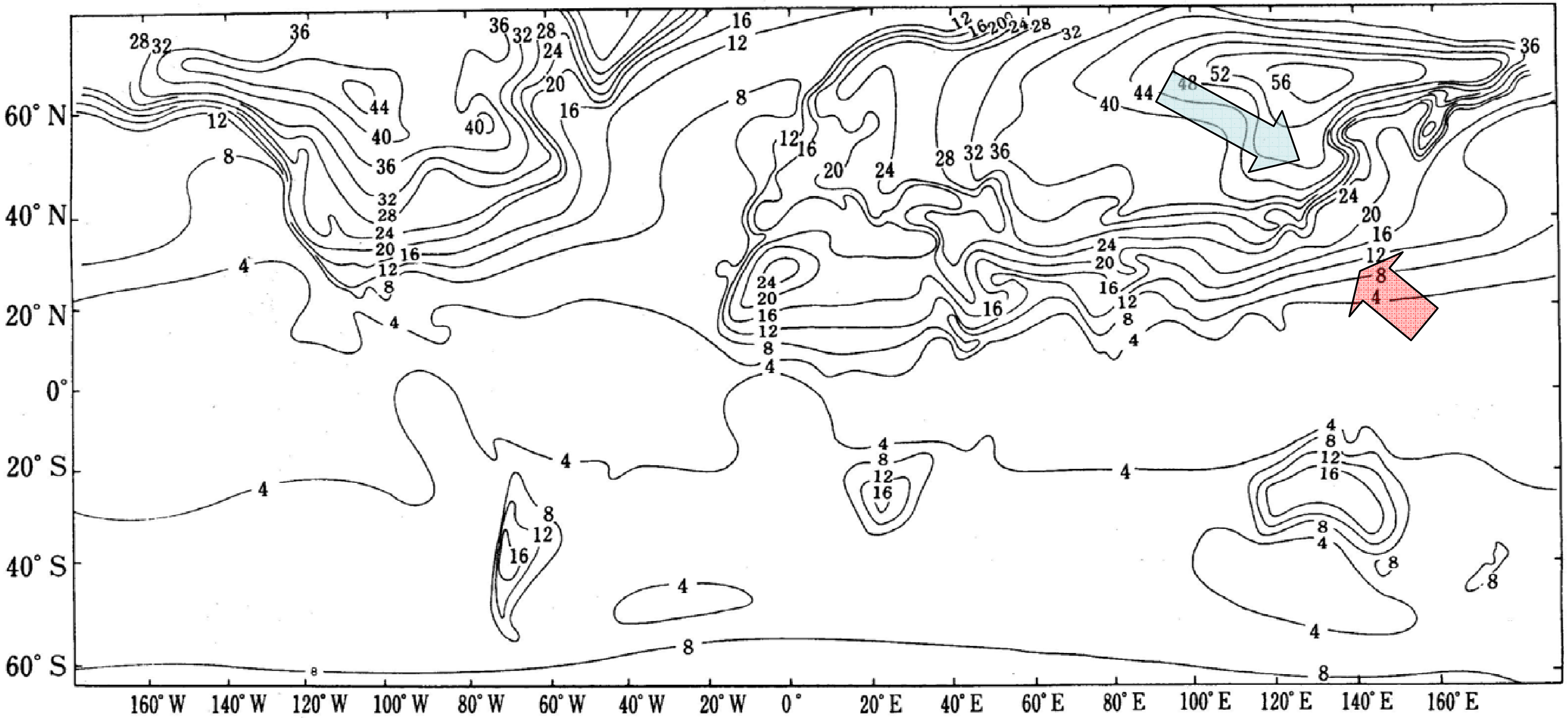
Characterized by wet-rice agriculture, and use of metal

Particularly, irrigated paddy-rice technique

↓

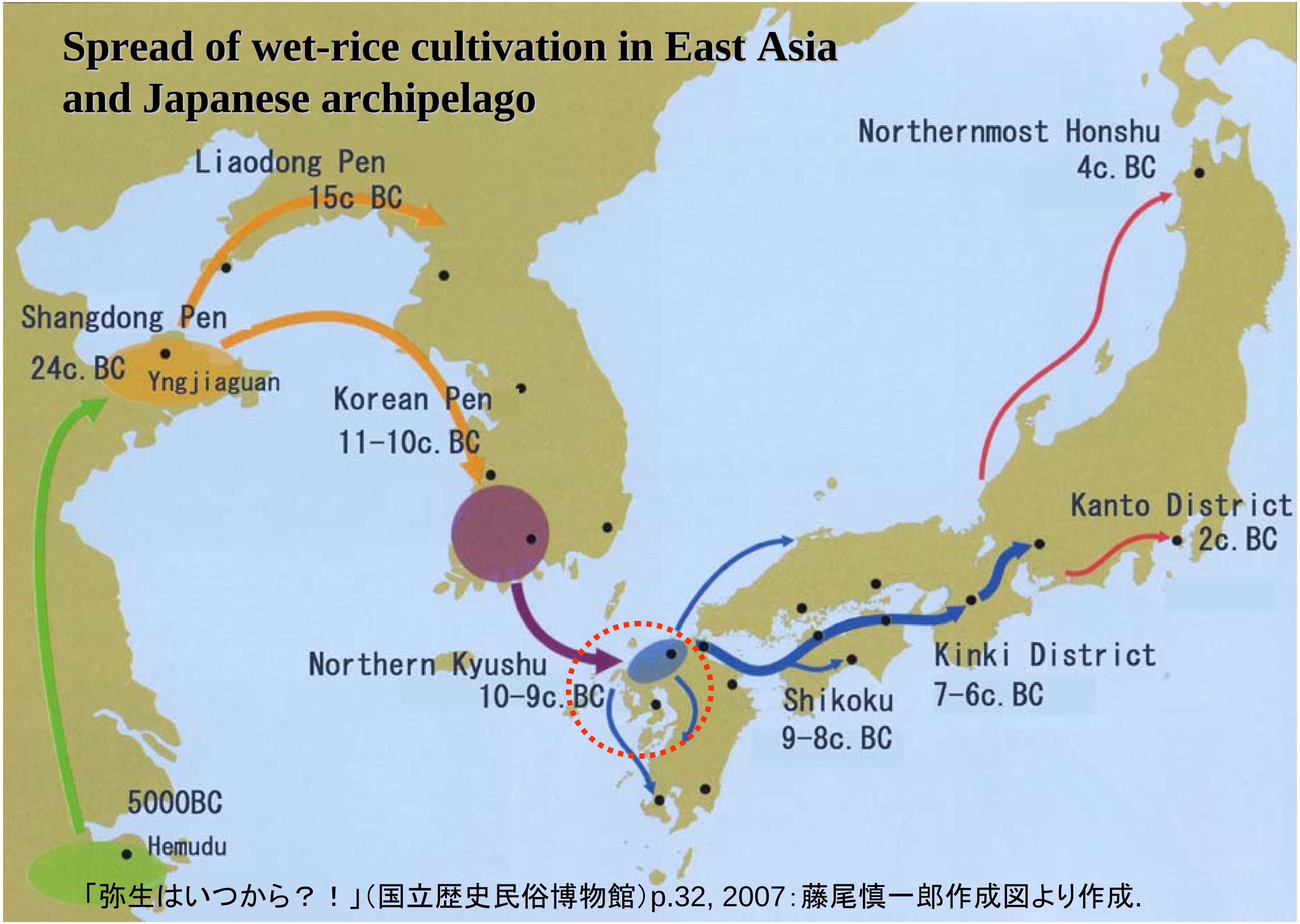
Requires warm and wet climates

Winter-summer temperature difference



Prepared from 佐伯理郎2001『エルニーニョ現象を学ぶ』盛山堂書店

Spread of wet-rice cultivation in East Asia and Japanese archipelago



「弥生はいつから？！」(国立歴史民俗博物館)p.32, 2007:藤尾慎一郎作成図より作成.

The ages are estimated from radiocarbon dates of pottery (soots) and artefacts (stakes etc.) found in archaeological sites related with rice fields.

The ages of earliest Yayoi periods coincide with those of the Dolmen appeared in northern Kyushu, Japan.

(Satodabaru site, Nagasaki Pref.)

Pottery used in the earliest stage of paddy-rice cultivation

菜畑遺跡出土の山の寺式(前10世紀後葉)
2730±40 ^{14}C BP　唐津市教育委員会　撮影 藤尾慎一郎

Yamanotera-type

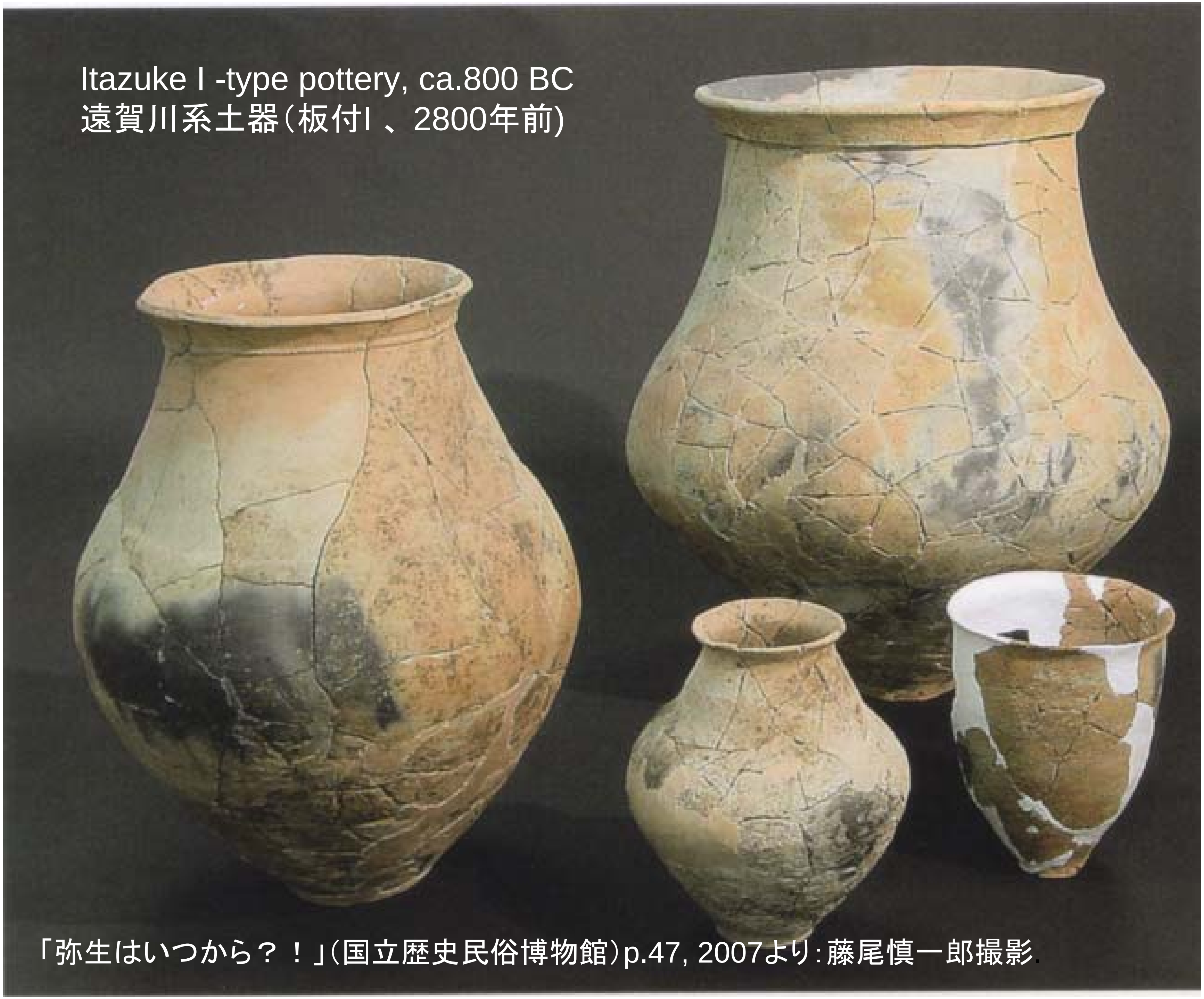
:2730±40 ^{14}C BP

(end of 10th c.BC～early 9th c.BC)

もっとも古い炭素14年代の弥生土器
福岡県橋本一丁田遺跡(夜臼Ⅰ式:前10世紀後半)
2765±40 ^{14}C BP　福岡市埋蔵文化財センター　撮影 藤尾慎一郎

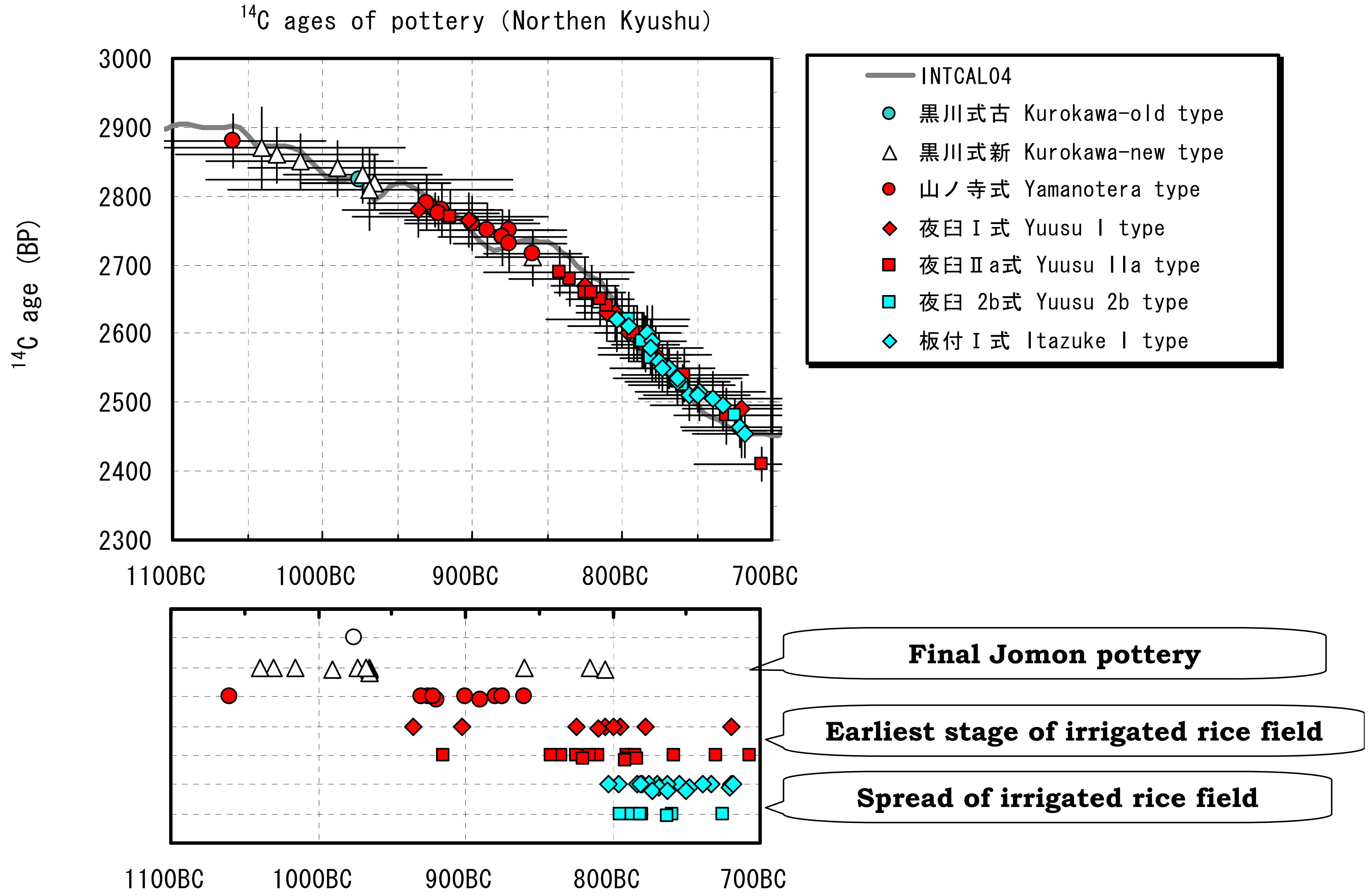
Yuusu I-type：2765±40 ^{14}C BP
（latter half of 10th c. BC）

Itazuke I -type pottery, ca.800 BC
遠賀川系土器(板付I 、2800年前)

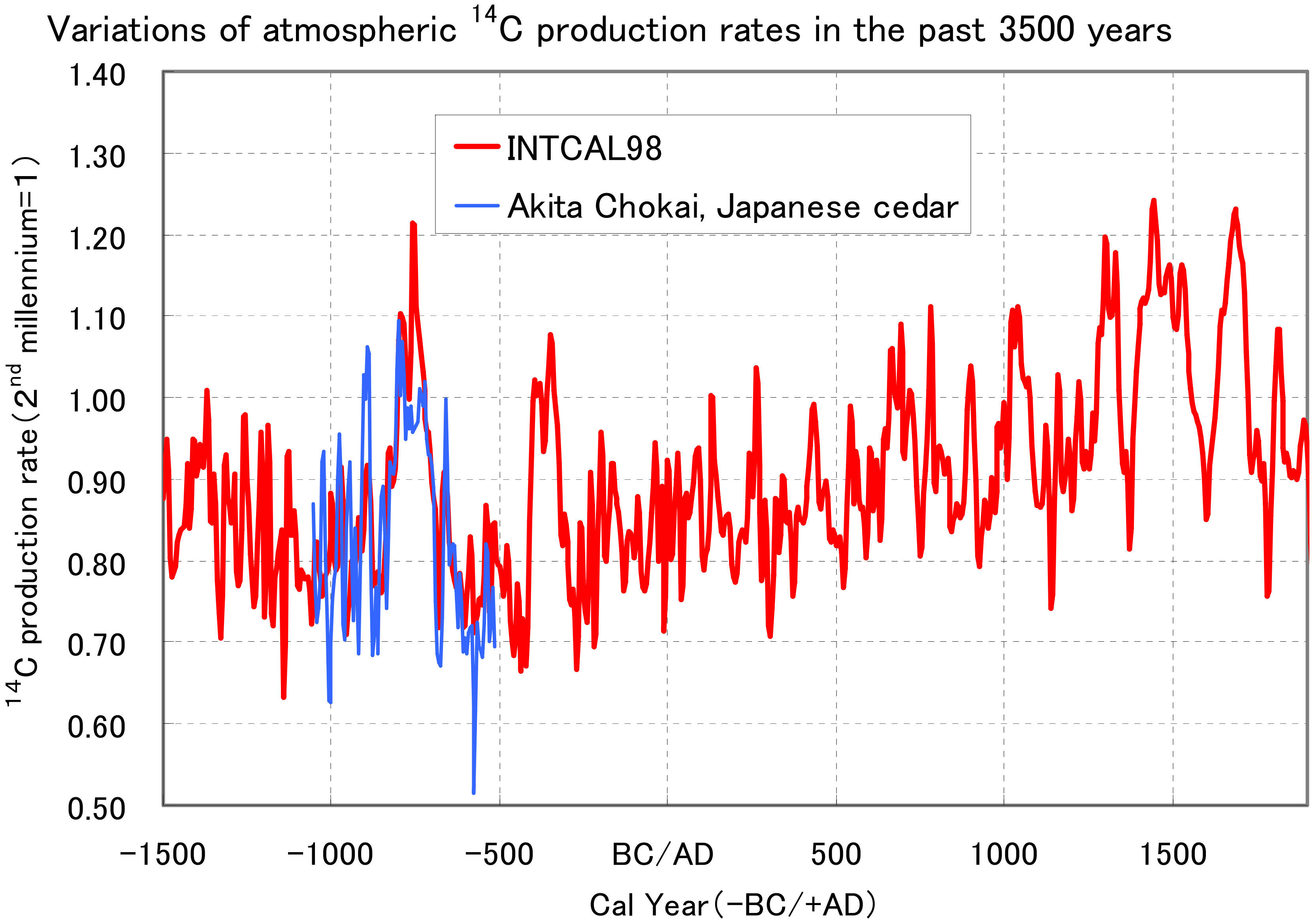


「弥生はいつから？！」(国立歴史民俗博物館)p.47, 2007より:藤尾慎一郎撮影.

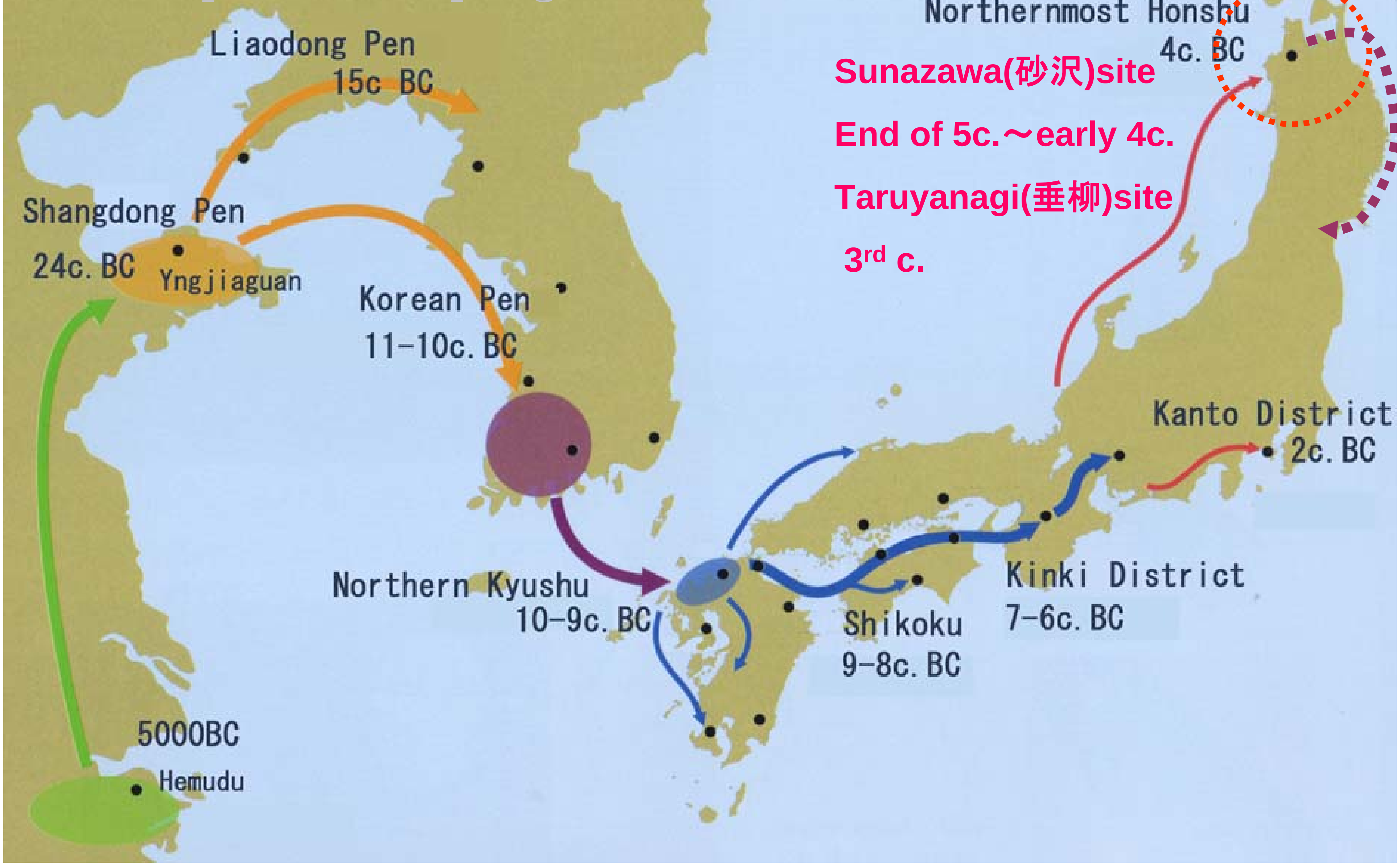
^{14}C dates in N. Kyushu districts in Jomon to Yayoi transition periods



Transition age of one pottery-type to another seems to correlate with climatic changes estimated from ^{14}C records.



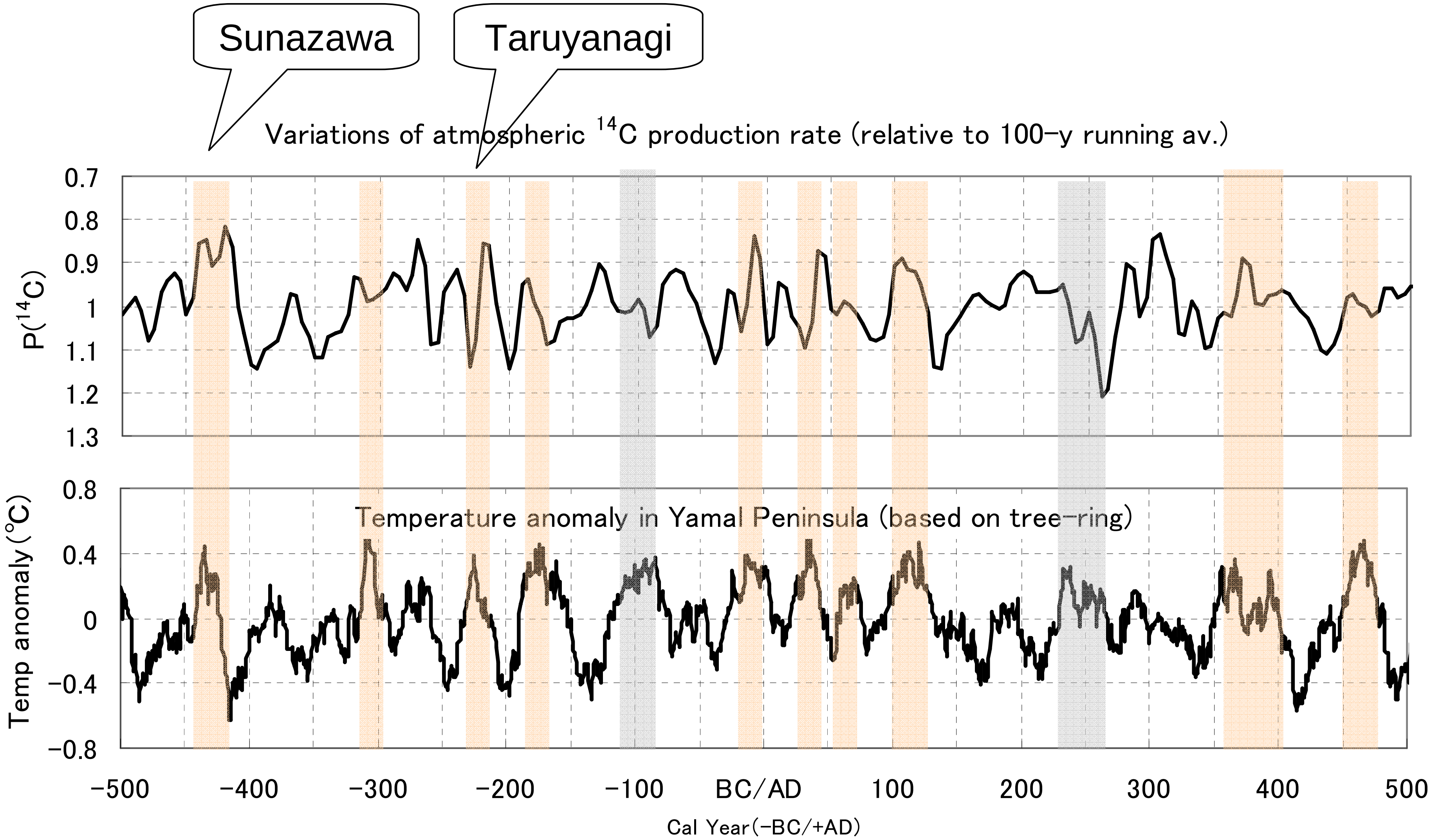
Spread of wet-rice cultivation in East Asia and Japanese archipelago



In 5^{th}~ 4^{th} c.BC and 3^{rd} c. BC,
Aomori was warm enough to produce rice.

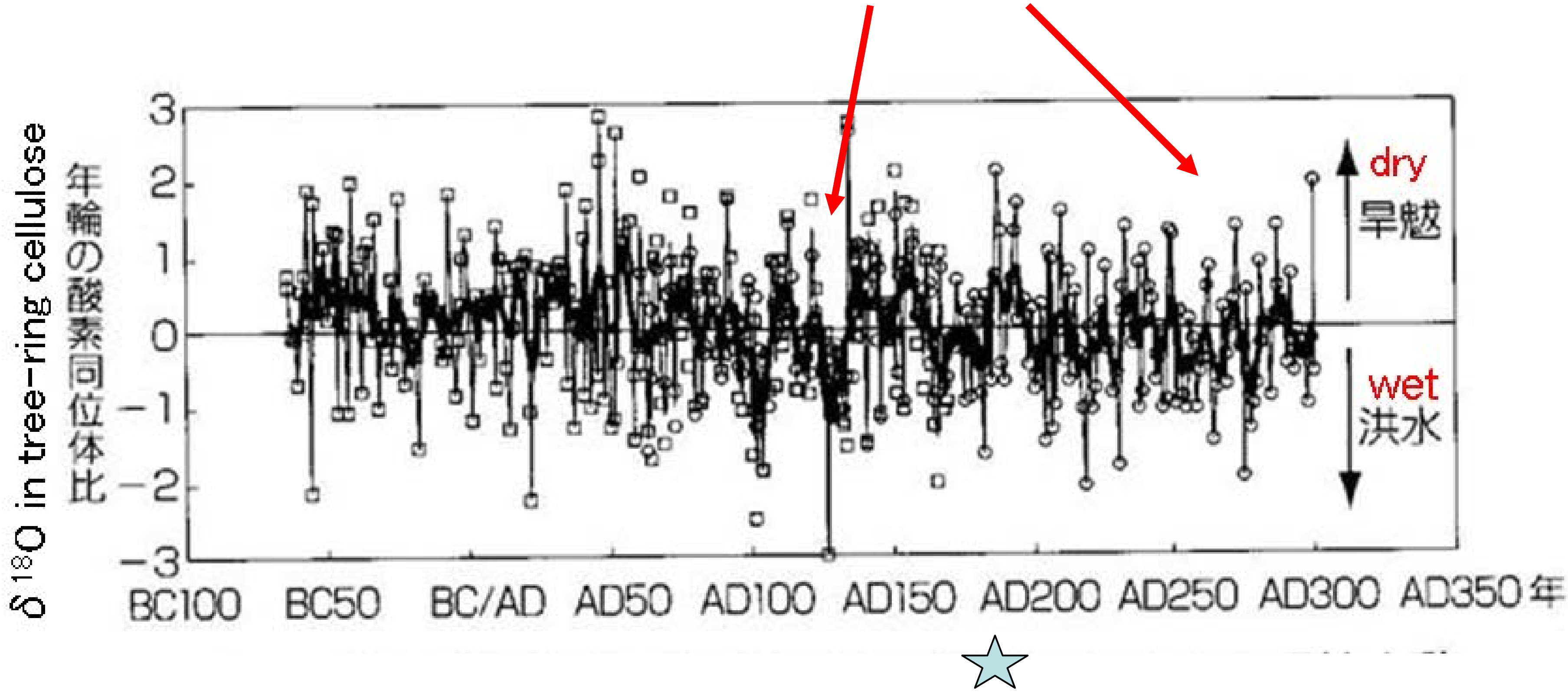
Sunazawa site (~400 BC) and Taruyanagi site (3rd c.BC)

Rice fields excavated
（津軽平野・田舎館村で
発見された弥生中期の
水田跡)



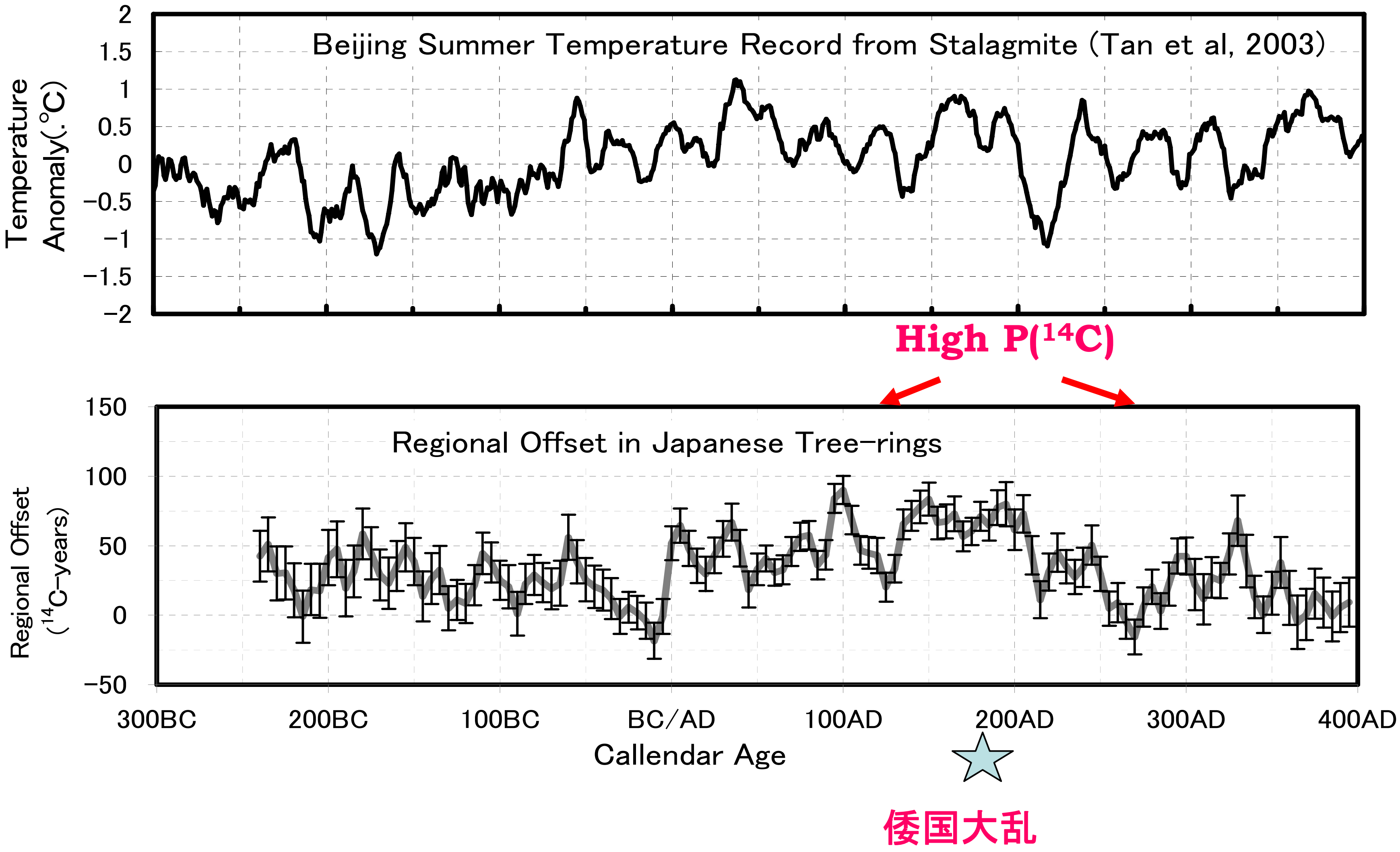
Yamal Peninsula (North-west Siberia) data of lower figure are from Hantemirov, R.M. and S.G. Shiyatov, 2002

High P(^{14}C)

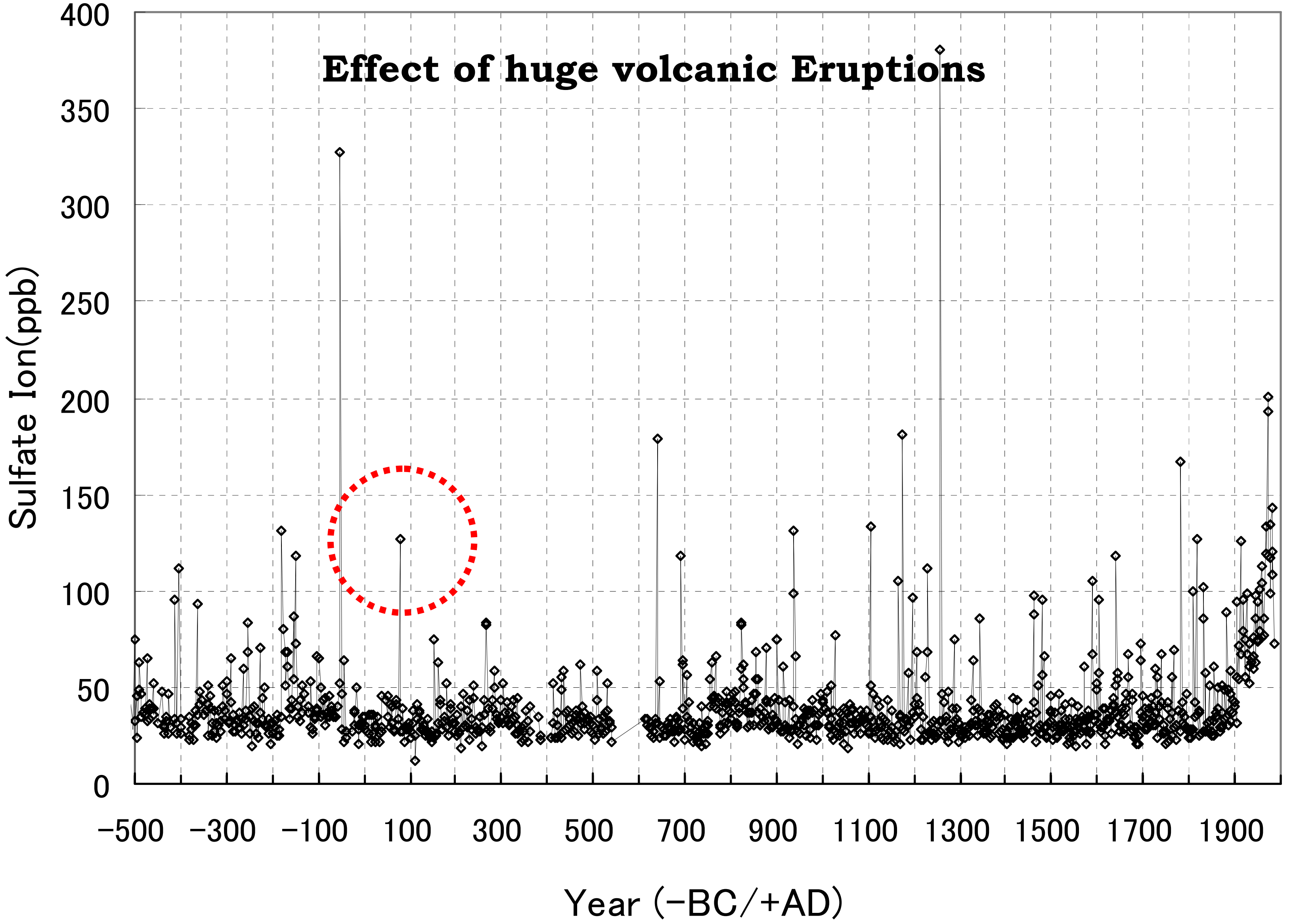


倭国大乱; extended war in western Honshu is.

Rainfall/Humidity in late Yayoi period (Kiso , central Japan) (from T. Nakatuka,2010)



Beijing summer temperature/precipitation proxy records (Tan et al.2003, upper) compared with the regional offsets measured for Japanese cedars and cypress



From Zielinski G.A. et al. 1994, Record of volcanism since 7000 B.C. from GISP Greenland Ice Core and implications for the volcano-climate system, Science 264, pp. 948-952

Summary

- **High summer temperature periods in East Asia for the last 2000 years coincide in most cases with the high solar activity periods estimated from variations of ^{14}C production rates.**
- **EL Nino and La Nina tend to occur in low solar magnetic activity, suggesting more stable climates in the high solar activity periods than in the low solar activity periods.**
- **Japanese tree-rings for the periods particularly in 1c. AD~2nd c. AD show deviations (offsets) in ^{14}C from INTCAL.**
- **Synchronous behavior of time series for Beijing warm time climate proxies from stalagmites and ^{14}C offsets in the Japanese tree-rings strongly suggests the effect of Eat Asian summer monsoon in these periods.**
- **Timing of wet-rice cultivation introduced to Japanese archipelago in 10~9c. BC and its spread to north in 5th c. BC ~4th c. BC seem to correlate with the climates estimated from ^{14}C records.**