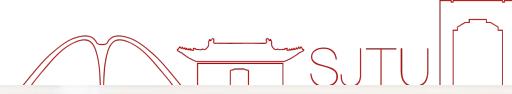




上海交通大学
SHANGHAI JIAO TONG UNIVERSITY



上海交通大学海洋学院

气候学与全球变化 Climate and Global Change

2022.04.29

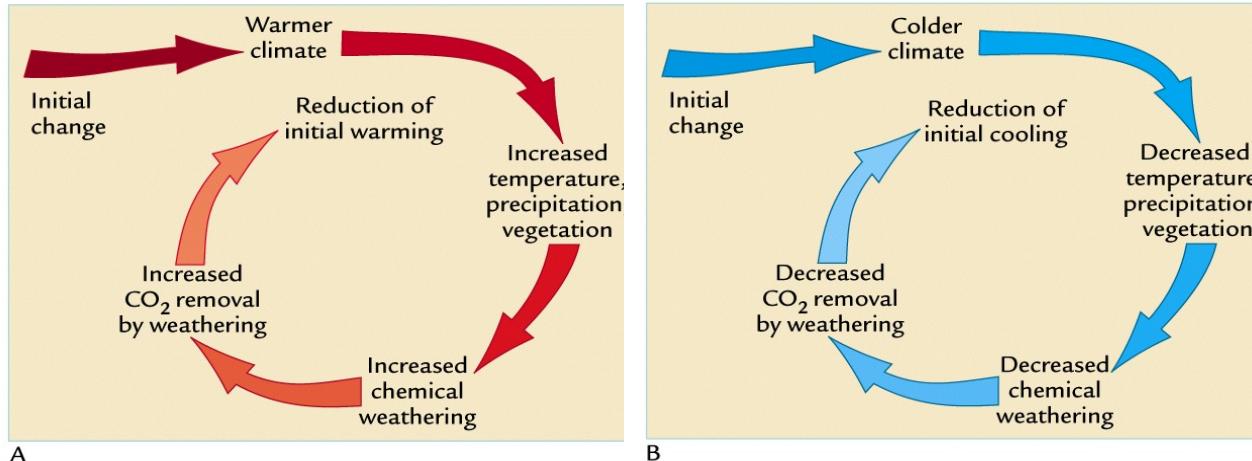


SCHOOL OF OCEANOGRAPHY
SHANGHAI JIAO TONG UNIVERSITY
上海交通大学 海洋学院



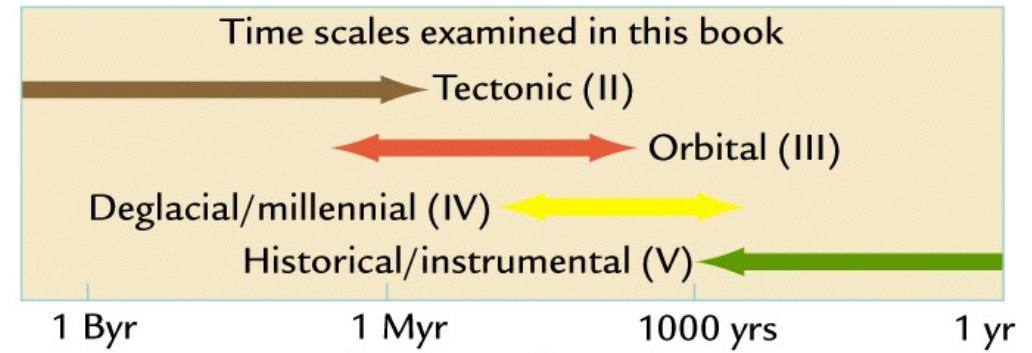
回顾

1. CO₂在构造尺度上的反馈： 化学风化-“地球温度调节器”



A

B



2. 构造与气候：

- “极地位置假说”
- 板块构造与CO₂



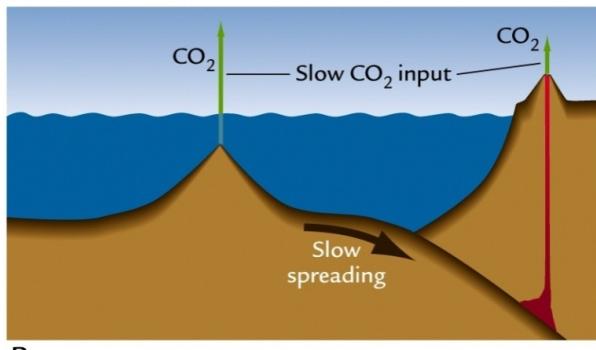
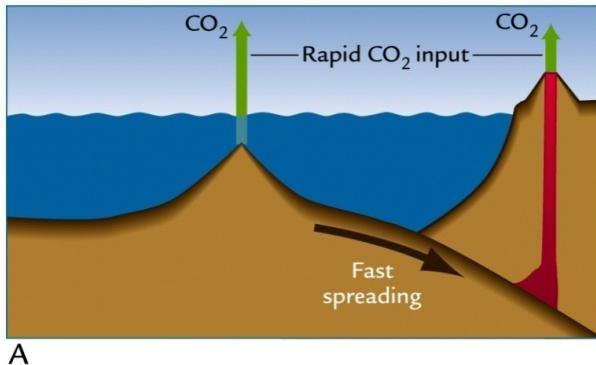
9.2.1 构造尺度 (tectonic scale)

b. 板块构造与气候 (~ 5.5亿年前 550Myr)

板块构造与CO₂ : BLAG spreading rate hypothesis

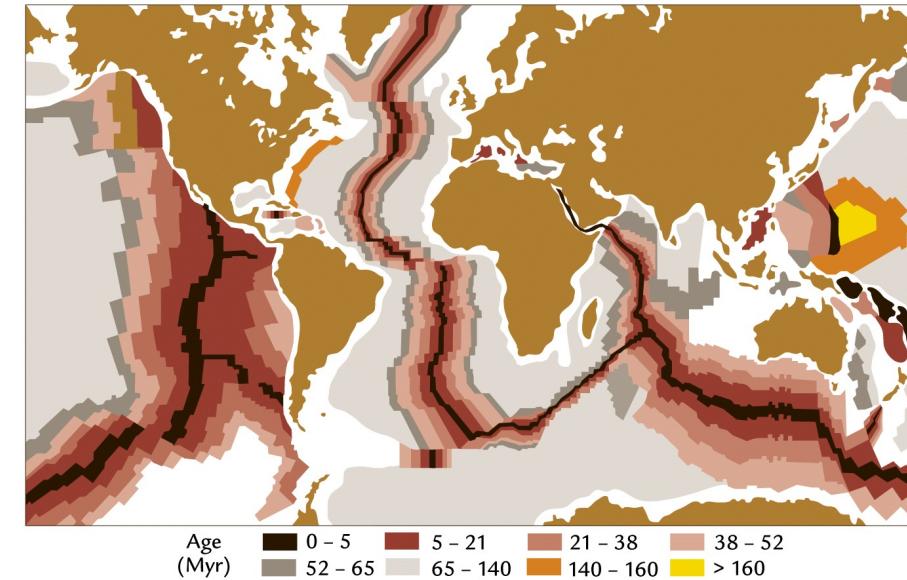
(Robert Berner, Antonio Lasaga, Robert Garrels, 1983)

大气 CO₂浓度由平均海底扩张速度驱动



海底扩张速度增快
→ 更多火山活动
→ 更多大气CO₂

海底年龄 → 海底扩张速度



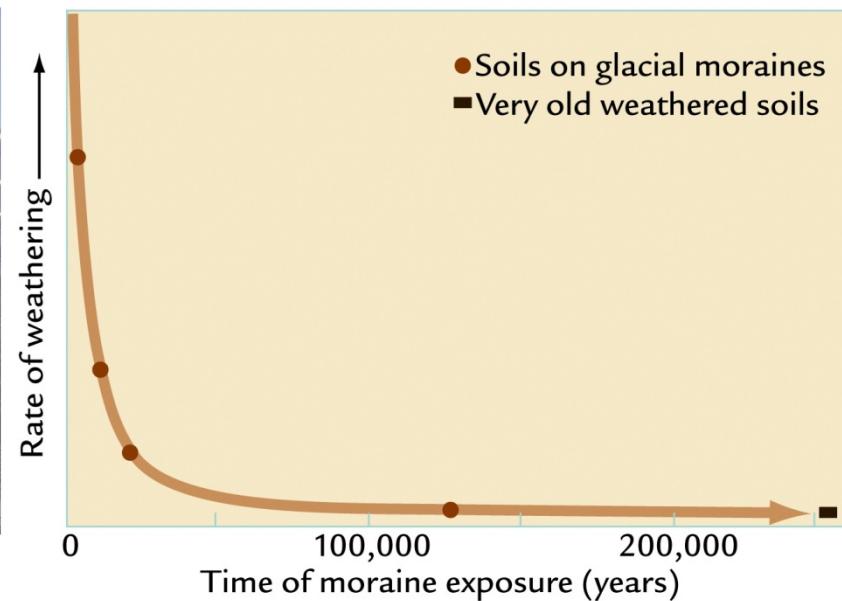


9.2.1 构造尺度 (tectonic scale)

b. 板块构造与气候 (~ 5.5亿年前 550Myr)

板块构造与CO₂ : Uplift-Weathering Hypothesis (岩石暴露和化学风化)

“新鲜” 岩石和矿物的暴露影响全球平均化学风化率



为什么新鲜的岩石风化效率高？

- 新鲜的岩石有更多的风化物质：未被风化的硅酸盐；
- 碎裂增加表面积；



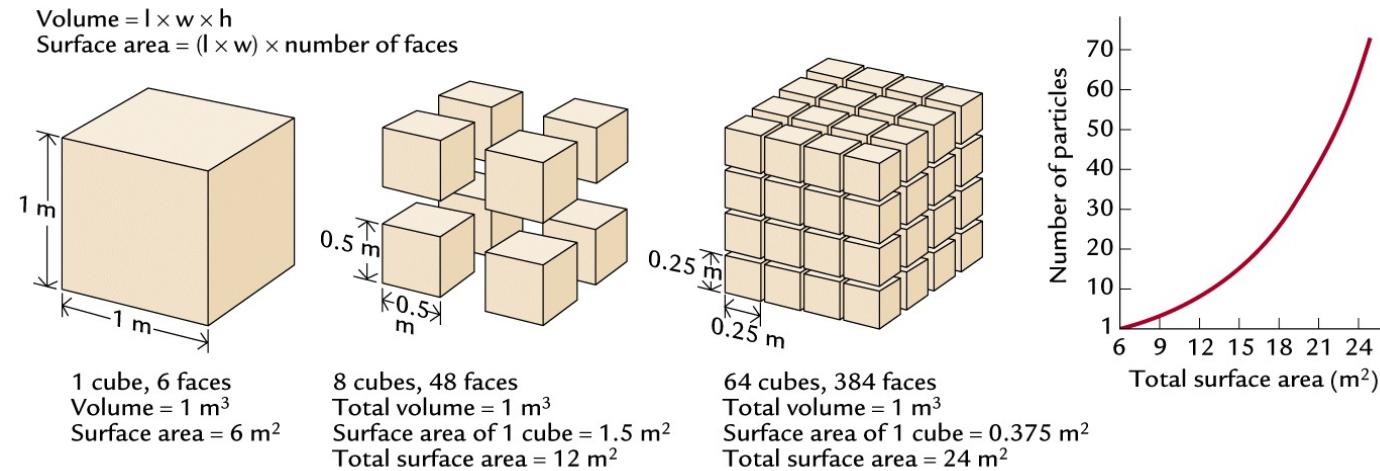
9.2.1 构造尺度 (tectonic scale)

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板块构造与CO₂ : Uplift-Weathering Hypothesis (岩石暴露和化学风化)

碎裂增加表面积

Dimensions of cube faces (m)	Number of cubes	Total surface area of cubes (m ²)	Total volume of cubes (m ³)
1.0	1	6	1
0.5	8	12	1
0.25	64	24	1
0.125	512	48	1
0.062	4096	96	1
0.031	32,768	192	1
0.016	262,144	384	1
0.008	2,100,000	768	1
0.004	16,800,000	1536	1
0.002	134,000,000	3072	1
0.001	1,100,000,000	6144	1



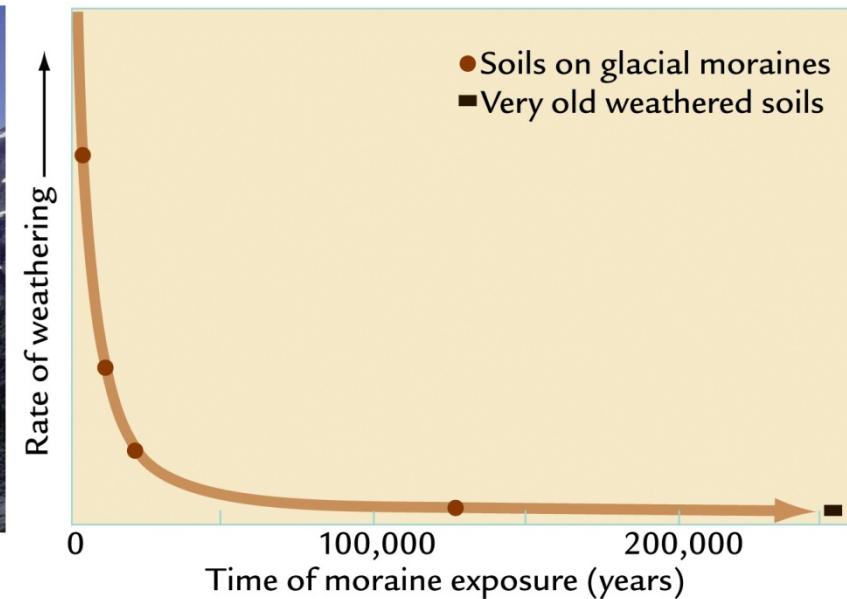


9.2.1 构造尺度 (tectonic scale)

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“新鲜” 岩石和矿物的暴露影响全球平均化学风化率



隆升

→ 形成新鲜岩石和矿物表面

→ 更强的风化

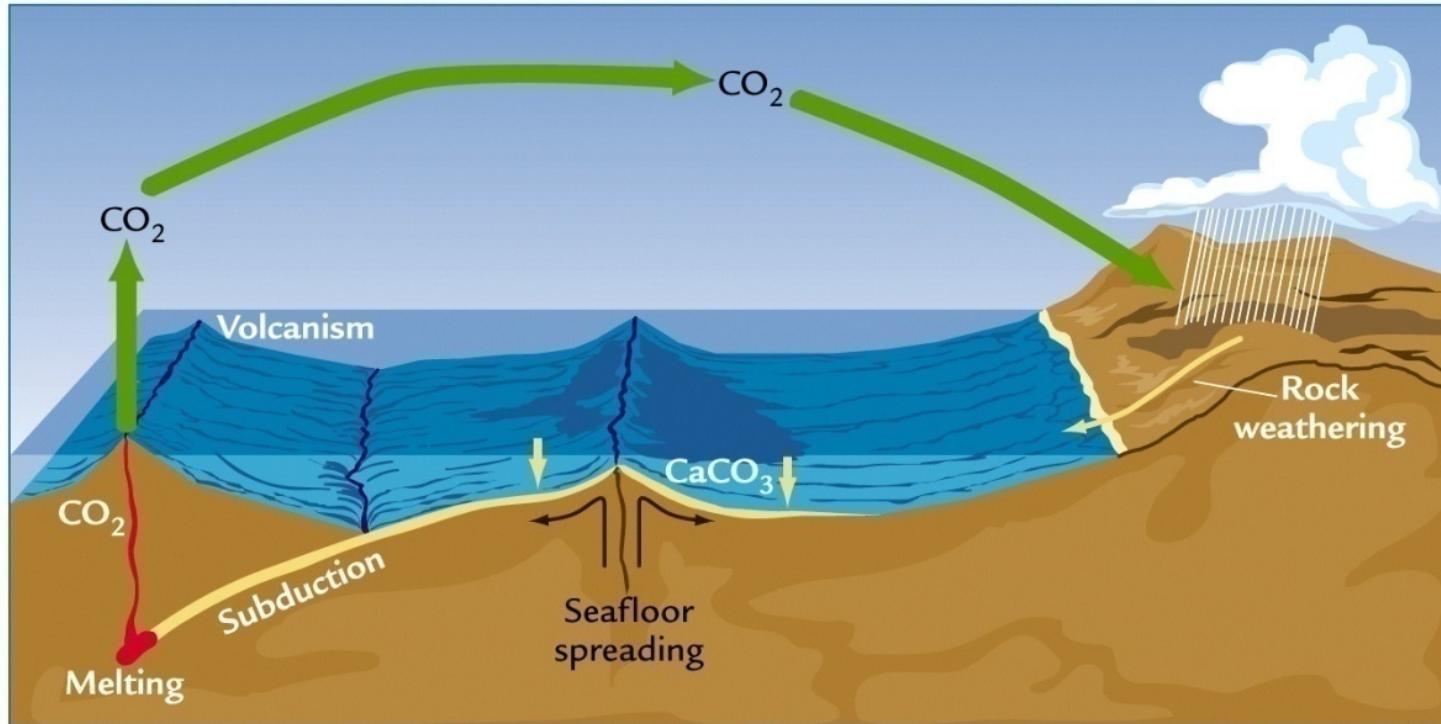
→ 减小大气CO₂



9.2.1 构造尺度 (tectonic scale)

b. 板块构造与气候 (~5.5亿年前 550Myr)

碳循环和大气CO₂稳定性



- BLAG spreading rate hypothesis
- Uplift-Weathering hypothesis

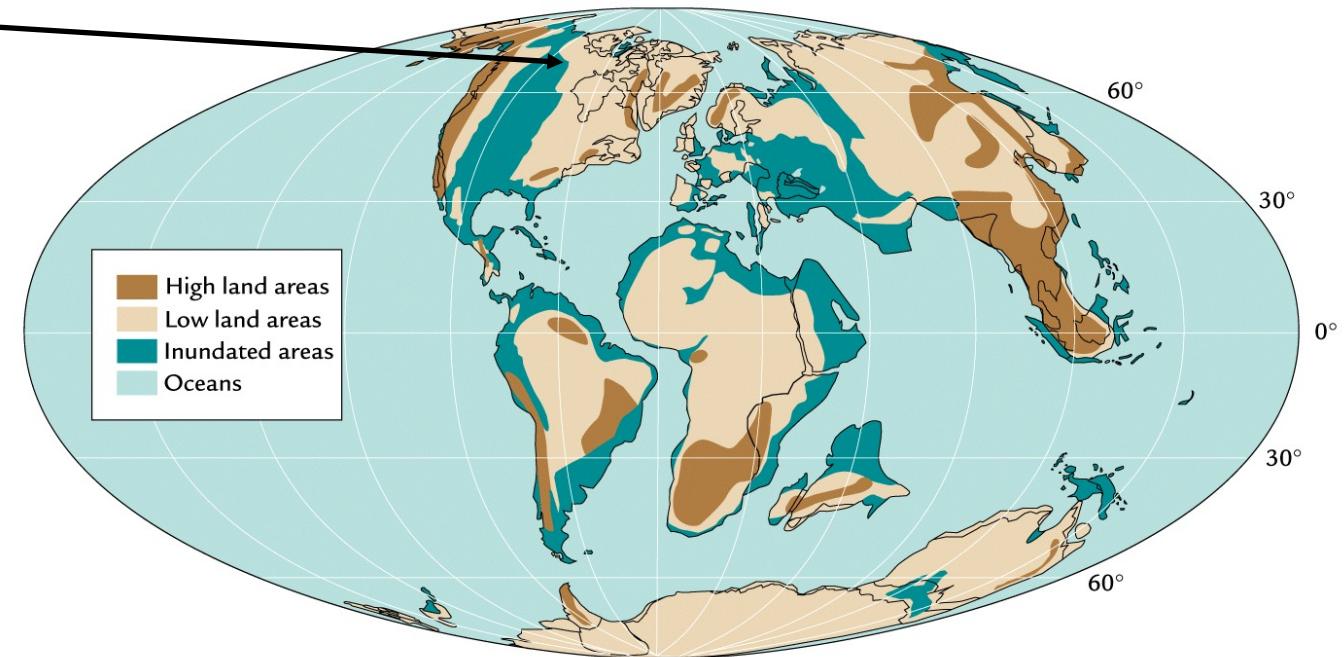
9.2.1 构造尺度 (tectonic scale)

c. 温室地球 (~一亿年前 100Myr)

Warm Arctic



1亿年前：白垩纪中期(mid-Cretaceous)

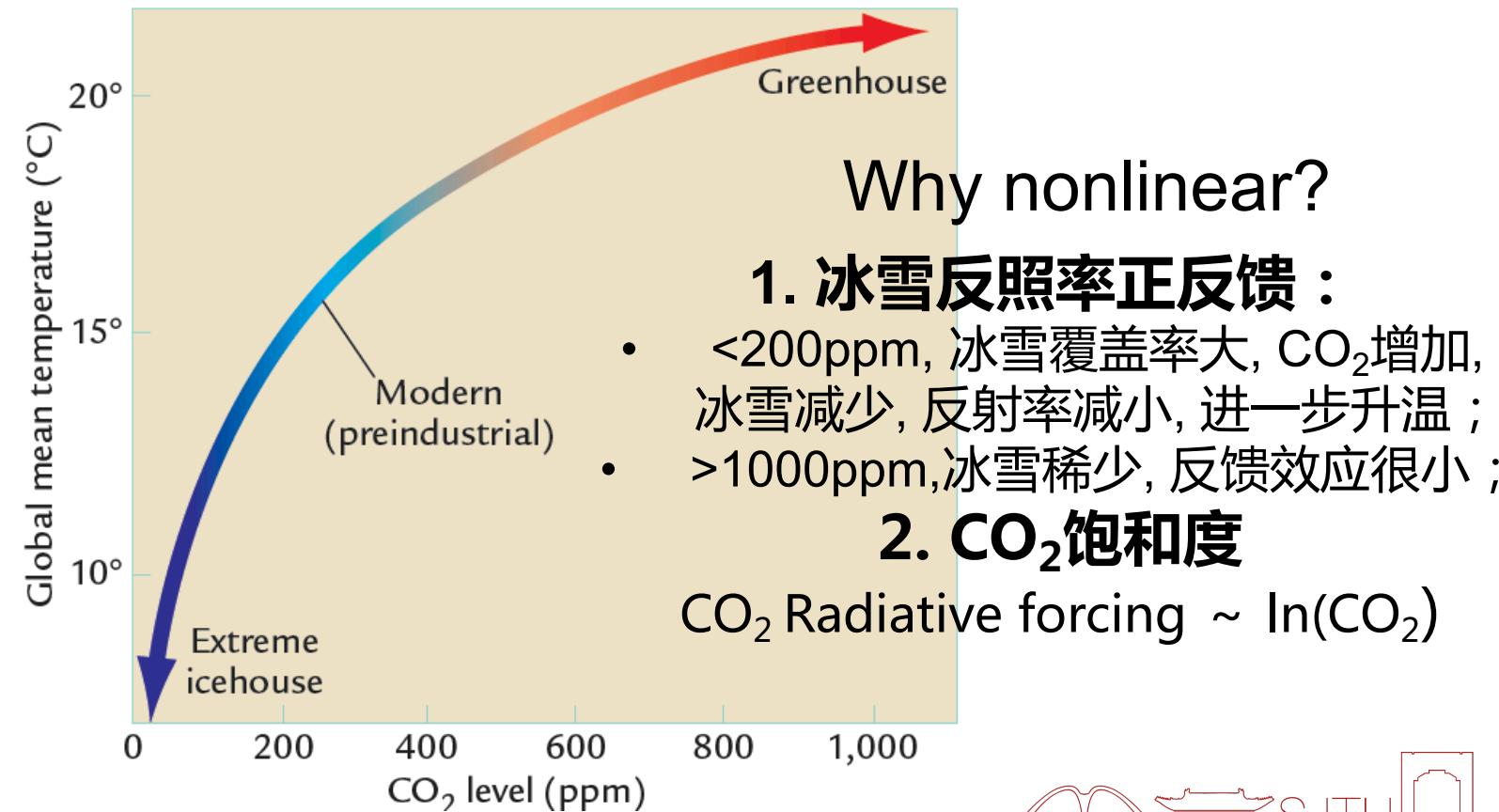
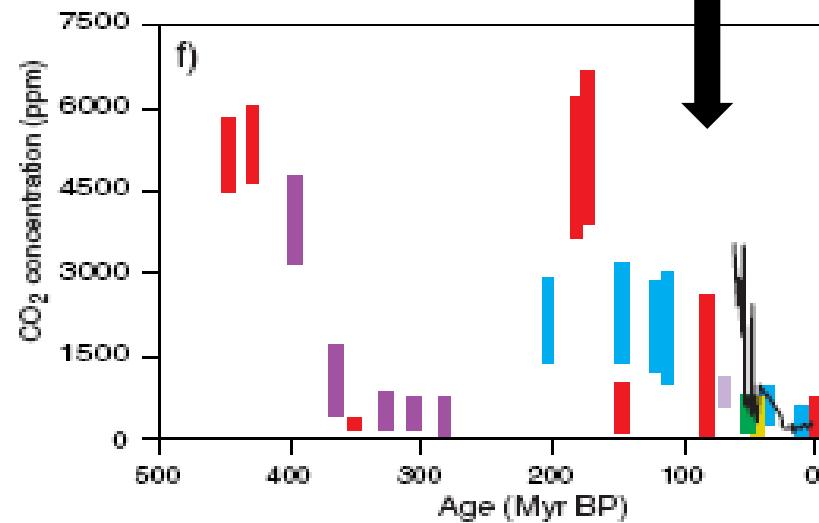


- 极地没有冰层；
- 珊瑚礁向极地 10° ；
- 海平面上升约100米

9.2.1 构造尺度 (tectonic scale)

c. 温室地球 (~一亿年前 100Myr)

CO₂对全球气候的影响

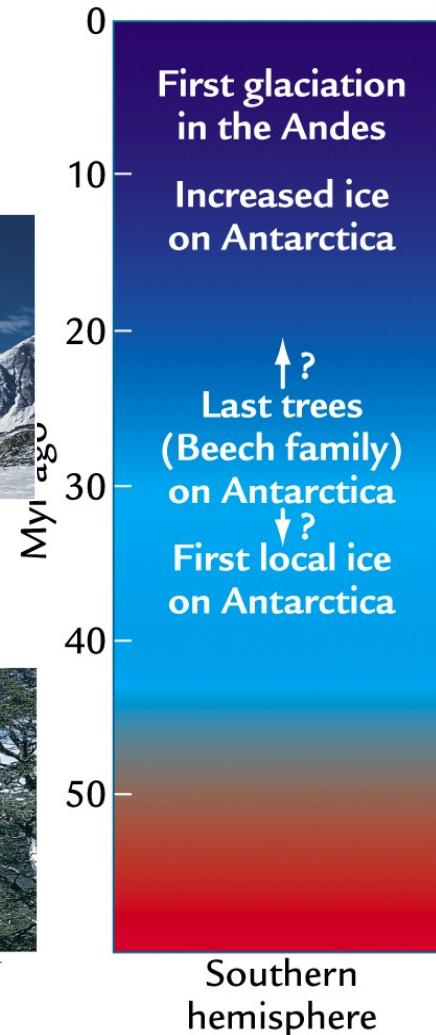


9.2.1 构造尺度 (tectonic scale)

c. 冰室气候 (~ 5000万年前 50Myr)

气候变冷的证据：陆地纪录

南极



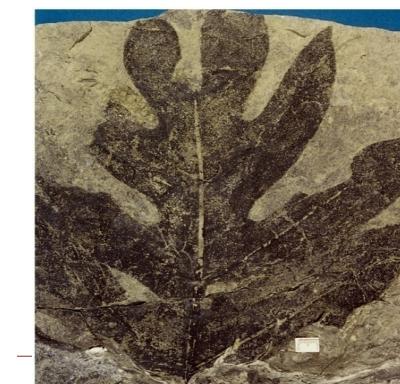
First
North American
and Eurasian ice

Spread of cool
boreal spruce
forest in the
Arctic

Broad-leaved
Evergreen and
deciduous forest
in the Arctic

Palm-like trees
and crocodile
ancestors north
of Arctic circle

北极



9.2.1 构造尺度 (tectonic scale)

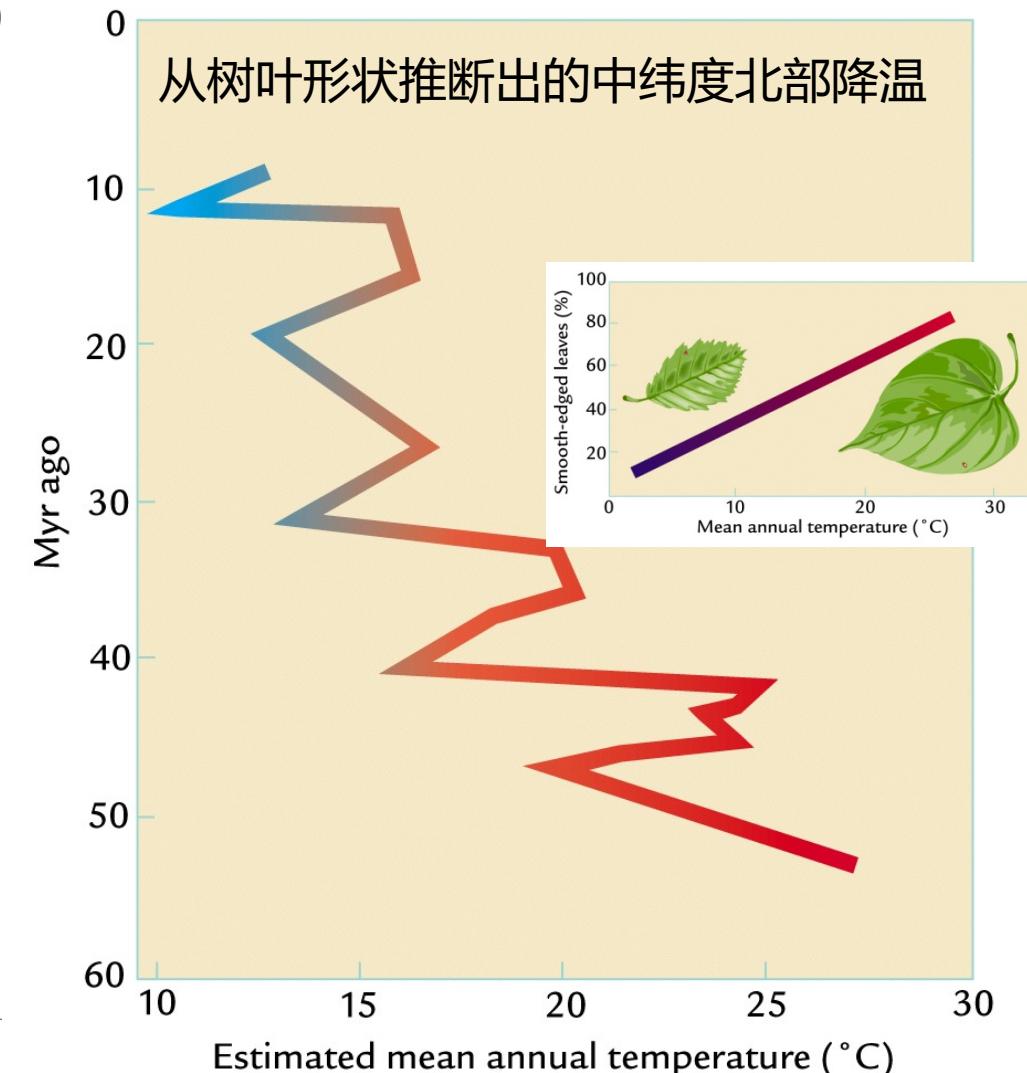
c. 冰室气候 (~ 5000万年前 50Myr)

气候变冷的证据：陆地纪录

现代植被中

- 温暖地区：光滑的圆形边缘；
- 寒冷地区：不规则边缘，锯齿状

陆地纪录的问题：
不完整，零星，区域性





第九章 地球气候的演变



9.2.1 构造尺度 (tectonic scale)

c. 冰室气候 (~ 5000万年前 50Myr)

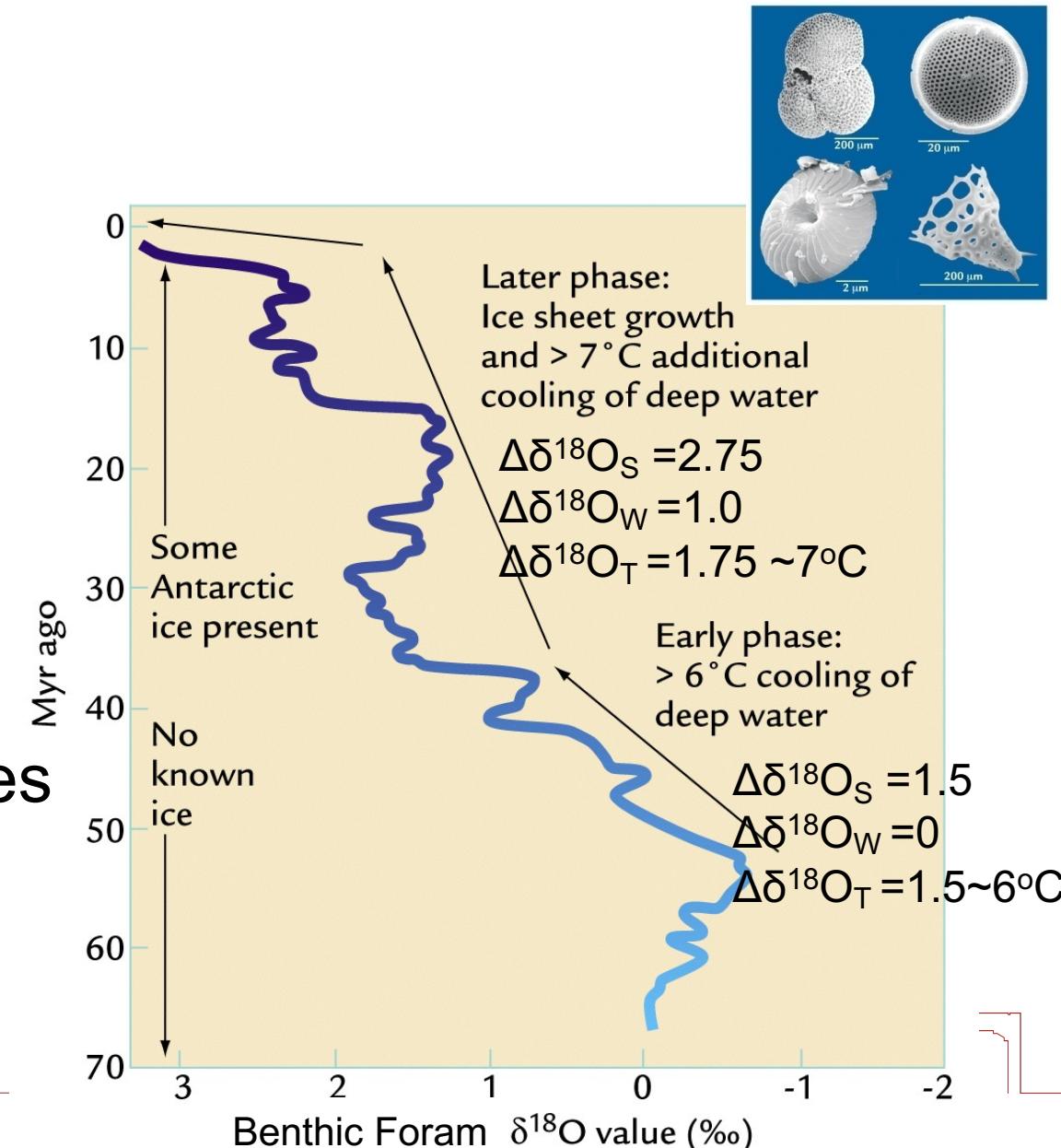
气候变冷的证据：有孔虫 $\delta^{18}\text{O}$

$$\Delta\delta^{18}\text{O}_{\text{shell}} = \Delta\delta^{18}\text{O}_W + \Delta\delta^{18}\text{O}_T$$

i) $\Delta\delta^{18}\text{O}_T = -\Delta T / 4^\circ\text{C}$: Cooler, increases



ii) $\Delta\delta^{18}\text{O}_W$: More continental ice, increases





第九章 地球气候的演变



9.2.1 构造尺度 (tectonic scale)

c. 冰室气候 (~ 5000万年前 50Myr)

气候为什么变冷？

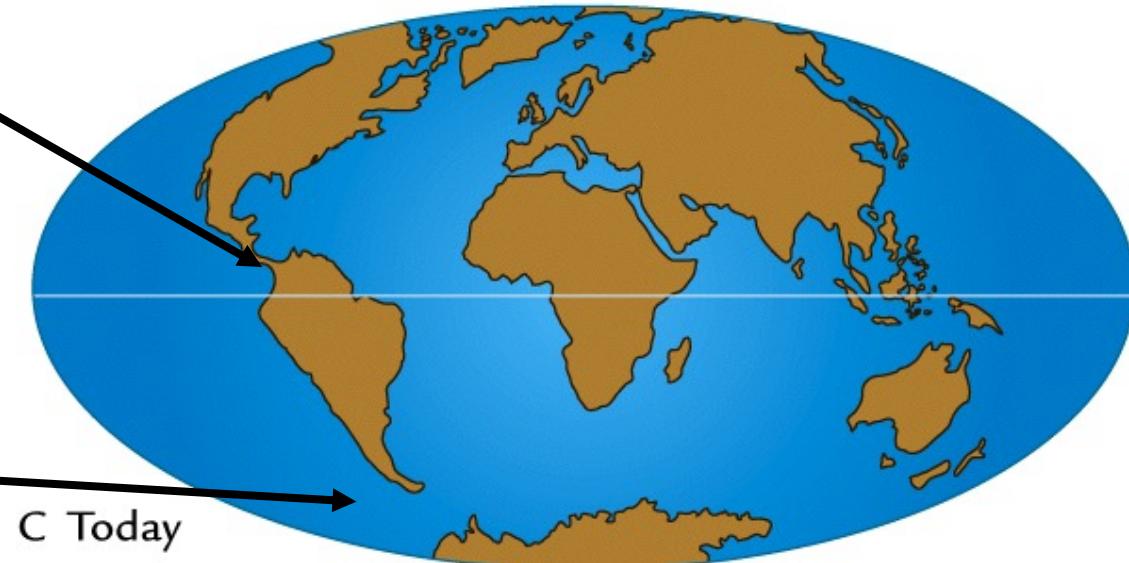
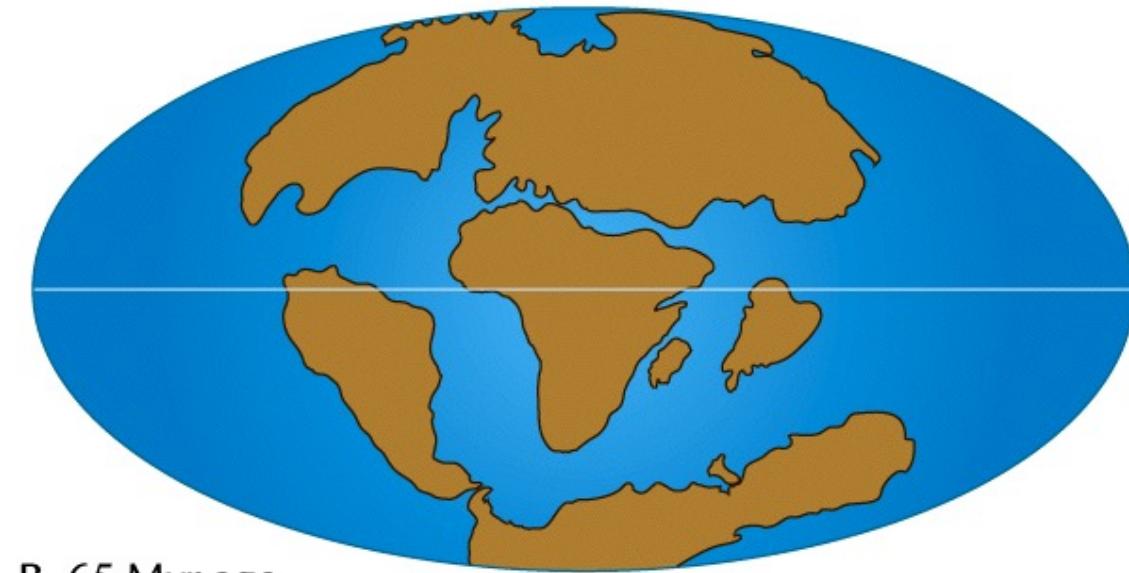
Ocean Gateway Hypothesis

巴拿马海峡的关闭的形成 (10-4Myr) 使温暖/盐度高的海水向北, 阻碍海冰生成, 促进蒸发从而促进北极陆地冰川形成。

但是模式模拟发现相反的作用(热量传输)。

Drake Passage的形成 (20Myr) 影响向极地的热量输送, 导致南极冰川。

但是模式模拟发现此作用效果不明显。

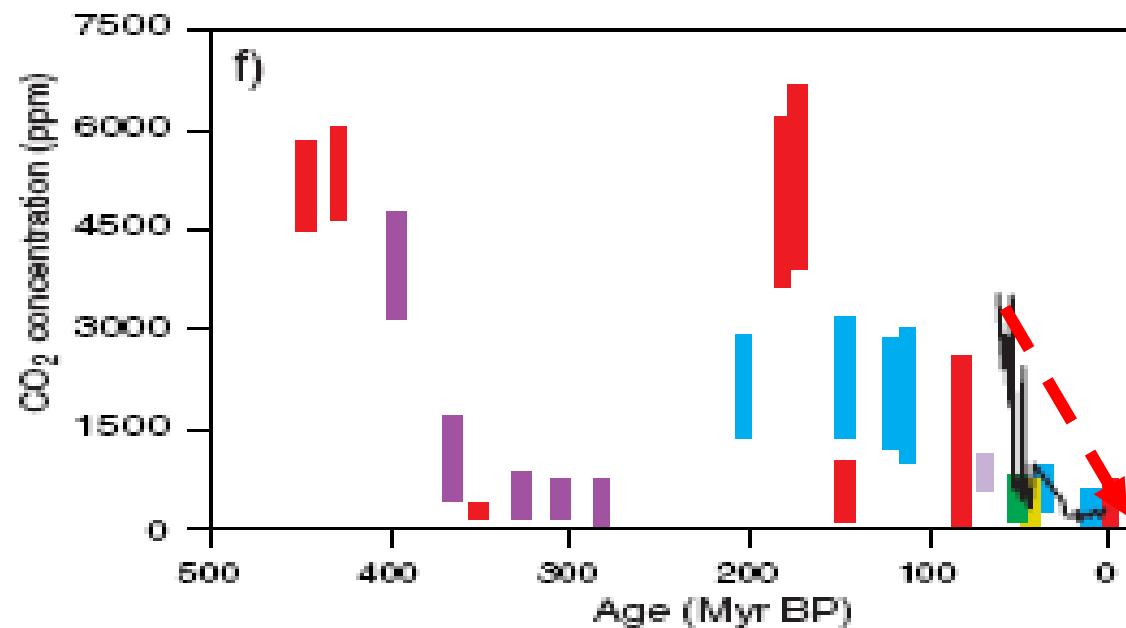


9.2.1 构造尺度 (tectonic scale)

c. 冰室气候 (~ 5000万年前 50Myr)

气候为什么变冷？

大气CO₂



大气CO₂降低原因？

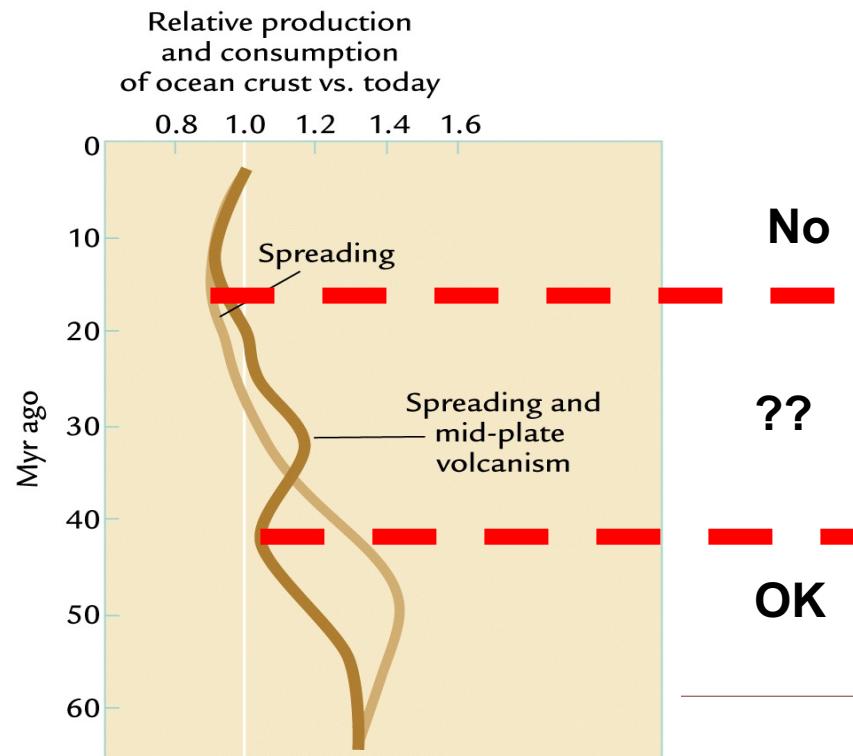
BLAG: 海底扩张速度减小?
隆升-风化: 增强?

9.2.1 构造尺度 (tectonic scale)

c. 冰室气候 (~ 5000万年前 50Myr)

气候为什么变冷 ? 大气CO₂降低原因 ?

BLAG: 海底扩张速度



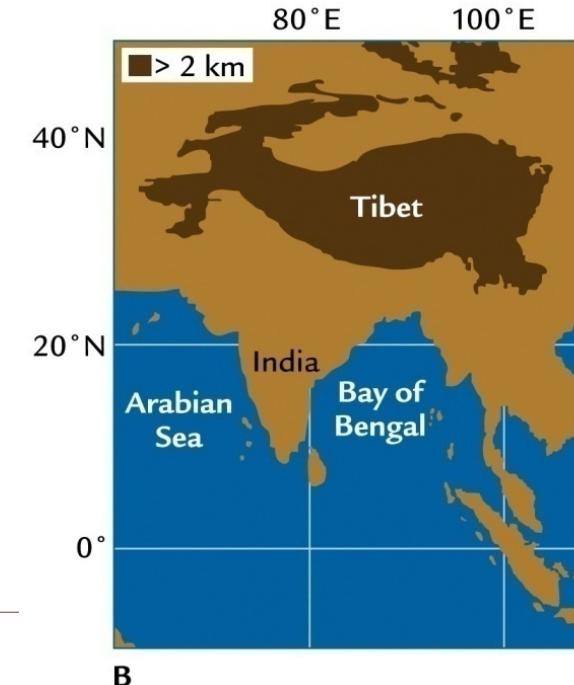
No

??

OK

隆升-风化

青藏高原隆升: ~ 20Myr





青藏高原隆升的气候效应

Asian monsoon

- An, Z., Kutzbach, J. Prell, W. & Porter, S., 2001: Evolution of Asian monsoons and phased uplift of the Himalaya-Tibetan plateau since Late Miocene times. *Nature*, 411, 62-66
- Boos and Kuang, 2010: Dominant control of the South Asian monsoon by orographic insolation versus plateau heating. *Science*, 463, 218-222

Potential Impact on global thermohaline

- Emile-Geay J., et al., 2003: Warren revisited: Atmospheric freshwater fluxes and “Why is no deep water formed in the North Pacific”, *Journal of Geophysical Research*, Vol.108(C6), 3178, doi:10.1029/2001JC001058

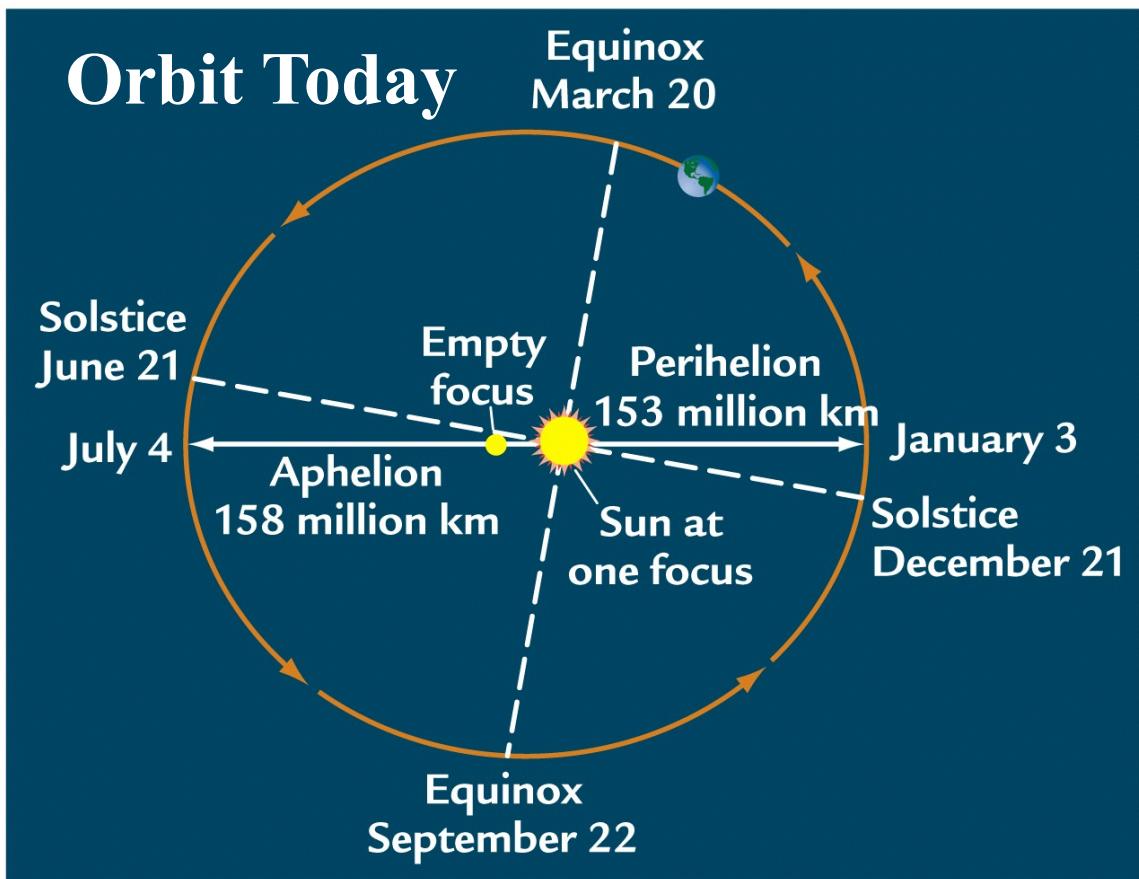


第九章 地球气候的演变

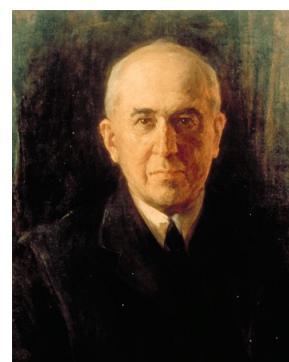
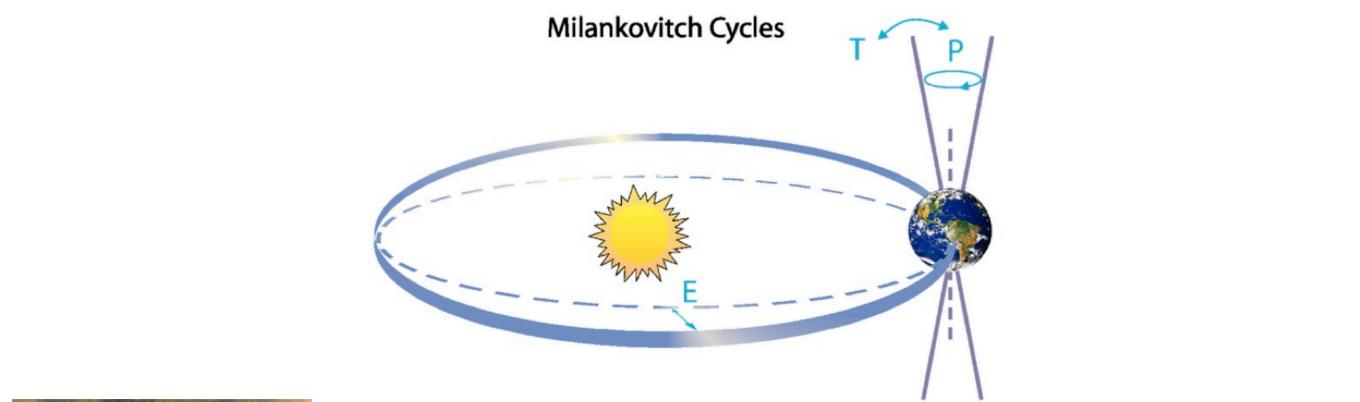


9.2.2 轨道尺度 (orbital scale)

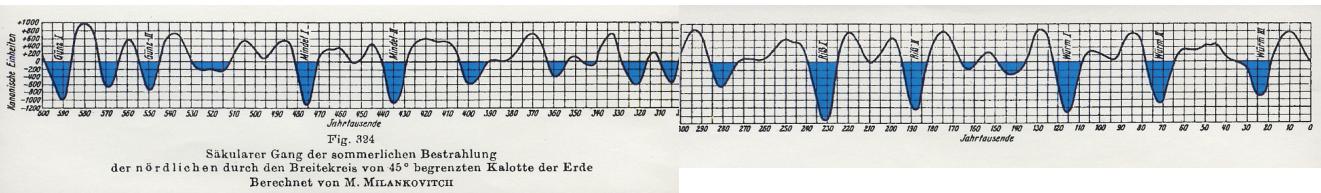
地球轨道和太阳辐射



- 倾斜自转轴 (Obliquity:Tilted Axis)
- 偏心轨道 (Eccentricity:Eccentric Orbit)
- 岁差 (Precession)



Milankovitch(1920):
accurate calculations of
insolation change due to
orbital changes.





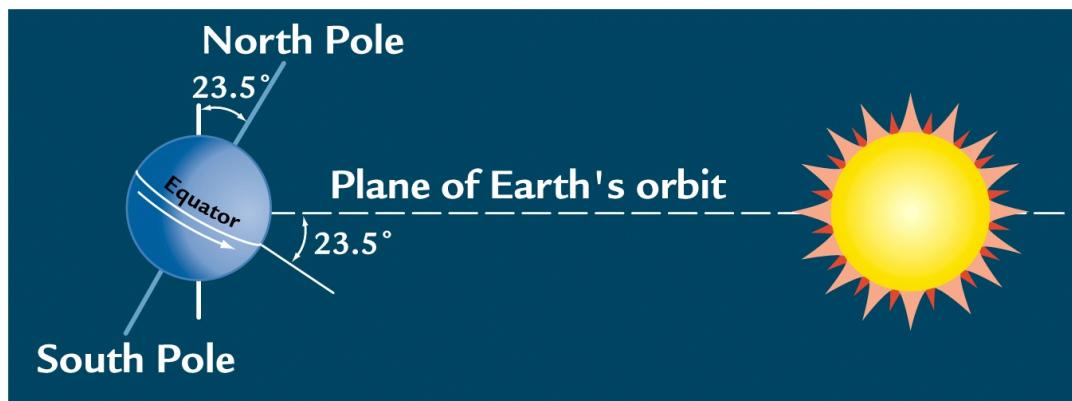
第九章 地球气候的演变



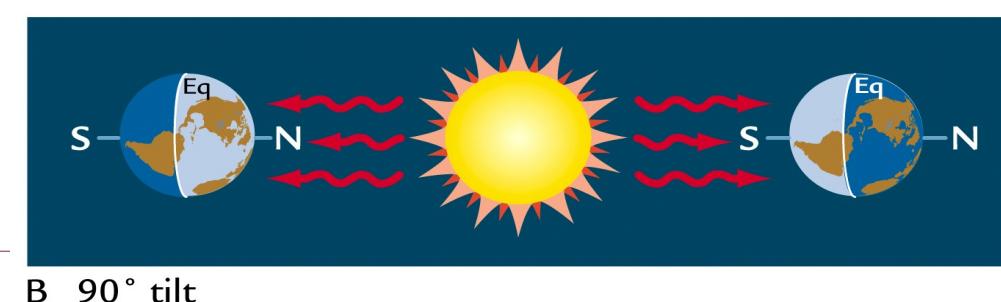
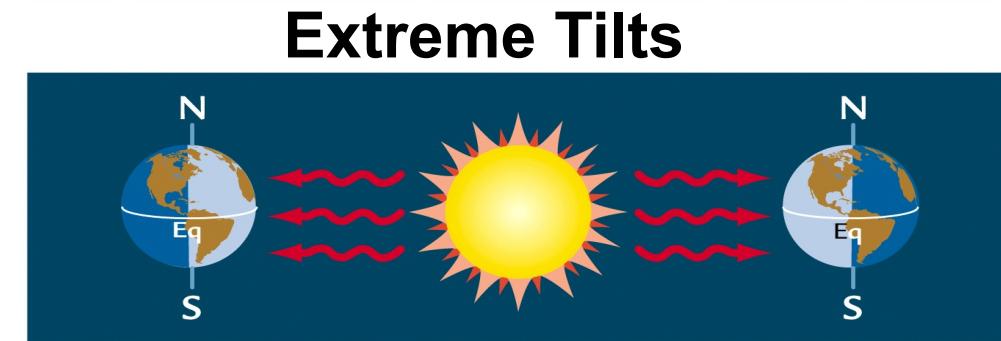
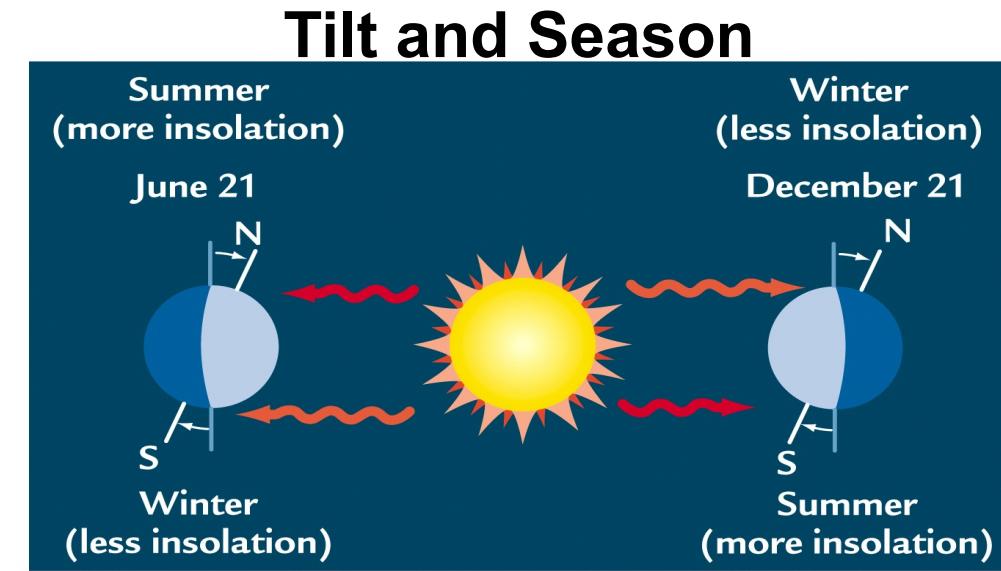
9.2.2 轨道尺度 (orbital scale)

地球轨道和太阳辐射

倾斜自转轴 (Tilted Axis)



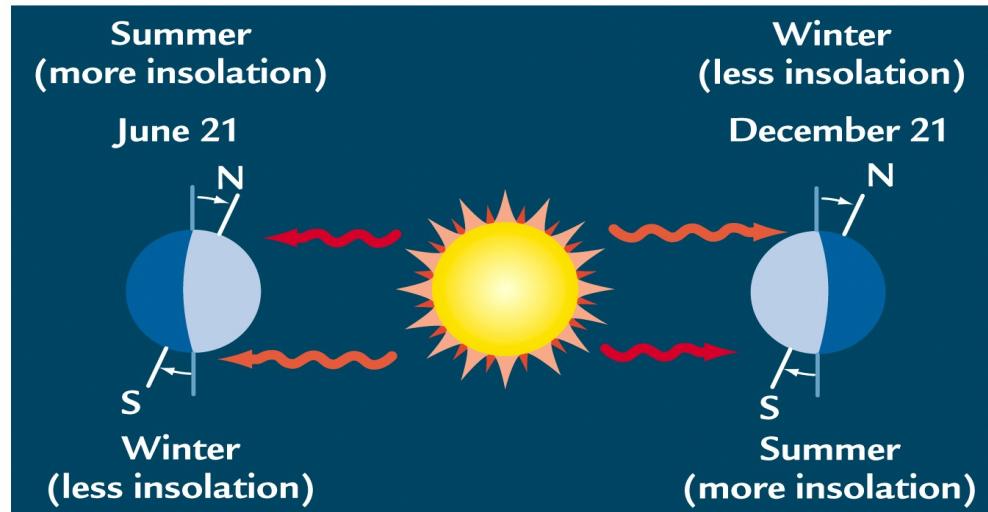
“季节”



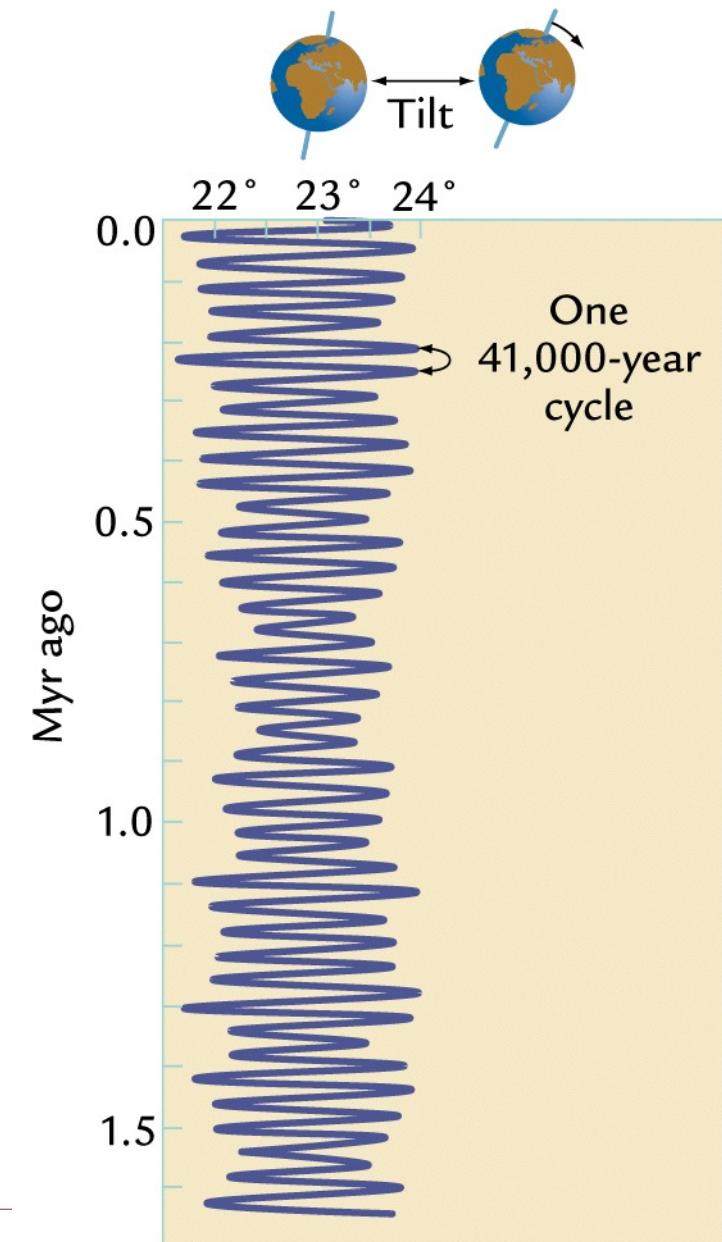
9.2.2 轨道尺度 (orbital scale)

地球轨道和太阳辐射

Tilt and Season



- 倾角的变化“放大”或“缩小”季节的变化，尤其是在两极地区。
- 地球倾角在 22.2° - 24.5° 间变化，周期为4.1万年。

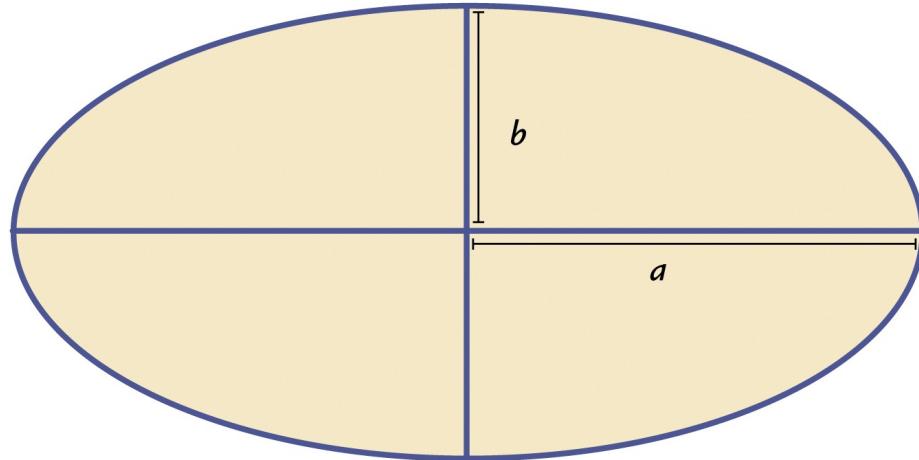




9.2.2 轨道尺度 (orbital scale)

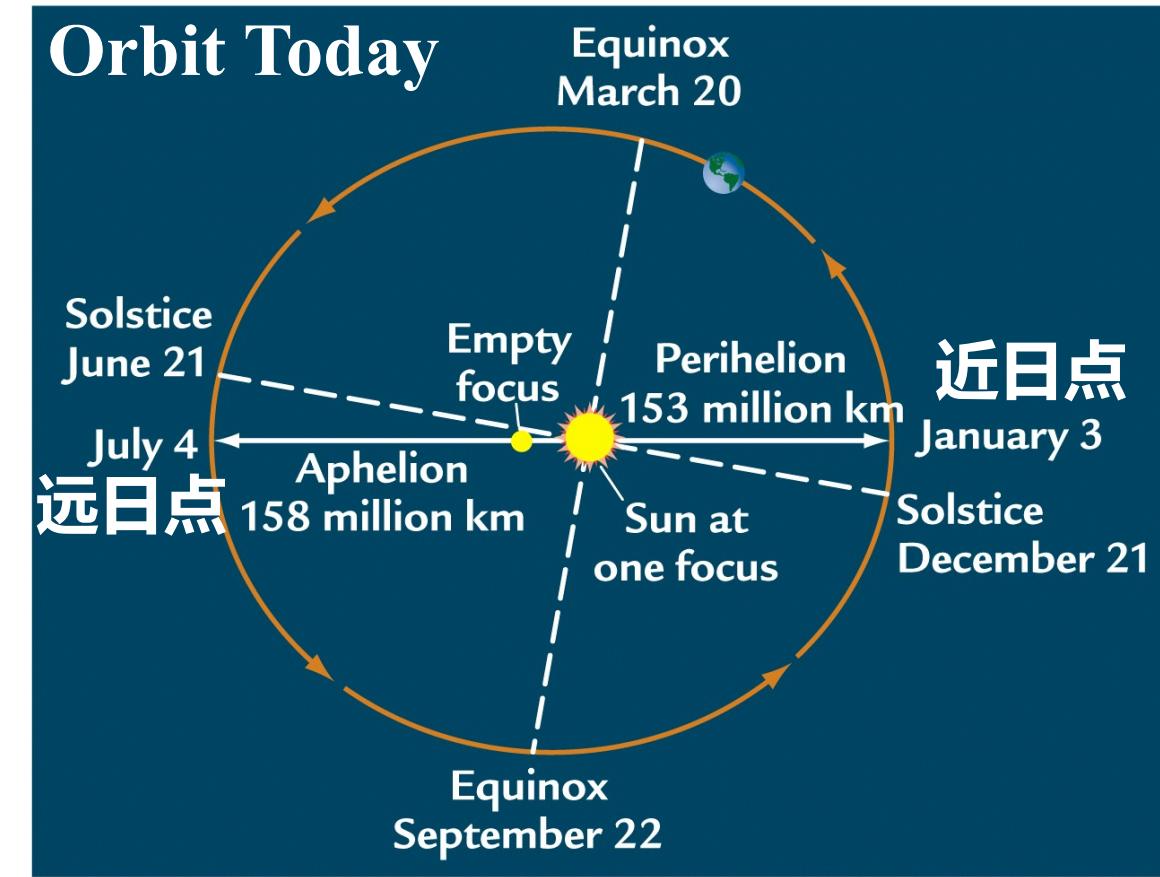
地球轨道和太阳辐射

Eccentric Orbit



$$\text{Eccentricity } \varepsilon = \frac{(a^2 - b^2)^{1/2}}{a}$$

是否影响季节？
很小，约百分之几



目前：近日点在北半球冬季，远日点在北半球夏季
-> 北半球的冬季辐射和南半球的夏季辐射比完全圆形轨道上的辐射略强。

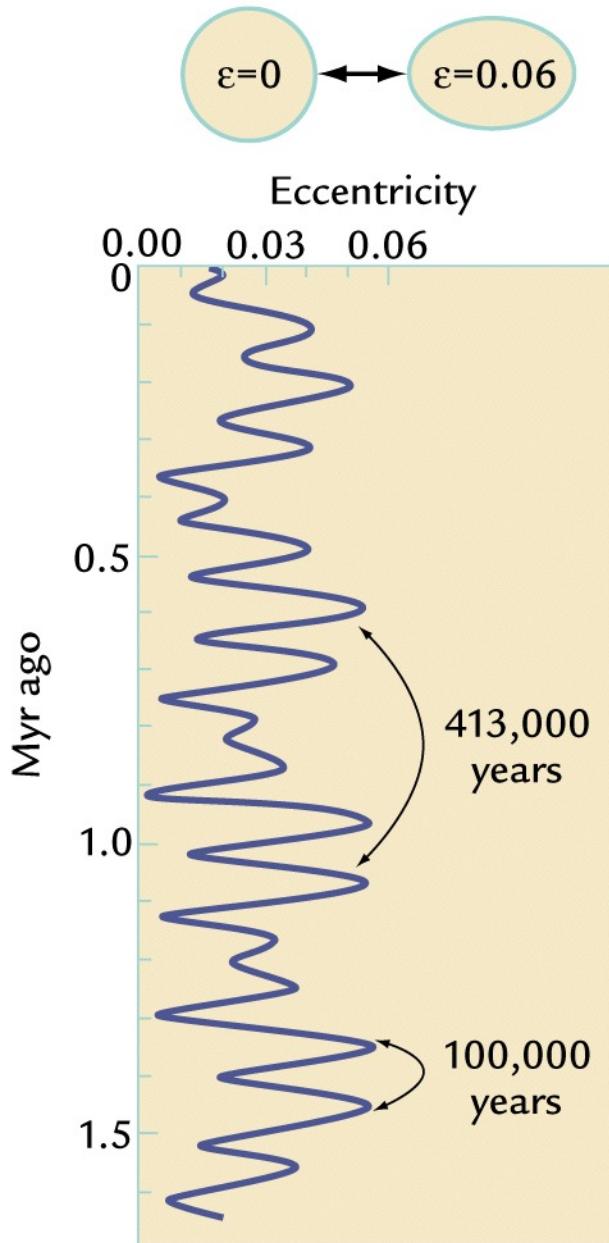


9.2.2 轨道尺度 (orbital scale)

地球轨道和太阳辐射

轨道偏心率的变化主要集中在两个周期：

- 10万年
- 41.3万年





第九章 地球气候的演变



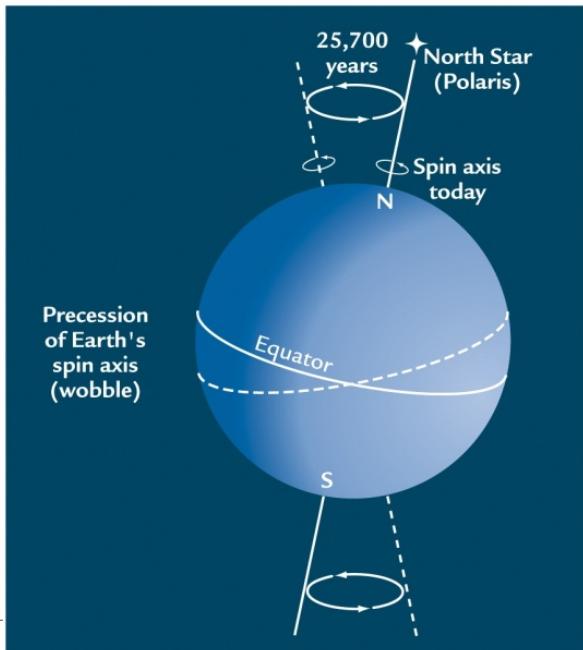
9.2.2 轨道尺度 (orbital scale)

地球轨道和太阳辐射

岁差(Precession): 二分二至点在宇宙中的相对位置。

Axial precession

~25700yrs



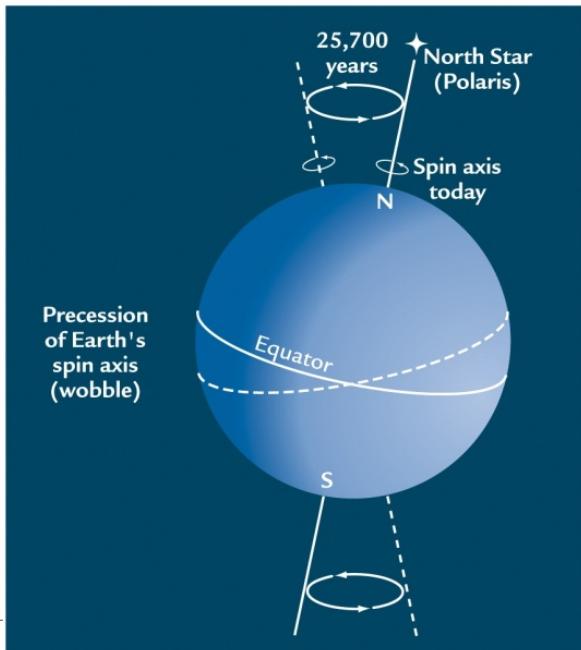


9.2.2 轨道尺度 (orbital scale)

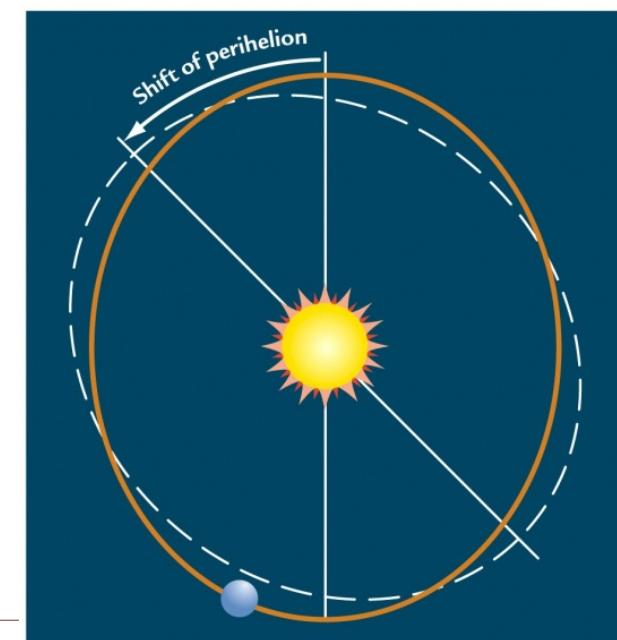
地球轨道和太阳辐射

岁差(Precession): 二分二至点在宇宙中的相对位置。

Axial precession
~25700yrs



Precession of the ellipse





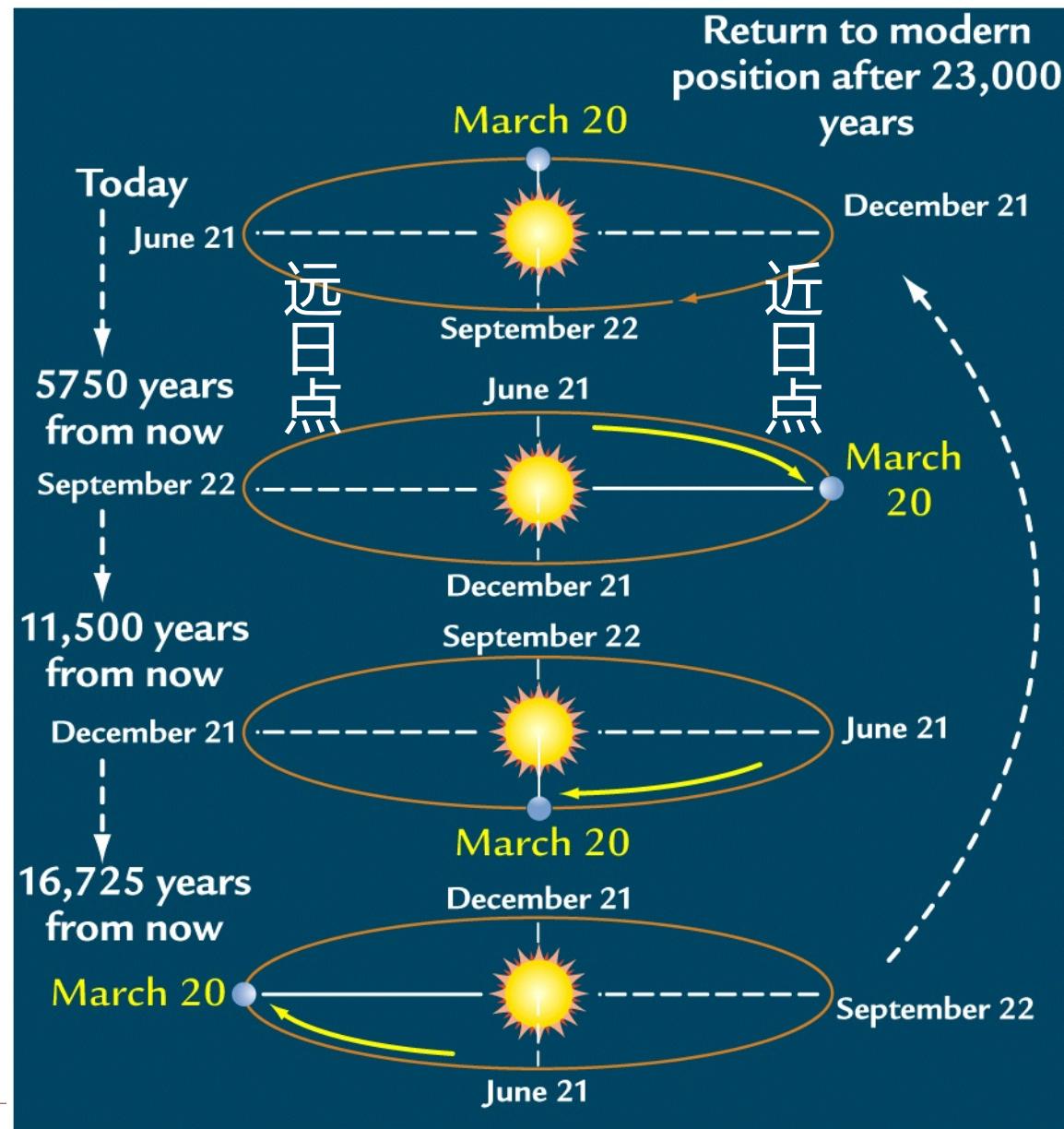
第九章 地球气候的演变



9.2.2 轨道尺度 (orbital scale)

地球轨道和太阳辐射

岁差(Precession):
二分二至点在宇宙中的相对位置。
周期 ~ 2万3千年





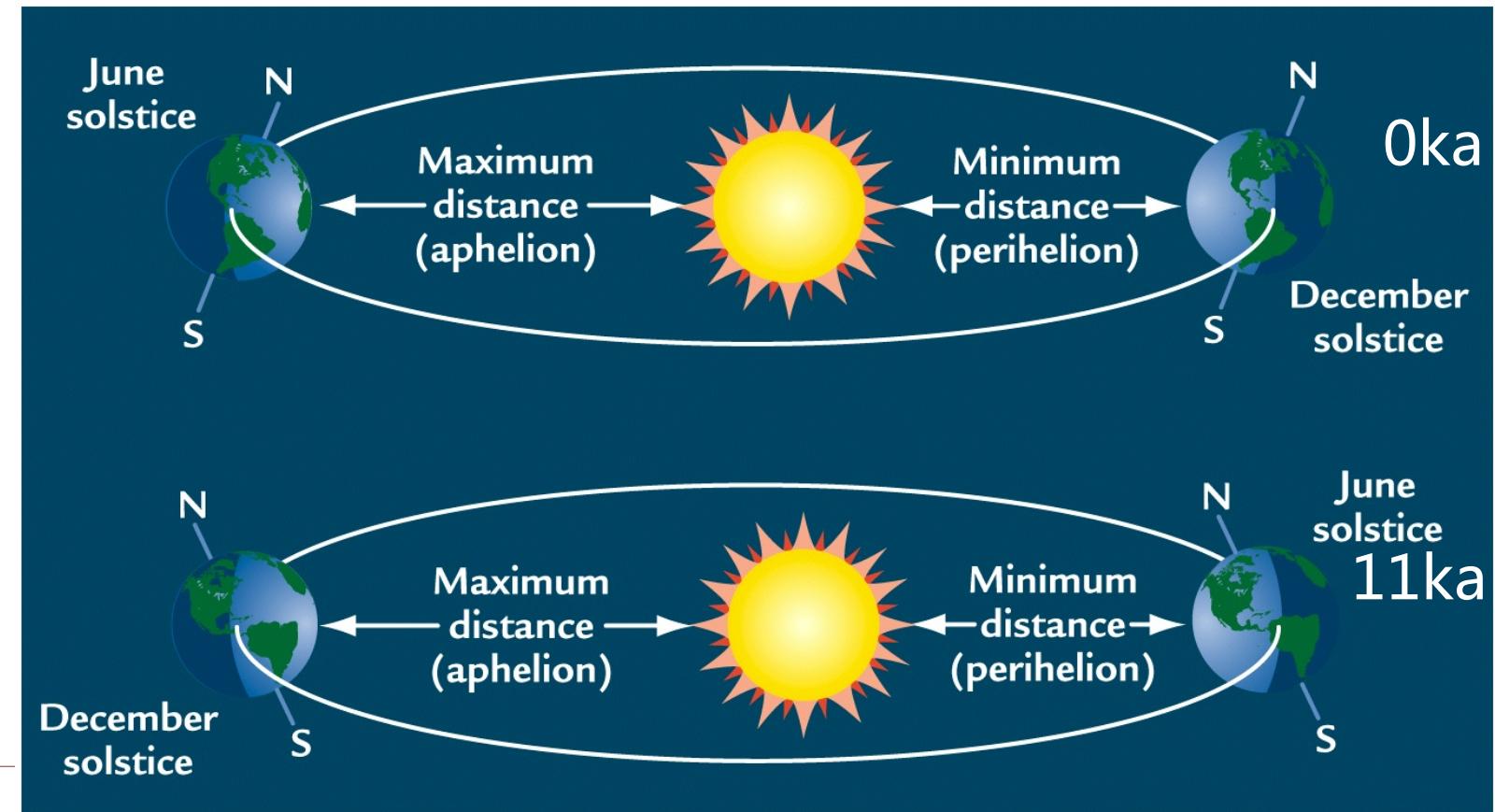
9.2.2 轨道尺度 (orbital scale)

地球轨道和太阳辐射

岁差(Precession)

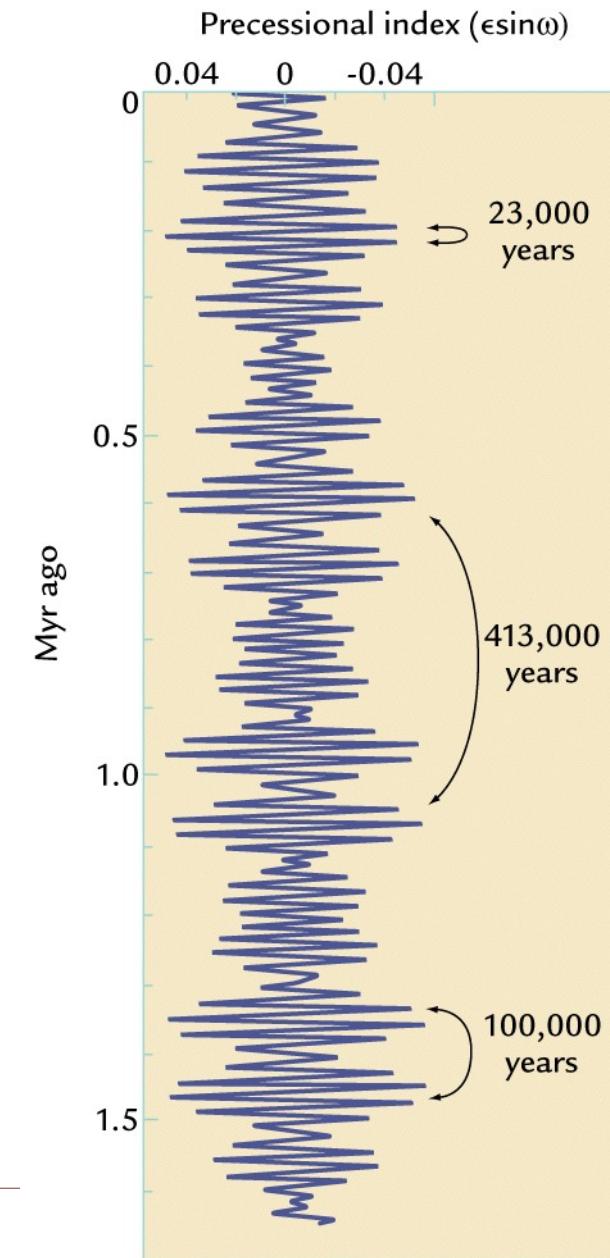
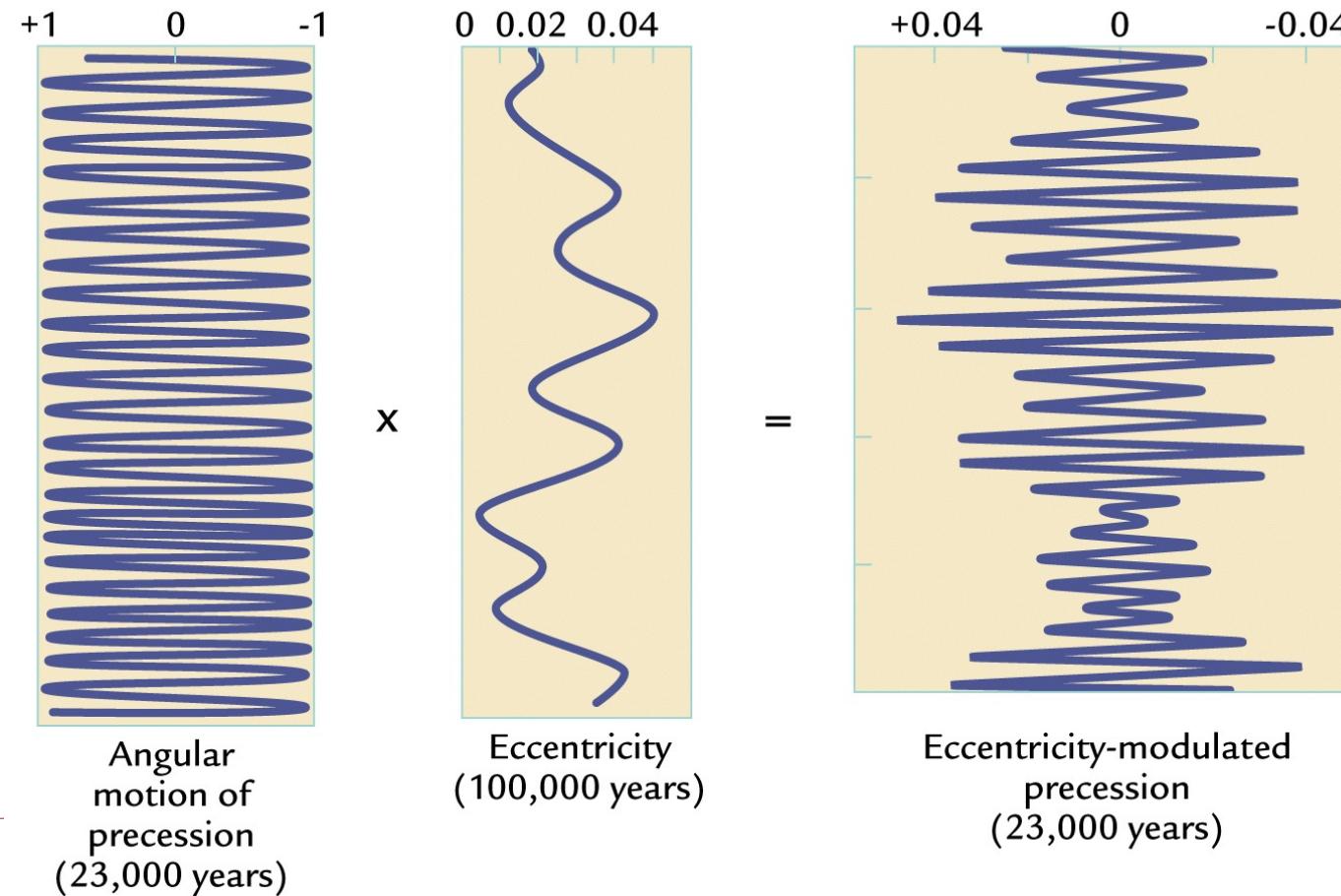
北半球夏至 ~ 远日点

北半球夏至 ~ 近日点



9.2.2 轨道尺度 (orbital scale)

地球轨道和太阳辐射 太阳辐射的岁差

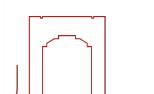
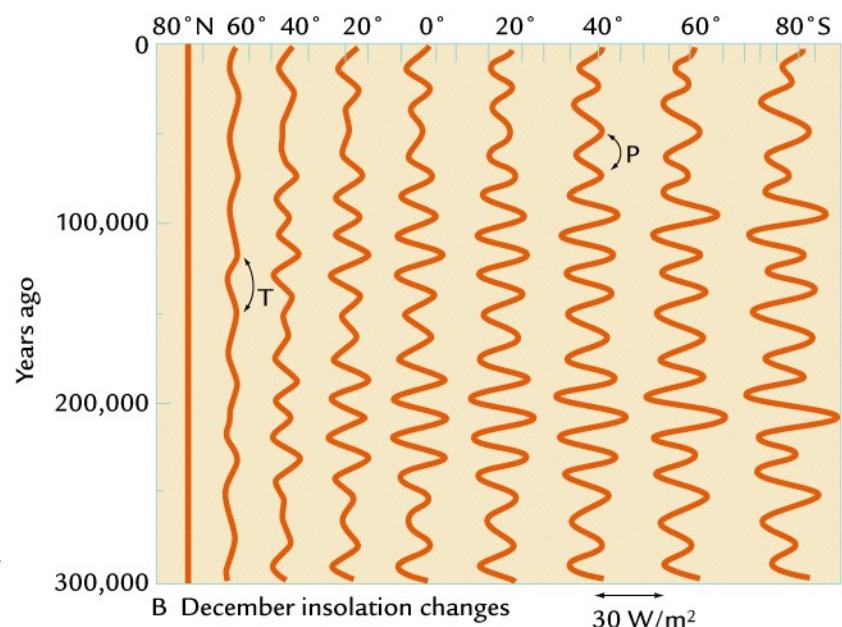
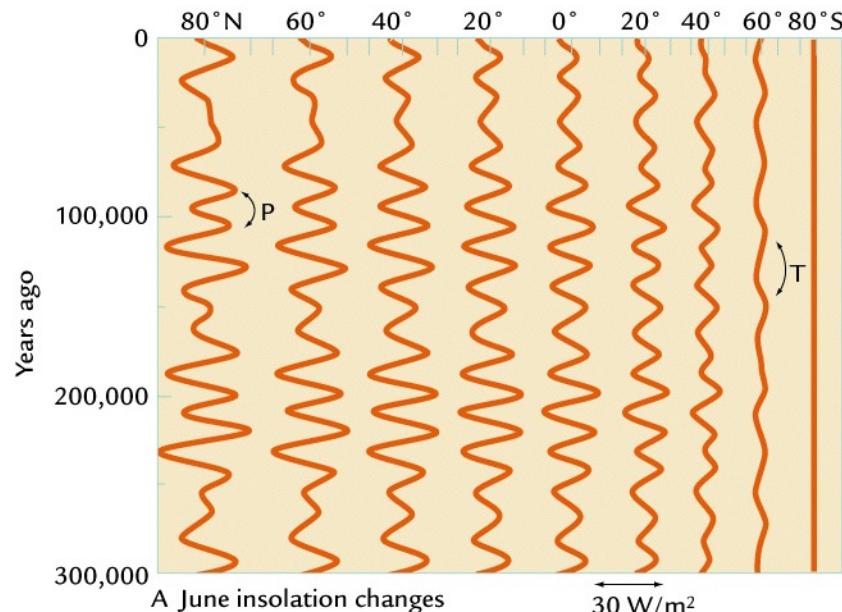




9.2.2 轨道尺度 (orbital scale)

太阳辐射的季节变化

- Where precession signal is large?
- Where tilt signal is large?
- What signal is dominant in the annual mean?
- What is the phase of each signal in different hemisphere?





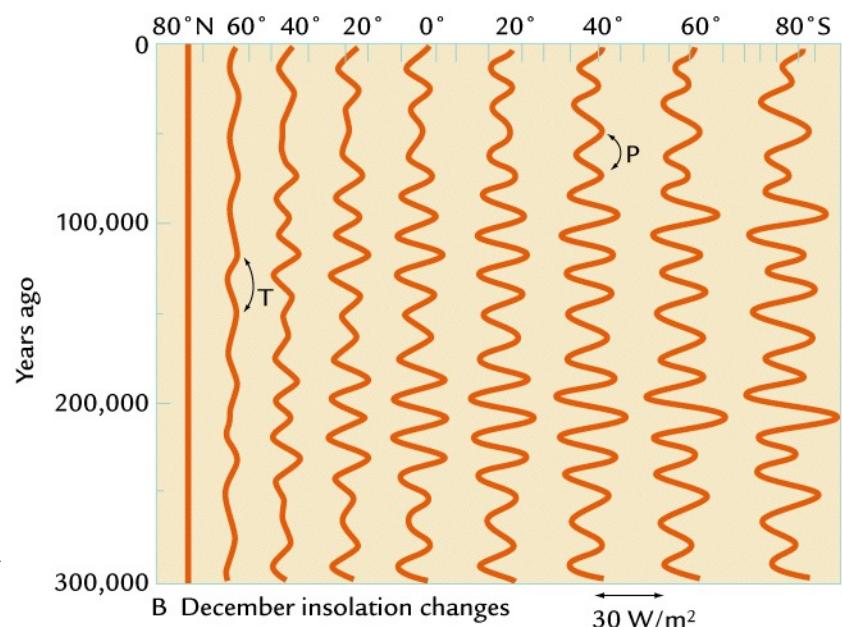
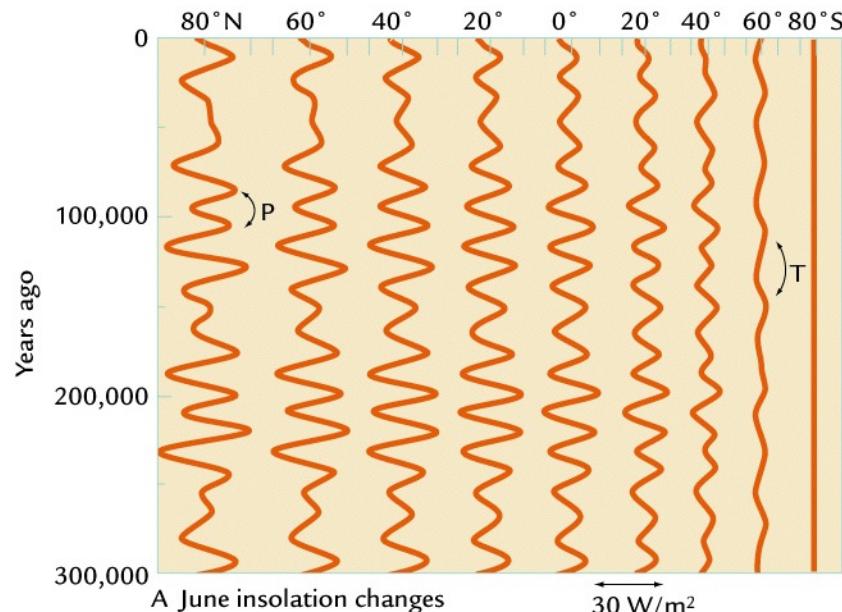
第九章 地球气候的演变



9.2.2 轨道尺度 (orbital scale)

太阳辐射的季节变化

- Where precession signal is large?
中低纬度
- Where tilt signal is large?
高纬度
- What signal is dominant in the annual mean?
岁差
- What is the phase of each signal in different hemisphere?





9.2.2 轨道尺度 (orbital scale)

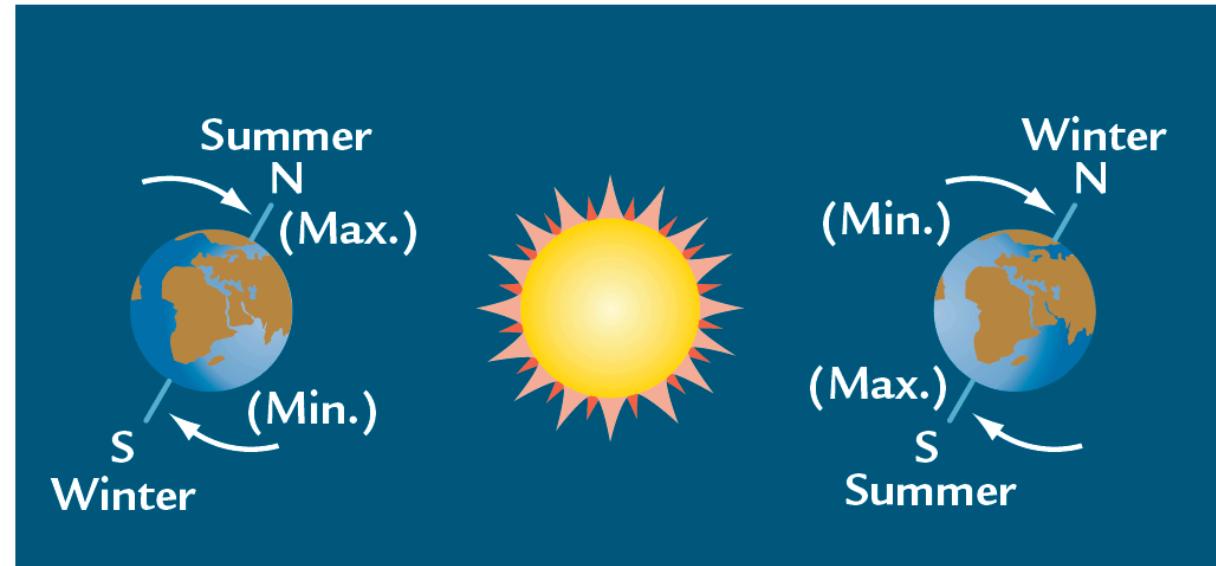
太阳辐射的季节变化

Tilt: in-phase

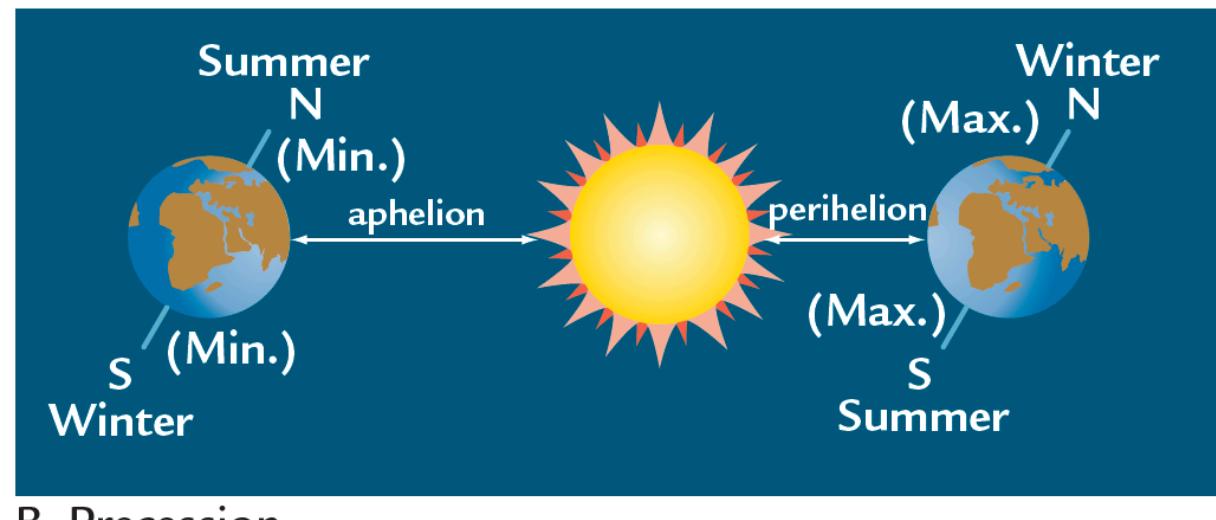
南北极均在夏季辐射最大，
冬季辐射最小。

Precession: out-of-phase

由于季节在南北半球相反，若北半球夏季在远日点，则南半球冬季也在远日点；北半球冬季在近日点，则南半球夏季也在近日点。



A Tilt



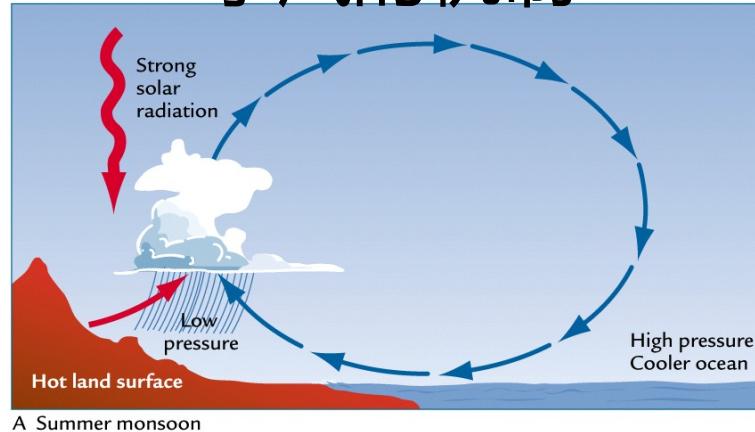
B Precession



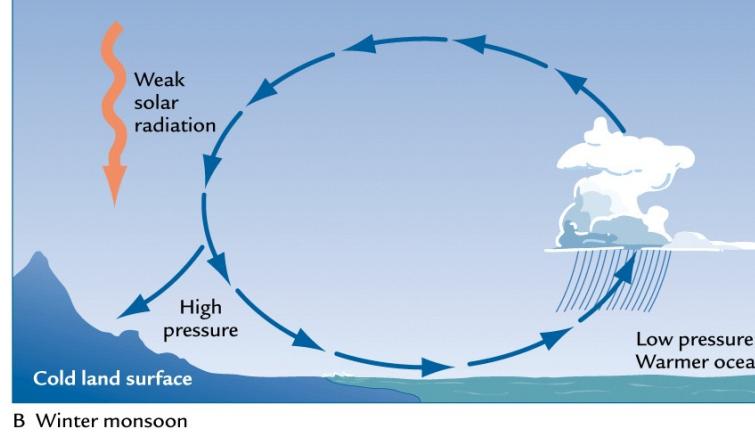
9.2.2 轨道尺度 (orbital scale)

轨道变化的气候影响：季风的变化

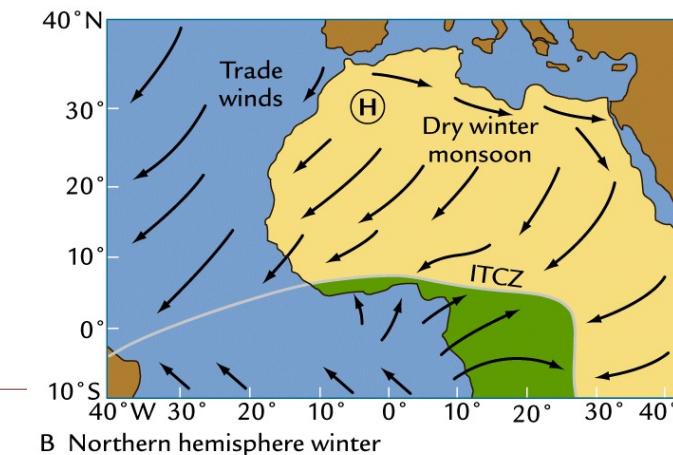
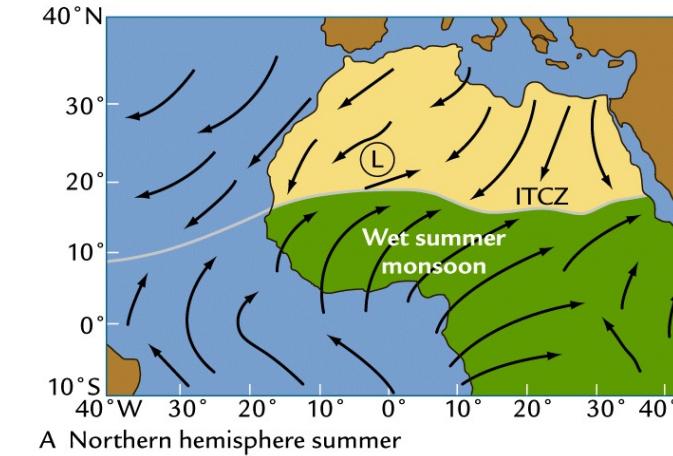
季风的机制



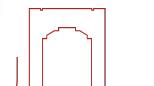
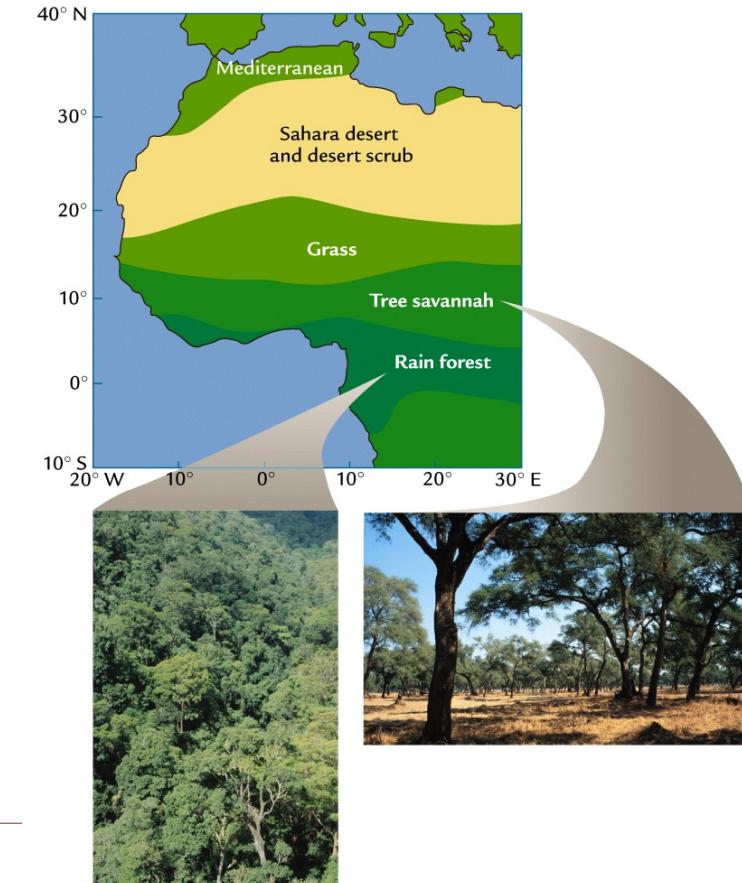
A Summer monsoon



B Winter monsoon



非洲季风与植被





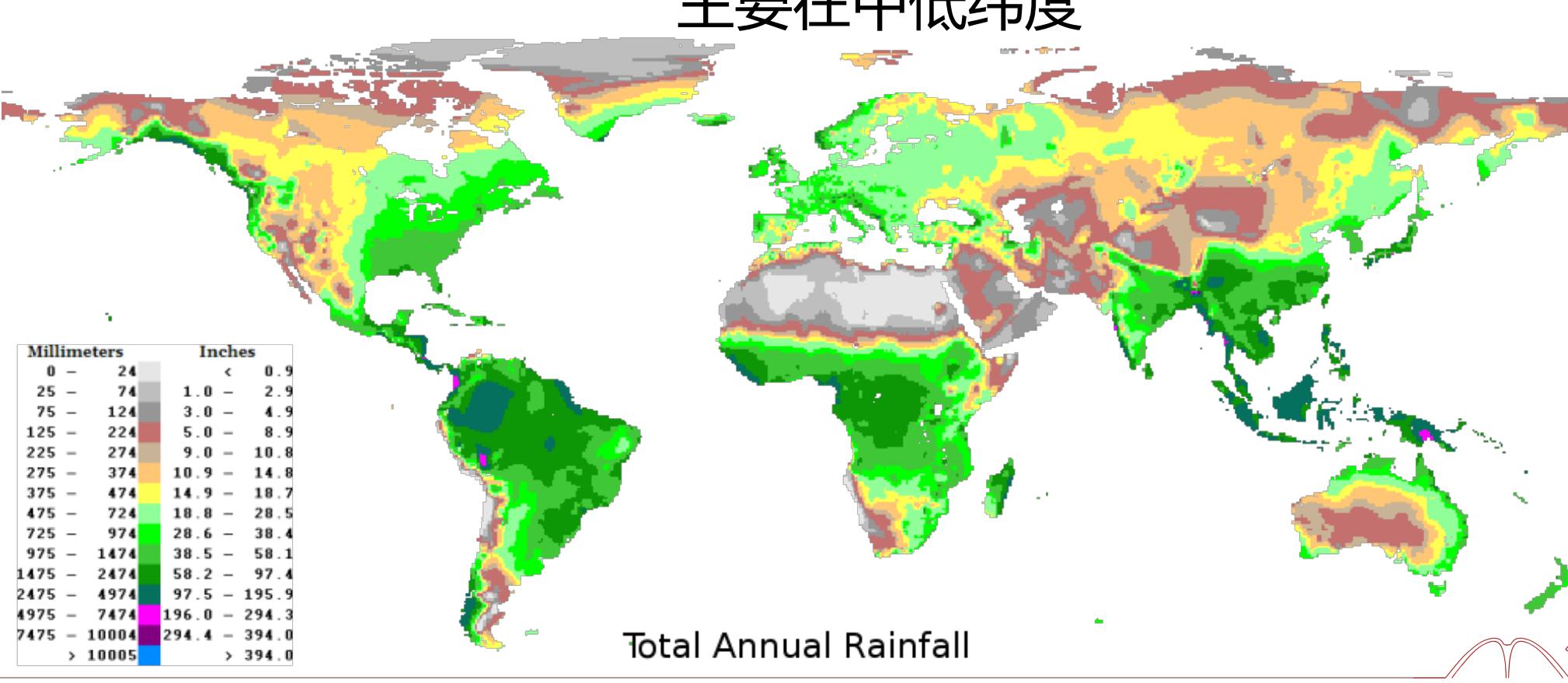
第九章 地球气候的演变



9.2.2 轨道尺度 (orbital scale)

轨道变化的气候影响：季风的变化

主要在中低纬度



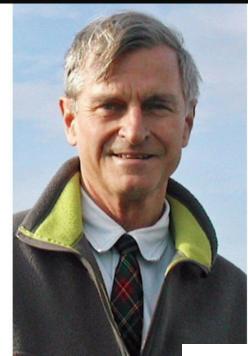


第九章 地球气候的演变



9.2.2 轨道尺度 (orbital scale)

轨道变化的气候影响：季风的变化

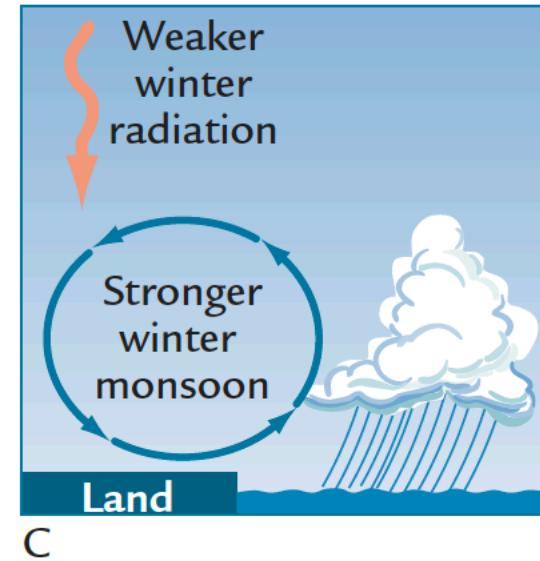
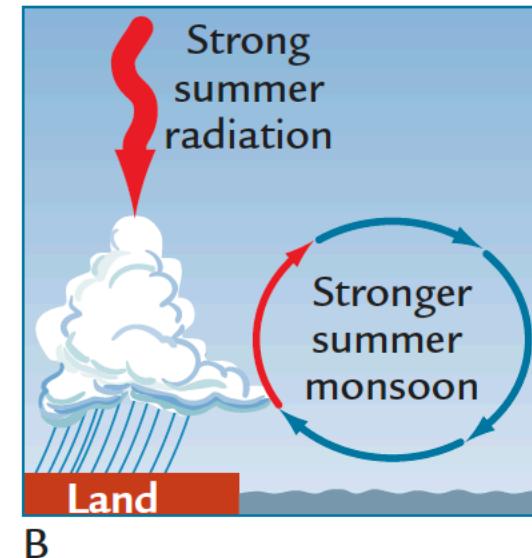
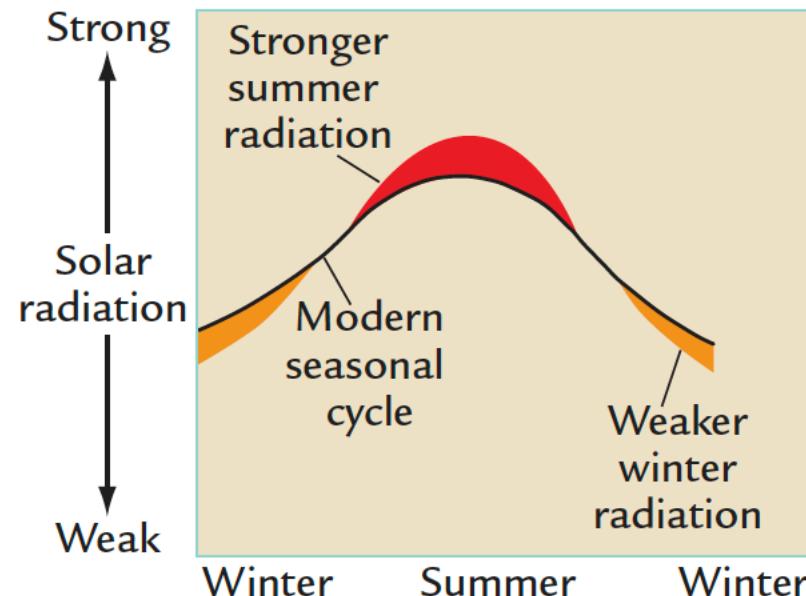


轨道季风假说

The Orbital Monsoon Hypothesis

John Kutzbach, 1981, Science

更强的夏季太阳辐射->更强的夏季风；
更弱的冬季太阳辐射->更强的冬季风



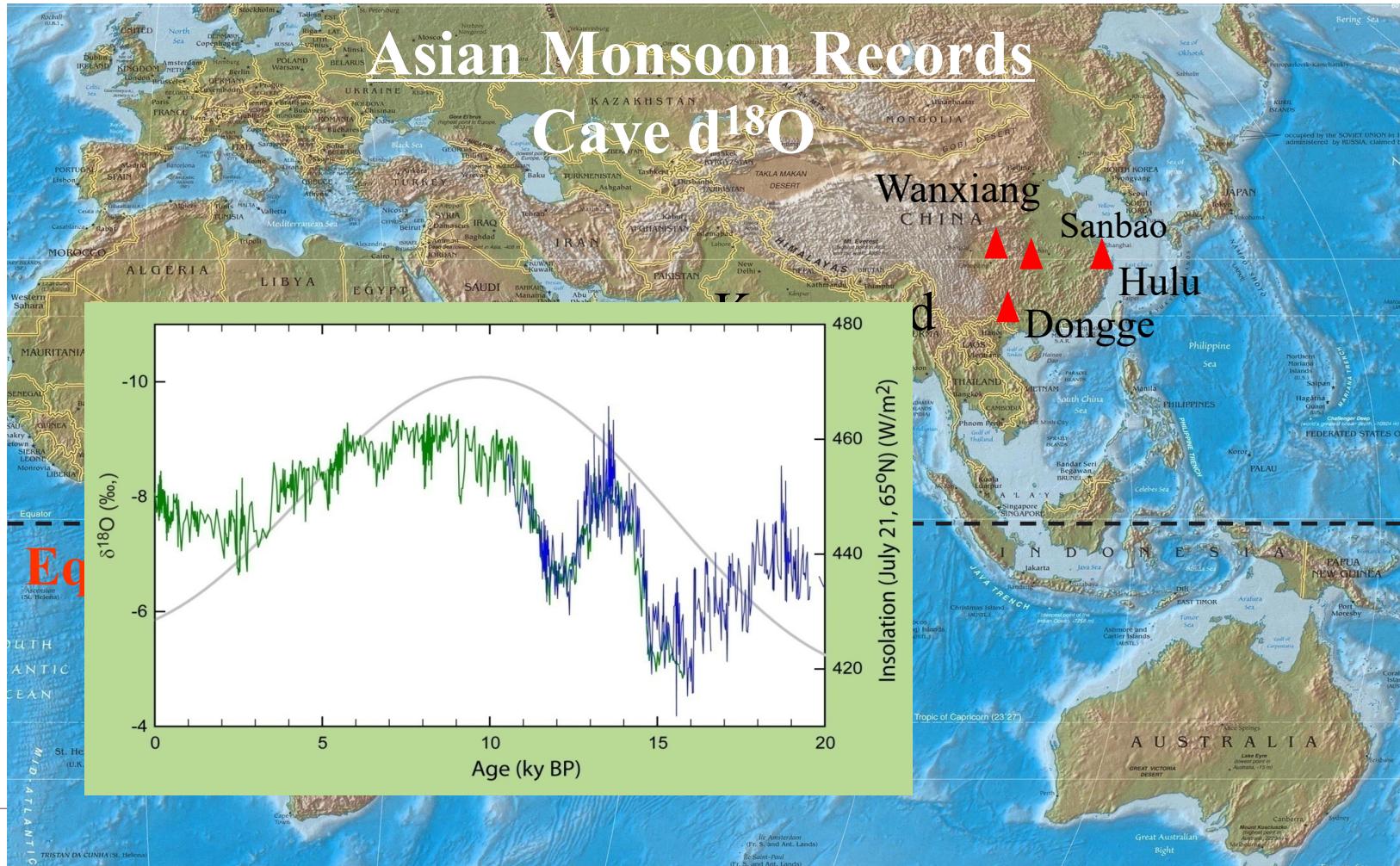


第九章 地球气候的演变



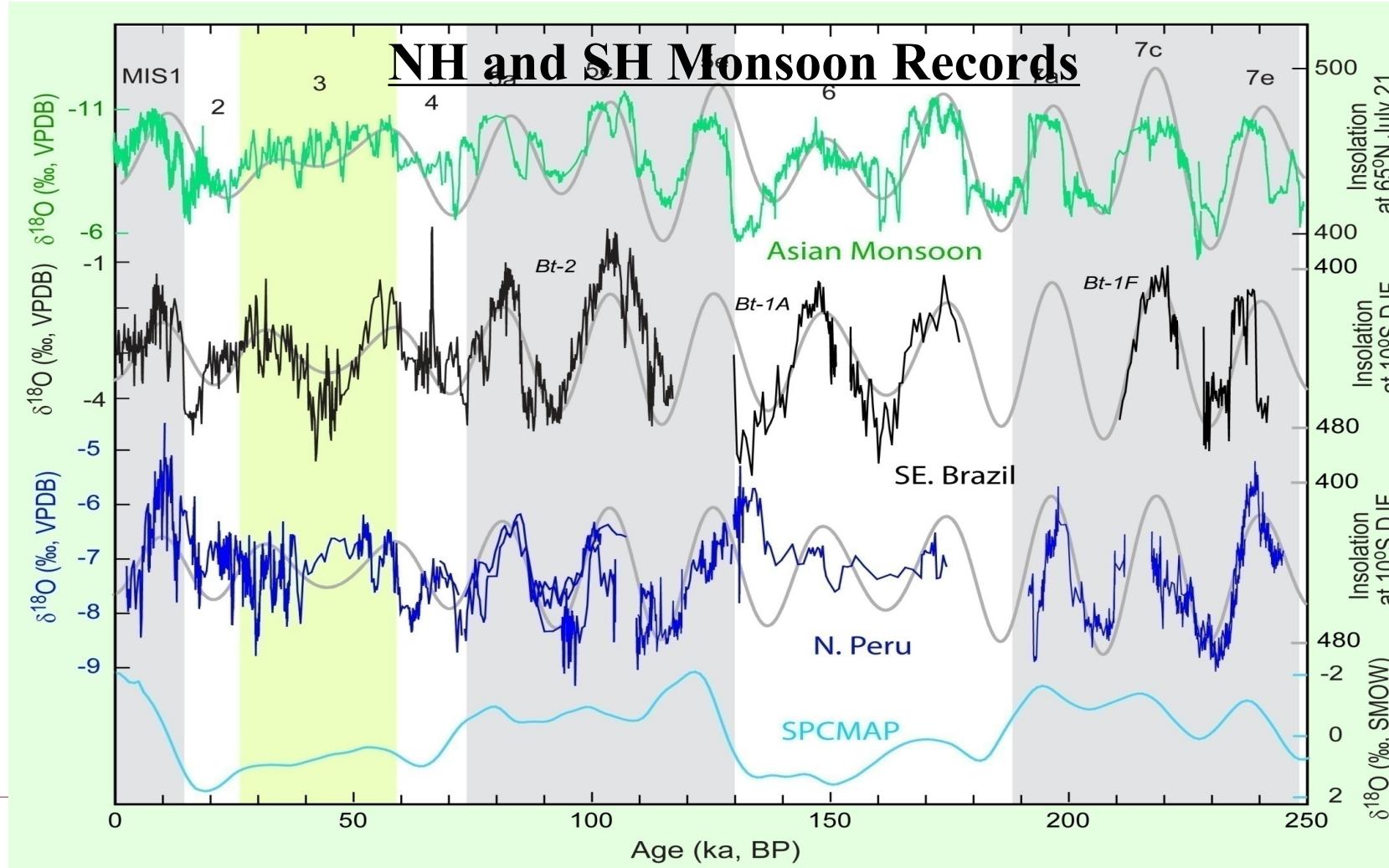
9.2.2 轨道尺度 (orbital scale)

轨道变化的气候影响：季风的变化



9.2.2 轨道尺度 (orbital scale)

轨道变化的气候影响：季风的变化



岁差周期

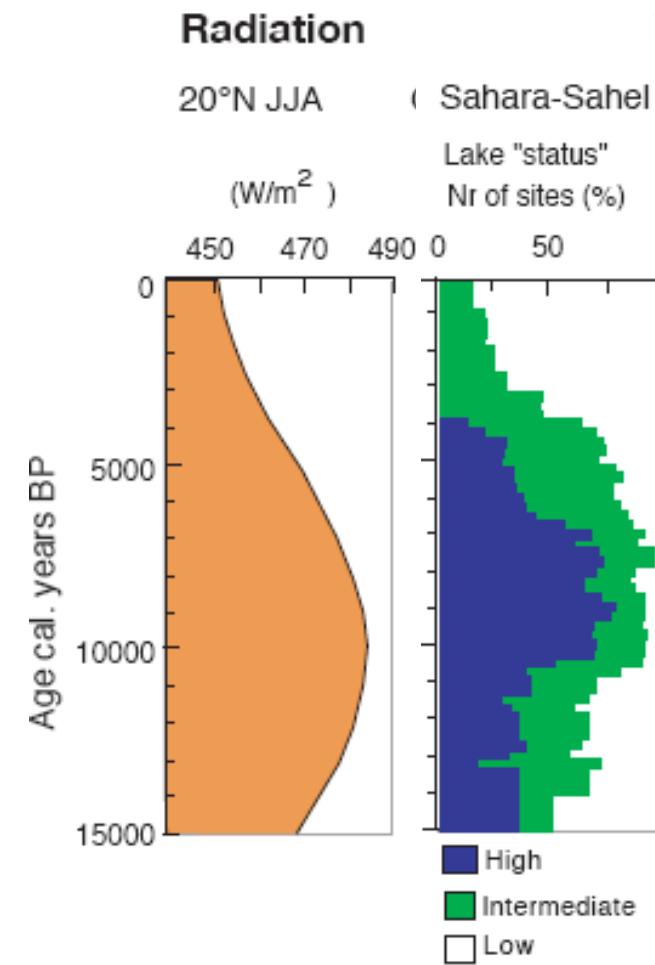
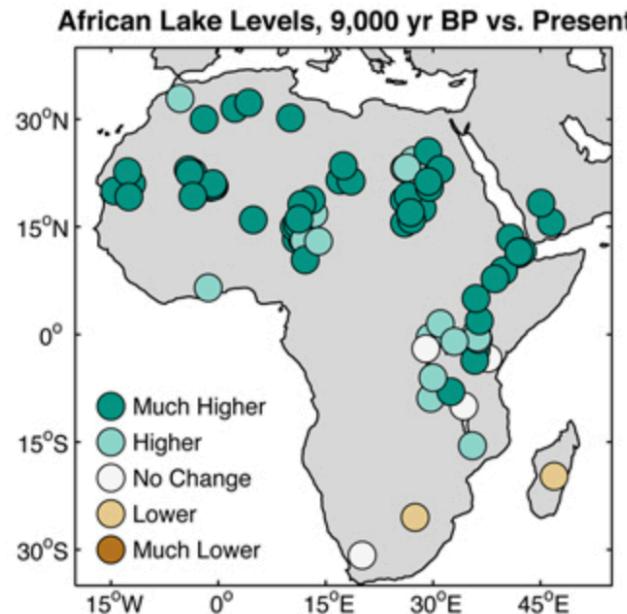


9.2.2 轨道尺度 (orbital scale)

轨道变化的气候影响：季风的变化



Green Sahara



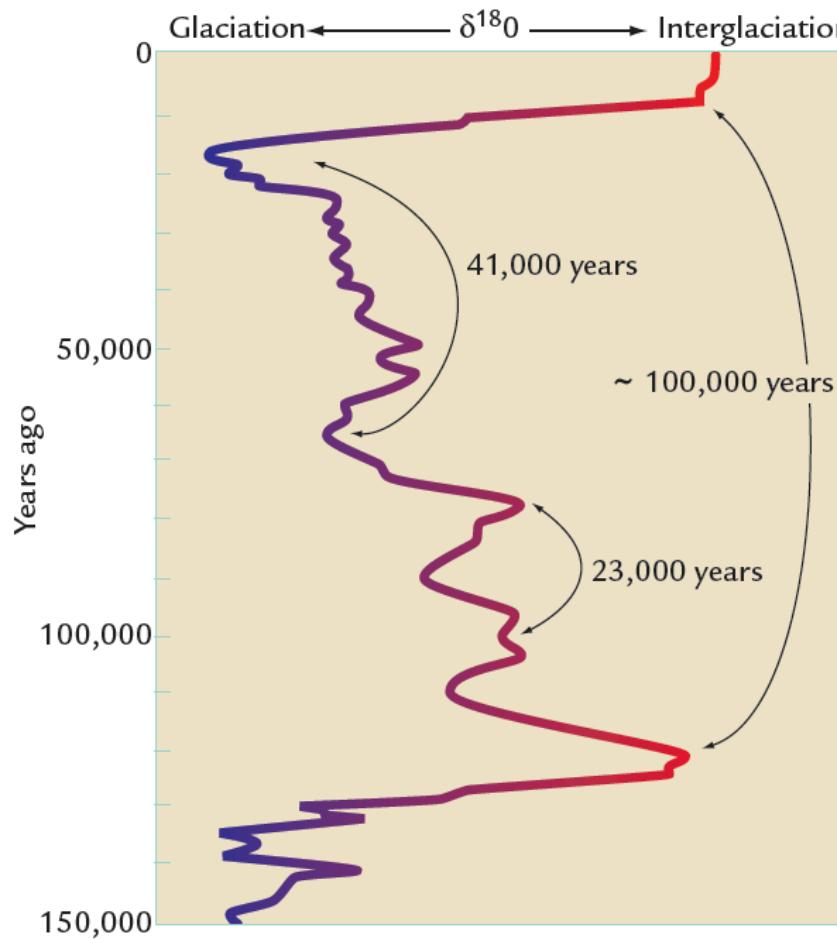
a

c

<https://www.nature.com/scitable/knowledge/library/green-sahara-african-humid-periods-paced-by-82884405/>

9.2.2 轨道尺度 (orbital scale)

轨道变化的气候影响：冰川的变化



CO_2 和 CH_4 的变化

