Upper Ocean heat content (OHC) changes in the tropical Pacific induced by orbital insolation and greenhouse gases (GHG)

Yue Wang① Zhimin Jian① Haowen Dang① Haiyan Jin① Xingxing Wang① Shuai Zhang② Li Luo③

① State Key Laboratory of Marine Geology, Tongji University, 200092, Shanghai, China; ② Hohai University, 210098, Nanjing, China; ③ Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 510640, Guangzhou, China

***Contact:** 163wangyue@163.com;* ***Webpage:** https://163wangyue.wordpress.com/*

1. Abstract

The ocean is the largest heat capacitor of the earth climate system and a main source of atmospheric moist static energy. Especially, upper ocean heat content changes in the tropics can be taken as the heat engine of global climate. Here we provide an orbital scale perspective on changes in OHC obtained from a transient simulation of the Community Earth System Model under orbital insolation and GHG forcing. Considering the vertical stratification of the upper ocean, we calculate OHC for the mixed layer and the upper thermocline layer according to the isotherm depths of 26℃ (Z26) and 20℃ (Z20) respectively. Generally, our simulated OHC are dominated by thickness changes rather than temperature changes of each layer. In details, there are three situations according to different forcing:

(1) Higher GHG induces positive mixed layer OHC anomalies inside the western Pacific warm pool but with neglected anomalies outside it. For the upper thermocline layer, there are negative OHC anomalies inside the warm pool and positive anomalies in the subtropical Pacific of two hemispheres. For the total OHC above 20℃ isotherm depth, positive anomalies mainly come from the mixed layer between 15ºS-15ºN and from the thermocline between 15º-30º. Lower obliquity induces similar spatial patterns of OHC anomalies as those of higher GHG, but total OHC anomalies are more contributed by upper thermocline anomalies.

(2) Lower precession results in positive mixed layer OHC anomalies in the core of warm pool (150ºE-150ºW, 20ºS-10ºN) and the subtropical northeastern Pacific, but with negative anomalies in other regions of the tropical Pacific. Upper thermocline layer OHC anomalies have similar patterns but with opposite signs relative to the mixed layer in regions between 15ºN-30ºS. As a combination, positive total OHC anomalies occupy large areas of 130ºE-120ºW from 30ºS to10ºN, while negative anomalies dominate the subtropical north Pacific, the western and eastern ends of the tropical Pacific.

If confirmed by paleoceanographic proxies, our simulated OHC results can be served as the first guide map of anomalous energetic storage & flows in the earth climate system under orbital forcing. Especially, the layer thickness between 26℃ and 20℃ represent the sharpness of the upper thermocline, associated upper ocean thermal structure plays a vital role in air-sea coupled dynamics from the tropical to midlatitude Pacific. How will the upper ocean thermal structure response to orbital forcing should acquire more attention from paleoceanographic community [1,2].

2. Model and Transient Experiment

- Model: **NCAR CESM** (version 1.0.4, T31_gx3)[3,4]
  - Atmosphere is CAM4 with a horizontal resolution of 3.75º (vertical 26 levels); Land is CLM4 with the same horizontal resolution of CAM4; Ocean is POP2 with a nominal 3º resolution (vertical 60 levels) and includes a sea ice component (CICE4);
  - Boundary conditions (topography / bathymetry, sea-land distribution, land ice-sheet, greenhouse gases) are set as 1950 AD values.
- **CESM_transient experiment**[5]
  - After a spin-up simulation of 200 model years with the fixed orbital insolation & GHG at 300kyr B. P., the CESM is integrated for another 3000 model years under the transient orbital forcings from 300ka to 0ka (that is 1 model year = 100 years).
  - Acceleration method[6-7]: the GHG and orbital parameters (eccentricity: e, obliquity: ε, precession: ω) are advanced by 100 years at the end of each model year.
- **Post-processing of model data**
  - For the last 2500 model years' monthly outputs, we first correct the "calendar effect" [8] caused by precession for each month and remove the linear trend. Then we perform linear regression analysis on annual mean outputs.
- **OHC of the mixed layer and upper thermocline OHC**
  - The isothermal depth of 26℃ (20℃) is defined as the bottom of the mixed layer (upper thermocline). The OHC is calculated according to following equations [9]: $OHC = \int_{z2}^{z1} C_p \, \rho \, T \, dz$
    Here C_p is specific heat capacity, ρ is potential density, T is temperature, and z is depth.

3. Orbital insolation and GHG forcings used in the transient simulation of CESM

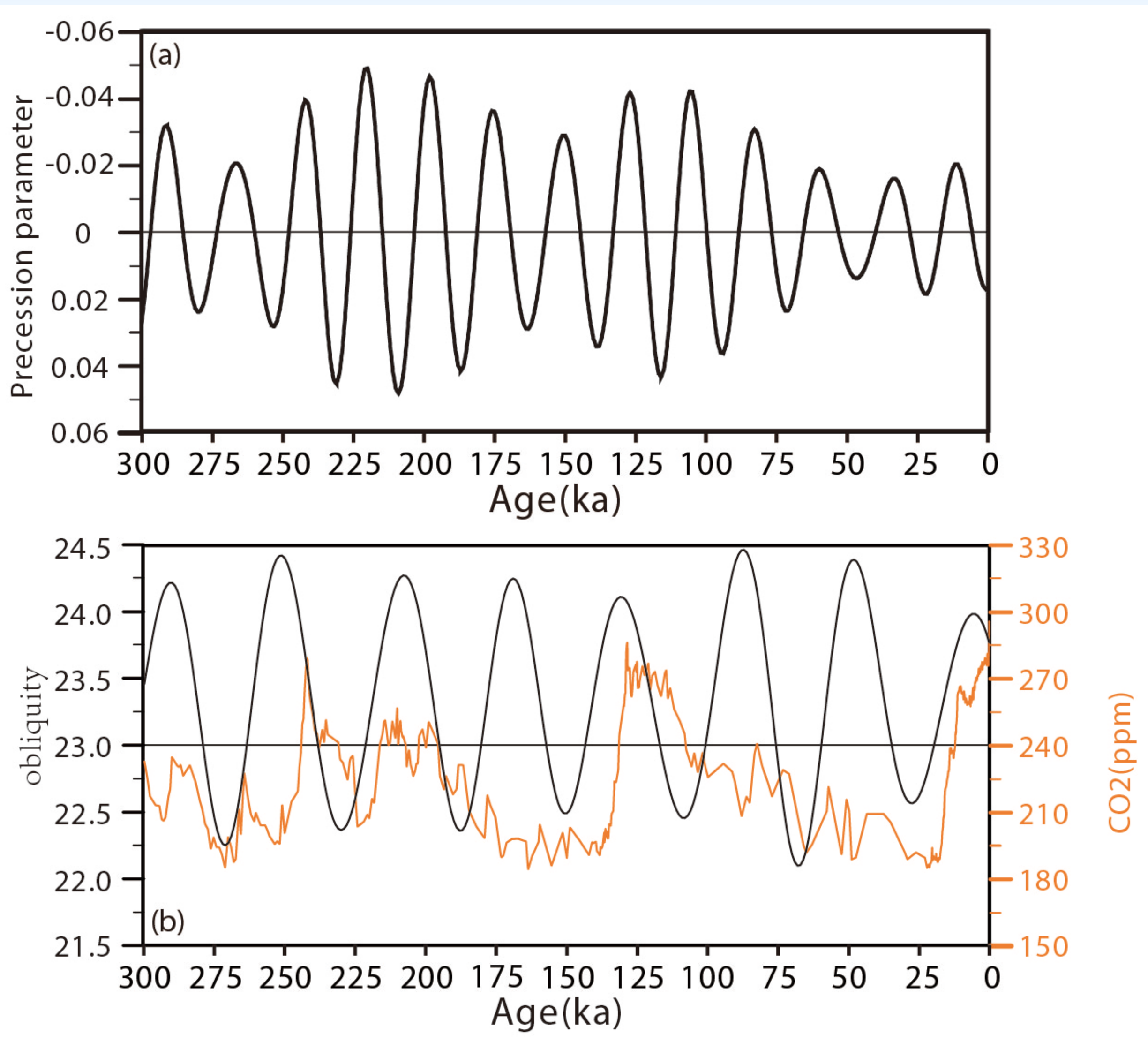

Fig.1 (a) precessional parameter changes since 300 ka: (b) obliquity and CO_2 changes since 300 ka.

4. Orbital forced OHC changes in the tropical Pacific

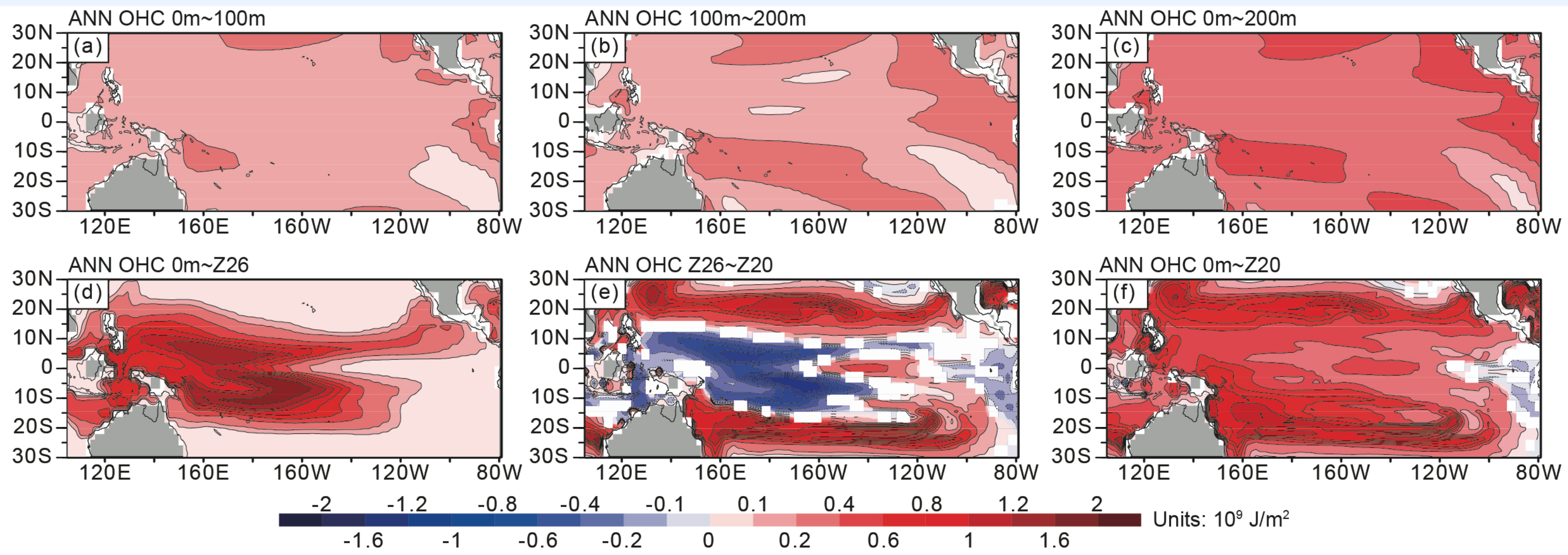

Fig 2. Regression coefficients of annual mean OHC against the normalized time series of the CO_2 forcing (yellow line in Fig. 1b): (a) the mixed layer OHC between 0m and 100m; (b) the upper thermocline OHC between 100m and 200m; and (c) the upper ocean OHC between 0m and 200m. (d)-(f) are OHC between 0m and Z26, between Z26 and Z20, and between 0m and Z20, respectively. The white shaded areas are not significant at the 90% level.

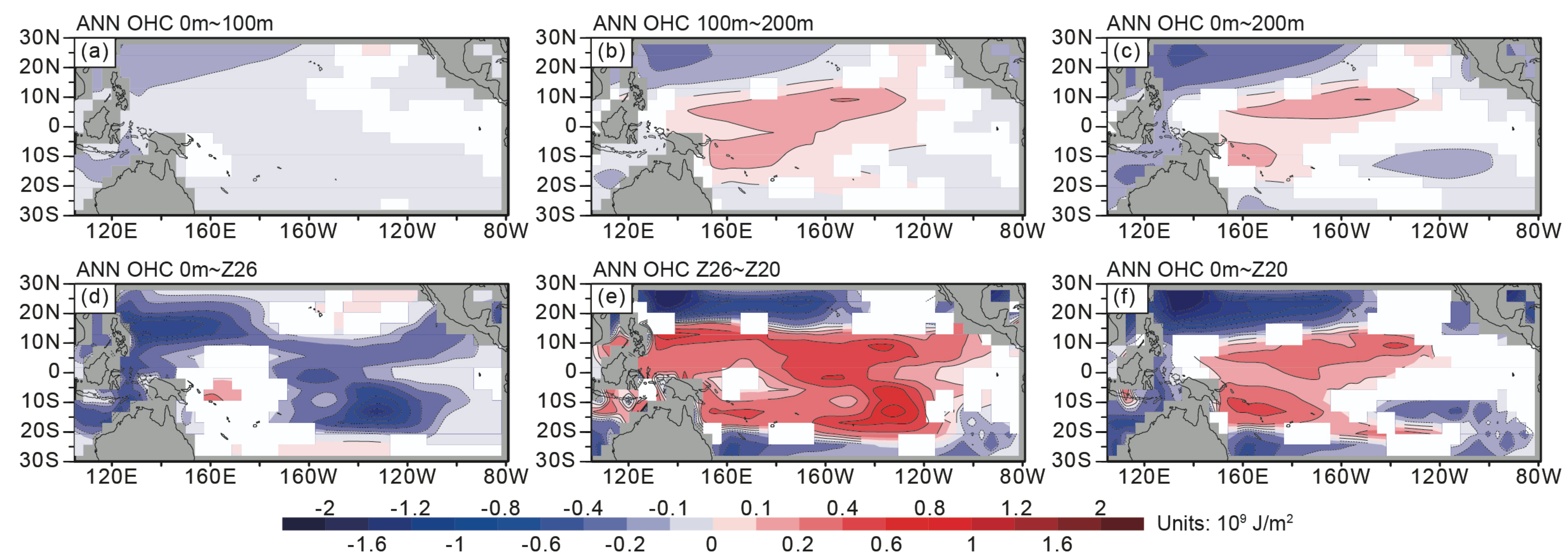

Fig 3. Same as Fig. 2 but for regression coefficients of annual mean OHC against the normalized time series of obliquity (black line in Fig. 1b).

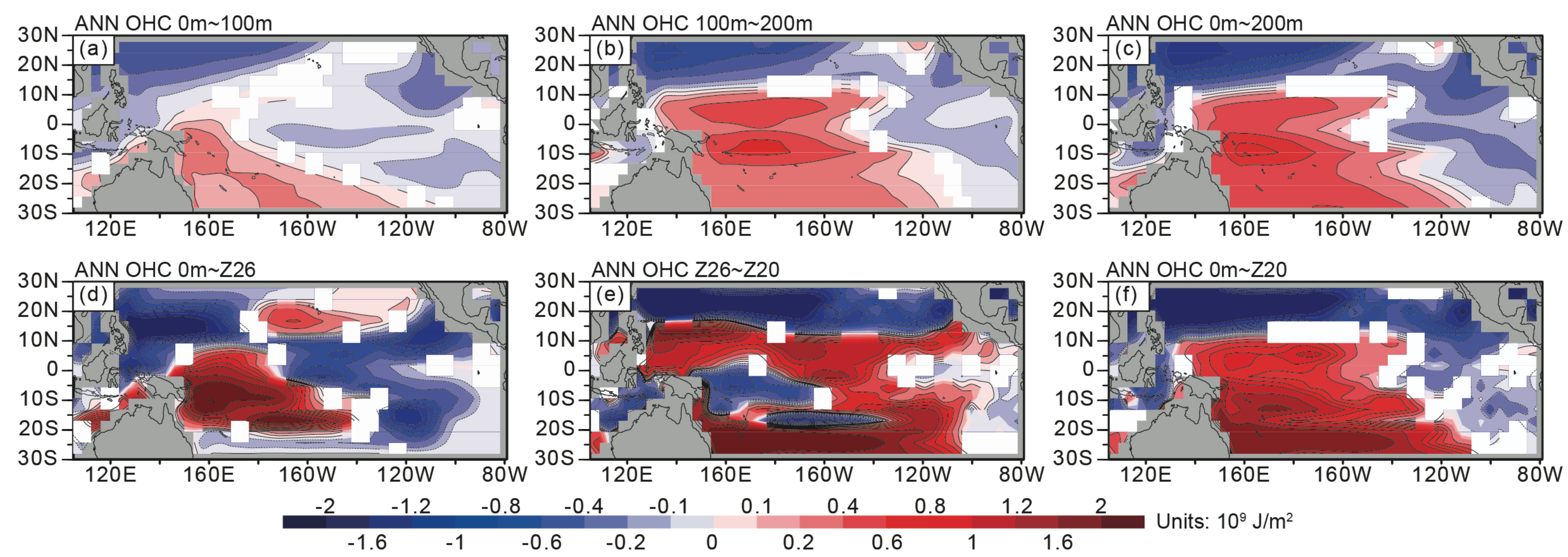

Fig 4. Same as Fig. 2 but for regression coefficients of annual mean OHC against the normalized time series of precession (multiplied by -1) (black line in Fig. 1a).

References: [1] Rosenthal Y., et al., 2013, *Science*, 342(6158): 617-621. [2] Rosenthal Y., et al., 2017, *Quat. Sci. Rev.*, 155:1-12. [3] Wang Y., et al., 2019, *J. Clim.*, doi: 10.1175/JCLI-D-18-0068.1. [4] Shields C.A., et al., 2012, *J. Clim.*, 25(12): 3993-4014. [5] Wang Y., et al., 2015, *J. Geophys. Res.*, 120: 3747-3760. [6] Wang Y., et al., 2012, *Geophys. Res. Letts.*, 39(14), doi:10.1029/2012GL052553. [7] Kutzbach, J.E., 2008, *Clim. Dyn.*, 30(6): 567-579. [8] Chen G.S., et al., 2011, *Clim. Dyn.*, 37(9-10):1949-1960. [9] Yang, et al., 2019, *Acta Oceanologica Sinica.*, *38*, 60-71.