Summer hydroclimate variability during BC 1st –AD 3rd centuries in Japan : its potential impact on the integration of Japanese nation.

Takeshi NAKATSUKA [1], Keiko OHNISHI [2], Kimitaka KAWAMURA [2], Hiromasa OZAKI [3, 4] & Takumi MITSUTANI [5]

[1] Graduate School of Environmental Studies, Nagoya University (e-mail: nakatsuka.takeshi@f.mbox.nagoya-u.ac.jp), [2] Institute of Low Temperature Science, Hokkaido University, [3] National Museum of Japanese History, [4] Paleo Labo Co., Ltd, [5] Nara National Research Institute for Cultural Properties

Abstract About 2ka, the Japanese archipelago had been consisted of many small countries, which prospered with rice paddy cultivation. However, Chinese literatures documented that large domestic warfare occurred in the late 2nd century and then Japanese countries were united under the leadership of a theocratic queen. Although archaeologists have discovered evidences of warfare, its causes and the subsequent unification process are still unclear. Hydroclimatic change may be one of the most important factors because rice paddies suffer from both flood and drought, but the past climate in Japan has not been well reconstructed for this period. In this study, we measured $\delta^{18}O$ with yearly resolution in tree-ring cellulose of two buried Japanese cypress trees in central Japan, whose ages range from BC 1st to AD 3rd centuries, to demonstrate summer hydroclimate variation based on the fact that Japanese tree-ring $\delta^{18}O$ has distinct negative correlations with local summer relative humidity and precipitation. The absolute age of each ring was determined by dendrochronological cross dating and certified by ^{14}C wiggle matching. The $\delta^{18}O$ was quite stable until the early 1st century, but it varied large with multi-decadal time scales during the 2nd century, which coincides with archaeological evidences of large floods in this period. These changes in summer hydroclimate apparently coincide with the occurrence of domestic warfare in the late 2nd century and the integration of Japanese nation in the early 3rd century, illustrating vulnerability of primitive agricultural societies to climate change.

Possible causes of Japanese domestic warfare in late 2nd century

1. Excess yield of rice due to the development of rice paddy cultivation
2. Declination of Chinese dynasty "Han"
3. Circulation of ironware over Japan
4. Natural disaster such as flood or drought

What kind of climate condition may cause disasters to the society ?

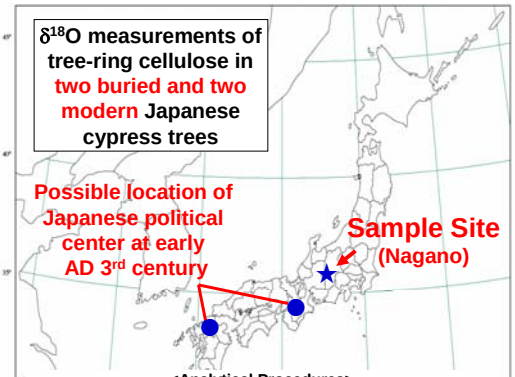
Potential relationship between precipitation and rice paddy cultivation at that time

1> Precipitation is the most important factor for rice paddy because both flood and drought seriously damage rice yield from paddies.

2> However, the absolute precipitation amount may not be critical for the rice yield because rice can be cultivated all over Japan now where annual precipitation ranges from 1000 to 4000 mm.

3> The most serious factor must have been **"temporal variation in precipitation amounts".**

$\delta^{18}O$ measurements of tree-ring cellulose in two buried and two modern Japanese cypress trees



<Analytical Procedures>

1) Slicing the tree-ring disks into thin boards of 0.7mm thickness.
2) Cutting the thin boards into yearly rings by razor blades.
3) Extraction of cellulose from the tree rings.
   3-1. Removal of lipid by organic solvents
   3-2. Removal of lignin by $NaClO_2$ solutions.
   3-3. Removal of hemi-cellulose by Alkaline solutions.
4) Measurement of oxygen isotopic ratios by TCEA-IRMS system

Factors controlling oxygen isotopic ratio ($\delta^{18}O$) of tree-ring cellulose in Japan

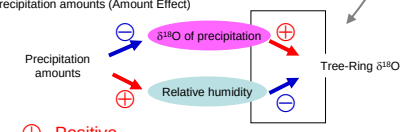
・Tree-ring $\delta^{18}O$ is mainly determined by $\delta^{18}O$ of Leaf Water in summer…

$$\delta^{18}O_{Leaf\ Water} = \delta^{18}O_{Precipitation} + (\varepsilon_e + \varepsilon_k)(1 - h),$$

ε_e, ε_k : equilibrium, kinetic isotope effects, h : relative humidity

・$\delta^{18}O_{Leaf\ Water}$ can be expressed as a linear function of "$\delta^{18}O$ of precipitation" and "relative humidity"…<**Craig-Gordon Equation**>

・In middle & low latitudes, $\delta^{18}O$ of precipitation has the negative correlation with precipitation amounts (Amount Effect)

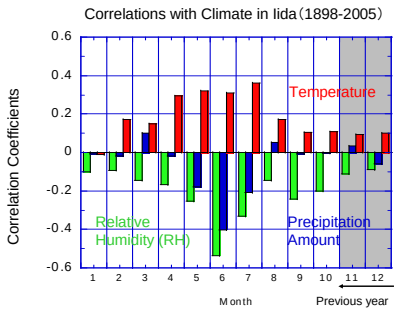


⊕ Positive
⊖ Negative

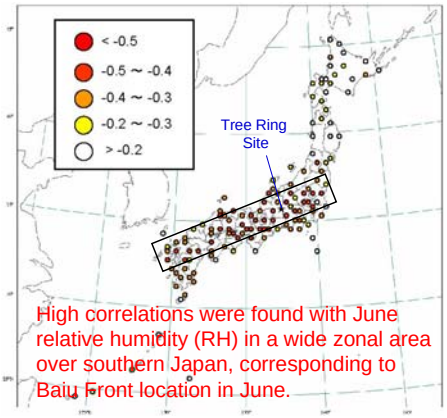
In middle latitudinal wet regions such as Japan, tree-ring $\delta^{18}O$ must have negative correlation with summer precipitation (relative humidity)

<Modern Trees>

Correlations between average tree-ring $\delta^{18}O$ of modern two trees and monthly mean meteorological records at nearest meteorological observatory



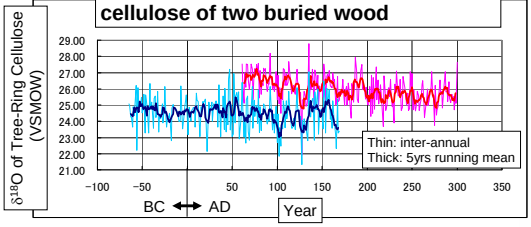
Spatial correlation between averaged tree-ring $\delta^{18}O$ of two cypress & June RH observed all over Japan during 1951-2005.



High correlations were found with June relative humidity (RH) in a wide zonal area over southern Japan, corresponding to Baiu front location in June.

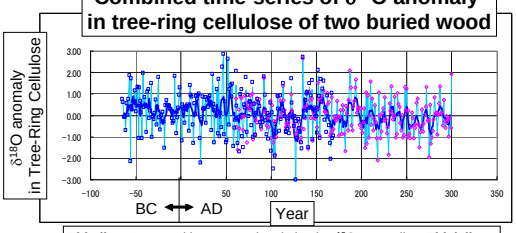
<Ancient Trees>

Temporal variations in $\delta^{18}O$ of tree-ring cellulose of two buried wood



Although the correlation between the two time series is very high (r=0.834) during the overlapped period, absolute values of the younger tree are about 2 ‰ higher than those of the older tree, probably reflecting a juvenile effect.

Combined time-series of $\delta^{18}O$ anomaly in tree-ring cellulose of two buried wood



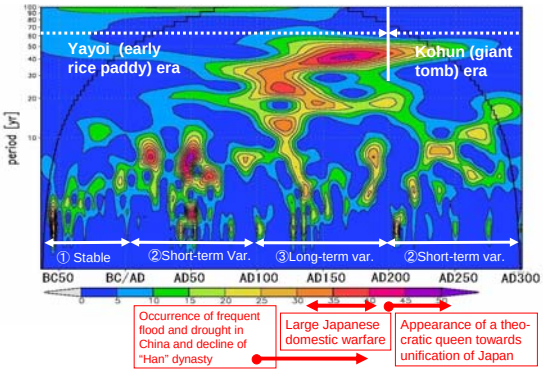
Thin line: Averaged inter-annual variation in $\delta^{18}O$ anomalies; **Thick line**: 5yrs running mean; **Square & diamond**: Anomalies from individual trees

[Method to combine the two $\delta^{18}O$ time series]

(1) Removal of the juvenile effect from early period of the younger tree.
(2) Calculation of inter-annual variations in $\delta^{18}O$ anomaly for each tree against the mean $\delta^{18}O$ values during the overlapped period.
(3) Combination of the two time series by averaging the two (or one) anomaly data for each year.

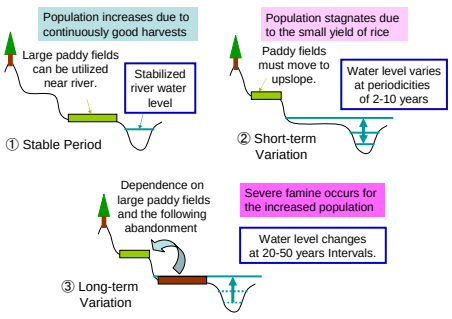
These processes may delete the long-term (>100yrs) signals from the original $\delta^{18}O$ time series.

Wavelet diagram of the $\delta^{18}O$ variation in the tree-ring cellulose at central Japan during BC1-AD3 centuries



Summer hydroclimate was quite stable in BC 1st century in Japan, but it became highly variable especially at the short-term periodicity less than 10 years in AD 1st century. After the beginning of AD 2nd century, the summer hydroclimate varied largely at multi-decadal time scale, and the long-term variations were finished at the end of AD 2nd century. Those changes in temporal variability of summer hydroclimate apparently coincide with the social and political situations in Japan and China, documented in Chinese old literatures and revealed at Japanese archaeological sites.

Possible relationship between Japanese society and hydroclimate at that time <Emerging mechanism>



Because people's lifetime was likely to be about 30 years at that time, societies without written characters could not memorize long-term climate changes. Therefore, if good harvests continued for more than 10 years, the social system must have adapted to the climate condition and increased the population very rapidly. Once the climate changed like in the AD 2nd century, the increased population must have failed to respond to the climate change and faced the severe famines due to the poor yield of rice.