Climate II

(Winter 2020/2021)

14th lecture:

Summary and outlook

(Summary of models, available data, link of past-present-future, knowledge transfer)

Gerrit Lohmann, Martin Werner

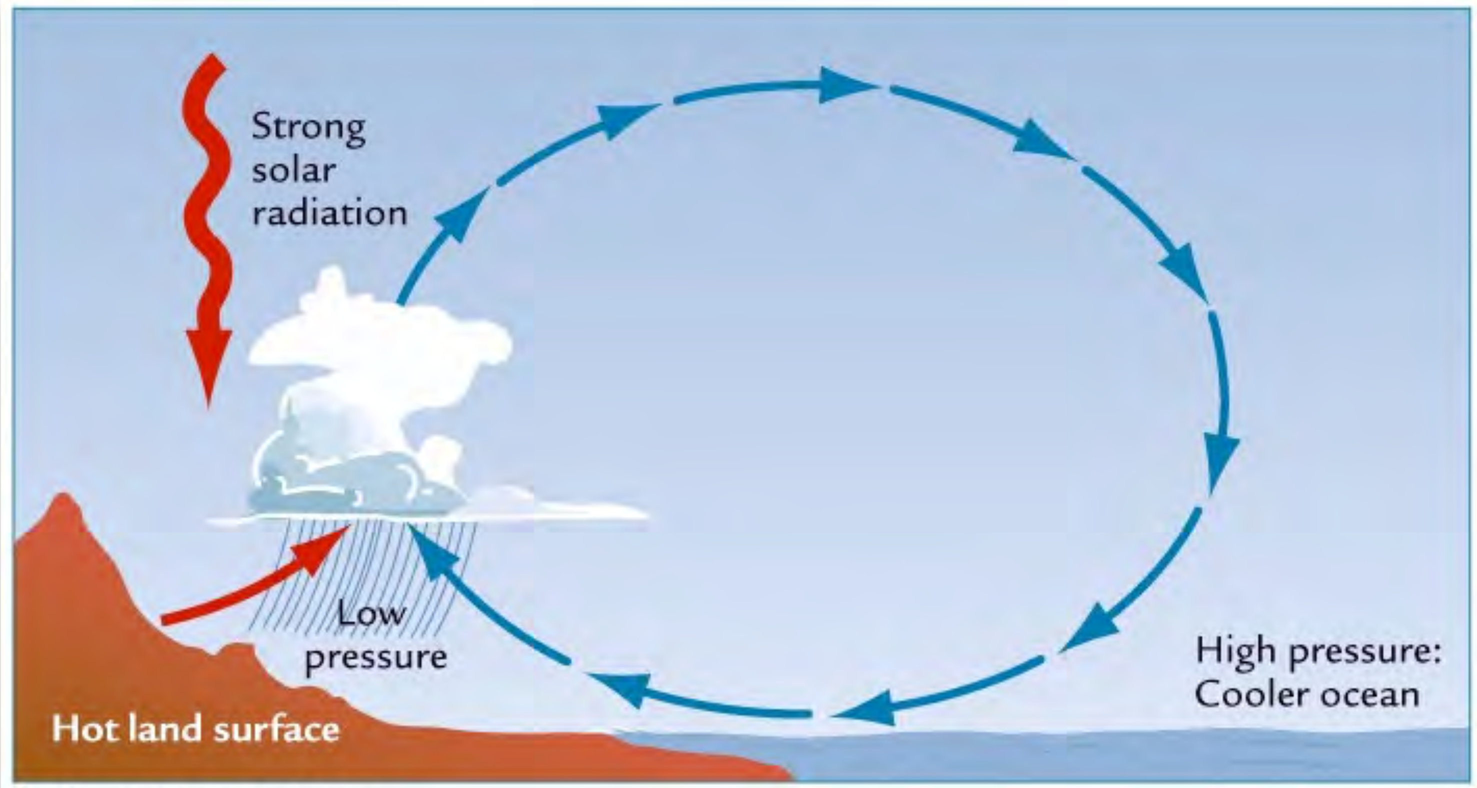
Tuesday, 10:00-11:45

(sometimes shorter, but with some exercises)

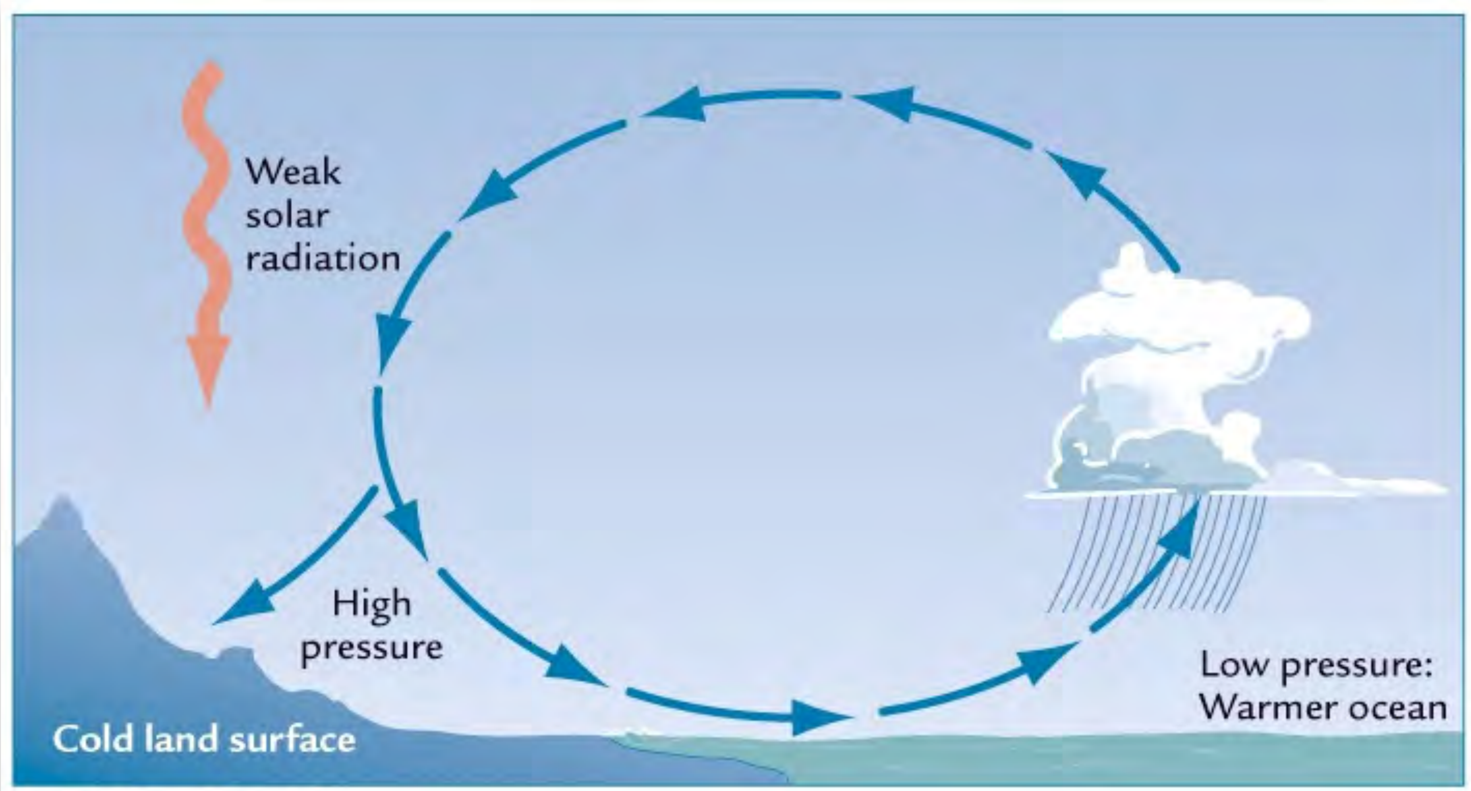
https://paleodyn.uni-bremen.de/study/climate2020_21.html

The monsoon circulation

- monsoon circulation driven by large seasonal temperature gradient between land surface and adjacent ocean water
- summer monsoon bring heavy convective rainfall events, winter monsoon cold, dry air to the land surfaces
- most strong summer monsoons occur in the Northern Hemisphere (larger land masses, plus high Tibetan mountains in Asia)



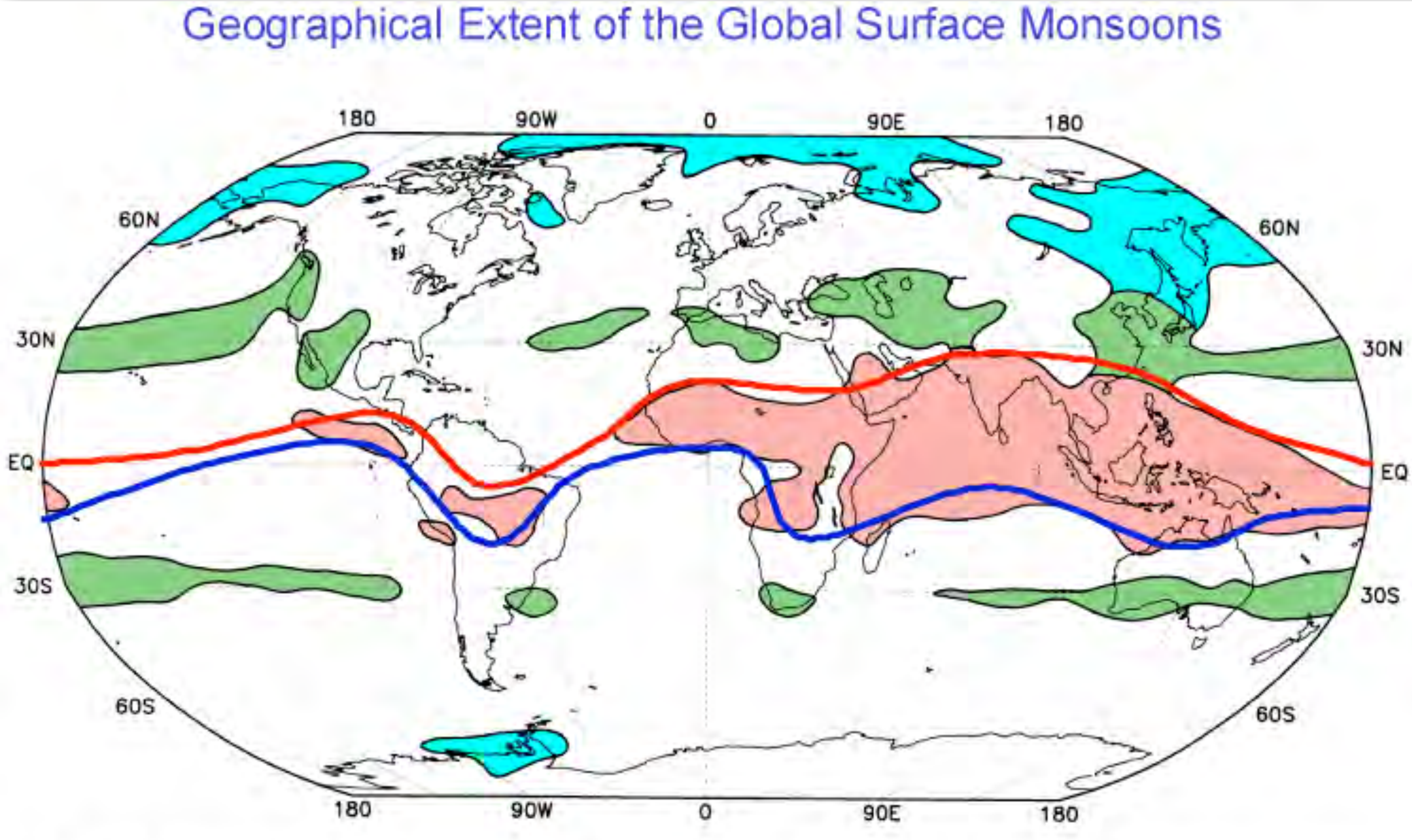
A Summer monsoon



B Winter monsoon

[from: Ruddiman, 2008]

The global monsoon circulation



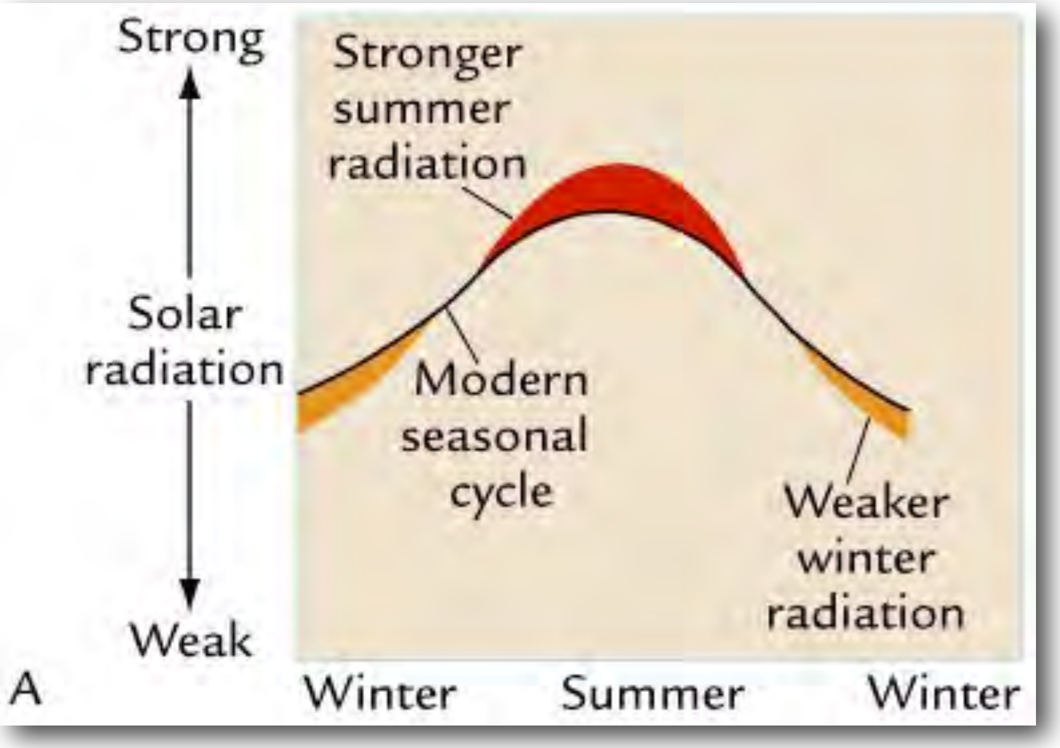
The red, green, and blue areas indicate the tropical, subtropical, and temperate-frigid monsoons, respectively. The red and blue thick lines represent the ITCZ in summer and winter, respectively.
(Li, J., and Q. Zeng, 2005)

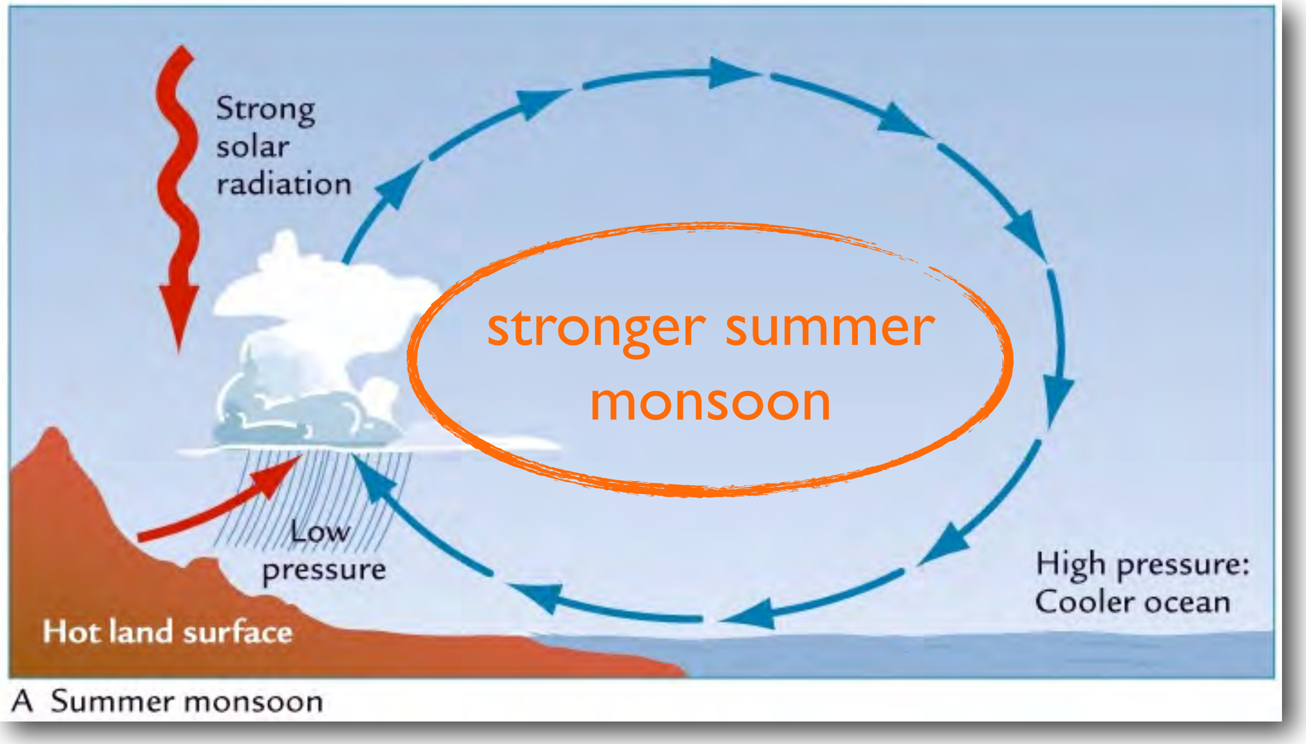
[http://www.lasg.ac.cn/staff/ljp/Monsoon.html]

Orbital-scale control of monsoon circulation

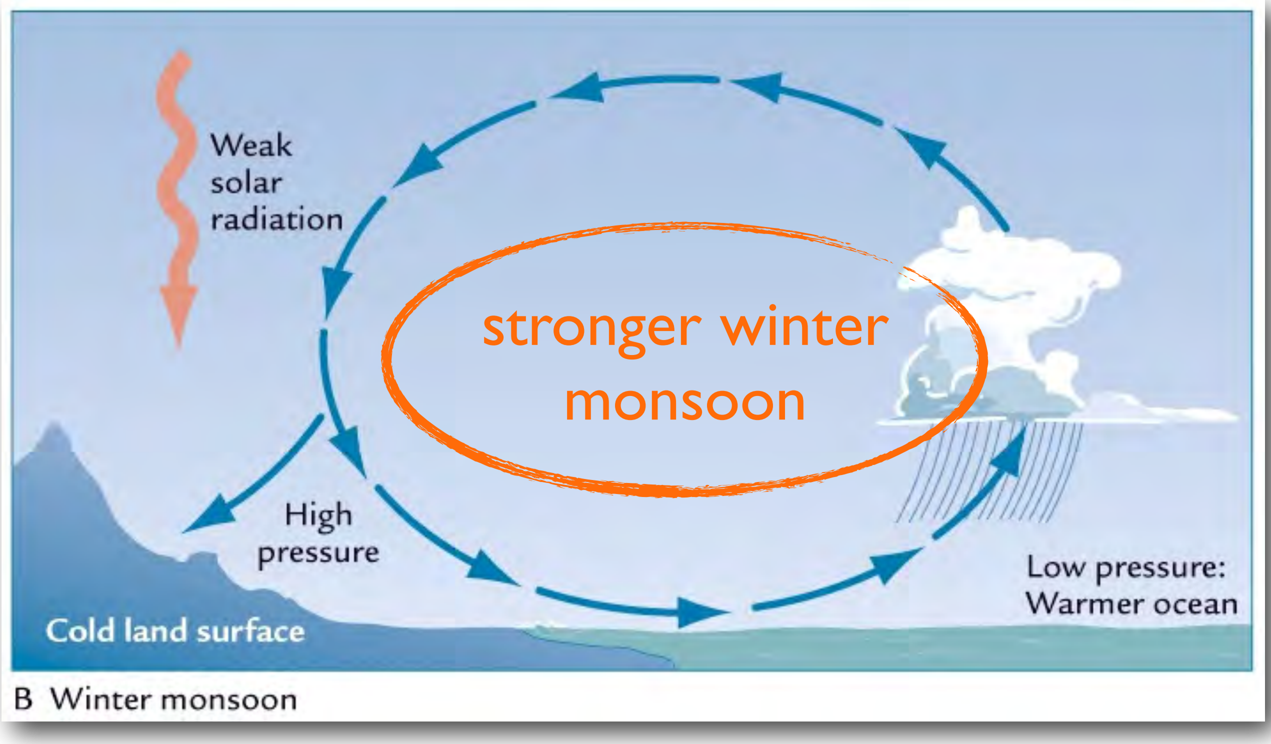
orbital monsoon hypothesis (J. Kutzbach, early 1980s)

- *stronger summer insolation caused by orbital changes should cause stronger summer monsoon*
- *vice versa for winter monsoon*
- *annual precipitation effects don't cancel each other out, as normal winter monsoon is often very dry, already*
  => summer monsoon changes dominate annual signal
  (nonlinear response of the climate system)





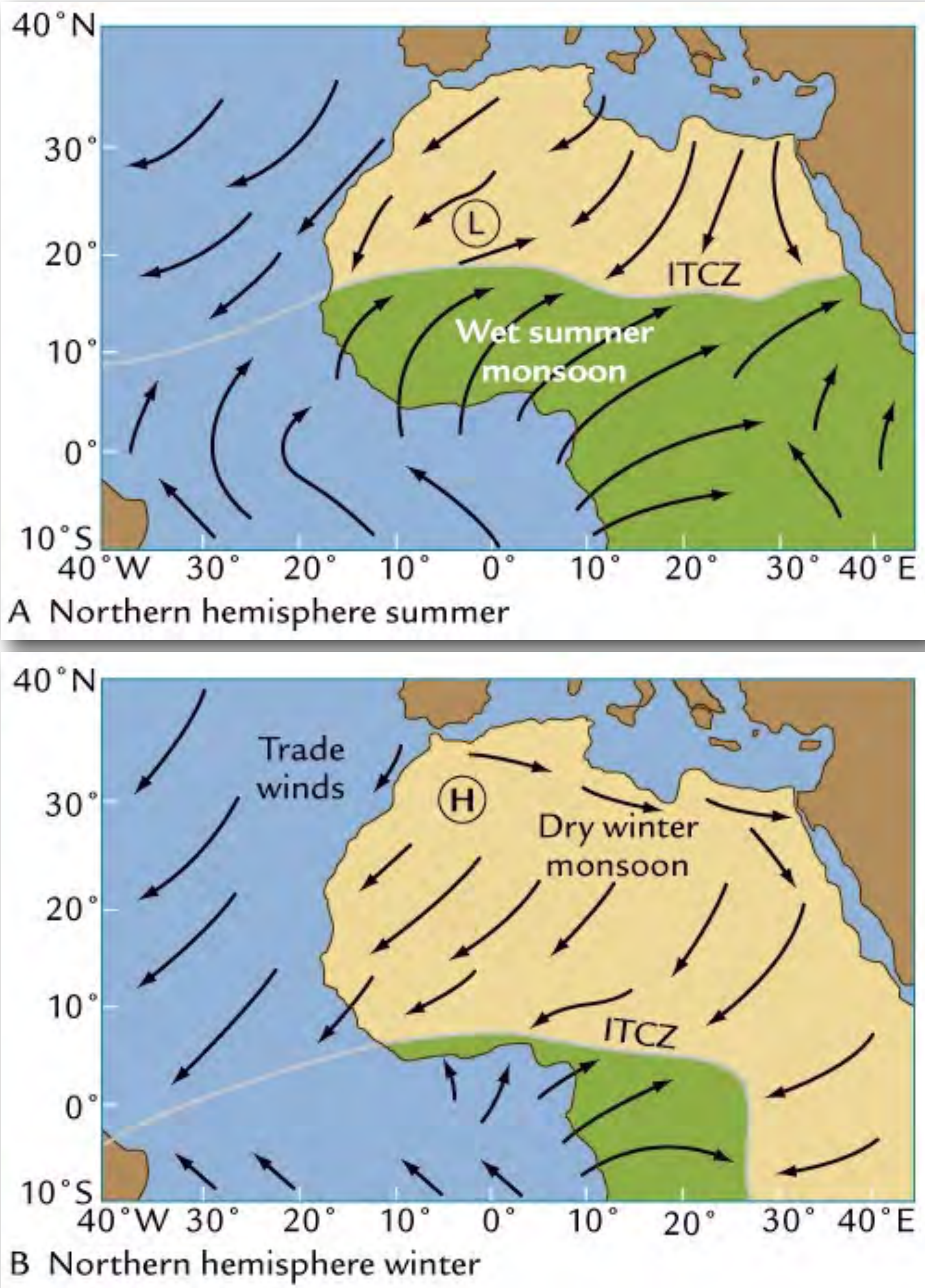
A Summer monsoon

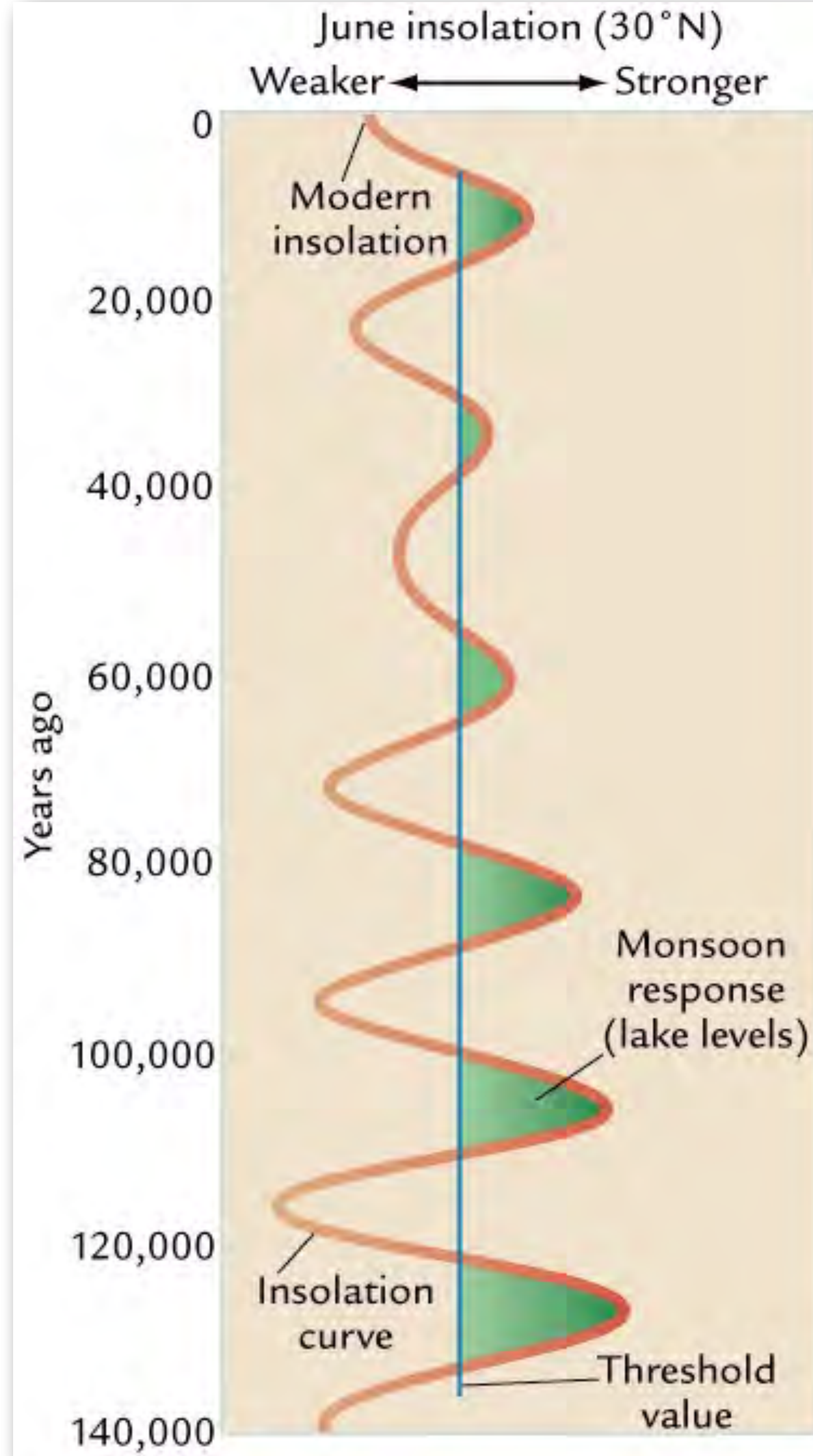


B Winter monsoon

[from: Ruddiman, 2008]

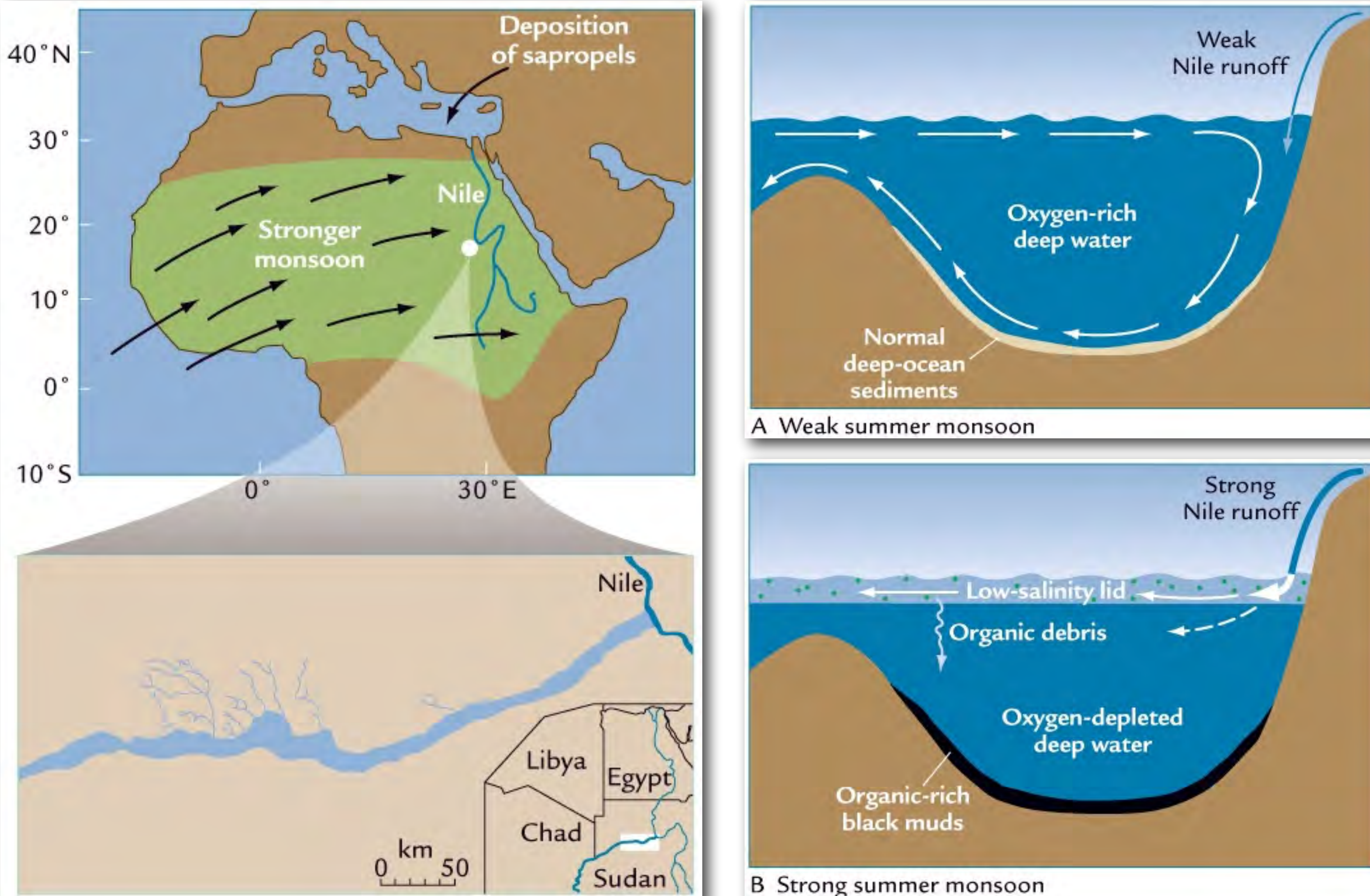
Orbital-scale control of North African monsoon circulation





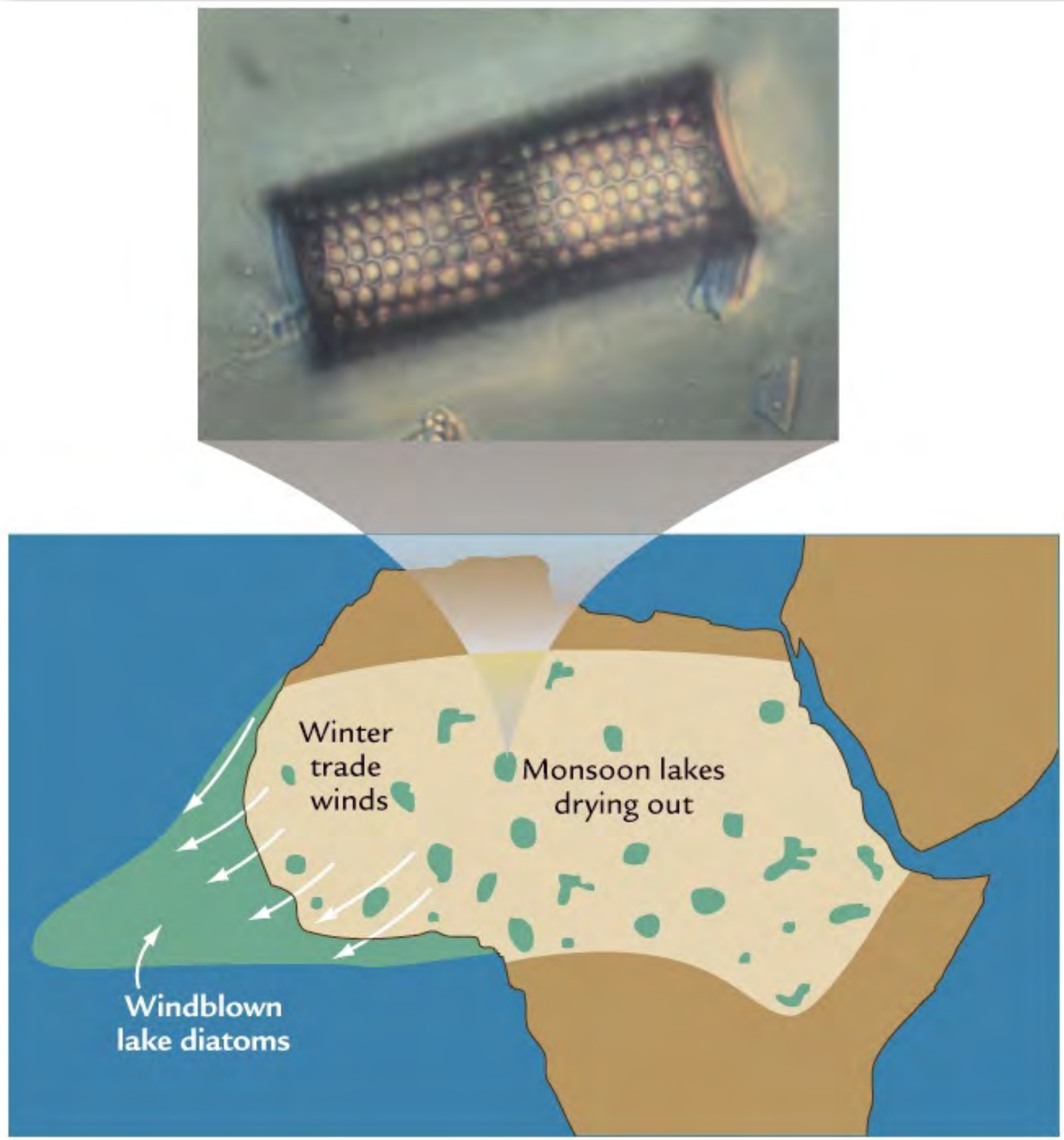
[from: Ruddiman, 2008]

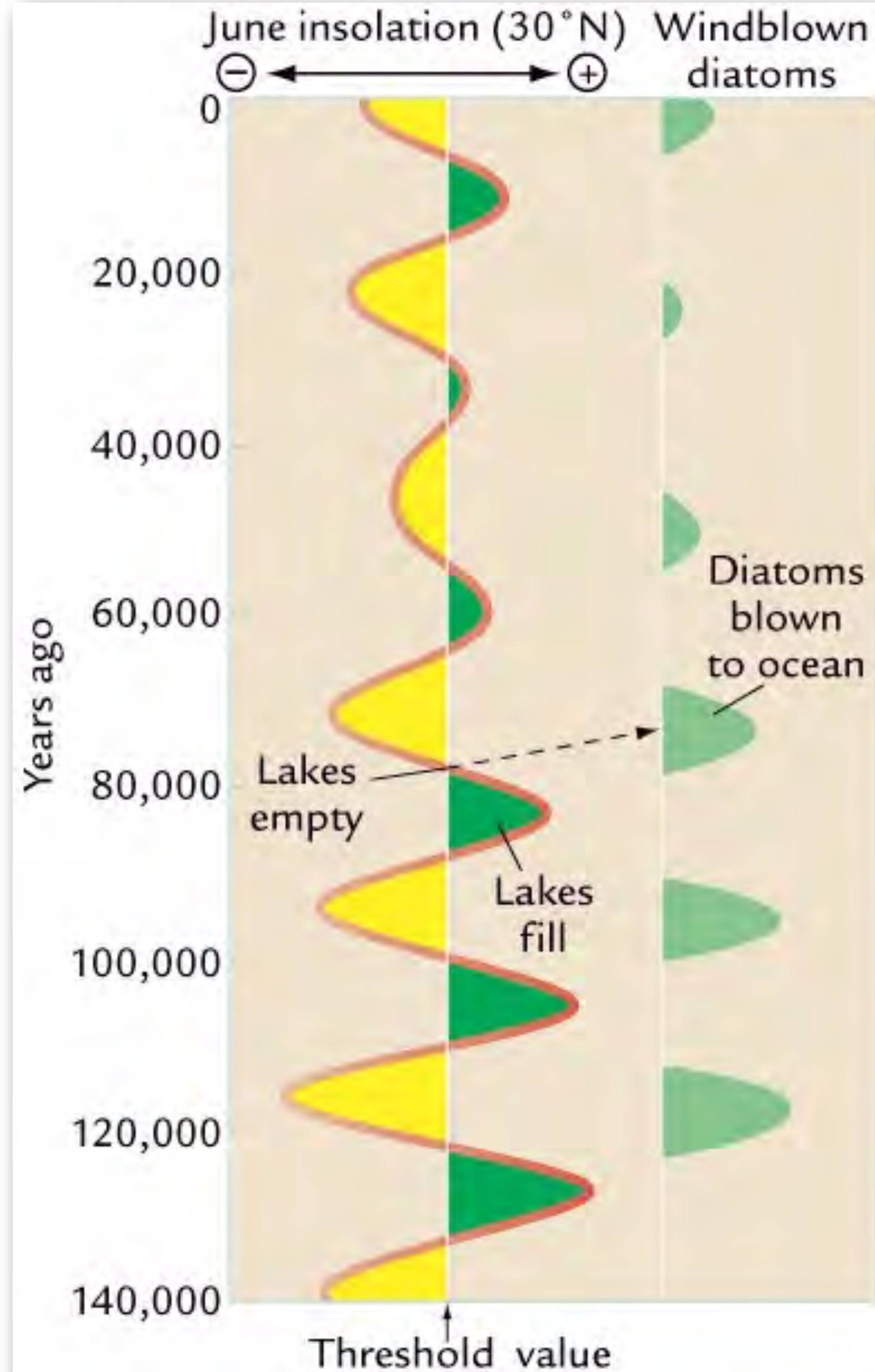
Orbital-scale control of North African monsoon circulation



[from: Ruddiman, 2008]

Orbital-scale control of North African monsoon circulation





[from: Ruddiman, 2008]

Orbital-scale control of Asian monsoon circulation

Millennial- and orbital-scale changes in the East Asian monsoon over the past 224,000 years

Yongjin Wang[1], Hai Cheng[1,2], R. Lawrence Edwards[2], Xinggong Kong[1], Xiaohua Shao[1], Shitao Chen[1], Jiangyin Wu[1], Xiouyang Jiang[1], Xianfeng Wang[2] & Zhisheng An[3]

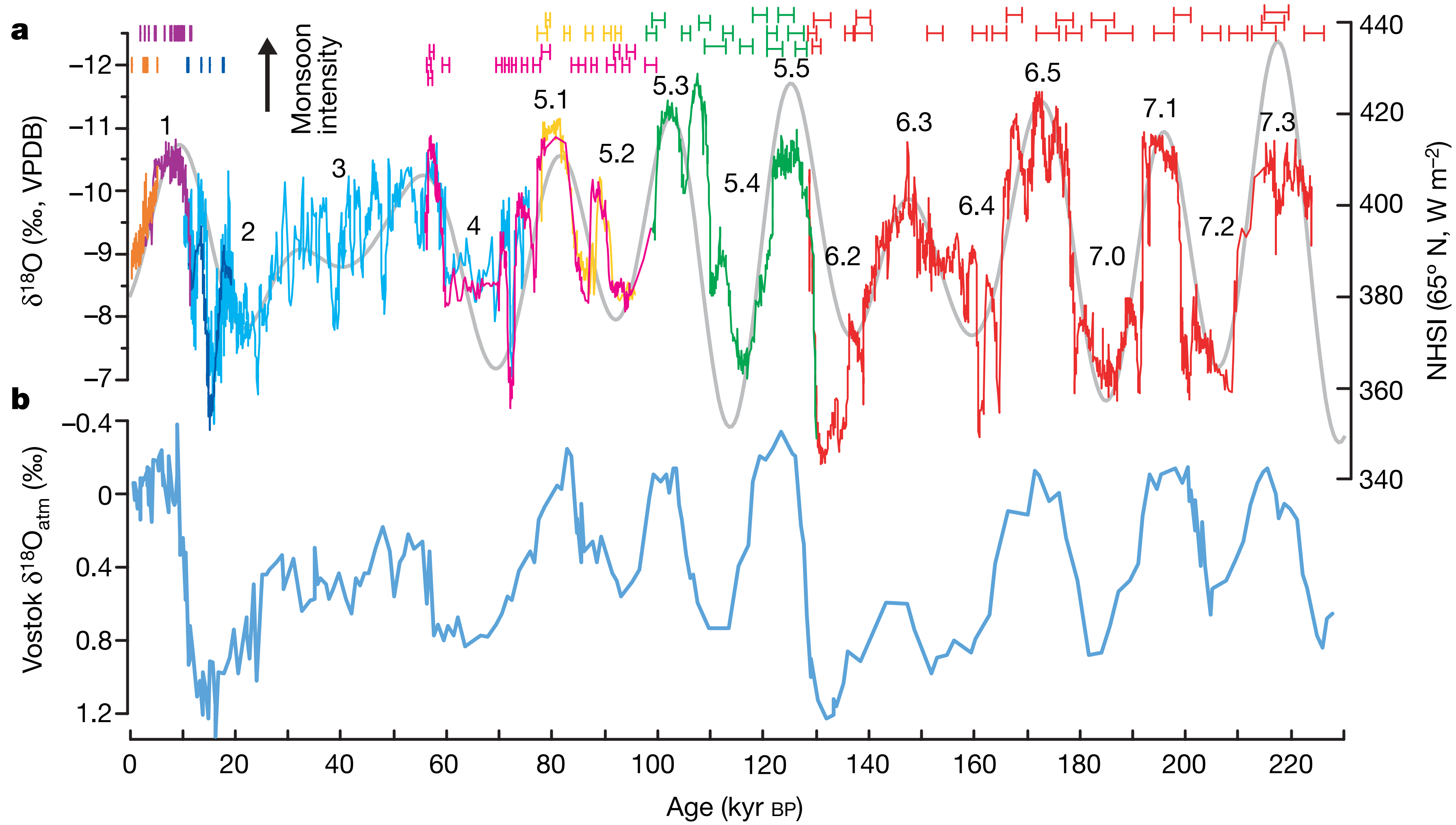
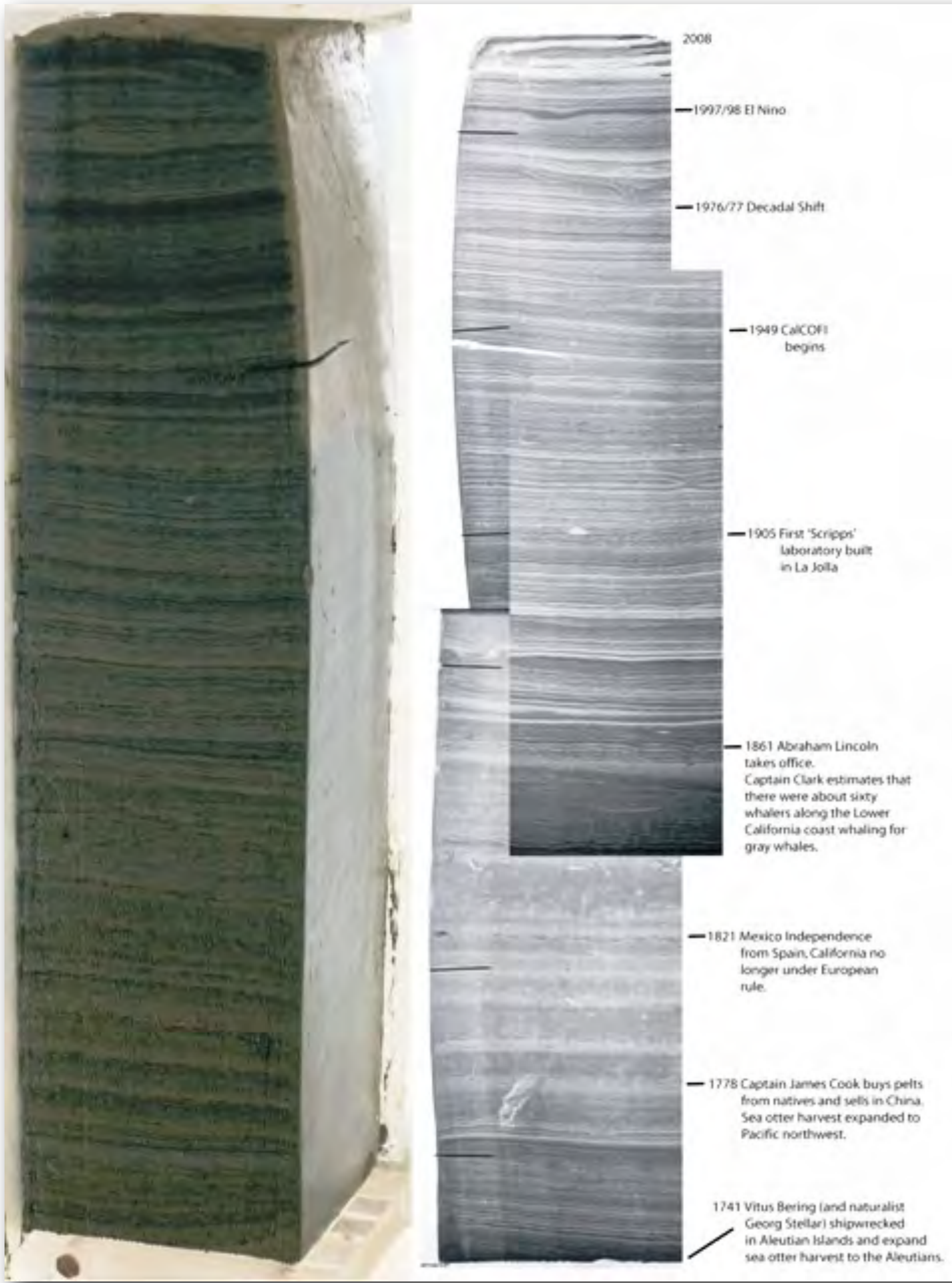


Figure 1 | Comparison of Sanbao/Hulu $\delta^{18}O$ records with NHSI and atmospheric $\delta^{18}O$ record over the past 224 kyr BP. **a**, Time versus Sanbao $\delta^{18}O$ records (red, stalagmite SB11; green, SB23; yellow, SB25-1; pink, SB22; dark blue, SB3; purple, SB10 and orange, SB26) and Hulu cave (blue)[2], and NHSI (Northern Hemisphere summer insolation, 21 July) at 65° N[10] (grey). For comparison, the Hulu $\delta^{18}O$ record is plotted 1.6‰ more negative to account for the higher Hulu values than Sanbao cave (see Supplementary Fig. 4). The ^{230}Th ages and errors (2σ error bars at top) are colour-coded by stalagmites. Numbers indicate the marine isotope stages and substages. **b**, The atmospheric $\delta^{18}O$ record from Vostok ice core, Antarctica[28].

Key climate archives

- ice cores
- marine sediment cores
- corals
- speleothems
- tree rings
- pollen
- …

Marine sediment cores

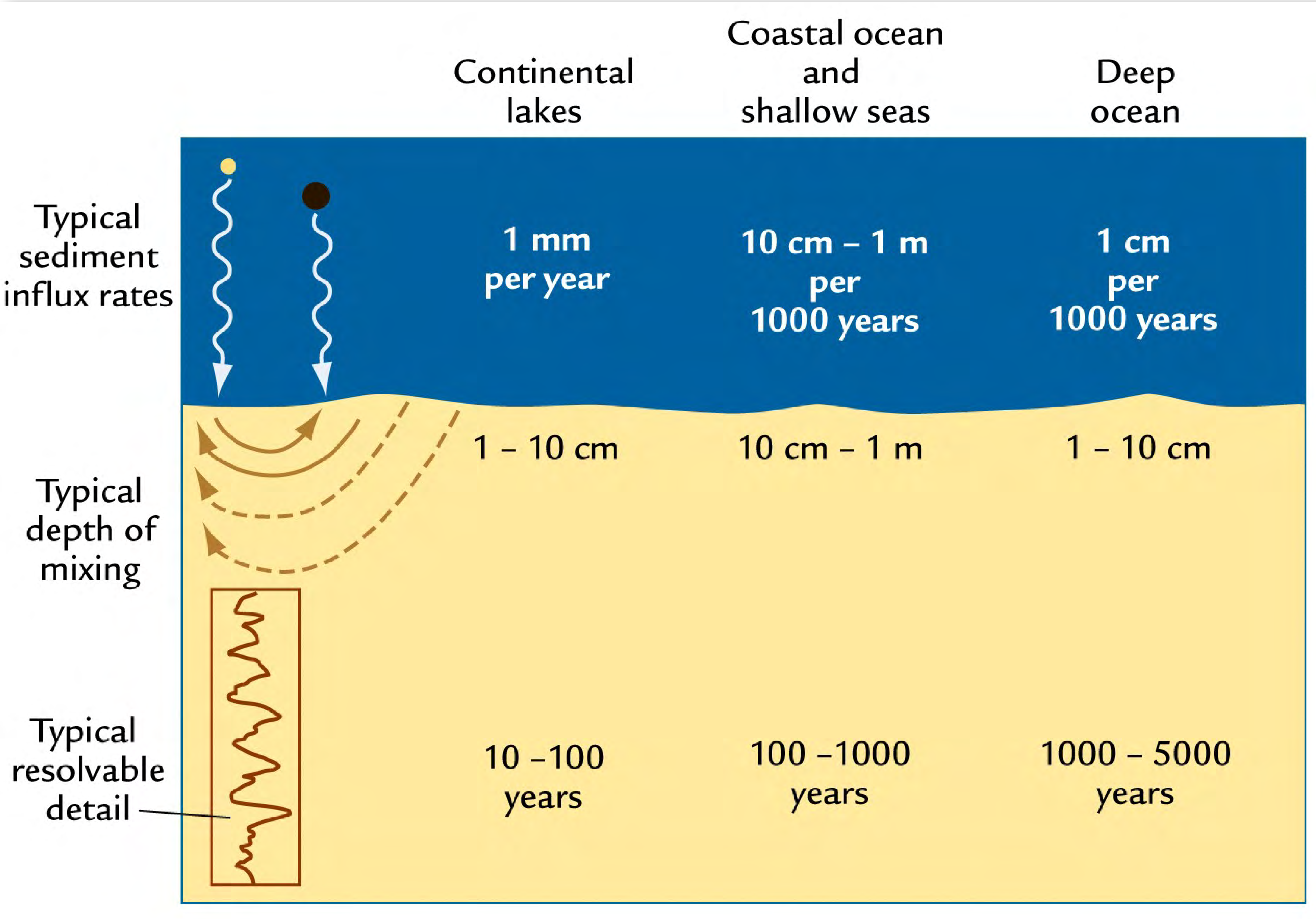


[http://www.hpu.edu/CNCS/Faculty_Staff/CV/DavidFieldCV.html]

1: Japan Sea (color alternation)
2: Japan Sea (laminated sediments)
3: East China Sea (deep sea sediments)
4: Arabian Sea (calcareous ooze)
5: Arabian Sea (calcareous ooze)
6: Sulu Sea (calcareous ooze)
7: Southern Ocean (diatom ooze)

These cores were recovered during cruises by the R/V Hakuho-Maru, Ocean Research Institute, University of Tokyo

Formation of marine sediments



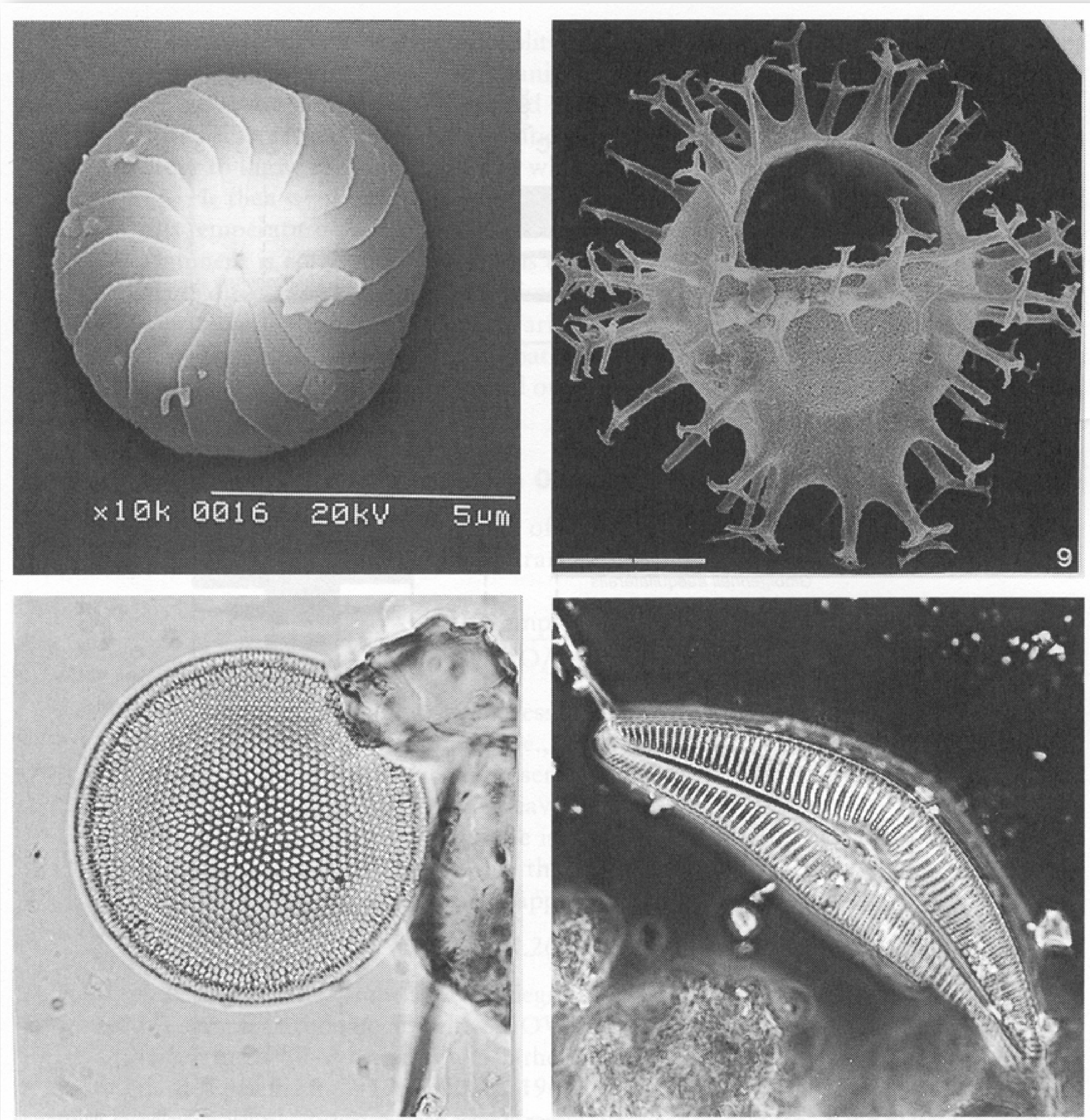
www.atmo.dal.ca/~lohmann/clch/Lecture9.ppt

Formation of marine sediments

- 70% of Earth‘s surface is covered by oceans
- yearly sediment production: approx. 6-11 billion tons (=10^{12}kg)
- sediment contains both biogenic and terrigenous material
- biogenic material:
    - planktic organism = live near the sea surface
    - benthic organism = live near the sea floor
    - biogenic material may be used as a proxy for
        - *water temperatures (surface waters, deep sea waters)*
        - *salinity*
        - *dissolved oxygen, trace substances, etc.*
- terrigenous material
    - is transported from land surfaces to the oceans by the wind
    - can be used as a proxy for aridity and/or changes in wind strength/wind directions

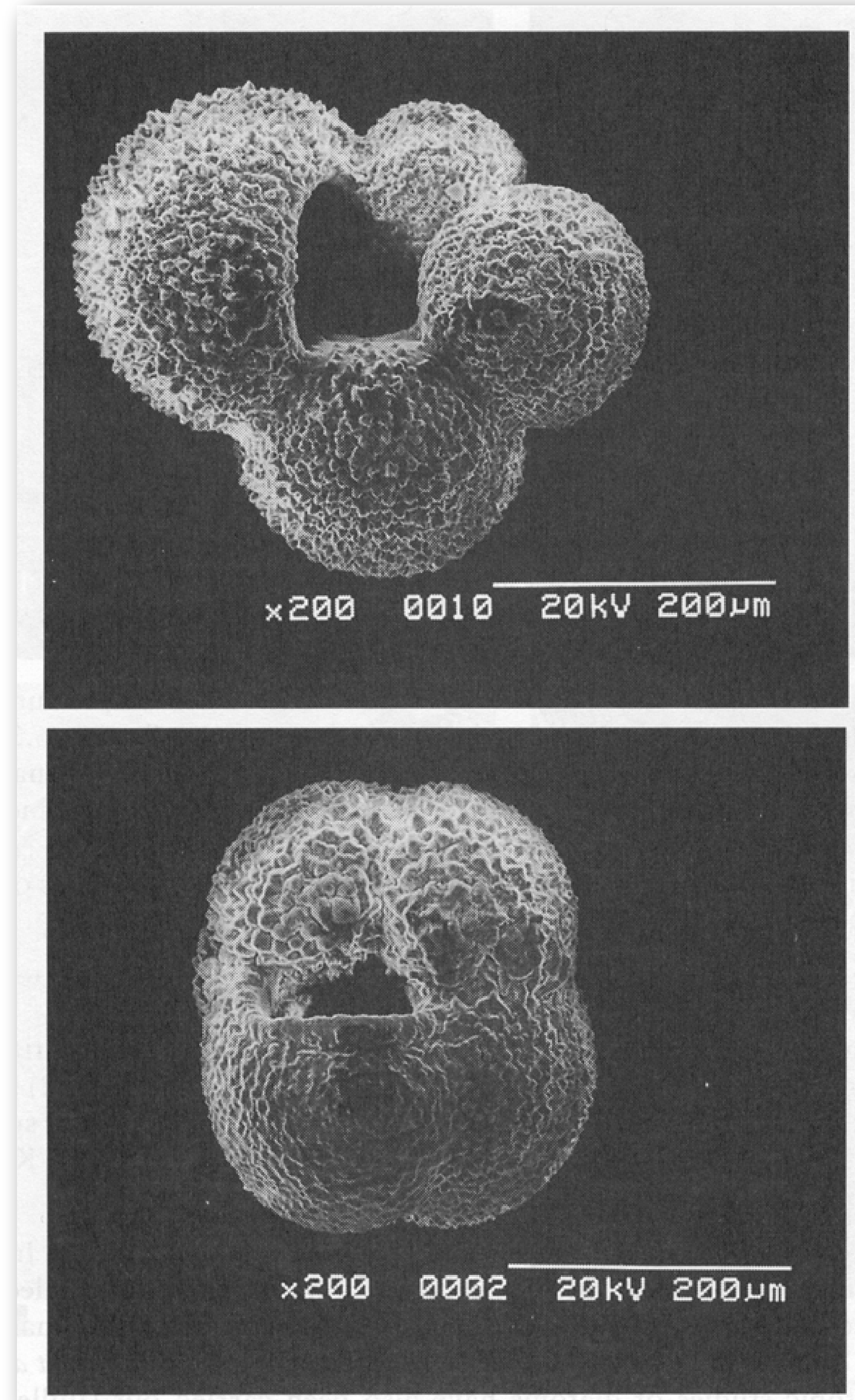
Formation of marine sediments

Coccolithophors
(Phytoplankton)



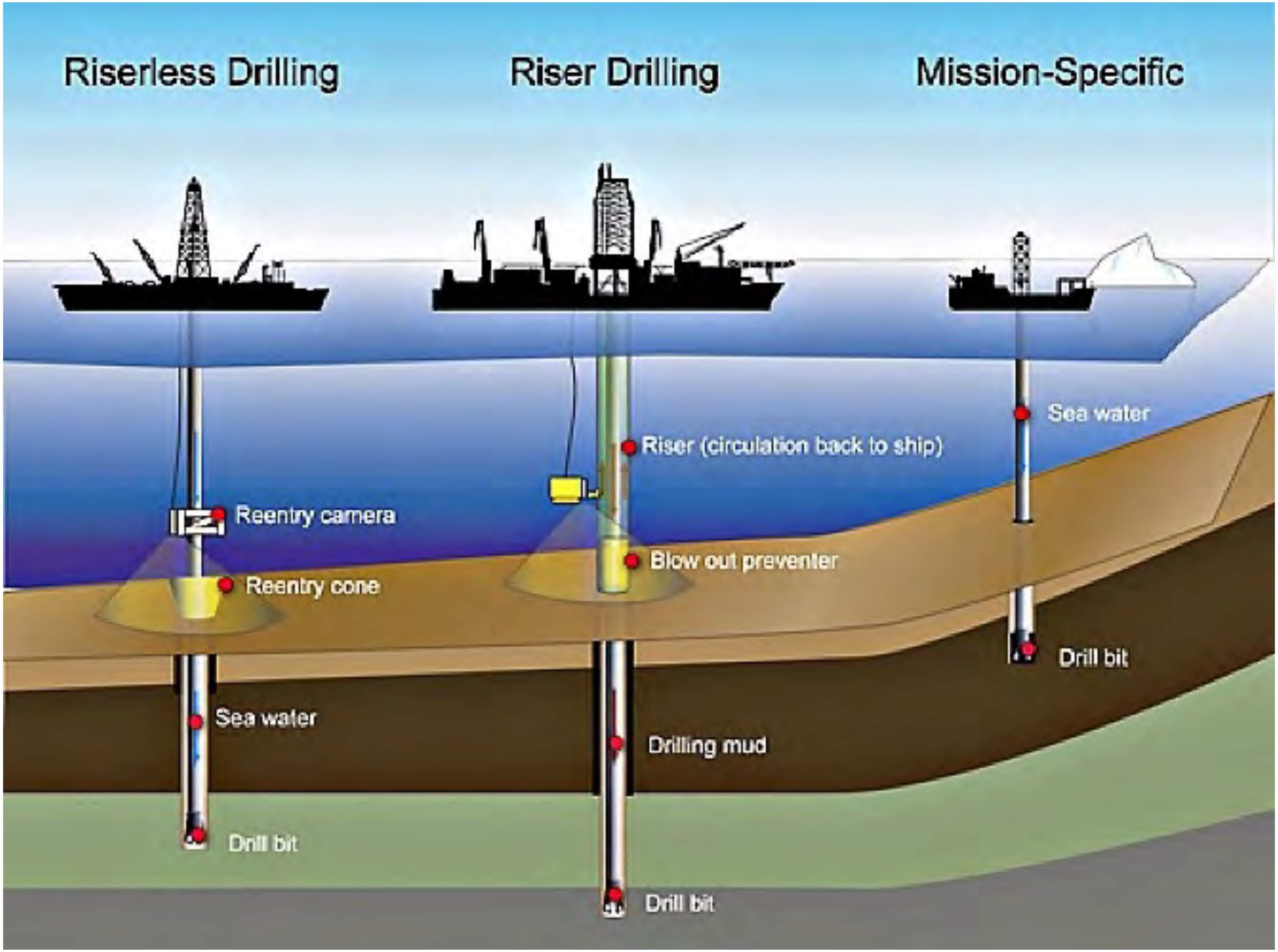
Bradley, Abb. 6.5

Foraminifers
(Zooplankton)

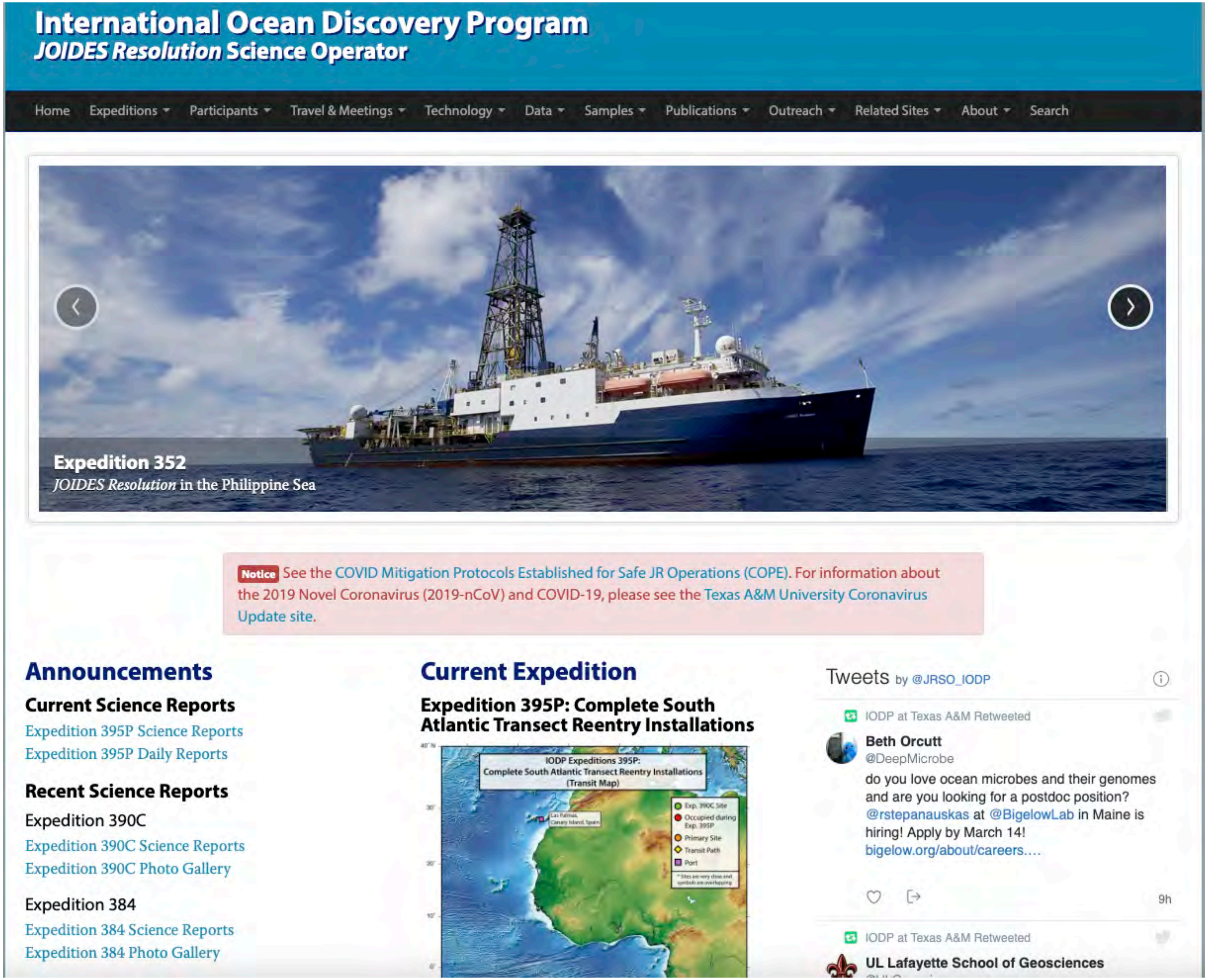


Bradley, Abb. 6.3

Drilling of marine sediment cores

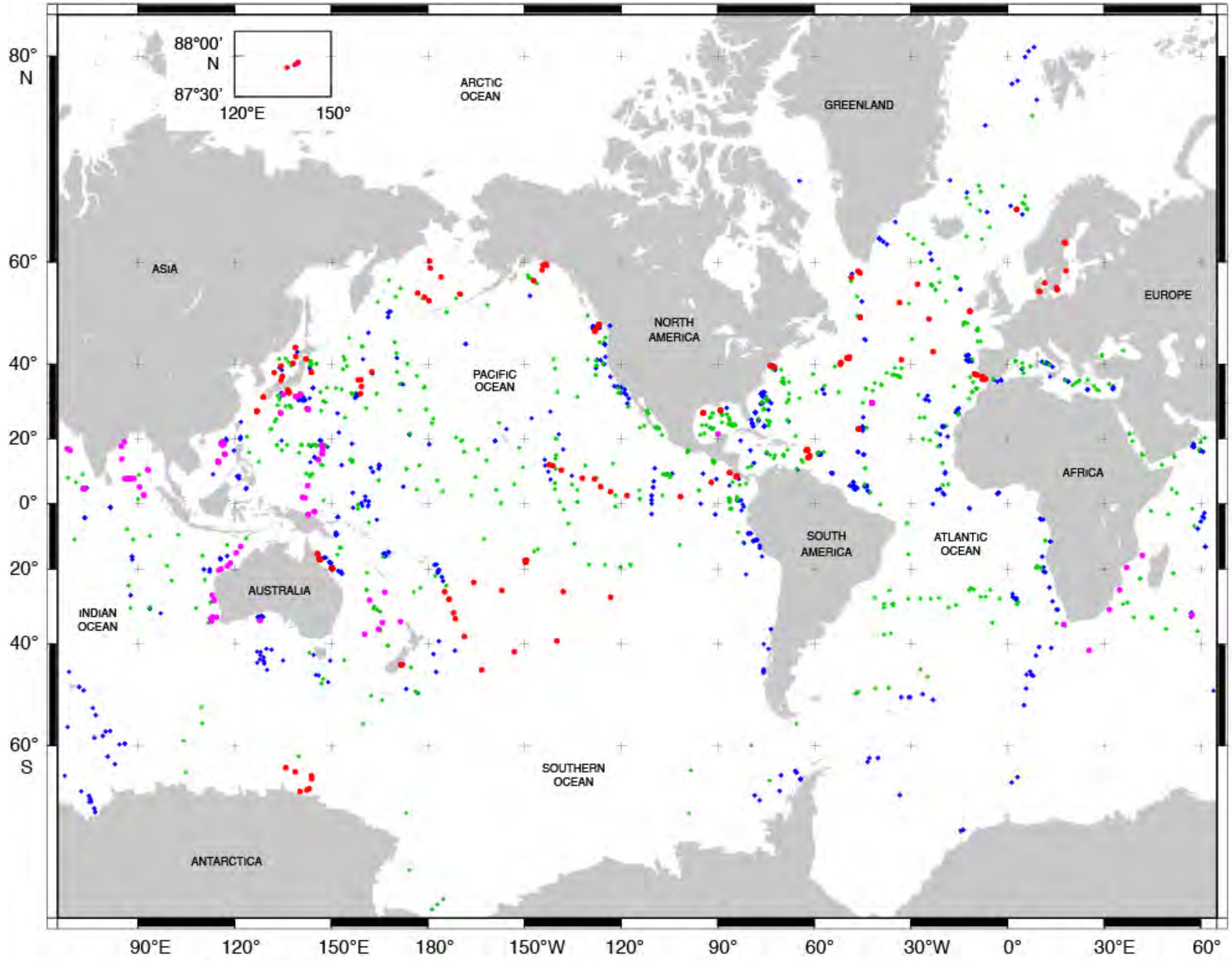


The International Ocean Discovery Programme (IOPD)



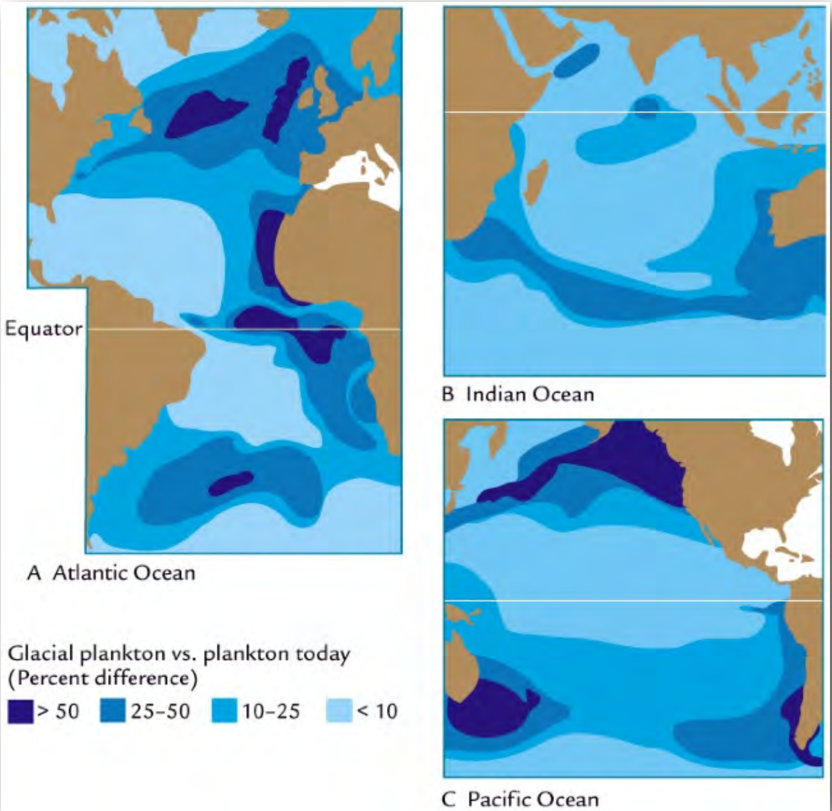
http://iodp.tamu.edu/index.html

Drill sites of international drilling programs



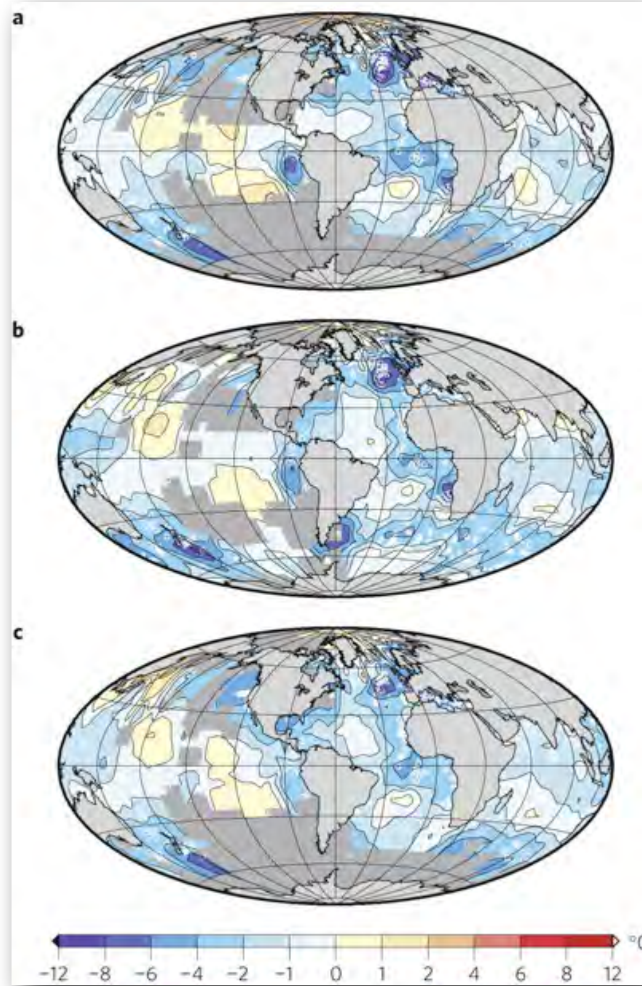
DSDP Legs 1–96 (●), ODP Legs 100–210 (●), IODP Expeditions 301–348 (●), IODP Expeditions 349–371 (●)

Examples of marine sediment analyses



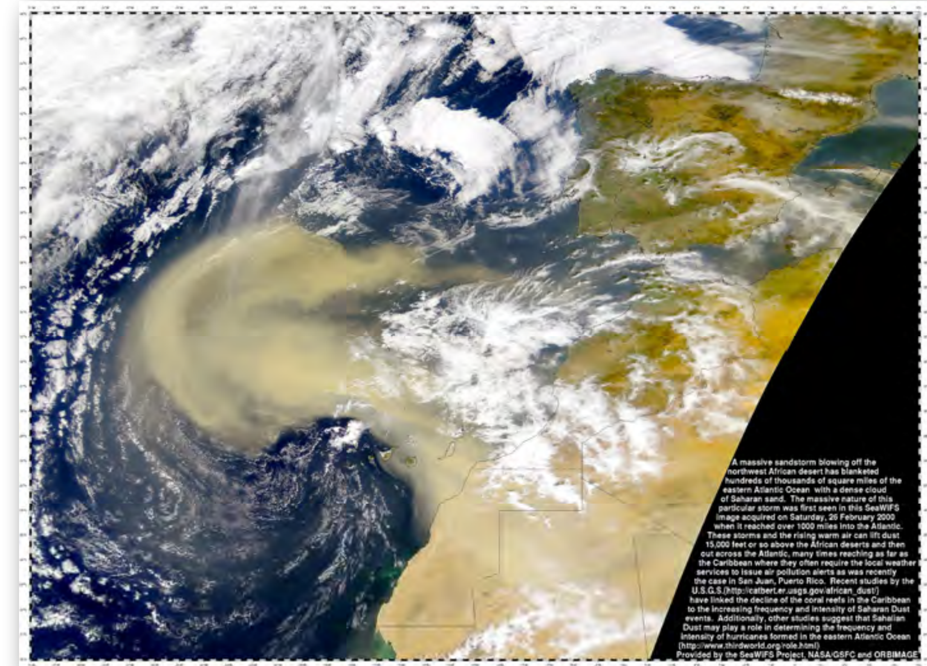
[from: Ruddiman, 2008]

plankton assemblages



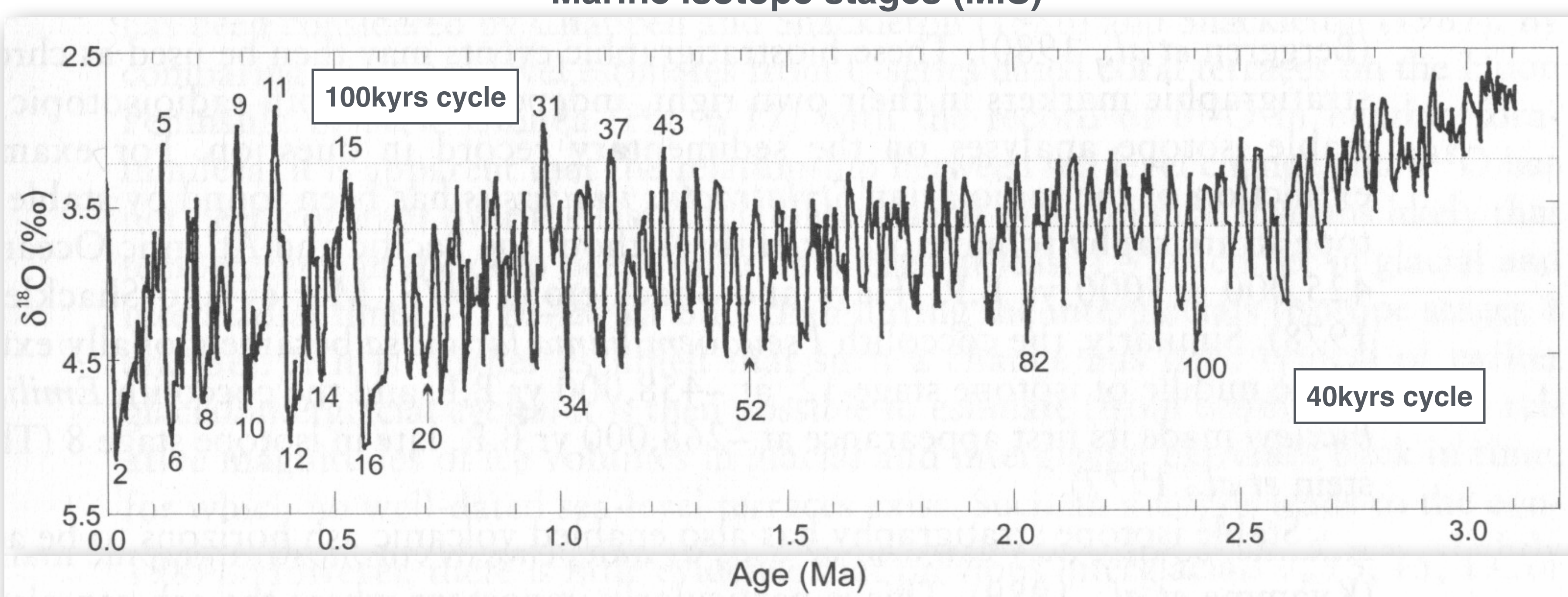
[MARGO Project Members, Nature Geoscience, 2009]

LGM SST reconstructions



dust & other inorganic material

Marine isotope stages (MIS)



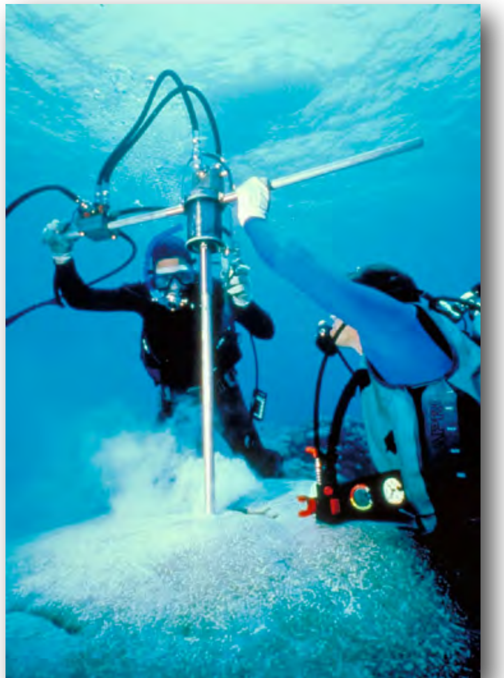
Corals

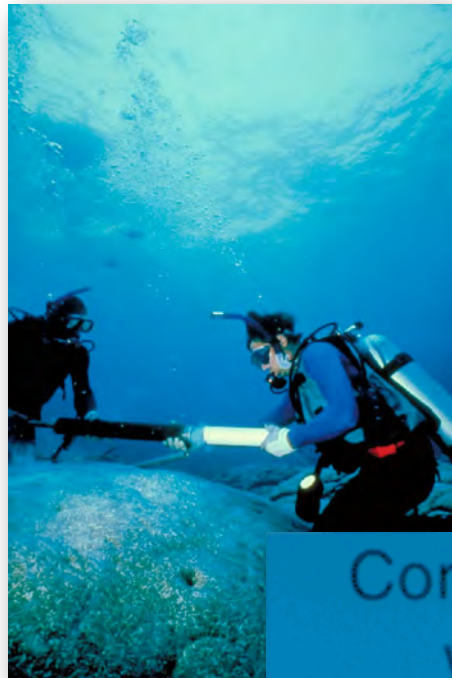
http://www.ncdc.noaa.gov/paleo/slides/

Corals

- main interest for paleoclimatological studies: Hermatypic corals (reef-building corals)
  - *exist mainly between 30°N - 30°S, with an average SST of 20°C*
  - *if SST are below 18°C, the coral reefs grow only very slowly or even die (at colder temperatures)*
- typical coral analyses:
  growth rates, isotopes, trace elements, …
- coral records may cover the last 100,000 years (or even older periods)
  - *often, corals just grow during warm climates*
- corals are a very promising climate archive for the reconstruction of tropical SST

Corals

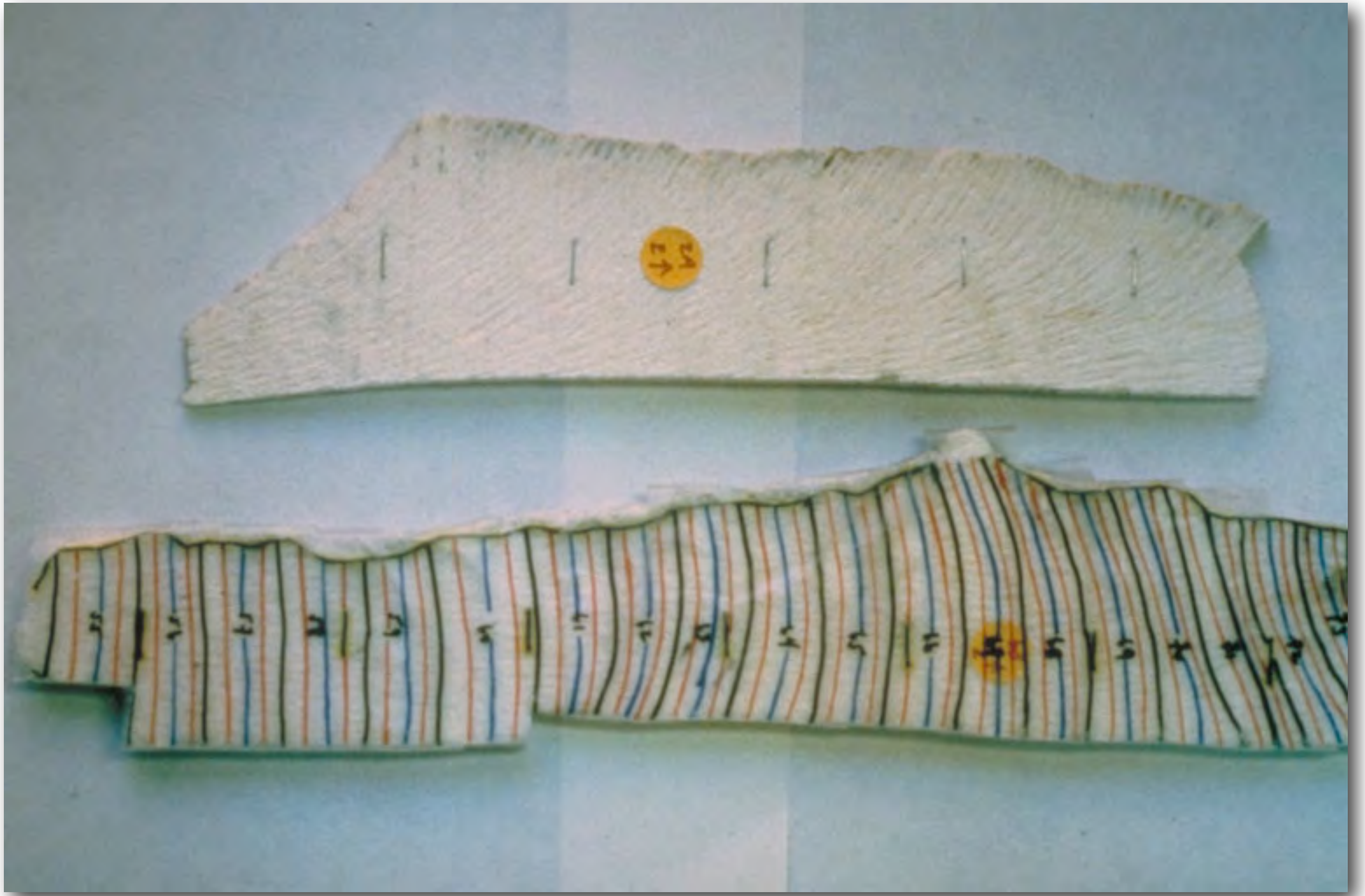




http://www.ncdc.noaa.gov/paleo/slides/

Growth of corals

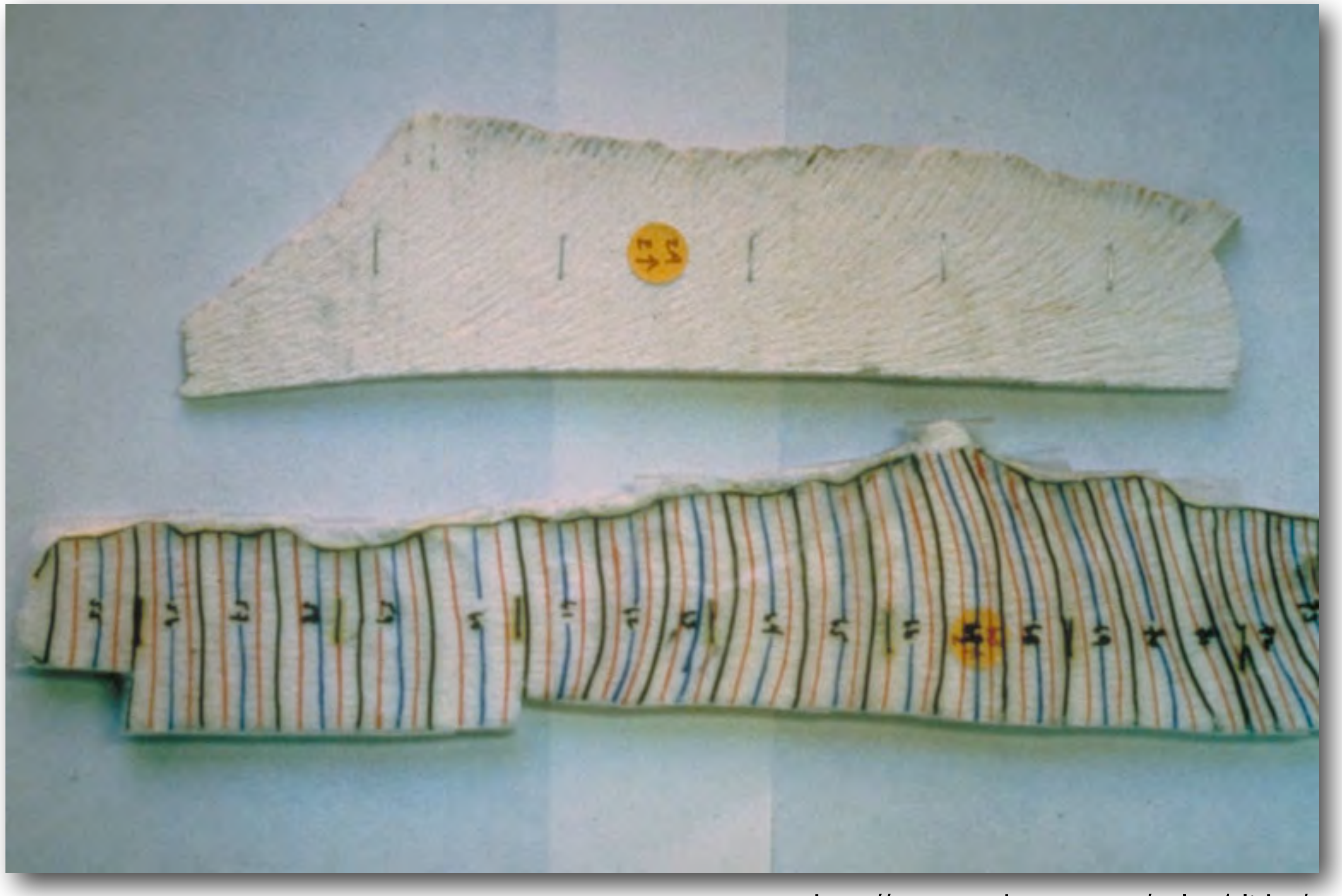
- coral growth varies with the season of the year
  - *growth rate depends on SST and available nutrients*
- higher (lower) density for warmer (colder) SST
  - *density variations allow the identification of annual layers*



http://www.ncdc.noaa.gov/paleo/slides/

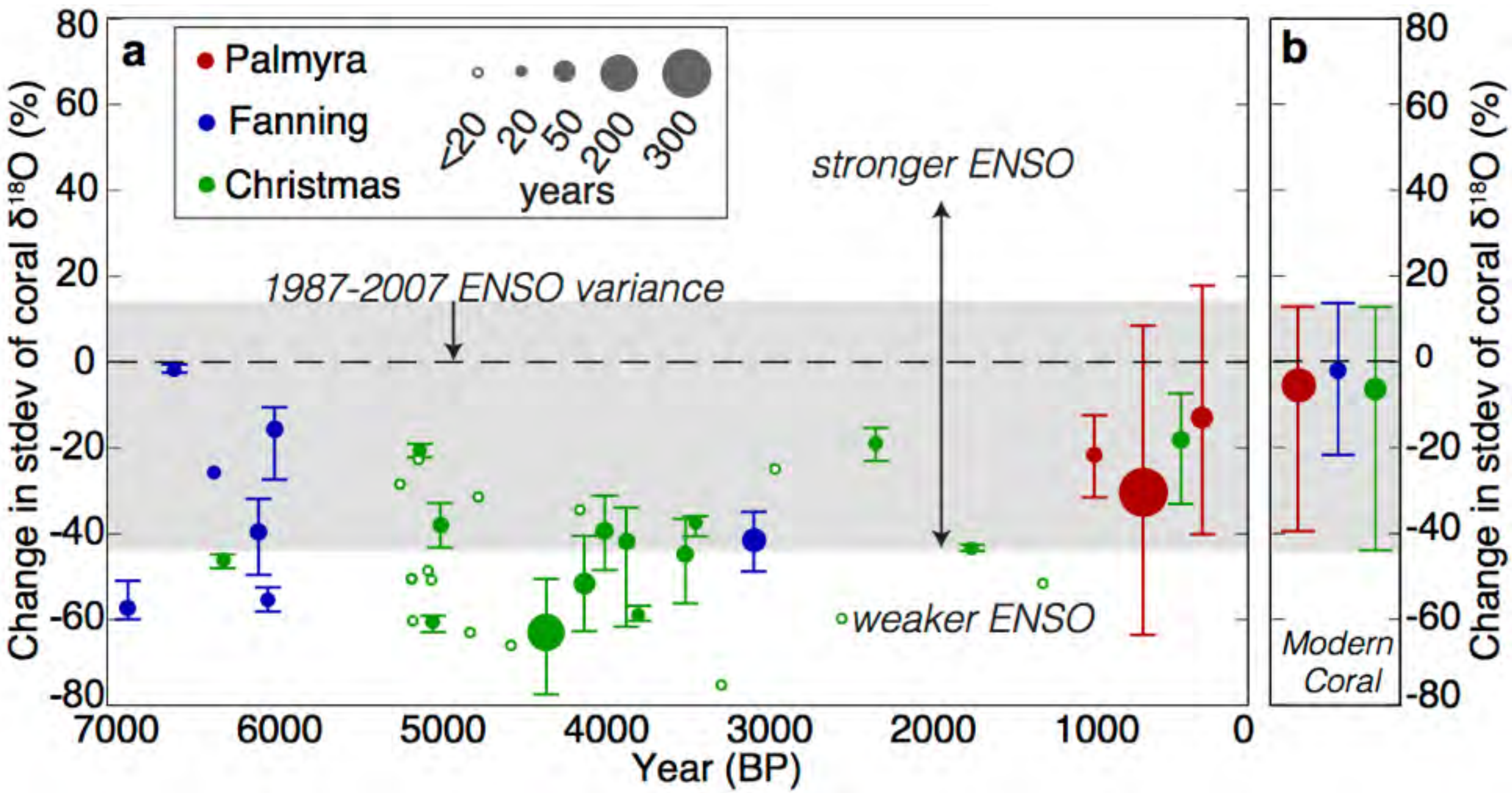
Analyses example: $\delta^{18}O$ measurements on corals

- Depletion/enrichment of ^{18}O in Calciumcarbonte ($CaCO_3$) can be measured on corals, too
- two different effects can influence ^{18}O in $CaCO_3$
    - *temperature-related fractionation (determined by SST changes)*
    - *changes of the ^{18}O content of the ocean water*
      (e.g., by large amounts of tropical rainfall in shallow, coastal waters)
- as corals mainly exist in tropical regions, the El Niño/Southern Oscillation phenomenon is often dominating the coral ^{18}O records
    - *$\delta^{18}O$ analyses on corals enable a reconstruction of past El Niño events*



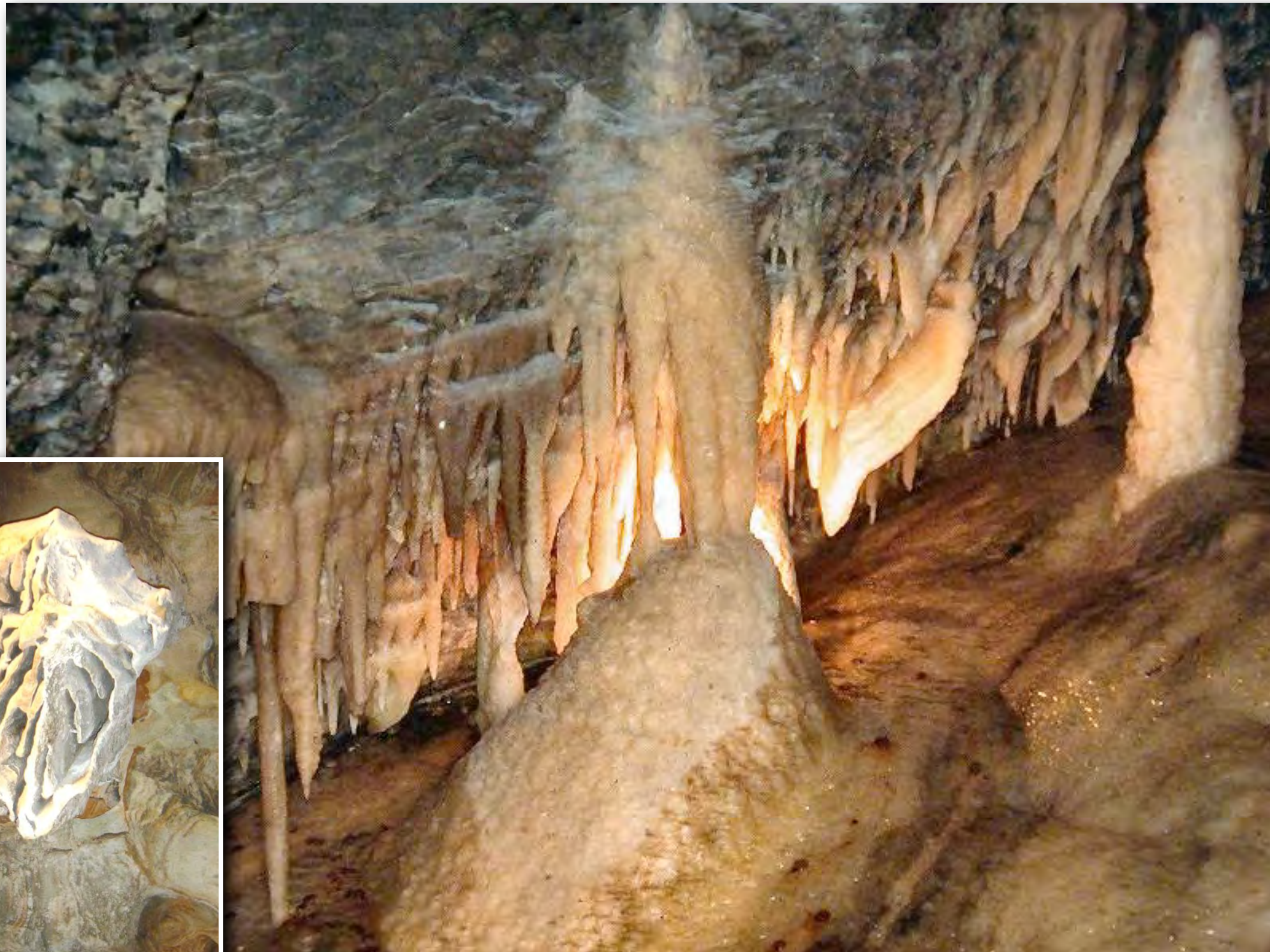
http://www.ncdc.noaa.gov/paleo/slides/

δ18O measurements on corals: El Niño reconstructions



https://usclivar.org/research-highlights/coral-reconstructions-central-tropical-pacific-climate-suggest-25-increase

Speleothems

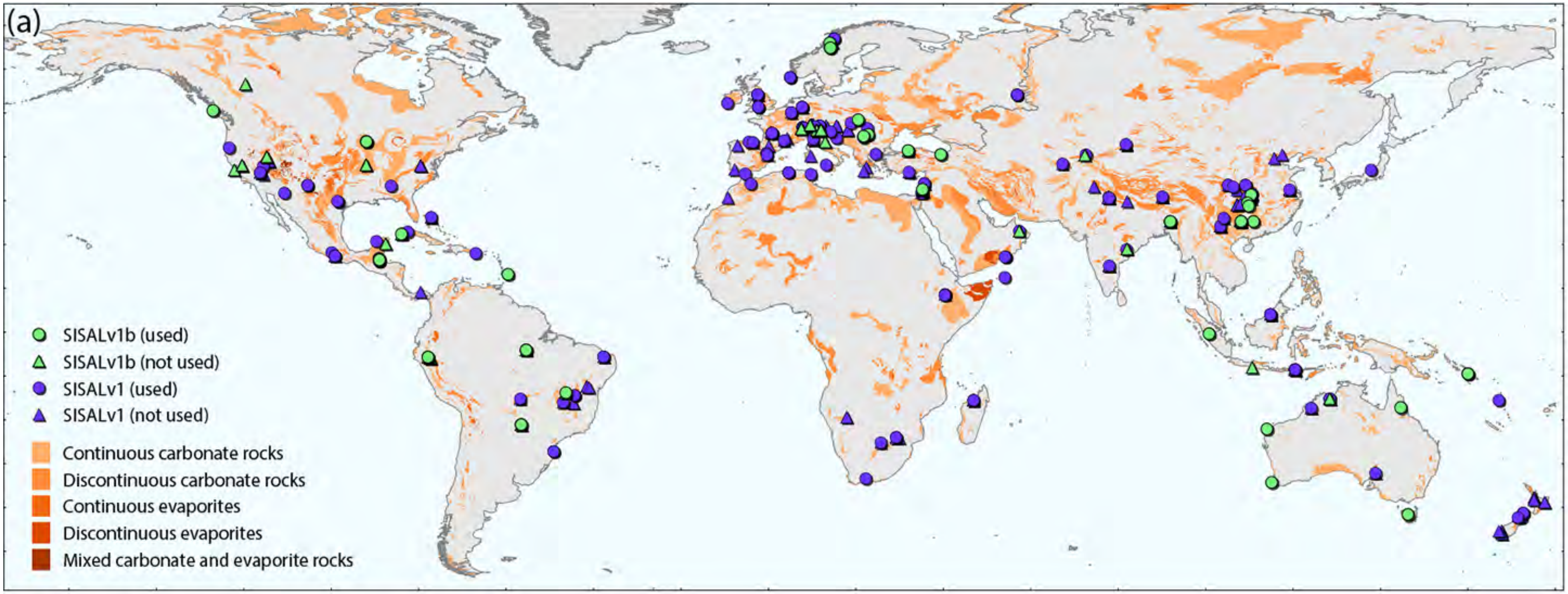


Speleothems

- The following conditions must exit for the formation of speleothems:
    - *The water entering the cave must contain CO_2 to dissolve $CaCO_3$*
    - *The soil above the cave should contain $CaCO_3$ which can be dissolved by water*
    - *The ceiling of the cave needs some fissures for water flowing into the cave*

- The growth rate of the speleothems is determined by several factors
    - *amount and rate of dripping water*
    - *CO_2 concentration of the drip water and within the cave*
    - *$CaCO_3$ concentration of the drip water*
    - *cave temperature*

Speleothem locations



[Comas-Bru et al., ClimPast, 2019]

Cave sites included in the SISAL database

Speleothems

Dating:

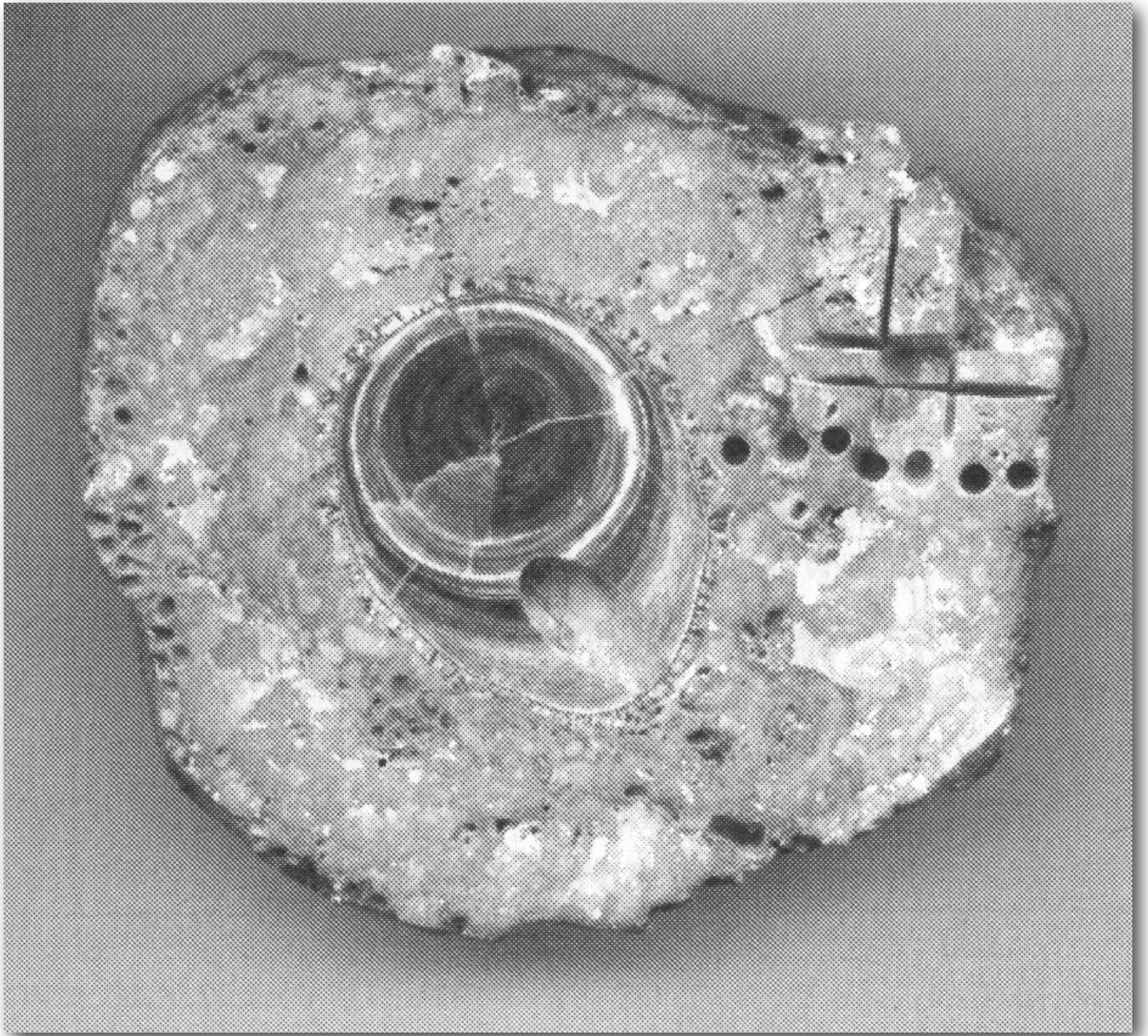
- thorium analyses ($^{230}Th/^{234}U$)
- alternative dating via thermal ionization mass spectroscopy (TIMS)

Age:

- up to 400,000-500,000 years

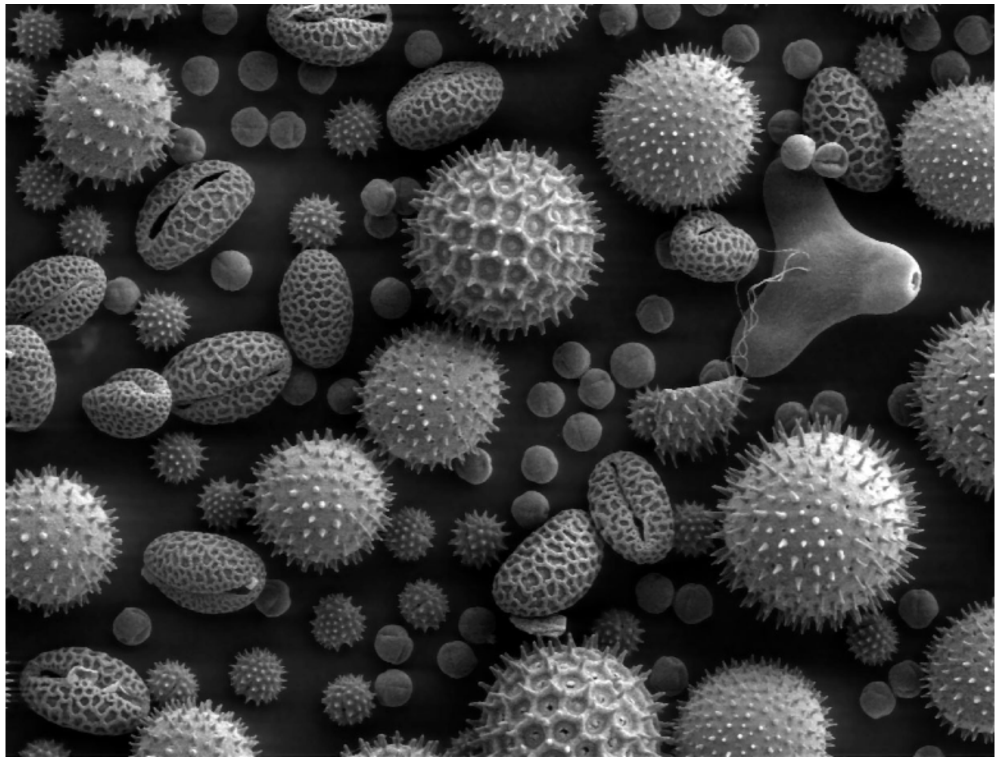
Analyses:

- *Growth rate, $\delta^{18}O$, $\delta^{13}C$, …*

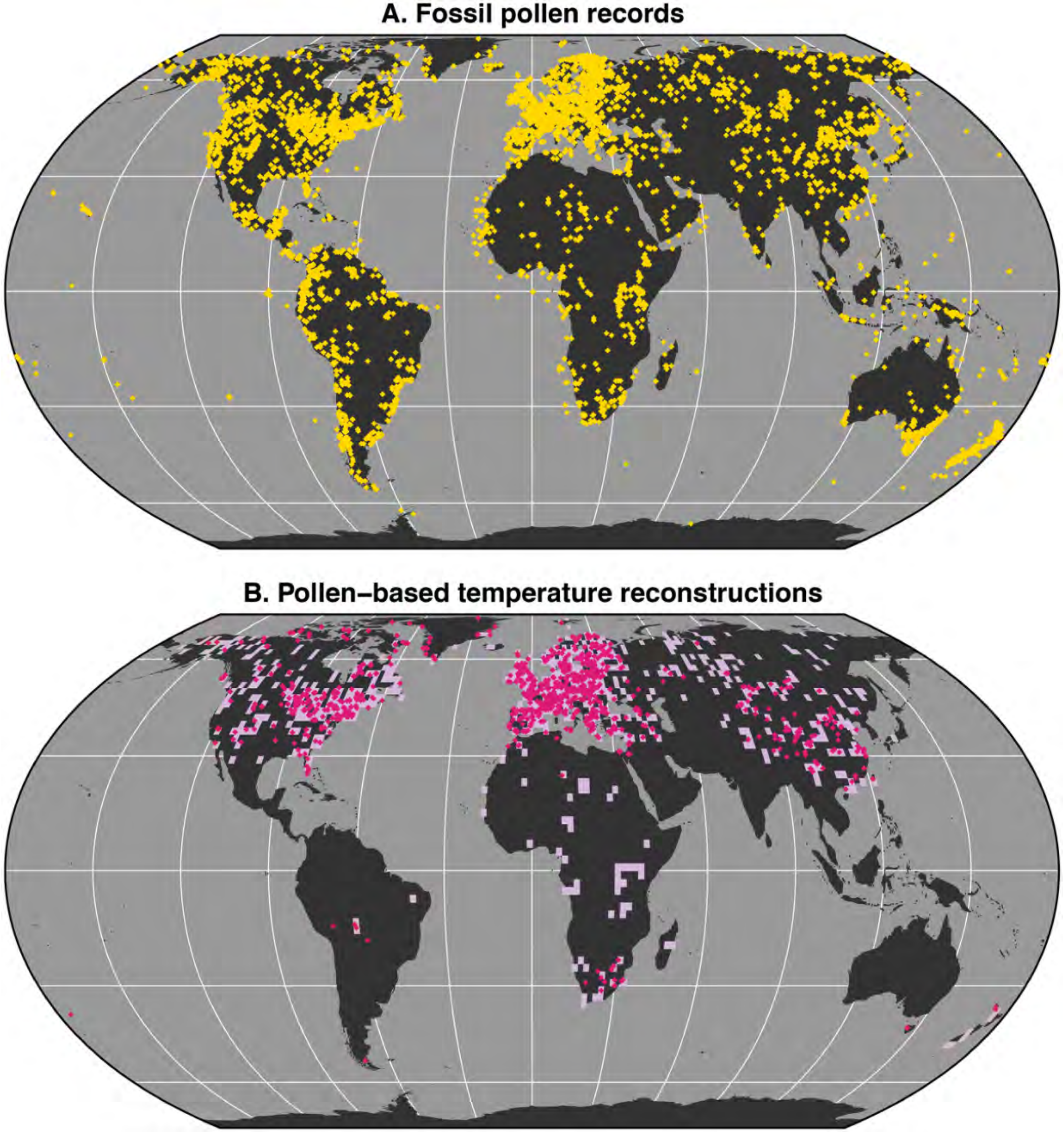


Bradley, Fig. 7.33

Pollen analyses



https://paleonerdish.wordpress.com/2013/08/19/pollen-analysis-and-the-science-of-climate-change/

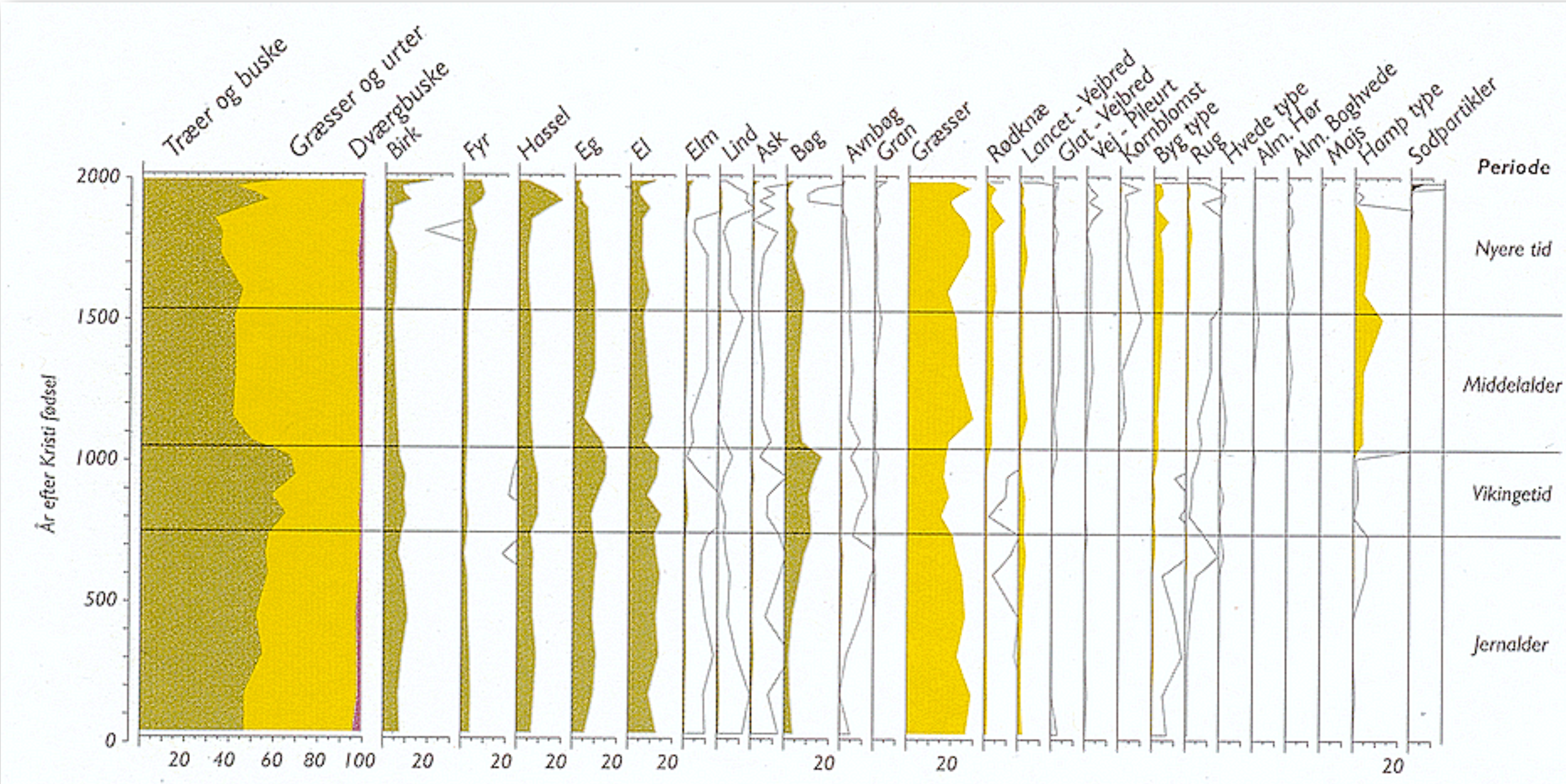


M. Chevalier et al.: Pollen-based climate reconstruction techniques for late Quaternary studies
Earth Science Reviews, 2020

Pollen analyses

- every year, about ~10^9 kg pollen and spores are emitted to the atmosphere
- a pollen compilation often represents the existing vegetation very well
- pollen can be classified very well due to their characteristic shape and colur
- pollen are stable on long time scales(!)
  - *pollen samples can be found both in lake sediments as well as in other terrestrial archives*
  - *the majority of pollen samples stems from the Holocene and/or the last glacial*
- The vegetation compostion at one location often relies on a very few number of climate parameters (hours of sunshine, temperature, precipitation)
  - *key issues for paleoclimate pollen analyses:*
    - *How fast does a vegetation pattern adapt to local climate changes?*
    - *Does it alwas adapt in the same manner?*

Pollen diagrams



http://www.geus.dk/departments/quaternary-marine-geol/research-themes/env-cli-pollen-uk.htm

Calibration of Pollen Studies

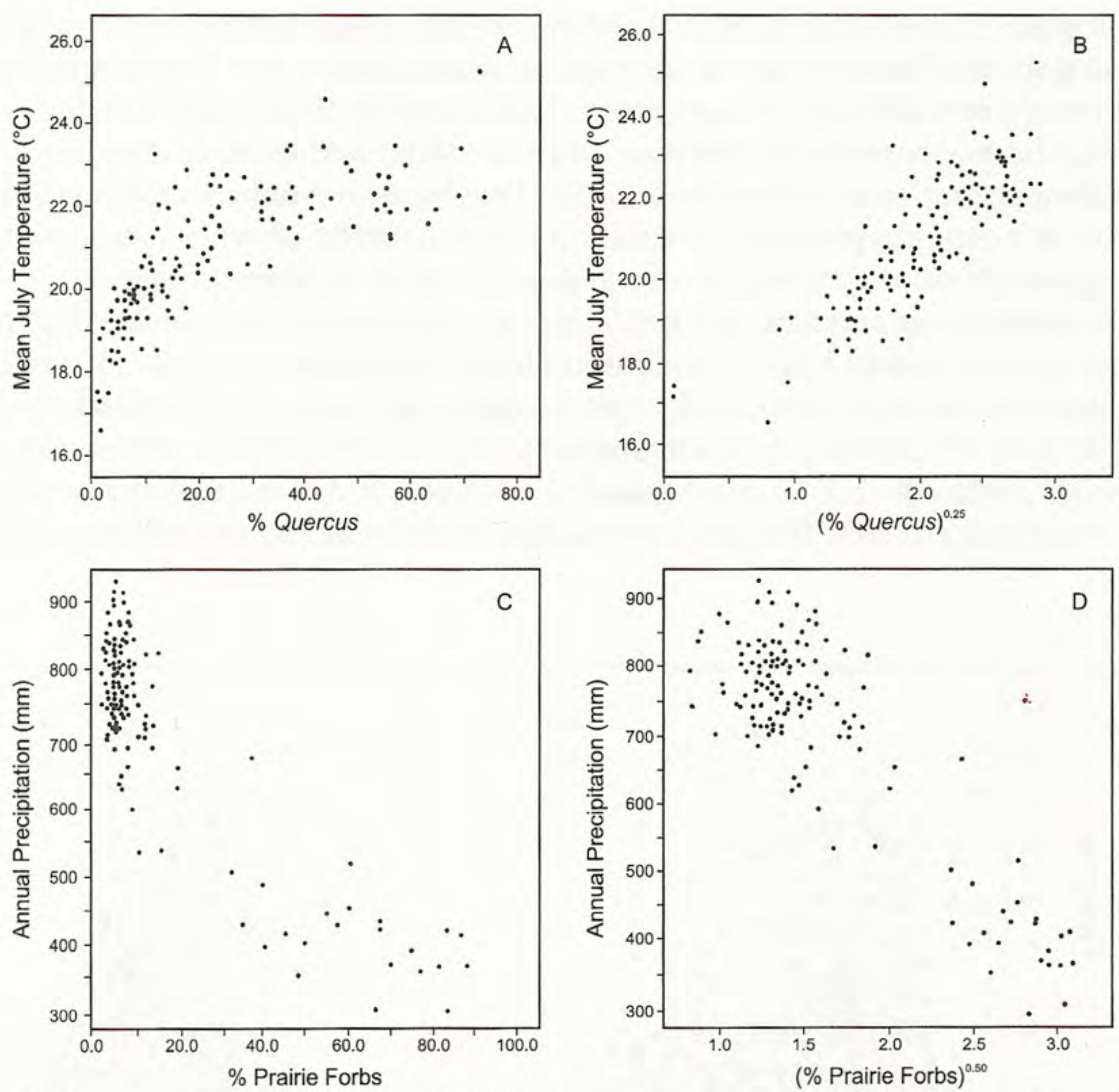


FIGURE 9.11 Scatter diagrams for **(A)** July mean temperature vs the percentages of *Quercus* (oak) pollen; **(B)** July mean temperature vs the percentages of *Quercus* pollen raised to the 0.25 power; **(C)** annual precipitation vs the percent of prairie-forb pollen (excluding *Ambrosia*) and **(D)** annual precipitation vs the percent of prairie-forb pollen raised to the 0.5 power (Bartlein *et al.*, 1984).

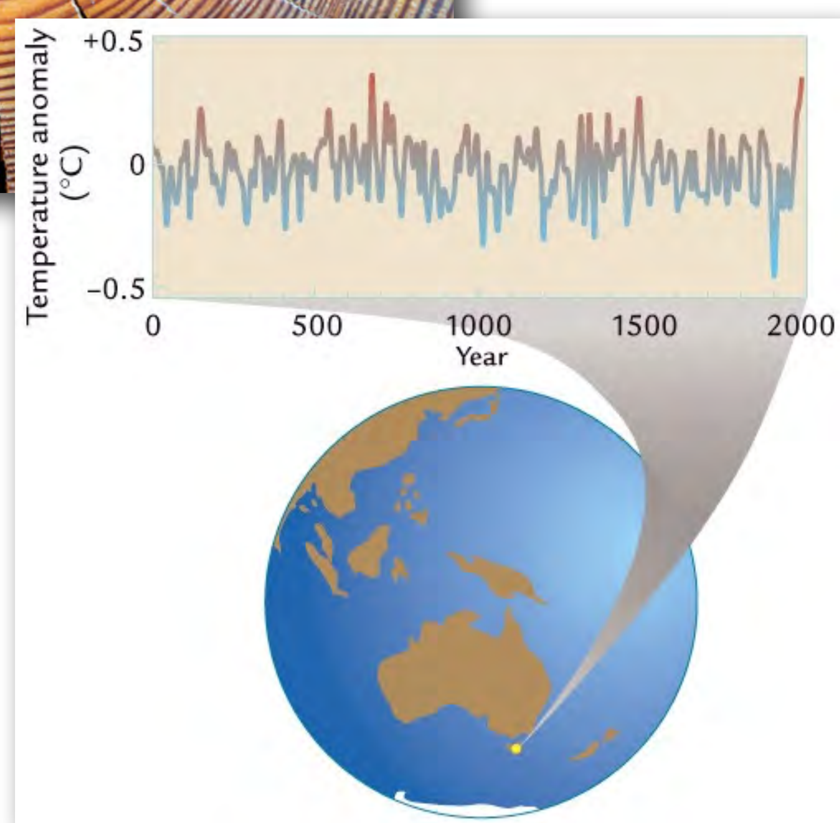
Bradley, Fig. 9.11

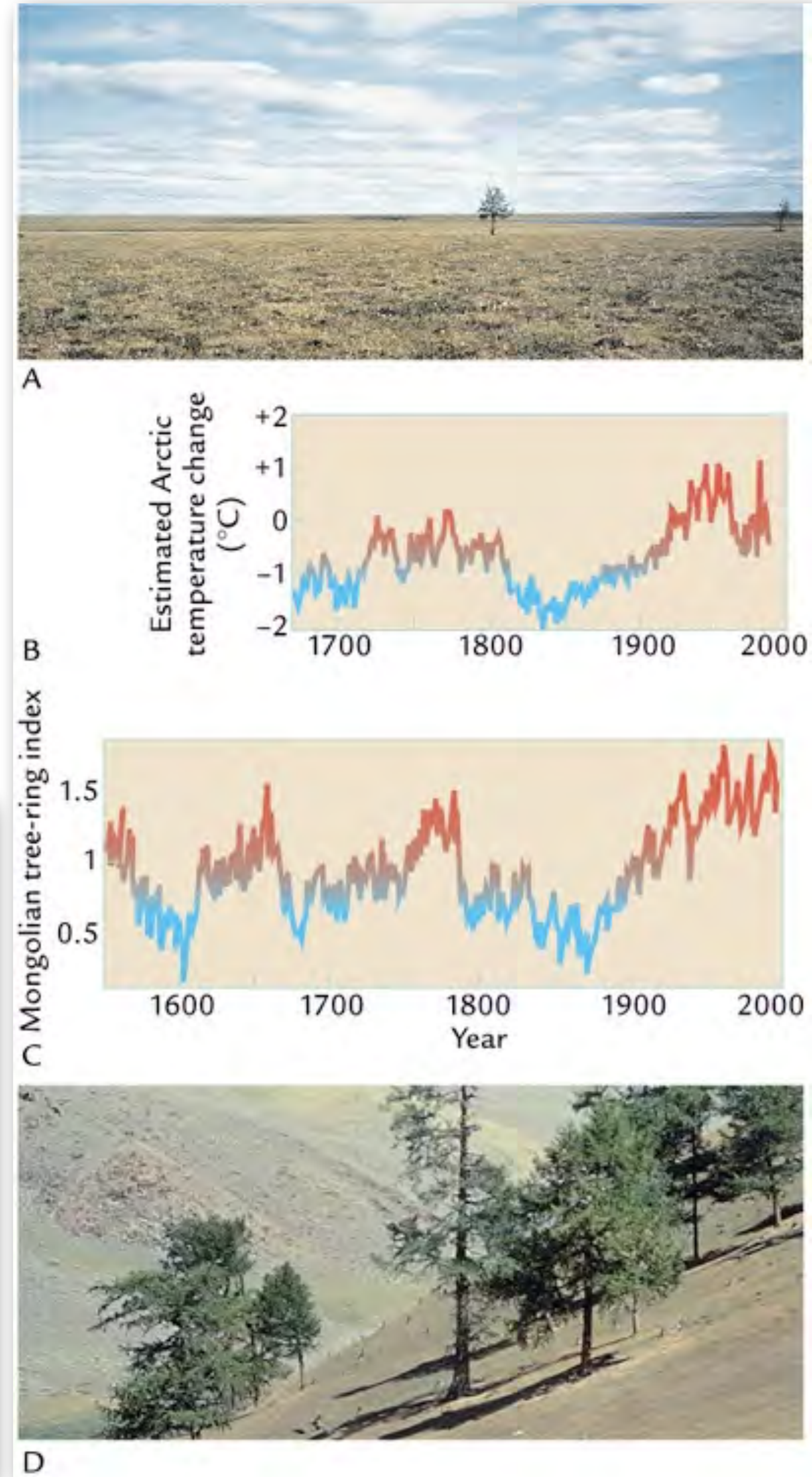
Tree Rings

https://www.sciencenews.org/article/tree-story-book-explores-what-tree-rings-can-tell-us-about-past

Tree Rings

- Variations of tree ring width and density are an indicator of (local) climate change
- the use of tree rings to reconstruct climate change is called dendroclimatology



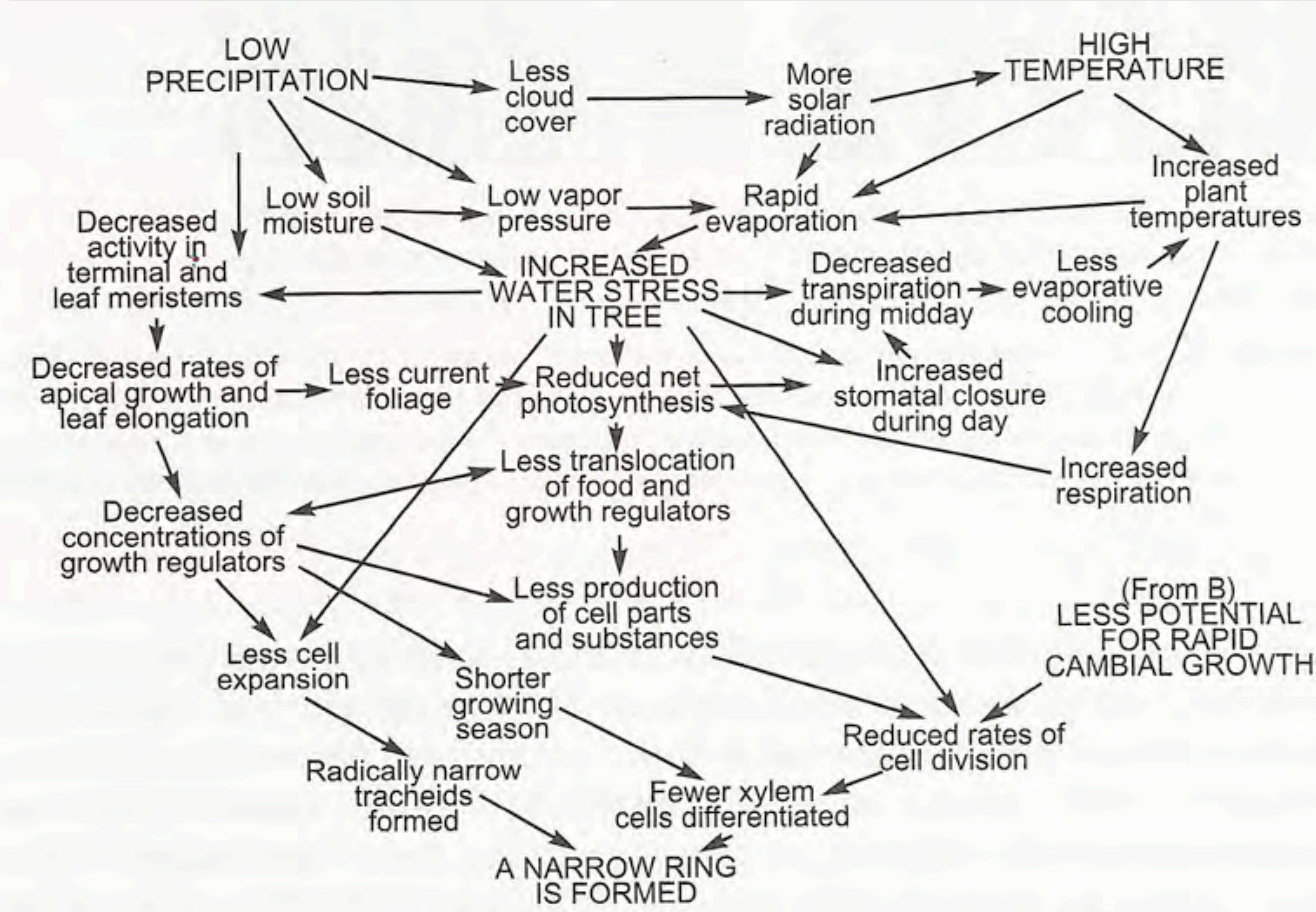


[from: Ruddiman, 2008]

Dendroclimatology

- The width of the annual tree rings is in general a complex function that depends on the tree species, tree age, available nutrients (in the soil and in the tree), sun shine hours, amount of precipitation, temperature, wind conditions, relative humidity, etc.)
  - *at suitable sites (and for suitable tree species) the function can be reduced to 1-2 influencing parameters, only*

The Imprint of Climate Changes in Tree Rings

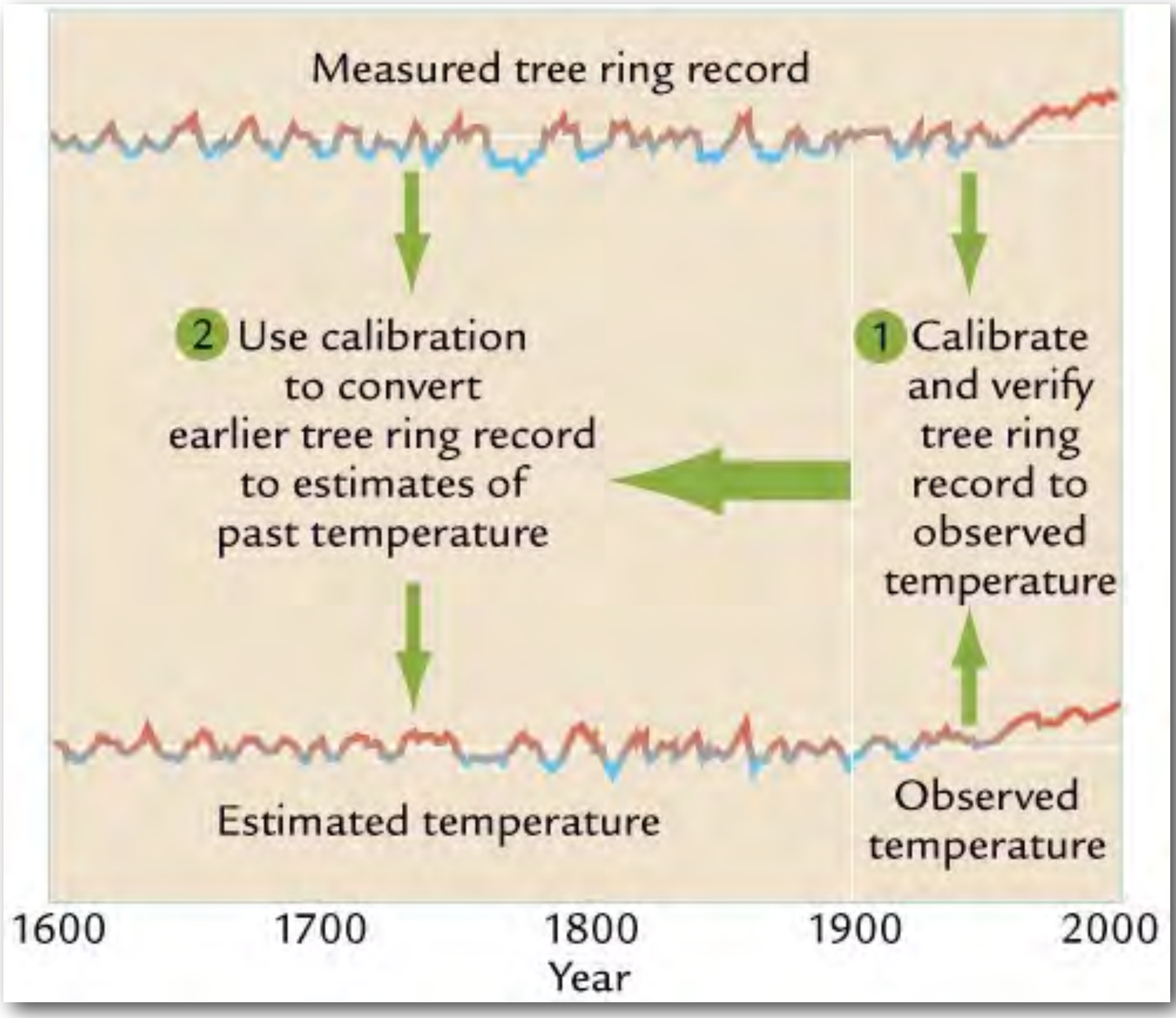


Bradley, Fig. 10.4

Dendroclimatology

- The width of the annual tree rings is in general a complex function that depends on the tree species, tree age, available nutrients (in the soil and in the tree), sun shine hours, amount of precipitation, temperature, wind conditions, relative humidity, etc.)
  - *at suitable sites (and for suitable tree species) the function can be reduced to 1-2 influencing parameters, only*
- Dating methods: ^{14}C, cross dating using several different trees
- Analyses: Density variations, ^{18}O

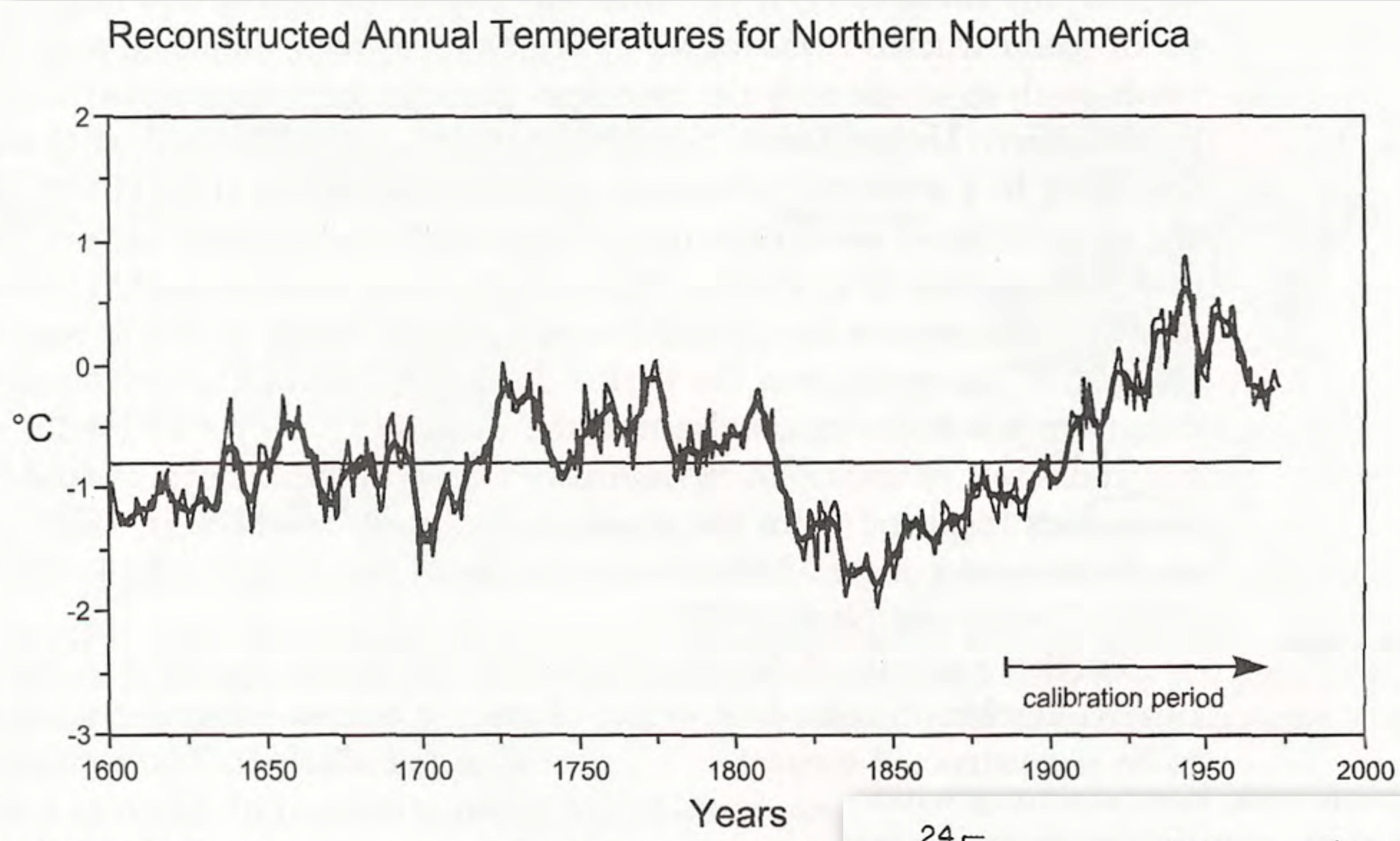
Climate reconstructions using tree ring records



[from: Ruddiman, 2008]

- a modern calibration (=relation between tree ring record and climate variable, e.g. temperature) is used to convert past tree ring variations into climate changes
  - *similar to other methods, one has to assume a priori that the the modern calibration curve can be applied for past times*

Climate reconstructions using tree ring records



- tree ring records can be a good proxy for regional climate changes during the last centuries

- many records show substantial warming in the 20th century
  - *however, the latest warming is missing in some of the tree records*

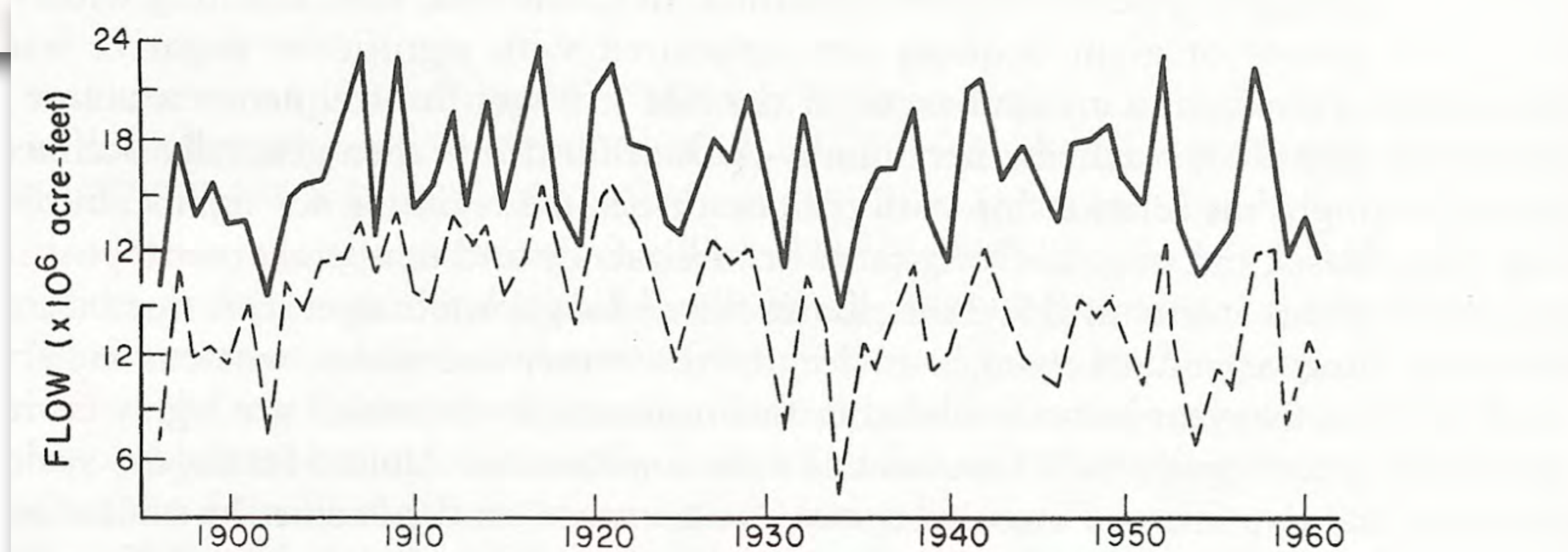


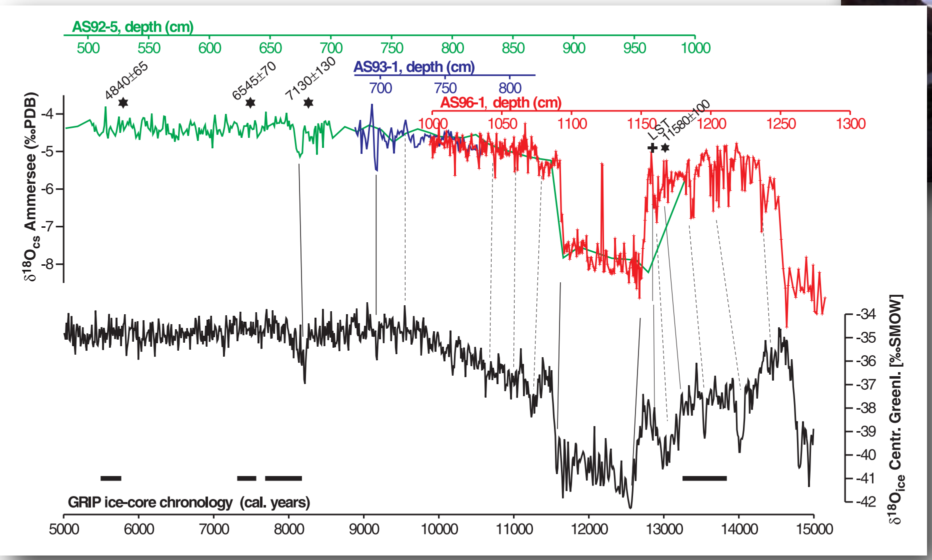
FIGURE 10.28 Runoff in the Upper Colorado River Basin. Reconstructed values (-----) are based on tree-ring width variations in trees on 17 sites in the basin. Actual data, measured at Lee Ferry, Arizona, are shown for comparison (——). Based on this calibration period, an equation relating the two days sets was developed and used to reconstruct the flow of the river back to 1564 (Fig. 10.29) (Stockton, 1975).

Bradley, Fig. 10.22, 10.28

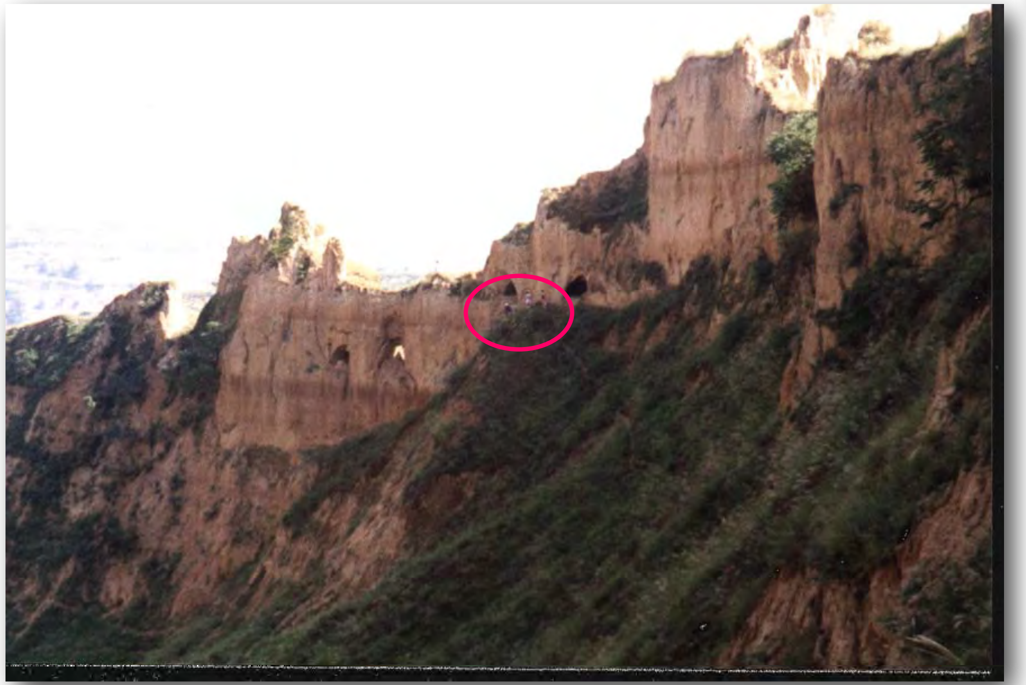
Further climate archives

- lake sediment cores
- loess archives
- snow-line reconstructions and glacier movements
- lake level changes
- ....

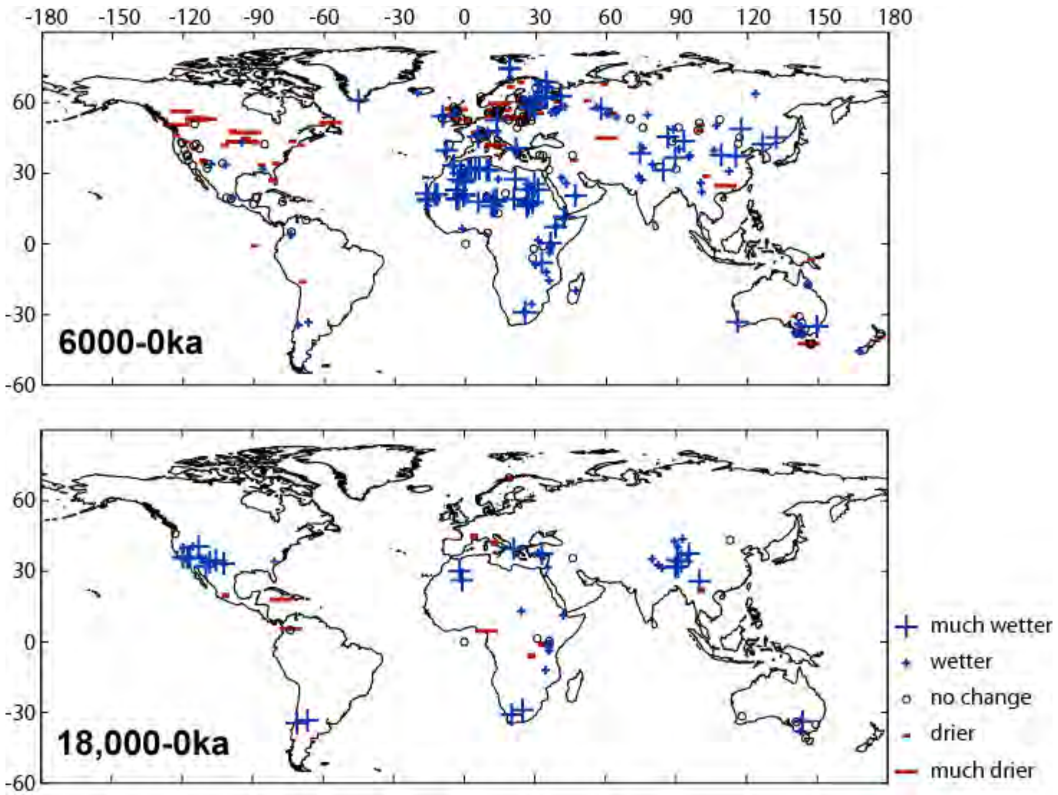
Nam Co lake, Tibetan Plateau



v. Grafenstein et al., Science, 1999

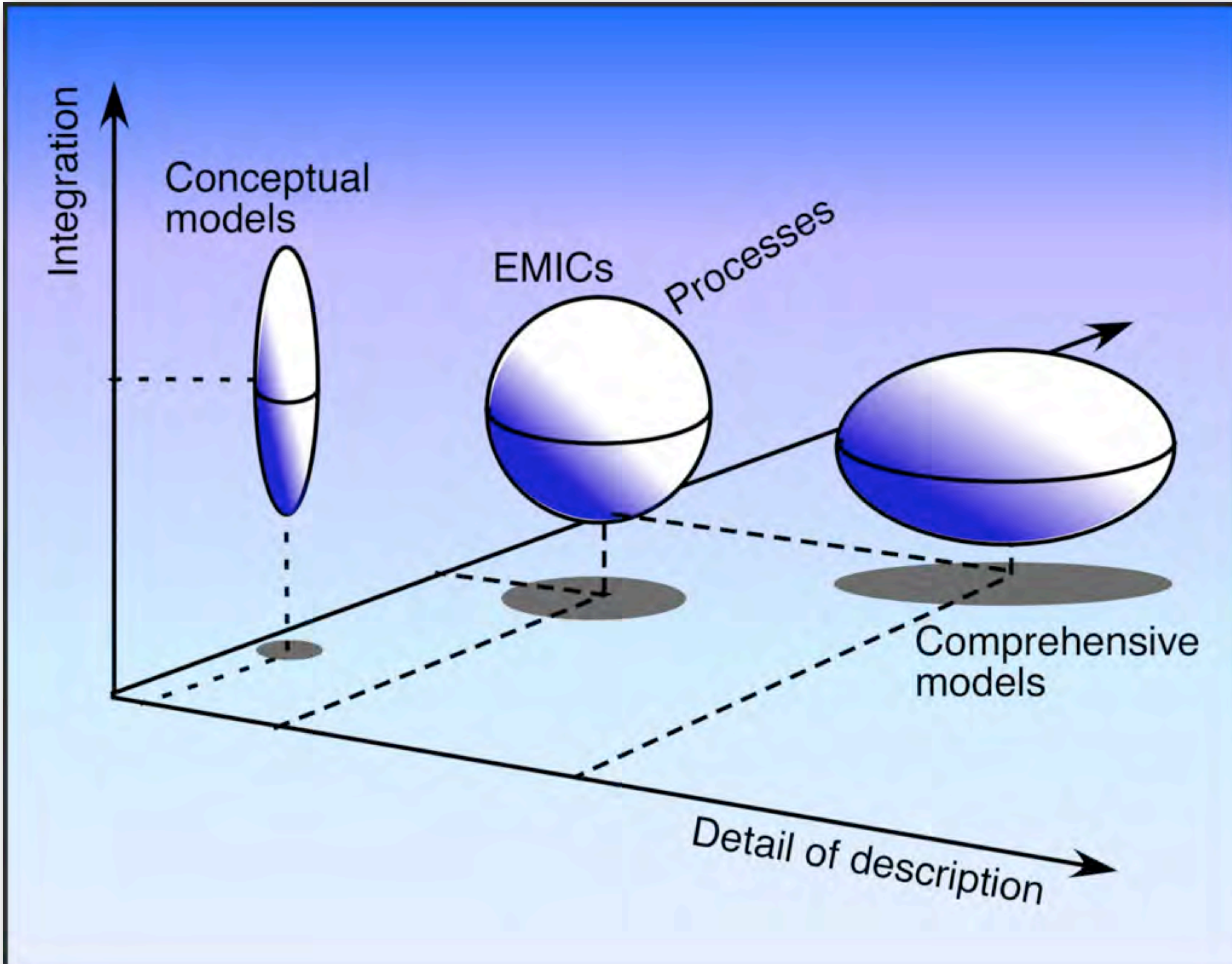


The loess/palaeosol sequence at Potou, Central Loess Plateau, China. The darkest of the bands seen in the sequence is the palaeosol complex S5. Search for the intrepid field-workers just above S4 for scale! http://www.aber.ac.uk/~qecwww/loessprog.html



PMIP Global Lake Status For The Mid-Holocene And Last Glacial Maximum
[https://pmip2.lsce.ipsl.fr/synth/lakestatus.shtml]

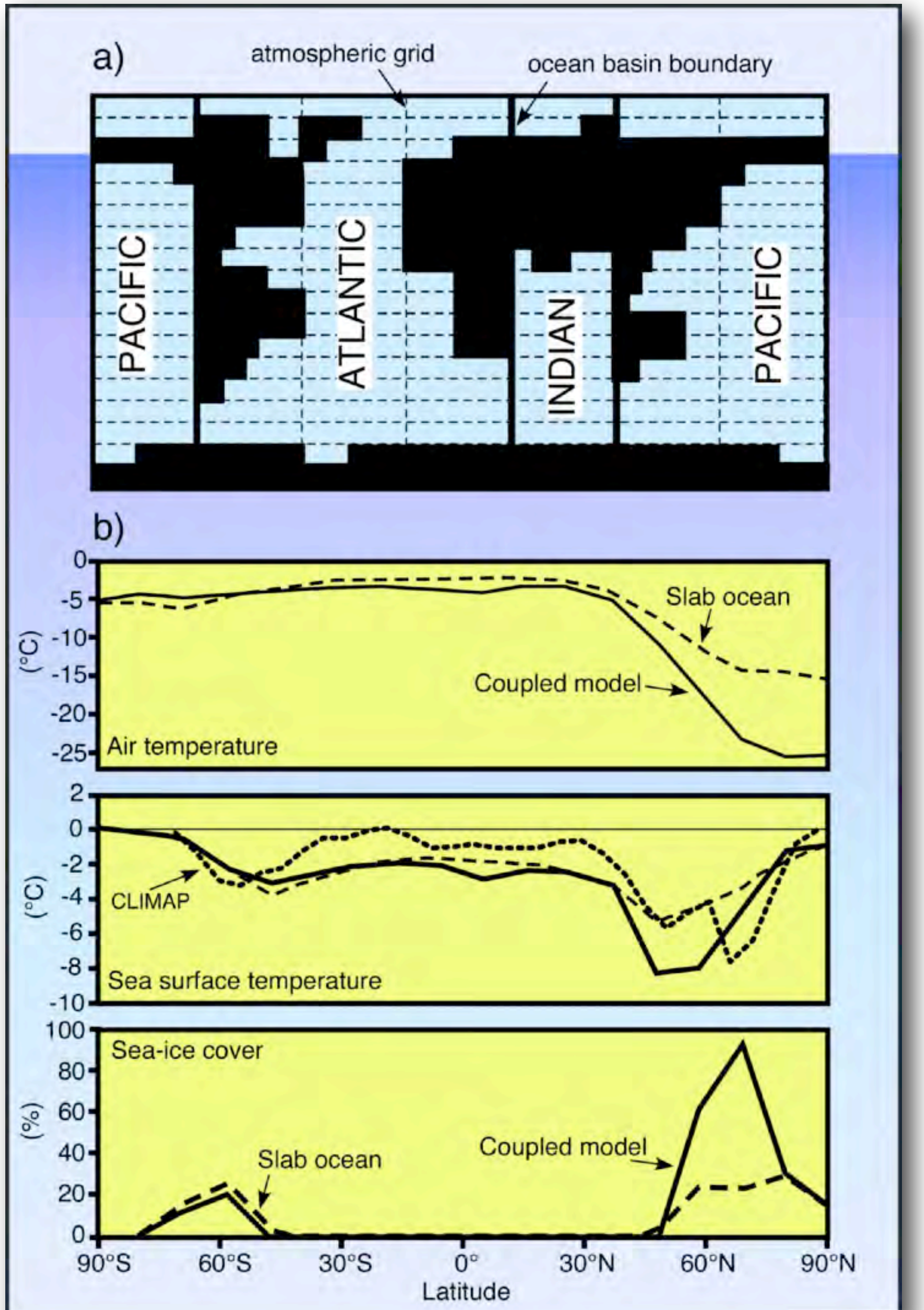
Summary of climate models

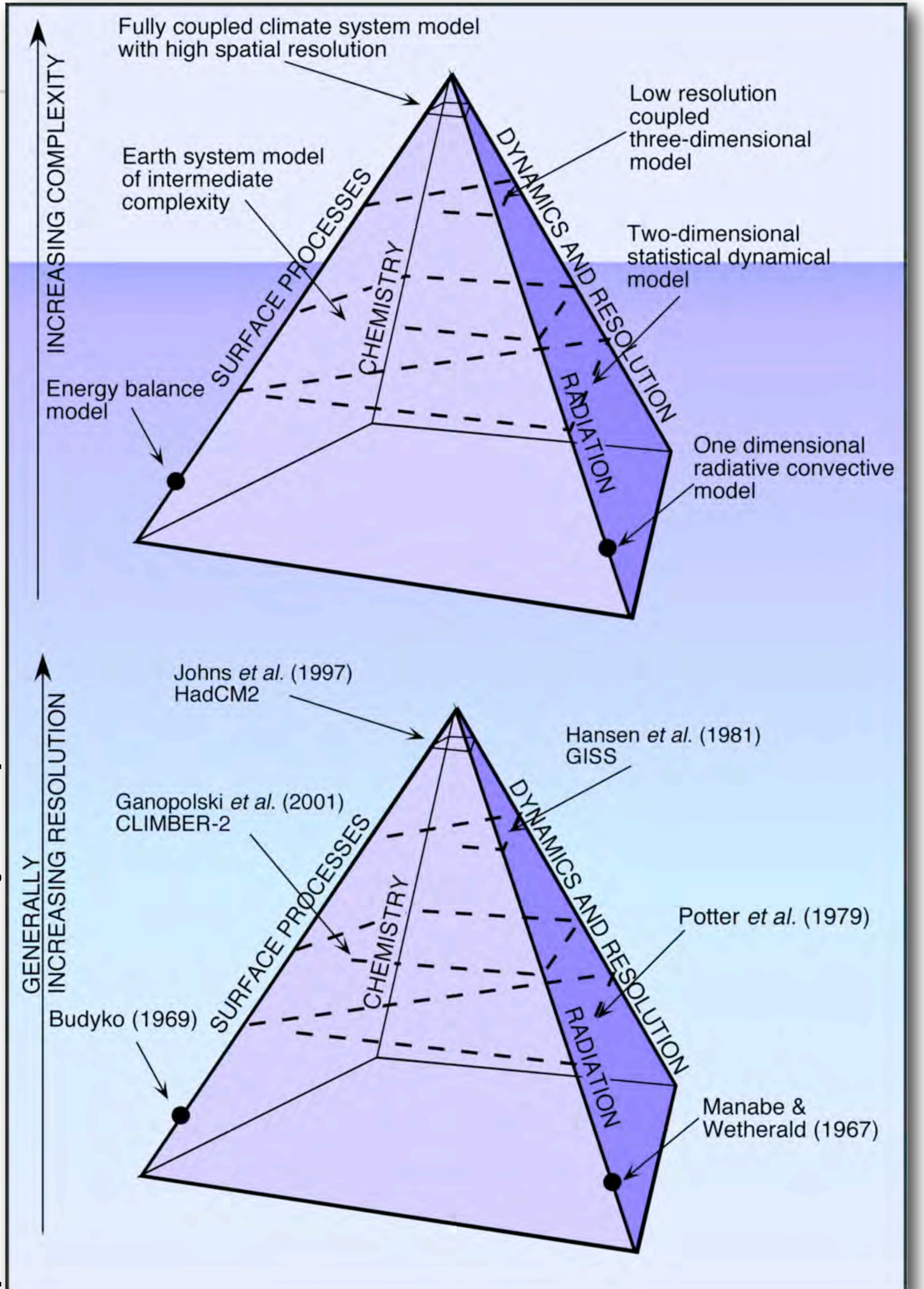


[McGuffie & Henderson-Sellers, A Climate Modelling Primer, 2005]

EMICS: Earth Models of Intermediate Complexity

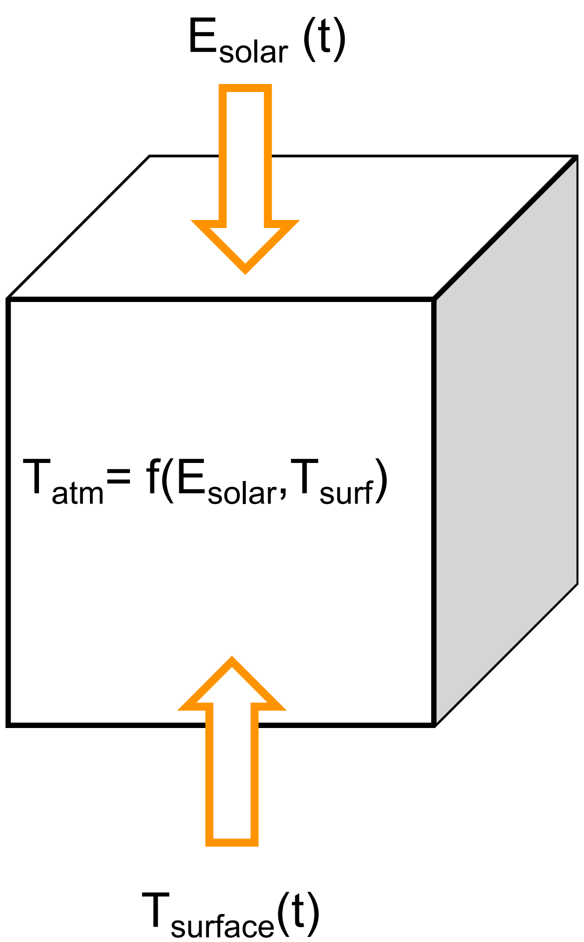
The CLIMBER-2 model





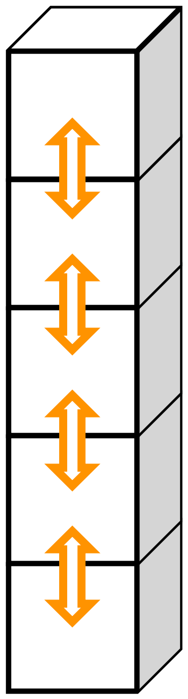
[McGuffie & Henderson-Sellers, A Climate Modelling Primer, 2005]

Dimensions of climate models



Box Model

Example:
mean temperature of the atmosphere as a function of solar energy input and mean surface temperature

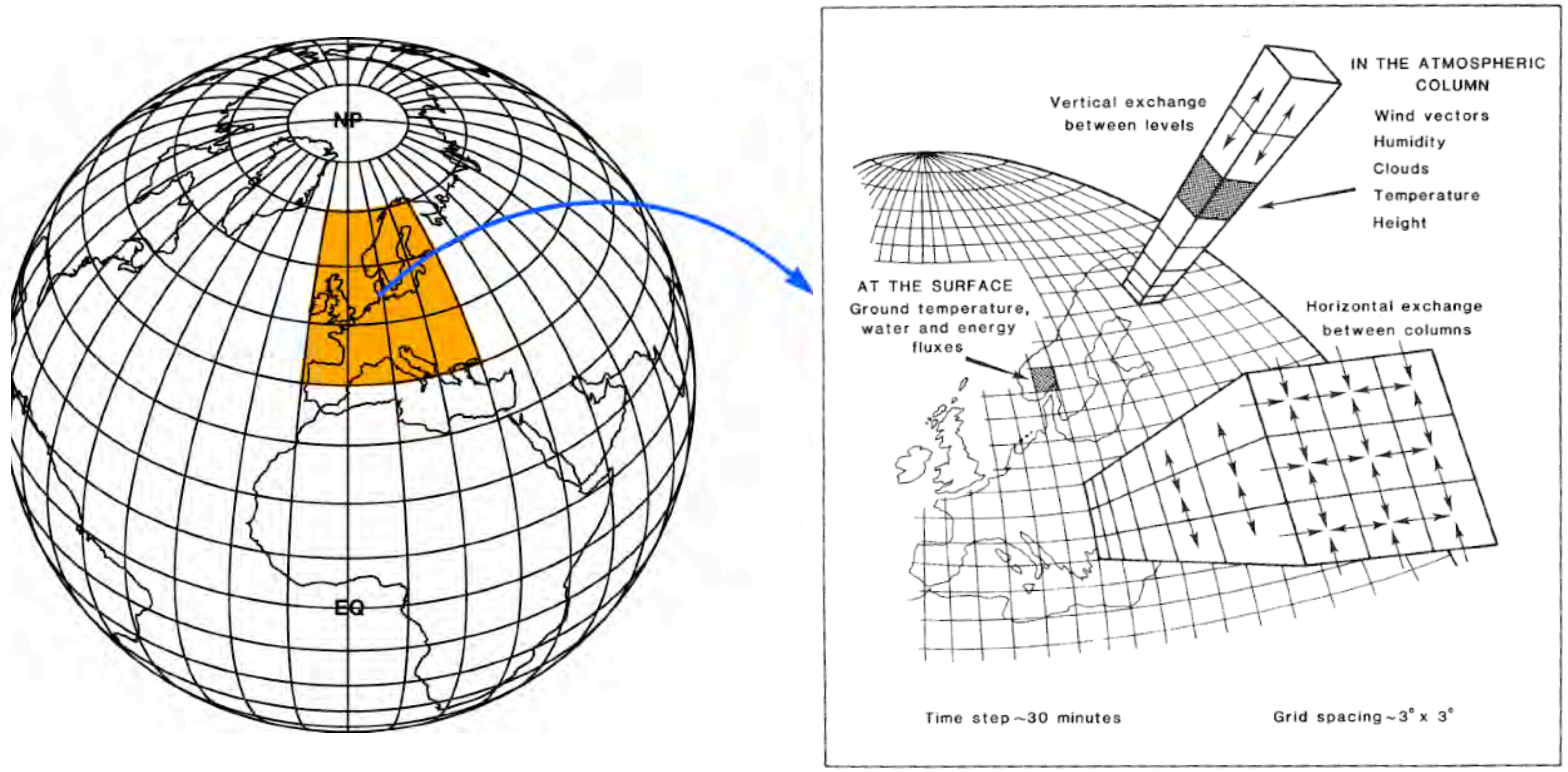


Column Model

Example:
vertical diffusion of smoke in the atmosphere

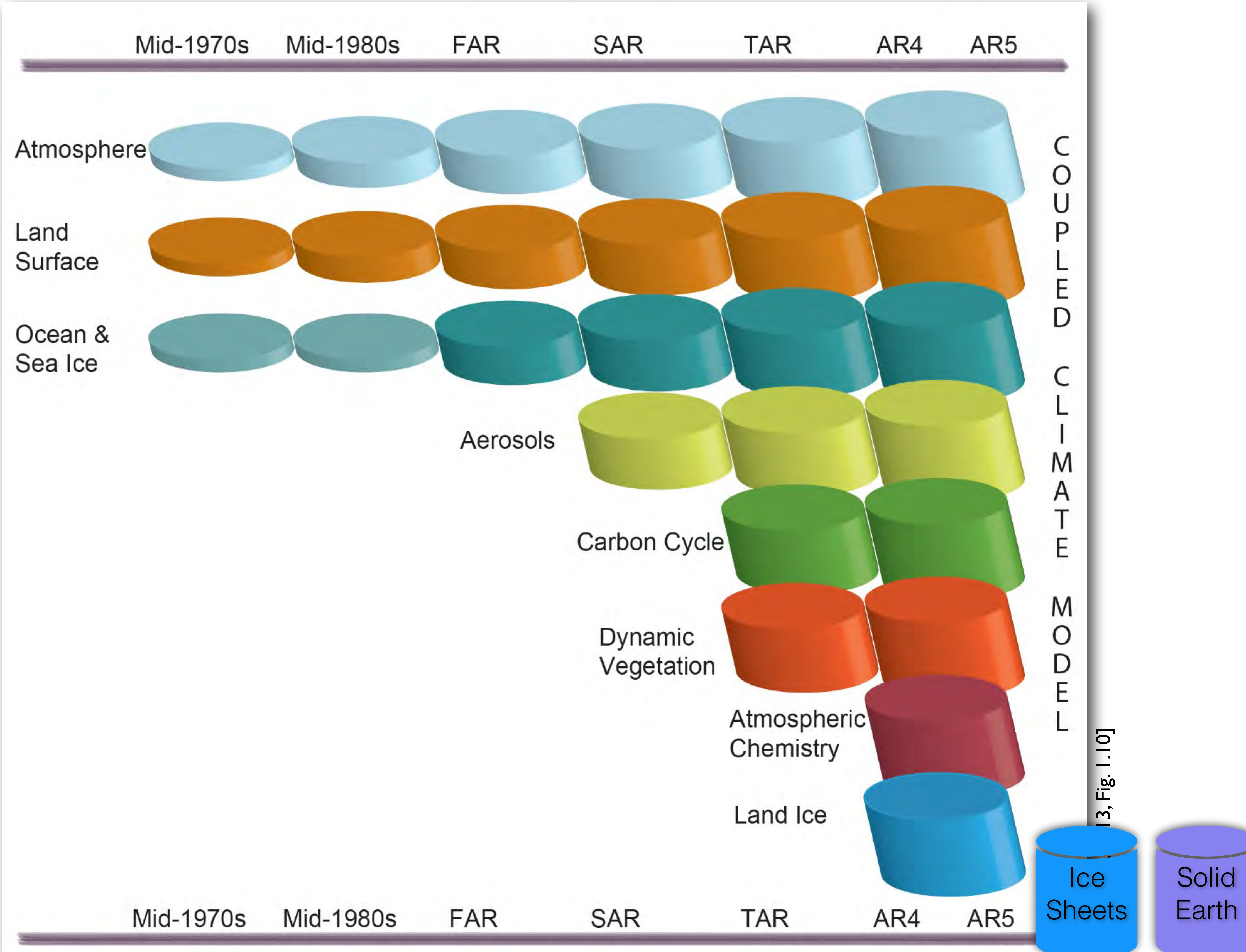
General Circulation Model

Example:
climate change scenario for the next 100 years

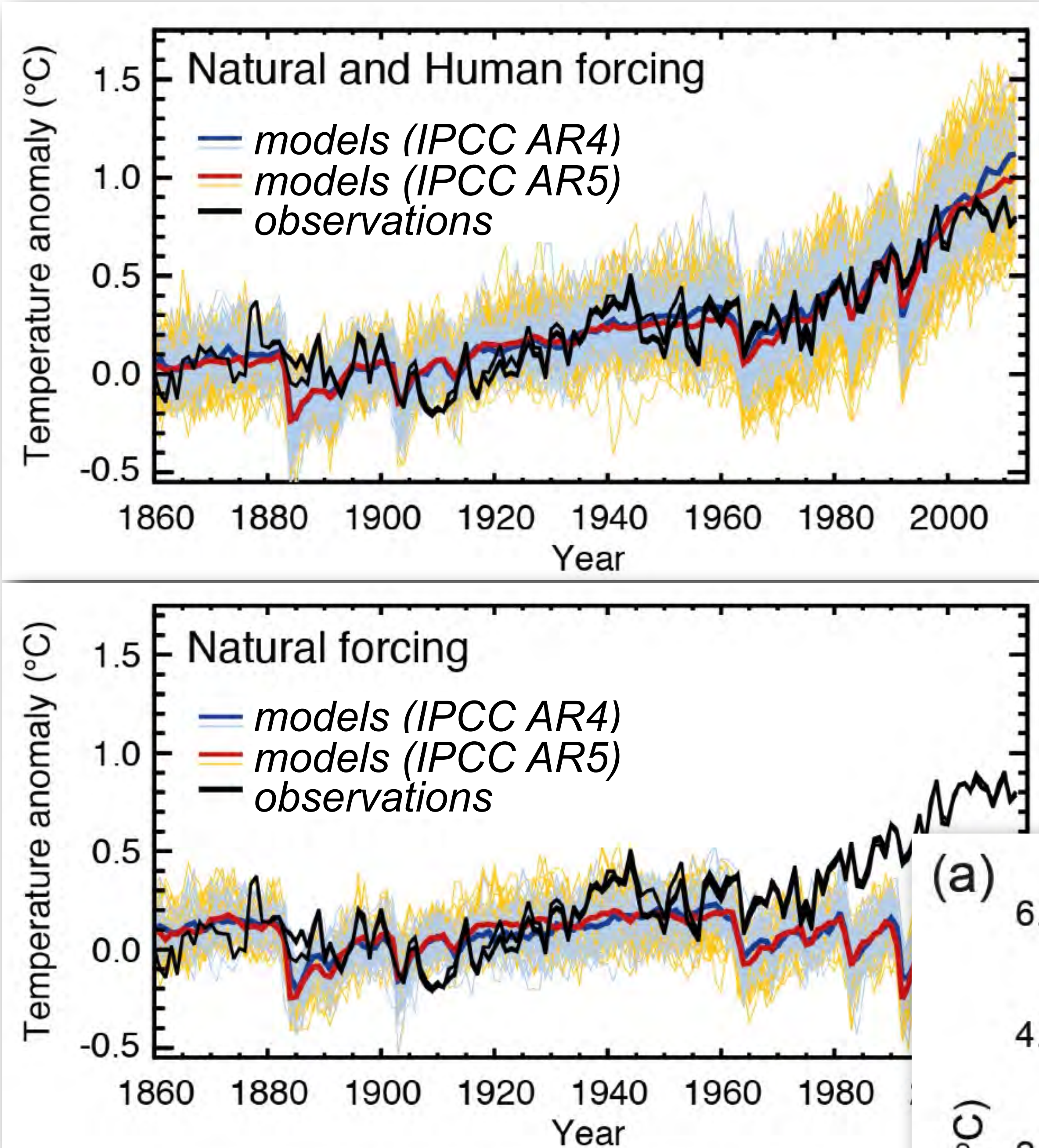


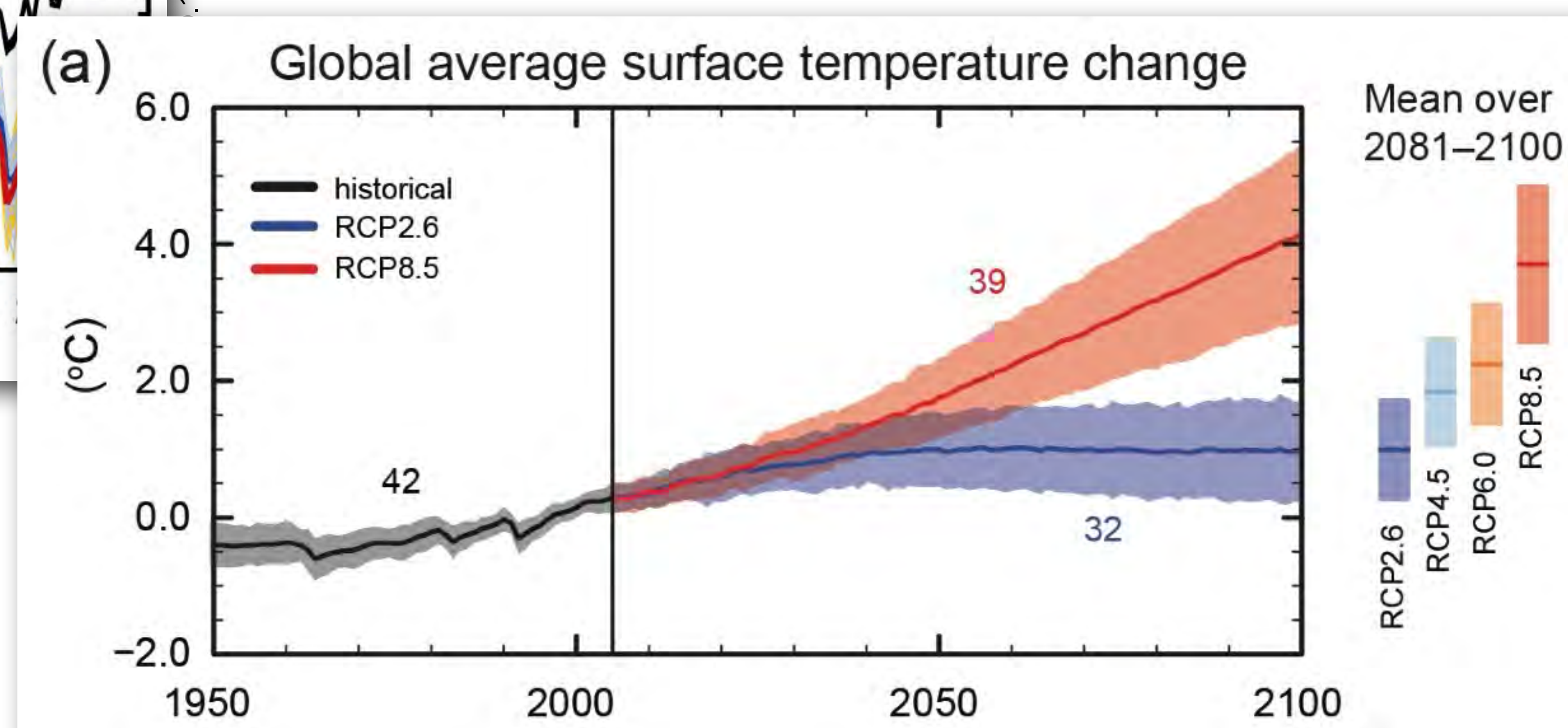
[McGuffie & Henderson-Sellers, A Climate Modelling Primer]

Historical development of complex climate models



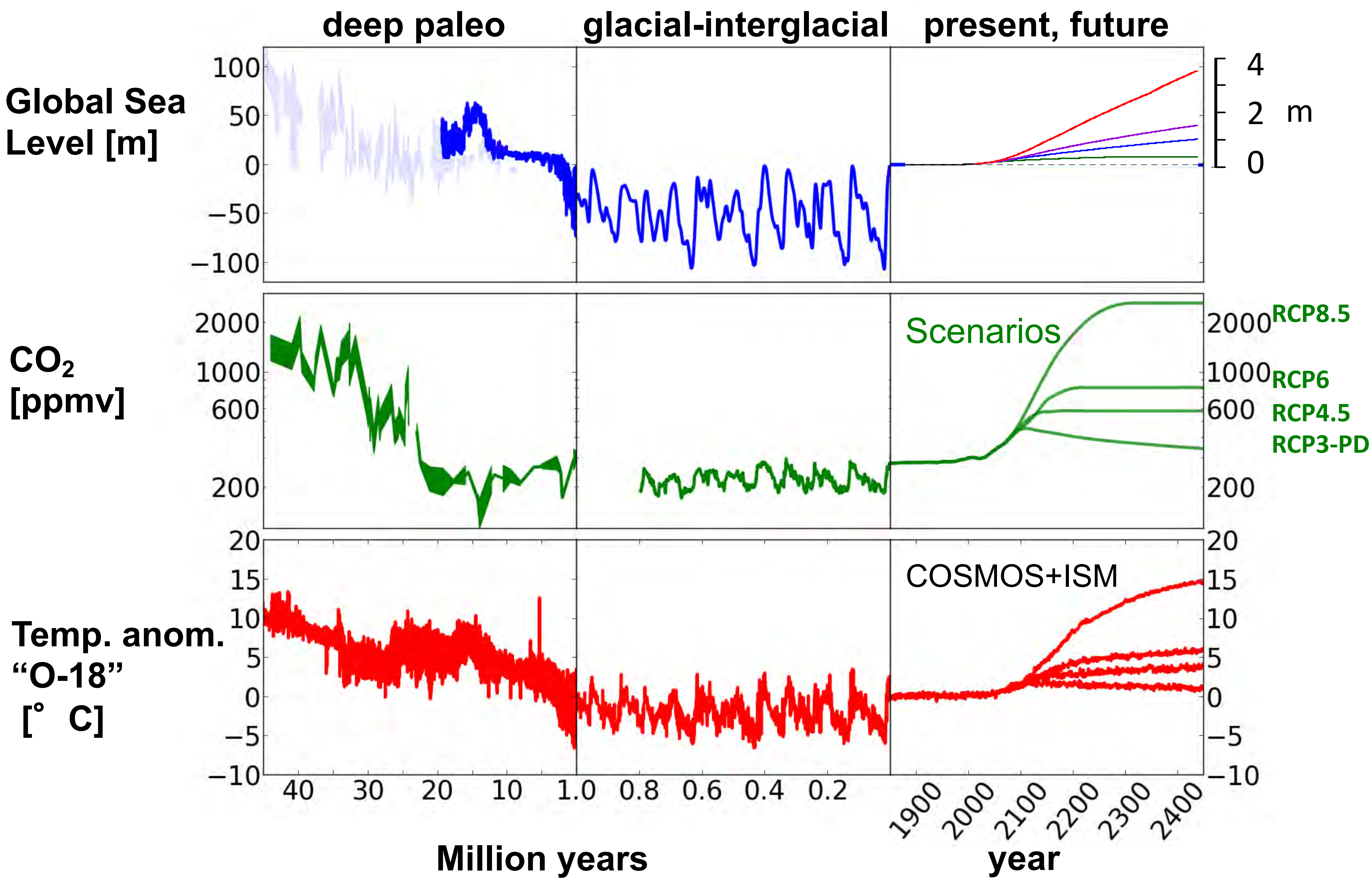
Link of past-present-future





[IPCC, AR5, 2013, Fig. SPM-07]

Link of past-present-future



(Kominz et al., 2008; Pagani et al., 2009; Kramer et al., 2011; Crowley & Kim 1995, Wei & Lohmann,)

Climate II

(Winter 2020/2021)

14th lecture:

Summary and outlook

(Summary of models, available data, link of past-present-future, knowledge transfer)

End of lecture.

Slides available at:

https://paleodyn.uni-bremen.de/study/climate2020_21.html