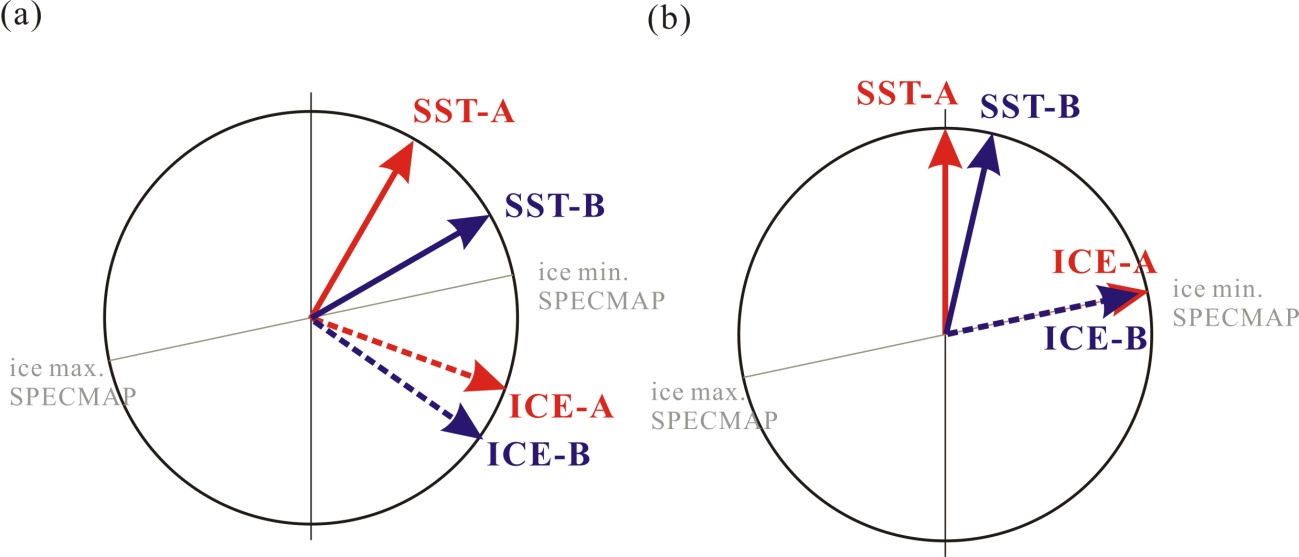
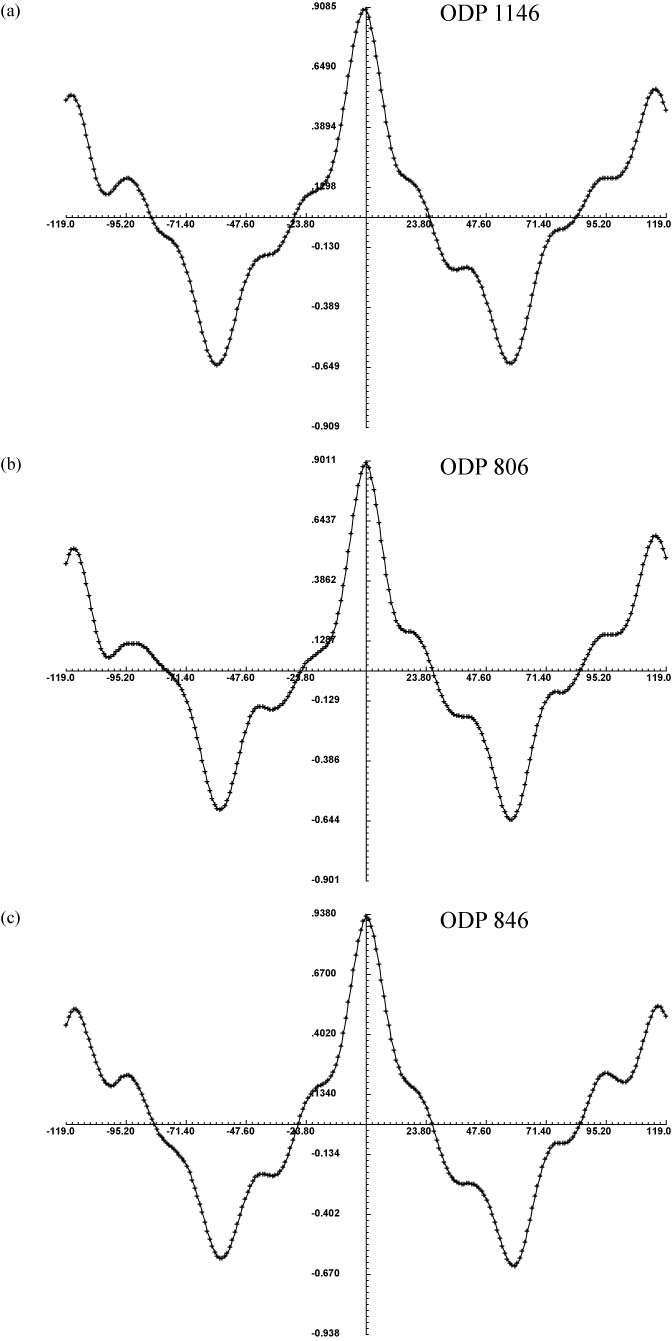
**Supplementary information**

18O records are used as the ice volume proxy and assumed that the phases to the ETP curve arte the same on the three orbital bands in this research. In addition, if phase relationships between the SST and ice volume in all orbital bands were constant, when the ice volume phase of one site is fixed on the SPECMAP ice volume phase (Imbrie et al., 1984), the SST phase will be also altered to ETP, but the phase relationship between the SST and ice volume in one site will not be altered (Fig. S1). Based on these assumptions, we tried to correlate all these six 18O records to the SPECMAP. For this purpose, we applied the cross correlation function of the 18O derived from these cores against the SPECMAP, and tried to find the lags of 18O records with the best cross correlation coefficient to SPECMAP.

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**Fig. S1.** Theschematic diagram of (a) original SST and ice volume phases of different sites; (b) fixing ice volume phases of different sites to the ice volume phases of SPECMAP on the eccentricity, obliquity and precession bands.

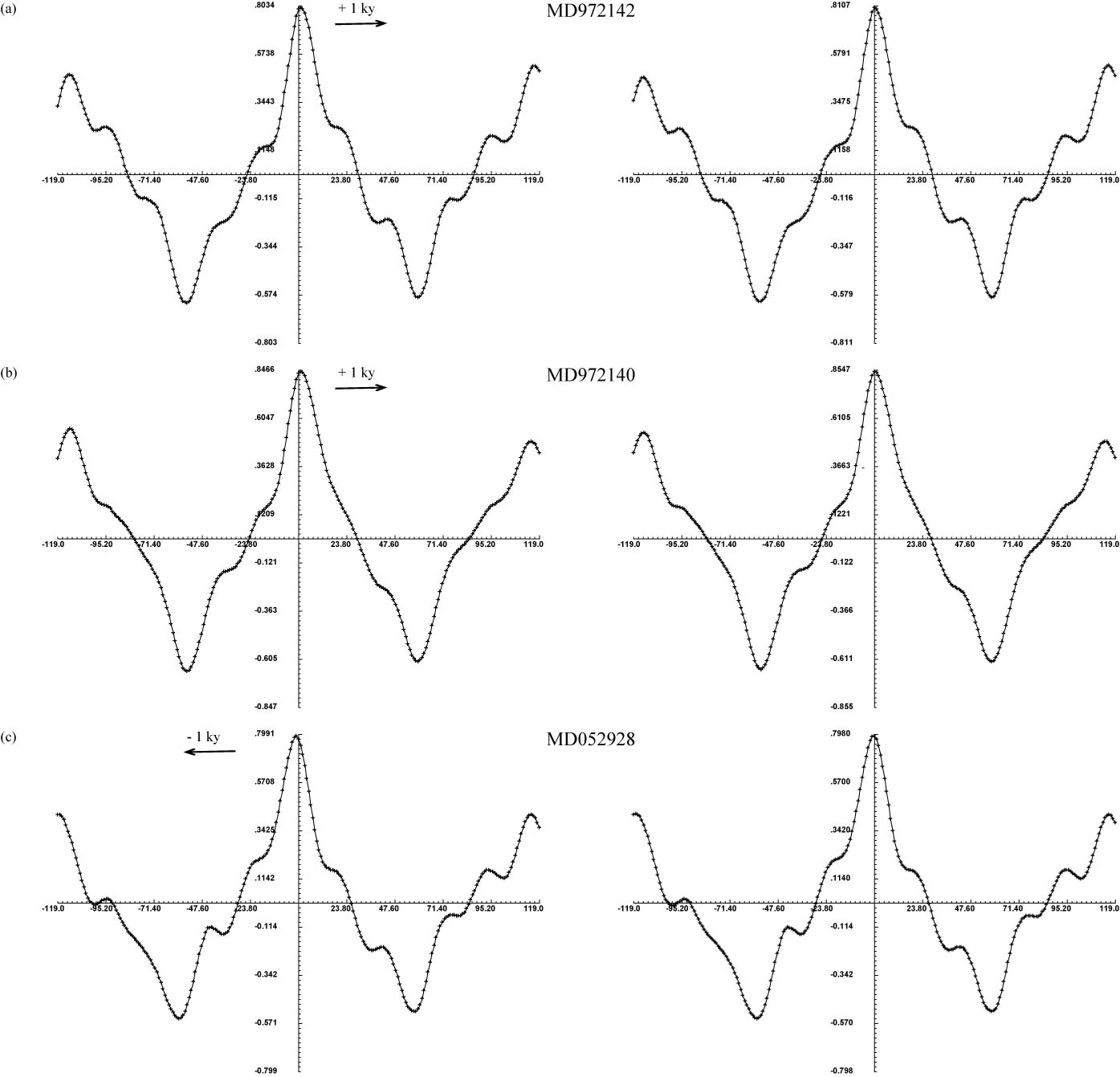
First, we interpolated all these six 18O into the same interval (t = 1kyr), then we used the Crospec function of Arand program (Howell et al., 2006) to evaluate the cross correlation function between the 18O derived from these records and SPECMAP, and tried to find the lag with the best cross correlation coefficient (Fig. S2, Fig. S3). According to our results, we found the original 18O of core ODP 1146, ODP806 and ODP 846 are correlated well to SPECMAP, and the cross correlation coefficient is 0.909, 0.901 and 0.938, respectively (Fig.S2). For MD972140, MD972142 and MD052928, however, the cross correlation coefficient between their original 18O and SPECMAP doesn’t reach the maximum (Fig. S3). We applied the cross correlation function and adjusted the lags shift of +1 kyr, +1 kyr and -1 kyr for MD972140, MD972142 and MD052928, respectively, within the better cross correlation coefficient (Fig. S3). The cross correlation coefficients are 0.855, 0.811 and 0.798 for MD972140, MD972142 and MD052928, respectively (Fig. S3). Then we shifted the 18O time series by +1 kyr, +1 kyr and -1 kyr for MD972140, MD972142 and MD052928, respectively (Fig. S4).



**Fig. S2.** The cross correlation function of 18O derived from ODP 1146, ODP 806 and ODP 846 to SPECMAP. The vertical axis indices the cross correlation coefficient, and the horizontal axis indicates the lags.

After adjusting the time series for MD972140, MD972142 and MD052928, we started to do cross spectral analysis for all records. All phase results after this adjustment are summarized in Table S1, Fig. S5, and Fig S6.

Fig. S5 indicates the 18O phases of these six records at the three orbital forcings: eccentricity (period: 100 kyr), obliquity (period: 41 kyr) and precession (period: 23 kyr) against to the ETP curve, the phases of SPECMAP against to ETP during 4-318 ka are also plotted. For ODP 806, ODP 846 and ODP 1146 we used the original age model for cross spectral analysis. For MD972140, MD972142 and MD052928,

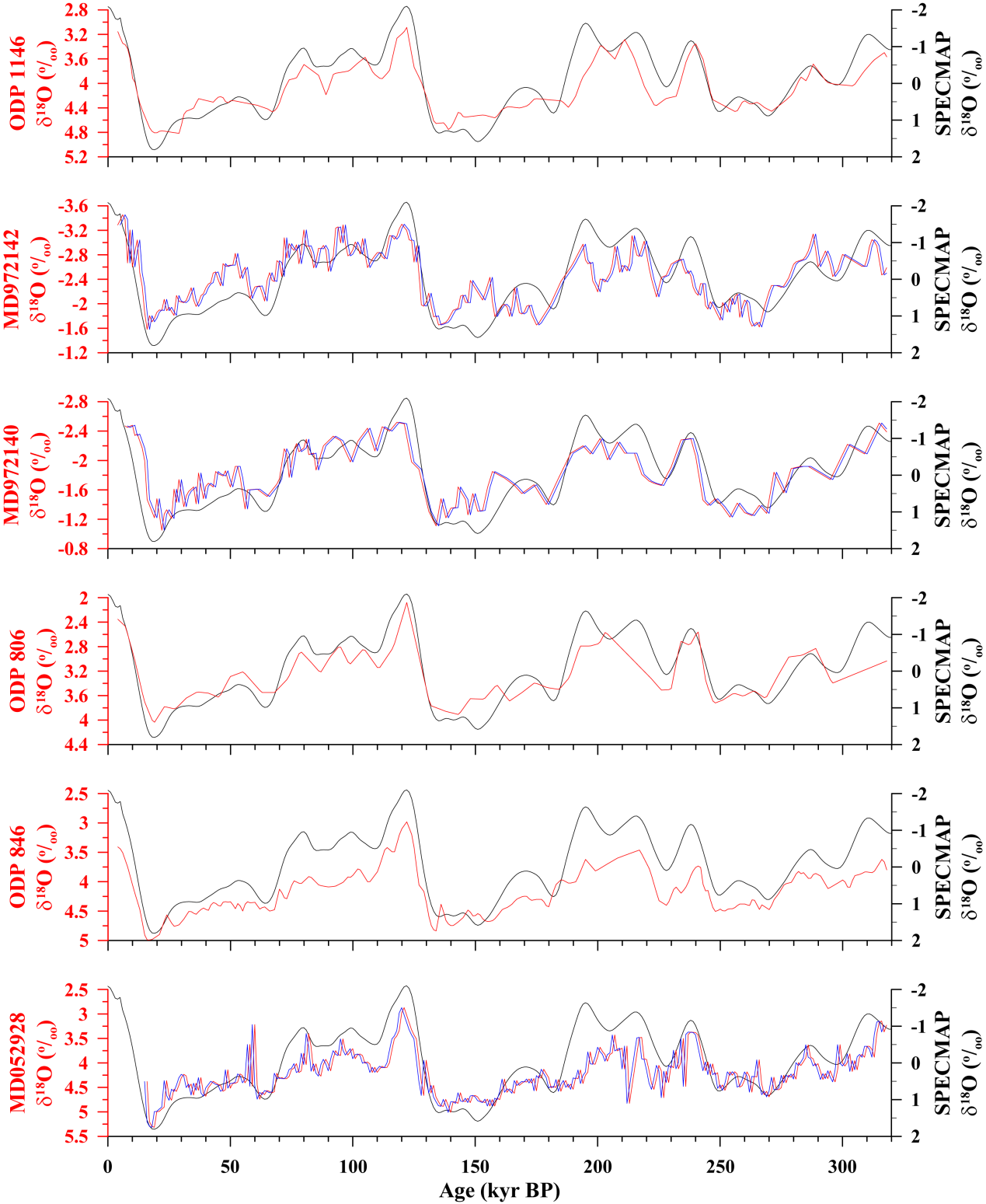


**Fig. S3.** The cross correlation function of 18O derived from MD972142, MD972140 and MD052928 to SPECMAP. The vertical axis indices the cross correlation coefficient, and the horizontal axis indicates the lags. The left column indicates the original 18O records to SPECMAP; the right column indicates the results after the lag shift.

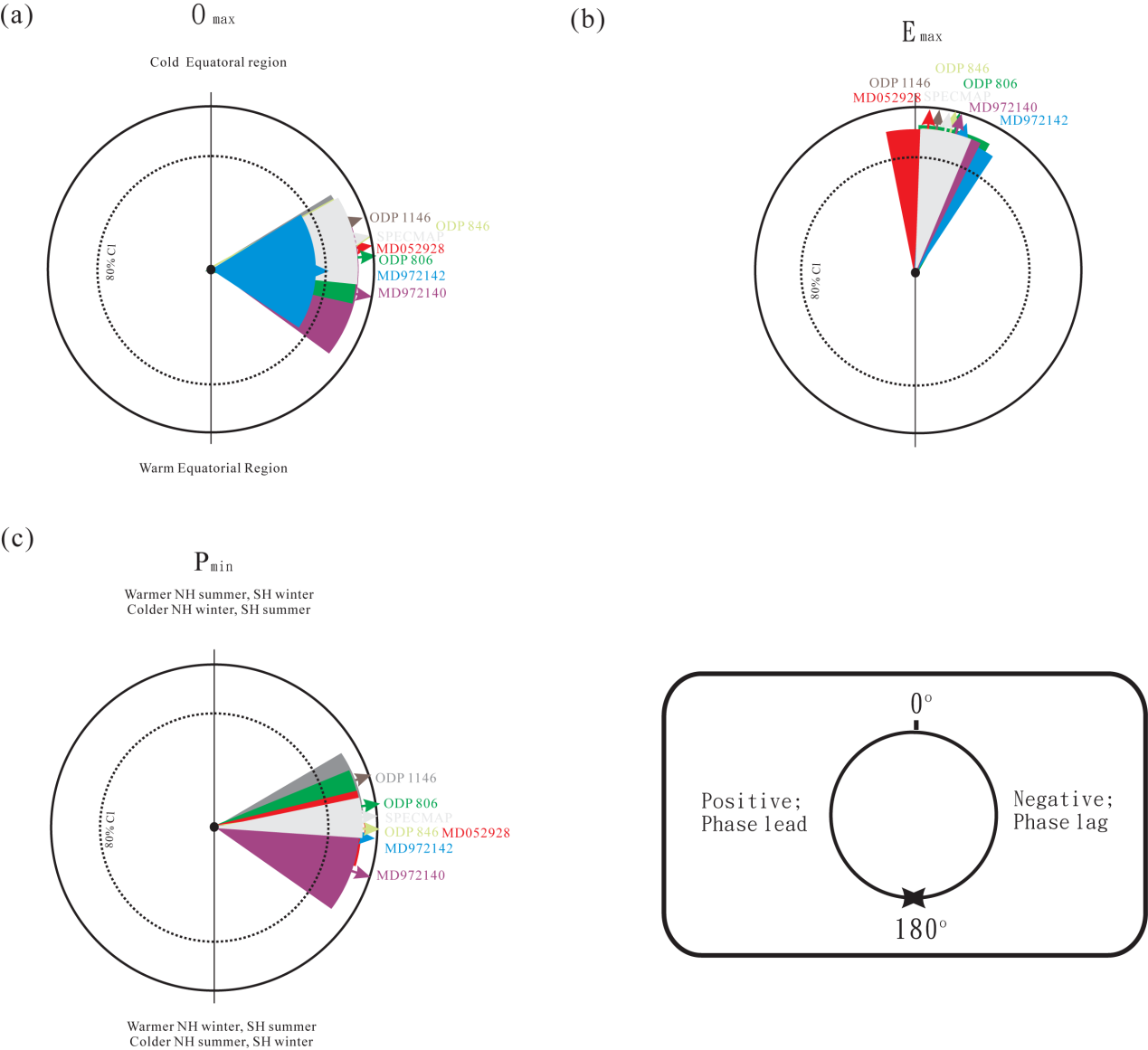
however, we applied the new time series after the lag shift. Our result indicates all these six 18O records are in phase with SPECMAP that we could assess these six records on the same reference time frame.

Based on our assumption, the phases of 18O and SST are stationary in the same core (Fig. S1), thus we also shifted the same time lags applied to 18O records for MD972142, MD972140 and MD052928 SST records. SST records derived from ODP 1146, ODP 806 and ODP 846 are still in their original age model. Our results of the tropical Pacific SSTs phases on all orbital bands were plotted on Fig. S6 and summarized on Table S1.

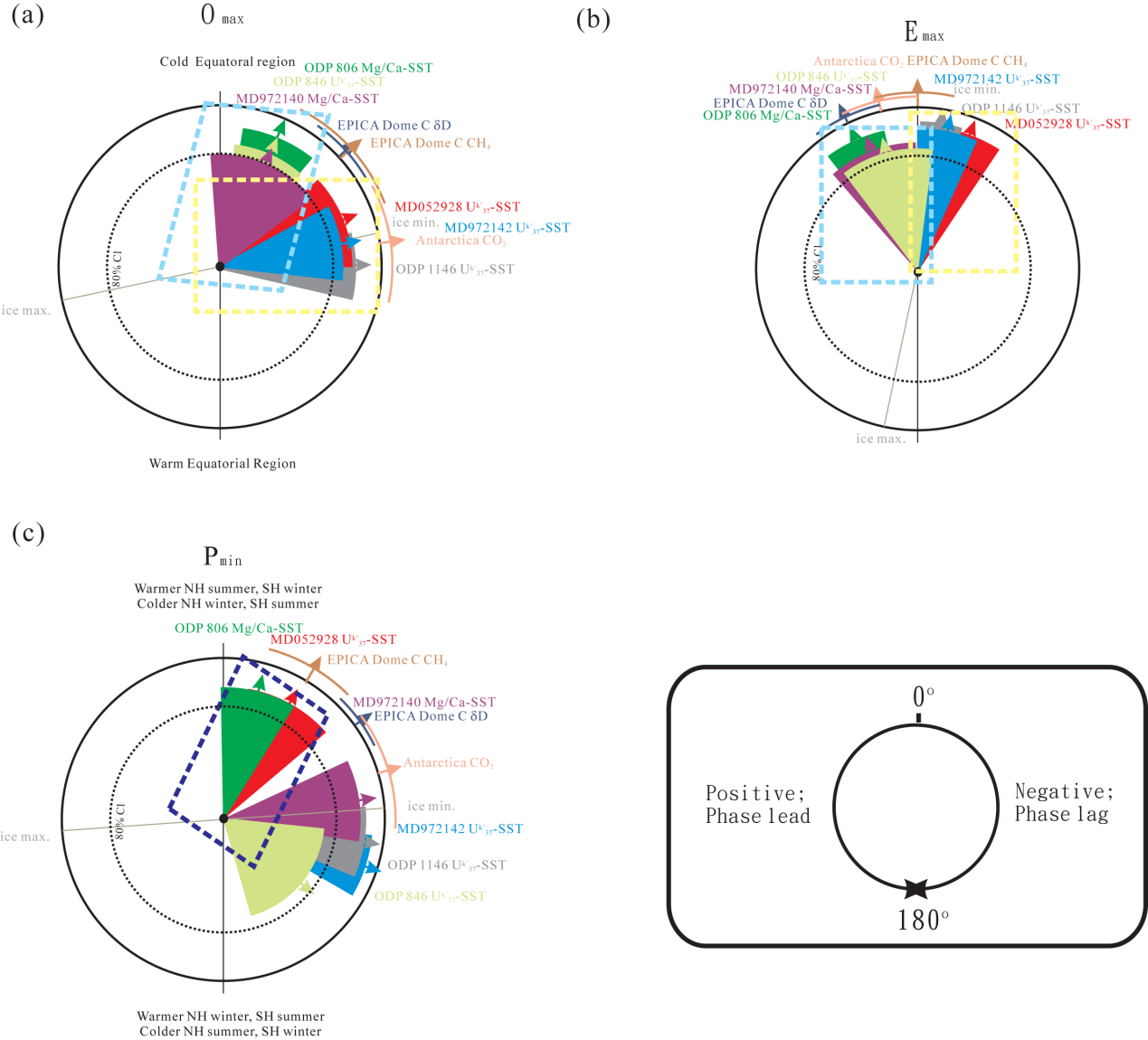
All SSTs could be separated into two groups at these three orbital bands. On the obliquity and eccentricity bands, MD972140, ODP 806 and ODP 846 located on the equatorial regions are belonged to the early group; the late group contains MD052928, MD972142, and ODP 1146 located on the marginal seas. For the precession band, however, the early group contains ODP 806, MD052928, located on the WPWP region, and MD972142 and ODP 1146 located on the South China Sea and MD972140 located on the western margin of the WPWP are enclosed in the late group. SSTs mean phases of early and late groups were estimated, respectively, on these three orbital bands. Mean phases are plotted on the Fig. 5 and listed on the Table 1. ODP 846 SST phase at the precession band is not used to calculate the mean phase that is due to its very low coherency to the ETP.



**Fig. S4.** The 18O record from these six cores against the SPECMAP. Blue lines in MD972142, MD972140 and MD052829 indicate results after lag shifts.



**Fig. S5.** The phase wheel of 18O records derived from these six cores in this study against ETP. (a) the obliquity band; (b) the eccentricity band; (c) the precession band. Arand program (Howell et al., 2006) is used to calculate the cross-spectra, the parameters: lags = 120, Bandwidth= 0.011, t = 1 kyrr. The eccentricity, obliquity maximum and precession minimum were assessed as the 0 phase, the clockwise rotation indicates the lag phase relationship and the counterclockwise indicates the lead phase. The fan-shaped area within the SST phase arrow indicates the SST phase error. The black dash circles indicate the 80% confidence intervals relative to ETP. Even MD972142 is with lower coherency to the ETP curve on the obliquity band, however, 18O records are in phase with SPECMAP in the three orbital bands.



**Fig. S6.** (a) The phase wheel of SST to ETP in the obliquity band; (b) the eccentricity band; (c) the precession band. In (a), (b) and (c) the phases of tropical Pacific SSTs are separated into 2 groups. The phases of Antarctica CO2, CH4, and D with errors (the arcs) are also plotted. The rectangles with light blue dash in (a) and (b) indicate SST records lead phases. The rectangles with light yellow dash in (a) and (b) indicate SST late group. The early group at the precession band is encompassed by the deep blue dash (c). Arand program (Howell et al., 2006) is used to calculate the cross-spectra, the parameters: lags = 120, Bandwidth= 0.011, t = 1 kyrr. The eccentricity, obliquity maximum and precession minimum were assessed as the 0 phase, the clockwise rotation indicates the lag phase relationship and the counterclockwise indicates the lead phase. The gray lines on the phase wheels indicate mean phases of ice volume changes derived from the SPECMAP at all orbital bands. The fan-shaped area within the SST phase arrow indicates the SST phase error. The black dash circles indicate the 80% confidence intervals relative to ETP.

**References:**

Howell, P., Pisias, N., Balance, J., Baughman, J., and Ochs, L.: ARAND Time-Series Analysis Software. Brown University, Providence RI, 2006.

Imbrie, J. Hays, J. D., Martinson, D. G., McIntyre, A., Mix, A. C., Morley, J.J., Pisias, N. G., Prell, W. L., and Shackleton, N. J.: The orbital theory of Pleistocene climate: Support from a revised chronology of the marine 18O record, in: Milankovitch and Climate, Part I, edited by: Berger AL et al., D. Riedel, Hingham, , Mass, 269–305, 1984.

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| **Table S1.** Tropical Pacific SST, 18Omin and Antarctic D, GHGs phases in this study. The ice volume minimum phases are based on the SPECMAP to ETP during 4-318 ka. | | | | | | | | | | | |
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|  |  |  |  |  |  |  |  |  |  |  |  |
| Orbital forcing |  | ***Emax*** |  |  |  | ***Omax*** |  |  |  | ***Pmin*** |  |
| Ice Volume minimum phases (o) | -12 | ± | 10 |  | -78 | ± | 18 |  | -86 | ± | 8 |
| 18Omin to ETP (o) (plotted on Fig. S5) |  |  |  |  |  |  |  |  |  |  |  |
| ODP 1146 | -8 | ± | 11 |  | -71 | ± | 14 |  | -71 | ± | 13 |
| MD972142 | -19 | ± | 15 |  | -91 | ± | 32 |  | -94 | ± | 12 |
| MD972140 | -16 | ± | 10 |  | -100 | ± | 27 |  | -108 | ± | 18 |
| ODP 806 | -15 | ± | 14 |  | -85 | ± | 18 |  | -82 | ± | 15 |
| ODP 846 | -14 | ± | 11 |  | -79 | ± | 18 |  | -91 | ± | 9 |
| MD052928 | -5 | ± | 16 |  | -82 | ± | 13 |  | -94 | ± | 12 |
| Mean phases of 18Omin to ETP (o) | -13 | ± | 5 |  | -85 | ± | 9 |  | -90 | ± | 6 |
| SST to ETP (o) (based on original age models) |  |  |  |  |  |  |  |  |  |  |  |
| ODP 1146 | -9 | ± | 8 |  | -89 | ± | 14 |  | -99 | ± | 14 |
| MD972142 | -21 | ± | 11 |  | -89 | ± | 17 |  | -124 | ± | 12 |
| MD972140 | 17 | ± | 20 |  | -33 | ± | 29 |  | -98 | ± | 17 |
| ODP 806 | 25 | ± | 12 |  | -24 | ± | 15 |  | -15 | ± | 16 |
| ODP 846 | 15 | ± | 22 |  | -24 | ± | 17 |  | -130 | ± | 34 |
| MD052928 | -17 | ± | 12 |  | -60 | ± | 22 |  | -14 | ± | 19 |
| SST to ETP after lags shift (o) |  |  |  |  |  |  |  |  |  |  |  |
| (Plotted on Fig. S6 (a), (b), (c)) |  |  |  |  |  |  |  |  |  |  |  |
| ODP 1146 | -9 | ± | 8 |  | -89 | ± | 14 |  | -99 | ± | 14 |
| MD972142 | -12 | ± | 12 |  | -79 | ± | 17 |  | -108 | ± | 12 |
| MD972140 | 21 | ± | 20 |  | -24 | ± | 28 |  | -82 | ± | 17 |
| ODP 806 | 25 | ± | 12 |  | -24 | ± | 15 |  | -15 | ± | 16 |
| ODP 846 | 15 | ± | 22 |  | -24 | ± | 17 |  | -130 | ± | 34 |
| MD052928 | -21 | ± | 12 |  | -69 | ± | 21 |  | -30 | ± | 19 |
| Mean Phases (plotted on Figure 6 (a), (b), (c)) |  |  |  |  |  |  |  |  |  |  |  |
| Early Group | 20 | ± | 11 |  | -24 | ± | 12 |  | -23 | ± | 12 |
| Late Group | -14 | ± | 6 |  | -79 | ± | 10 |  | -96 | ± | 8 |
| Antarctic Ice Core Records (o) |  |  |  |  |  |  |  |  |  |  |  |
| EPICA Dome C D | 25 | ± | 12 |  | -48 | ± | 13 |  | -54 | ± | 10 |
| EPICA Dome C CH4 | 1 | ± | 13 |  | -48 | ± | 21 |  | -30 | ± | 15 |
| Antarctic Composite CO2 | 13 | ± | 13 |  | -82 | ± | 20 |  | -73 | ± | 20 |
|  |  |  |  |  |  |  |  |  |  |  |  |