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Reconstruction of southeast Tibetan Plateau summer cloud cover over the past two centuries using tree ring δ^{18}O

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Abstract

A tree-ring δ^{18}O chronology of Linzhi spruce, spanning from AD 1781 to 2005, was developed in Bomi, Southeast Tibetan Plateau (TP). During the period with instrumental data (1961–2005), this record is strongly correlated with regional summer cloud cover, which is supported by a precipitation δ^{18}O simulation conducted with the isotope-enabled atmospheric general circulation model LMDZiso. A 225-yr regional cloud cover reconstruction was therefore achieved. The observed cloud cover increased in the 1980s and this increase is not unprecedented in the entire reconstruction. The reconstructed cloud cover appears smaller and more stable in the 20th century than previously. A late 19th century decrease in our reconstructed cloud cover is consistent with a decrease in the TP glacier accumulation recorded in ice cores. Our data reveal a strong anomaly in the 1810s, which coincides with volcanic eruption in 1809 and the 1815 Tambora volcanic eruption.

1 Introduction

Clouds formed by condensation of atmospheric moisture release latent heat in the atmosphere and can scatter, absorb and reflect radiative fluxes. Through their impacts on the atmosphere and surface energy budgets, they play a crucial role in the climate system (Yu et al., 2004; Stephens et al., 2005). Cloud feedbacks are particularly important in the response of the climate system to radiative perturbations (Dufresne and Bony, 2008). Regional cloud cover is also sensitive to atmospheric aerosol load, which is strongly affected by volcanic eruptions (Robock, 2000) and human activities (Khain et al., 2005; You et al., 2010), with potential positive feedbacks (Jacobson 2001; Ramanathan et al., 2005).

On the Tibetan Plateau (TP), a significant increase in low clouds has been shown on the East TP since the 1980s (You et al., 2007), as well as a decreased cloud variability (Zhang et al., 2008). An increase in night cloud cover (Duan and Wu, 2006), which has amplified the fast reginal warming on TP (Duan and Wu, 2006; Wang et al., 2008), is also reported. Because of the important role of cloud cover in climate dynamics, it is crucial to place the recent changes in a longer time scale to understand the full spectrum of cloud cover variability beyond the short instrumental records and to investigate whether these changes exceed the natural cloud cover variability.

Oxygen stable isotopes archived in tree-ring cellulose have been reported to be proxies of cloud cover variations (Hilasvuori and Berninger, 2010; Kress et al., 2010). We have recently measured tree-ring cellulose δ^{18}O in Bomi (southeast TP) and examined its correlations with local and regional climatic parameters during the instrumental period (Shi et al., 2011). The Bomi tree-ring δ^{18}O is significantly correlated with summer cloud cover (28–31° N 90–95° E, June–August, $R^2 = 0.40$, $p < 0.01$, 1956–2005), therefore opening a door for using longer tree-ring δ^{18}O records to reconstruct past variability in summer cloud cover for southeast TP.

Compared to other tree-ring proxies, tree-ring δ^{18}O has several advantages: (i) little evidence of age effects (Masson-Delmotte et al., 2005; Etien et al., 2008; Liu et al., 2008; Shi el al., 2011); (ii) strong and stable correlations with moisture parameters, which are largely influenced by relative humidity (Barbour, 2007; Sternberg, 2009); and (iii) the ability to document past climate variability in moist and warm areas, where no clear factor is limiting tree growth (Cook et al., 2010; Fichtler et al., 2010; Managave et al., 2010; Sano et al., 2010).

In this manuscript, we extend the Bomi tree-ring cellulose δ^{18}O record back to AD 1780 and reconstruct the summer regional cloud cover for the past 225 yr. The variability of this reconstruction is analyzed in terms of trends, regime shifts and frequency of extreme years. Our reconstruction is also compared with past snow accumulation and δ^{18}O derived from ice cores.

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2 Material and method

2.1 Sampling site and strategy

Our tree-ring sampling was conducted in Gangcun Natural Forest Reserve (95.55° E, 29.87° N, ca. 2760 m) which is located 20 km West of Bomi city and 60 km from the turning point of Yaluzangbo-Brahmaputra River (Fig. 1). The forest is well protected and does not exhibit any sign of anthropogenic influence. The main species of this forest are Linzhi spruce (*Picea likiangensis var. lintziensis)* and East Himalayan Fir (*Abies spectabilis)*. Linzhi spruce is a shallow rooted and shade tolerant species, mainly distributed within moist areas of southeast TP. We selected 27 Linzhi spruce trees that have no distorted stem or internal rot for sampling. One core per tree was collected at breast height, using an increment borer of 5.14 mm inner diameter. The length of cores ranges from 30 cm to 55 cm and most cores reach the pith of the tree.

2.2 Sample preparation and crossdating

Cores were air dried and polished with progressively finer sandpaper until rings were clearly visible. Tree-ring widths (TRW) were measured using the videoment® system and cross-dated by visual inspection of the ring-width pattern. A total of 26 cores were successfully cross-dated and the dating quality was checked using the COFECHA software (Holmes, 1998).

2.3 Tree-ring δ^{18}O measurement

Among the successfully cross-dated cores, 11 old ones (labeled O1 to O11 following age ascendant order) having regular ring boundaries and no missing rings were chosen for tree-ring δ^{18}O analyses. Each ring of each core was cut using a scalpel blade and stored in an individual plastic tube. For the time period 1956–2005, individual tree-ring δ^{18}O measurements were conducted on five trees and compared to the value obtained on the pooled six other trees (Shi et al., 2011). Prior to 1956, all the 11 tree samples were pooled before $\delta^{18}O$ measurements. This sampling strategy is justified as we previously demonstrated that four trees with one core per tree were sufficient to represent a population signal (Shi et al., 2011).

Each wood sample was milled, and alpha cellulose was extracted by chemical extraction, following the procedure described in Raffalli-Delerce et al. (2004). Samples of 0.1–0.2 mg of cellulose were packed in silver capsules and $\delta^{18}O$ was measured with a high temperature analyzer (TC/EA) coupled with a Finnigan MAT252 mass spectrometer at LSCE (Gif/Yvette of France) (Shi et al., 2011). The $\delta^{18}O$ measurements were conducted with reference to CC31 cellulose standards (31.85 ‰), and the standard deviations of 10 consecutive CC31 (0 to 2 values being rejected) was controlled under 0.20 ‰. Each sample was measured at least two times, and up to four times if the cellulose amount was sufficient. The analytical uncertainty is defined as the standard deviation of replicate measurements.

3 Results

3.1 Tree-ring $\delta^{18}O$ chronology

The tree-ring $\delta^{18}O$ and analytical uncertainties are displayed in Fig. 2a, together with the number of trees pooled for $\delta^{18}O$ analysis.

3.2 Calibration and verification of the tree-ring $\delta^{18}O$ in relation to cloud cover

Our previous calibration study (Shi et al., 2011) revealed a significant correlation with regional June-August cloud cover ($R^2 = 0.40$, $n = 46$, $P < 0.01$). Two outlier years, 1978 and 1991, are detected (Fig. 3, blue arrows). The $\delta^{18}O$ measurements of 1978 showed very heterogeneous cellulose, and six measurements were conducted with an estimated analytical uncertainty of ±0.5 ‰. When ignoring this outlier year, 50 % variance of June–August cloud cover can be explained by tree-ring $\delta^{18}O$ ($n = 45$, $P <$

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0.01) (Fig. 3). The linear calibration equation relating June–August cloud cover (CC_{JJA}, expressed in %) and tree ring cellulose $\delta^{18}O$ (in ‰) is:

$$CC_{JJA} = -1.45 \times \delta^{18}O + 116. \tag{1}$$

Leave-one-out cross verification was conducted. RE (reduction of error statistic) and CE (coefficient of efficiency) are both equal to 0.44, which means that the linear calibration is statistically significant.

The uncertainty on the reconstructed cloud cover arises from the uncertainty associated with the linear model and from the uncertainty on the $\delta^{18}O$ measurements (on average ±0.20 ‰). We have used a bootstrap method to test the quality of the linear regression model, and taken into account the uncertainties of the proxies by randomly modifying the proxy data within their uncertainty range. The standard deviation of the residuals obtained over verification sub-datasets was ±1.48 % (10 000 iterations). In order to have a conservative estimate of the quality of the reconstruction, we consider the 1.5σ error on the reconstructed CC_{JJA} of ±2.2 ‰.

3.3 Reconstruction of the cloud cover variability

The history of summer cloud cover (28–31° N, 90–95° E) was reconstructed by applying the Eq. (1) to the 225-yr tree-ring $\delta^{18}O$ chronology (Fig. 2b). The long-term variability of the cloud reconstruction was analyzed using the first component of SSA (Singular Spectrum Analysis) using the SSA-MTM toolkit (Ghil et al., 2002). To test the mean value shift of cloud reconstruction, a regime shift analysis was conducted with software Regime Shift Detection v3.2 (Rodionov, 2004). The long-term trend is shown in Fig. 2b, and three major shifts in years 1807, 1818 and 1887 are found. From the 1780s to the 1880s the reconstructed CC_{JJA} shows a plateau of relatively high values, interrupted by an 11-yr sharp minimum (from 1807 to 1817). A downward trend is observed from the 1870s to the 1890s, followed by small fluctuations around stable mean values. The recent increasing trend is not unprecedented and appears small in comparison to past regime shifts.

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To depict the inter-annual variability, we investigated extreme years with high/low cloud cover in this reconstruction, as well as the moving standard deviation (STD) of the residual record (cloud reconstruction minus the mean regime). The extreme cloud cover is defined as those exceeding 1.5 standard deviation from the base level (dashed blue lines in Fig. 2b), and represented with red and blue vertical bars respectively (Fig. 2b). From the 1920s onwards, few extreme years are evidenced and the variability of the 31-yr moving STD is low (Fig. 2c). The inter-annual to decadal variability of the reconstructed cloud cover appears to have been maximum in the years 1900–1930, and about 25 % higher than during the last 50 yr (Fig. 2c).

4 Discussion

4.1 The 1807–1817 anomaly

In this section, we focus on the regime shift observed from 1807 to 1817. This period is characterized by the lowest level in the reconstructed regional cloud cover. Widespread descriptions of anomalous meteorological conditions during this period are available worldwide with the year 1816 being depicted as "the year without a summer" (Stothers, 1984). The interval 1815–1817 is recognized as the worst starvation recorded in documented history in the adjacent Yunnan province, Southwest China (Yang et al., 2005). According to large-scale tree-ring based temperature reconstructions in Northern Hemisphere, the 1810s is the coldest decade of the past 250 yr to 600 yr (Briffa et al., 1998, 2001; Briffa and Osborn, 1999;Esper et al., 2002). This climate anomaly is attributed to a large eruption of unknown origin in 1809 (Dai el al., 1991; Dai, 2010) followed by the 1815 massive eruption of the Tambora Volcano (Briffa et al., 1998). A cold anomaly was also evidenced in southeast TP (150km southwest of our site) in a TRW based summer temperature reconstruction, which showed the 1810s–1820s as the coldest period in the last 242 yr (ca. 0.5 °C below the mean) (Liang et al., 2009). As the δ^{18}O of Bomi tree cellulose is positively correlated to summer temperature (Shi et

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al., 2010), such a cooling should result in a decreased cellulose $\delta^{18}O$. As we observe a positive $\delta^{18}O$ anomaly during the 1807–1817 period, the possible temperature effect on $\delta^{18}O$ can be ruled out.

Therefore, does the cellulose $\delta^{18}O$ anomaly of the 1810s reflect changes in large-scale moisture advection, or a regional cloud cover/moisture condition? The Asian precipitation $\delta^{18}O$ can be affected by large scale moisture transport changes, such as shift of inter-tropical convergence zone (LeGrande and Schmidt, 2009). As precipitation $\delta^{18}O$ accounts for about 46 % of tree-ring $\delta^{18}O$ variation (Sternberg, 2009), a large-scale shift of precipitation isotopic composition could be recorded in tree-ring $\delta^{18}O$ and misinterpreted as a local climate signal (Sternberg, 2009). We have therefore compared our record with published ice-core $\delta^{18}O$ from Dunde, Dasuopu and Guliya drilling sites (only decadal averaged data are available) (Thompson et al., 1989, 1997, 2000) (Fig. 4). There is no evidence for a positive isotopic anomaly in the ice core records which could explain the abrupt Bomi tree-ring $\delta^{18}O$ maximum in 1807–1817. This comparison seems to rule out the possibility that this cellulose $\delta^{18}O$ anomaly is caused by large scale precipitation $\delta^{18}O$ change.

The oxygen isotopic compositions of regional precipitation and vapor were simulated using the isotope-enabled general circulation model LMDZ (Hourdin et al., 2006) nudged by atmospheric reanalyses over the 1981–2007 period after 3 yr of spin-up (Gao et al., 2010; Risi et al., 2010). The simulated summer precipitation and vapor $\delta^{18}O$ at Bomi are significantly anticorrelated with the simulated summer regional (25° N–35° N, 85° E–100° E) cloud water content and low cloud cover ($R = -0.41$, $P < 0.05$ in both cases). Spatially, correlation is maximum with cloud water content upstream the air mass trajectories. In the model, this anticorrelation mostly results from the amount effect, with an anticorrelation between precipitation $\delta^{18}O$ and regional precipitation amount, itself closely linked with the regional low cloud cover and cloud water content. Cellulose $\delta^{18}O$ therefore appears related to cloud cover through the link with the precipitation $\delta^{18}O$, and possibly (albeit not quantitatively investigated) through leaf water enrichment effects (Shi et al., 2010).

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We therefore conclude that the most likely explanation for the Bomi 1810s anomaly is a regional decrease in cloud cover associated with a decrease in monsoon activity upstream air mass trajectories that also correlates with a decrease in relative humidity. This is consistent with several tree-ring ecophysiological studies showing that relative humidity is the major driving force of cellulose δ^{18}O (Roden and Ehleringer, 2000; Helliker and Richter, 2008; Sternberg, 2009; Young et al., 2010).

4.2 Comparison with ice-core δ^{18}O and other regional reconstructions

LMDZ simulation shows that the precipitation δ^{18}O in Bomi is not significantly correlated with that of Dunde and Dasuopu region (R are roughly 0.1), however this simulation is conducted in recent 27 yr (1981–2007), there is no hint for a widespread precipitation δ^{18}O anomaly before 1981. Long-term ice core δ^{18}O measurement from the closest glaciers, in the Kangri Karpo Mountains (Fig. 1), has not yet been conducted. Therefore our results were compared to more distant ice cores (Fig. 4). Among them the farthest Guliya ice core record exhibits higher δ^{18}O since the 1890s (1.7 ‰ higher in 1890s–1980s than 1780s–1880s), consistent with the sign of the Bomi tree-ring δ^{18}O shift (0.6 ‰ higher in 1887–2005 than 1780–1886). However, the significance of this comparison is limited by the distance between the sites and the different moisture paths (westerly flow for Guliya, versus mostly monsoon flow for Bomi) (Tian et al., 2001).

Yao et al. (2008) reconstructed past annual precipitation accumulation using four TP ice cores (Dasuopu, Dunde, Guliya, Puruogangri). Dunde, Guliya and Puruogangri Glacier depict a dramatic decreased accumulation at the end of the 19th century (Yao et al., 2008), consistent with a reduced low-level jet since the late 19th century in the Indian Ocean (Gong and Luterbacher, 2008). These results support our interpretation of the 1890s regime shift detected in the Bomi tree-ring δ^{18}O in terms of moisture availability/regional cloud cover. We note that ice cores on Southwest TP, Dasuopu and Qomolangma (126 km southeast to Dasuopu) exhibit opposite precipitation trend (Kaspari et al., 2008).

These drier conditions since the late 19th century contradict another tree-ring δ^{18}O reconstruction of annual precipitation in North Pakistan, showing that post-1850s is the wettest period of the last millennium (Treydte et al., 2006). This mismatch could be due to the different climate contexts, since the precipitation of North Pakistan is concentrated in winter and controlled by westerly flow, while Bomi precipitation mainly falls in summer and is dominated by Indian monsoon flow (Gao et al., 2010).

5 Conclusions and perspectives

A 225-yr record of tree-ring cellulose δ^{18}O is obtained for Southeast TP. Based on the relationship between the tree-ring δ^{18}O and cloud cover in the period 1956–2005, the summer cloud cover is reconstructed for the past 225 yr.

Our reconstruction suggests less cloudy conditions in the 20th century than during the 19th century, ruling out simple correlations with the local temperature trends. The occurrence of years of extreme low or high cloud cover appears to have strongly decreased since the 1920s, suggesting a relatively stable summer cloud in Southeast TP in spite of the increasing impact of human activities on climate. The increase in cloud cover since 1980s does not exceed the range of variability in the past two centuries. Our data highlight a phase of reduced cloud cover from 1807 to 1817, coincident with a cold period which may be induced by volcanic eruptions. The sudden increased tree-ring δ^{18}O in 1807–1817 can neither be explained by colder conditions nor by a precipitation δ^{18}O anomaly (not detected in ice core records), and therefore reflects reduced cloud cover/drier conditions, very likely enhanced by two large volcanic eruptions in 1809 and 1816.

More regional tree ring δ^{18}O records are needed to investigate the spatial changes associated with the regime shifts recorded at Bomi. Process-based understanding of the links between cloud cover and tree-ring cellulose δ^{18}O must be further investigated using atmospheric/land surface isotopic models and ecophysiological models. The tree-ring δ^{18}O data offer the potential for multi-centennial comparisons with climate model results at the regional scale.

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References

Barbour, M. M.: Stable oxygen isotope composition of plant tissue: a review, Funct. Plant Biol., 34(2), 83–94, doi:10.1071/FP06228, 2007.

Briffa, K. R. and Osborn, T. J.: Perspectives: Climate warming – Seeing the wood from the trees, Science, 284(5416), 926–927, 1999.

Briffa, K. R., Jones, P. D., Schweingruber, F. H., and Osborn, T. J.: Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years, Nature, 393(6684), 450–455, 1998.

Briffa, K. R., Osborn, T. J., Schweingruber, F. H., Harris, I. C., Jones, P. D., Shiyatov, S. G., and Vaganov, E. A.: Low-frequency temperature variations from a northern tree ring density network, J. Geophys. Res., 106(D3), 2929–2941, 2001.

Cook, E. R., Anchukaitis, K. J., Buckley, B. M., D'Arrigo, R. D., Jacoby, G. C., and Wright, W. E.: Asian monsoon failure and megadrought during the last millennium, Science, 328(5977), 486–489, doi:10.1126/science.1185188, 2010.

Dai, J. H.: Volcanoes and climate, Wiley Interdisciplinary Reviews: Climate Change, 1(6), 824–839, 2010.

Dai, J. H., Mosleythompson, E., and Thompson, L. G.: ice core evidence for an explosive tropical volcanic-eruption 6 years preceding Tambora, J. Geophys. Res., 96(D9), 17361–17366, 1991.
Duan, A. M. and Wu, G. X.: Change of cloud amount and the climate warming on the Tibetan Plateau, Geophys. Res. Lett., 33(22), L22704, doi:10.1029/2006gl027946, 2006.
Dufresne, J.-L. and Bony, S.: An assessment of the primary sources of spread of global warming estimates from coupled atmosphere–ocean models, J. Clim., 21(19), 5135–5144, 2008.
Esper, J., Cook, E. R., and Schweingruber, F. H.: Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability, Science, 295(5563), 2250–2253, 2002.
Etien, N., Daux, V., Masson-Delmotte, V., Stievenard, M., Bernard, V., Durost, S., Guillemin, M. T., Mestre, O., and Pierre, M.: A bi-proxy reconstruction of Fontainebleau (France) growing season temperature from A.D. 1596 to 2000, Clim. Past, 4, 91–106, doi:10.5194/cp-4-91-2008, 2008.
Fichtler, E., Helle, G., and Worbes, M.: Stable-carbon Isotope time series from tropical tree rings indicate a precipitation signal, Tree-Ring Res., 66(1), 35–49, 2010.
Fritts, H. C.: Tree rings and climate, New York: Academic Press, 1976.
Gao, J., Masson-Delmotte, V., Yao, T., Tian, L., Risi, C., and Hoffmann, G.: Precipitation water stable isotopes in the south Tibetan Plateau: observations and modeling, J. Clim., doi:10.1175/2010JCLI3736.1, accepted, 2010.
Ghil, M., Allen, M. R., Dettinger, M. D., Ide, K., Kondrashov, D., Mann, M. E., Robertson, A. W., Saunders, A., Tian, Y., Varadi, F., and Yiou, P.: Advanced spectral methods for climatic time series, Rev. Geophys., 40(1), 1003, doi:10.1029/2000rg000092, 2002.
Gong, D. Y. and Luterbacher, J.: Variability of the low-level cross-equatorial jet of the western Indian Ocean since 1660 as derived from coral proxies, Geophys. Res. Lett., 35(1), L01705, doi:10.1029/2007gl032409, 2008.
Helliker, B. R. and Richter, S. L.: Subtropical to boreal convergence of tree-leaf temperatures, Nature, 454(7203), 511–514, doi:10.1038/Nature07031, 2008.
Hilasvuori, E. and Berninger, F.: Dependence of tree ring stable isotope abundances and ring width on climate in Finnish oak, Tree. Physiol., 30(5), 636–647, doi:10.1093/treephys/tpq019, 2010.
Holmes, R. L.: Computer-assisted quality control in tree-ring dat-ing and measurement, Tree-Ring B., 43, 69–78, 1998.

Hourdin, F., Musat, I., Bony, S., Braconnot, P., Codron, F., Dufresne, J.-L., Fairhead, L., Filiberti, M.-A., Friedlingstein, P., Grandpeix, J.-Y., Krinner, G., LeVan, P., Li, Z.-X., and Lott, F.: The LMDZ4 general circulation model: climate performance and sensitivity to parametrized physics with emphasis on tropical convection, Clim. Dynam., 27(7–8), 787–813, 2006.

Jacobson, M. Z.: Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols, Nature, 409, 695–697, doi:10.1038/35055518, 2001.

Kaspari, S., Hooke, R. L., Mayewski, P. A., Kang, S., Hou, S., and Qin, D.: Snow accumulation rate on Qomolangma (Mount Everest), Himalaya: synchroneity with sites across the Tibetan Plateau on 50–100 year timescales, J. Glaciol., 54(185), 343–352, 2008.

Khain, A., Rosenfeld, D., and Pokrovsky, A.: Aerosol impact on the dynamics and microphysics of deep convective clouds, Q. J. Roy. Meteor. Soc., 131(611), 2639–2663, doi:10.1256/Qj.04.62, 2005.

Kress, A., Saurer, M., Siegwolf, R. T. W., Frank, D. C., Esper, J., and Bugmann, H.: A 350 year drought reconstruction from Alpine tree ring stable isotopes, Glob. Biogeochem. Cy., 24, GB2011, doi:10.1029/2009gb003613, 2010.

LeGrande, A. N. and Schmidt, G. A.: Sources of Holocene variability of oxygen isotopes in paleoclimate archives, Clim. Past, 5, 441–455, doi:10.5194/cp-5-441-2009, 2009.

Liang, E. Y., Shao, X. M., and Xu, Y.: Tree-ring evidence of recent abnormal warming on the southeast Tibetan Plateau, Theor. Appl. Climatol., 98(1–2), 9–18, doi:10.1007/s00704-008-0085-6, 2009.

Liu, X. D. and Chen, B. D.: Climatic warming in the Tibetan Plateau during recent decades, Int. J. Climatol., 20(14), 1729–1742, 2000.

Liu, Y., Cai, Q., Liu, W., Yang, Y., Sun, J., Song, H., and Li, X.: Monsoon precipitation variation recorded by tree-ring δ^{18}O in arid Northwest China since AD 1878, Chem. Geol., 252(1–2), 56–61, 2008.

Managave, S. R., Sheshshayee, M. S., Borgaonkar, H. P., and Ramesh, R.: Past break-monsoon conditions detectable by high resolution intra-annual delta O-18 analysis of teak rings, Geophys. Res. Lett., 37, L05702, doi:10.1029/2009gl041172, 2010.

Masson-Delmotte, V., Raffalli-Delerce, G., Danis, P. A., Yiou, P., Stievenard, M., Guibal, F., Mestre, O., Bernard, V., Goosse, H., Hoffmann, G., and Jouzel, J.: Changes in European precipitation seasonality and in drought frequencies revealed by a four-century-long tree-ring isotopic record from Brittany, western France, Clim. Dynam., 24(1), 57–69, 2005.

Mitchell, T. D. and Jones, P. D.: An improved method of constructing a database of monthly climate observations and associated high-resolution grids, Int. J. Climatol., 25(6), 693–712, doi:10.1002/Joc.1181, 2005.

Raffalli-Delerce, G., Masson-Delmotte, V., Dupouey, J. L., Stievenard, M., Breda, N., and Moisselin, J. M.: Reconstruction of summer droughts using tree-ring cellulose isotopes: a calibration study with living oaks from Brittany (western France), Tellus, 56(2), 160–174, 2004.

Ramanathan, V. and Ramana, M. V.: Persistent, widespread, and strongly absorbing haze over the Himalayan foothills and the Indo-Gangetic Plains, Pure Appl. Geophys., 162(8–9), 1609–1626, doi:10.1007/s00024-005-2685-8, 2005.

Risi, C., Bony, S., Vimeux, F., and Jouzel, J.: Water stable isotopes in the LMDZ4 General Circulation Model: model evaluation for present day and past climates and applications to climatic interpretation of tropical isotopic records, J. Geophys. Res., 115, D12118, doi:10.1029/2009JD013255, 2010.

Robock, A.: Volcanic eruptions and climate, Rev. Geophys., 38(2), 191–219, 2000.

Roden, J. S. and Ehleringer, J. R.: There is no temperature dependence of net biochemical fractionation of hydrogen and oxygen isotopes in tree-ring cellulose, Isot. Environ. Healt. S., 36(3), 303–317, 2000.

Rodionov, S. N.: A sequential algorithm for testing climate regime shifts, Geophys. Res. Lett., 31(9), L09204, doi:10.1029/2004gl019448, 2004.

Sano, M., Sheshshayee, M. S., Managave, S., Ramesh, R., Sukumar, R., and Sweda, T.: Climatic potential of delta O-18 of Abies spectabilis from the Nepal Himalaya, Dendrochronologia, 28(2), 93–98, doi:10.1016/j.dendro.2009.05.005, 2010.

Shi, C., Masson-Delmotte, V., Risi, C., Eglin, T., Stievenard, M., Pierre, M., Wang, X., Gao, J., Bréon, F.-M., Zhang, Q.-B., and Daux, V.: Sampling strategy and climatic implications of tree-ring stable isotopes in Southeast Tibetan Plateau, Earth. Planet. Sc. Lett., 301(1–2), 307–316, 2011.

Stephens, G. L.: Cloud feedbacks in the climate system: a critical review, J. Clim., 18(2), 237–273, 2005.

Sternberg, L. D. L. O.: Oxygen stable isotope ratios of tree-ring cellulose: the next phase of understanding, New Phytol., 181(3), 553–562, doi:10.1111/j.1469-8137.2008.02661.x, 2009.

Stothers, R. B.: The Great Tambora Eruption in 1815 and its aftermath, Science, 224(4654), 1191–1198, 1984.

Thompson, L. G., Mosleythompson, E., Davis, M. E., Bolzan, J. F., Dai, J., Yao, T., Gundestrup, N., Wu, X., Klein, L., and Xie, Z.: Holocene Late Pleistocene Climatic Ice Core Records from Qinghai-Tibetan Plateau, Science, 246(4929), 474–477, 1989.

Thompson, L. G., Yao, T., Davis, M. E., Henderson, K. A., MosleyThompson, E., Lin, P. N., Beer, J., Synal, H. A., ColeDai, J., and Bolzan, J. F.: Tropical climate instability: The last glacial cycle from a Qinghai-Tibetan ice core, Science, 276(5320), 1821–1825, 1997.

Thompson, L. G., Yao, T., Mosley-Thompson, E., Davis, M. E., Henderson, K. A., and Lin, P. N.: A high-resolution millennial record of the South Asian Monsoon from Himalayan ice cores, Science, 289(5486), 1916–1919, 2000.

Tian, L., Masson-Delmotte, V., Stievenard, M., Yao, T., and Jouzel, J.: Tibetan Plateau summer monsoon northward extent revealed by measurements of water stable isotopes, J. Geophys. Res., 106(D22), 28081–28088, 2001.

Treydte, K. S., Schleser, G. H., Helle, G., Frank, D. C., Winiger, M., Haug, G. H., and Esper, J.: The twentieth century was the wettest period in northern Pakistan over the past millennium, Nature, 440(7088), 1179–1182, doi:10.1038/Nature04743, 2006.

Wang, B., Bao, Q., Hoskins, B., Wu, G., and Liu, Y.: Tibetan plateau warming and precipitation changes in East Asia, Geophys. Res. Lett., 35, L14702, doi:10.1029/2008GL034330, 2008.

Yang, Y., Man, Z., and Zheng, Y.: A serious famine in Yunnan (1815–1817) and the eruption of Tambola Valcano. Fudan journal (Social Science) (in Chinese with English abstract), Fudan Journal, 1, 79–85, 2005.

Yao, T., Duan, K., Xu, B., Wang, N., Guo, X., and Yang, X.: Precipitation record since AD 1600 from ice cores on the central Tibetan Plateau, Clim. Past, 4, 175–180, doi:10.5194/cp-4-175-2008, 2008.

You, Q. L., Kang, S. C., Wu, Y. H., and Yan, Y. P.: Climate change over the yarlung zangbo river basin during 1961-2005, J. Geogr. Sci., 17(4), 409–420, doi:10.1007/s11442-007-0409-y, 2007.

You, Q. L., Kang, S. C., Flugel, W. A., Sanchez-Lorenzo, A., Yan, Y. P., Huang, J., and Martin-Vide, J.: From brightening to dimming in sunshine duration over the eastern and central Tibetan Plateau (1961–2005), Theor. Appl. Climatol., 101(3–4), 445–457, doi:10.1007/s00704-009-0231-9, 2010.

Young, G. H. F., McCarroll, D., Loaderand, N. J., and Kirchhefer, A. J.: A 500-year record of summer near-ground solar radiation from tree-ring stable carbon isotopes, Holocene, 20(3), 315–324, doi:10.1177/0959683609351902, 2010.

Yu, R. C., Wang, B., and Zhou, T. J.: Climate effects of the deep continental stratus clouds generated by the Tibetan Plateau, J. Clim., 17(13), 2702–2713, 2004.
Zhang, X. Q., Peng, L. L., Zheng, D., and Tao, J.: Cloudiness variations over the Qinghai-Tibet Plateau during 1971-2004, J. Geogr. Sci., 18(2), 142–154, doi:10.1007/s11442-008-0142-1, 2008.

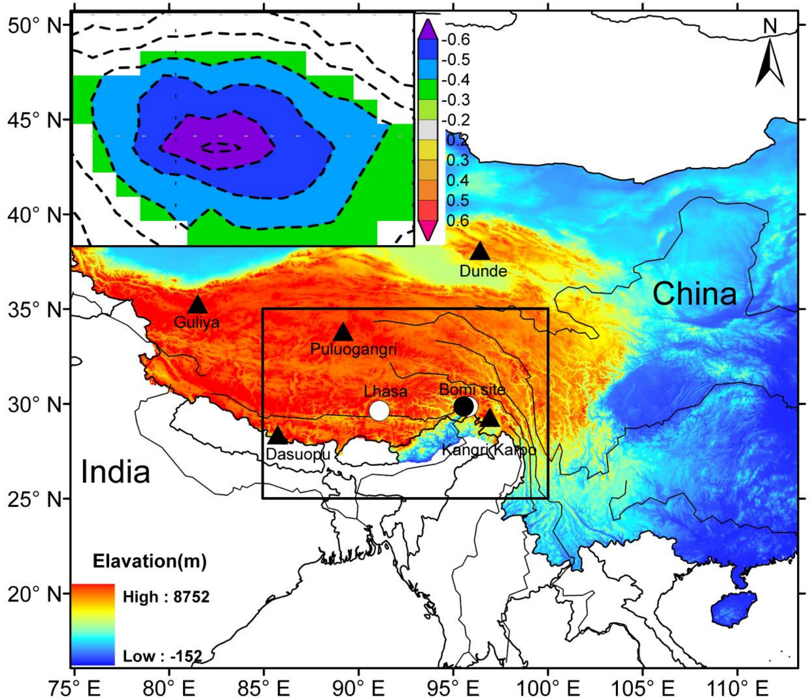

Fig. 1. Map of the study area and location of sites: tree ring sampling site (black circles), Bomi and Lhasa meteorological stations (white circles), glacier ice core drilling sites (black triangles). The shading depicts the local topography. The subplot in the top-left corner shows the inter-annual correlation coefficients between Bomi tree-ring cellulose δ^{18}O and the regional cloud cover data (25° N–35° N 85° E–100° E, rectangular in the map); contours are displayed for increments of the correlation coefficients ($P < 0.05$, $n = 46$). The cloud data were obtained from CRU version 2.0 (Mitchell and Jones, 2005).

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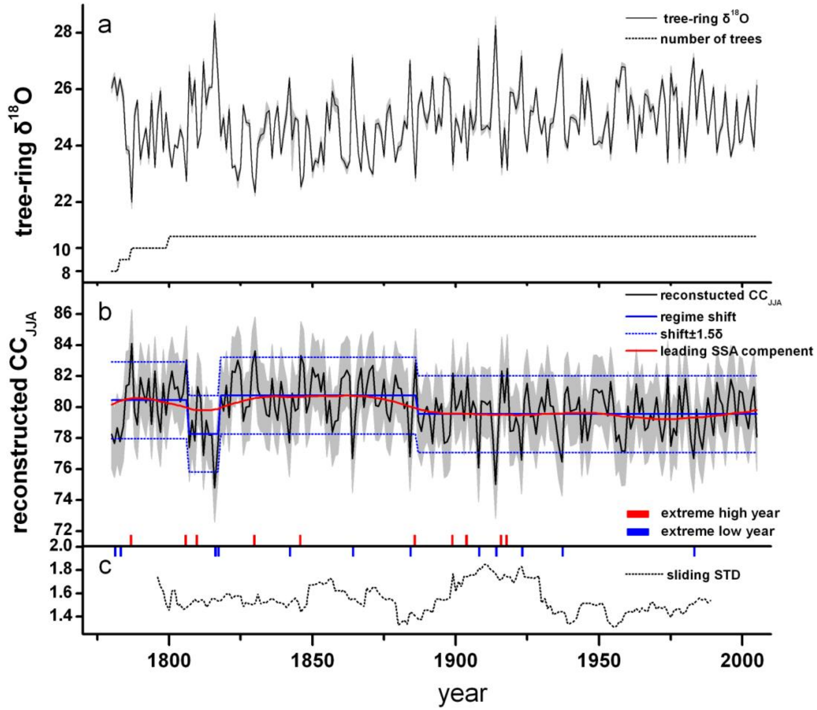

Fig. 2. (a) Tree-ring δ^{18}O with measurement uncertainty (grey shading) and number of pooled trees. **(b)** Reconstructed cloud cover and regime shift. The black line is the reconstructed CC_{JJA}, with its uncertainty depicted in grey shading (confidence level 85 %); the solid blue line is the regime shifts (window length = 15 yr, confident at 95 %); the thick red line is the leading SSA component of the reconstructed CC_{JJA}; the red and blue bars correspond to extreme high/low cloud cover years (exceeding 1.5 standard deviations at the base of regime). **(c)** 31 yr moving standard deviation (STD) of the CC_{JJA} residual.

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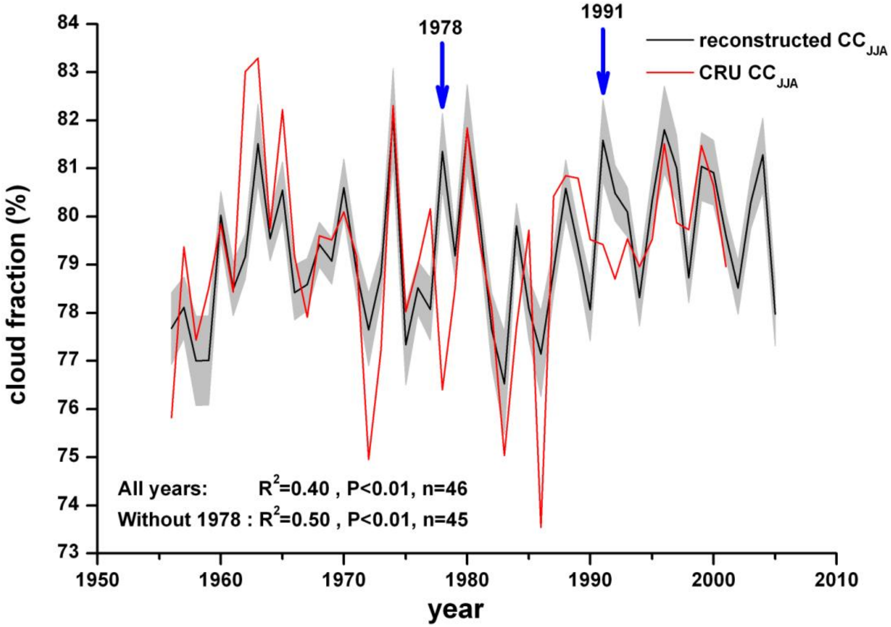

Fig. 3. Reconstructed and CRU June-August cloud covers (CC_{JJA}) over 1956–2005. The blue arrows indicate the outlier years of 1978 and 1991.

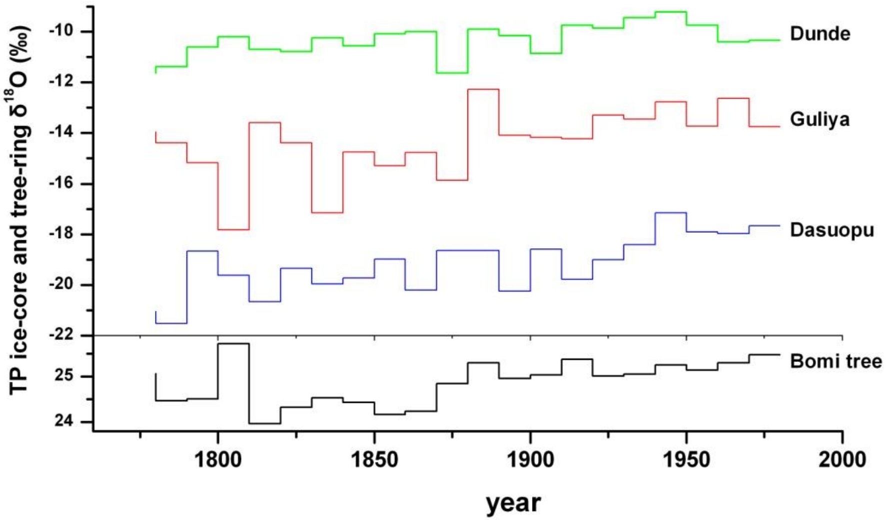

Fig. 4. Comparison of tree-ring δ^{18}O and ice-core δ^{18}O records on Tibetan Plateau (Thompson et al., 1989, 1997, 2000).

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