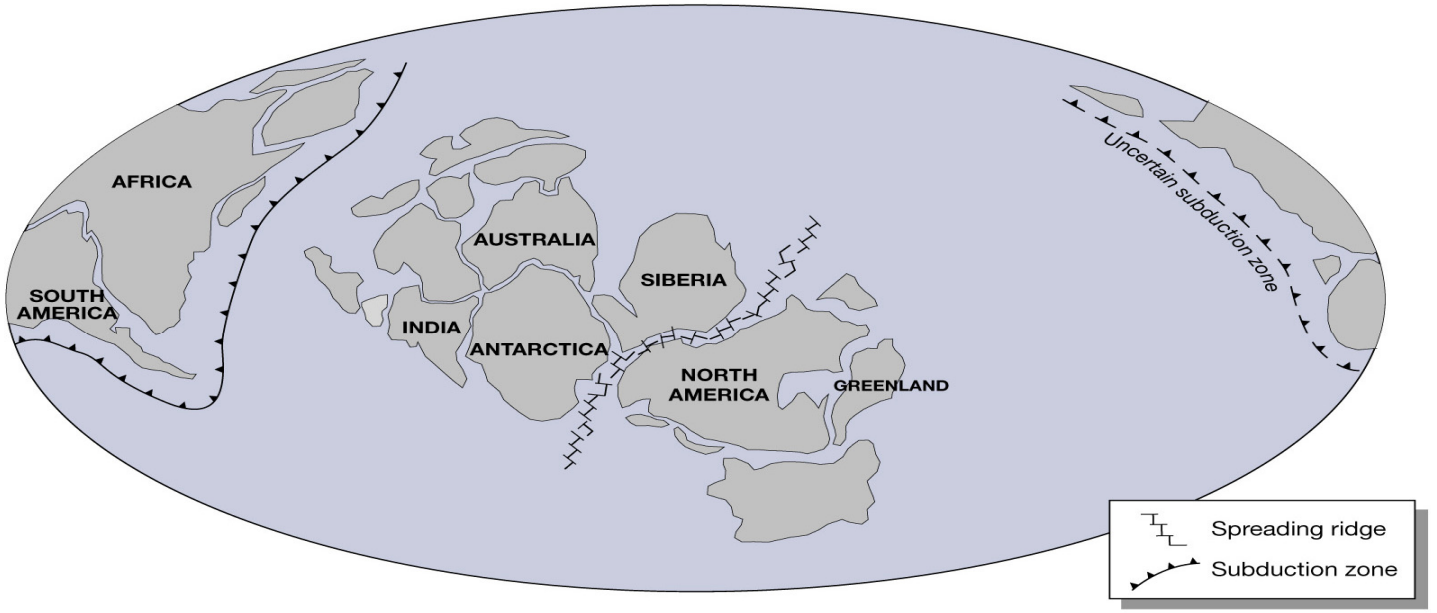
Cryosphere components

- Continental ice sheets: ice shelves, mountain glaciers
- sea ice: lake and river ice too
- permafrost (frozen ground)
- Dynamic system
  - seasonal changes
  - moving glaciers
  - climatic changes

Climate Regulation

- Sun produced less radiation in the past, yet the oceans weren't frozen
- Best hypothesis: greater GH effect
  - impact outgassing CO_2
  - lessened silicate weathering due to lower temp and less land area
  - increased CH_4 produced by microorganisms in low O_2 environments
- Anti-GH effect: Haze from CH_4 absorbs red and near infrared light, cooling earth

Long Term Climate Record



- short intense Glacial and longer inter-glacial periods
- "Snowball Earth" (0.6-0.7 byr ago):

Evidence from magnetic field lines in rocks in Australia are in an orientation suggesting that the rocks were formed at the equator. These rocks were mixed with glacial deposits

- BIFs,Cap Carbonates

Geological evidence

Glaciation Evidence:

- glacial debris (tillites)
- Striations
- Dropstones

Geological indicators

- Oxygen isotopes: the colder the water, the more 18O can be incorporated into minerals
- Fossils

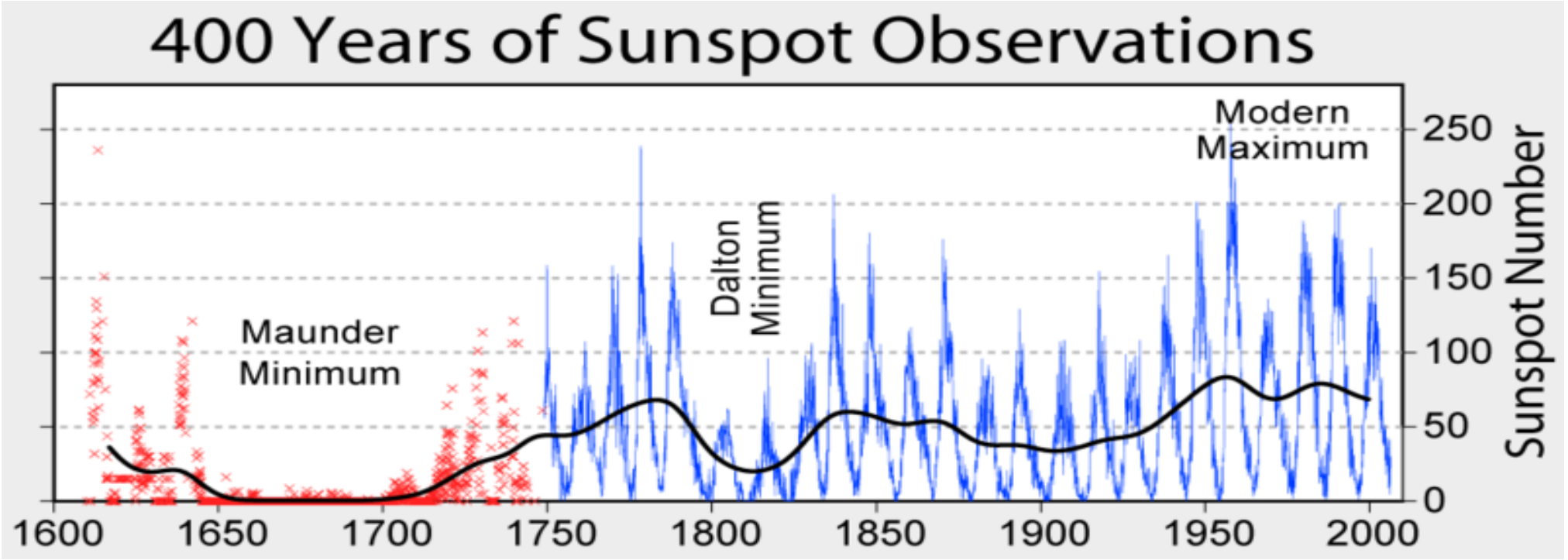
Younger Dryas

- warming begins after last glacial max (21,000 yrs ago)
- North American ice sheet melt water flows into North Atlantic
- Fresh water influx prevents formation of NADW → slowing/stopping of THC resulting in significant cooling.

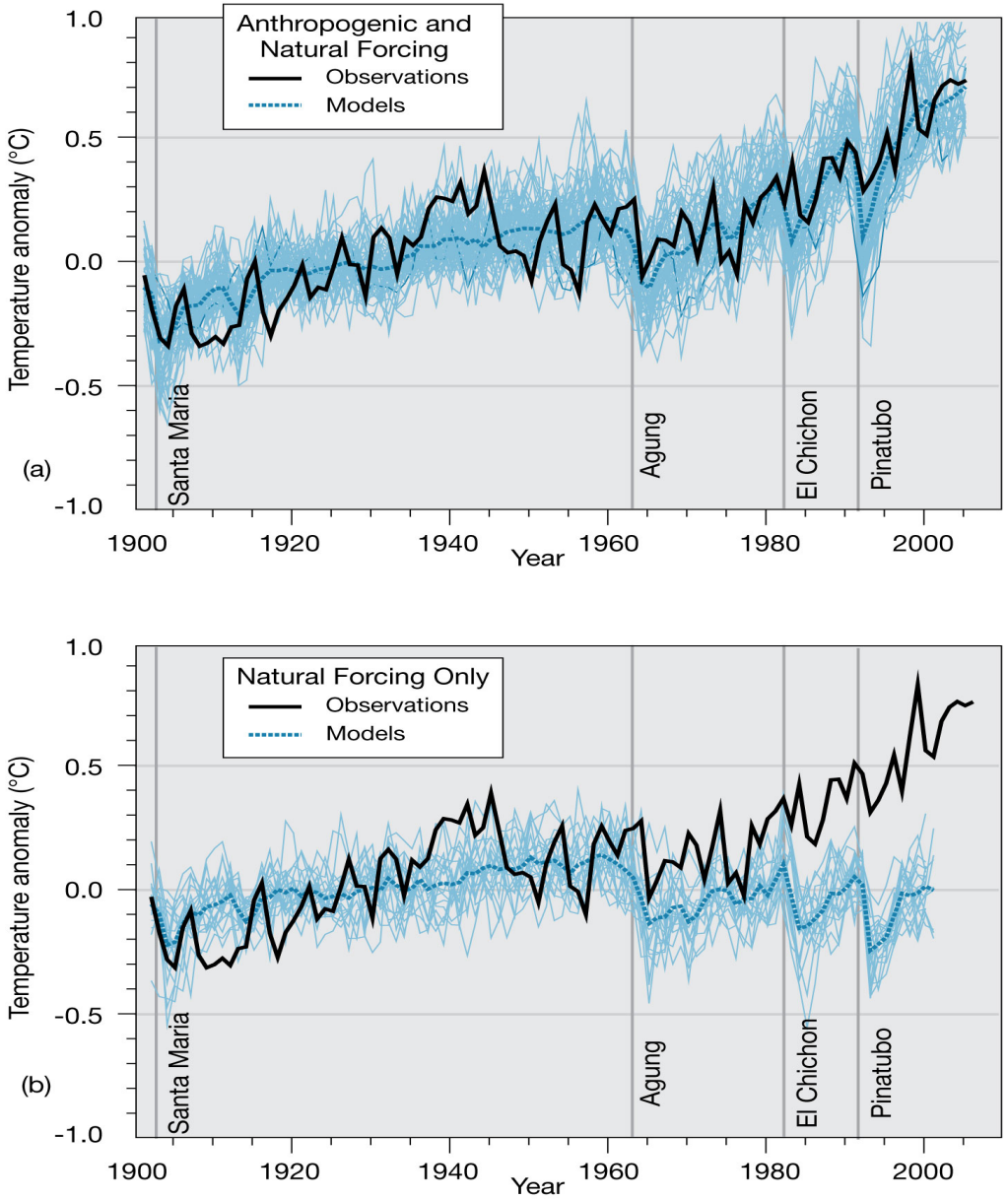
- Mid- Holocene
- warming until the Holocene climatic optimum (slightly warmer than today)
- Medieval Warm period (max temp. ~1100 AD)
- Little Ice Age
- evidence of cooling all over the world, but not necessarily at the same time
- Possible cooling to do sulfate aerosols from volcanoes
- for reference Pinatubo (1991) caused temp. decrease 0.5 degrees C 1.5 years later.

Solar forcing

- 11 year cycle
- sunspot minimum during little ice age
- Solar output only changes by ~0.1%



Anthropogenic Effects



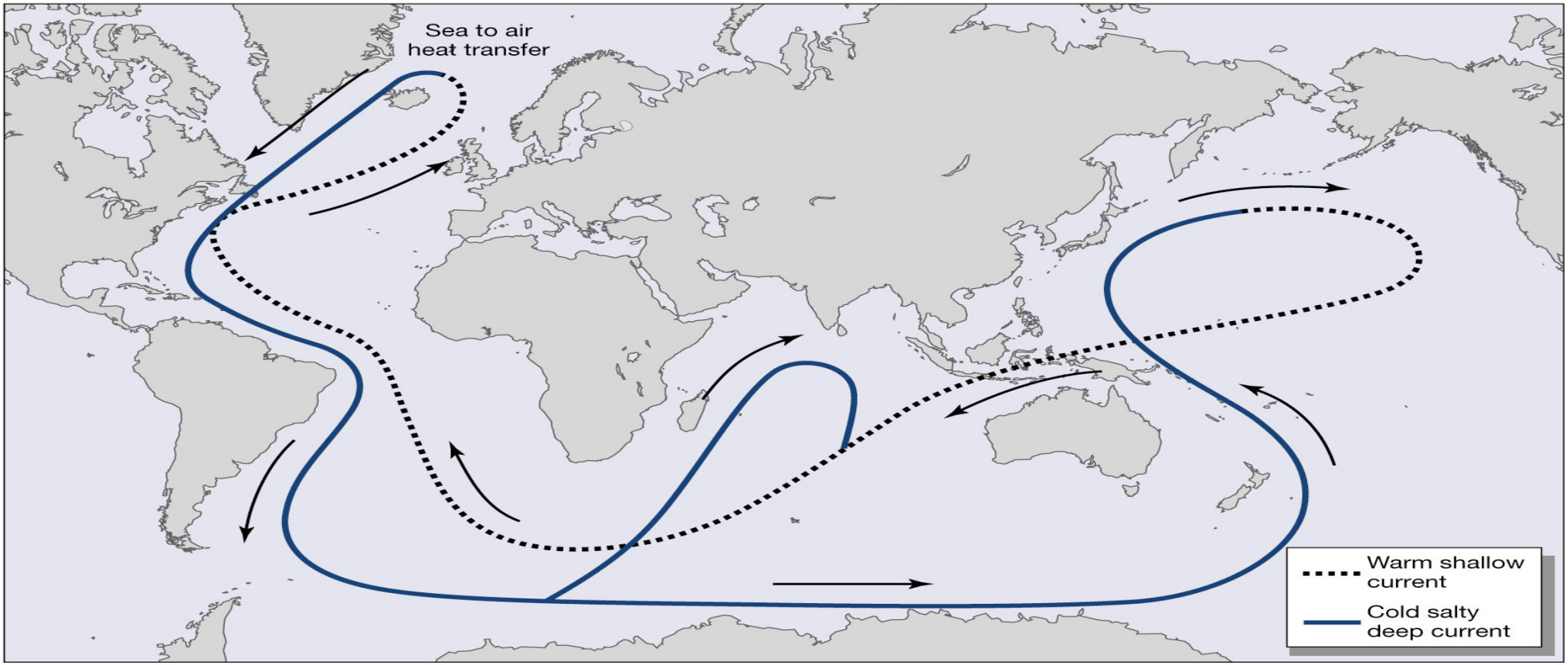
- modeling that includes natural forcing only suggests anthropogenic forcing has played a significant role in the last few decades
- fossil fuel burning has greatly exceeded fossil fuel formation

Carbon Reabsorption

- Reforestation: fastest but CO_2 is released when plants decay
- CO_2 fertilization
- Dissolution in Oceans: fast but not permanent
- Dissolution of Seafloor Carbonates: slow
- Silicate weathering: slowest but most permanent

Impacts

- Circulation change
  - Will THC slow or shut down as in Younger



- Sea level rise
  - melting of land ice
    - Greenland: 6-7m (more likely)
    - Antarctica: 60-70m (less likely)
  - thermal expansion of oceans
  - changes in ocean basins (glacial rebound)
- Ecosystem Effects
  - some plants thrive in high CO_2 environments (depends on species and nutrients)
  - disease carrying insects may spread to different regions
  - fisheries will change due to changed circulation
- Human impacts
  - aside from the above...
  - more drought/flood → food/water shortages

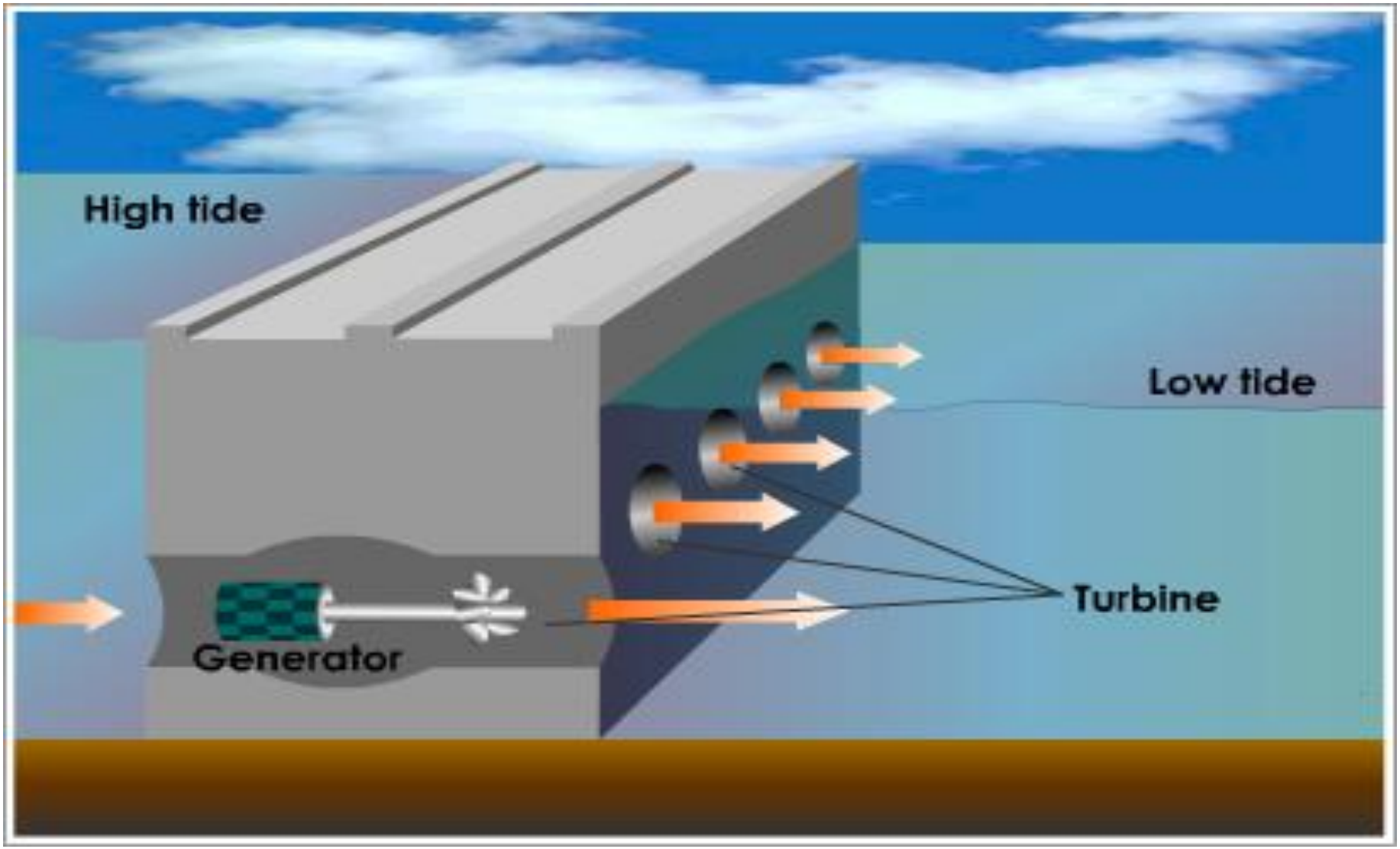
Adaptation to Climate Change

- Sea Level Rise
  - Building flood proof structures
  - moving inland
- Water shortages
  - decrease demand
  - collect rain water
  - look for ground water
  - desalination

Slowing Global Warming

- May help, but inevitable
- Kyoto Protocol: reduce emissions 5%v below 1990 levels
- Conservation (difficult with population growth)
- Alternative Energy:
  - Nuclear fission (France)
  - Nuclear fusion (still experimental)
  - Wind (NREL)
  - Geothermal

- Tidal
- Biomass Fuel
- Solar



Other Possible Solutions

- Carbon Capture
  - promising, but unknown effects of acidification
- Geoengineering
  - Inject sulfate aerosols into the atmosphere to cool the planet
  - Problems:
    - relatively short residence time
    - Expensive, and world wide