東亞夏季風變化與湖泊富營養化

陈发虎 、刘建宝、 陈建徽等

fhchen@lzu.edu.cn

兰州大学资源环境学院

中科院青藏高原研究所卓越创新中心

2017.2.14 中央研究院

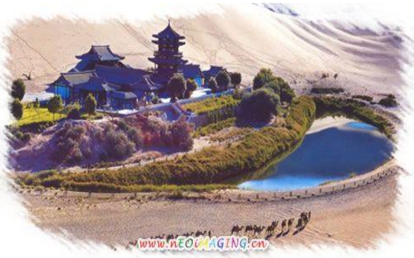
Outlines

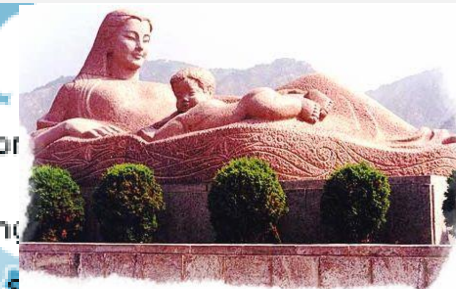

Desert
Lanzhou
China
Loess
Russia
Mongolia
Ancinet Silk Road
Beijing
Lanzhou
Xi' an
Tibetan Plateau
Bhutan
Nepal
India
China
Burma
Laos
Vietnam

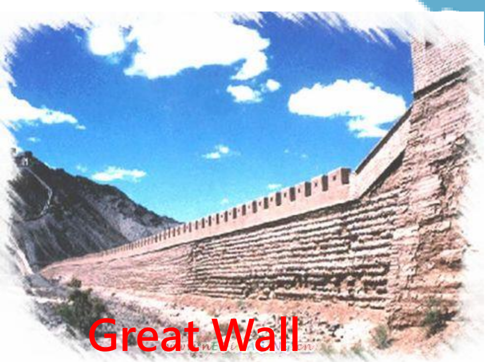
兰州大学简介
Brief Introduction to LZU

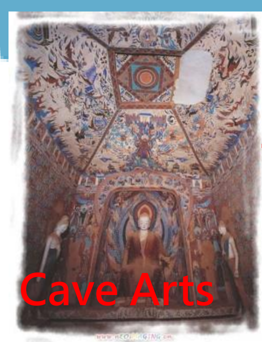
地理位置 Location

一本书：读者
一条路：丝绸之路
一碗面：牛肉面
一个窟：莫高窟
一条河：黄河
农业起源：大地湾
人文始祖：天水伏羲
万国大会：张掖
周朝/秦朝：发源地









东西1600 km，
4800年粟黍西传，4000年麦作东传
丝绸之路2300年历史；
西通西域中东东欧，东通陕西长安；
南临青藏高原，北望蒙古高原

一、兰州大学历史概况

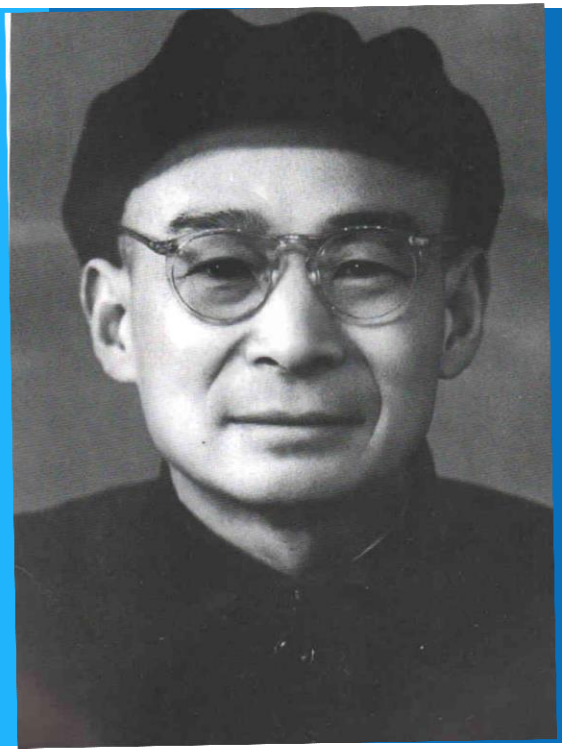

兰州大学 LANZHOU UNIVERSITY
历史沿革
创建甘肃法政学堂
首批进入"211工程"行列
续签省部共建协议
确定为综合大学
次年由高等教育部直接管理
建校100周年
1909 1928 1945 1953 1996 2001 2002 2004 2006 2009 2011
定名国立兰州大学
签订省部共建协议
进入"985工程"行列
续签省部共建协议
改建为兰州中山大学
原甘肃省草原生态研究所并入
原兰州医学院并入

本科教育

恢复高考以来的本科生获得院士名单

南大 12人
北大 10人
吉大 10人（含合校，原吉大7人
复旦 9人
清华 9人
浙大 8人（含合校，原浙大6人）
兰大 7人（自然地理3人）
武大 7人（含合校，原武大5人）

人才培养



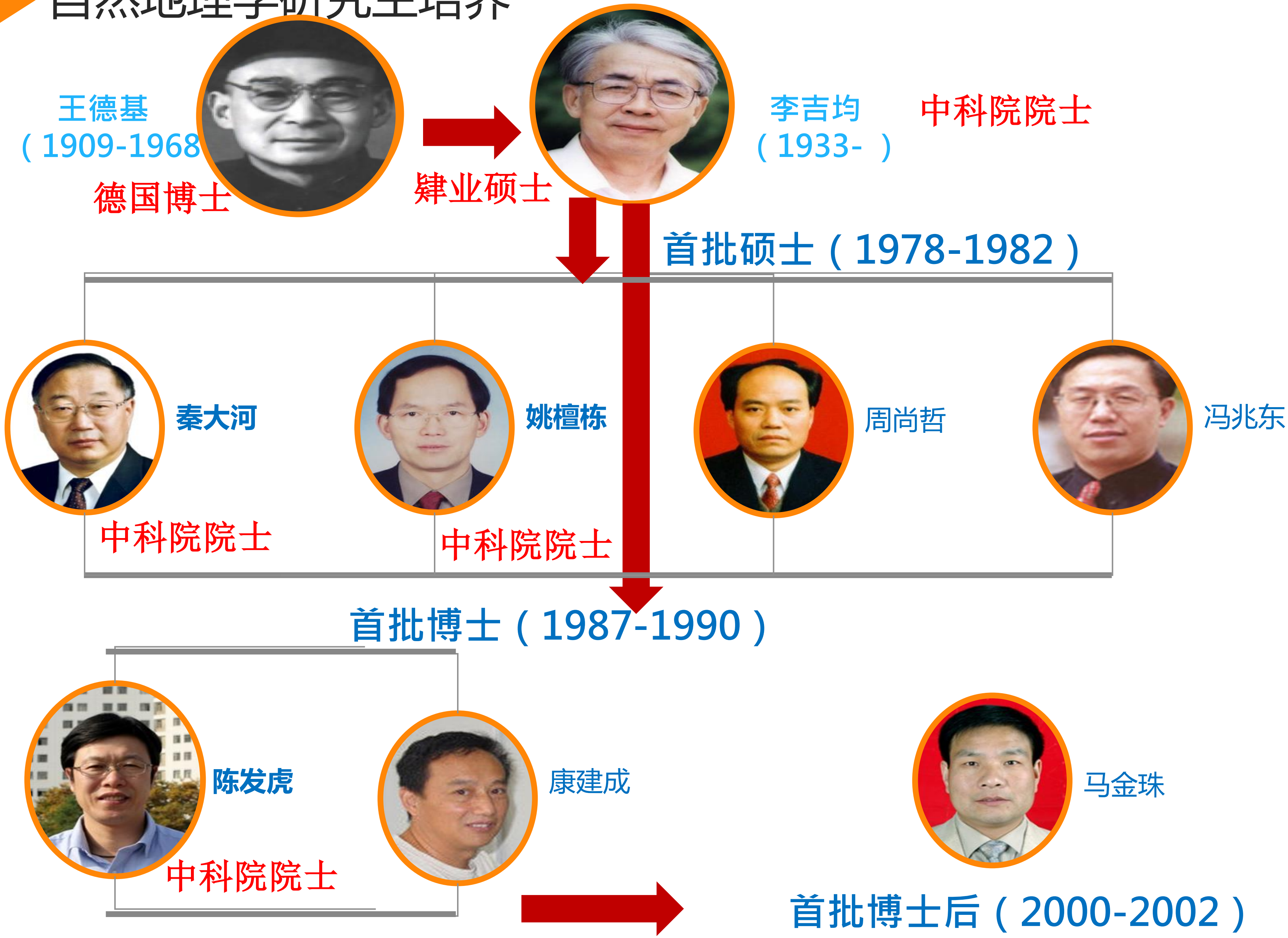
人物介绍：

湖南宜冲桥人。
1930年考入南京中央大学地理系
1934年毕业留校任助
1936年底洪堡奖学金资助赴德留学
1946受聘为兰州大学教授，任**地理系首届系主任**。
1952年，当选全国地理学会理事，兼任甘肃分会理事长。

王德基
（1909-1968）

地理系首届系主任

自然地理学研究生培养


王德基
（1909-1968
德国博士
肄业硕士
李吉均
（1933- ）
中科院院士
首批硕士（1978-1982）
秦大河
中科院院士
姚檀栋
中科院院士
周尚哲
冯兆东
首批博士（1987-1990）
陈发虎
中科院院士
康建成
马金珠
首批博士后（2000-2002）

兰州大学地理学（1946-

中科院院士
2人

李吉均 院士

陈发虎 院士

千人特聘
教授 2人

张廷军 千人、院长

贺缠生 千人

杰青/名师/长江

潘保田 杰青

孙东怀 杰青、萃英

王乃昂 名师

勾晓华 长江

萃英特聘教授
优青、青年长江

孟兴民 萃英

聂军胜 萃英、优青

衣育红 萃英

董广辉，青年长江

新世纪
骨干

安成邦

戴霜

杨永春

强明瑞

夏敦胜

岳东霞

饶志国

张家武

王杰

李育

兰州大学地理学人才培养

入选中科院院士 4人

陈发虎（2015）、姚檀栋（2007）、秦大河（2003）、李吉均（1991）

研究生入选杰出青年 9人 长江 3人

康世昌（1995，2013）、吴海斌（1999，2012）、潘保田（1988，2010）

岳天祥（1989，2009）、葛全胜（ 1999，2006）、陈发虎（1984，2002）

冯兆东（1982，2001）、方小敏（1988，2000）、姚檀栋（1982，1994）

勾晓华（1994,2015）

本科生入选杰出青年 8人

效存德（1988，2014）、康世昌（1988，2013）、吴海斌（1992，2012）

田立德（1987，2010）、潘保田（1979，2010）、陈发虎（1980，2002）

冯兆东（1974，2001）、姚檀栋（1974，1994）

博士后入选杰青

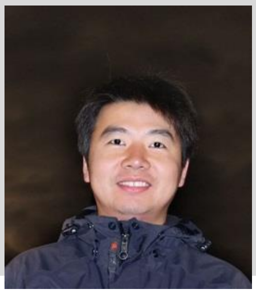
王训明（2003，2012）

兰州大学-课题组成员

季风气候

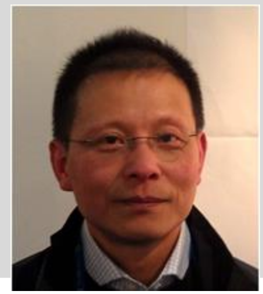
陈发虎
院 士，环境变化

陈建徽
副教授，西风-季风变化



刘建宝
讲 师，季风演化

靳立亚
教 授，古气候模拟



张家武
教 授，湖泊记录

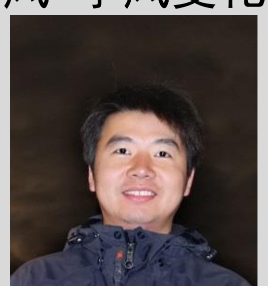
饶志国
教 授，有机地球化学

西风气候

陈发虎
院 士，环境变化

勾晓华
教授，树轮气候

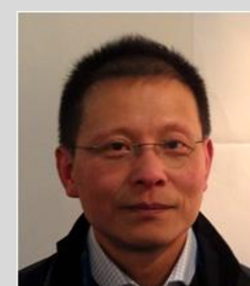
陈建徽
副教授，西风-季风变化



黄 伟
讲 师，气候变化

黄小忠
副教授，湖泊记录

靳立亚
教 授，古气候模拟



Prof. Fahu Chen

Dr. Jianbao Liu

Prof. John Smol
加拿大院士

Dr. Kathleen Rühland

Prof. **Jianhui Chen**

Shengqian Chen

刘建宝

1. **Liu J,** Rühland K, Chen J, ...Chen FH*, et al. 2017. Aerosol-weakened summer monsoons decrease lake fertilization in the Chinese Loess Plateau. ***Nature Climate Change***, in Press
2. **Liu J,** Chen J, Zhang X, Li Y, Rao Z, Chen F, 2015. Holocene East Asian summer monsoon records in northern China and their inconsistency with Chinese stalagmite $\delta^{18}O$ records. ***Earth-Science Reviews***, 148: 194-208.
3. **Liu J,** Chen F, Chen J, et al. 2015. Weakening of the East Asian Summer Monsoon at 1000-1100 AD within the Medieval Climate Anomaly: possible linkage to changes in the Indian Ocean-western Pacific. ***Journal of Geophysical Research – Atmospheres***, 119, 2209-2219
4. **Liu J**, Chen J, Kandasamy S, et al. 2014, Chemical weathering over the last 1200 years recorded in the sediments of Gonghai Lake, Lvliang Mountains, North China: a high-resolution proxy of past climate. ***Boreas***, 43, 914-923
5. **Liu J**, Chen F, Chen J, Xia D, Xu Q, et al. 2011. Humid Medieval Warm Period recorded by magnetic characteristics of sediments from Gonghai Lake, Shanxi, North China. ***Chinese Science Bulletin***, 56, 2464-2474
6. **Liu J**, Kandasamy S, Chen J, et al, 2016. A 14.7 Ka Record of Earth's Surface Processes from the Arid-Monsoon Transitional China. ***Earth Surface Processes and Landforms***, 1711-1715
7. Yang X, **Liu J***, Liang F, Yuan D, Yan Y, Chen F. et al**,** 2014. Holocene stalagmite $\delta^{18}O$ records in southern China and their correlation with those in the Indian monsoon region. ***The Holocene***, 24, 1657-1664 (通讯作者)
8. Chen F, **Liu J**, Xu Q, Li Y, Chen J, Wei H, et al, 2013, Environmental magnetic studies of sediment cores from Gonghai Lake: implications for monsoon evolution in North China during the late glacial and Holocene. ***Journal of Paleolimnology***, 49, 447-464

中国现代的季风研究始于上世纪30年代，由**竺可桢**、**涂长望**等研究了中国大陆夏季风分类以及夏季风在中国大陆上北进过程。

在20世纪 50-60 年代,**叶笃正**先生领导了对亚洲大气环流和季风的结构、季节突变以及**青藏高原**的作用进行了大量研究 ,得到了许多成果。

季风变迁研究一直是学术界关注的重大问题，**刘东生**、**安芷生**、**丁仲礼**等开展了杰出工作

東南季風與中國之雨量

竺可楨

1934

浙大校长

(一)中國古籍上關於季風之紀載

季風西文作Monsoon，源於阿拉伯字Mausim，意即季候也。我國古稱信風。此風在阿拉伯海及印度洋中流行最盛，中古時代南亞海上貿易，全爲阿拉伯人所操縱。當時海洋船舶來往，惟風是賴，故阿拉伯商人於季風向背之季候，亦知之最稔。我國晉代高僧法顯於安帝隆安三年（西曆399A.D.），自長安出發，經敦煌鄯善赴天竺尋求戒律，越十五載，取道南海而歸。依日本安永重鐫沙門法顯自記游天竺事（1）稱「法顯住此（摩梨帝國在恆河河口）二年，寫經及畫像，於是載商人大船，

，到師子國。……法顯住此國二年，更求得彌沙塞律藏本

悉漢土所無者。得此梵本已，即載商人大船上，可有二百餘

毀壞。得好信風，東下三日，便值大風。……如是九十許

國五月日，復隨他商人大舶上，亦二百許人，賚五十日糧，

行趣廣州。」

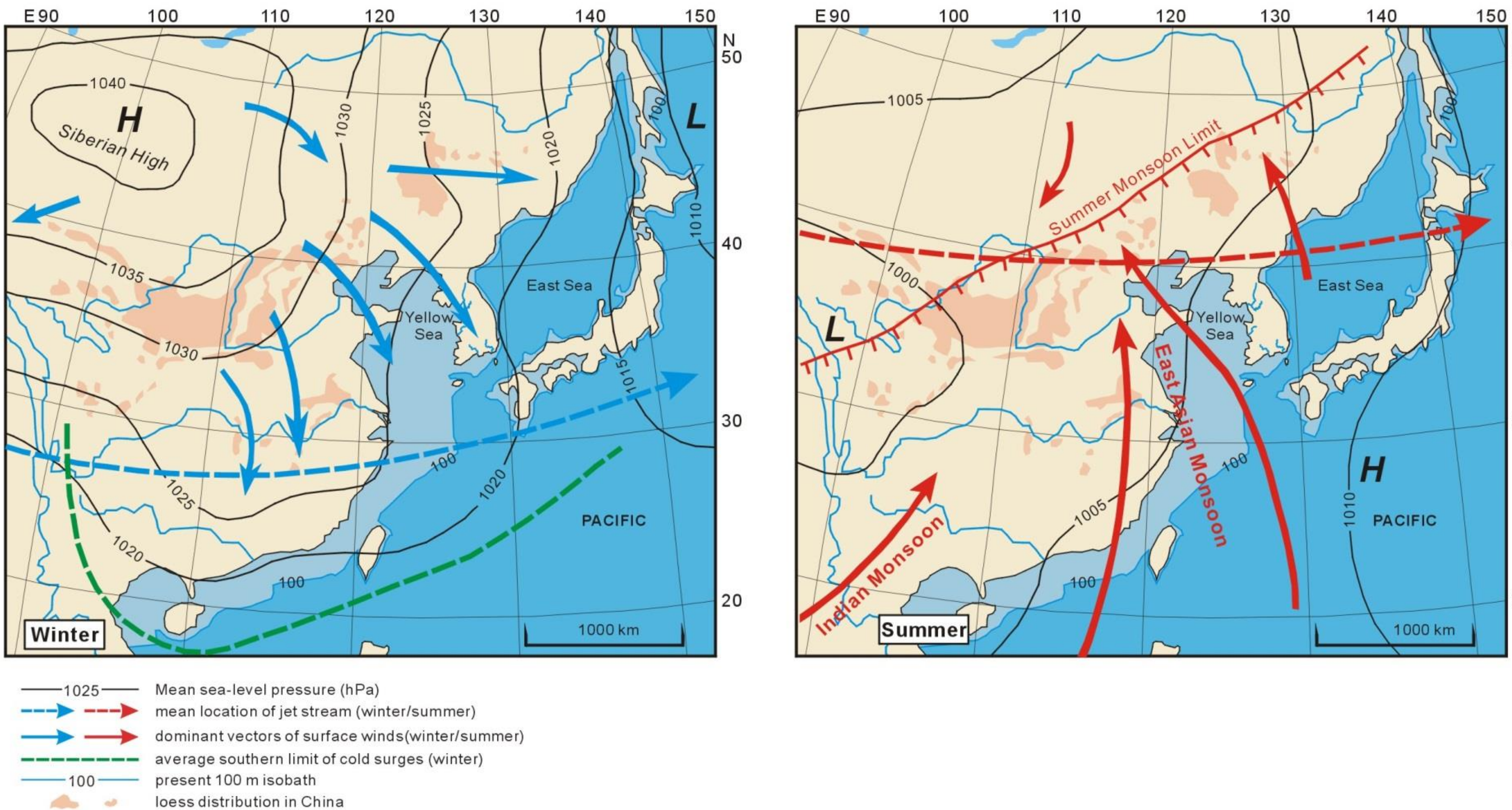
。法顯之所以居留耶婆提（即今爪哇）至五閱月之久者，非欲

顯於陰歷十一月間抵耶婆提時值東北季風盛行南海，故必須

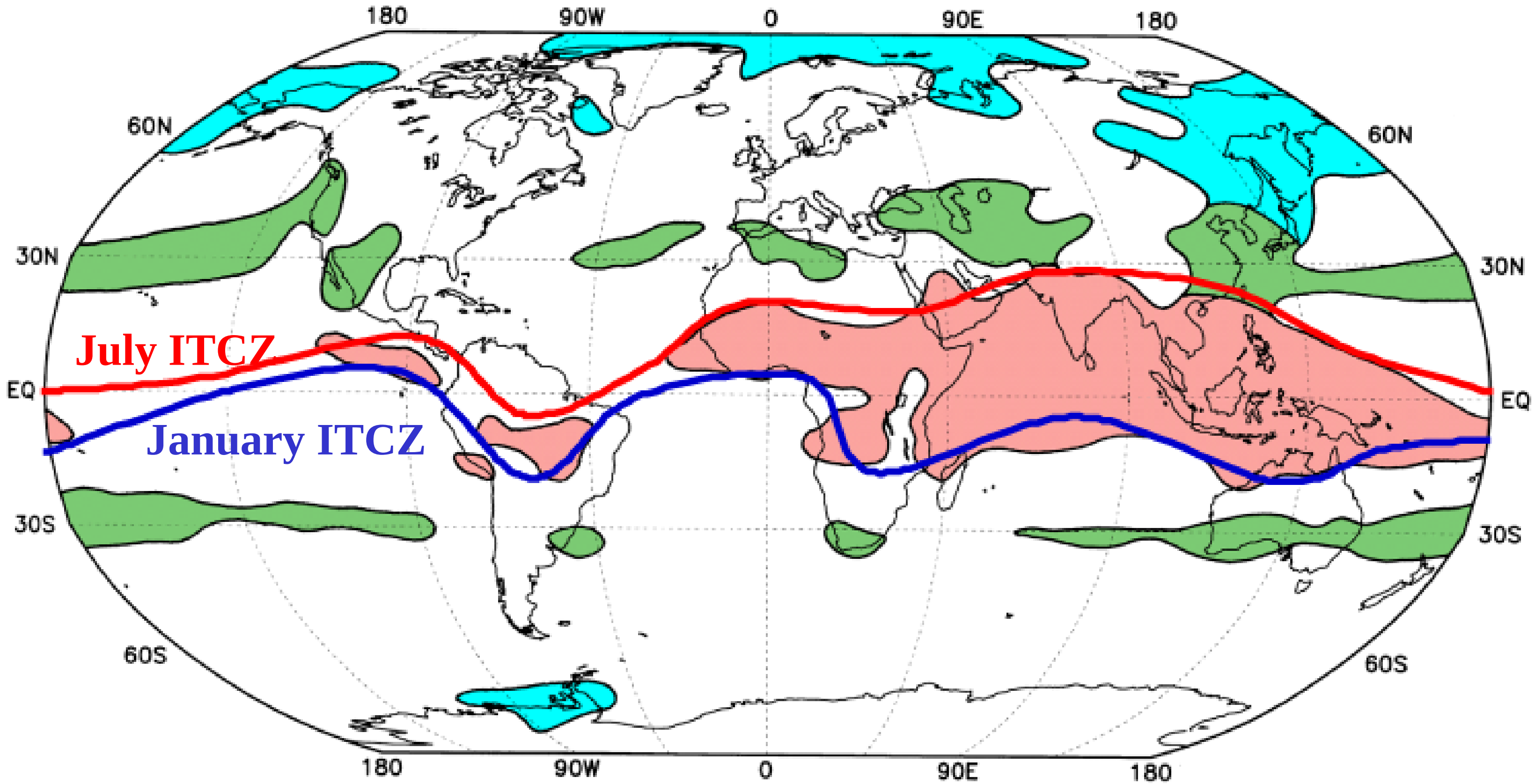
耳。

季　风

冬季　　　　夏季



海陆热力差异

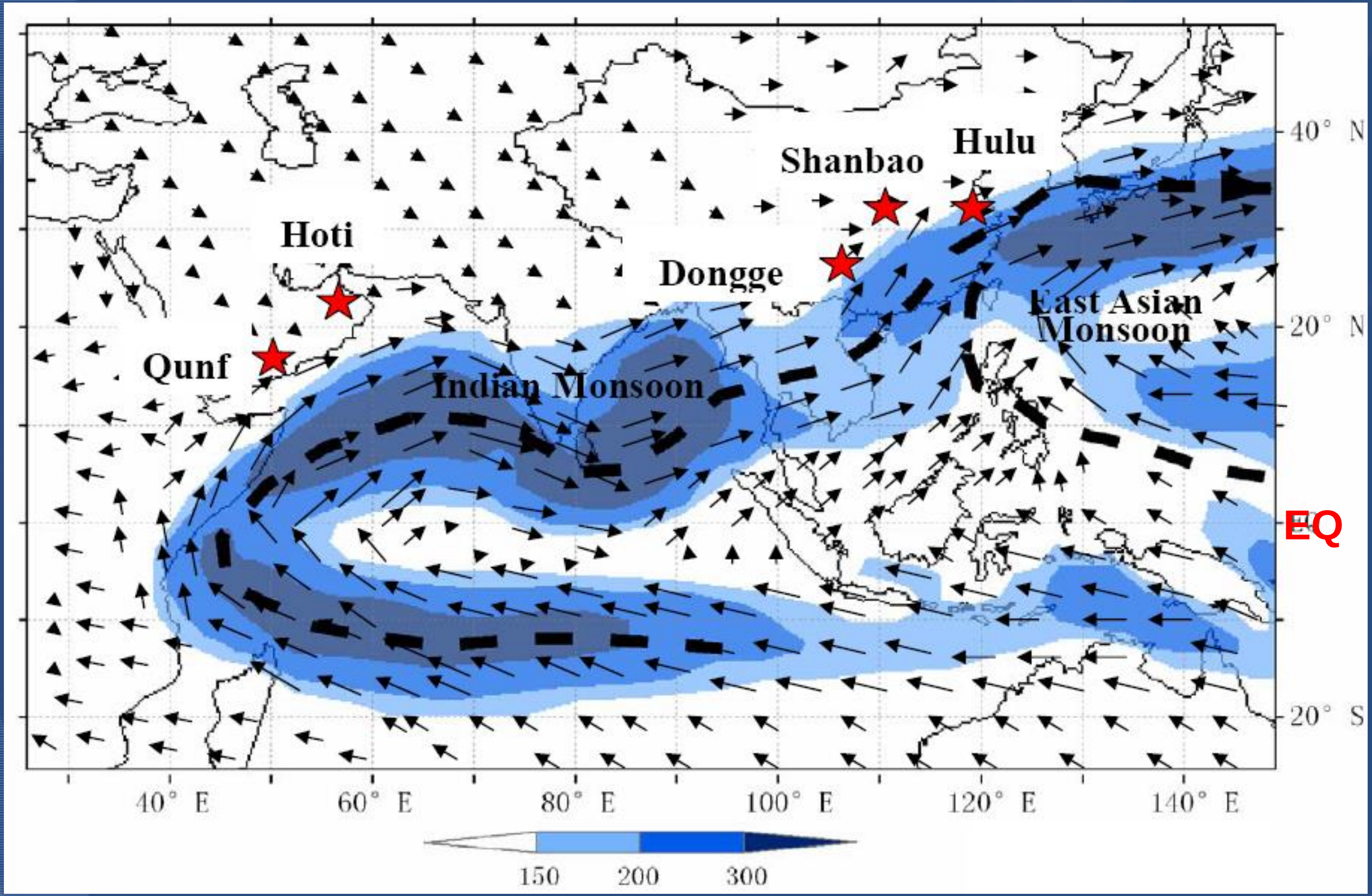


Red, **Green** **and** **Blue** areas-Tropical, Subtropical and temperate Monsoon

ITCZ seasonal migration (Li and Zeng, 2005)

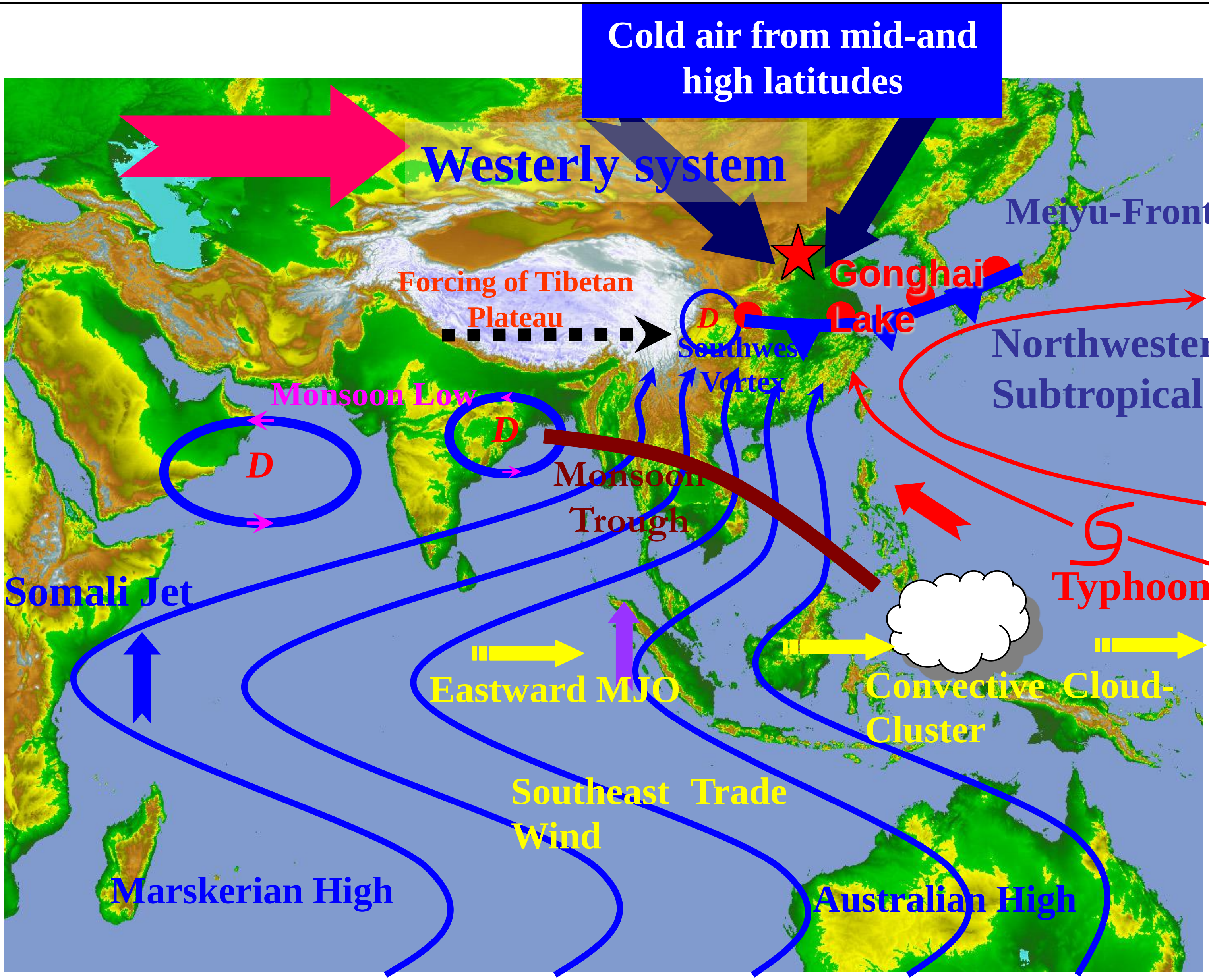
Monsoon Asia and Westerly Asia

Ding YH et al., 2006



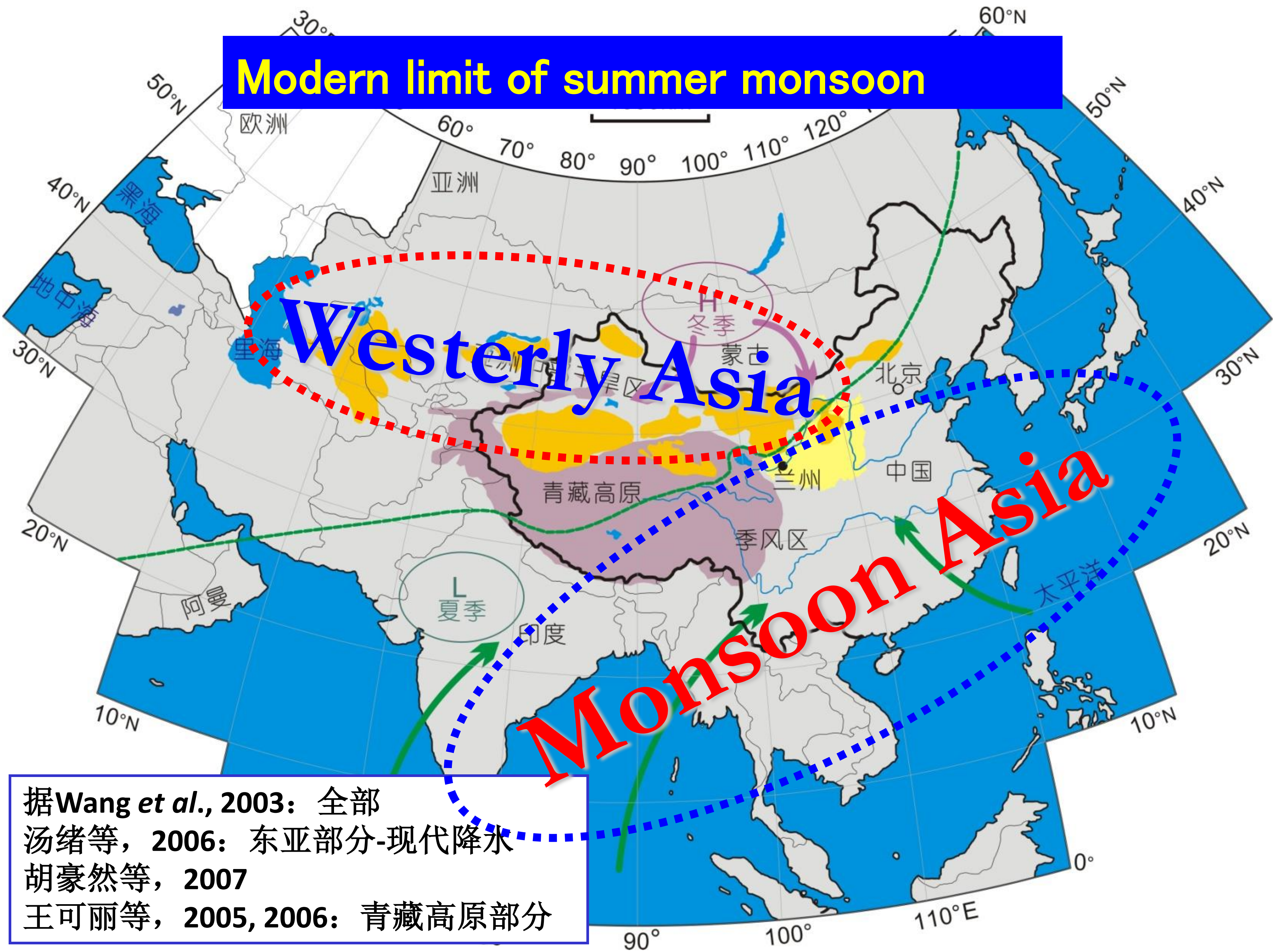
Onset of Asian summer monsoon (from the end of March to early July). ***The strong moisture transport zone is shaded***

Asian Monsoon System



From YH Ding

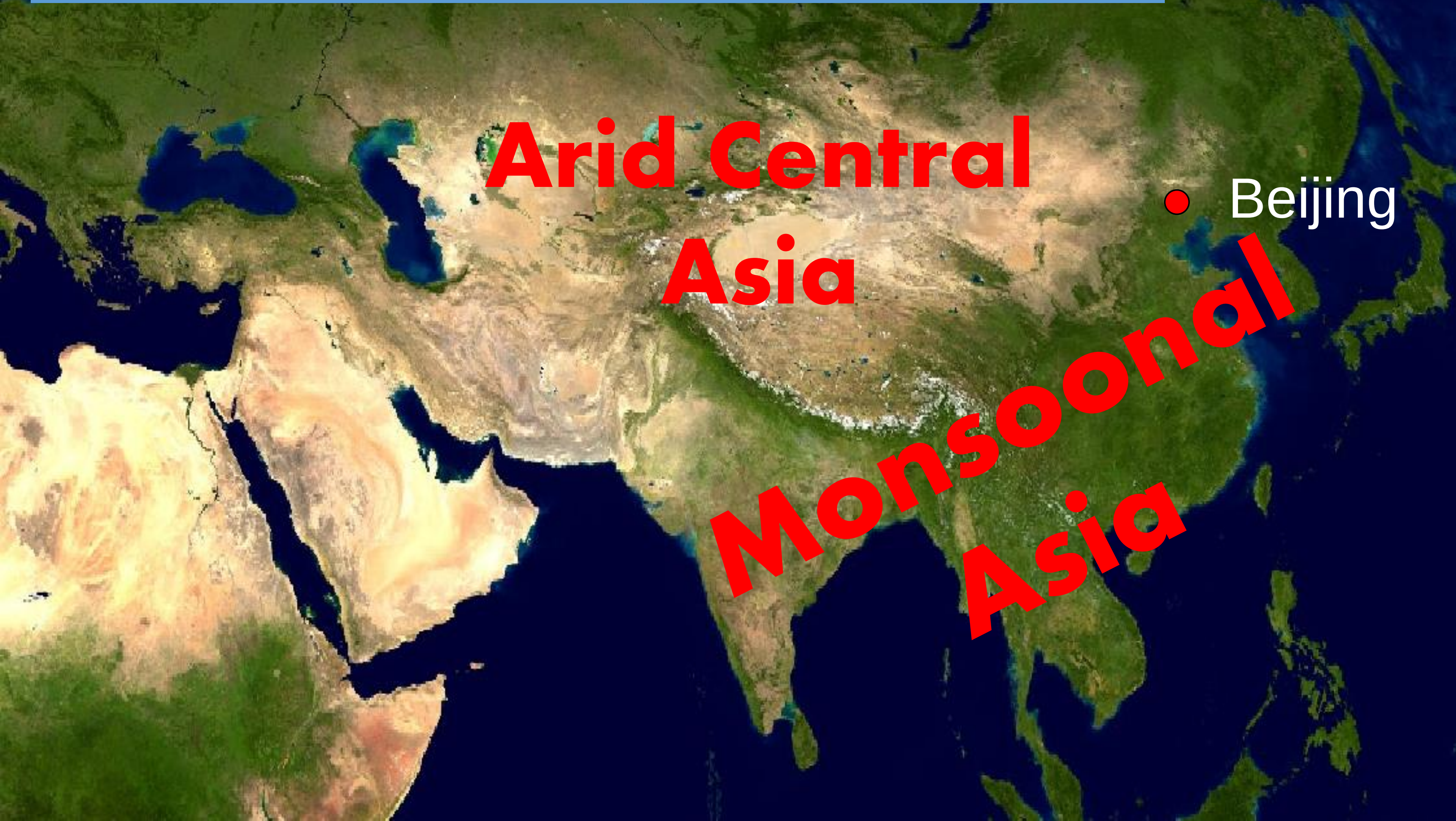
Modern limit of summer monsoon



据Wang *et al.*, 2003：全部
汤绪等，2006：东亚部分-现代降水
胡豪然等，2007
王可丽等，2005, 2006：青藏高原部分

Monsoon Importance:

- Interhemispheric heat and moisture transport
- Affecting >60% of the world's population



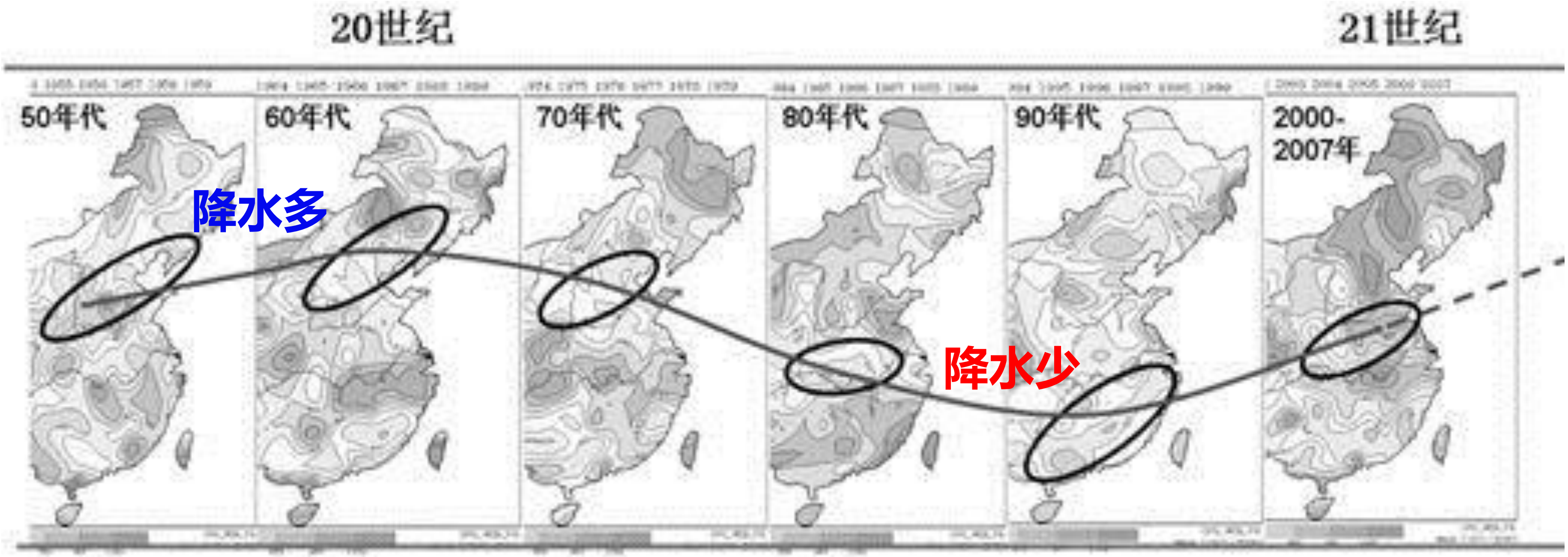
基于“风”和“雨”的古夏季风强度指标

	特征和过程	指标	地质载体
风	风力搬运	粉尘	黄土、冰芯
		风媒花粉	湖泊沉积物、海洋沉积物
	风力驱动上升流	浮游动植物、底栖有孔虫	海洋沉积物
	风力驱动的海表结构	生产力（地化指标）	
		水平SST梯度	
		温跃层深度（微体化石）	
雨	河流径流	海表盐度（浮游生物及其$\delta^{18}O$）	海洋沉积物
		纹层沉积、腐泥沉积	
	降水	湖泊水位	湖泊沉积
		湖泊盐度（微体化石、同位素）	
		植被（孢粉、碳屑）	
		石笋$\delta^{18}O$、示踪元素、GDGT	洞穴沉积物
		树轮宽度及其同位素	树轮
		大气甲烷浓度及$\delta^{18}O_{atm}$	冰芯包裹气体
		^{10}Be、$\delta^{13}C_{org}$	黄土沉积
	风化和成壤作用	黏土矿物、化学风化指数、磁化率	海洋、湖泊以及黄土沉积

Wang PX et al., 2014, CP

表征风的指标多为**海洋地质记录**；表征雨的指标多为**陆地地质记录**

东亚夏季风强度变化与我国东部季风区雨带变化的关系



上世纪50年代到70年代，我国是“北方多雨、南方少雨”的降雨形势。上世纪70年代到上世纪末，北方少雨，南方多雨。

Ding YH, 2013

EASM strength indicator:
Precipitation in northern China

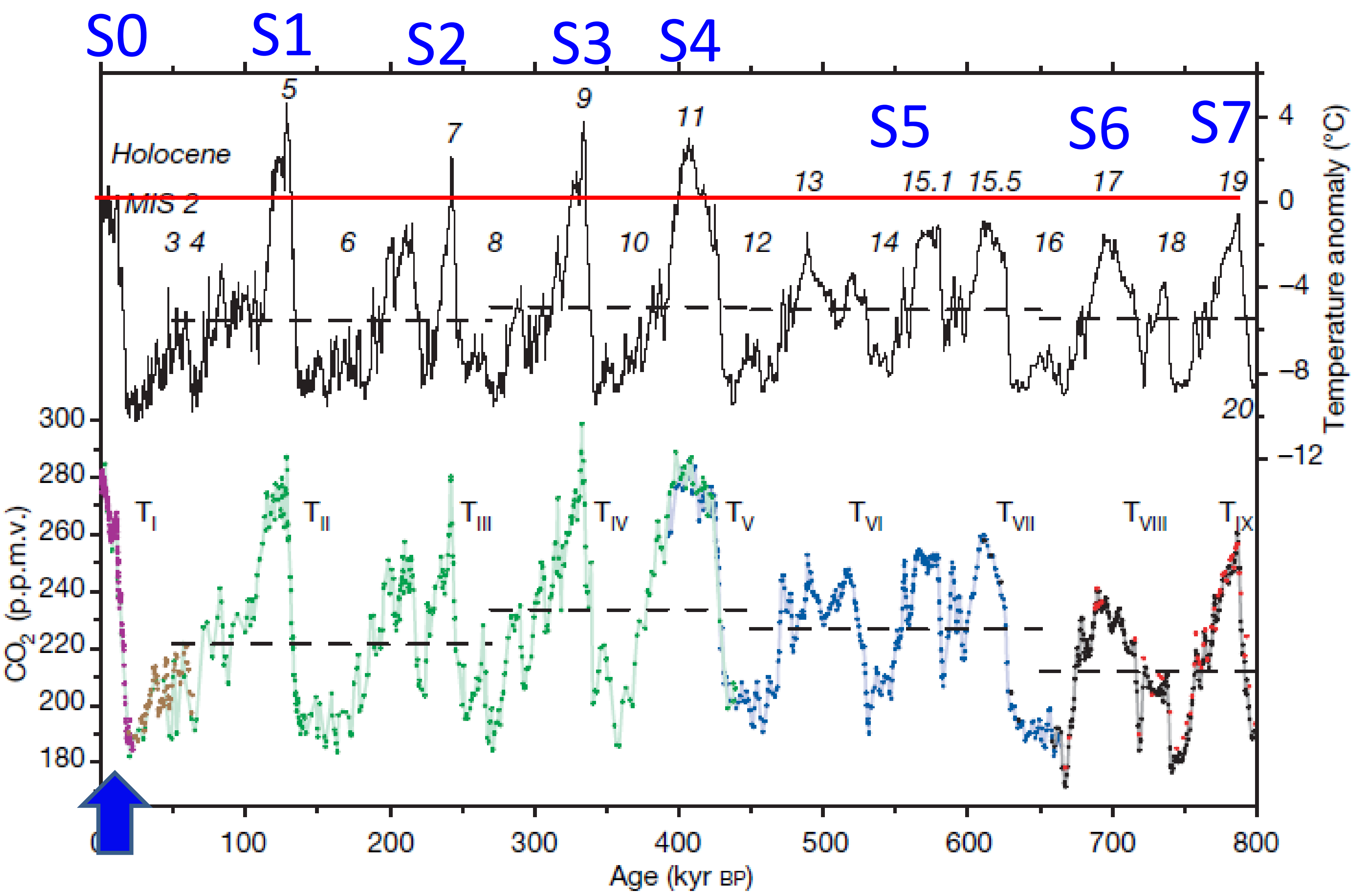
"Increases in the intensity of the summer monsoon across eastern China are best characterized as an intensified southerly monsoon wind and the accompanying intensified rainfall in northern China, but not by significant rainfall changes in southern China."

Wang B et al., 2008, JoC

Precipitation in northern China is the best indicator for EASM intensity

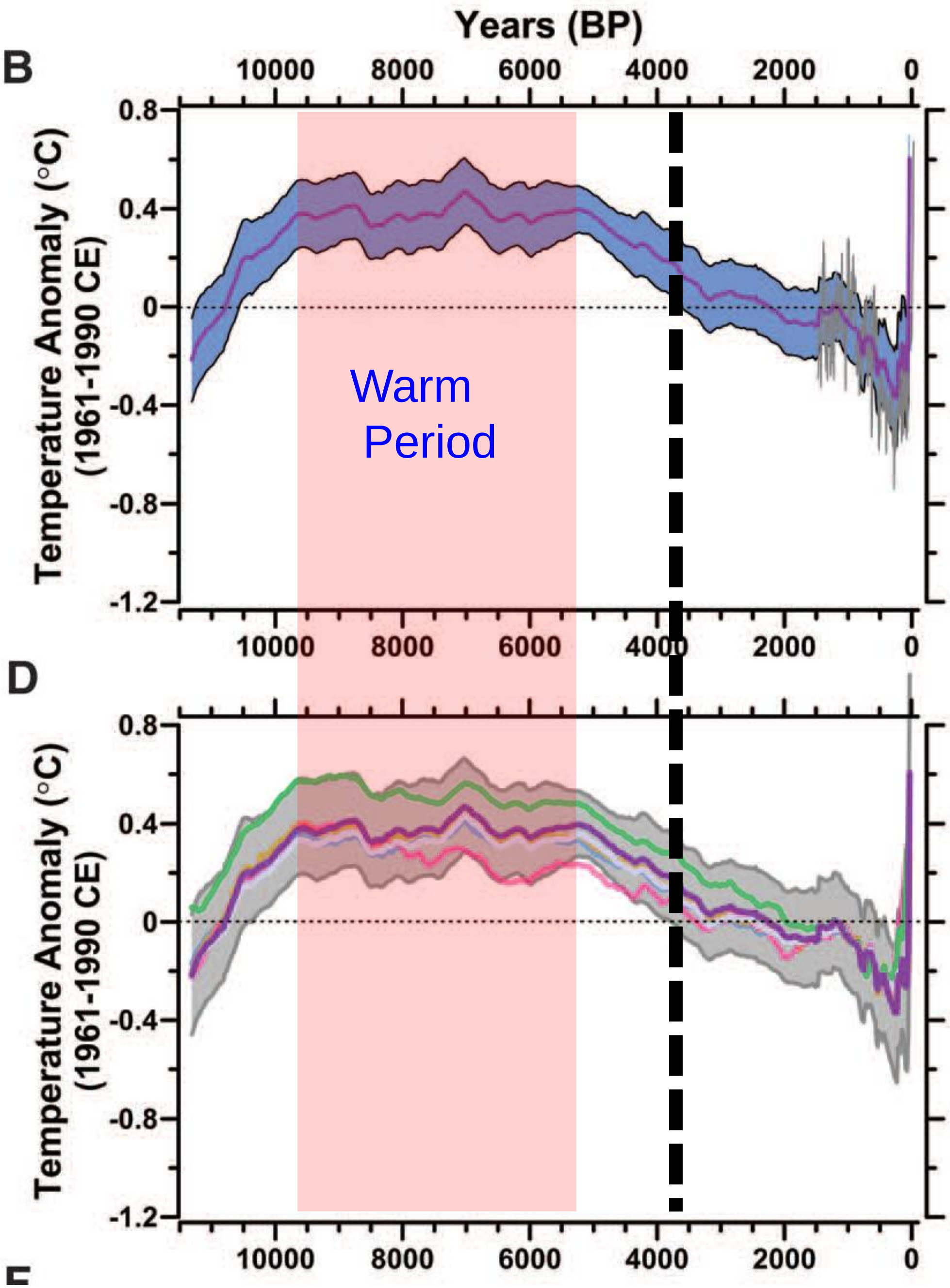
"The southerly wind has been used traditionally as an index for the EASM with clear dynamic implications on moisture import. An intensified low level southerly wind, ..., enhances the moisture transport ...into northern China, ..., leading to more frequent and heavier rainfalls there."

Liu ZY et al., 2014, QSR



(Lüthi et al., 2008; Petit et al., 1999; Pepin et al., 2001; Raynaud et al., 2005; Siegenthaler et al., 2005; Monnin et al., 2001; Indermühle et al., 2000; Jouzel et al., 2007; Parrenin et al., 2007)

Lüthi et al., 2008

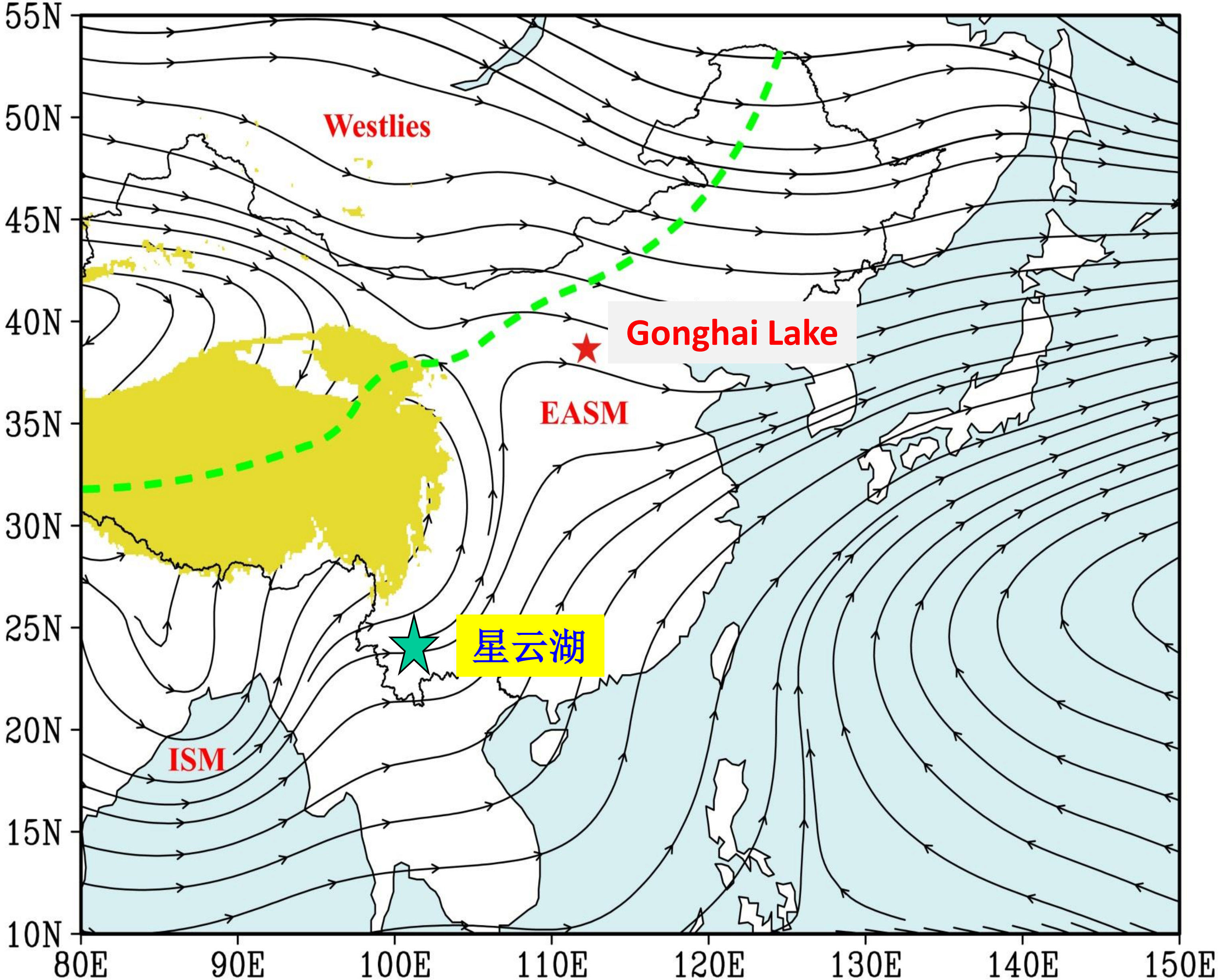


Temperature during Holocene

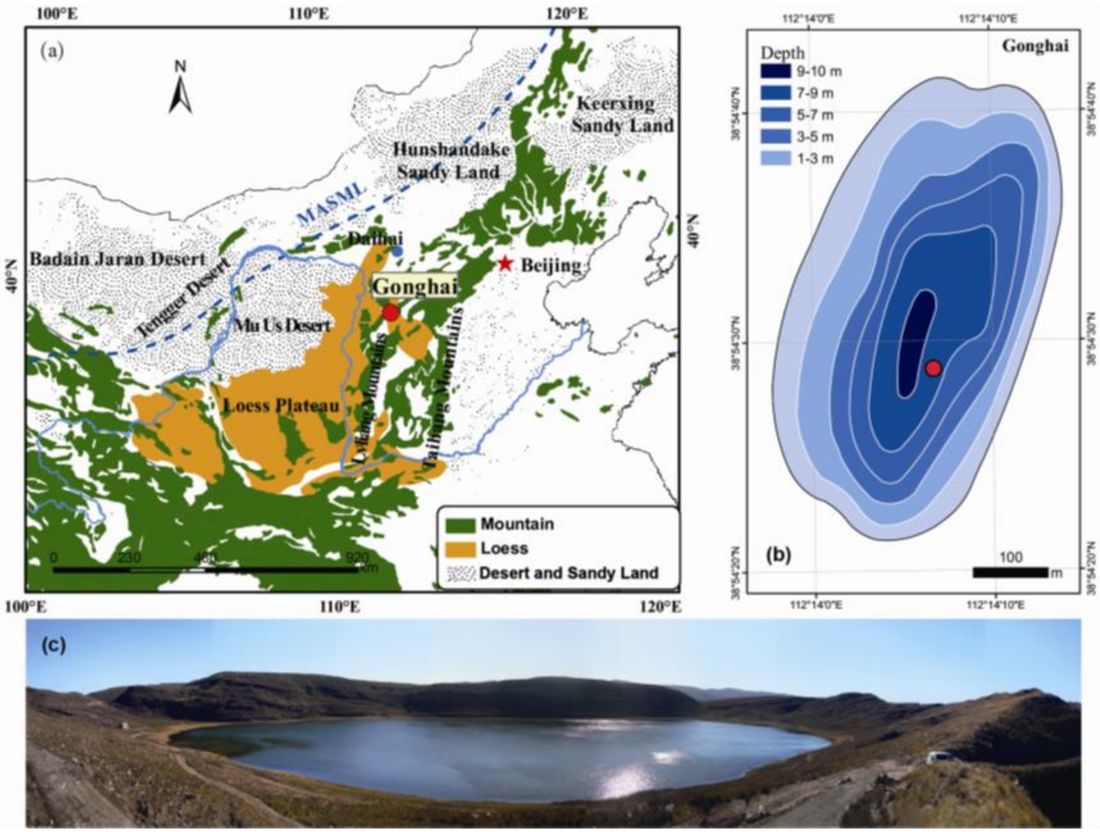
不同方法集成的
全球温度变化
（相对于**1961-1990**）

Marcott，et al.,
Science，2013

Summer (June-July-August, JJA) mean 700 hPa streamline based on NCEP/NCAR Reanalysis (1971–2000)

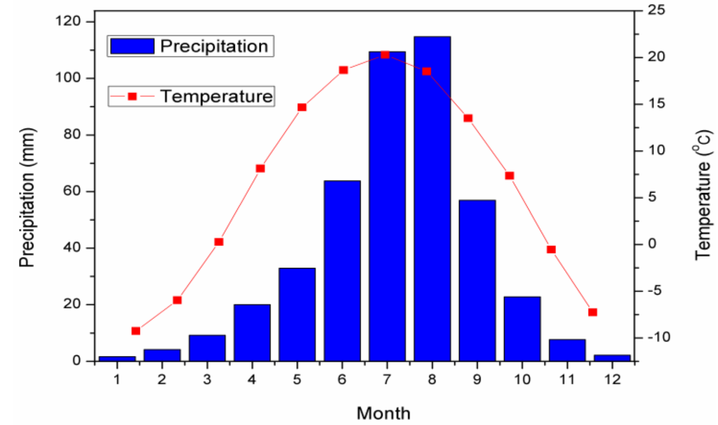


Location and climatic representativeness

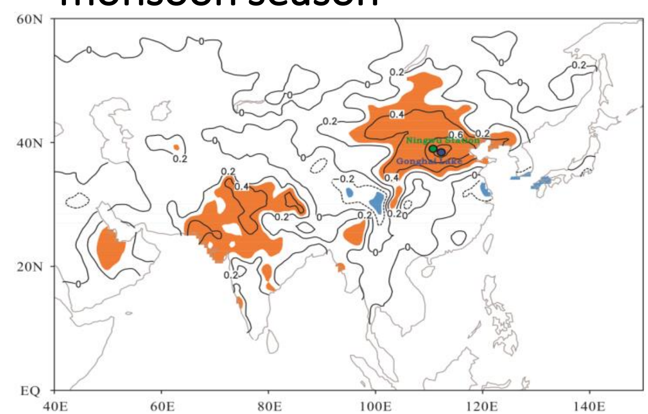


A small, closed alpine lake (1,860 m a.s.l.) located in the fringe of the modern EASM

An ideal site for North China precipitation reconstruction

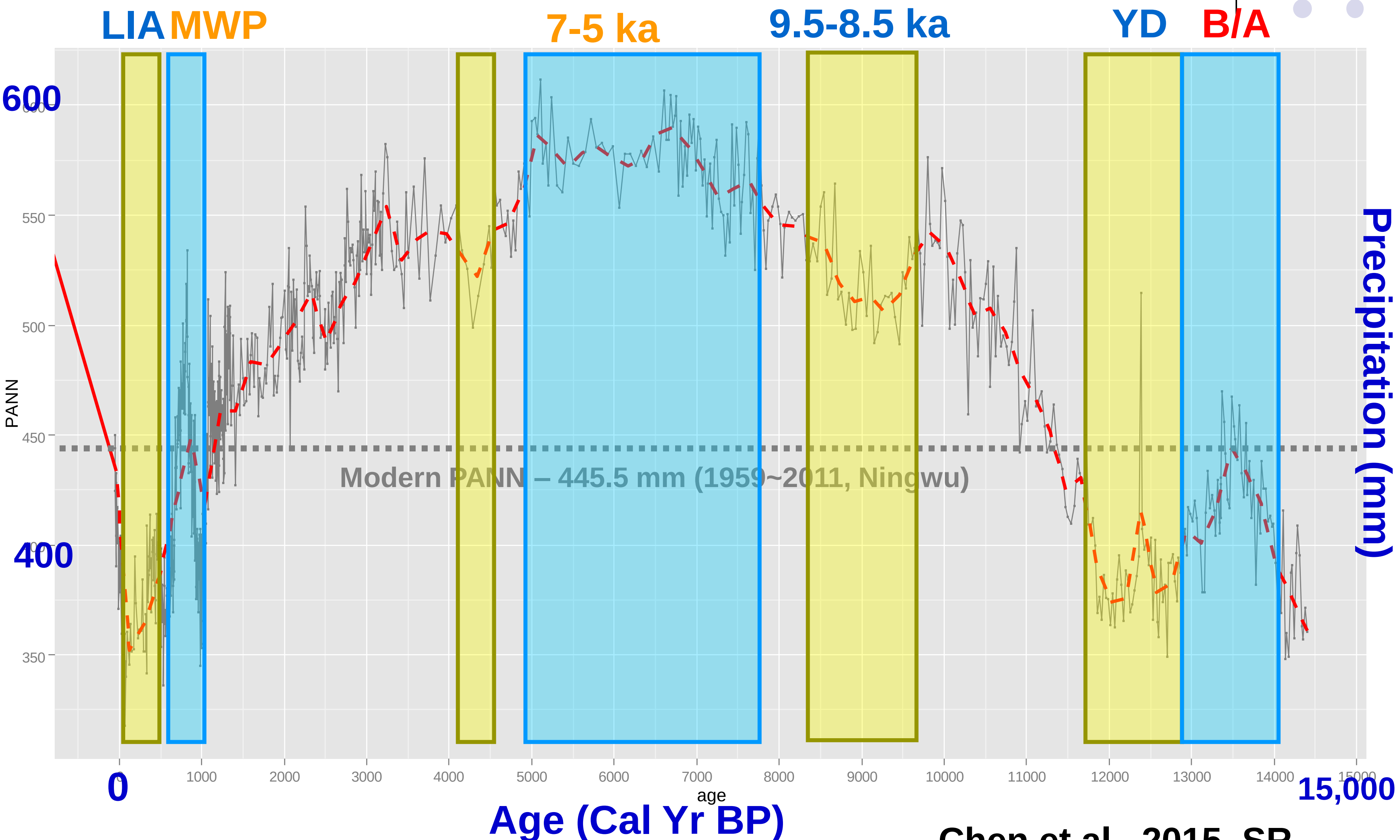


77 % of the 445 mm annual precipitation occurs during monsoon season



Precipitation at Gonghai is representative of North China

EASM variability since the last deglaciation



Chen et al., 2015, SR

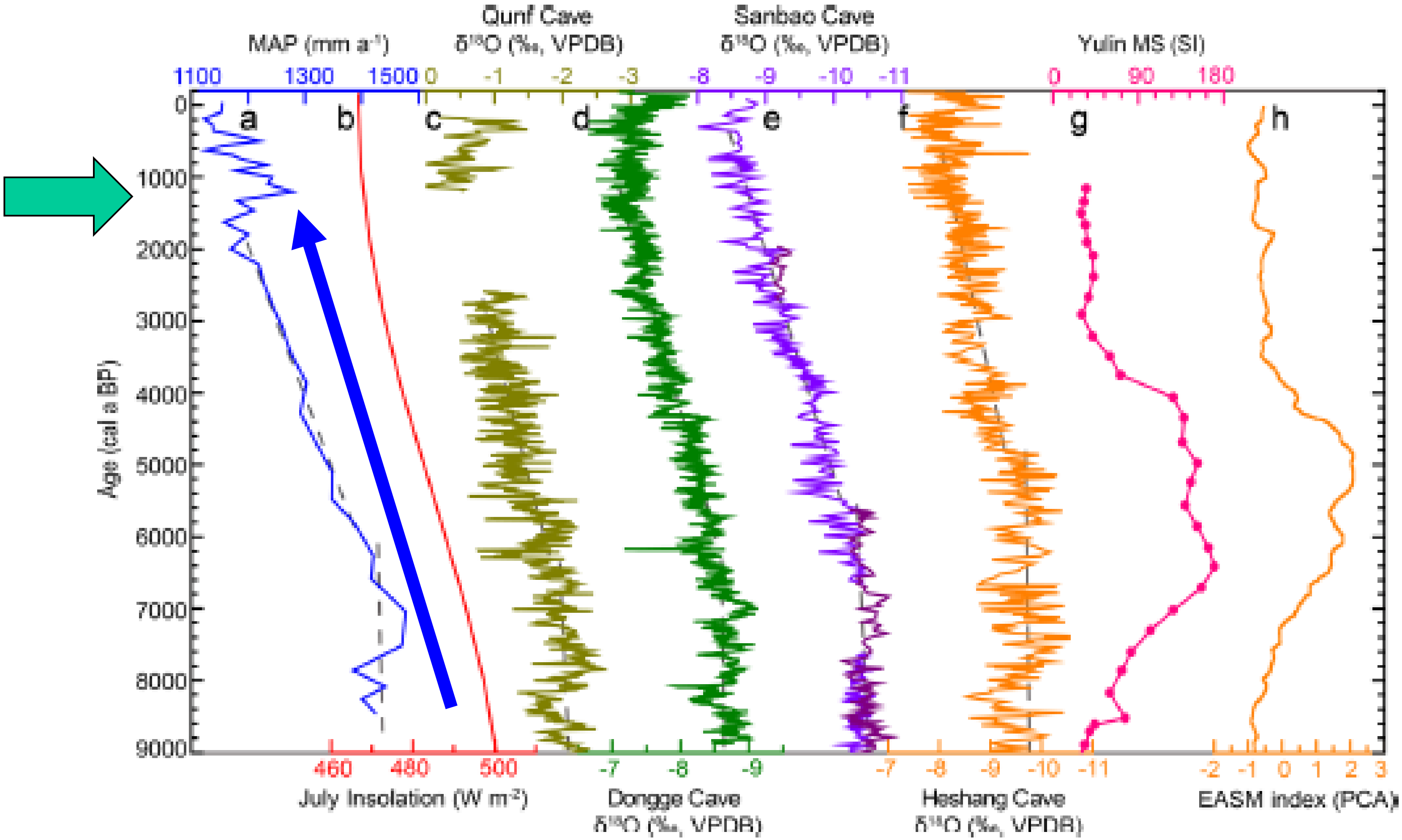
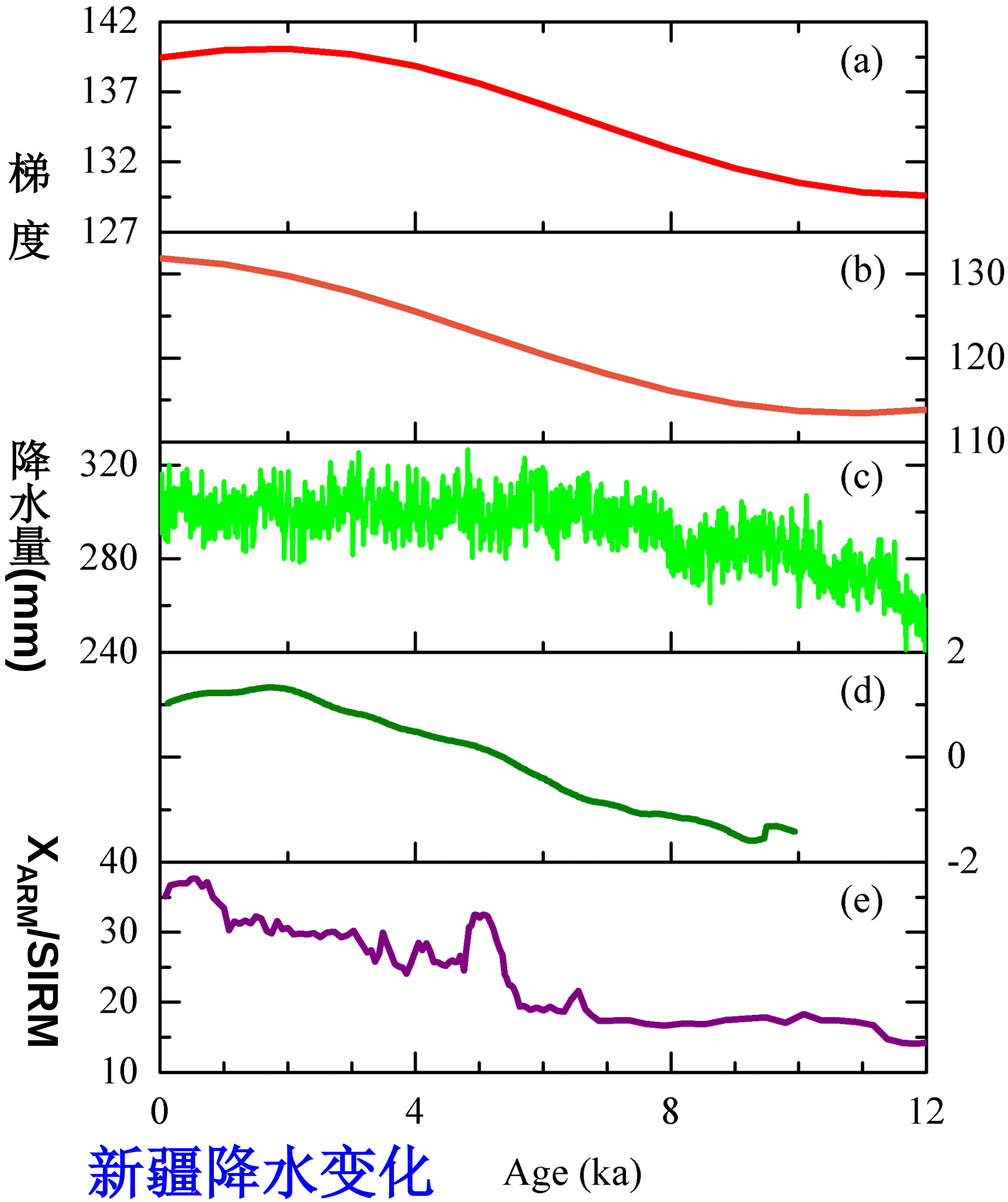


Figure 7. Variation of the reconstructed MAP (a), July insolation change at 25°N latitude (b; Laskar *et al.*, 2004), speleothem oxygen isotopes from Qunf Cave (c; Fleitmann *et al.*, 2003), Dongge Cave (d; Wang *et al.*, 2005b), Sanbao Cave (e; Dong *et al.*, 2010) and Heshang Cave (f; Hu *et al.*, 2008) over the last 9000 years. The grey dashed lines demonstrate the general trend comprising a plateau indicating a strong monsoon and a monotonous decrease. Curve g is the magnetic susceptibility of the Yulin loess–palaeosol profile, Chinese Loess Plateau (Lu *et al.*, 2013), and curve h is the proxy-based EASM index (after Wang *et al.*, 2010). This figure is available in colour online at wileyonlinelibrary.com.

印度夏季风变化，中世纪暖期夏季风增强

新疆降水变化



Summer insolation gradient
(35ºN-55ºN)
(Rossby, et al., 1939)

Winter insolation gradient
(35ºN-55ºN)
(Rossby, et al., 1939)

Stimulate Annual precipitation
(mm)
(Area: 35ºN-53ºN, 60ºE-90ºE)

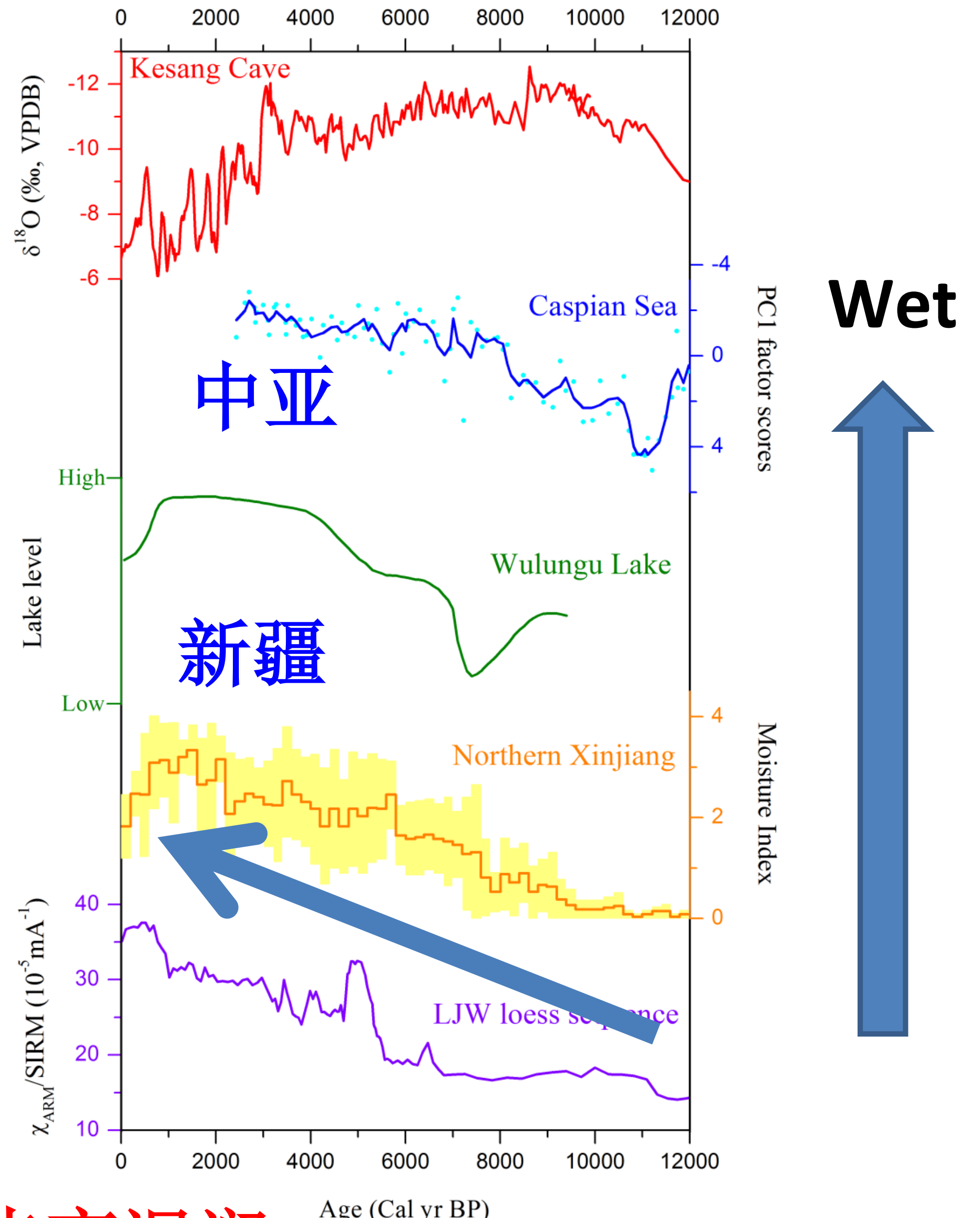
AO evolution recorded by proxy

Trend of moisture evolution
in core area of ACA, indicated by
χ_{ARM}/SIRM in LJW10 section
(10^{-5} Am^2kg^{-1})

Chen et al., 2016，QSR
Zhang et al., 2016, Holocene

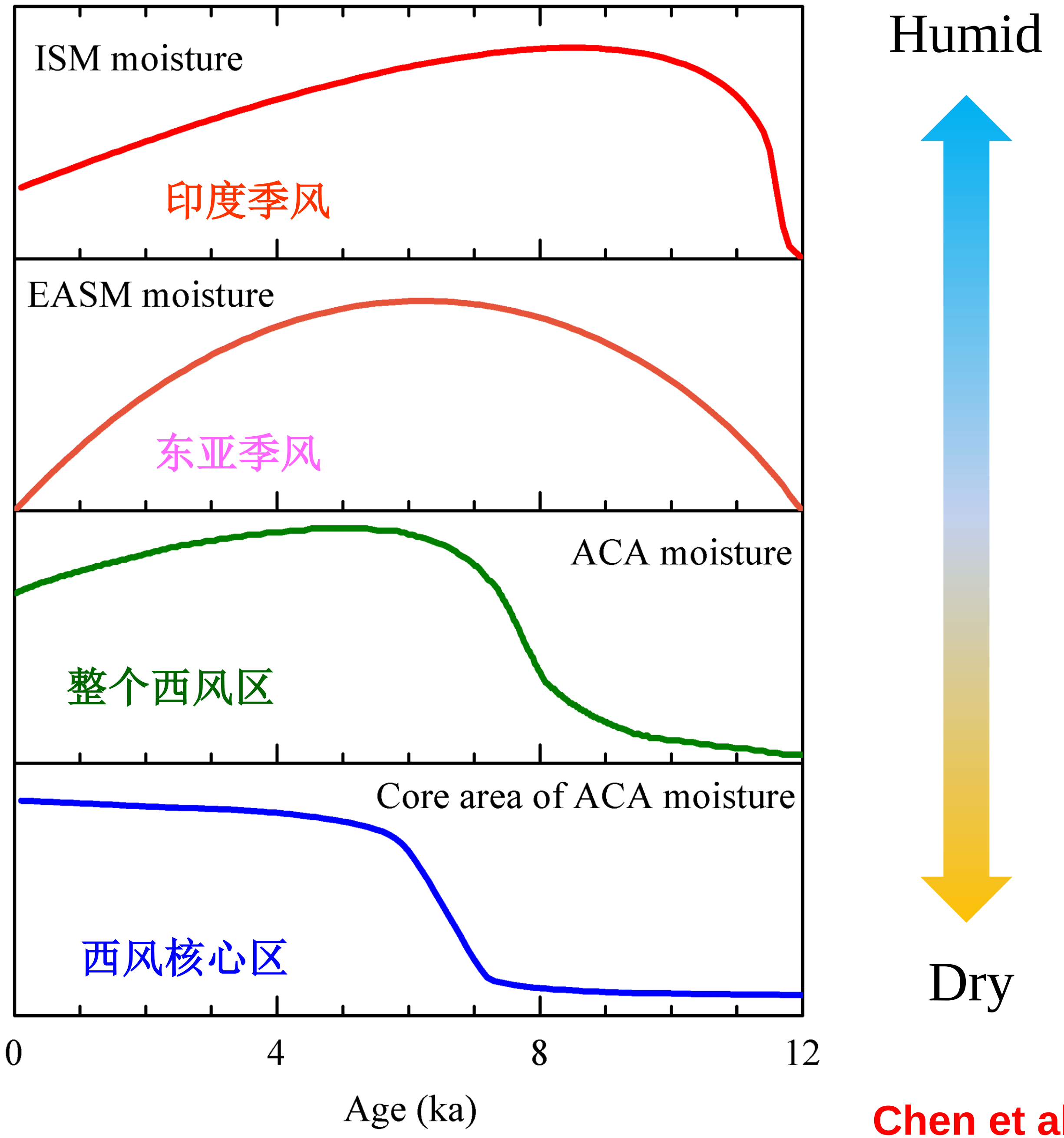
ACA Core area

1. The Holocene moisture evolution history recording from Tienshan Mts. Loess is **similar** with Lacustrine sediments.
2. **Speleothem $\delta^{18}O$** may record a complex signals rather than clean rainfall or moisture signal.
3. **Humid late Holocene** is significant in core ACA area.
4. **Persistent wetting trend** during Holocene in core ACA area.



亚洲中部干旱区气候逐步变湿润

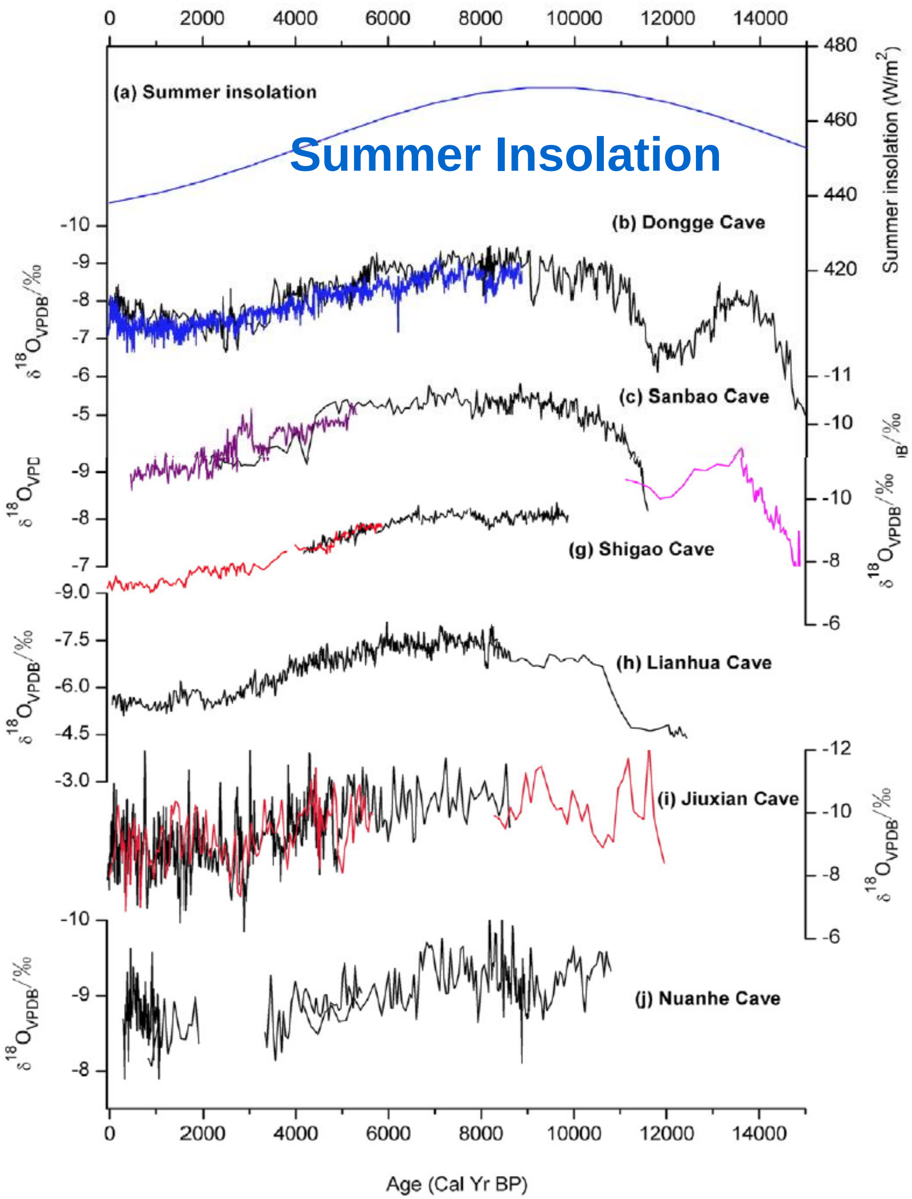
Chen et al., 2016, QSR



现代间冰期尺度

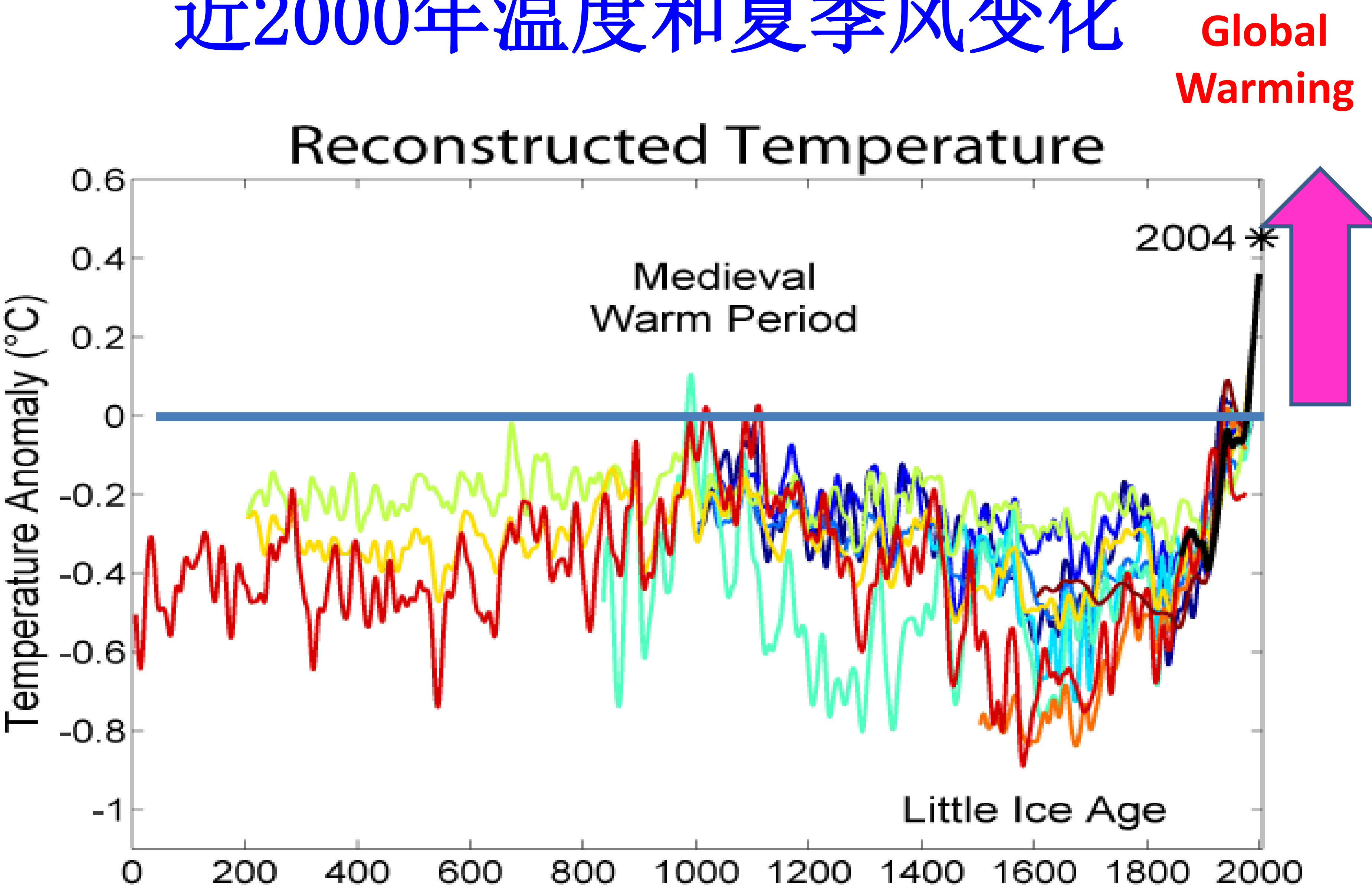
Chen et al., 2016，QSR

Oxygen Isotope of Chinese Cave Speleothem: Summer Monsoon proxy?

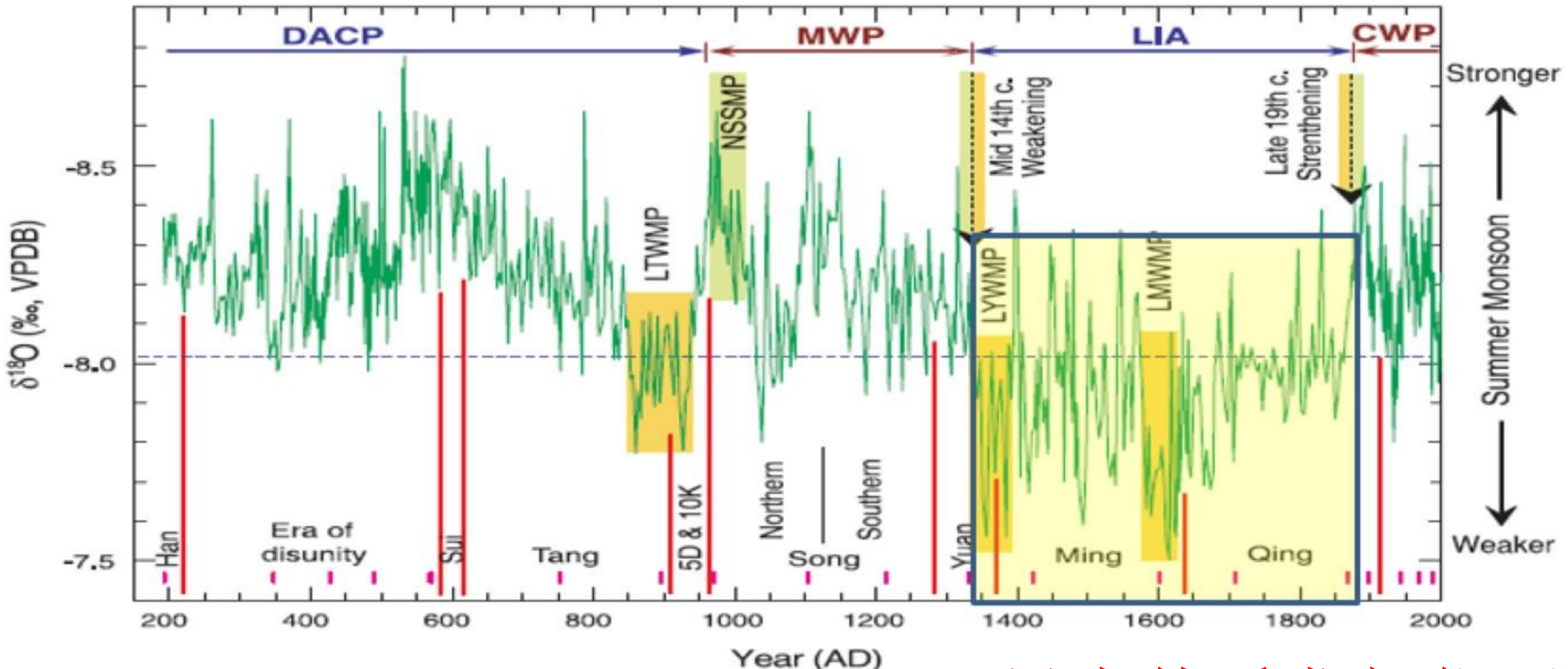


Similarity between speleothem oxygen isotope records in monsoonal China and their consistent variations with changes in the Northern Hemisphere summer insolation

近2000年温度和夏季风变化



http://www.globalwarmingart.com/wiki/File:2000_Year_Temperature_Comparison_png



干旱事件诱发朝代更替

REPORTS

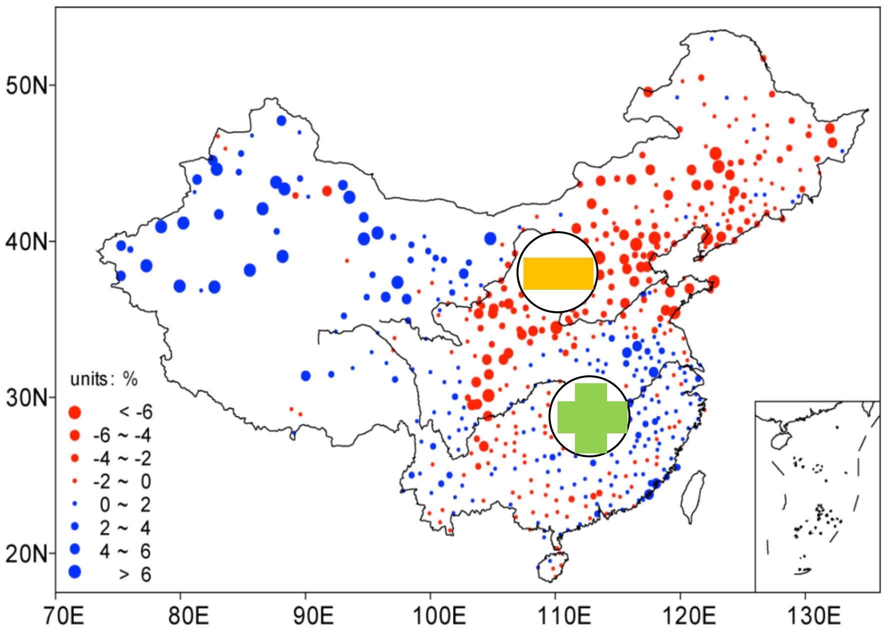
A Test of Climate, Sun, and Culture Relationships from an 1810-Year Chinese Cave Record

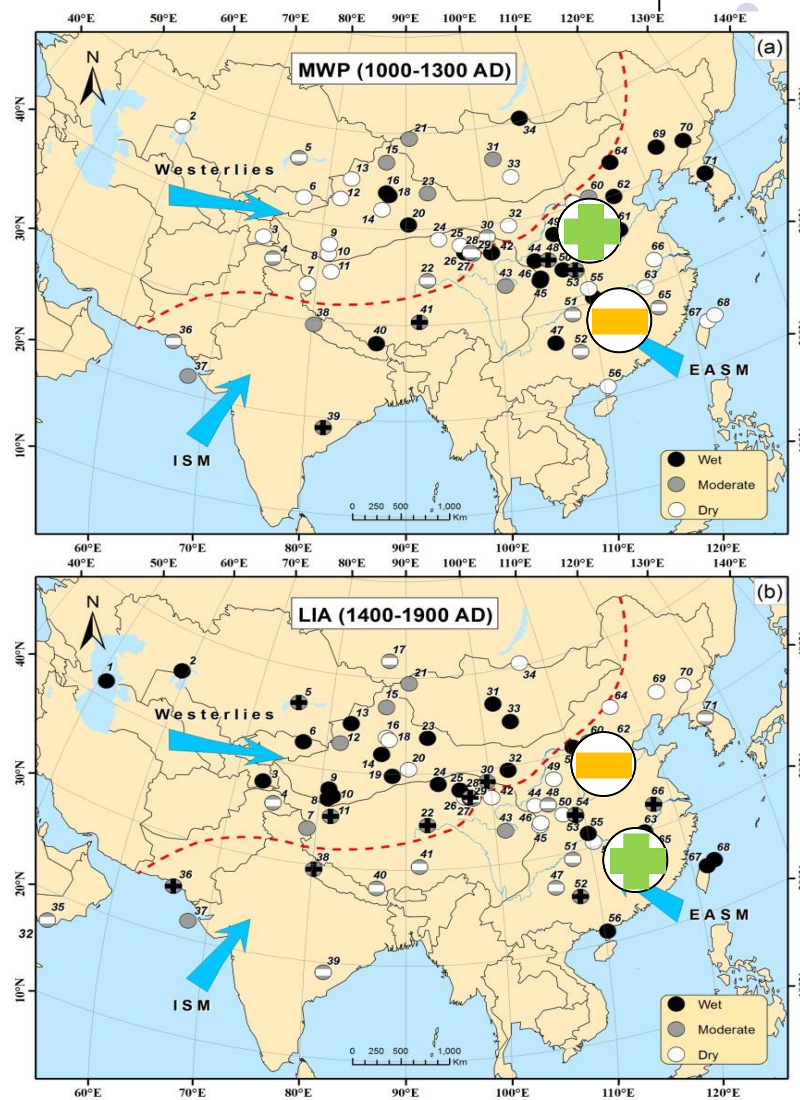
Pingzhong Zhang,[1] Hai Cheng,[2*] R. Lawrence Edwards,[2] Fahu Chen,[1] Yongjin Wang,[3] Xunlin Yang,[1] Jian Liu,[4] Ming Tan,[5] Xianfeng Wang,[2] Jinghua Liu,[1] Chunlei An,[1] Zhibo Dai,[1] Jing Zhou,[1] Dezhong Zhang,[1] Jihong Jia,[1] Liya Jin,[1] Kathleen R. Johnson[6]

Science, 7 Nov., 2008；万象洞石笋

North-South precipitation dipole pattern in monsoonal China

Rainfall Trend in China





Instrumental period (1957-2007)

Ding YH et al., 2007, IJoC

Last millennium (MWP & LIA)

Chen JH et al., 2015, QSR

Strengthened summer monsoon during warm periods of the historical and geological past

Unlike major warming periods in the past:

- Recent warming period affected by anthropogenic forcings: greenhouse gases, aerosols and land-use changes
- Rapid economic growth, industrialization and urbanization make Asia becoming major source of aerosols

Aerial transport of pollutants…

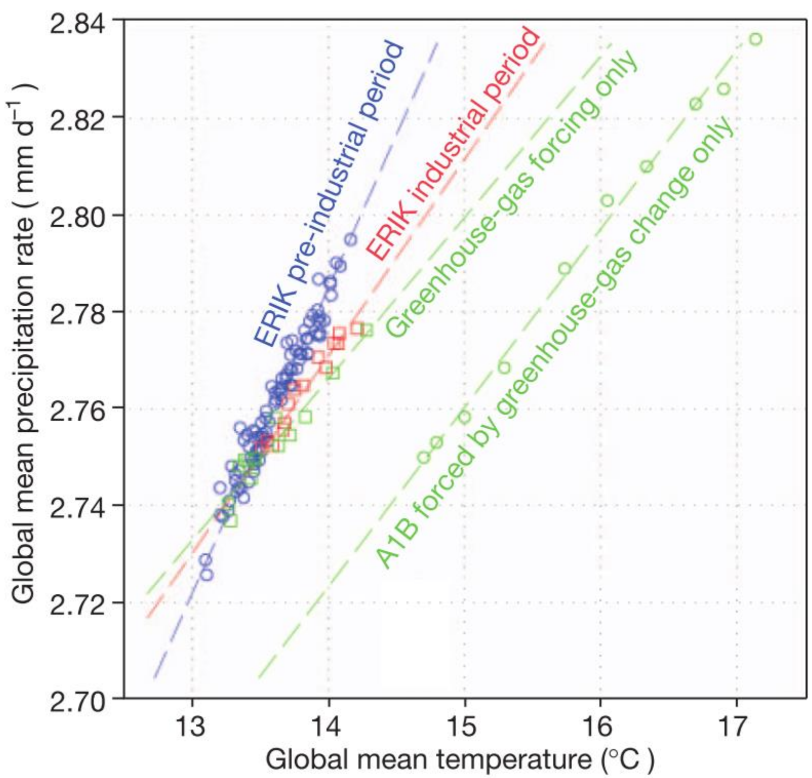
雾霾天气

And we are changing the climate...

doi:10.1038/nature11784

Divergent global precipitation changes induced by natural versus anthropogenic forcing

Jian Liu[1,2], Bin Wang[3], Mark A. Cane[4], So-Young Yim[3] & June-Yi Lee[3]

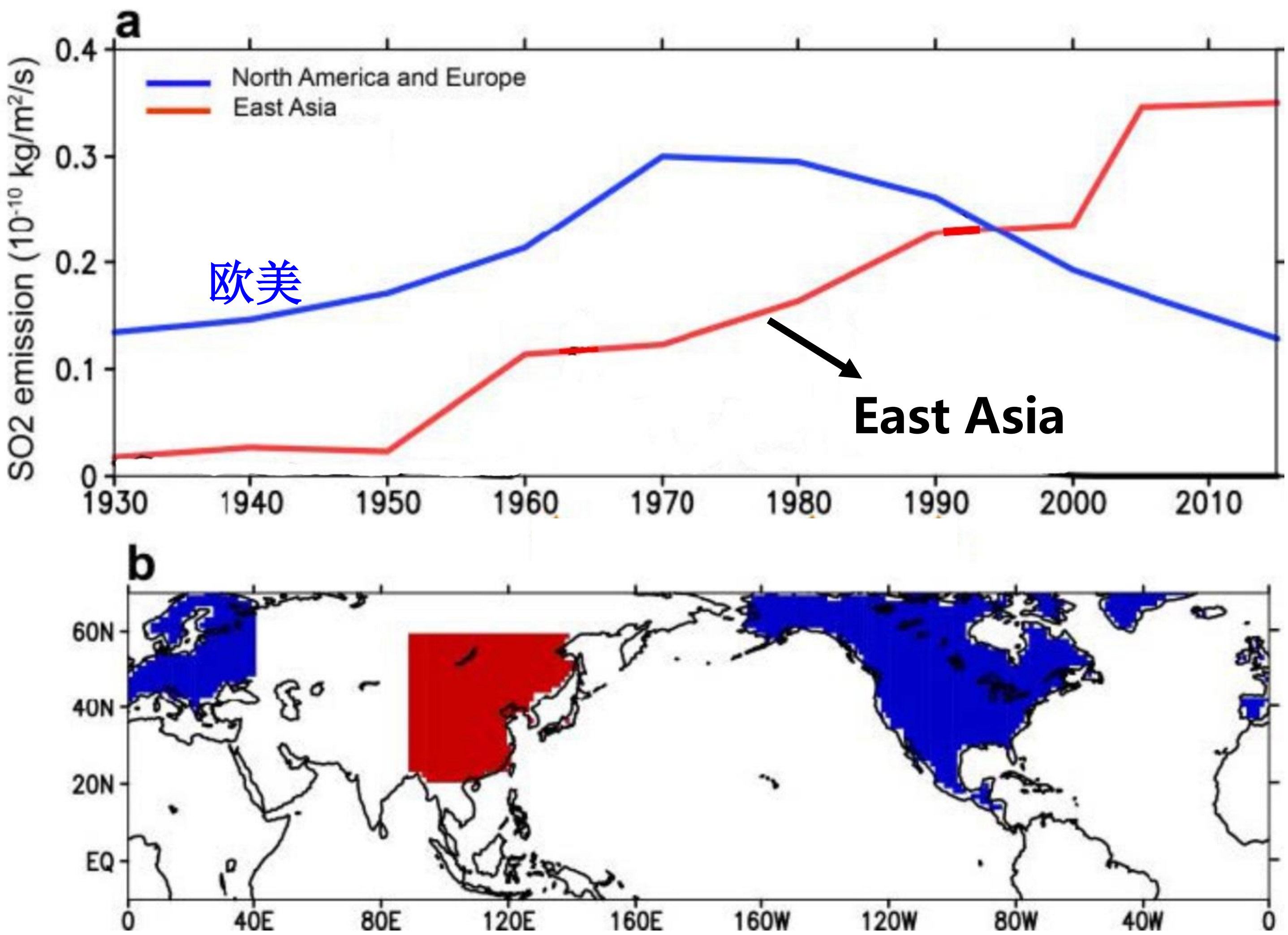


Although the late twentieth century is **warmer** than the Medieval Warm Period, rainfall is **less**.

这种改变会对全球生态系统造成什么影响？

Liu et al., 2013. *Nature*

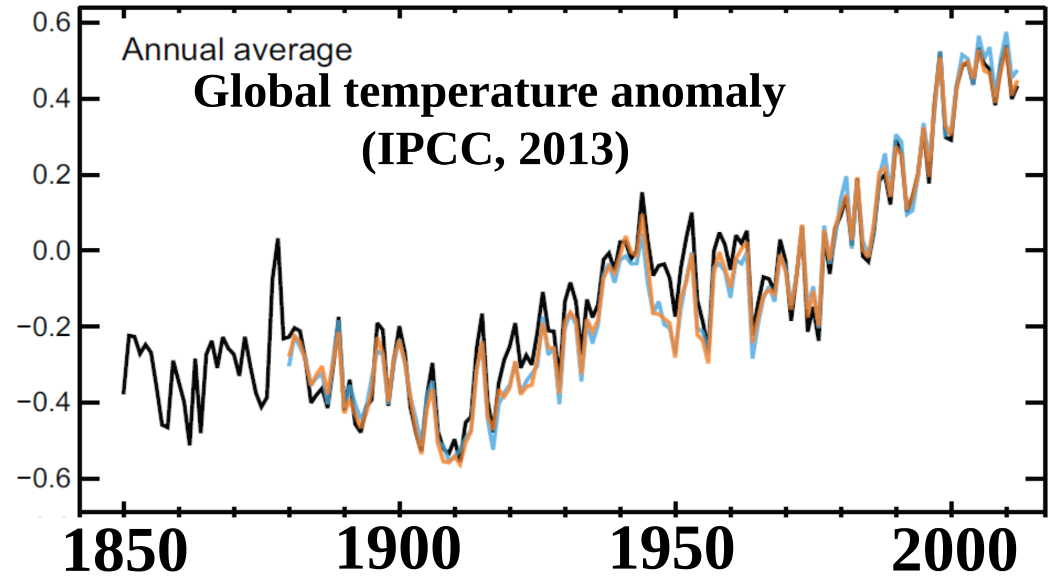
Aerosols striking increased over the past decades

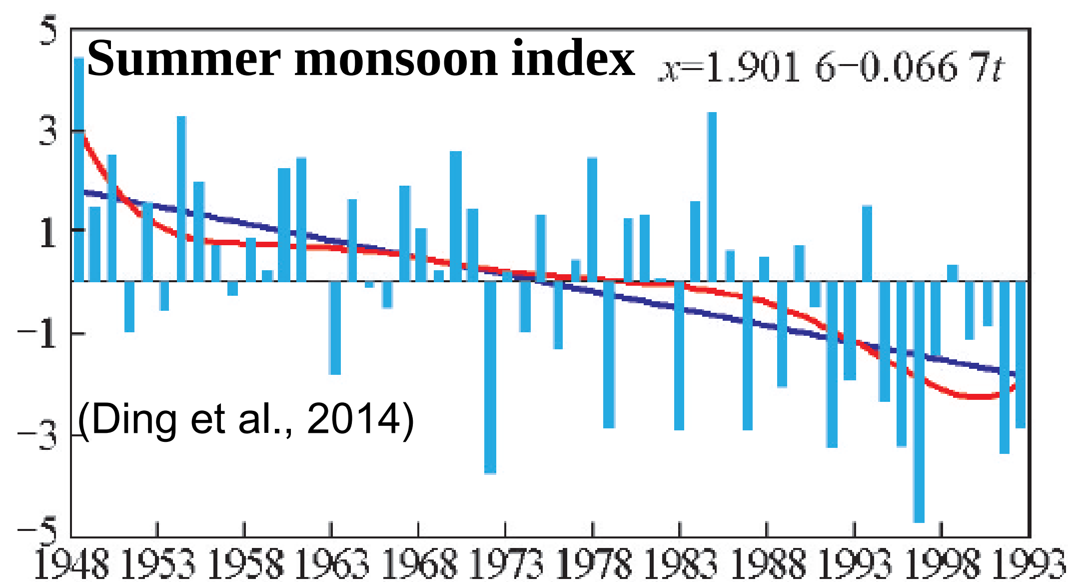


Takahashi *2016, Nature CC*

Global warming coincided with weakened summer monsoon since 1950s

Recent studies argued that increases of **anthropogenic aerosols** play an important role in affecting Asian summer monsoon intensity





Aerosols weaken Asian summer monsoon

Climate Effects of Black Carbon Aerosols in China and India

Surabi Menon,[1,2]* James Hansen,[1] Larissa Nazarenko,[1,2] Yunfeng Luo[3]

Menson et al., 2002, **Science**

Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle

V. Ramanathan*†, C. Chung*, D. Kim*, T. Bettge‡, L. Buja‡, J. T. Kiehl‡, W. M. Washington‡, Q. Fu§, D. R. Sikka¶, and M. Wild‖

*Scripps Institution of Oceanography, University of California at San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0221; ‡National Center for Atmospher Research, Boulder, CO 80307; §University of Washington, Box 351640, Seattle, WA 98195-1640; ¶40 Mausam Vihar, New Delhi, 110 051, India; and ‖Swiss Federal Institute of Technology, Winterhurerstrasse, 190 CH-8057 Zurich, Switzerland

This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected on April 30, 2002.

Ramanathan et al., 2005, **PNAS**

Anthropogenic Aerosols and the Weakening of the South Asian Summer Monsoon

Massimo A. Bollasina,[1] Yi Ming,[2]* V. Ramaswamy[2]

Bollasina et al., 2011, **Science**

Anthropogenic aerosols are a potential cause for migration of the summer monsoon rain belt in China

Shaocai Yu[a,b,1], Pengfei Li[a,b], Liqiang Wang[a,b], Peng Wang[a,b], Si Wang[a,b], Shucheng Chang[a,b], Weiping Liu[a,b], and Kiran Alapaty[c,1]

Yu et al., 2016, **PNAS**

Outlines

1 亚洲夏季风演化

2 2000年湖泊生态响应

3 基本结论

美国著名的科学杂志Science (vol.317, page 1166, 2007) 对于太湖饮用水危机事件进行了报道

水体、湖泊富营养化

Pea soup. Hans Paerl samples cyanobacteria in ailing Taihu lake.

ECOLOGY

Doing Battle With the Green Monster of Taihu Lake

In attempting to subdue a vicious algal bloom, scientists aim to restore the health of a major lake in China and hone strategies for heading off toxic soups elsewhere

TAIHU LAKE, CHINA—As the motorboat glides through a carpet of fetid algae, Hans Paerl leans over the side and scoops up some of the tea-green muck with a plastic sampling bottle. In early June, a bloom of cyanobacteria, also called blue-green algae, fanned out across Taihu, China's third-largest lake. The growth was unchecked when a team led by Paerl, a cyanobacteria expert at the University of North Carolina, Chapel Hill, arrived last month to help colleagues at the Nanjing Institute of Geography and Limnology combat the foul bloom.

Much is at stake. Taihu, fed by the Yangtze River, helps irrigate millions of hectares of grains and cotton in a lush agricultural region between Shanghai and Nanjing. When it's healthy, the lake also provides drinking water for more than 2 million people, and it sustains one of China's most important fisheries for crabs, carp, and eels. The bloom that has turned Taihu into a toxic nightmare shows no signs of abating and may last until winter, experts say.

The ecological drama has far-reaching consequences. "It's safe to say that it's a pretty serious problem, and not just in China," says Paerl. At one time a villain largely confined to small lakes, algal blooms have of late gotten serious footholds in larger water bodies. Paerl warns that lakes such as Victoria in Africa and Erie and Okeechobee in the United States could be on the brink of becoming perennial algal soups.

That could pose a grave health risk. Some cyanobacteria, such as *Microcystis aeruginosa*, make toxins that can damage the liver, intestines, and nervous system. "Toxic cyanobacteria in drinking-water supplies pose a direct threat to public health," says Brett Neilan of the University of New South Wales in Sydney, Australia. Microcystis causes symptoms including diarrhea and liver failure. Reining in the algae at Taihu, Neilan says, could help prevent disasters elsewhere.

It wasn't long ago that Taihu enjoyed a cleaner reputation. A popular 1980s song, "Taihu Beauty," boasted of "white sails above the water, green reeds along the water, fish and shrimp below the water." Back then, says Paerl, Taihu rarely suffered blooms. Now they arrive like clockwork every summer, forcing locals to resort to bottled drinking water.

The root cause of Taihu's ills is an accumulation of nutrient-rich sewage and agricultural runoff in the shallow lake. That resulted in severe eutrophication: a surfeit of minerals and organic nutrients that nourishes algal growth. Unusually hot, dry conditions in early summer appear to have been the spark that ignited this year's bloom.

After the bloom reached nightmarish proportions 2 months ago, cleanup crews skimmed more than 6000 tons of algae from the lake and laid a polyvinyl chloride barrier to prevent algae from getting swept into pipes that funnel water to a drinking-water plant. But some organisms still seep through, says Qin Boqiang of the institute in Nanjing, and currents cannot flush away algae in water enclosed by the barrier.

Simply "cleaning out the algae" will not solve the problem, says Qin. He emphasizes the need to reduce nutrients, especially phosphorus and nitrogen, in the agricultural runoff and sewage. Paerl and Qin are conducting experiments to determine how much nutrient concentrations must fall to arrest a bloom. They also hope to unravel the dynamics of bloom formation. "The reason we developed this collaborative effort is that we have similar problems in the United States," says Paerl. "We thought, 'Why not combine our expertise?' "

Other researchers are probing the molecular biology of cyanobacteria toxins. With global temperatures rising, warmer surface water leads to less mixing, which favors the growth of toxic cyanobacteria. Deciphering the toxins' biological role and how the environment influences their production may suggest strategies for making blooms less venomous, Neilan says.

Cyanobacteria have a long history of acquiring remarkable adaptations, such as nitrogen fixation and gas vesicles that keep them afloat and enable them to outcompete diatoms and green algae for light and nutrients. They can lie dormant in extreme conditions—surviving droughts and freezing—then roar to life when conditions improve. Cyanobacteria are "very tough," Paerl says. "They're the cockroaches of lakes."

To control Taihu's little green pests, the government in the nearby city of Wuxi crafted an aggressive recovery strategy. The plan promulgates tough emissions standards for phosphorus and nitrogen for factories near Taihu and requires the installation of facilities that remove nutrients from sewage. Nutrient-rich agricultural runoff would be stemmed by banning chemical fertilizers, pesticides, and detergents that contain phosphorus or nitrogen. The amount of clean water pumped from Taihu is projected to reach 1 million tons per day by the end of 2008, and industries in Wuxi must meet a water-recycling rate of 78% by 2010.

"There's no doubt that Taihu is going to be a challenge," says Paerl. Degradation of the lake's water quality was a slow-motion train wreck that played out over several decades. It may take many more years to banish the blooms and bring back the Taihu Beauty of yore.

–LUCIE GUO

Lucie Guo is a freelance writer based in Boston.

CREDIT: HANS PAERL

营养盐与温度，谁对蓝藻水华暴发贡献大?

CLIMATE

Blooms Like It Hot

Hans W. Paerl[1] and Jef Huisman[2]

A link exists between global warming and the worldwide proliferation of harmful cyanobacterial blooms.

Nutrient overenrichment of waters by urban, agricultural, and industrial development has promoted the growth of cyanobacteria as harmful algal blooms (see the figure) (*1*, *2*). These blooms increase the turbidity of aquatic ecosystems, smothering aquatic plants and thereby suppressing important invertebrate and fish habitats. Die-off of blooms may deplete oxygen, killing fish. Some cyanobacteria produce toxins, which can cause serious and occasionally fatal human liver, digestive, neurological, and skin diseases (*1*–*4*). Cyanobacterial blooms thus threaten many aquatic ecosystems, including Lake Victoria in Africa, Lake Erie in North America, Lake Taihu in China, and the Baltic Sea in Europe (*3*–*6*). Climate change is a potent catalyst for the further expansion of these blooms.

Rising temperatures favor cyanobacteria in several ways. Cyanobacteria generally grow better at higher temperatures (often above 25°C) than do other phytoplankton species such as diatoms and green algae (*7*, *8*). This gives cyanobacteria a competitive advantage at elevated temperatures (*8*, *9*). Warming of surface waters also strengthens the vertical stratification of lakes, reducing vertical mixing. Furthermore, global warming causes lakes to stratify earlier in spring and destratify later in autumn, which lengthens optimal growth periods. Many cyanobacteria exploit these stratified conditions by forming intracellular gas vesicles, which make the cells buoyant. Buoyant cyanobacteria float upward when mixing is weak and accumulate in dense surface blooms (*1*, *2*, *7*) (see the figure). These surface blooms shade underlying nonbuoyant phytoplankton, thus suppressing their opponents through competition for light (*8*).

Cyanobacterial blooms may even locally increase water temperatures through the intense absorption of light. The temperatures of surface blooms in the Baltic Sea and in Lake IJsselmeer, Netherlands, can be at least 1.5°C above those of ambient waters (*10*, *11*). This positive feedback provides additional competitive dominance of buoyant cyanobacteria over nonbuoyant phytoplankton.

Global warming also affects patterns of precipitation and drought. These changes in the hydrological cycle could further enhance cyanobacterial dominance. For example, more intense precipitation will increase surface and groundwater nutrient discharge into water bodies. In the short term, freshwater discharge may prevent blooms by flushing. However, as the discharge subsides and water residence time increases as a result of drought, nutrient loads will be captured, eventually promoting blooms. This scenario takes place when elevated winter-spring rainfall and flushing events are followed by protracted periods of summer drought. This sequence of

[1]Institute of Marine Sciences, University of North Carolina at Chapel Hill, Morehead City, NC 28557, USA. E mail: hpaerl@email.unc.edu [2]Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, 1018 WS Amsterdam, Netherlands. E mail: jef.huisman@science.uva.nl

CREDITS: (TOP) HANS PAERL/UNIVERSITY OF NORTH CAROLINA; (BOTTOM) SATELLITE PHOTO, DIGITALGLOBE

Unde
covere
River
Victori

ECOLOGY

Resilience to Blooms

Justin D. Brookes[1] and Cayelan C. Carey[2]

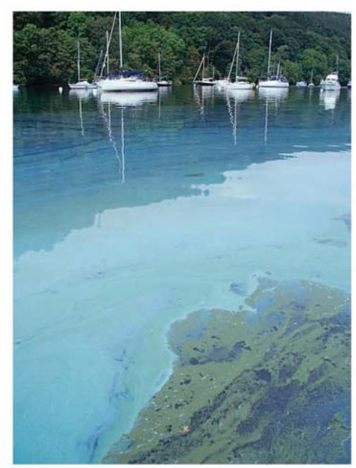
Managing nitrogen and phosphorus pollution of fresh water may decrease the risk of cyanobacterial blooms, even in the face of warming temperatures.

Cyanobacterial blooms (see the figure) present health risks worldwide for humans and livestock that drink or use contaminated water, and also represent substantial economic costs to communities due to water treatment, lost tourism and recreation revenue, and declining property values (*1*). These explosive growths occur in fresh and marine water, and may be increasing globally. One recommendation is that water managers must address the effects of climate change when combating cyanobacterial blooms (*2*). However, recent studies suggest that controlling nutrients may be more important in increasing aquatic ecosystem resilience to these blooms.

A number of factors may potentially contribute to an increase in blooms, primarily climate change and changing land use. Most climate change modeling scenarios predict that aquatic systems will experience increases in temperature, thermal stratification (*2*), and water column stability, all factors that favor cyanobacteria over other phytoplankton (*2*, *3*). Thermal stratification leads to a greater propensity for cyanobacterial blooms, as many cyanobacteria have gas-filled vesicles that enable them to rise to the water surface and form dense blooms (*2*, *4*). In addition to climate change, deforestation, human and commercial animal waste, and agricultural fertilization have increased nutrient runoff into aquatic systems (*5*), also favoring cyanobacterial blooms.

What is the relative importance of warming temperature versus nutrient (nitrogen and phosphorus) loading in driving cyanobacterial dynamics? Many modeling studies (*6*, *7*), historical data analyses (*4*, *8*), and experimental studies (*9*, *10*) show increased nutrient concentrations as a consistently more important driver of blooms than warming temperatures. For example, in Lake Müggel (Müggelsee), Germany, cyanobacteria did not directly benefit from increased water temperatures; rather, blooms decreased as nutrient loading was reduced (*4*, *11*). Whereas some studies indicate that increasing nutrients and temperatures may exert a synergistic effect on cyanobacterial dominance (*4*, *6*, *7*), nutrient loading, notably nitrogen and phosphorus, is the primary factor in the expansion of blooms (*12*).

There are several mechanisms by which increased nutrients lead to the dominance of



Big bloom. A cyanobacterial bloom in Lake Windermere, England, in June 2007. See SOM text for suggested resources related to cyanobacerial blooms.

PHOTO CREDIT: LOUISE MILES/FRESHWATER BIOLOGICAL ASSOCIATION

[1]School of Earth and Environmental Science, University of Adelaide, Adelaide 5005, Australia. [2]Department of Ecology and Evolutionary Biology, Cornell University, Ithaca, NY 14853, USA. E-mail: justin.brookes@adelaide.edu.au, ccc99@cornell.edu

Science, 2008, 2011

自然温暖时期　亚洲夏季风增强

人为变暖　　　亚洲夏季风减弱

暖期是否更有利湖泊富营养化？

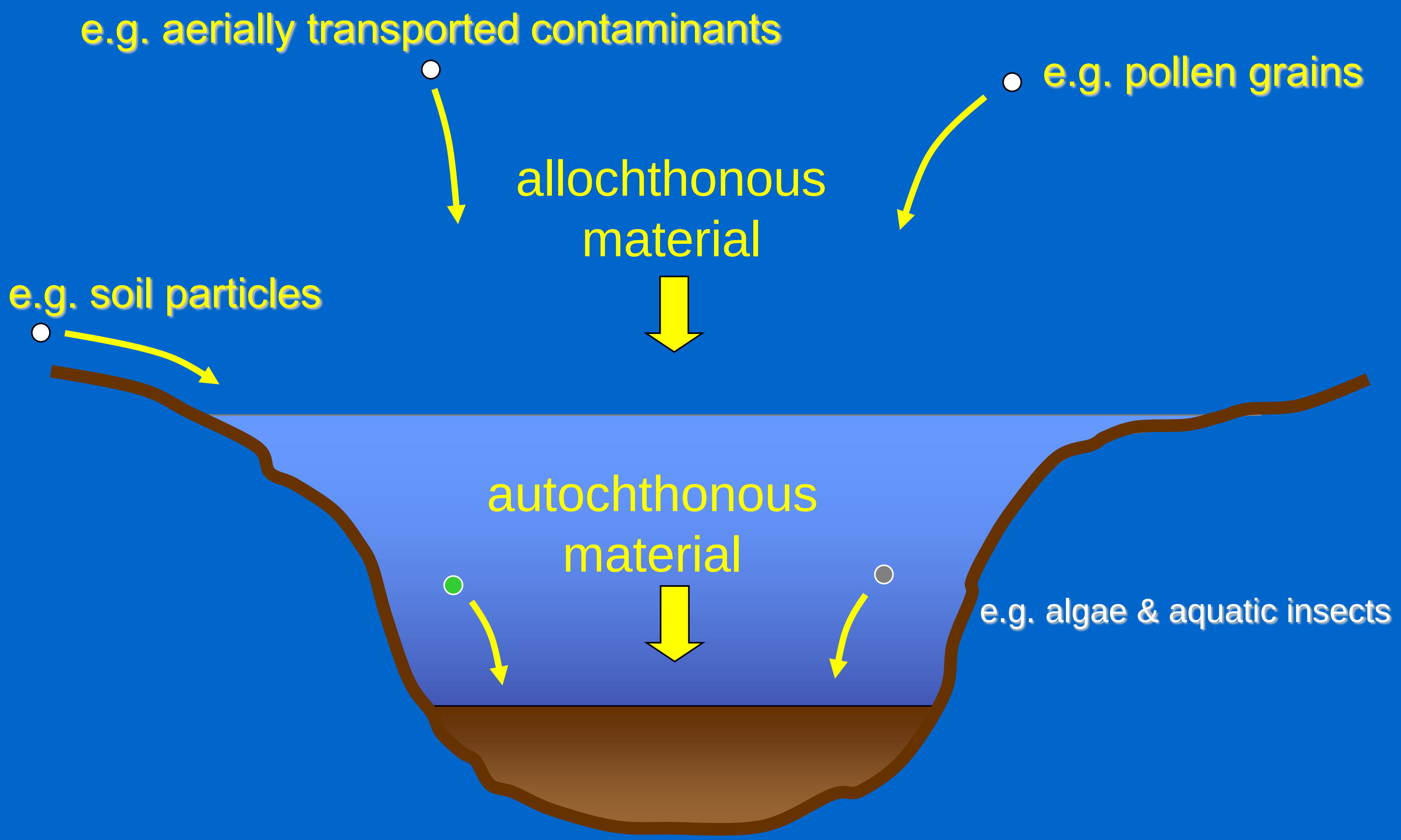
生态系统对两类气候变暖响应是否存在差异？

The past matters …

挖掘过去信息，寻找答案

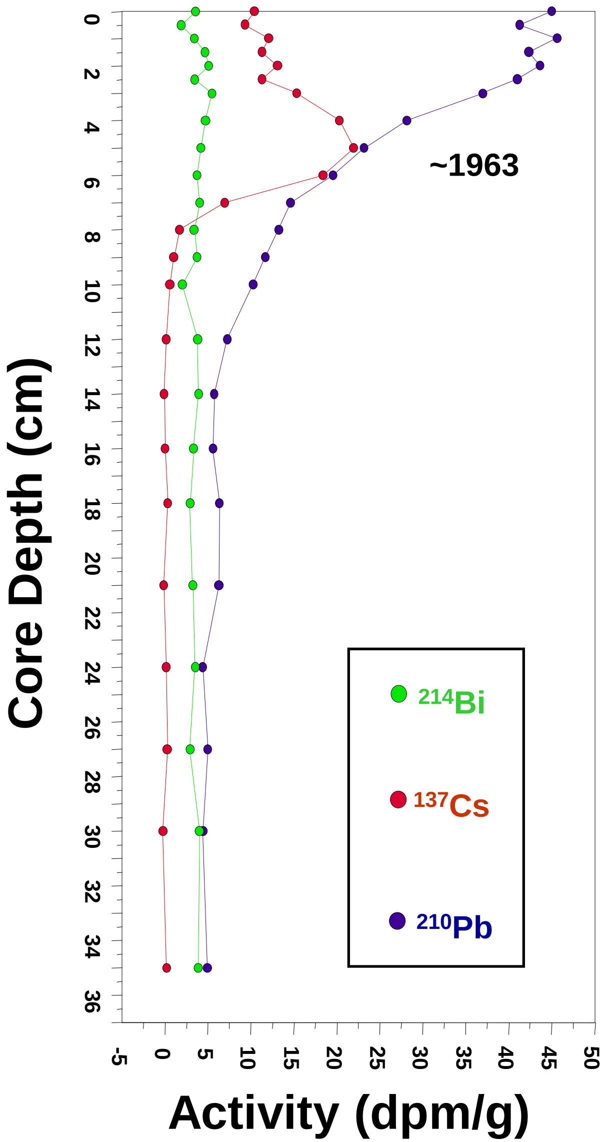
http://www.virginmedia.com/money/features/worst-financial-bad-habits.php?ssid=5

Paleolimnology:
Sediments as environmental archives



Dating the sedimentary sequences

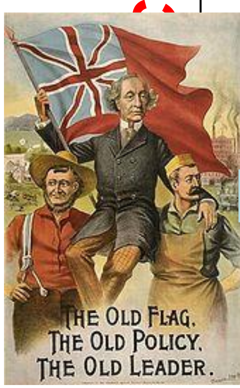
- ^{210}Pb & ● ^{137}Cs (radioisotopes)



Youngest

Record

2010
2007
2004
2002
2000
1998
1996
1994
1992
1990
1987
1985
1981
1976
1972
1950
1946
1936
1926
1920
1910
1900
1890
1856
1850
1846



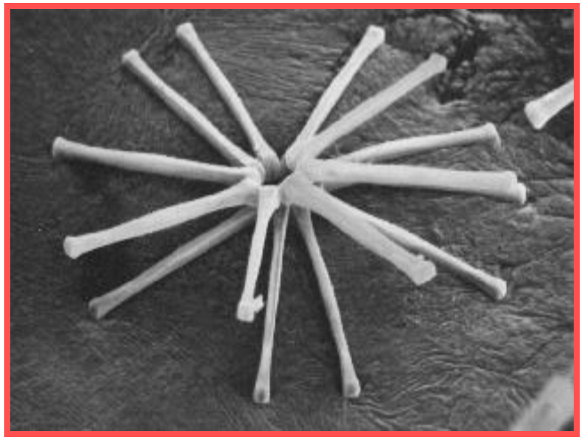
From the Aquatic System

藻类
Algae

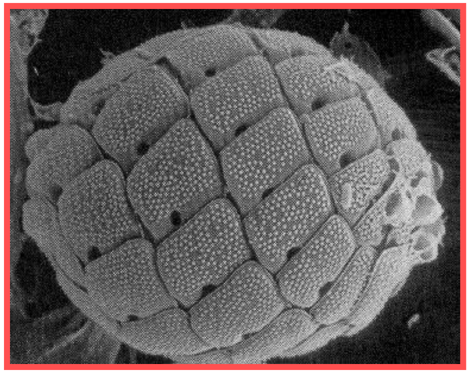
枝角类
Cladocerans

摇蚊
Chironomids

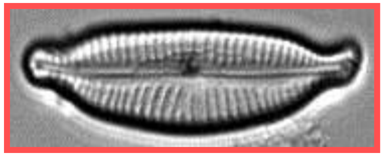
活体



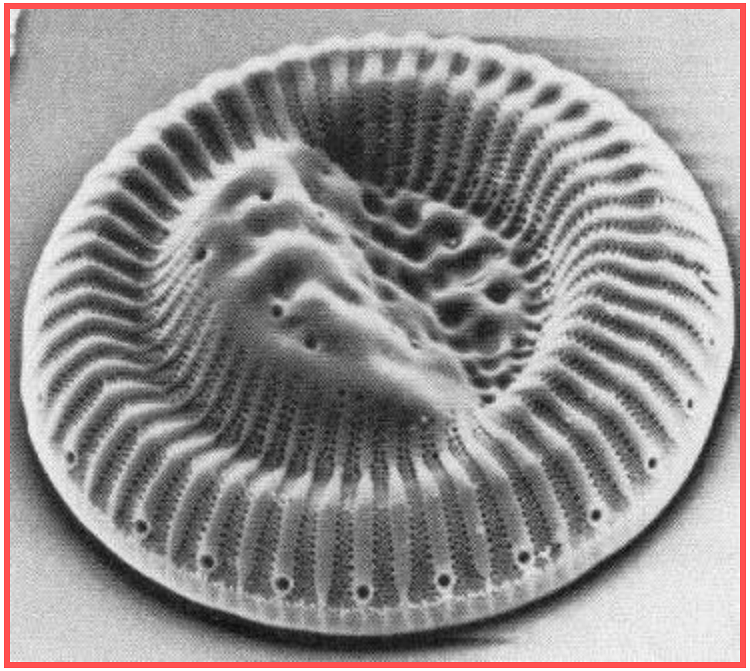
化石

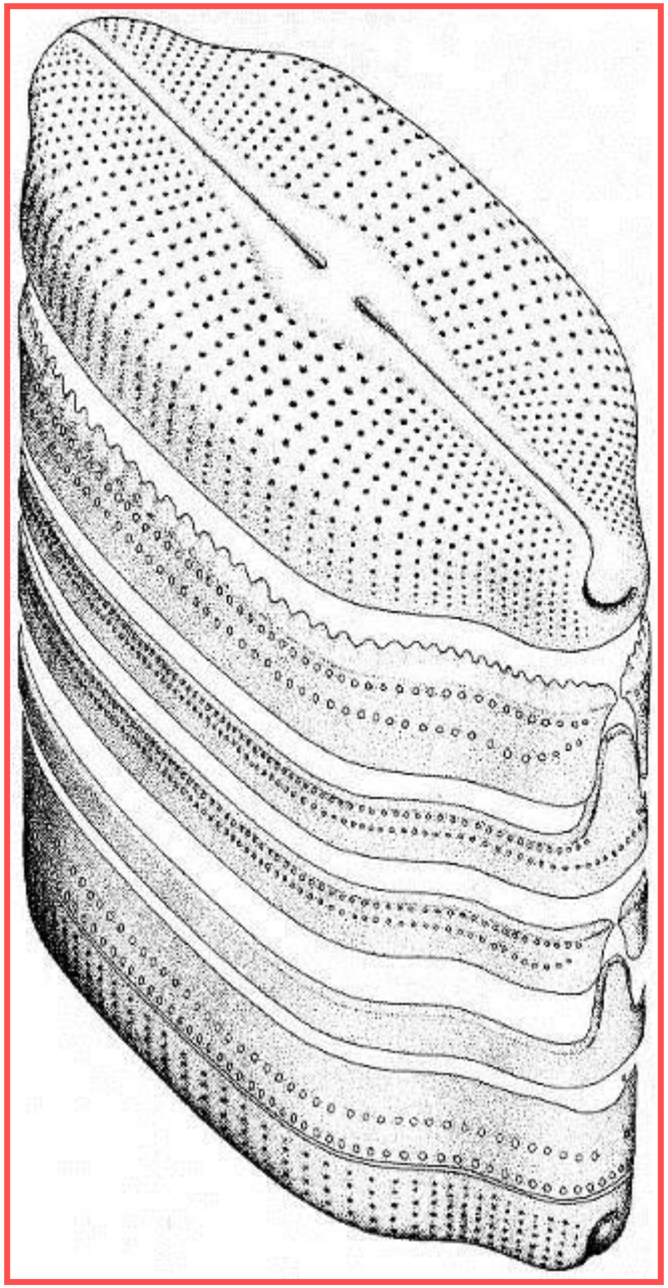


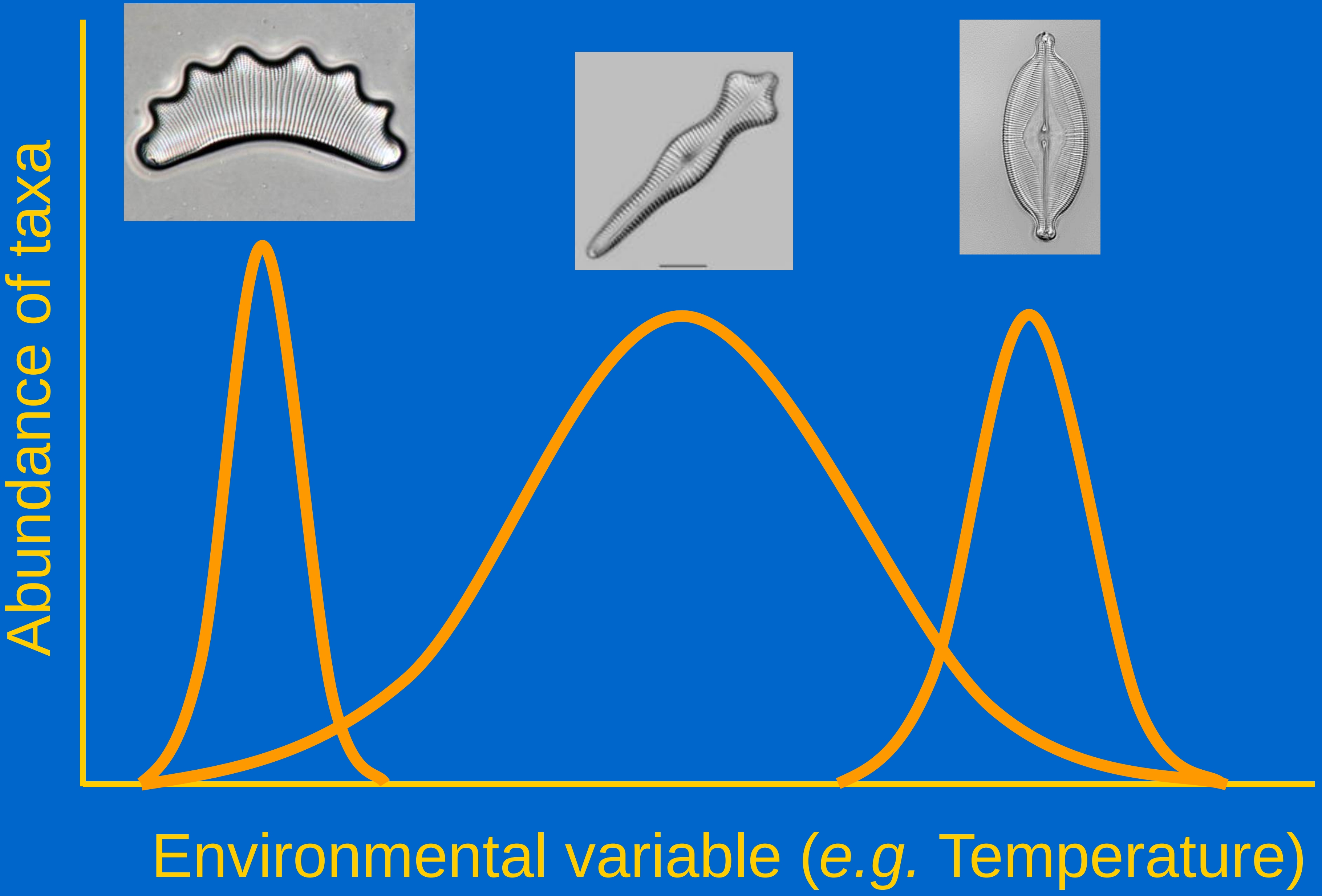
Diatoms

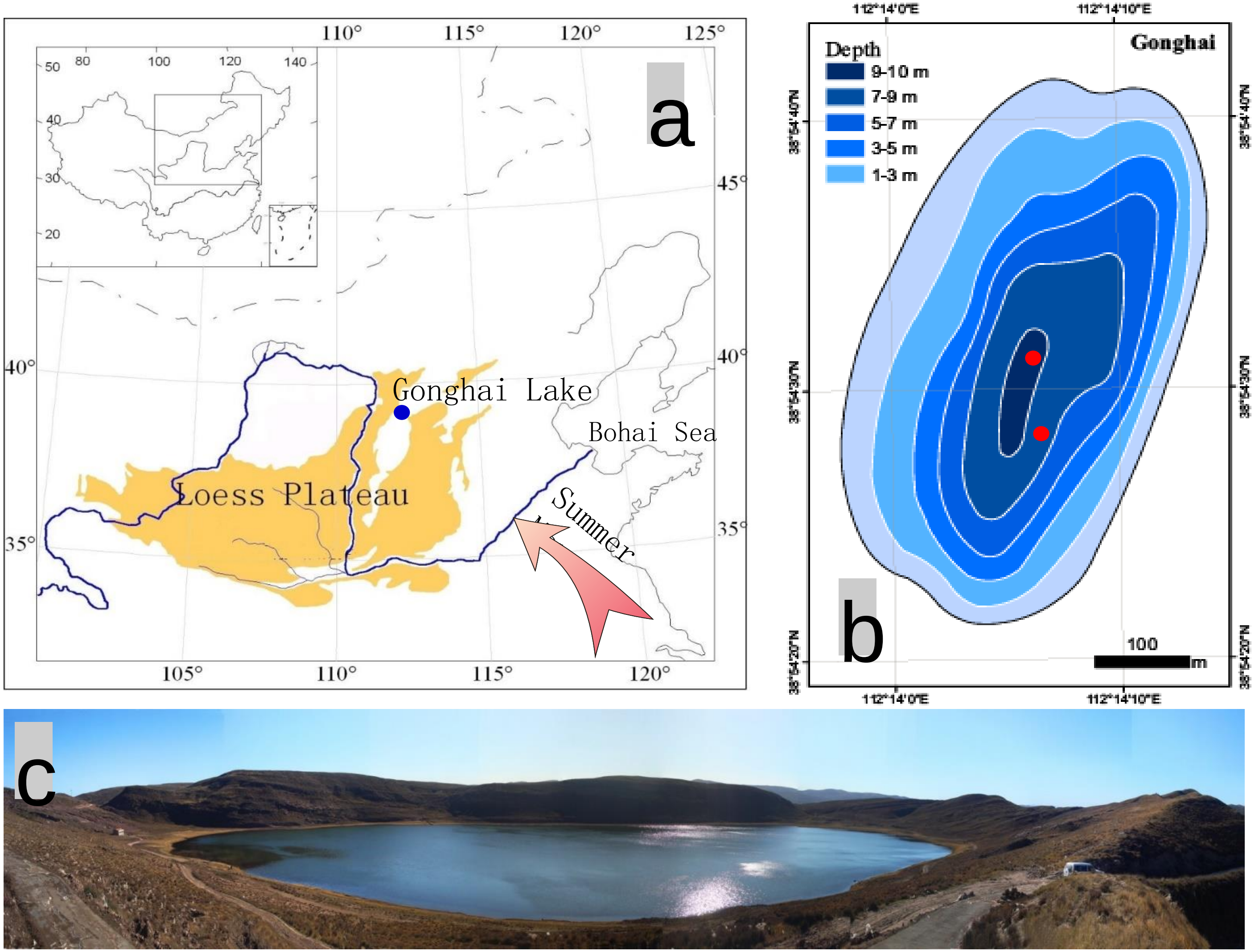


- Bacillariophyta
- abundant and diverse
- siliceous cell walls (frustules)
- excellent indicators of lake nutrient levels and lake properties, such as extent of lake ice and thermal stratification





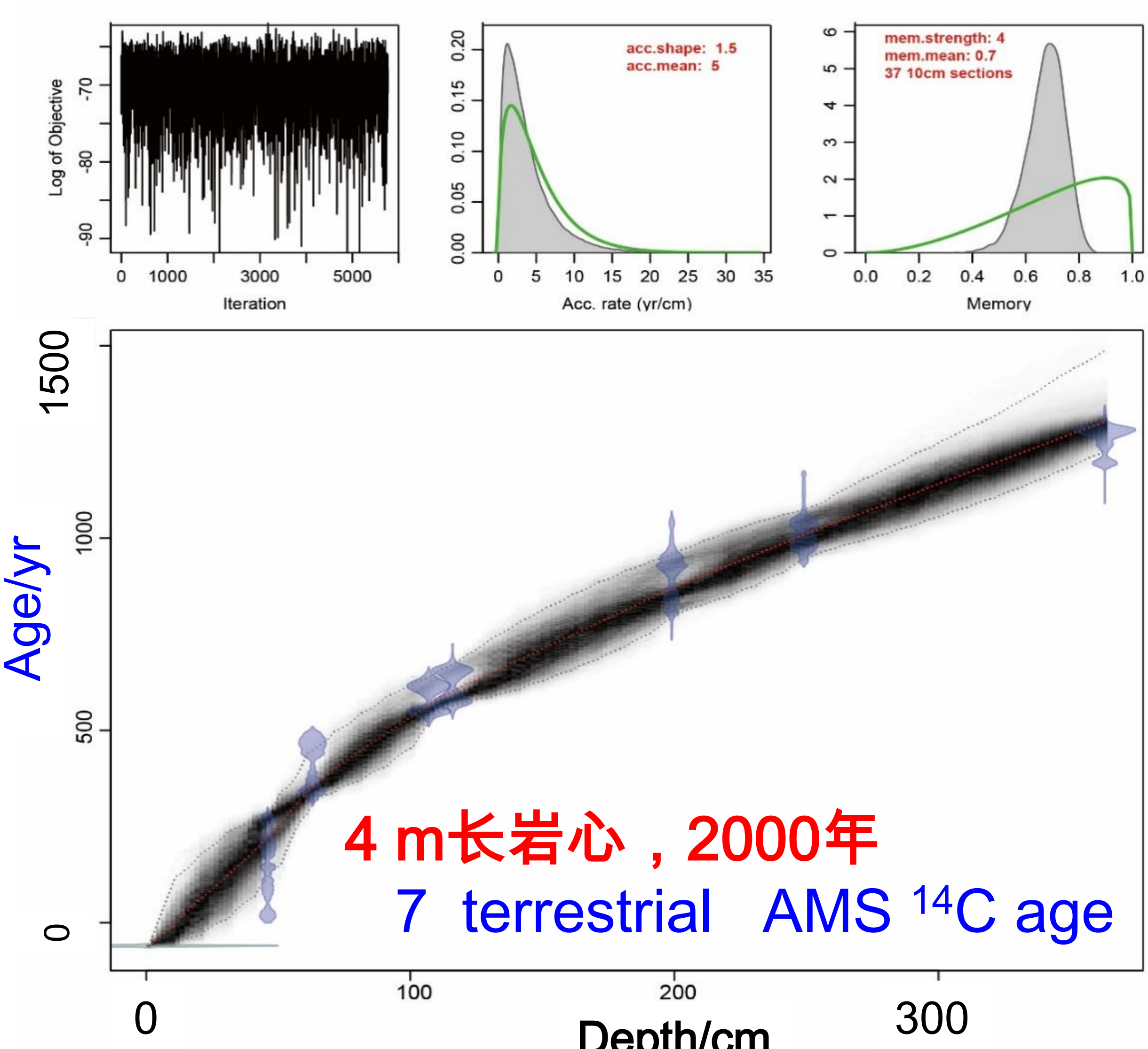

Abundance of taxa
Environmental variable (*e.g.* Temperature)

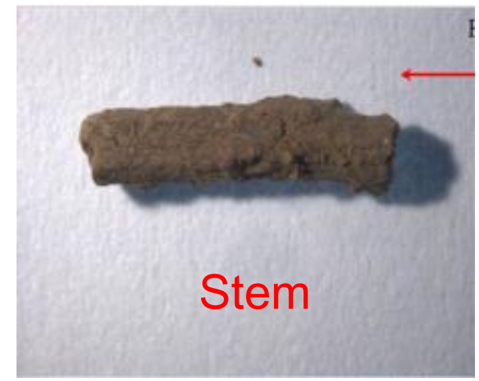


山西公海

- Undisturbed catchment with little human activities
- Ideal monitor of lake ecological and climatic change

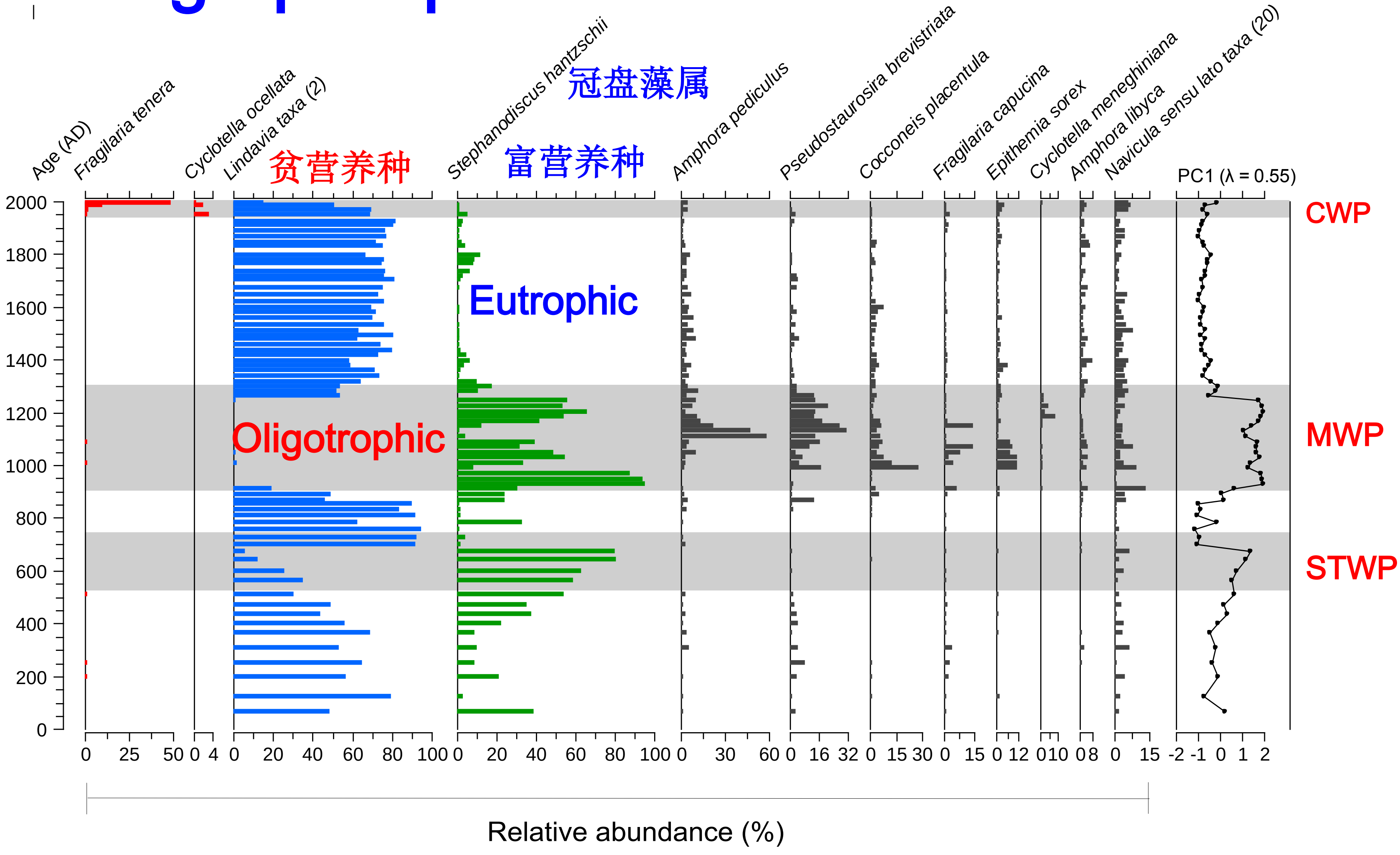
High-resolution chronology of long-drilled core





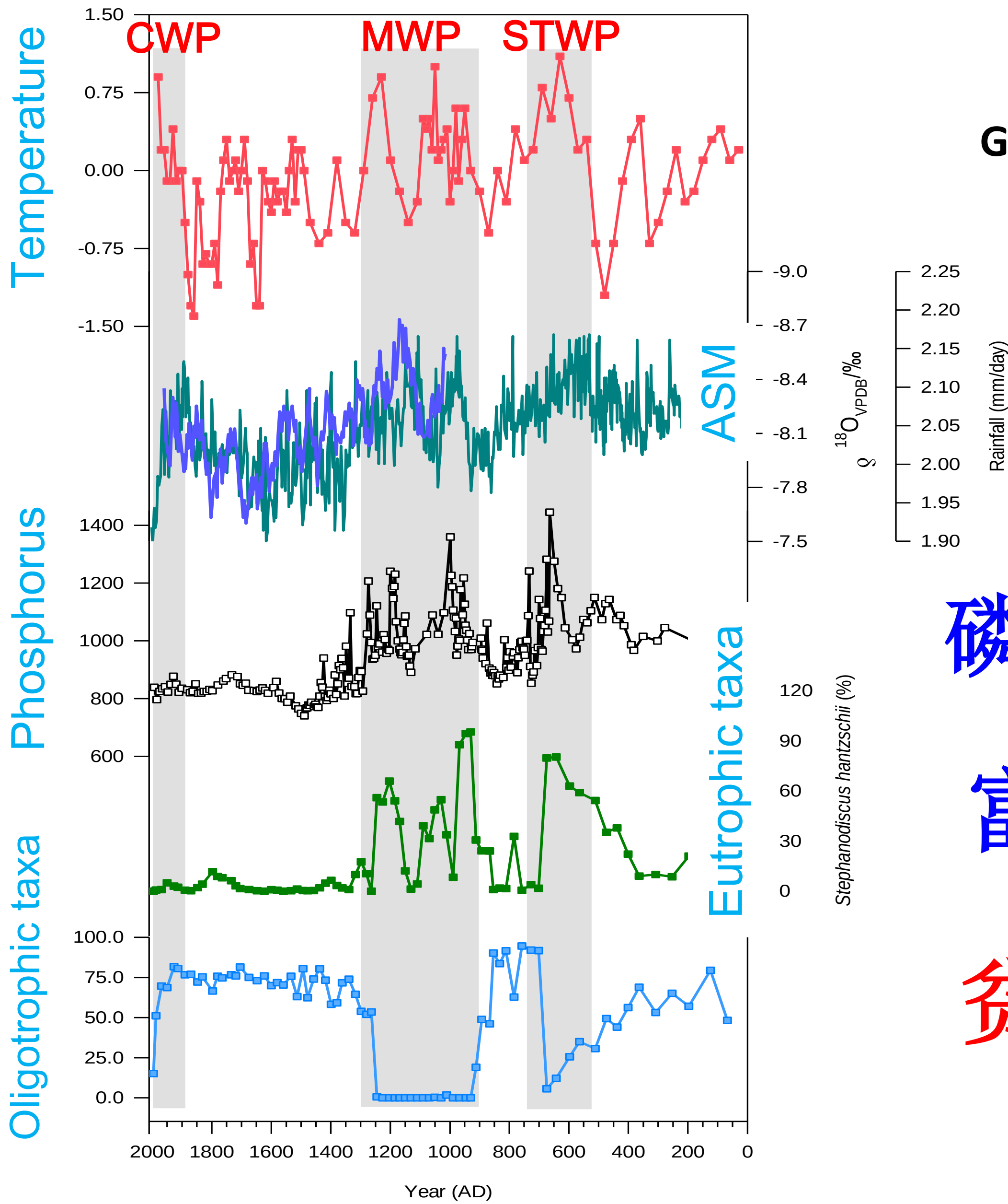
样品间隔5年

Stratigraphic profile of diatom taxa



Dramatic eutrophication correspond to the natural warm periods

Aquatic ecosystem variation over past two millennium



Ge et al., 2003

Zhang et al., 2008

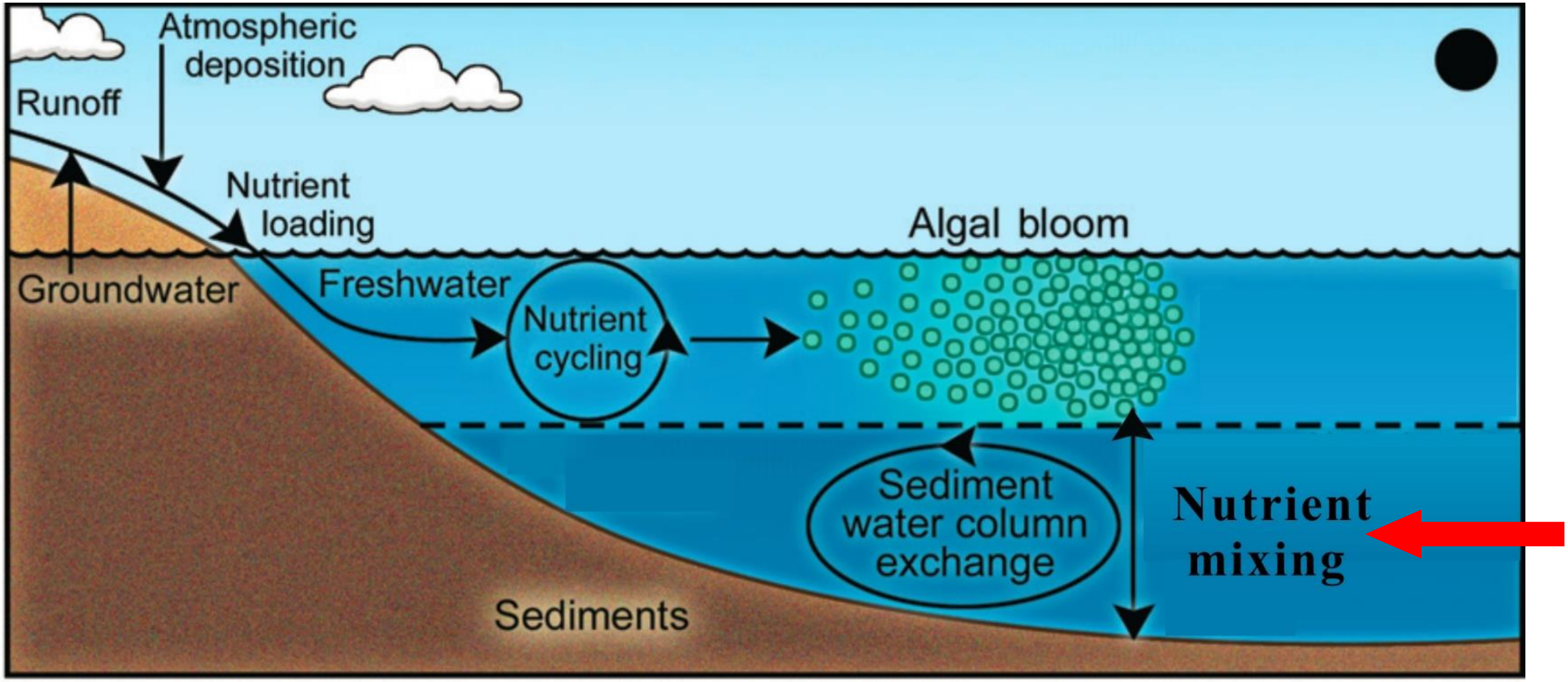
磷含量

富营养种

贫营养种

The past warm periods:

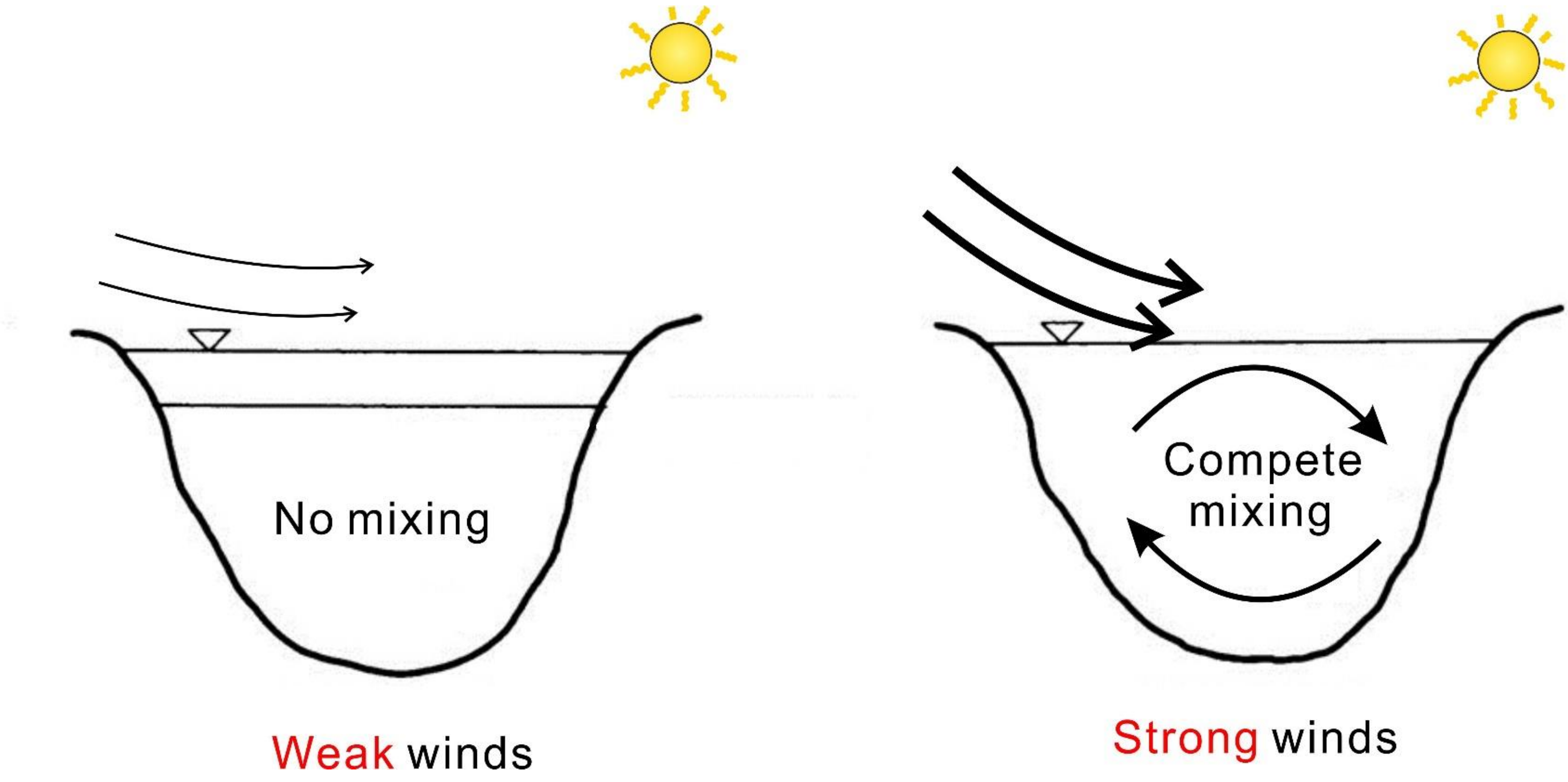
Stronger summer monsoon → more rainfall → stronger erosion → more nutrition inputs (P) → increased lake fertilization



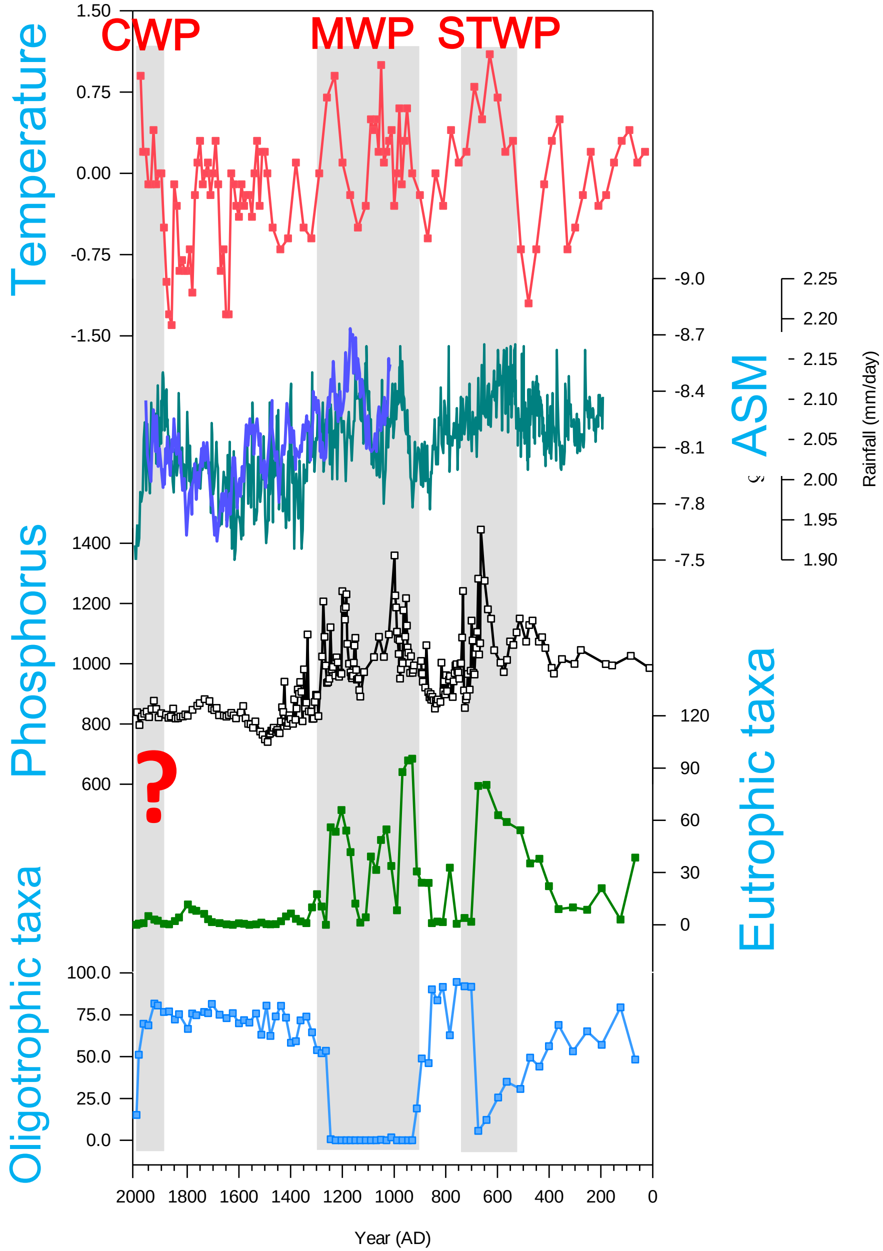
Perel and Justić, 2011, Treatise on Estuarine and Coastal Science

The past warm periods:

Stronger summer monsoon → increased wind intensity → stronger mixing

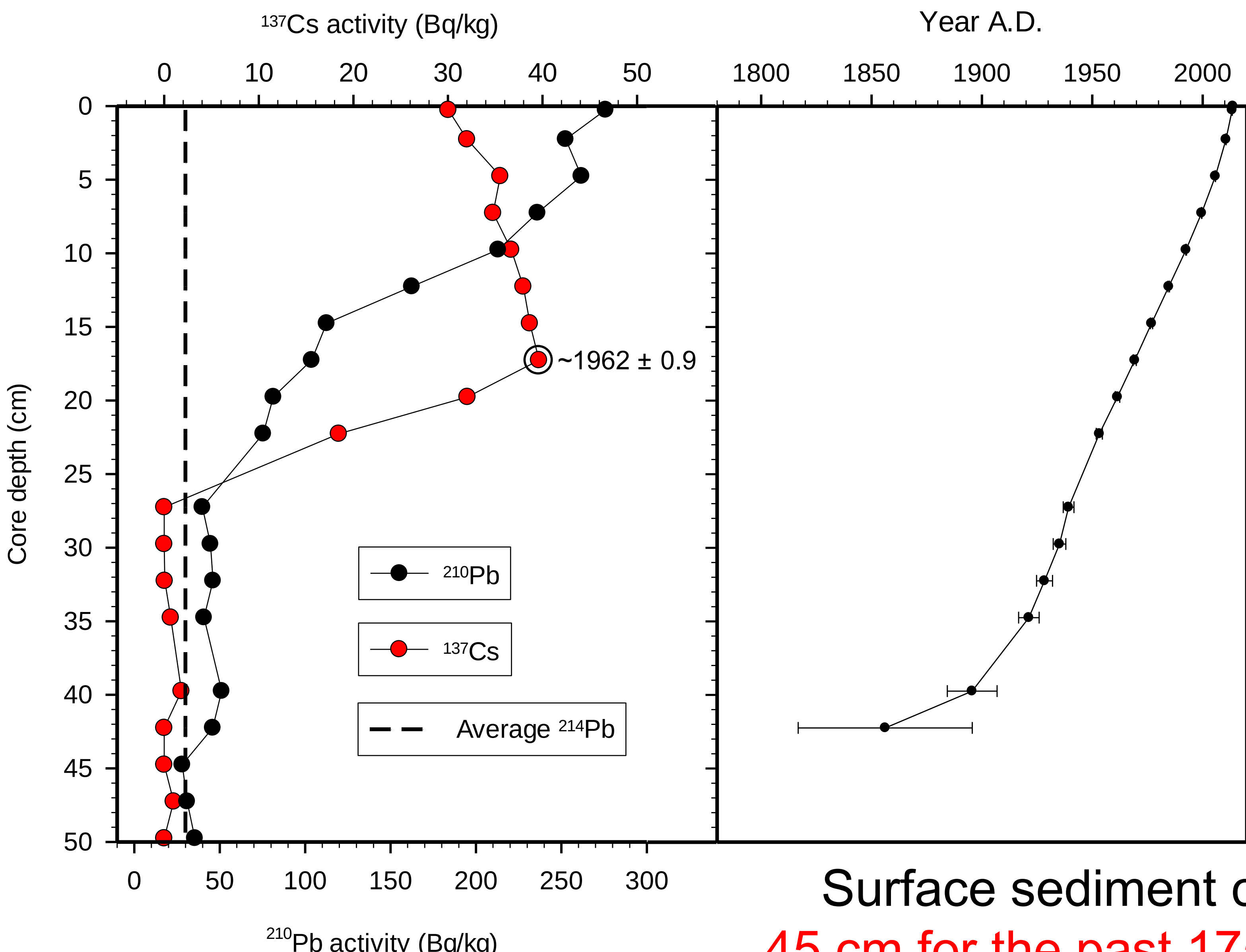


Aquatic ecosystem variation over past two millennium



During natural warm period, the stronger summer monsoon resulted in increasing lake fertilization due to more nutrient input by more precipitation and stronger wind intensity

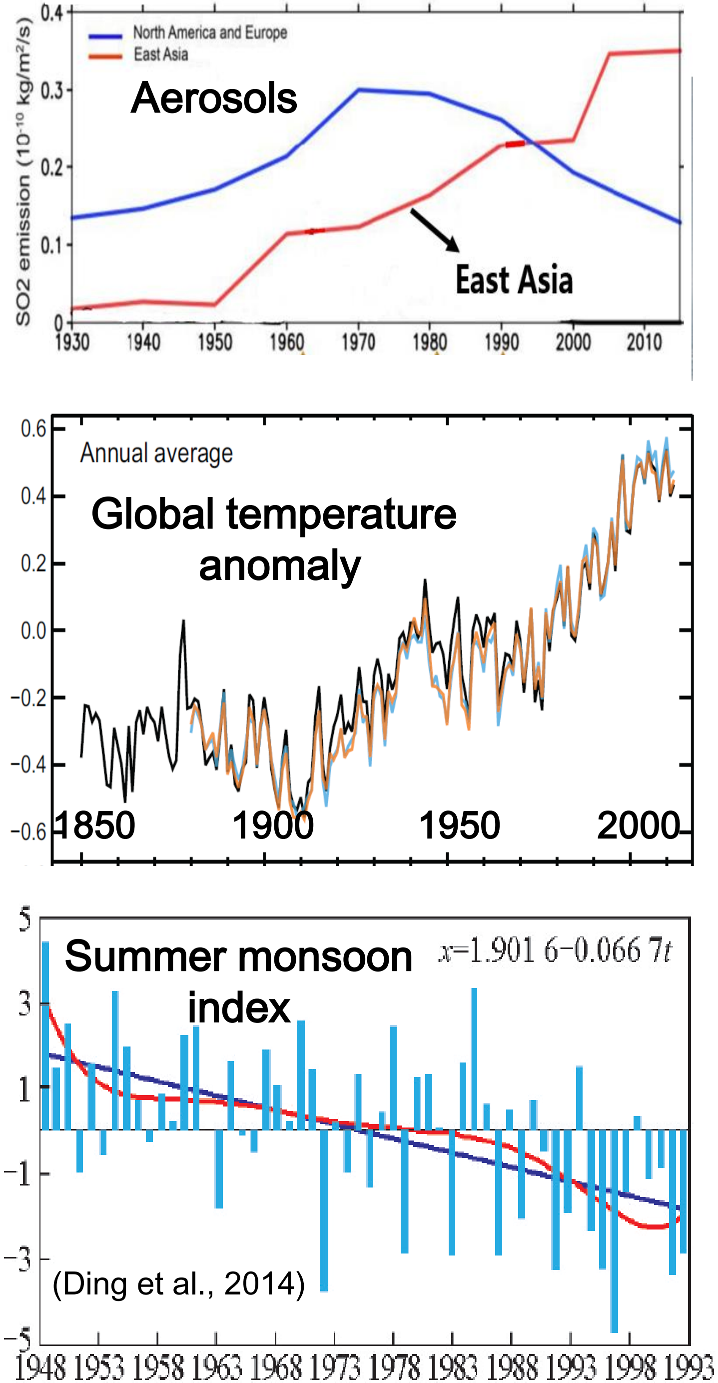
High-resolution chronology of surface drilled core



Surface sediment core

45 cm for the past 175 years

硅藻 ~4 yr间隔

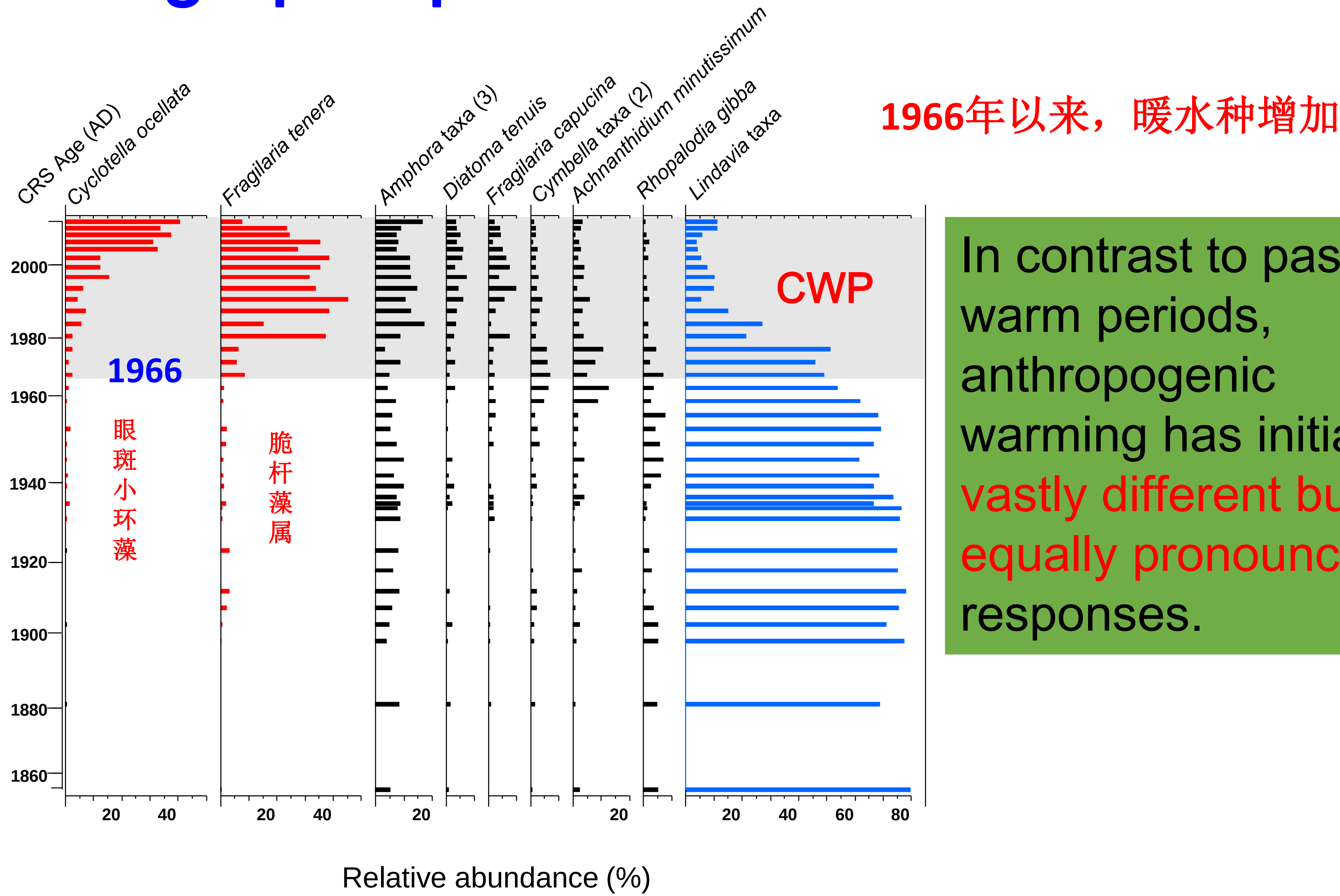


Striking increase of Asian aerosols have weakened ASM (both wind intensity and rainfall) over the past decades:

Weaker winds—weaker mixing —less nutrition

Less rainfall—weaker erosion—less nutrition

Stratigraphic profile of diatom taxa



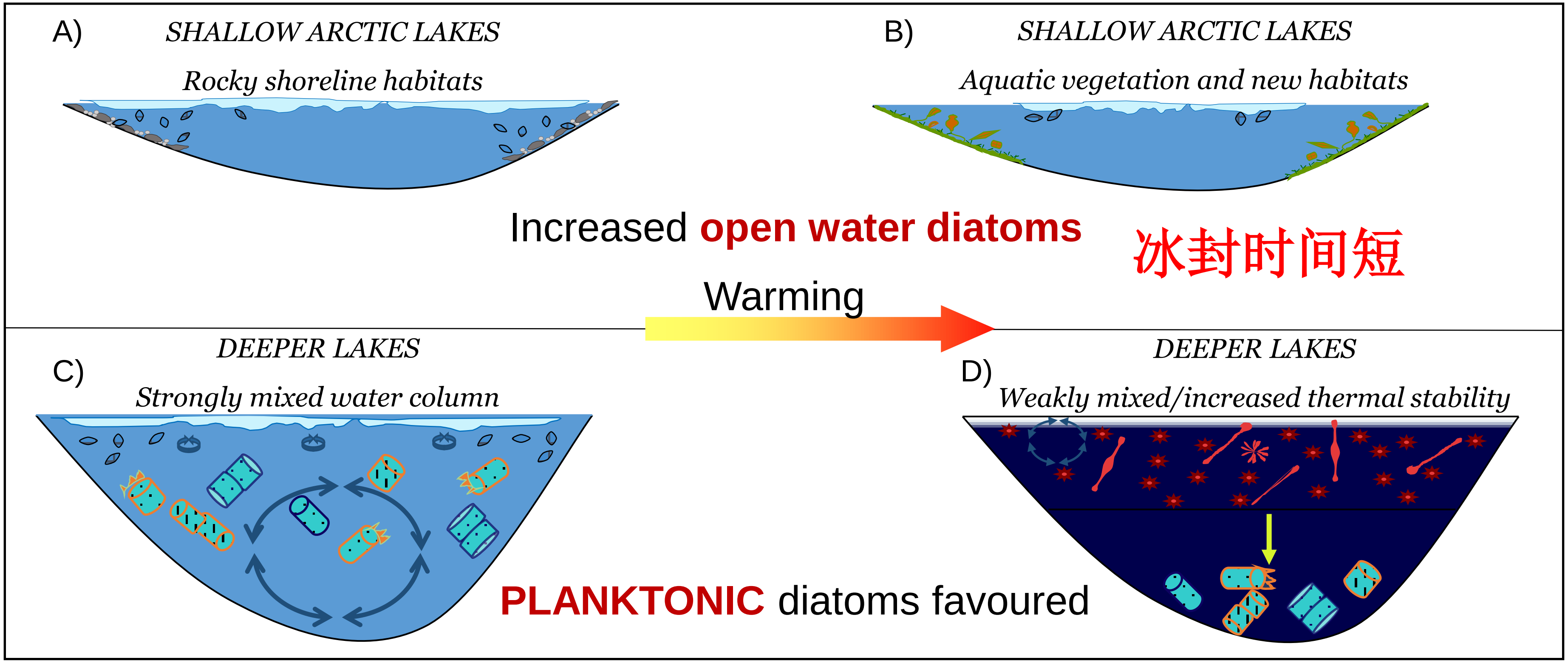
In contrast to past warm periods, anthropogenic warming has initiated vastly different but equally pronounced responses.

Increase in planktonic and open water diatoms

Effects of warming on diatoms

冷
Longer ice-cover period

暖
Longer open water period

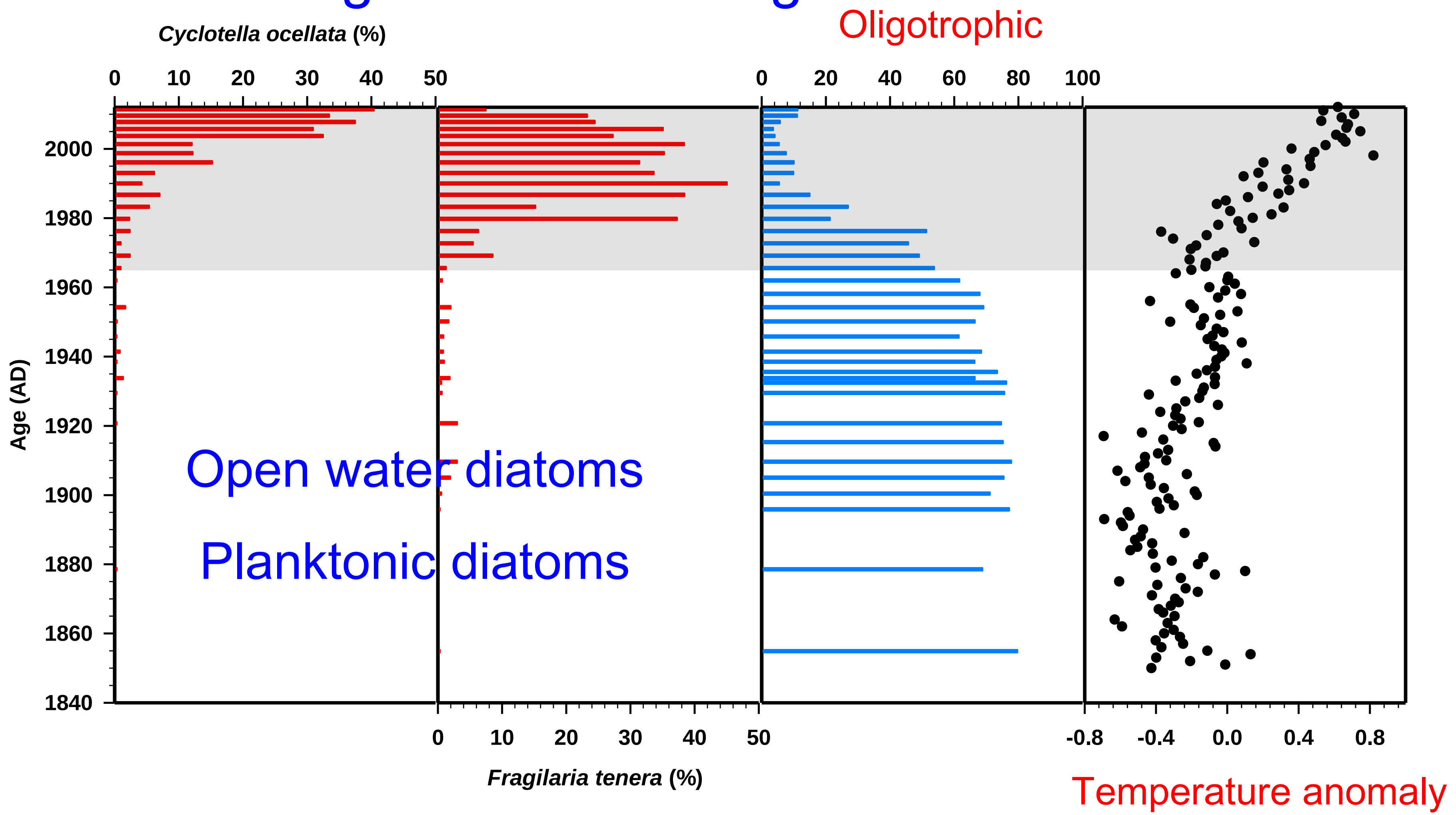


湖水混合

湖水分层

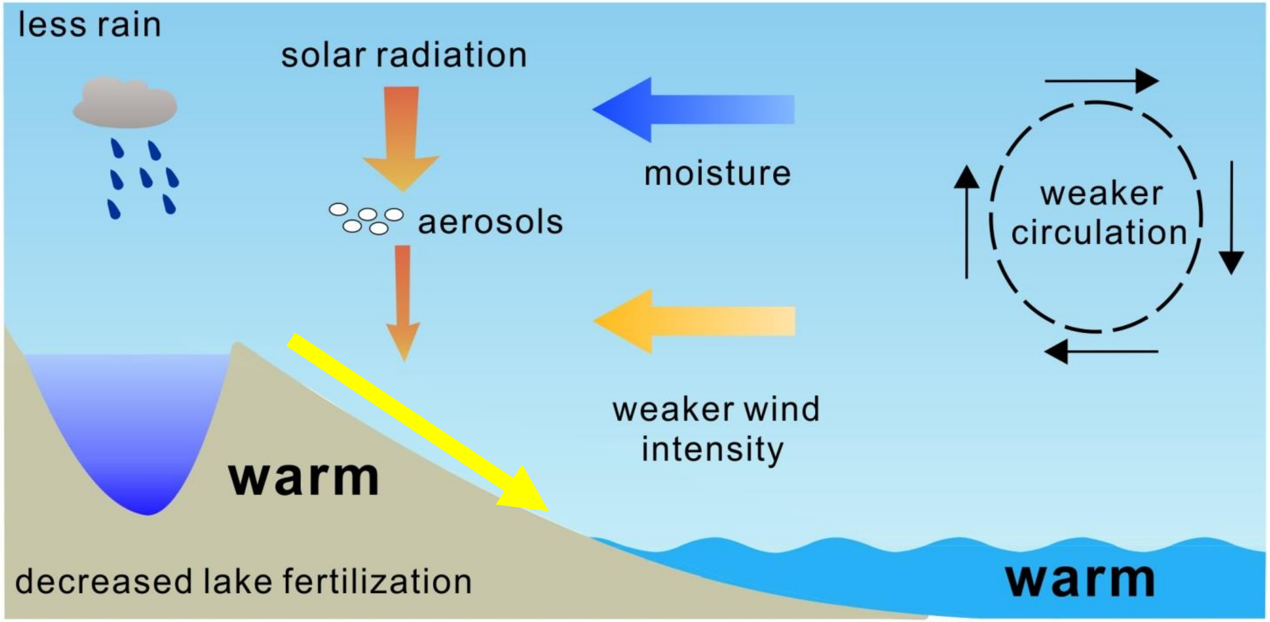
Rühland, Paterson and Smol (2015) JOPL

Distinct change in the **life strategy** of the diatom assemblages with warming



Warming is the main driver of rapid changes in alpine lake ecosystem, but not in the same way as the natural warm periods.

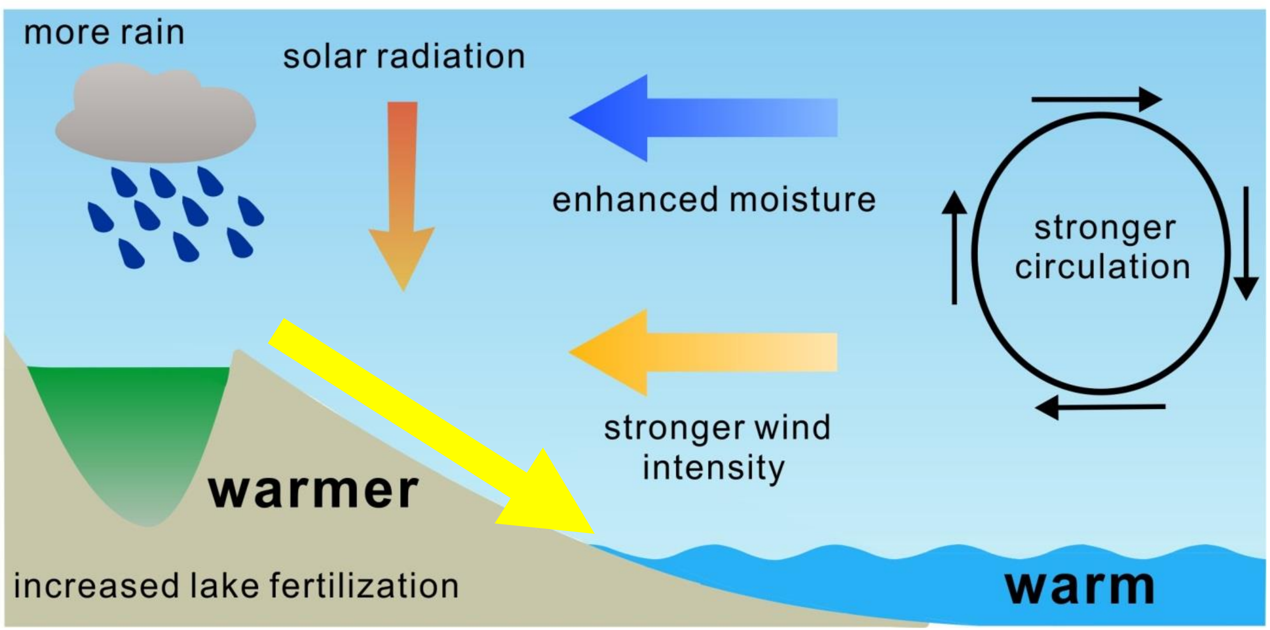
a



Anthropogenic
warm period

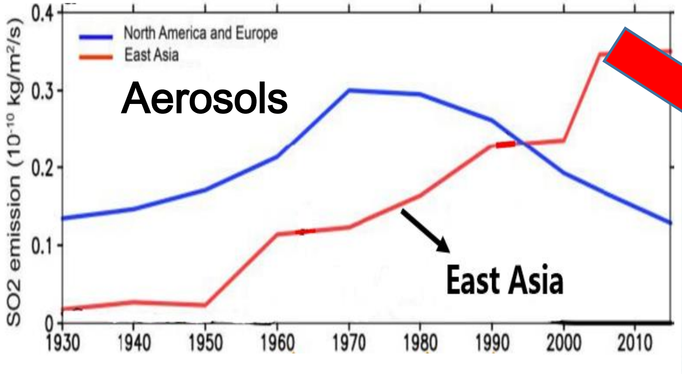
弱季夏风

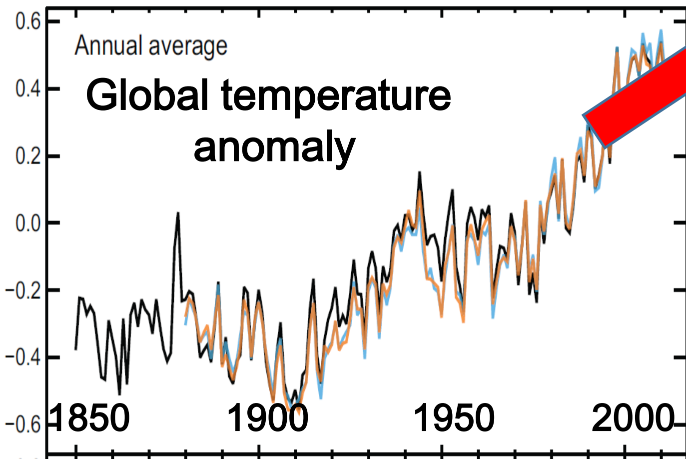
b

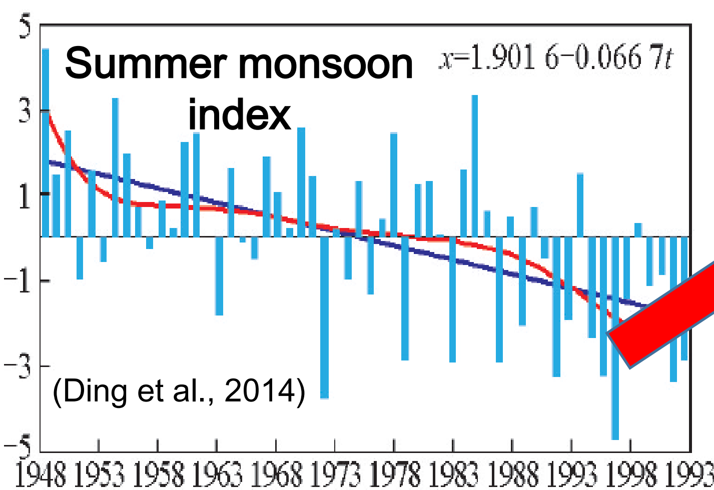


Natural
warm period

强夏季风







Continued environmental efforts to decrease anthropogenic aerosols in Asia

whilst global warming continues, will lead to the return of severe eutrophication, further impairing the already stressed fresh water supply of the region.

全球变暖-气溶胶减少-夏季风增强-湖泊富营养化

Outlines

1 亚洲夏季风演化

2 2000年湖泊生态响应

3 基本结论

基本认识

- 末次冰消期以来的东亚夏季风演化：14.7-7ka持续增强，7.8-5.3ka夏季风最强盛，3.3 ka以来快速减弱。

- 末次冰消期和全新世东亚夏季风总体上受太阳辐射驱动，但高纬冰盖以及冰川融水注入大西洋引起的AMOC的减弱对早全新世东亚夏季风有重要调控作用。晚全新世受到ENSO+太阳活动的影响。

- 东亚夏季风降水在中全新世最高，与石笋记录的夏季风演化历史存在差异。石笋记录不能客观指示东亚夏季风强度的变化，不是一个有效指标。

基本结论

- 过去2000年自然暖期（中世纪，隋唐）高山湖泊发生显著的湖泊富营养化，但现代暖期湖泊没有出现富营养化。
- 自然暖期时，夏季风强盛，土壤侵蚀增加，导致湖泊营养物质增加，湖泊出现富营养化，隐含暖期湖泊会发生富营养化。
- 现代暖期人为排放气溶胶增加，导致夏季风减弱，土壤侵蚀减少，尽管高山天然湖泊快速响应全球变暖，但没有出现湖泊富营养化。
- 过去暖期湖泊生态系统变化不能作为现代和未来人为暖期湖泊生态变化的相形物，但控制粉尘气溶胶排放（含治理雾霾）会增强亚洲夏季风，进而可能引起高山湖泊的大范围富营养化。

Liu JB et al, 2017, NCC