

Responses of the East Asian  
monsoon to the Cenozoic tectonic  
movement.



## Evolution of the China climate pattern

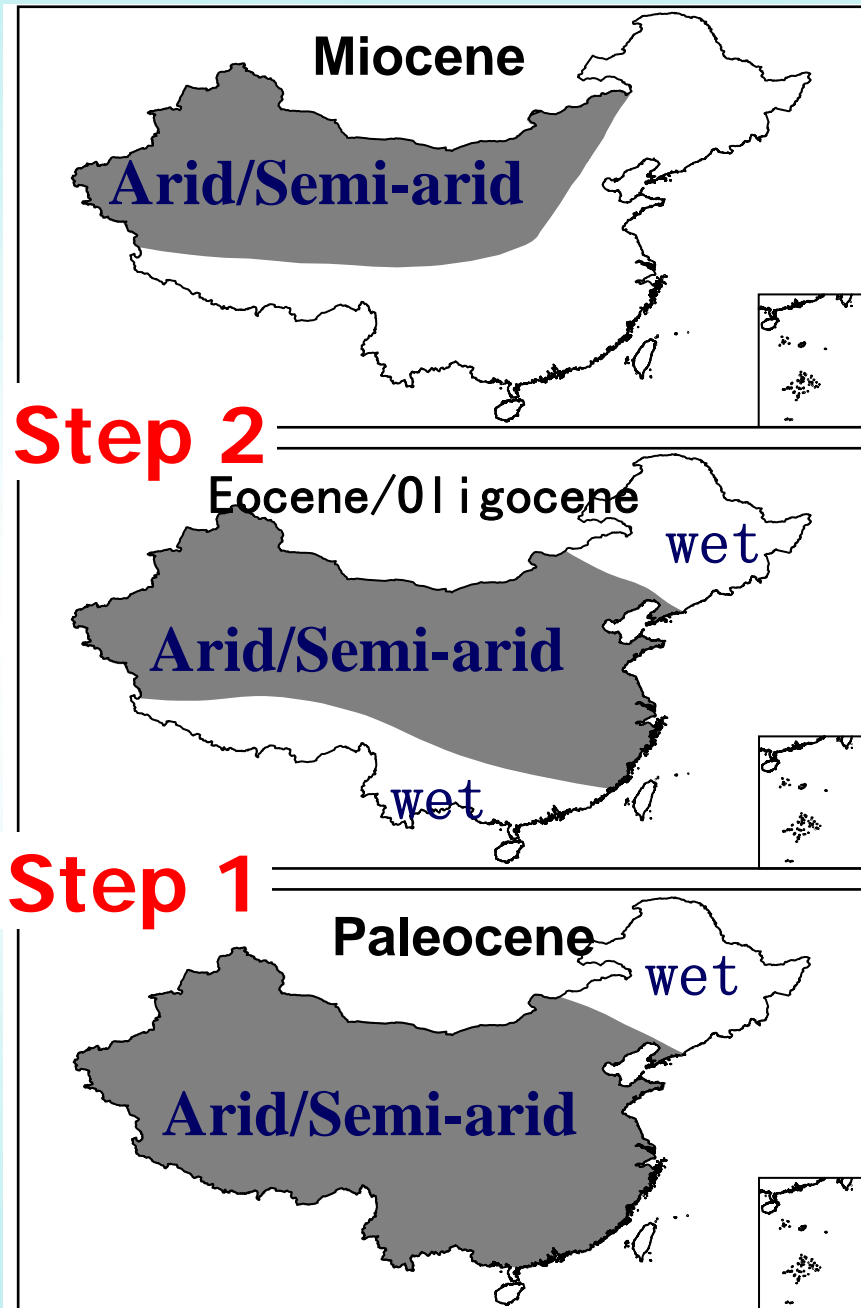
# Arid/semi-arid area in China

## Two patterns

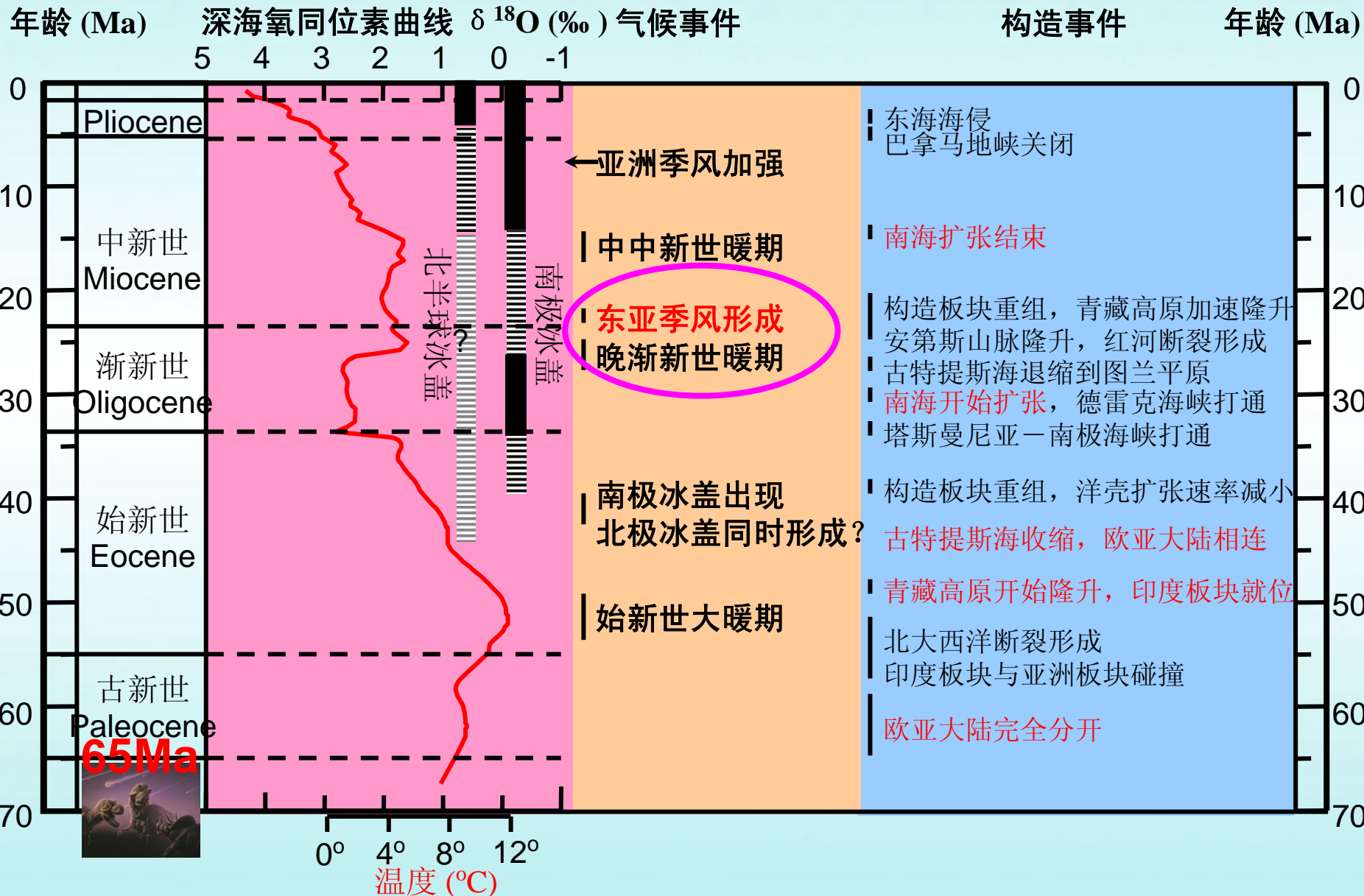
1. Non-Monsoon dominant
2. Monsoon-dominant

## Two steps

1. North-south diff.
2. East-west diff.



- 永久性冰盖
- ▨ 部分或短暂冰雪覆盖
- ▨ 有争议冰期



# How about the mechanisms of the monsoon-dominant climate formed in China

## •Uplift of TB

加强季风环流  
加剧亚洲内陆干旱  
海洋的反馈

(e.g. Manabe and Terastra 1974;  
Ruddiman and Kutzbach, 1989; Prell  
and Kutzbach, 1992; An et al., 2001;  
Liu and Yin, 2002; Kitoh, 2004)

## •Retreat of the Paratethys Sea

增强亚洲气候的大陆性  
加剧亚洲内陆干旱

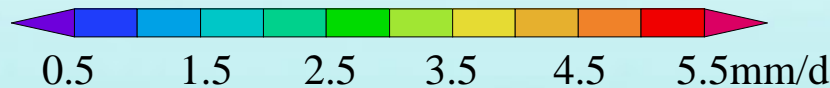
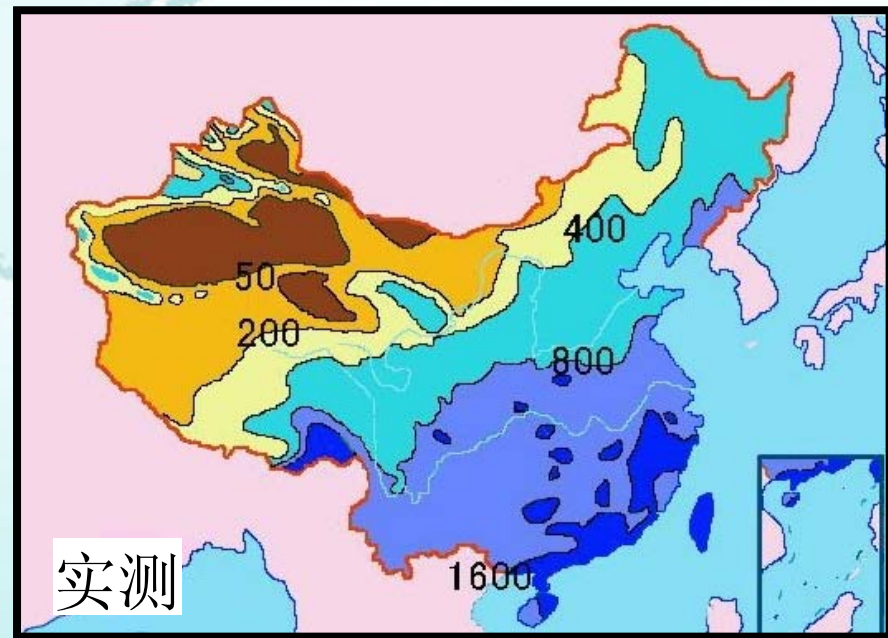
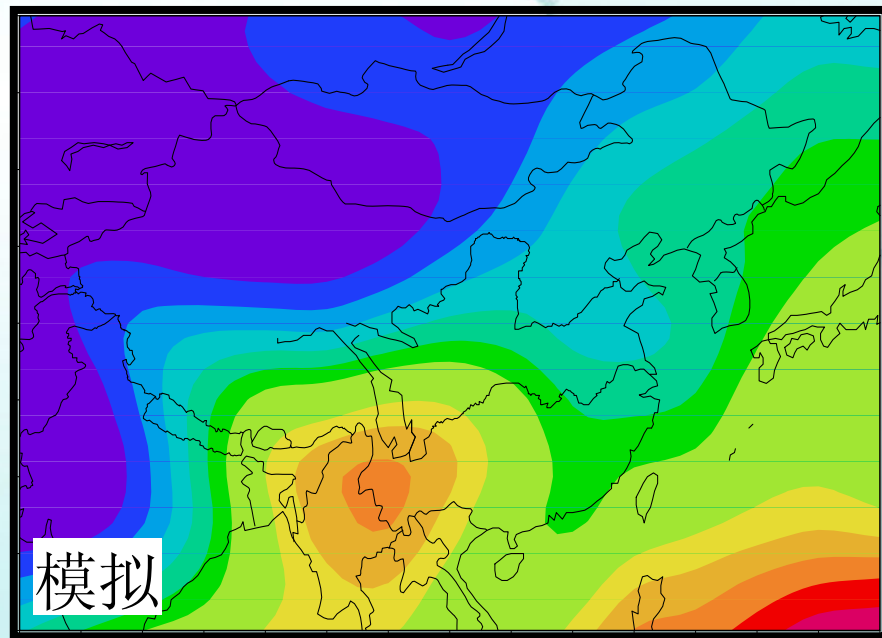
(Ramstein et al, 1997; Fluteau et al,  
1999)

## •Enlargement of SCS

(李吉均和赵志军, 2003; Wang et  
al, 2003 )

# IAP AGCM

- ❖ 中科院大气物理研究所自主发展 (Zeng et al., 1987)
- ❖ 分辨率:  $5^{\circ}$  in LON.  $4^{\circ}$  in LAT., 9 levels
- ❖ 具有较强的模拟能力 (Zhang, 1990; Liang, 1996; Bi, 1993)
- ❖ 用于古气候的模拟 (e.g., Wang 2001; Jiang et al, 2003, 2005)

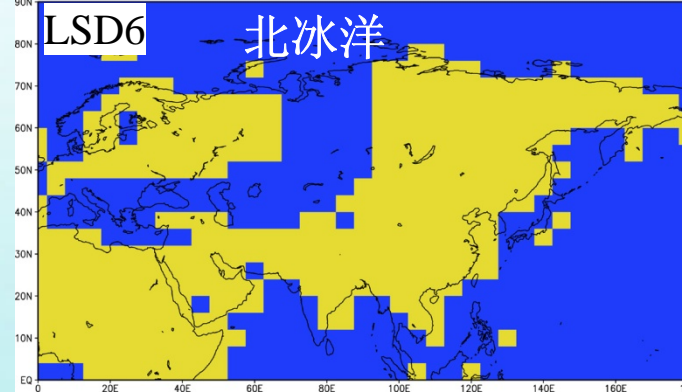
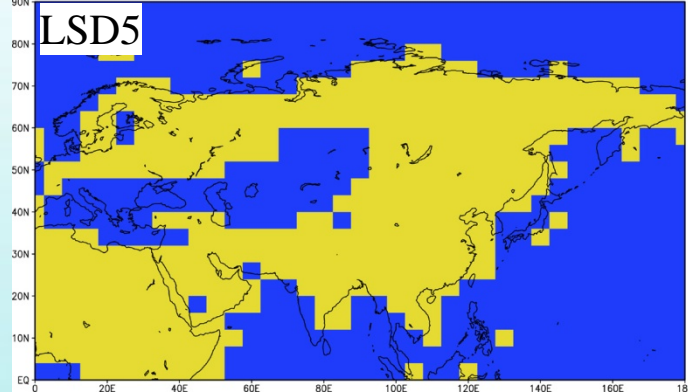
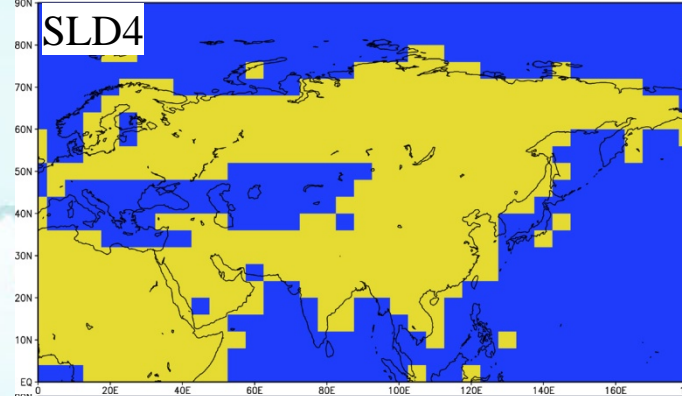
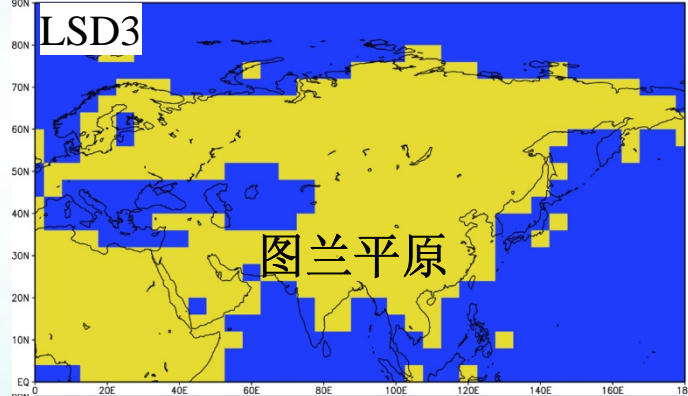
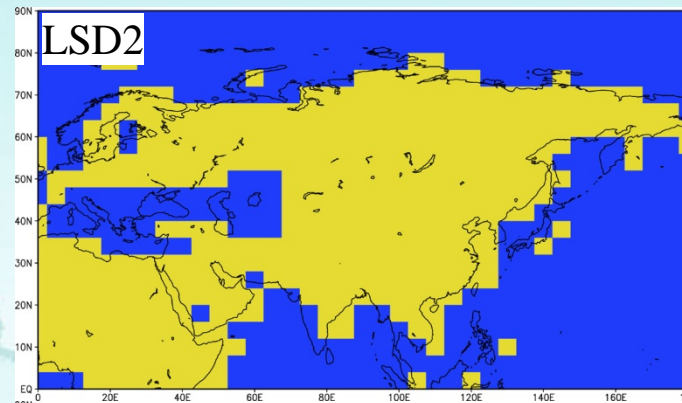
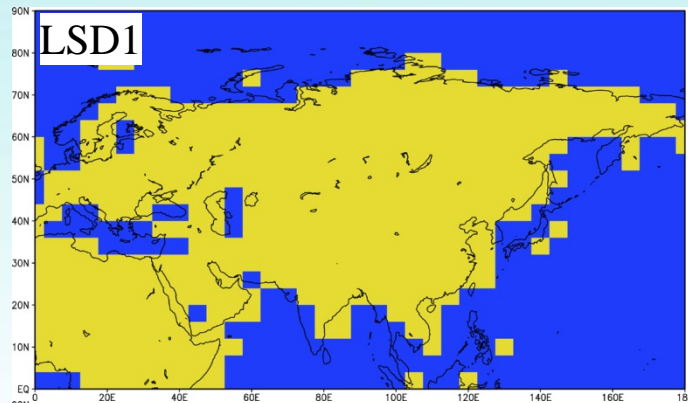


现代气候年平均降水量, 模拟结果(左), 实测(右)

A faint, light blue map of the Tethyan region, showing the Mediterranean Sea, the Red Sea, and the Indian Ocean, is centered in the background. The map highlights the area around the Tethyan Sea and the Indian Ocean, with the Tethyan Sea to the north and the Indian Ocean to the south.

**Roles of TB uplift  
and Paratethys Sea retreat**

# Paratethys Sea



黄色：陆地  
蓝色：海洋

( Dercourt et al., 1993; Rögl, 1998; Harzhauser et al., 2002 )

# TB Plateau

高原条件	T1000	T0750	T0500	T0375	T0250
最大高度 (m)	4472.1	3354.1	2236.0	1793.4	1529.0
平均高度 (m)	2717.8	2189.5	1561.1	1247.0	932.8
高原面积 ( $10^4\text{km}$ )	大约 400	大约 400	大约 300	大约 180	大约 20



# **Other boundary conditions unchanged**

**Modern insolation and vegetation**

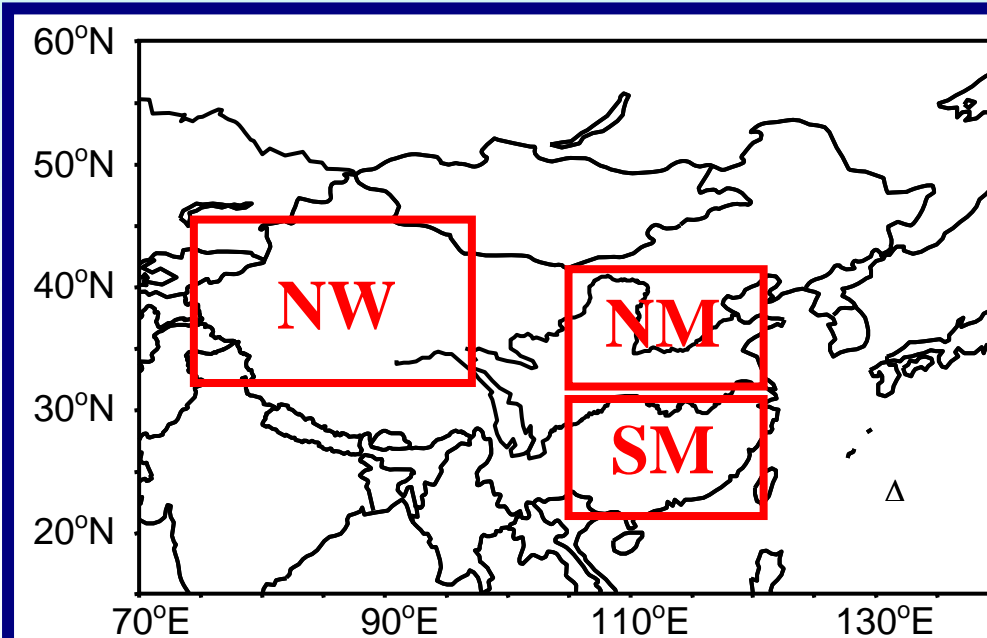
**SST and Seaice/ice sheets from Dowsett et al.(1999) for mid-pliocene**

**CO<sub>2</sub> : 345ppmv.**

**Total 30 sensitivity experiments**

**12 years for each experiment, last 10 years for the analysis**

# Indexes



**SM:现代南方季风区**

(22-30°N, 105-120°E)

**NM:现代北方季风区**

(34-42°N, 105-120°E)

**NW:西北内陆区**

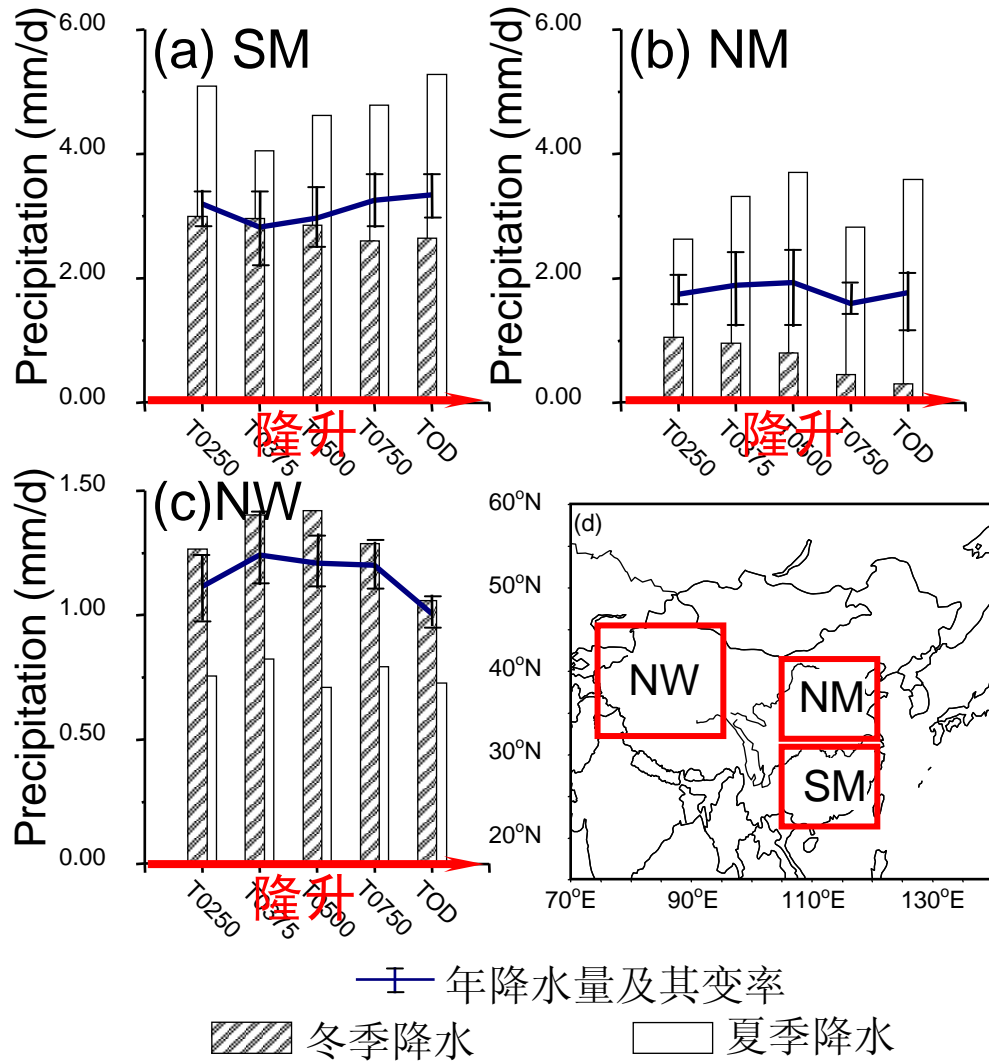
(34-46°N, 75-95°E)

$$MSW = \begin{cases} 1/2 \cdot (U_w + U_s) \cdot \cos(|a_w - a_s| - 180^\circ) & 90^\circ \leq |a_w - a_s| \leq 270^\circ \\ 0 & |a_w - a_s| < 90^\circ \text{ or } |a_w - a_s| > 270^\circ \end{cases}$$

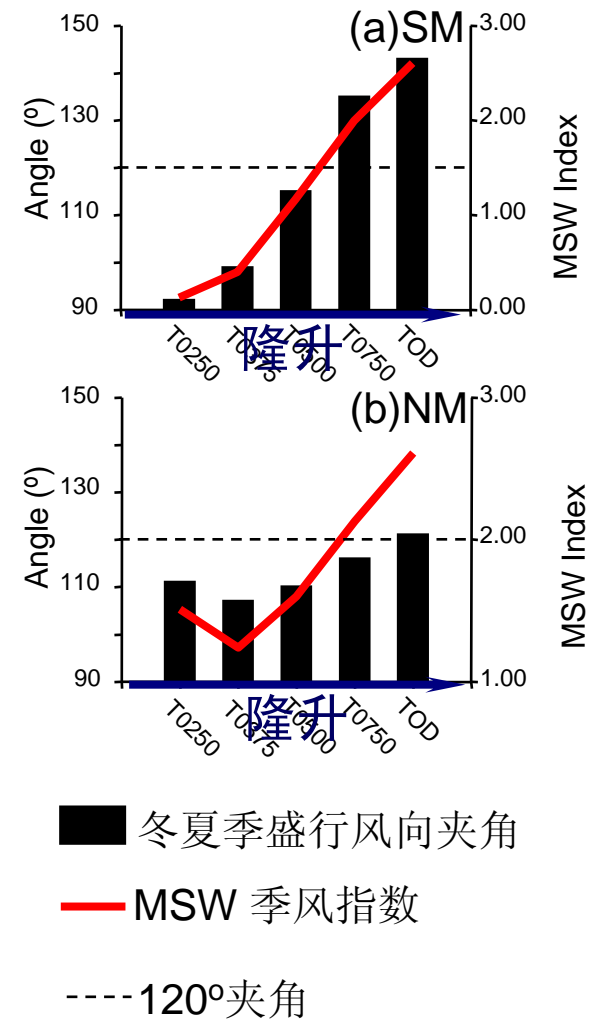
(Liu and Yin, 2002)

冬夏季盛行风向的夹角

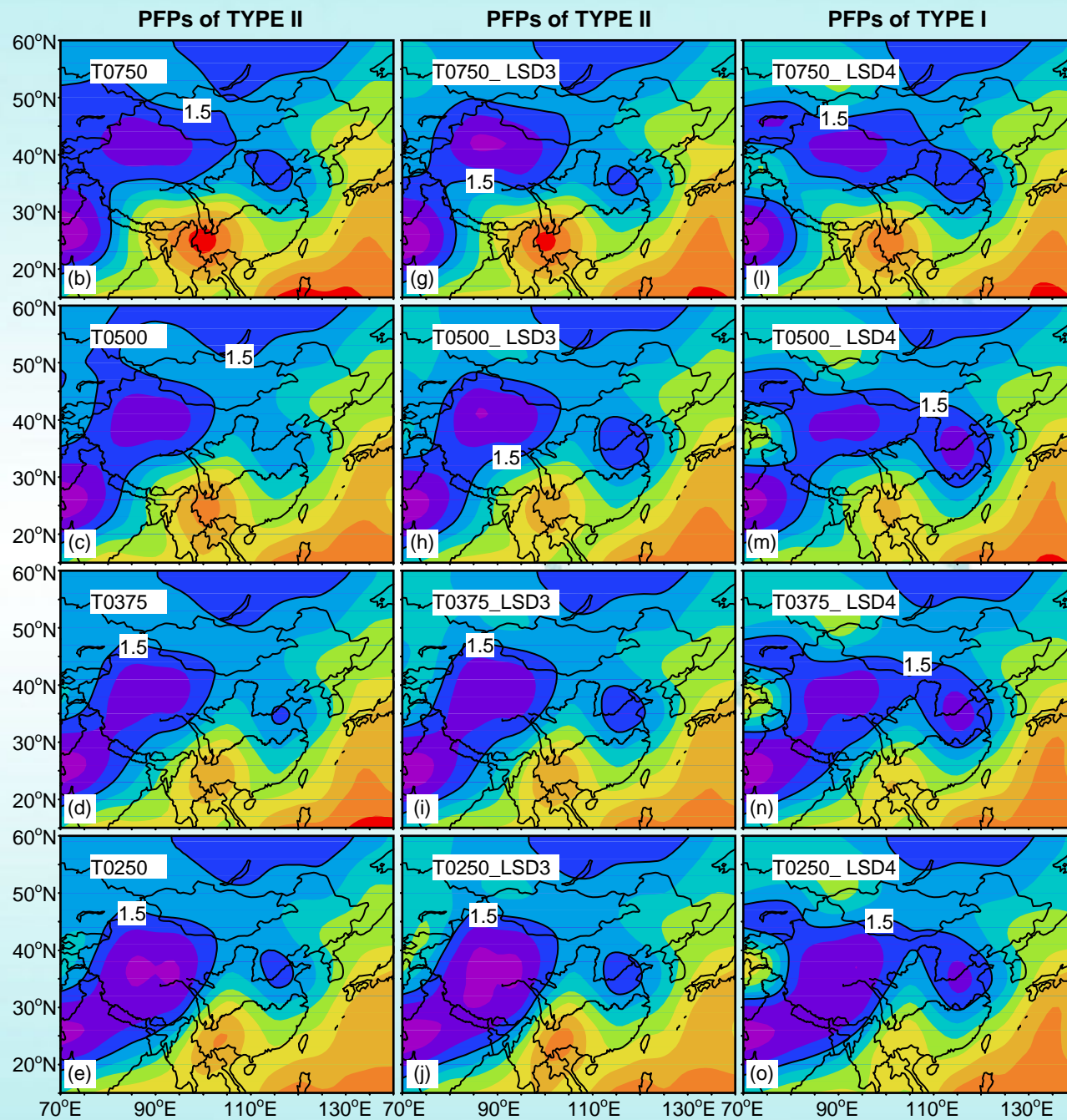
## Precipitation change



## MSW指数的变化



支持已有的结论 (e.g. Ruddiman and Kutzbach, 1989; Liu and Yin, 2002)



## Precipitation change

Two Types

*Zonal* (type I)

*Non-zonal* (type II)

年降水量

<1.5mm/d的区域  
可以被认为是干旱  
区/半干旱区

与古气候格局

恢复相一致

年降水量(mm/d)模拟

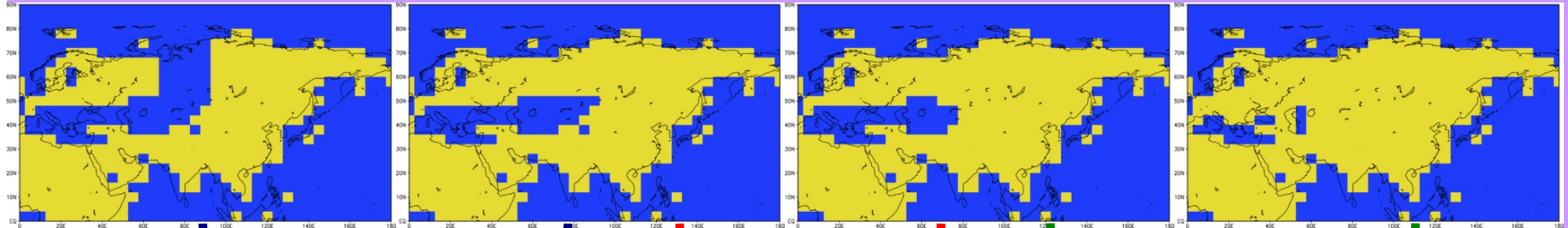
# Precipitation change

**LSD6**  
连接北冰洋

**LSD4**  
西伯利亚南部

**LSD3**  
图兰平原

**LSD1**  
现代



**Phase 1**

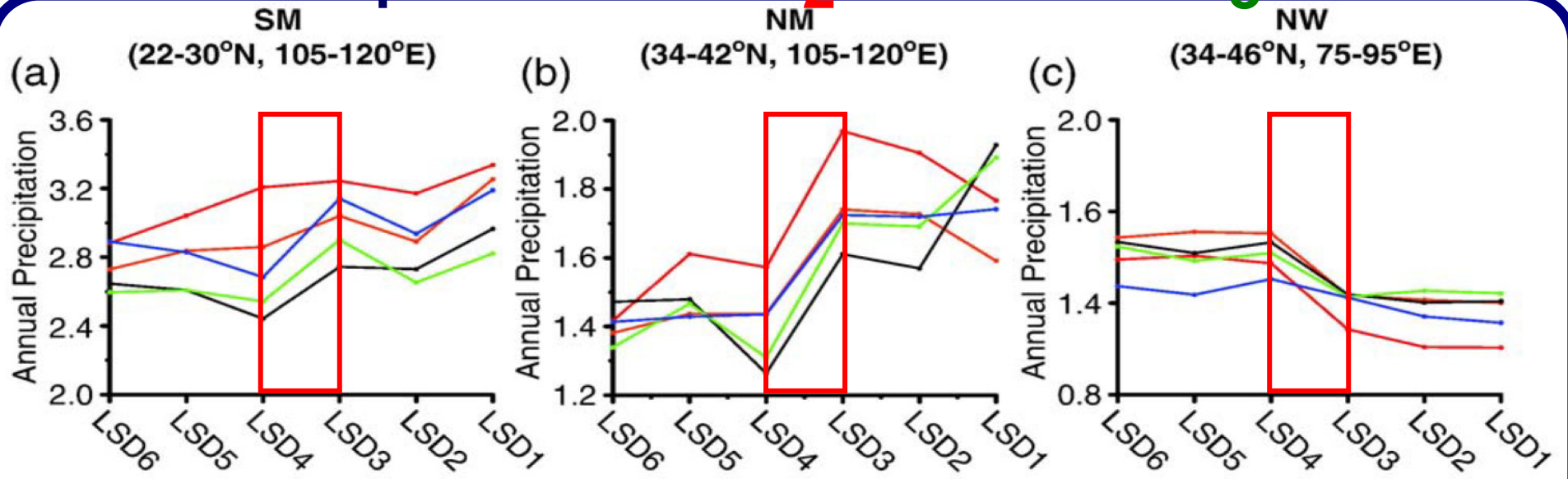
**Phase 2**

**Phase 3**

1

2

3

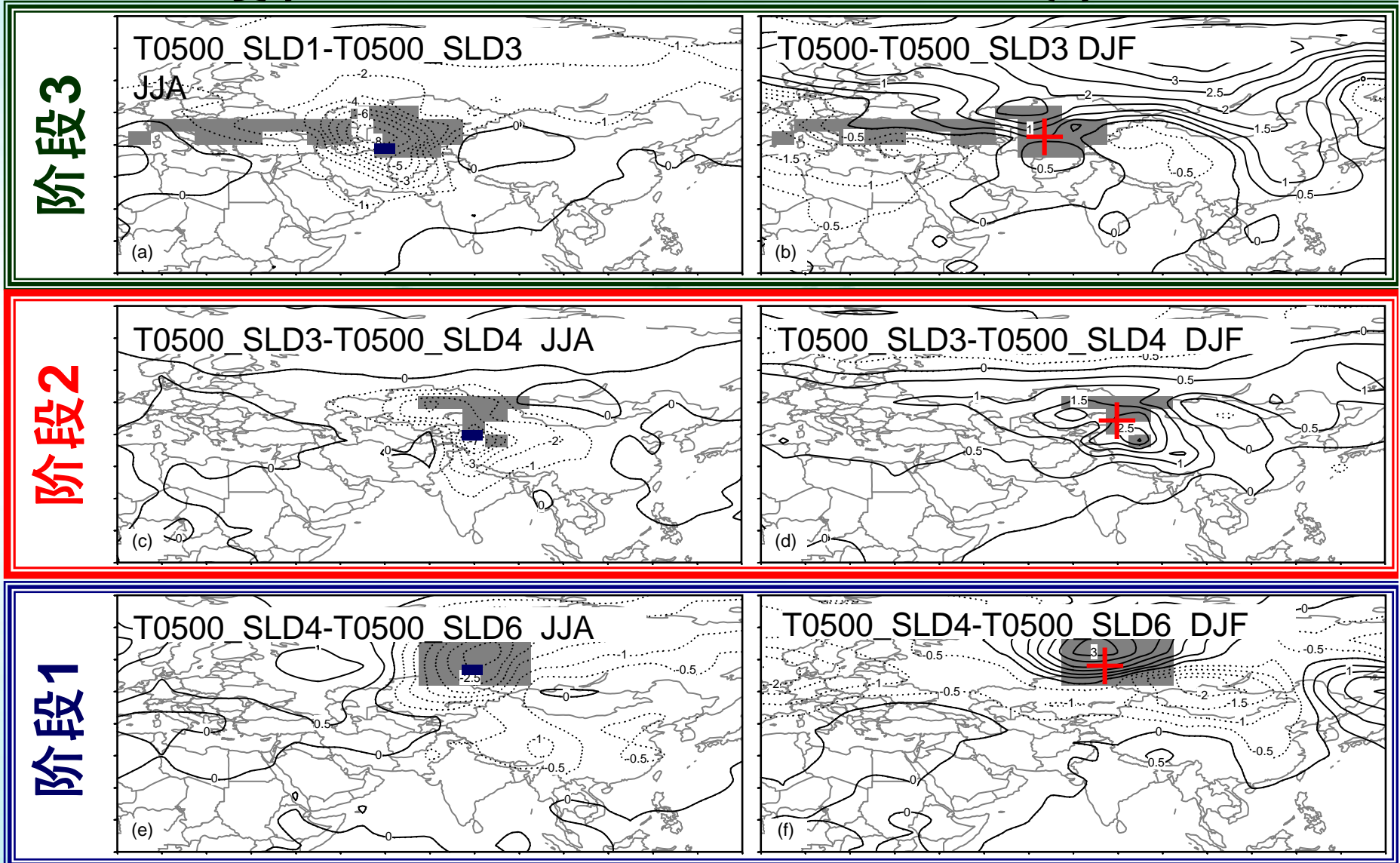


古特提斯海退缩过程中，年降水量(mm/s)的变化

# SLP Change

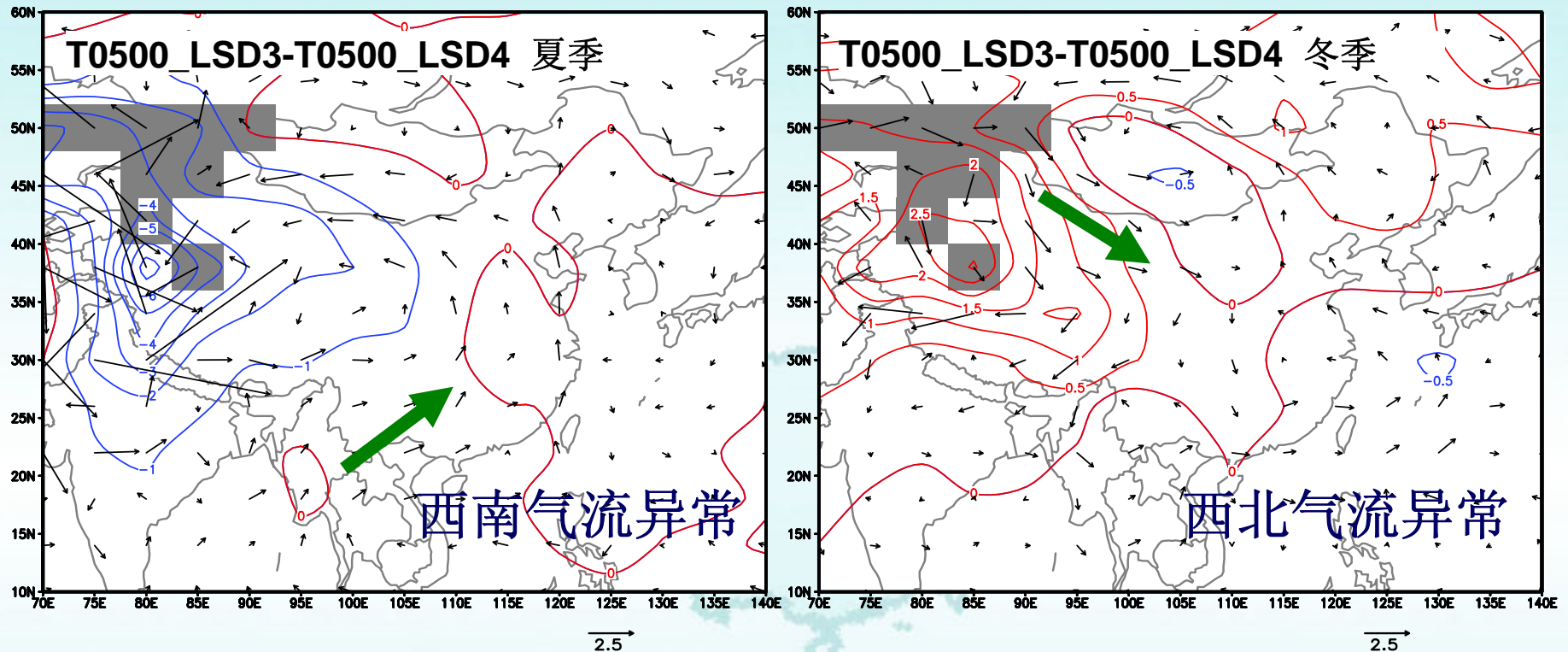
夏季

冬季



古特提斯海退缩过程中，海平面气压场(hPa)的变化 (Zhang et al, 2006)

# SLP and Velocity Changes



古特提斯海收缩导致的气压结构异常(hPa)和850hPa环流异常(m/s)

蓝色：气压降低区；红色：气压升高区

1. 古特提斯海收缩，改变海陆热力差异，导致**气压结构重组**；
2. 在古特提斯海**从西伯利亚南部退缩到图兰平原**这一阶段，气压结构的重组，加强了东亚季风环流。

## Summary of this part

Paratethys Sea retreat may change the land-sea thermal contrast, change the pressure structure, and enhance the east Asian monsoon circulation (after LSD3).

TB uplift may enhance the winter Syberia High and summer Indian Low, thus strengthen the monsoon circulation. Resulting the increase of precipitation in E China and decrease the precipitation the NW China.

# Composite Experiments



# Changes of the boundary conditions

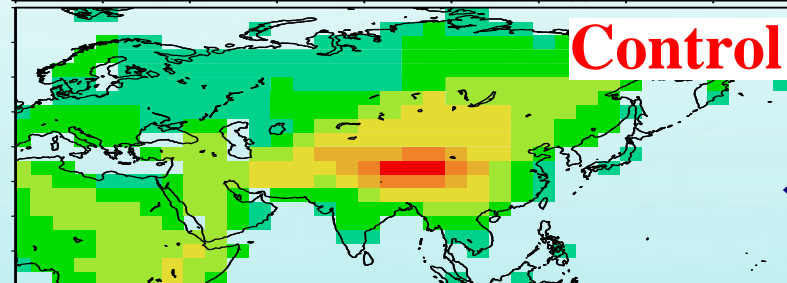
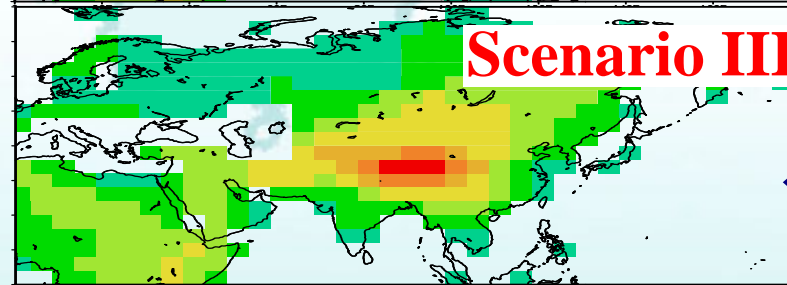
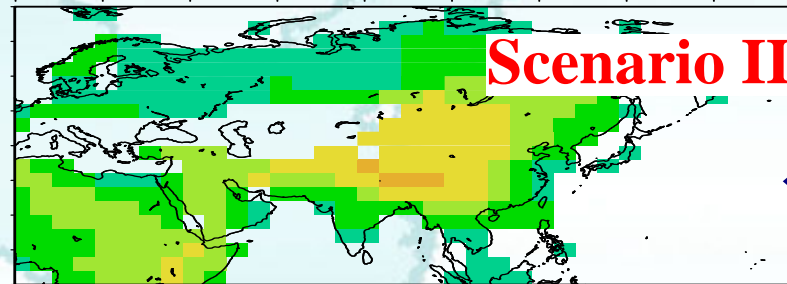
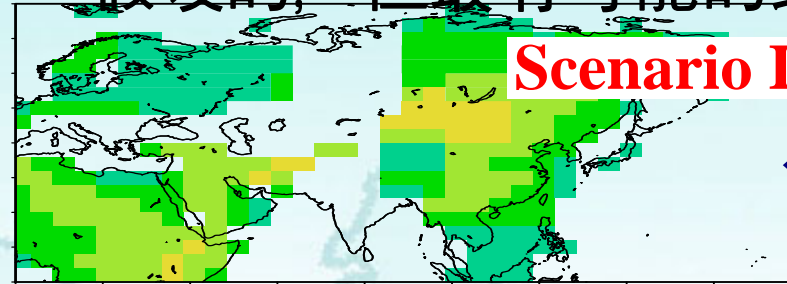
来自地质记录的场景

1. 欧、亚大陆分开  
无高大山脉和现代边缘海

2. 印度半岛接近现代位置  
很低的青藏高原  
边缘海很小  
古特提斯海与北冰洋分离

3. 较大的南海  
高大的青藏高原  
古特提斯海变得很小  
小东海

假设的, 但最有可能的组合场景



低地形  
大特提斯海  
无印度半岛  
无南海  
无东海

中地形  
中特提斯海  
小南海  
小东海

小特提斯海  
小东海

现代地形海  
陆分布条件

0 200 500 1000 2000 3000 4000 meter

## Other Boundary Conditions remain unchanged

试验只考虑地形和海陆分布变化对东亚环境的影响。

太阳辐射和植被用现代条件。

海表温度和冰量用Dowsett 等(1999)恢复的上新世中期的海表温度场/冰量条件。

大气 CO<sub>2</sub> 浓度固定在345ppmv。

所有试验积分12年，统计分析后10年的结果。

# M/I, S/N 比值和SNS季风指数

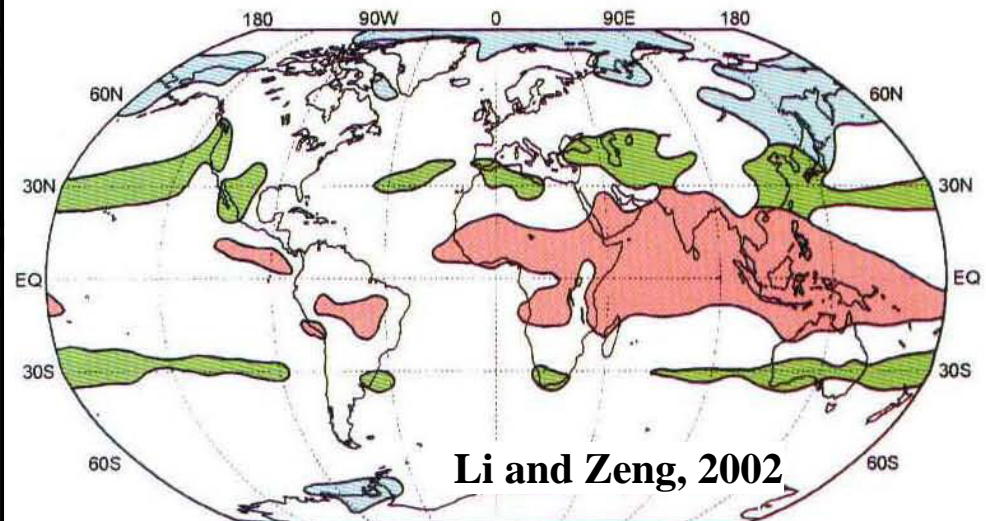
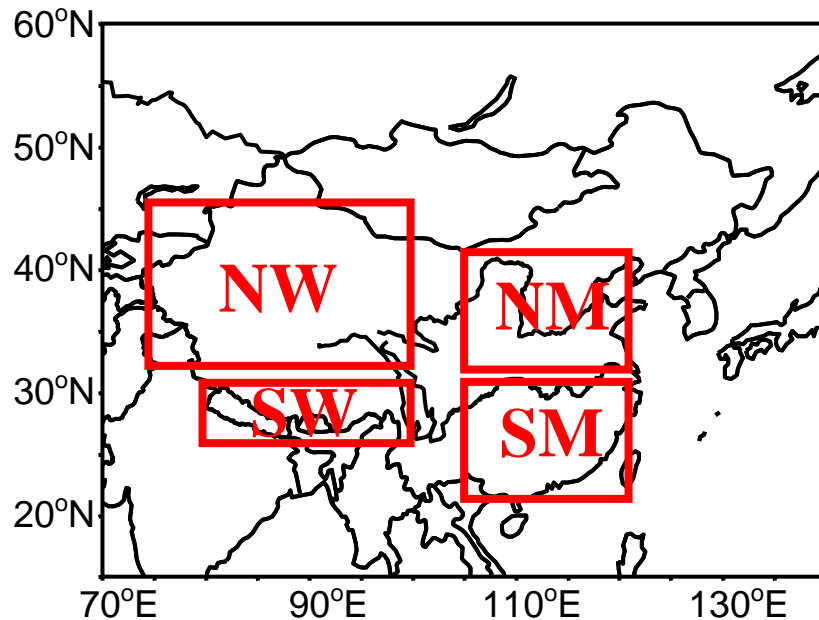
$$M/I = \frac{\text{东部地区年平均降水量(NM+SM)}}{\text{西北内陆年平均降水量(NW)}}$$

$$S/N = \frac{\text{南部地区年均降水量 (SM+SW)}}{\text{北部地区年均降水量 (NM+NW)}}$$

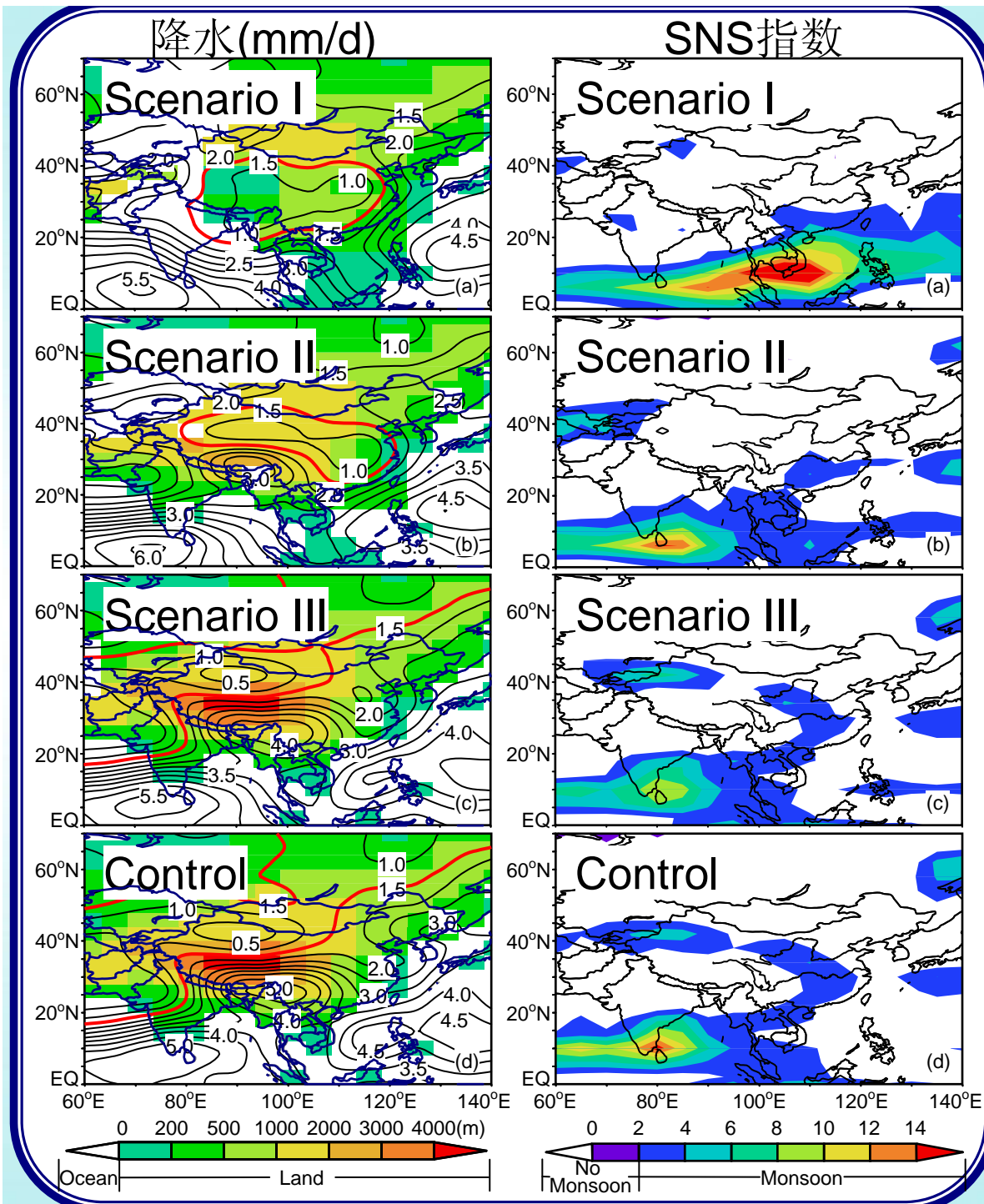
$$SNS = \frac{\| F1-F7 \|}{\| F \|} - 2$$

F1, F7: 一月和七月风矢量  
F: 年平均风矢量

(Zeng and Zhang, 1998;  
Li and Zeng, 2002, 2003)



SNS指数定义的全球季风区的分布  
红色: 热带, 绿色: 副热带, 蓝色: 温带/寒带



## 降水场的模拟

两种形态的降水场

带状

非带状

降水场变化两个步骤

藏南降水增加

东部降水增加

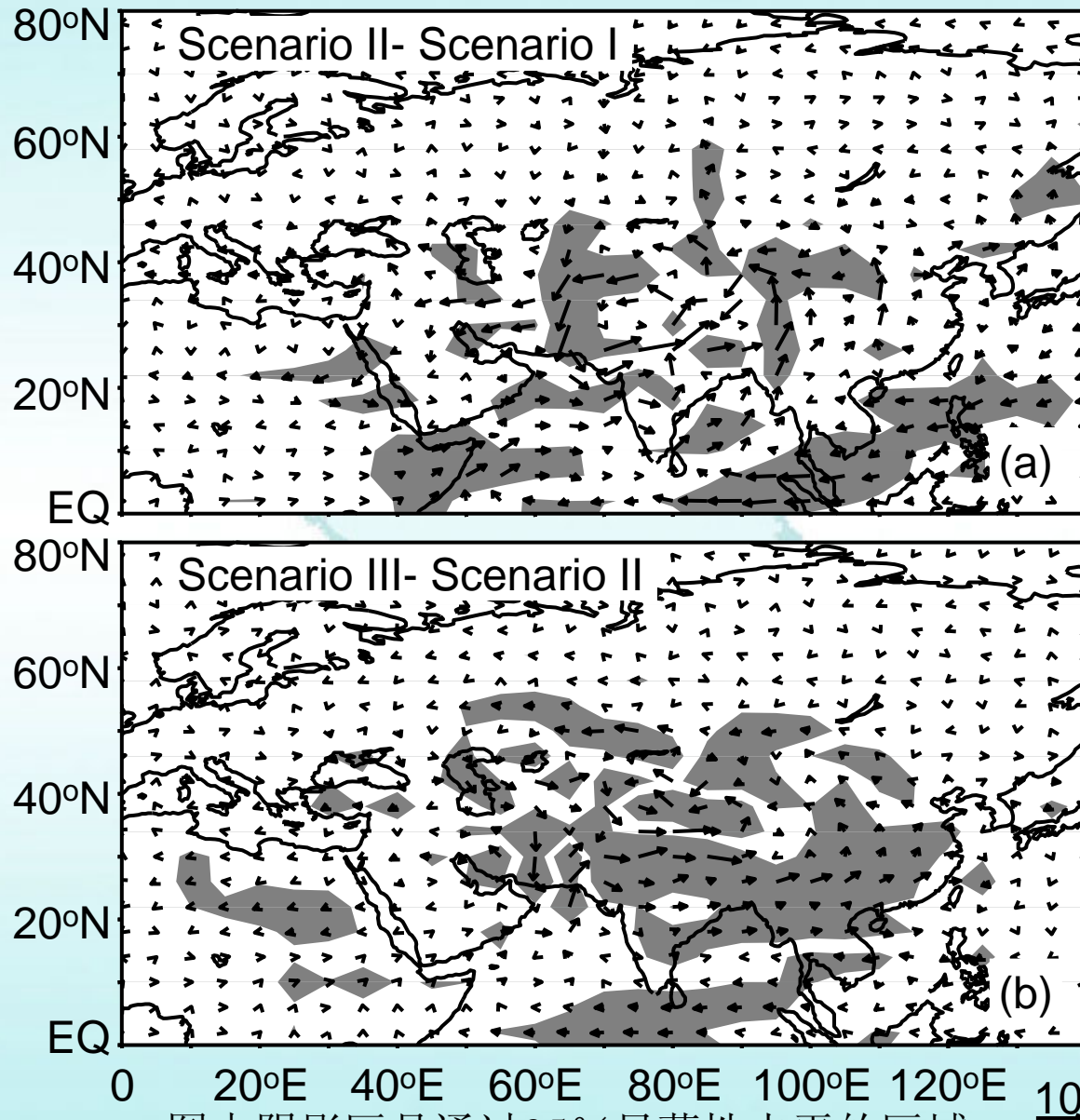
年降水量  $< 1.5 \text{ mm/d} =$

干旱/半干旱区

模拟结果很好地再现

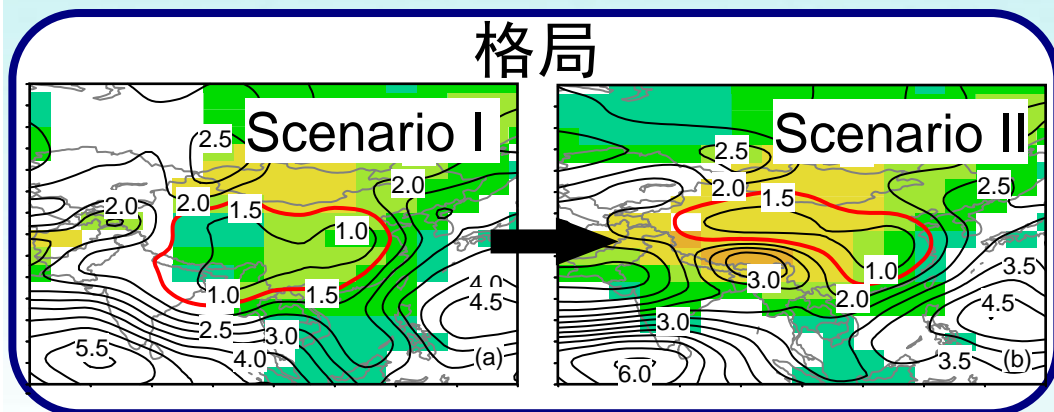
了古环境格局的演化

# 夏季850hPa风场(m/s)的变化

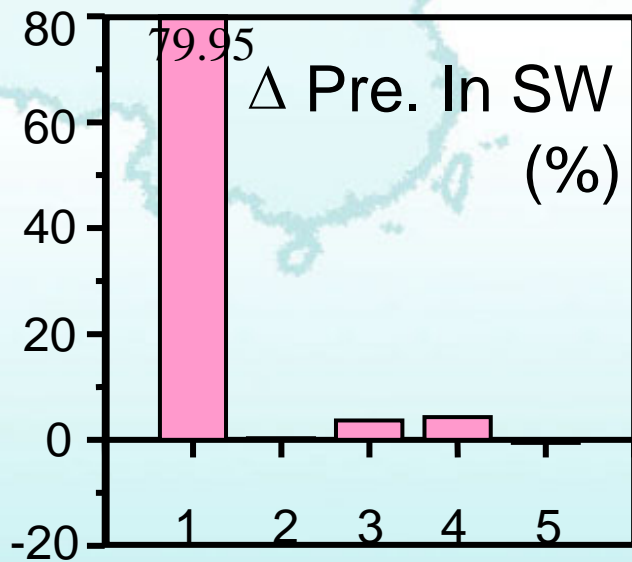
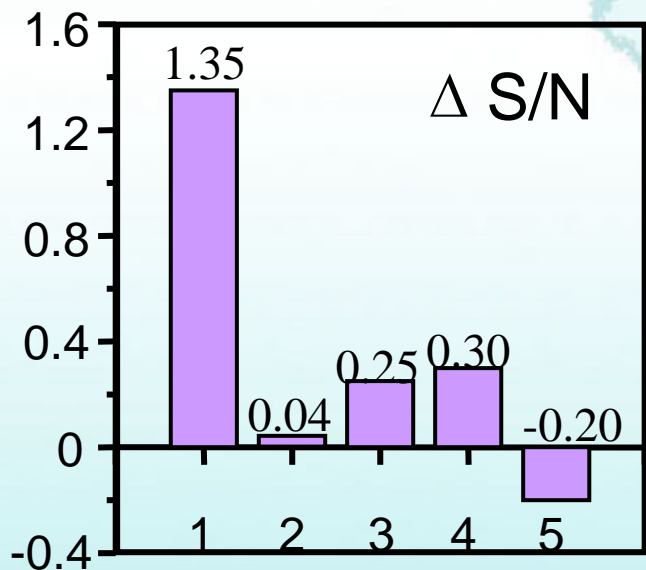


图中阴影区是通过95%显著性水平的区域

# I: How the North-South precipitation difference formed?



- 条件
1. 地形: 低 → 中
  2. 古特提斯: 大 → 中
  3. 印度半岛: 无 → 现代
  4. 南海扩张: 无 → 小
  5. 东海海侵: 无 → 小

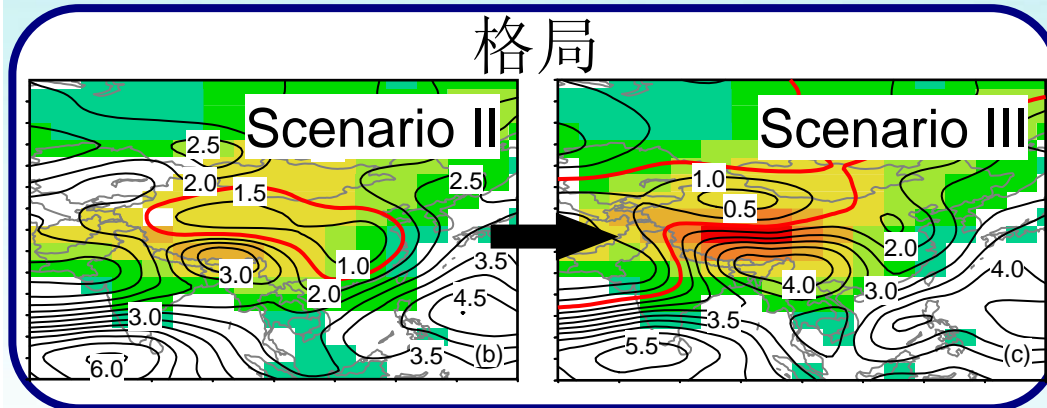


左: 各因素导致的 S/N 比值的变化

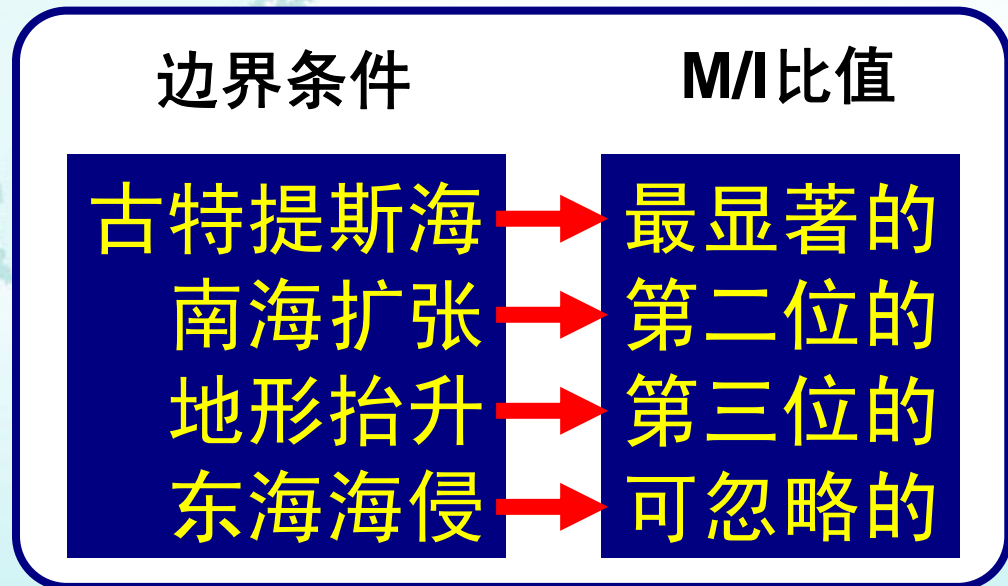
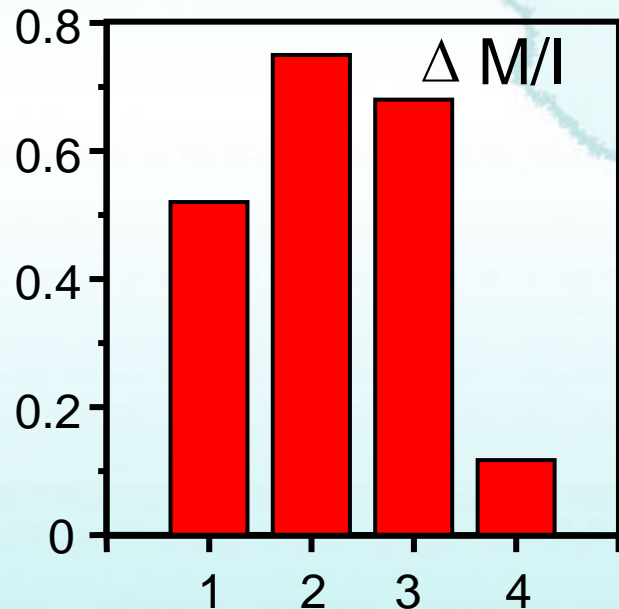
右: 各因素导致的 西南地区降水的变化

地形变化（青藏高原隆升）的主导作用

## II: How the monsoon-dominant climate formed?



- 条件
- |    |       |   |   |    |
|----|-------|---|---|----|
| 1. | 地形:   | 中 | → | 现代 |
| 2. | 古特提斯: | 中 | → | 小  |
| 3. | 南海:   | 小 | → | 现代 |
| 4. | 东海:   | 小 | → | 现代 |



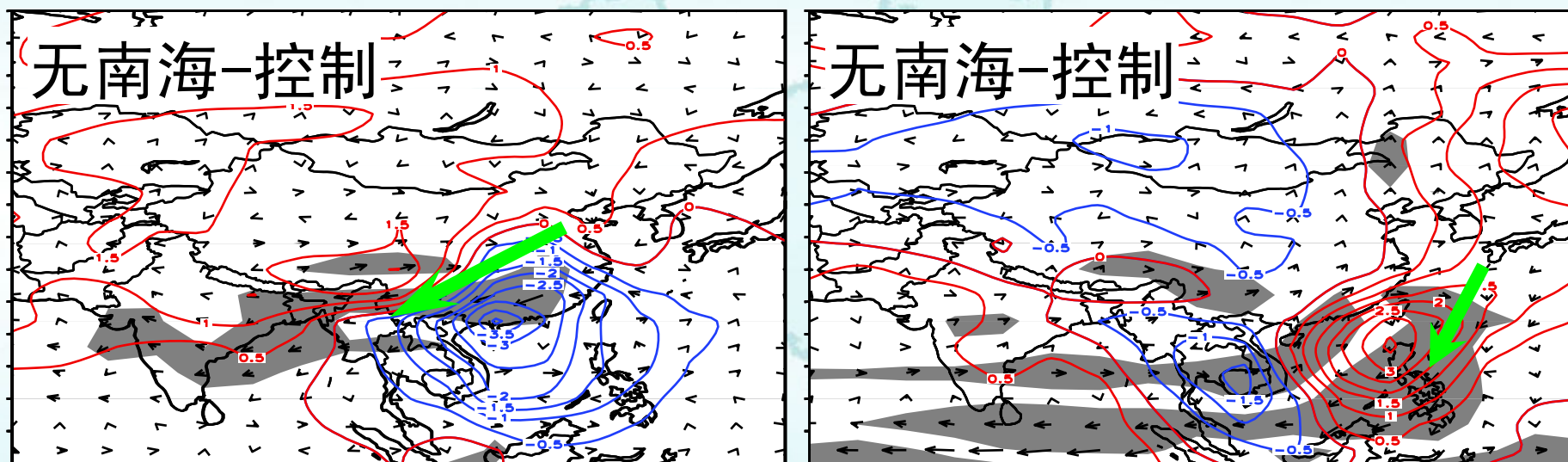
古特提斯海收缩、南海扩张、地形（青藏高原）隆升的**共同作用**导致了气候格局的转型。

## Roles of the TB uplift and the Paratethys sea

Paratethys sea: Change the land-sea contrast, enhance the East Asian monsoon circulation.

TB uplift: Enhance the Siberia High in winter, and enhance the Indian Low in summer, thus enhance the East Asian monsoon circulation; increase the precipitation in the East China, and decrease the precipitation the Northwest China.

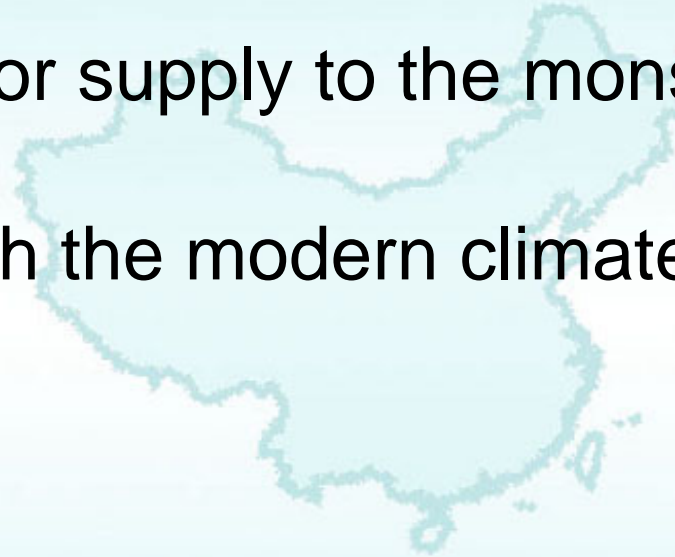
## Role of the South China Sea Expansion



夏季(左) 冬季(右)  
海平面气压异常(hPa)及风场异常 (m/s)

## Role of the South China Sea Expansion

- Water vapor supply to the monsoon region
- Agrees with the modern climate





**Thanks !**