

Happening today...

The Pacific atoll nation of Tuvalu will disappear under the waves today, giving weight to predictions that it will become the first victim of rising global sea levels.

“...we expect most of the areas will be flooded by the sea for an hour or so,” Hilia Vavae, of the Tuvalu Meteorological Office, said.

...a decade ago, then Prime Minister Bikenibeu Paeniu warned "the world's first victims of climate change" would be the 11,500 Tuvaluans.

...Current Prime Minister Saufatu Sopo'aga says his Government is thinking of suing Australia and the United States for carbon emissions.

In today's (Thurs Feb 19) issue of *The Press*, a national New Zealand newspaper

(Similar story in 2003: The Arctic-based Inuit peoples announced that they plan to sue the Bush Administration over loss of homeland (icesheet), which is melting, leaving bare sea and/or destroying foundations for their buildings and homes.)

Lecture 25

Announcements:

Handout of articles to read over the weekend:

1) **Jim Hansen: Defusing the Global Warming Time Bomb**

(*Scientific American*, March 2004) - nicely links together ideas about paleoclimate and future climate change

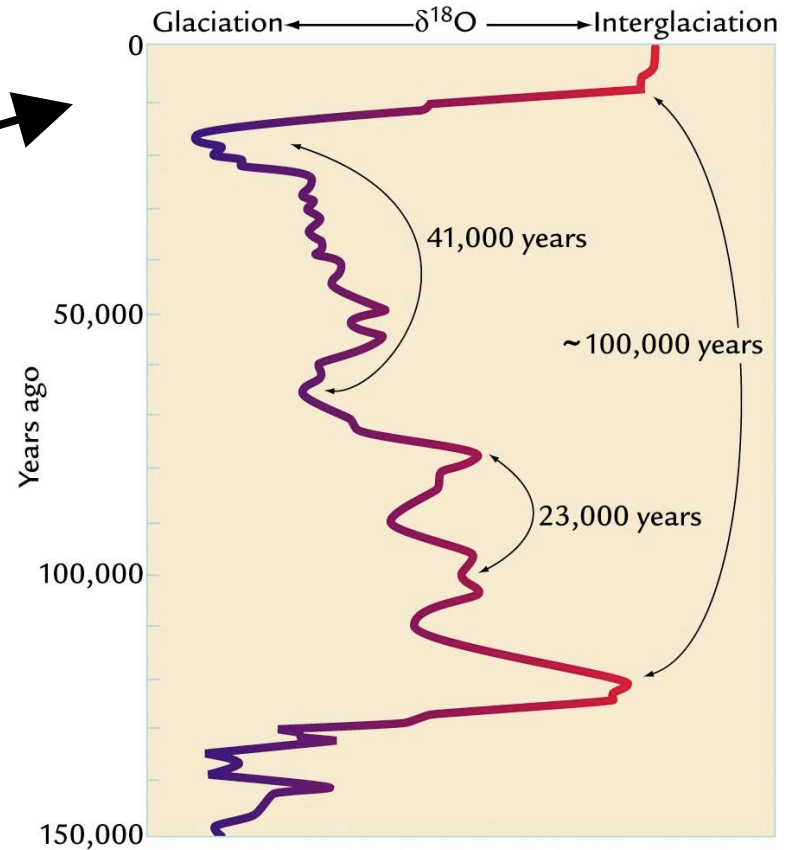
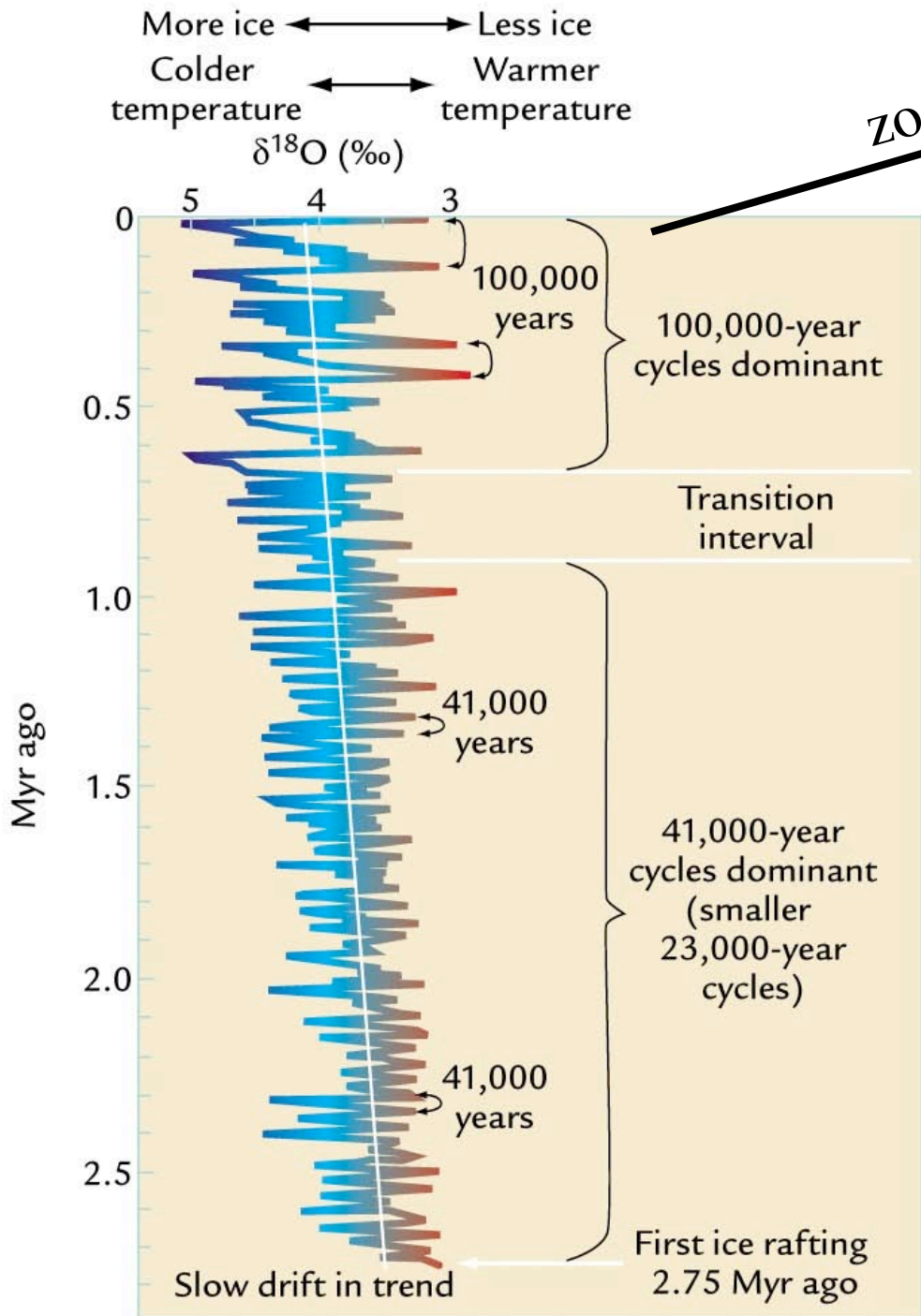
2) **IPCC 2001 Summary for Policymakers**

(also available at class website under “Articles”)

Monday: Guest lecture by Prof. Richard Gammon

Homework #4 - will give out on Monday.

Today: Astronomical theory of climate change: Ice ages and what it this historical record tells us about global warming.



Ocean sediment record and changes in oscillations.

Currently, we have dominant 100 k.y. cycles

Where do these cycles come from?

Three Changes in Orbital Parameters

1. Eccentricity
100,000 years

2. Obliquity (or Tilt)
41,000 years

3. Precession
26,000 years

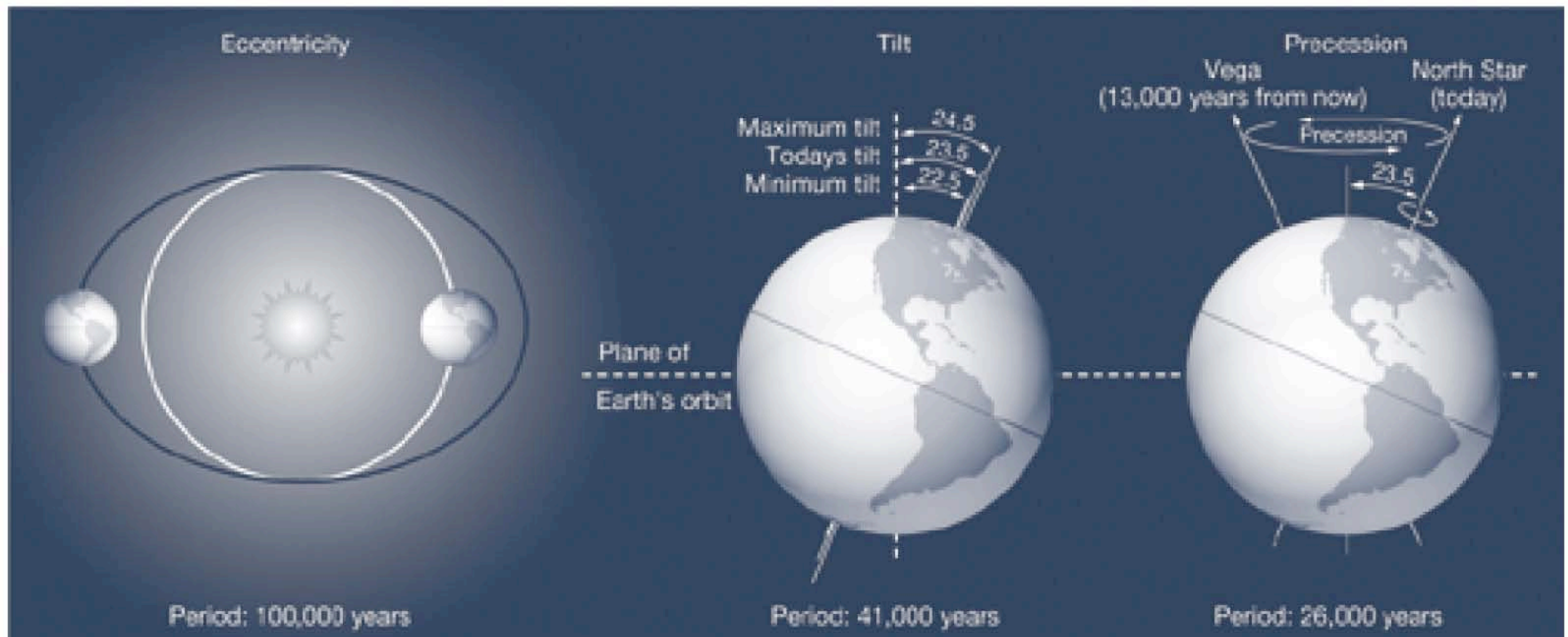
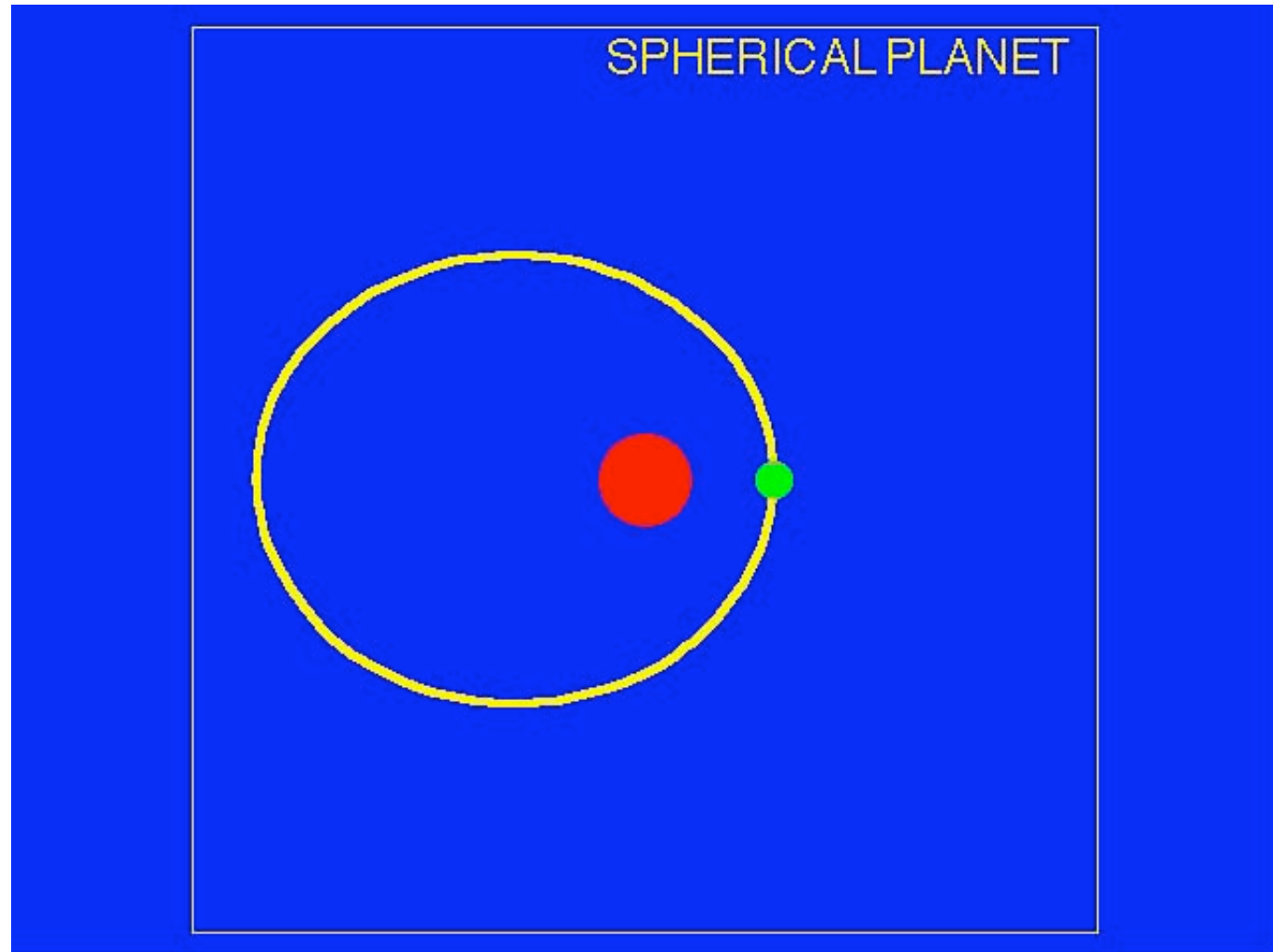


Fig 14-5

Milanokovitch cycles -- cycles in Earth's climate due to orbital variations (after Serbian mathematician, Milutin Milankovitch)

4. Precession of perihelion: 21 k.y. cycle



Orbital Theory: Small Trigger, Amplified by Feedback

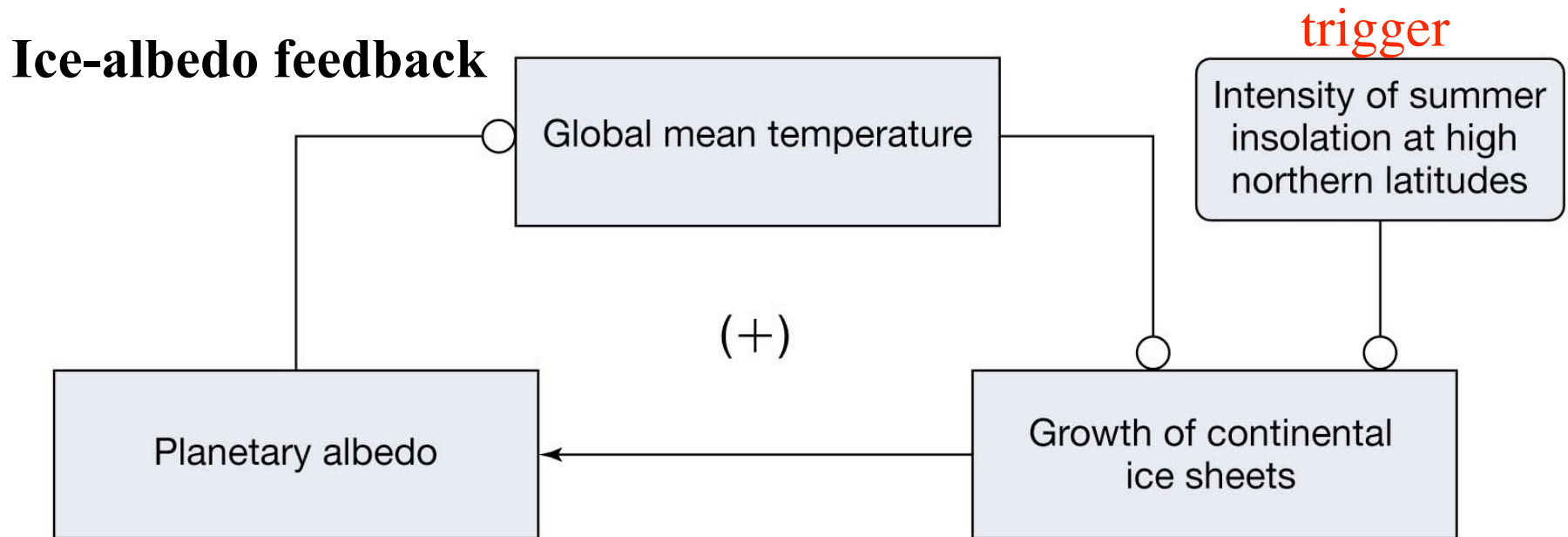


Fig 14-9

Trigger with feedback causes ice-sheets...

to grow and keep growing

or

to melt and keep melting

- Other feedbacks are needed to explain the magnitude of the changes.
- Importantly, greenhouse gases (e.g., CO₂ and CH₄) are involved.

Testing evidence against theory

1. Calculate insolation (i.e. solar flux) oscillations due to orbital changes
2. Compare oscillations in the ^{18}O data (temperature measure) with predicted oscillations.

Orbital Theory

**Solar Energy to
NH in June
(calculated for each parameter
then added together)**

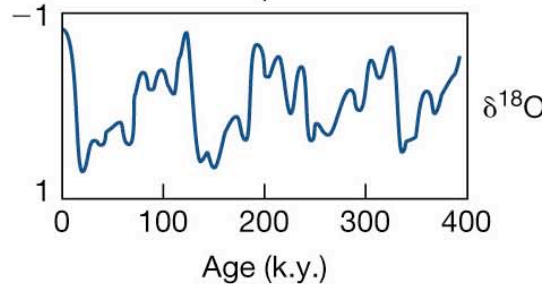
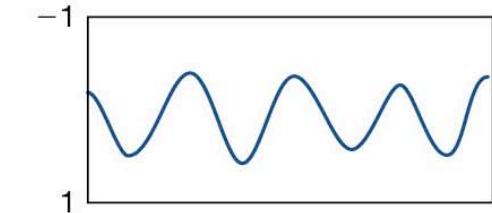
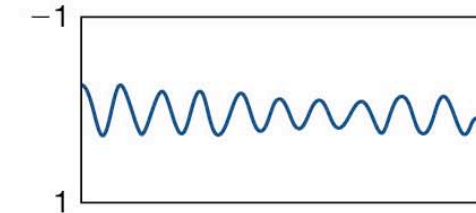
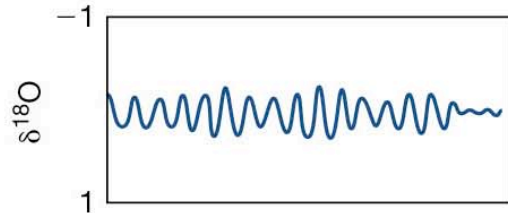
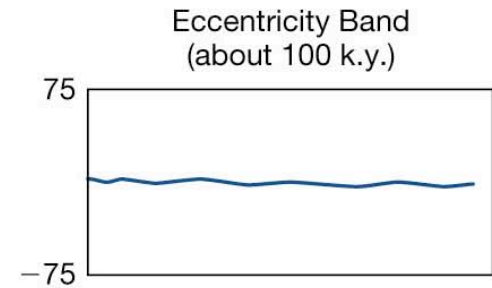
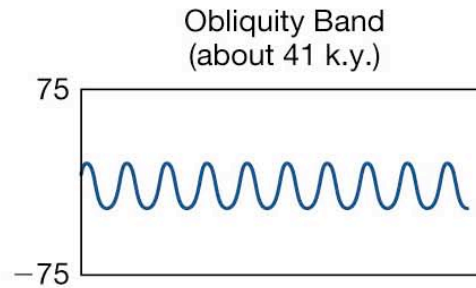
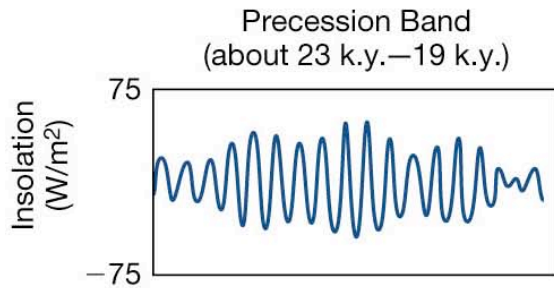
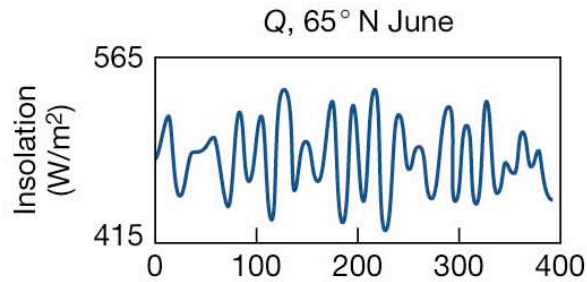


Fig. 14-8

**Ocean Sediment Record
of Glacial Ice Volume
(measured then subjected
to "frequency analysis")**

**Problem:
100 k.y. cycle
is anomalous**

Test of orbit theory: results

1) Climate response matches relative magnitude of the forcing at frequencies of **precessional** and **obliquity** frequencies.

2) Response matches **frequency but not amplitude of 100 k.y. eccentricity cycle** forcing.

=>A feedback must amplify the 100 k.y. response somehow.

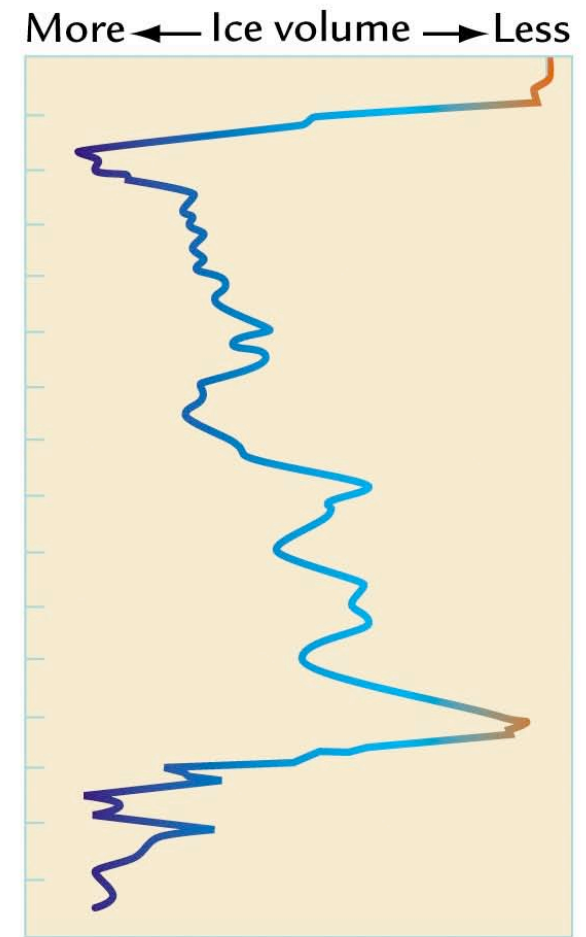
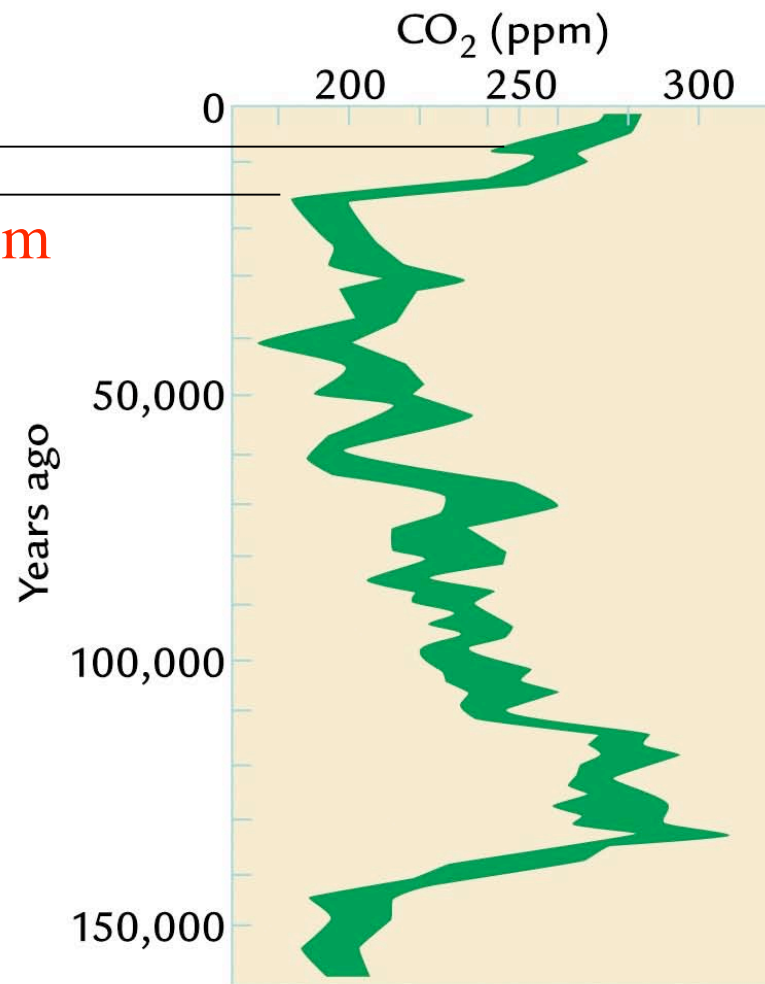
We also need to consider CO₂

To account for the 100 k.y. cycle, we need to also take into account the correlation with greenhouse gas fluctuations.

The feedback must involve CO₂ (and CH₄, which has same pattern)

rise in ~4 k.y.
from 190-→240 ppm
(deglaciation)

Qu.)
Today CO₂
is >370 ppm.
Can we enter
another ice age
in 100 k.y. time?



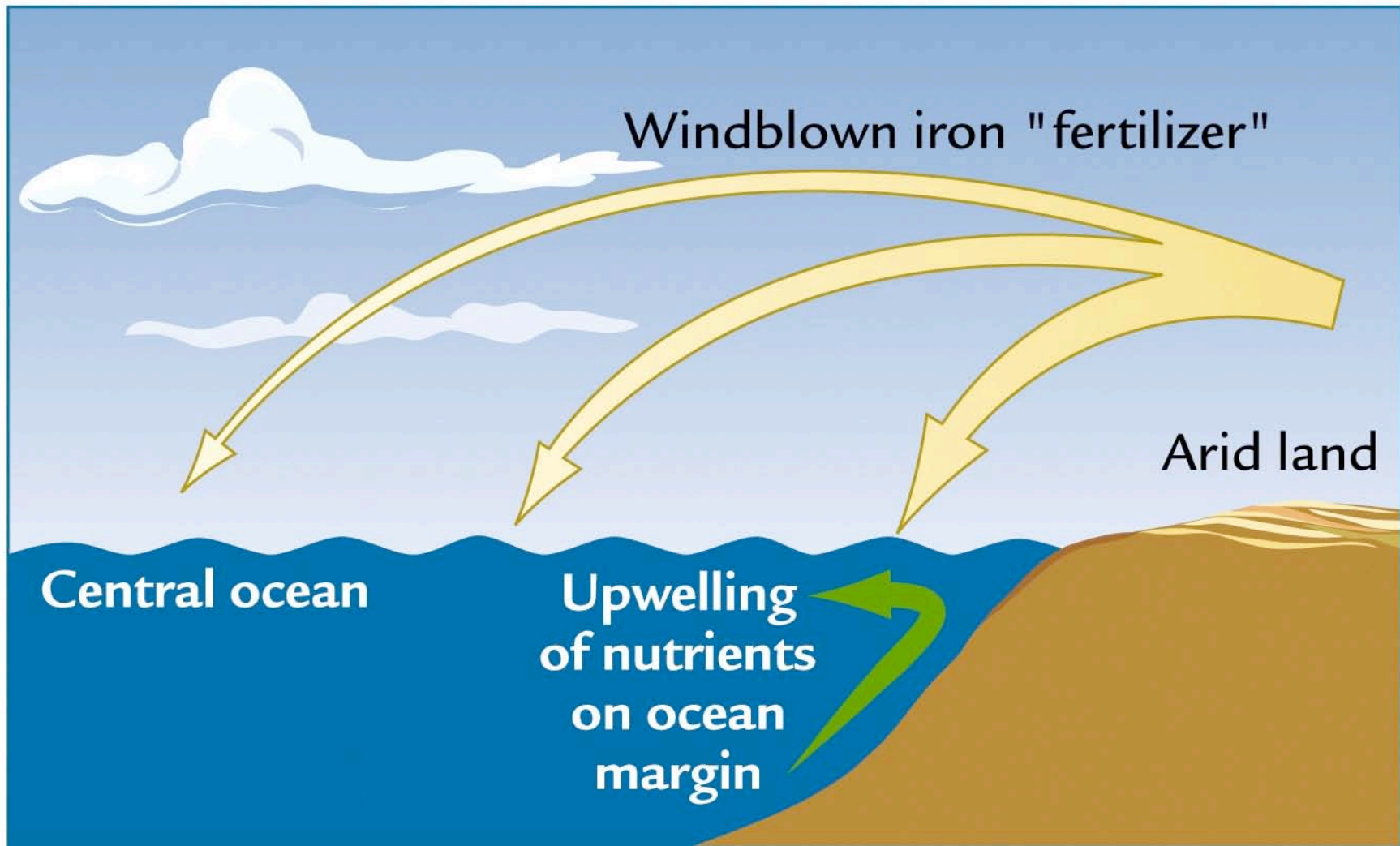
Positive feedbacks on CO₂?

Biology: Could biology extract more CO₂ in glacial times? Speculative ideas:

- *iron fertilization hypothesis*: iron is used in nitrogen fixation by cyanobacteria. Aridity causes more dust (which supplies iron) to be transported to the oceans. Enhances productivity and carbon removal.
- *coral reef hypothesis*: Release CO₂ via
$$\text{Ca}^{2+} + 2\text{HCO}_3^- = \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$$

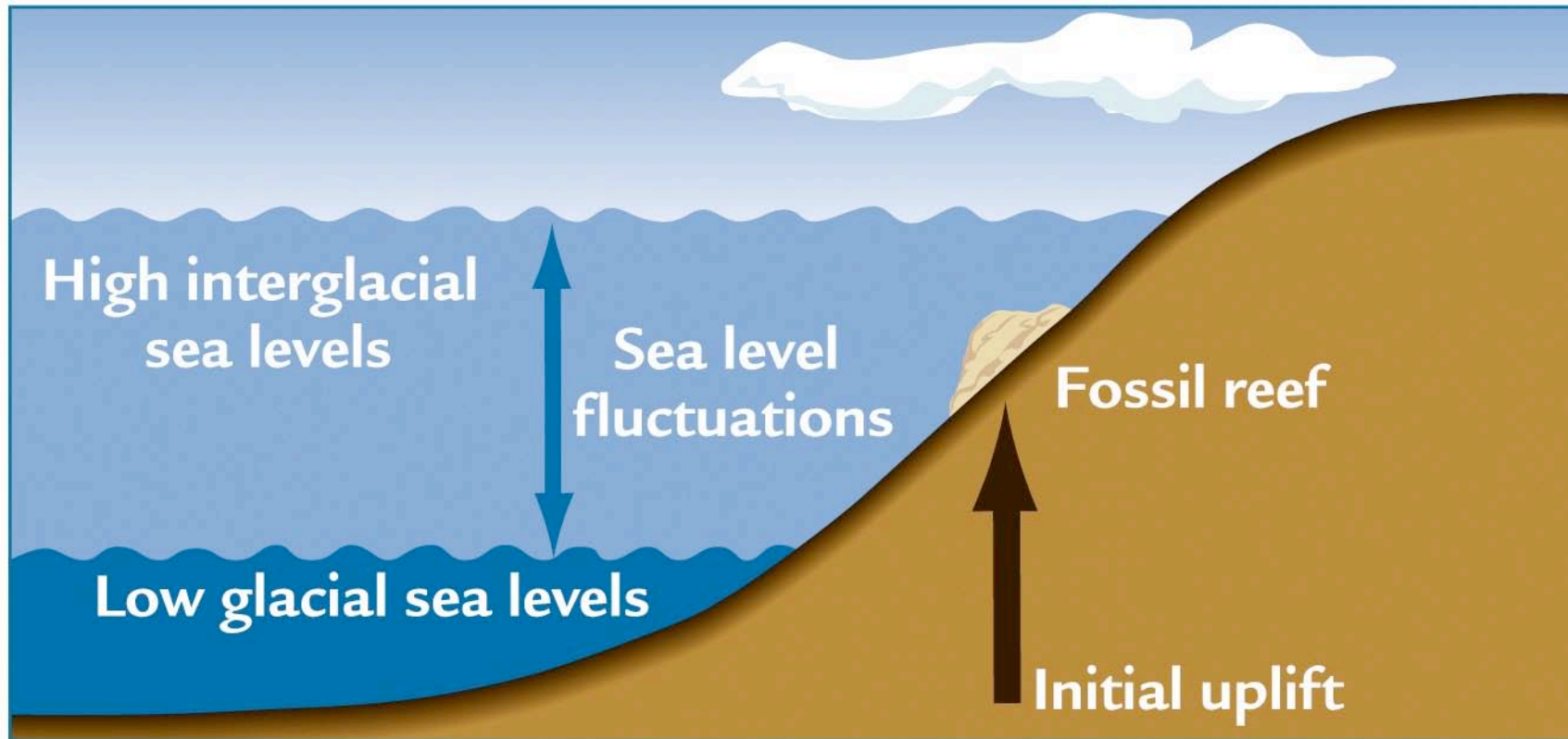
(imbalance of CO₂ is only ~10⁴ yrs because its removed by silicate weathering in the longer term carbononate-silicate cycle)
Ancient reefs exposed to drop in sea-level dissolve in chemical weathering (reverse of above reaction), which removes CO₂
- *algae aerosols and clouds*: algae release sulfur-based gases that can get transformed into cloud condensation nuclei, or CCN (cloud particles condense on these). Cold, less stratified water is better for algae growth because of more mixing of nutrients. Hence positive feedback, i.e. produce more CCN, more clouds, colder, produce more CCN, etc.

iron fertilization hypothesis



coral reef hypothesis

take up CO₂ via acid weathering
during glacial; reef building in interglacial and release of CO₂



B Subsequent changes

Glacial-Interglacial relevance for global warming

To predict global warming, we need to know:

- 1) **future forcings** (W/m^2) - greenhouse gas emission scenarios (future lifestyles, economics, Third World development, policy, etc.). We explore a full range of plausible possibilities.
- 2) **“climate sensitivity”** - what warming ($^{\circ}\text{C}$) per amount of forcing?

[(3) response time scales.]

For (2), we have computer models. But we may have doubts, e.g. clouds are poorly modeled and perhaps a warmer world has more clouds that counteracts greenhouse warming by high albedo.

BUT....we have the real world of the past.

Glacial-interglacial cycles tell us the Earth's climate sensitivity with all of the real Earth's feedbacks incorporated.

Climate sensitivity

$$\Delta T = \lambda \Delta F \quad (\text{Note the Kump textbook doesn't have this; but it's the basic equation in the global warming debate})$$

Δ : delta symbol refers to change in some quantity

ΔF : forcing (change in energy balance) $[\text{W}/\text{m}^2]$

ΔT : response (change in mean global surface temperature) $[\text{C}]$

λ : climate sensitivity (all feedbacks) $[\text{C per W}/\text{m}^2]$

CO_2 , CH_4 in ice cores and the well-mapped glacial icesheet extent allow us to deduce ΔF between last glacial maximum and today.

$\Delta F = \text{a } 6.5 \text{ W}/\text{m}^2 \text{ increase. Also } \Delta T \sim \text{a } 5^\circ\text{C increase.}$

Qu.) What is the value of λ ?

$$\lambda = \Delta T / \Delta F = 5 / 6.5 \approx 3/4 \text{ }^\circ\text{C per W}/\text{m}^2$$

Climate model climate sensitivity

IPCC: The world's General Circulation Models (GCMs) produce about a 3°C global warming with a doubling of CO₂

If you double CO₂:

the change in forcing (from radiation theory), $\Delta F = 4 \text{ W/m}^2$

Hence $\Delta T = \Delta F / \lambda = 3/4 \text{ }^\circ\text{C per W/m}^2$

i.e., they give the SAME result as the real Earth based on paleoclimate.

The models are producing the correct response even if it is for the wrong reasons (i.e. even if there is a somewhat incorrect feedback mix in the model it is giving us the correct overall result).

Bottom line:

The glacial record gives us empirical confidence in IPCC predictions.