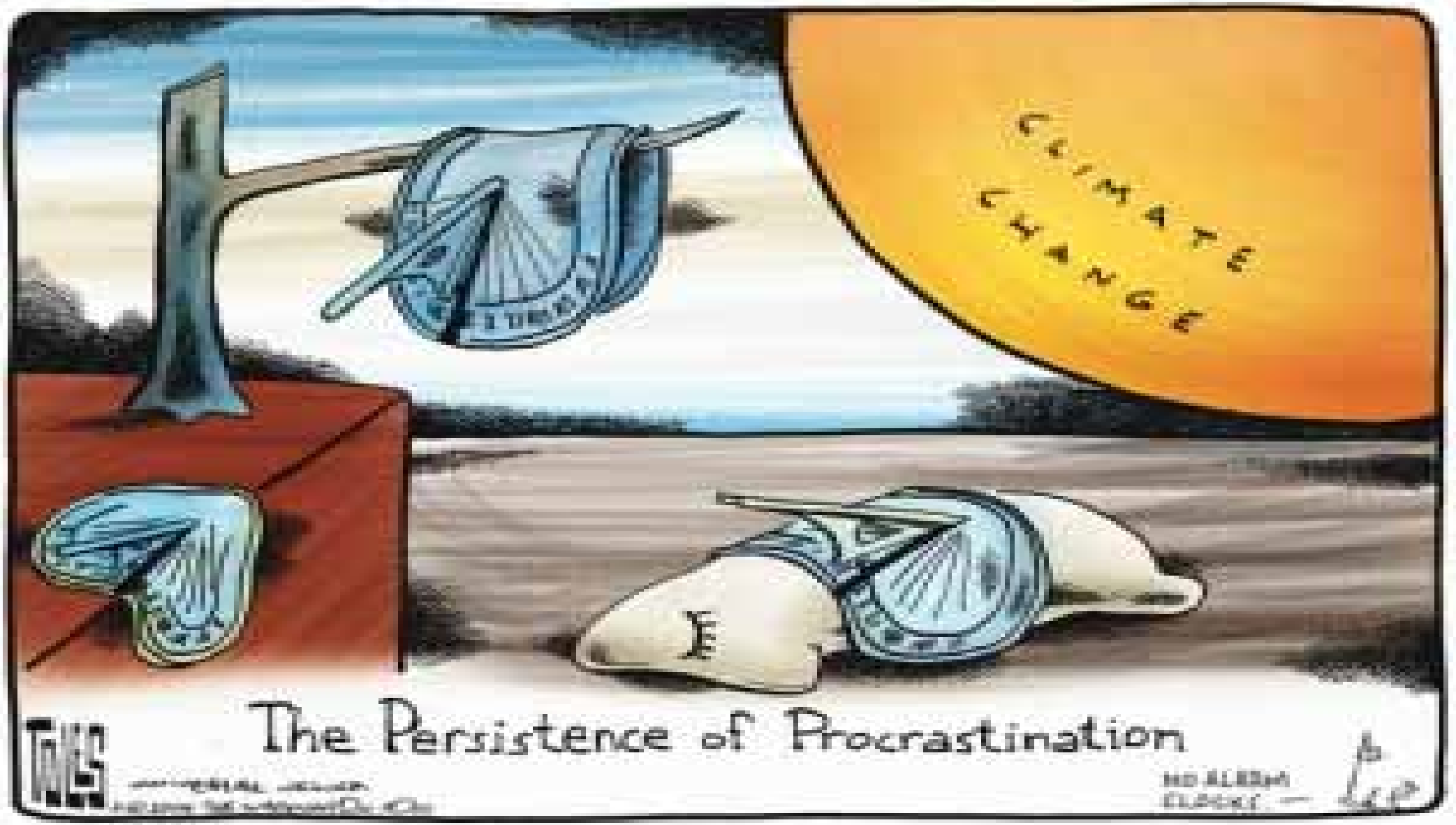
Geo-engineering Climate

Crazy Idea?

Or Last Hope?

(what do you call what we are doing now?)


CLIMATE CHANGE
The Persistence of Procrastination

The key questions

Is it possible to actively manage climate?

Is this a good idea?

Engineering Ideals

- Simple control process
- Linear response to the control
- Unique and known outcome from regulation
- Immediate response
- Reversible

Basic Points

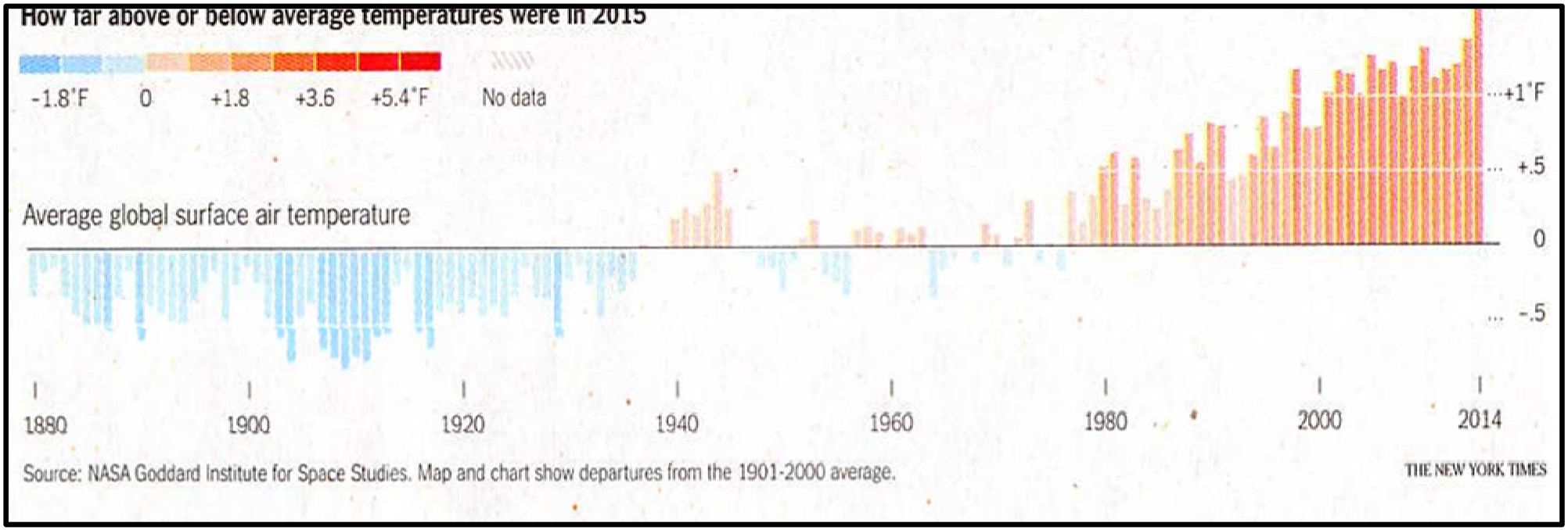
(1)Climate modification is possible via energy management or CO_2 management schemes.

(Nat. Acad. Sci. Reports, 2015)

(2) Whatever is done, there is no returning to climate of the pre-industrial world – there is a human fingerprint on the climate system

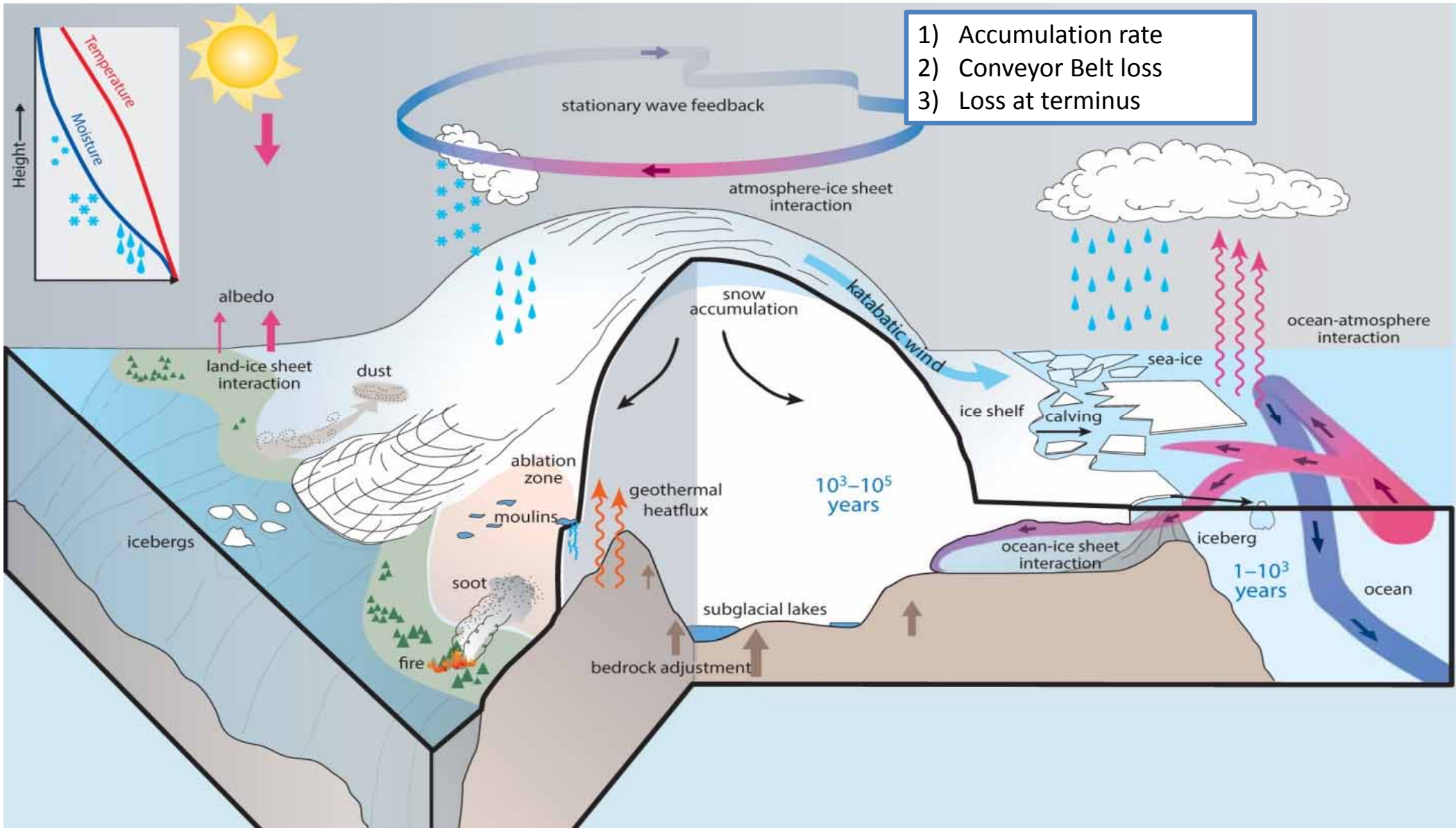
We can change climate, but it will be different from pre-industrial times, there is no going back

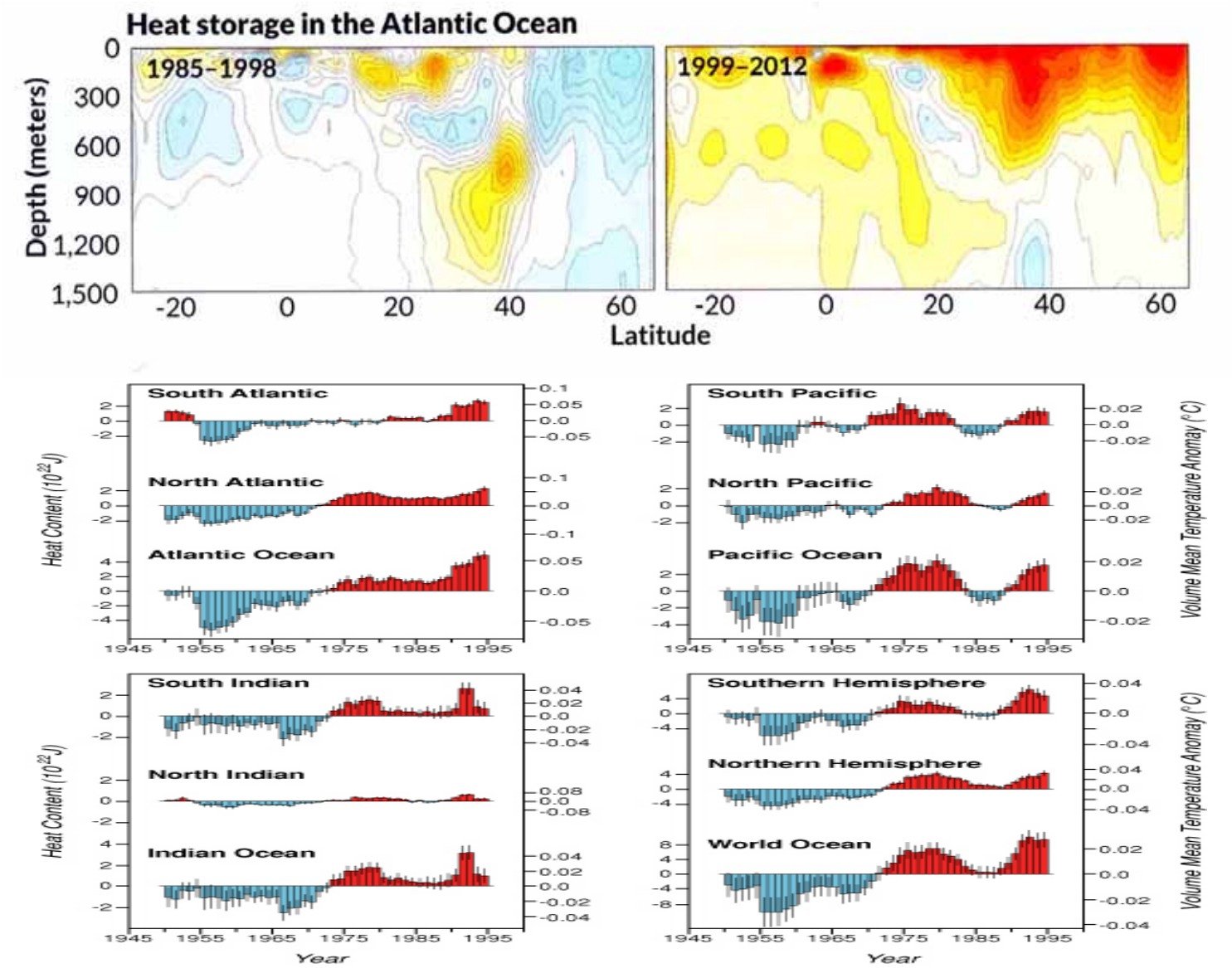
(paraphrase: NAS report on Geo-engineering)



Rapid Retreat Syndrome

- *Historical Contingency*
- *Ice Shelf – glacier terminus anchoring*
  once lost, hard to regain


1) Accumulation rate
2) Conveyor Belt loss
3) Loss at terminus
Temperature
Moisture
Height
stationary wave feedback
atmosphere-ice sheet interaction
albedo
land-ice sheet interaction
dust
snow accumulation
katabatic wind
ocean-atmosphere interaction
sea-ice
ice shelf
calving
ablation zone
moulins
geothermal heatflux
10^3–10^5 years
icebergs
soot
fire
ocean-ice sheet interaction
iceberg
1–10^3 years
ocean
subglacial lakes
bedrock adjustment


Heat storage in the Atlantic Ocean
1985–1998
1999–2012
Depth (meters)
0
300
600
900
1,200
1,500
-20
0
20
40
60
Latitude
South Atlantic
North Atlantic
Atlantic Ocean
South Pacific
North Pacific
Pacific Ocean
South Indian
North Indian
Indian Ocean
Southern Hemisphere
Northern Hemisphere
World Ocean
Heat Content (10^{22} J)
Volume Mean Temperature Anomay (°C)
1945
1955
1965
1975
1985
1995
Year

Anthropogenic CO_2

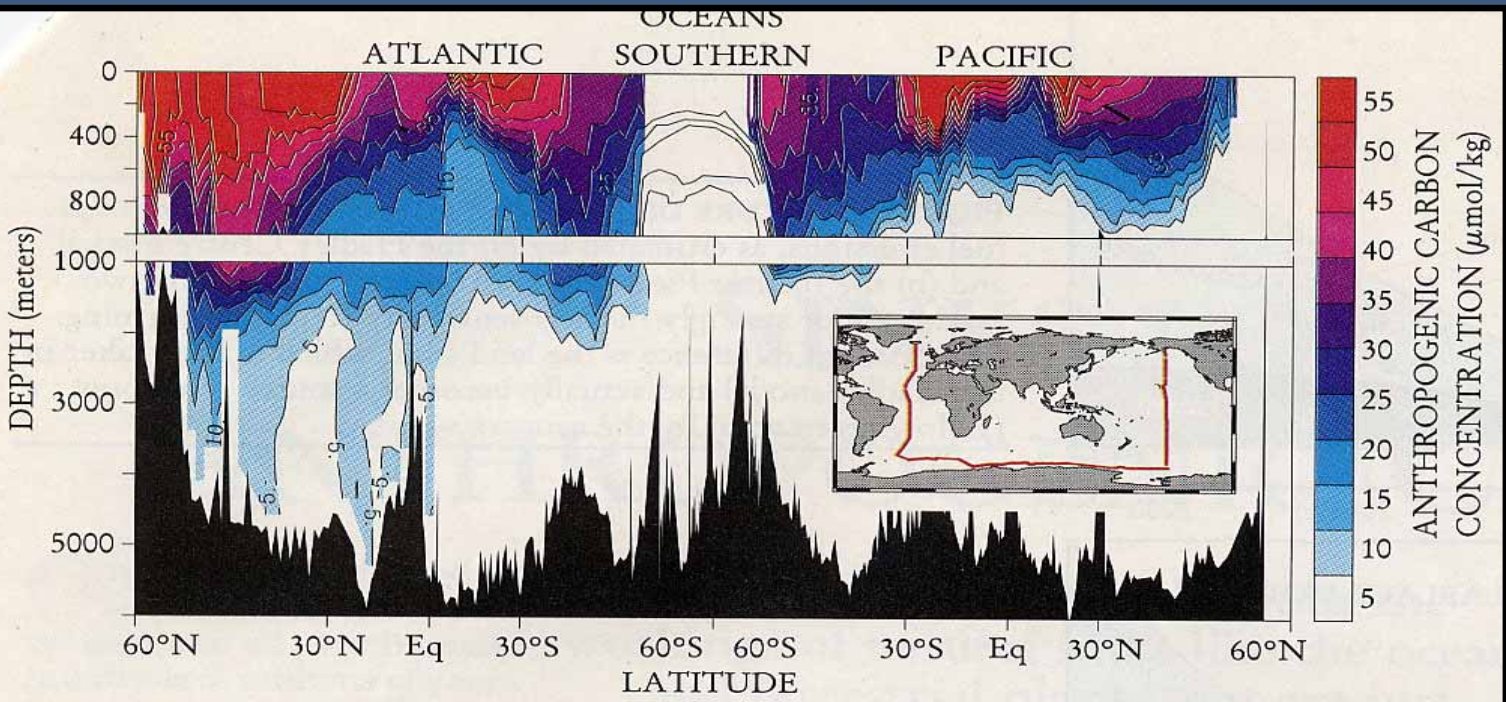


FIGURE 4. ANTHROPOGENIC CARBON CONCENTRATIONS IN THE OCEAN along the track shown as a red line in the inset.[18] The black area represents the depth of the ocean floor. The anthropogenic carbon dioxide concentrations are separated from the natural background by using a recently developed analysis[18] applied to high-precision measurements of dissolved inorganic carbon. Uncertainties in this separation technique are so large south of 60° S that they are shown there as contour lines only. Anthropogenic carbon has penetrated significantly below about 2000 meters of the water column only in the North Atlantic, where surface waters sink directly into the abyss.

Oppositely Turning Wheels: The Conveyor Belt

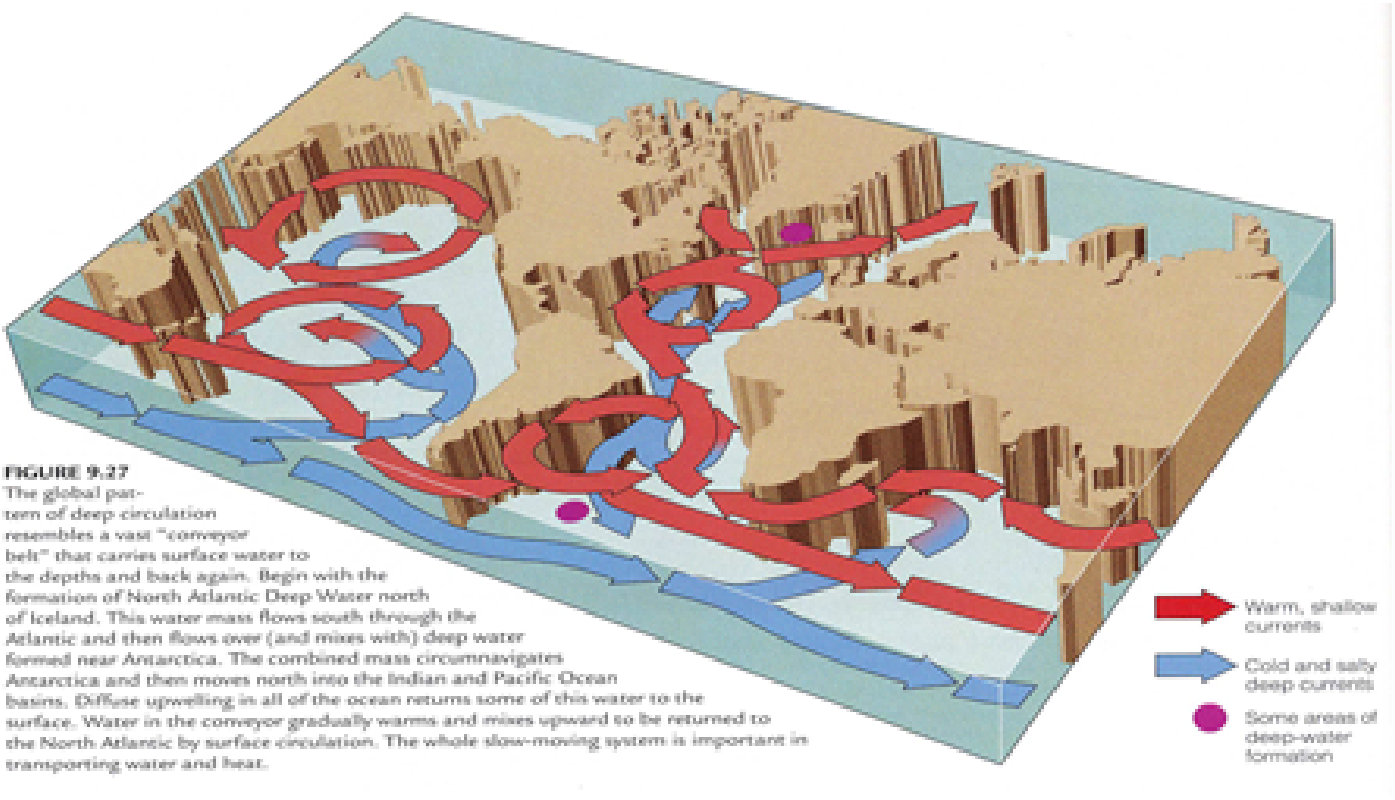
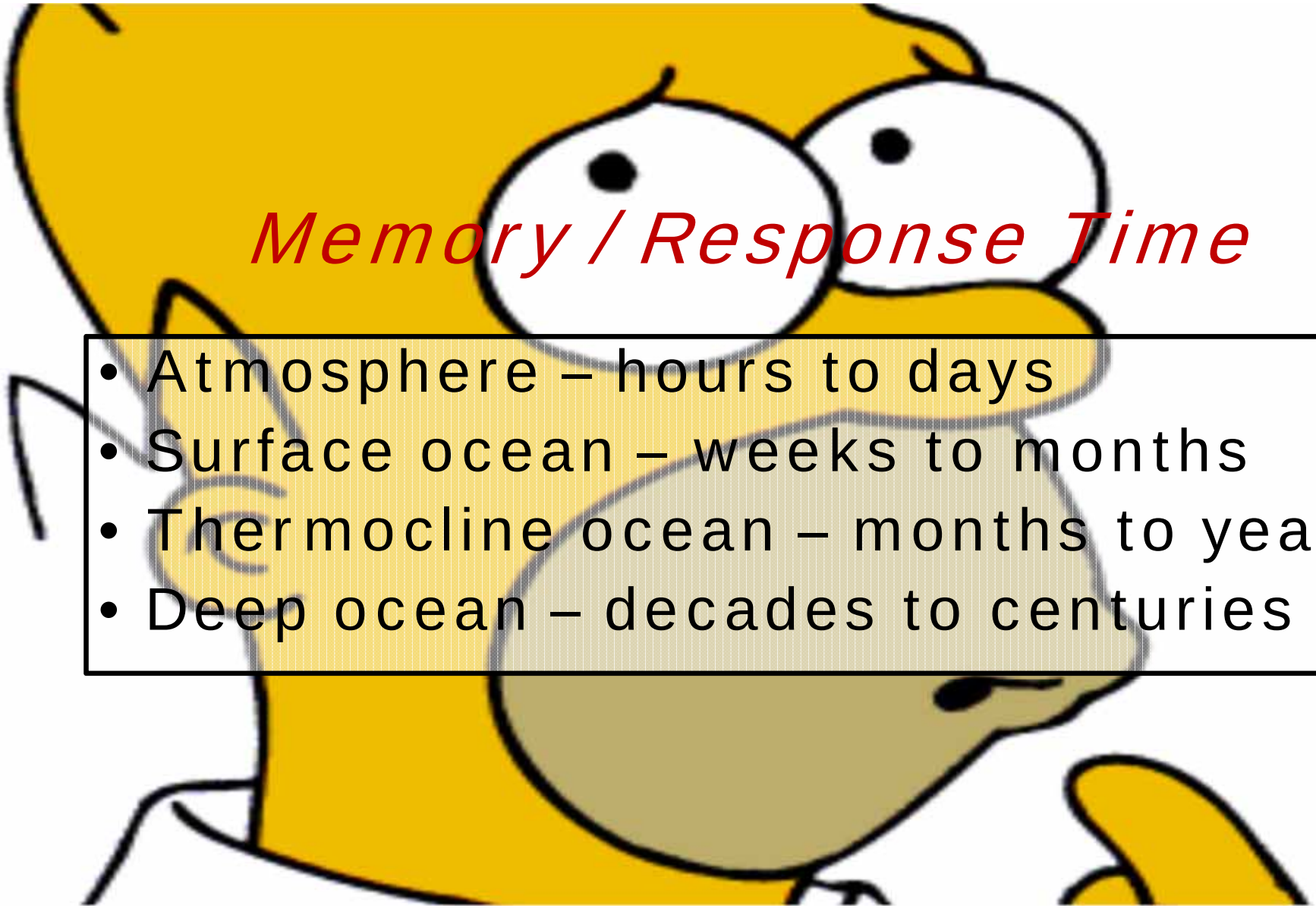


FIGURE 9.27
The global pattern of deep circulation resembles a vast "conveyor belt" that carries surface water to the depths and back again. Begin with the formation of North Atlantic Deep Water north of Iceland. This water mass flows south through the Atlantic and then flows over (and mixes with) deep water formed near Antarctica. The combined mass circumnavigates Antarctica and then moves north into the Indian and Pacific Ocean basins. Diffuse upwelling in all of the ocean returns some of this water to the surface. Water in the conveyor gradually warms and mixes upward to be returned to the North Atlantic by surface circulation. The whole slow-moving system is important in transporting water and heat.



Memory / Response Time

- Atmosphere – hours to days
- Surface ocean – weeks to months
- Thermocline ocean – months to years
- Deep ocean – decades to centuries

Engineering?

- NAS reports 2015:

  carbon sequestration, sunshine regulation
- Carbon trapping schemes

  from natural → trees

  to human orchestrated chemical
- Key is permanent reservoir storage (grow the 'savings account') elsewhere than in atmosphere

Carbon Dioxide:

The oceans store most of it

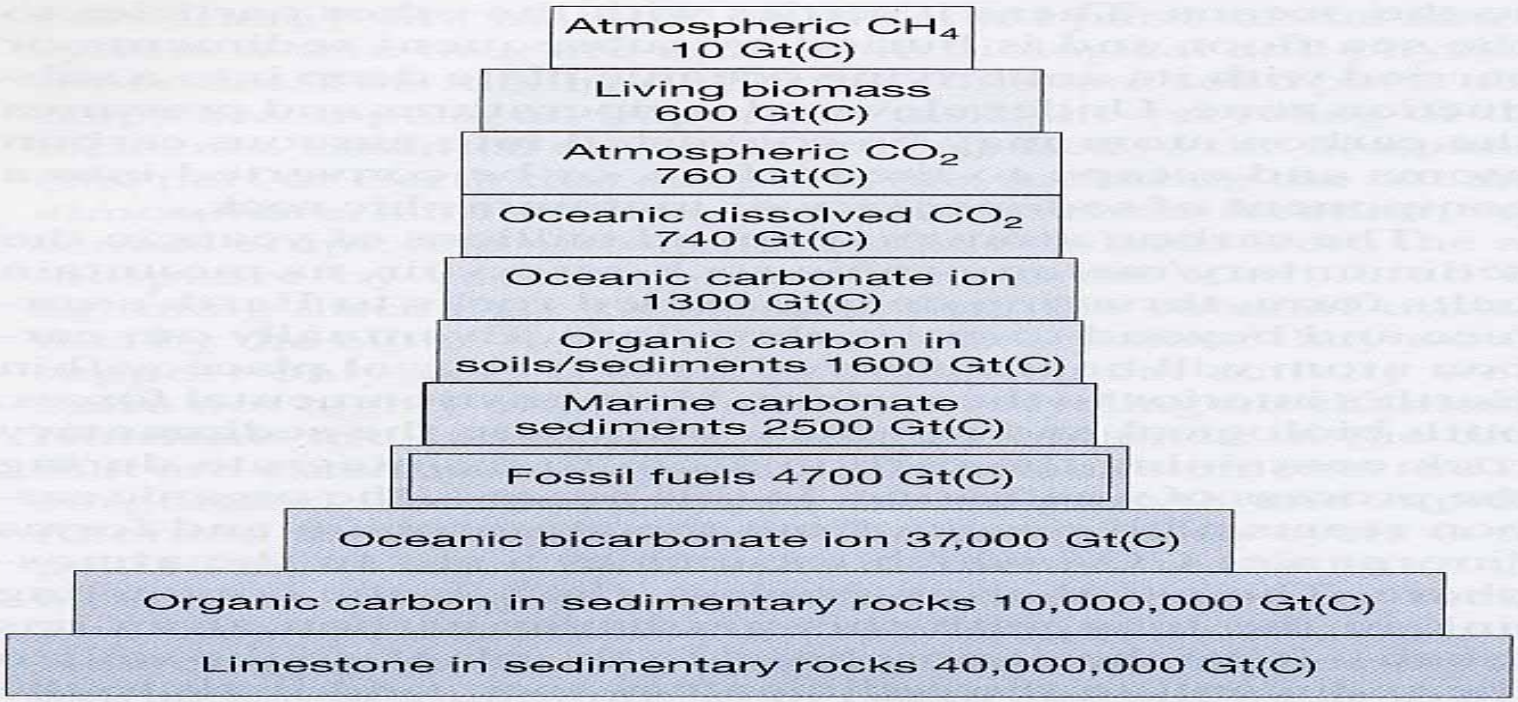


FIGURE 8-3
Reservoirs of carbon at or near Earth's surface.

Rock + Water + CO_2

Capture with natural substances

Water + carbon dioxide

$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$

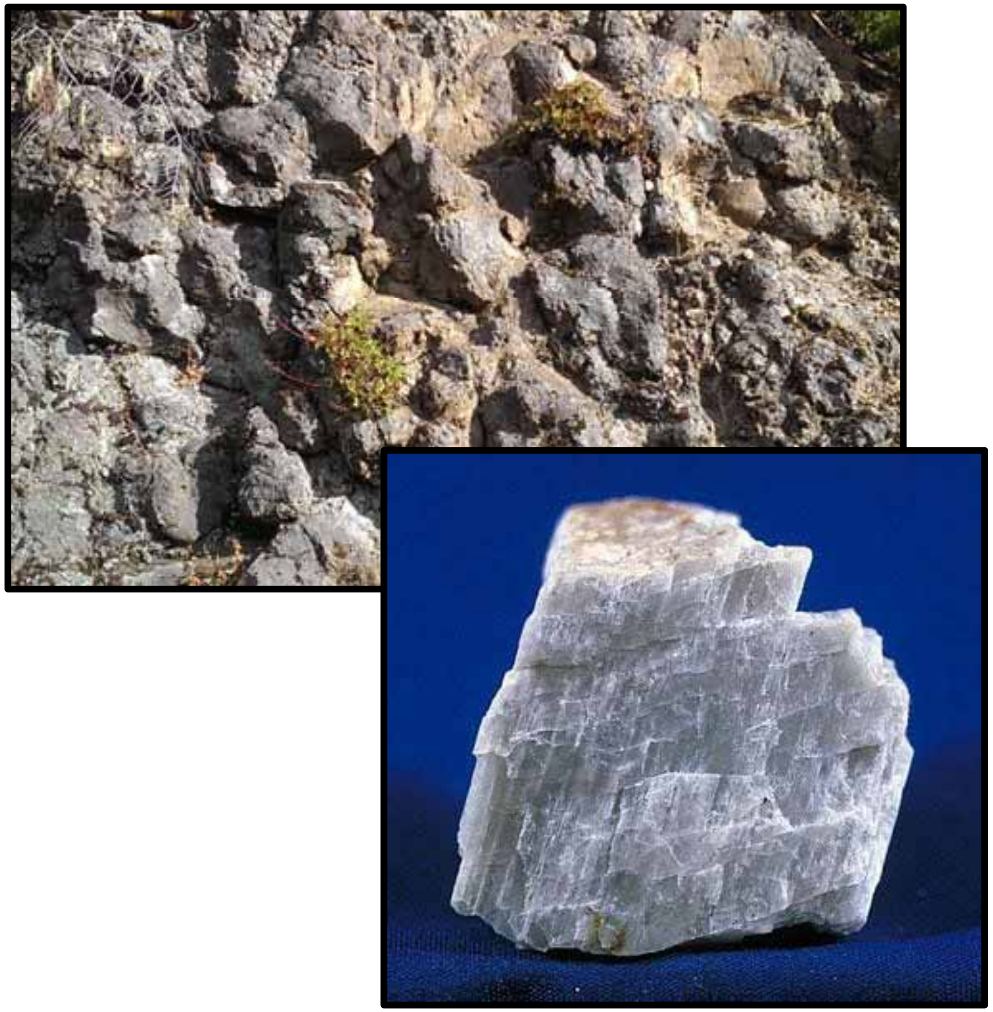
Add a base (NaOH) & it keeps going

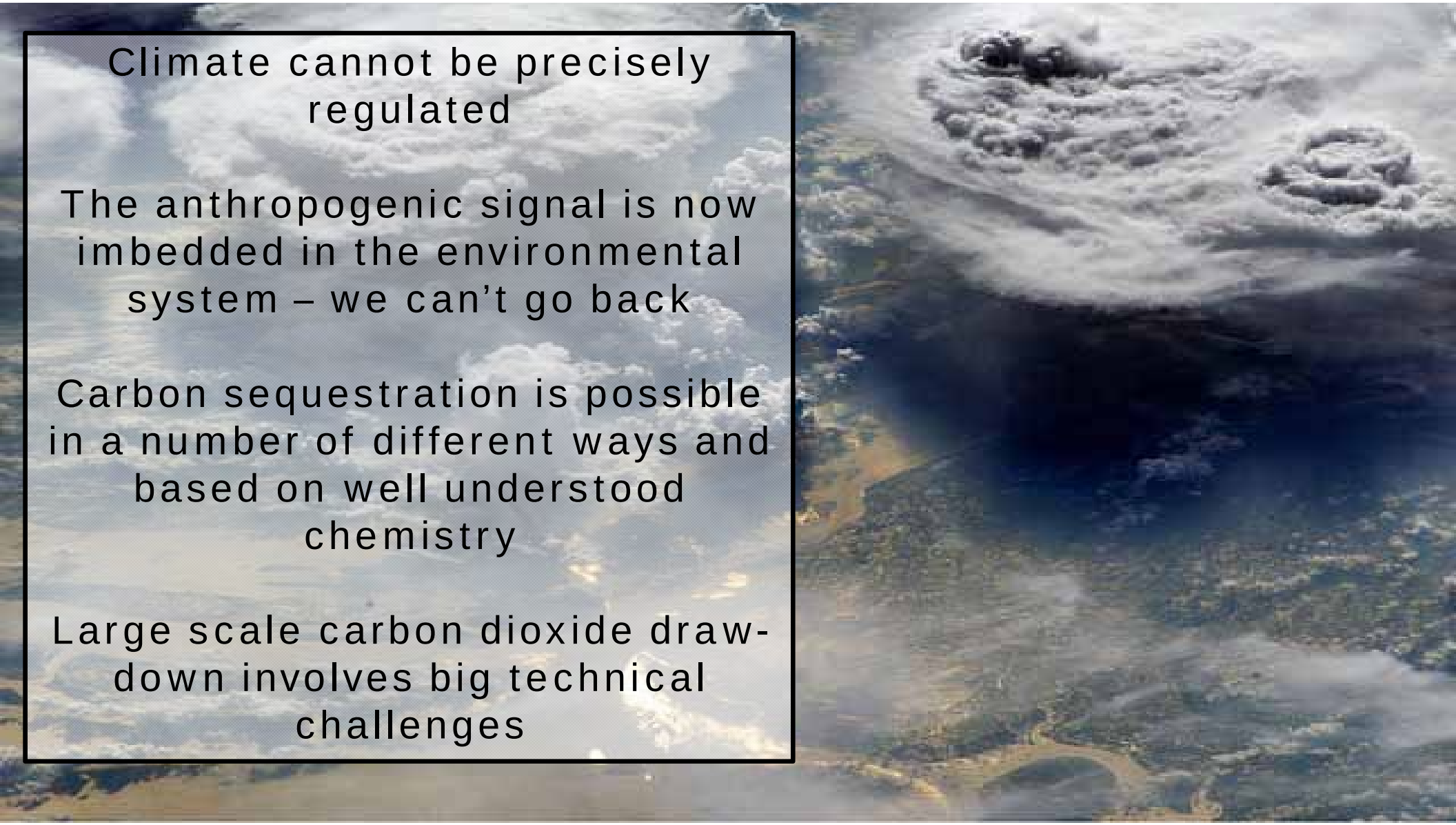
Add some basalt rock

Feldspar + H_2O + H^+ →
clay mineral + free Ca^{2+}

$Ca^{2+} + HCO_3 \rightarrow$ Calcite + H

To reduce atmospheric CO_2 by 45% (return to pre-industrial conc.)
Convert to HCO_3^-
Inject in ocean: raise oceanic bicarbonate by < 1%





Climate cannot be precisely regulated

The anthropogenic signal is now imbedded in the environmental system – we can't go back

Carbon sequestration is possible in a number of different ways and based on well understood chemistry

Large scale carbon dioxide draw-down involves big technical challenges

Resources to Learn More

Fixing Climate: What Past Climate Changes Reveal About the Current Threat--and How to Counter It
Wallace S. Broecker and Robert Kunzig
Hill and Wang, Farrar, Straus and Giroux
03/31/2009
ISBN: 9780809045020
ISBN10:0809045028

Matter, J., et al., 2016, Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emission, Science, v. 352, p. 1312-1314.

History of the Greenland Ice Sheet: paleoclimatic insights

Quaternary Science Reviews

Volume 29, Issues 15–16, July 2010, Pages 1728–1756

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Abstract:

Paleoclimatic records show that the Greenland Ice Sheet consistently has lost mass in response to warming, and grown in response to cooling.

Moreover, snowfall has increased when the climate warmed, but the ice sheet lost mass nonetheless; increased accumulation in the ice sheet's center has not been sufficient to counteract increased melting and flow near the edges.

The evidence suggests nearly total ice-sheet loss may result from warming of more than a few degrees above mean 20th century values, but this threshold is poorly defined (perhaps as little as 2 °C or more than 7 °C)