Preindustrial Anthropogenic Affects on Climate

Climate of the Holocene
G610
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11/27/2012
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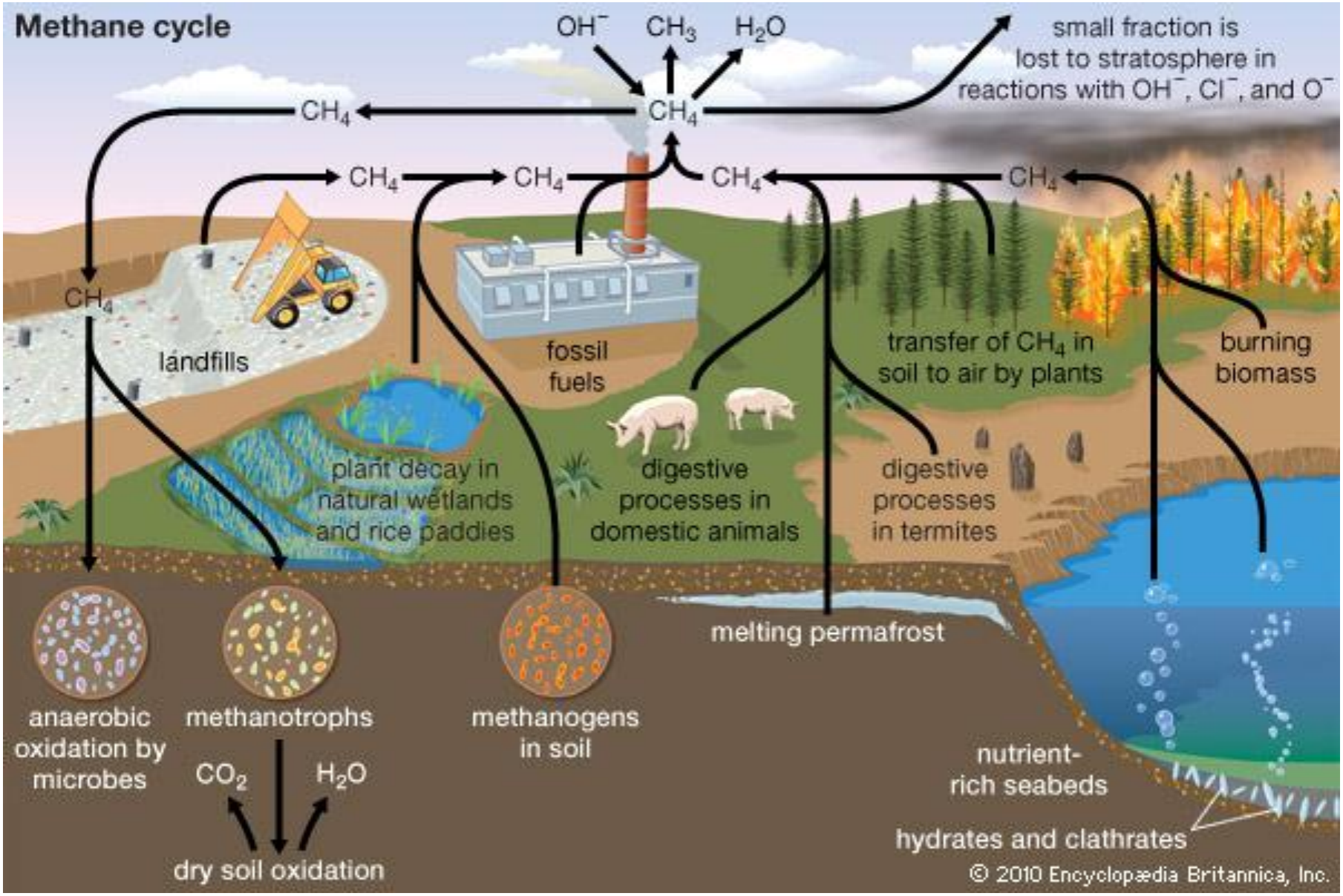
Methane Background

- Facts
  - CH_4
  - 2nd most important GHG
    - Accounts for 20% atm forcing
  - Atmospheric residence time: 9-15yrs
  - 20x more effective GHG than CO_2
- Emission Sources
  - Biogenic: wetlands, rice paddies, ruminants
  - Geologic: mud volcanoes, micro seepage
  - Pyrogenic: fires, biofuel, coal burning


Methane cycle
OH^-
CH_3
H_2O
small fraction is lost to stratosphere in reactions with OH^-, Cl^-, and O^-
CH_4
landfills
fossil fuels
transfer of CH_4 in soil to air by plants
burning biomass
plant decay in natural wetlands and rice paddies
digestive processes in domestic animals
digestive processes in termites
melting permafrost
anaerobic oxidation by microbes
methanotrophs
methanogens in soil
CO_2
H_2O
dry soil oxidation
nutrient-rich seabeds
hydrates and clathrates
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Methane Isotope Fracination

- Source can be inferred from carbon isotope ratio
  - ^{12}C preferentially taken up by biogenic sources
- Standard: Pee Dee Belmnite (PDB)
  - Cretaceous marine fossil
  - Anomalously high $^{13}C/^{12}C$ ratio
- $^{13}C/^{12}C$
  - Biogenic: $\delta\ ^{13}C = -60 \pm 5$ ‰
  - Geologic: $\delta\ ^{13}C = -38 \pm 7$ ‰
  - Pyrogenic: $\delta\ ^{13}C = -22 \pm 3$ ‰

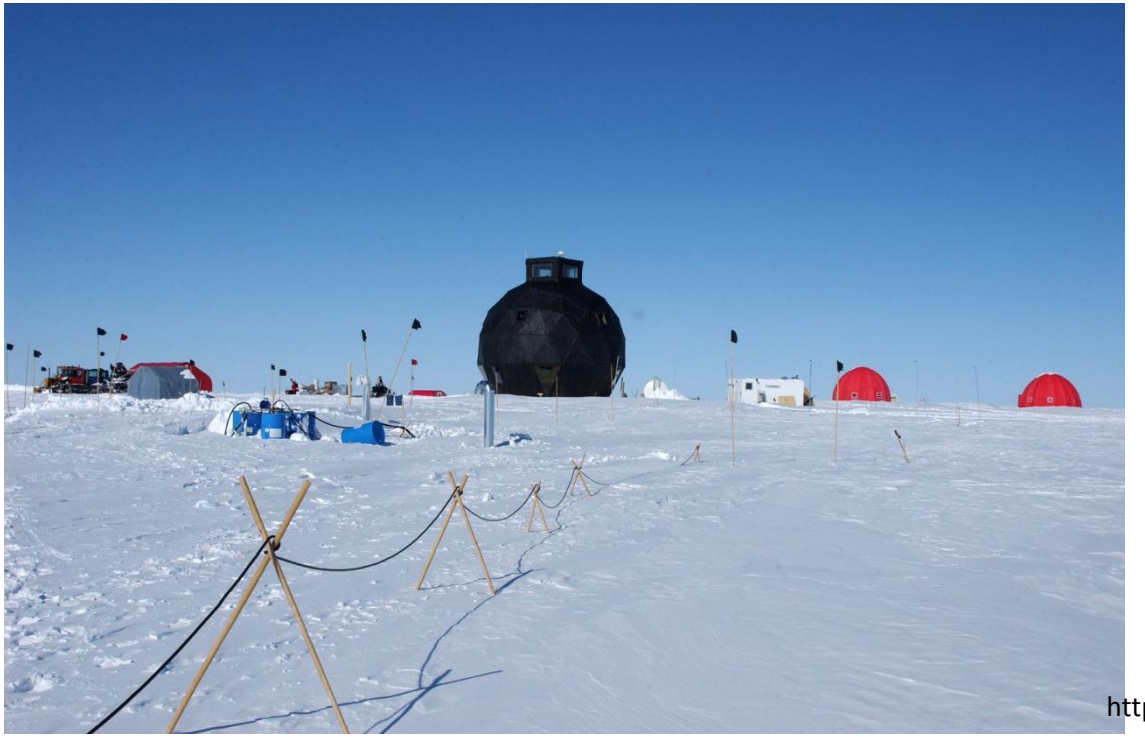
http://en.wikipedia.org/wiki/File:Passaloteuthis_bisulcata.JPG

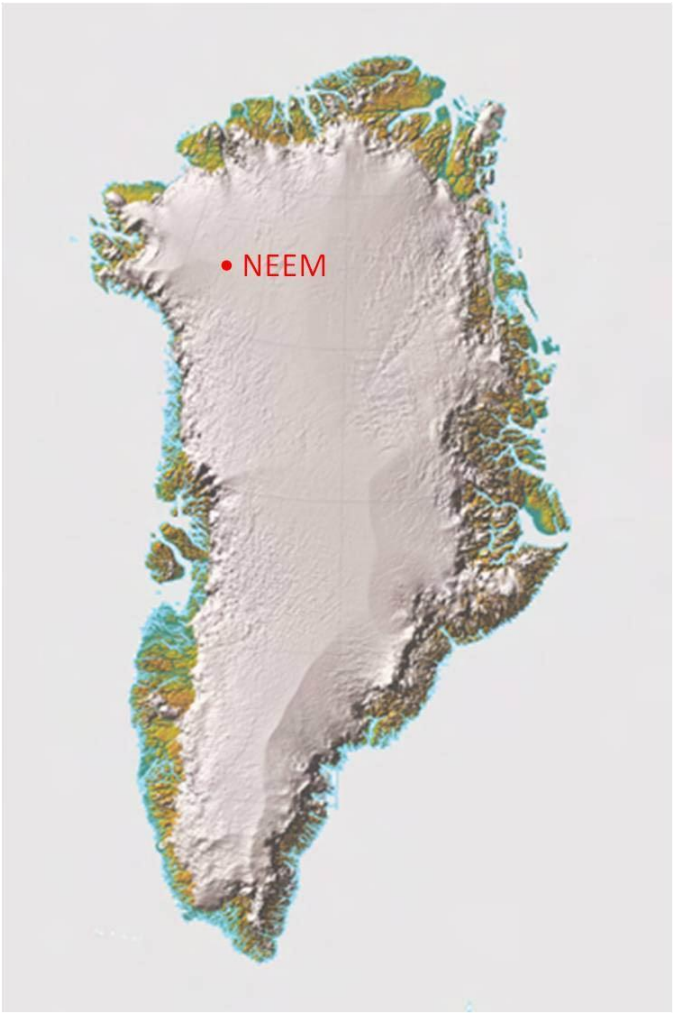
Study Overview (Sapart)

- Ice core sampling
  - 2000 yr $\delta\ ^{13}C$ record
    - North Greenland Eemian Ice Drilling Programme (NEEM)
      - 47 samples
    - EUROCORE
      - 9 samples
  - Dry extraction
    - Small sample size: 200-800g ice sample
    - Ice layers are “grated” over perforated cylinder
    - Vacuum extraction system removes freed gas molecules
  - Isotope ratio mass spectrometry
- Model CH_4 and $\delta^{13}C$
  - Infer possible source/sink variations

NEEM

- Started 6/2009
- Reached Bedrock 7/27/2010
- 2,537.36m





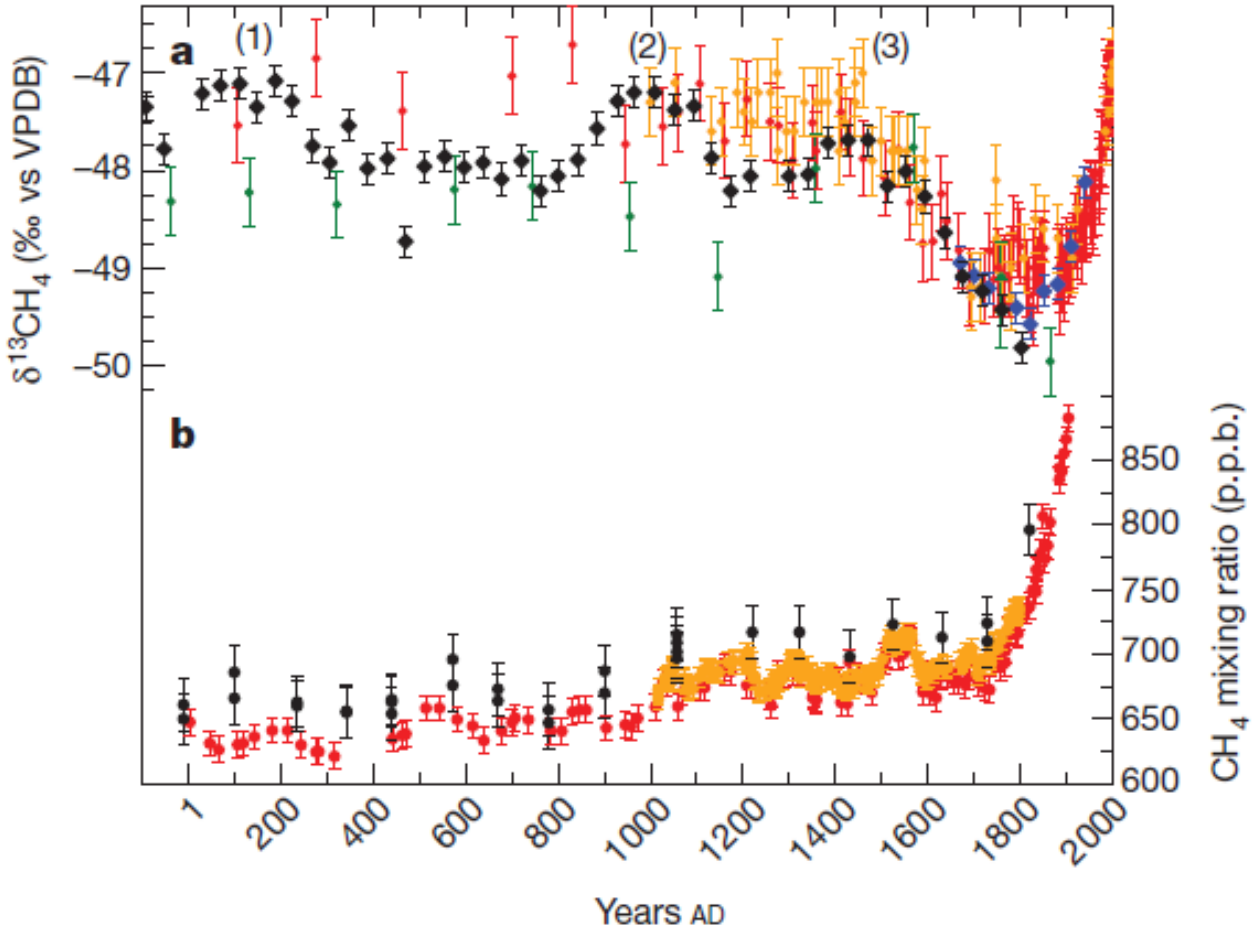
http://instaar.colorado.edu/sil/about/news_detail.php?news_ID=15

(http://www.awi.de/en/news/press_releases/detail/item/neem_deep_ice_core_drilling_project_in_greenland_reaches_bedrock_conclusions_on_climate_conditio/?cHash=98f98b888b17d3e032c0e5808770e636)

Previous Studies Determined

- Before AD 1500
  - $\delta\ ^{13}C$ larger than expected
- Post AD 1500 to AD 1800
  - $\delta\ ^{13}C$ decrease by 2 ‰
- AD 1800
  - $\delta\ ^{13}C$ minimum
    - Hypotheses
      - » Drop in biomass burning in Americas due to colonial expansion
      - » ^{13}C depleted agricultural sources
- Post 1800
  - Abrupt increase associated w/ industrialization

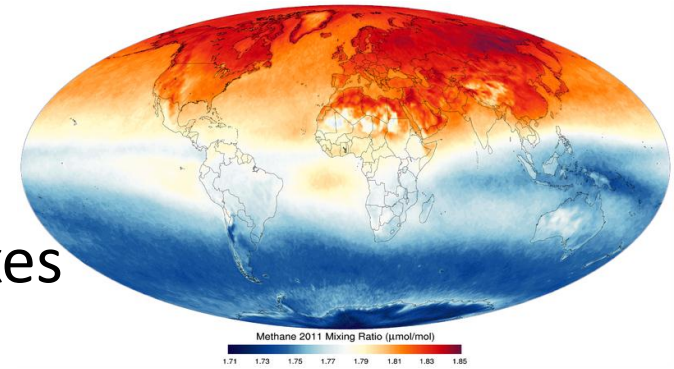
Primary Observations



- 3 centennial-scale excursions in $\delta^{13}C$
  - 100 BC to AD 1600
  - Declining long term
- CH_4 increase of ~70 ppb

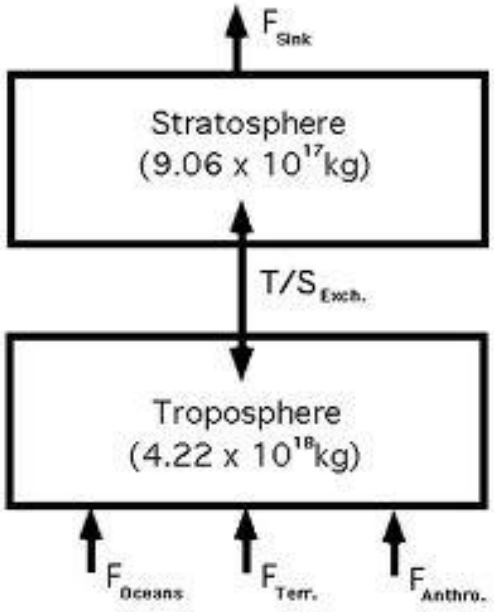
(Sapart et al., 2012)

Two-box Model



http://en.m.wikipedia.org/wiki/File:AIRS_Methane.png

- Box Model
  - Simplify complex systems into boxes
  - Homogeneous
  - Linked by flux ([quantity]·[time]$^{-1}$·[area]$^{-1}$)
- One box for each hemisphere
  - Inputs: CH_4 sources
  - Outputs: OH oxidation (tropo), soil Sink, Stratospheric loss
- Model calculates $\delta^{13}C$ and CH_4
  - Each hemisphere
  - 1 yr resolution



http://www.agu.org/pubs/crossref/2002/2002GB001911.shtml

Model Results

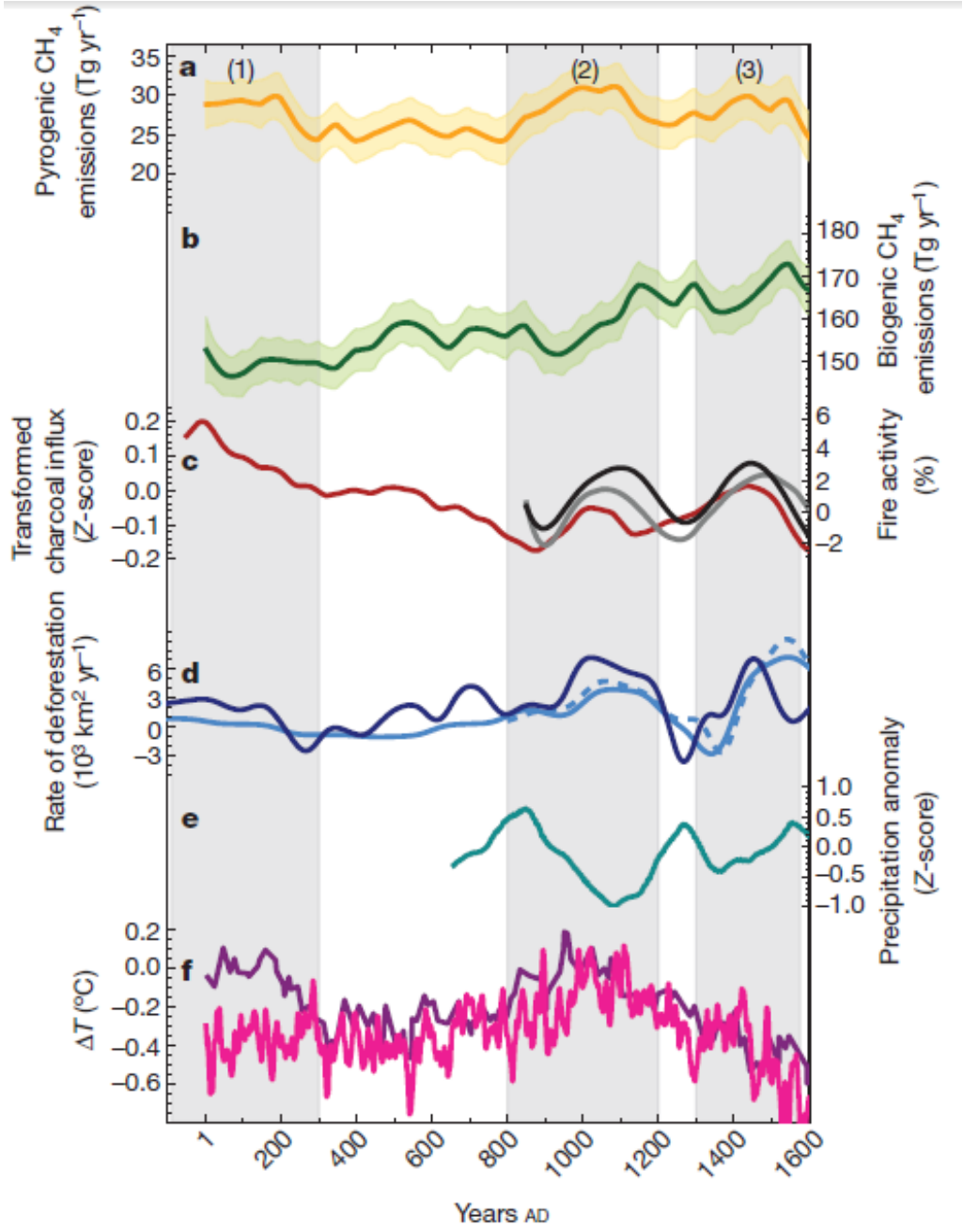
- Step 1: Single sources were varied to account for isotope variation
- Results:
  - 70 ppb corresponds to 28 Tg CH_4
    - Not from geologic and pyrogenic sources alone
    - Driven by biogenic emissions
  - ^{13}C excursions
    - Increase in ^{13}C sources (pyrogenic or geological)

    Or
    - Decrease in depleted sources (biogenic)
  - Short-term geologic fluctuations deemed unlikely
    - Biogenic vs. pyrogenic

Model results compared to Northern Hemispheric charcoal index

- Step 2: Comparison of Pyrogenic and biogenic to NHCI
- Goal:
  - Determine origins of variations in CH_4 sources
  - Fire activity
  - Deforestation rates
  - Precipitation estimates
  - Temperature
- Kelly presents

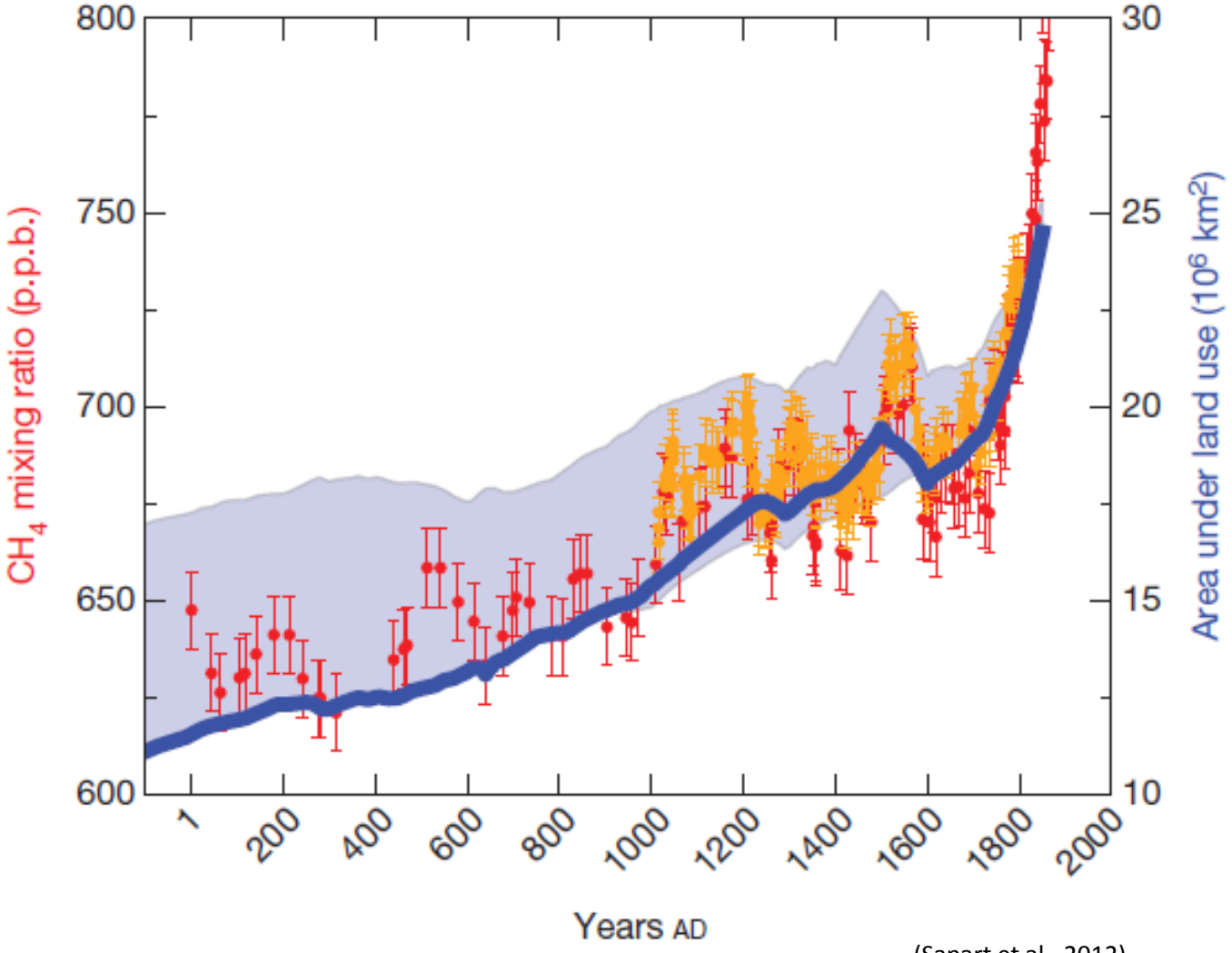
Reconstructed CH_4 Emissions



(Sapart et al., 2012)

- <u>Fire Activity and Deforestation: :</u> Modeled from extrapolated land use observations (linear and non-linear)
- <u>Precipitation Anomaly</u>: Tree Rings from Finland
- <u>Temperature:</u>
  - (Purple) Low res climate proxies with tree ring data
    - Wavelet transform
  - (Pink) NEXT = extra tropical Northern Hemisphere (30-90°)
    - 30 temp proxies (model)
- Qualitative correlation with N Hemispheric charcoal index
- Poor quantitative correlation

CH_4 compared to land use



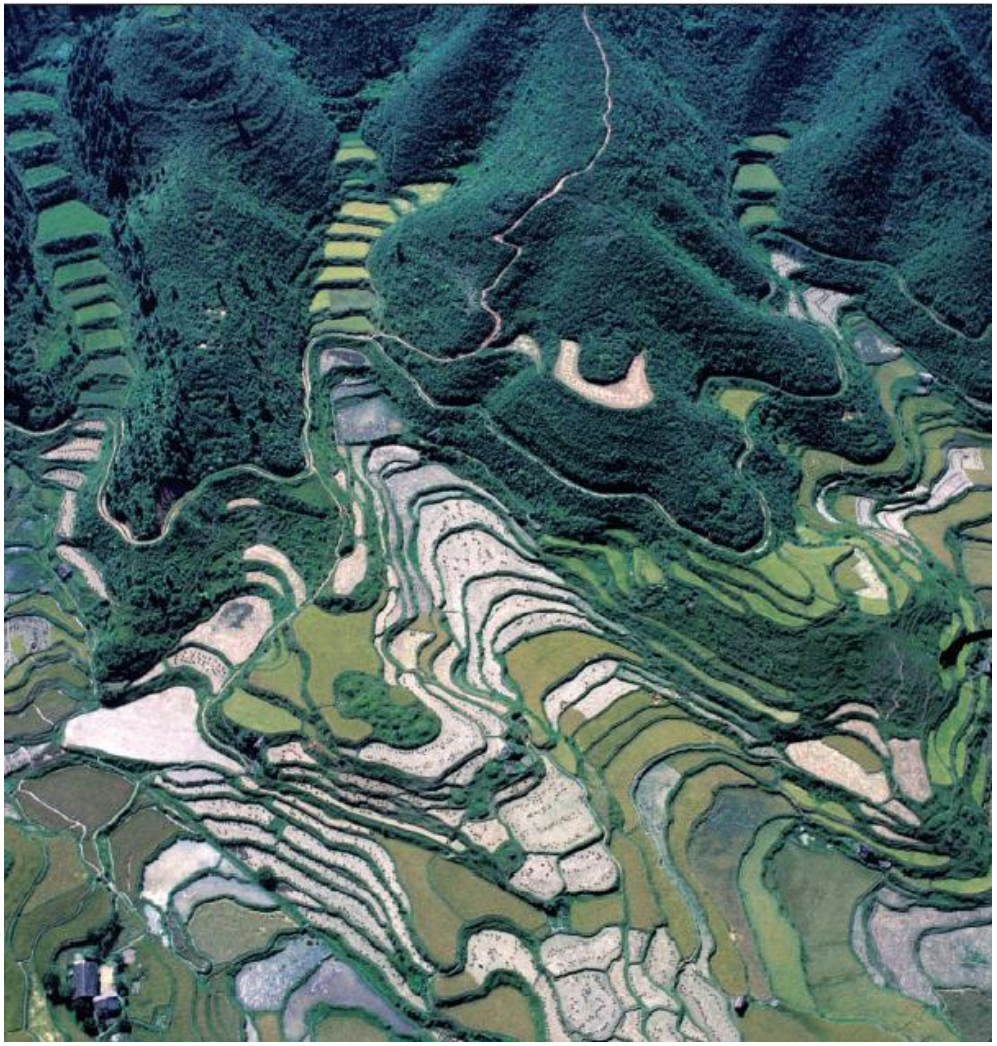
(Sapart et al., 2012)

Excursion explanations

- **Stage 1:**
  - Deforestation drop ~AD 200
    - Fall of Han dynasty and Roman Empire decline
  - Increased Industrialization 100 BC - AD 200
    - Heavy metals in Greenland ice core, other sed records
    - Charcoal as fuel in Roman Empire and China/India
- **Stage 2:**
  - AD 800 – AD 1200
    - Drop in biogenic source
    - Rise in pyrogenic source
      - Extended drought in N. Europe caused wildfire intensity
      - Deforestation from population expansion
- **Stage 3:**
  - Correlated to LIA (N Hemi temp and precip drop)
    - Drop in biogenic source
  - Increased fire activity and charcoal index

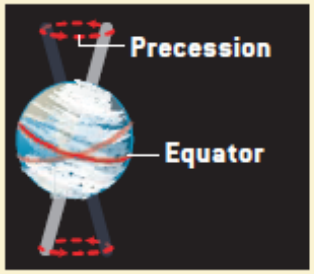
- **Overall:**
  - Human activities contributed to variations in CH_4 emissions before pre-industrial times (mentions rice agriculture expansion)

How did humans first alter global climate? (Ruddiman)

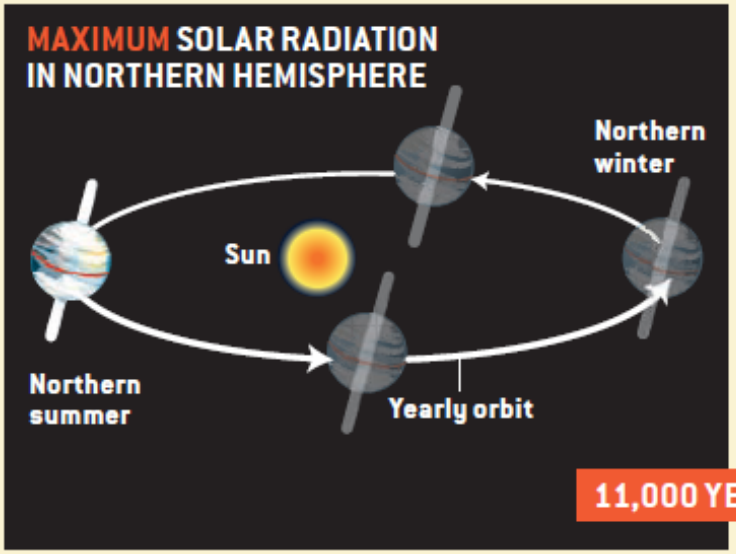


Observations

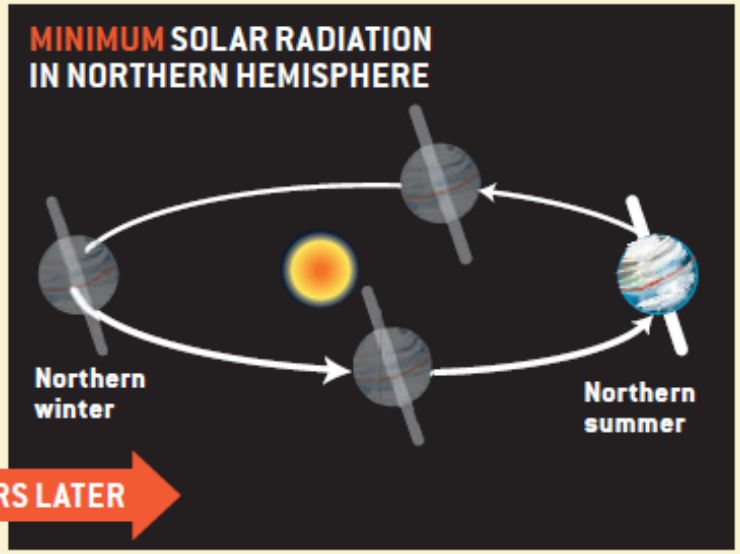
- GHG began rising
  - 8ka: CO_2
  - 5ka: CH_4
  - Natural trends indicate should have dropped
- Long term climate change dominated by solar cycles
  - Eccentricity 100ka
  - Obliquity 41ka
  - Precession 22ka (CH_4 correlates)
- Vostok ice core confirmed
  - CO_2 and CH_4 rose and fell in regular patterns with solar intervals and glacial/interglacial periods
  - “Virtually” all of past 400ka



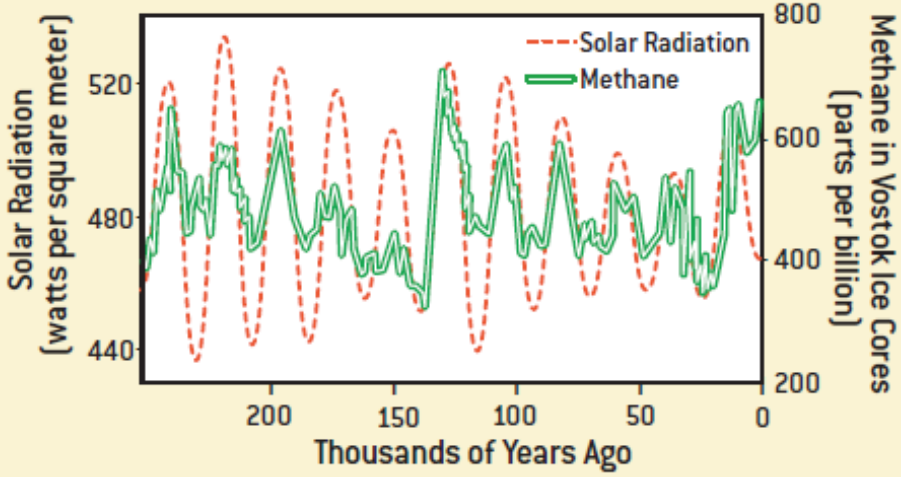
Wobble in the earth's axis of rotation, known as precession, is one of the three orbital cycles that account for sunlight variations in the Northern Hemisphere. Like a toy top about to fall, the earth's axis traces imaginary circles in space, making one revolution every 22,000 years.

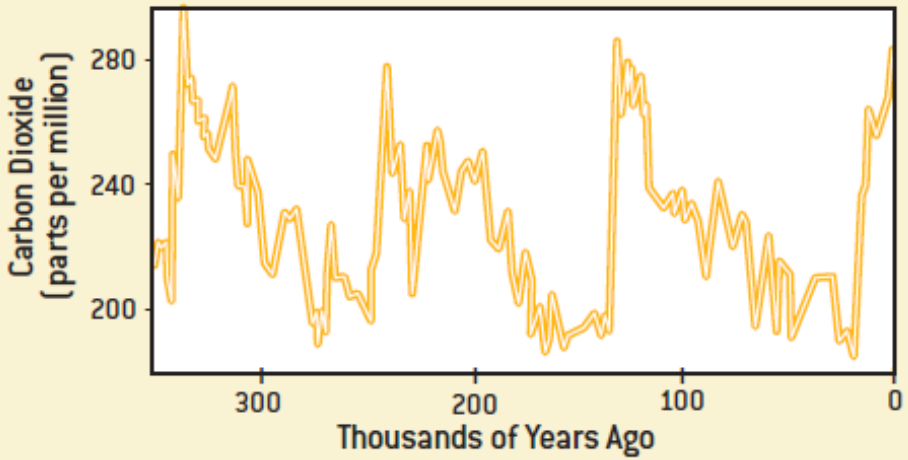


Summer warmth in the Northern Hemisphere peaks once every 22,000 years, when the yearly northern summer coincides with the earth's closest passage to the sun and the Northern Hemisphere receives the most intense sunlight.



Summer heat bottoms out 11,000 years later, after the earth's axis has shifted (precessed) to the opposite position. The Northern Hemisphere then receives the least summer sunlight, because the earth is farthest from the sun.





Human Connection

http://www.pbase.com/daveb/image/42673320

- Agriculture: 11ka ago
  - Fertile Crescent
  - Rice cultivation began 5ka ago
    - Coincides with abrupt CH_4 rise
    - 3ka spreads to Indochina and India
  - 2ka ago every crop today was cultivated
- Deforestation: ~8ka (Europe and China)
  - Estimates based on:
    - Doomsday Book
      - AD 1086
      - 90% of forested lowlands cleared in England
    - Population density of 10ppl/km^2
      - Infer deforestation rates in China and India
        - » 1000's yrs prior

CH_4
Precession max
- 700ppb

Started dropping by 100 ppb

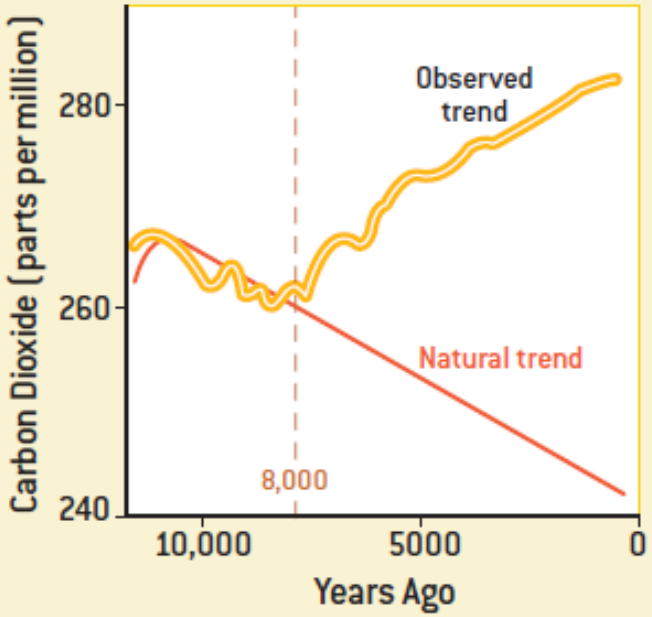
11,000 years ago: Early peoples invent agriculture in Mesopotamia and China

Paleolithic sickle blade

Carbonized wheat

8,000 years ago: Late Stone Age Europeans begin clearing forests to grow wheat, barley, peas and other nonindigenous crop plants

10,000 YEARS AGO — **8,000 YEARS AGO**



8,000 years ago: CO_2 trend, which has been falling for 2,500 years, bottoms out and suddenly reverses direction

7,500 years ago: Humans adapt wild rice for cultivation

CO_2
- Complex (3 cycles)
- Peak at 10.5ka

Decline

Rise

CH_4

700ppb (pre-industrial)

- 250ppb higher previous cycles

But… began rising

5,000 years ago: Farmers in the south of China begin flooding lowlands near rivers to grow rice

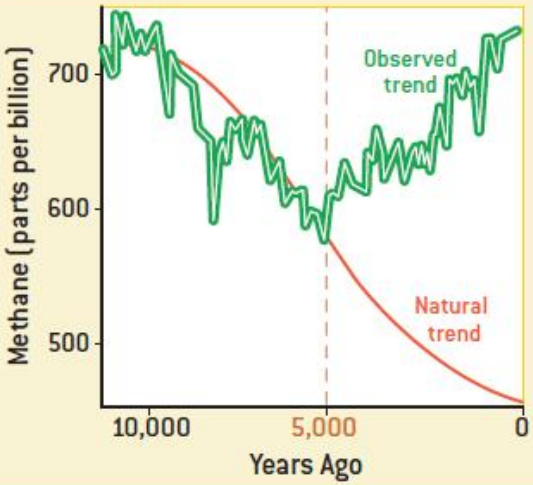
2,000 years ago: Europe, India, Southeast Asia and China have cleared much of their natural forest cover to grow crops such as wheat

200 years ago: Combustion of fossil fuels and accelerating deforestation result in unprecedented releases of greenhouse gases

Otto engine

6,000 YEARS AGO | 4,000 YEARS AGO | 2,000 YEARS AGO | PRESENT

5,000 years ago: Methane trend, which has been falling for 6,000 years, suddenly reverses direction



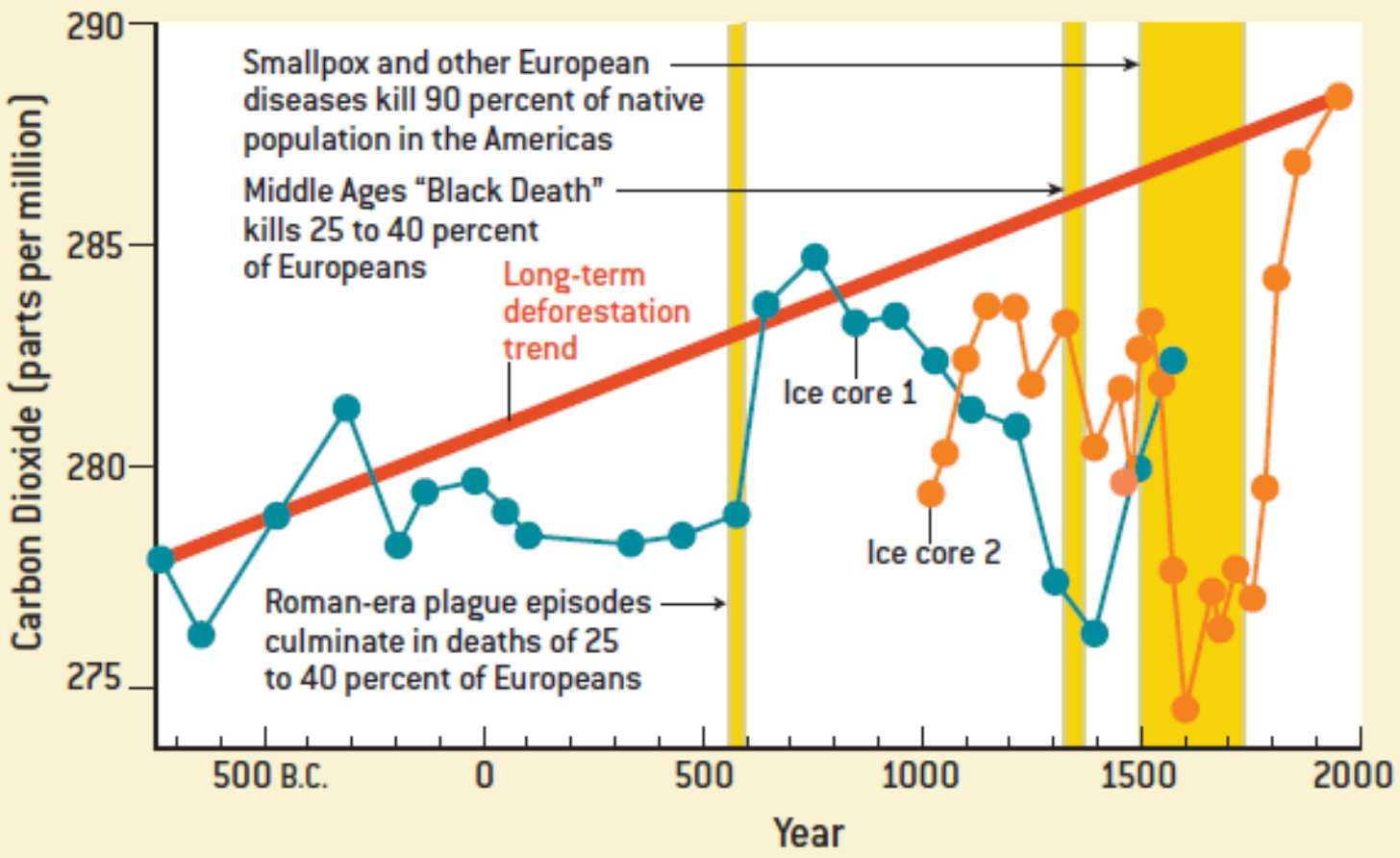
2,000 years ago: Farmers in Southeast Asia begin to construct terraced rice paddies on steep hillsides

Rising

CO_2

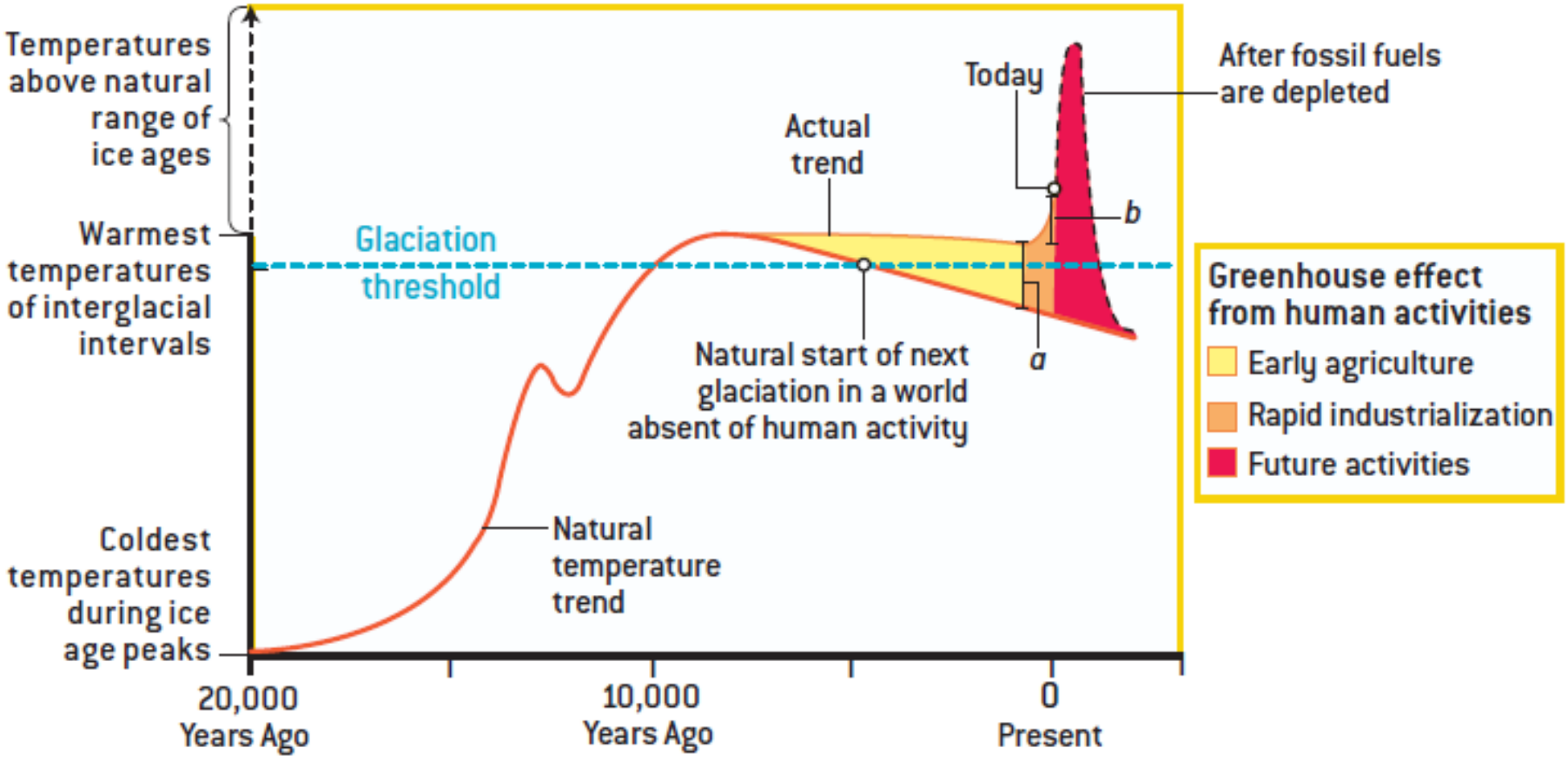
- Pre-industrial 285ppm
- 40ppm higher previous cycles

CO_2 link to disease



MOST DRAMATIC DROPS in atmospheric CO_2 concentrations during the past 2,000 years (as recorded in two Antarctic ice cores) occurred around the same periods that disease outbreaks were taking the greatest toll on human life (*yellow bars*).

Future Predictions

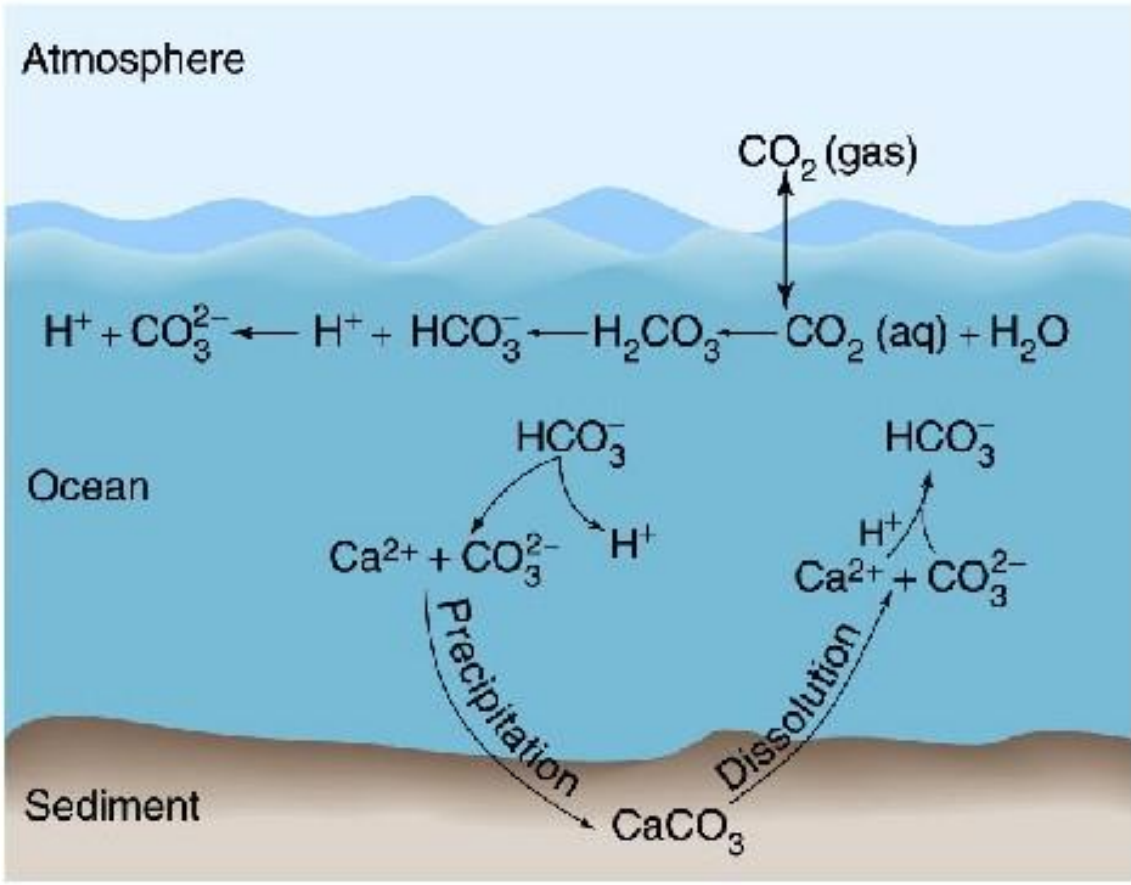


Opposing Views (Broecker and Stocker)

- Natural explanation
- 40 ppm increase in atm CO_2
  - Requires enormous deforestation
    - Reason
      - Ocean's dissolved inorganic carbon inventory
        - » 5x the atmospheric input
        - » Ocean:
          - 8ka = time to dissolve the atmospheric CO_2
          - Equilibrate entire ocean

Ocean CO_2 dissolution

- CO_2 neutralized by $CaCO_3$
- Model
  - w/ $CaCO_3$ interaction
    - 700 GtC
- Forest biomass
  - 2x larger 8ka ago than in AD 1800



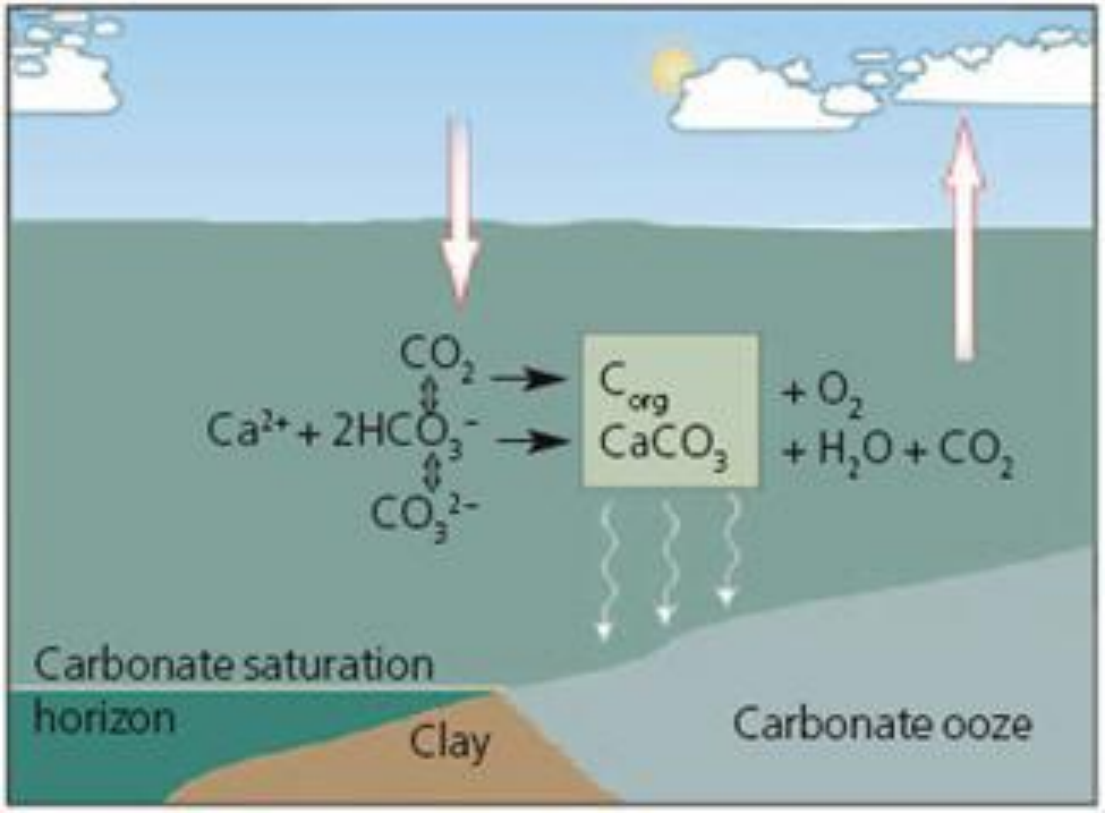
http://www.jochemnet.de/fiu/OCB3043_28.html

Alternate Explanation

- $CaCO_3$ compensation from CO_2 extraction
  - CO_2 used to create forests after ice receded
- Rationale:
  - Atmospheric CO_2 drops
  - Ocean
    - Replenishes atmosphere
    - Carbonate ion content increases (CO_3^{2-})

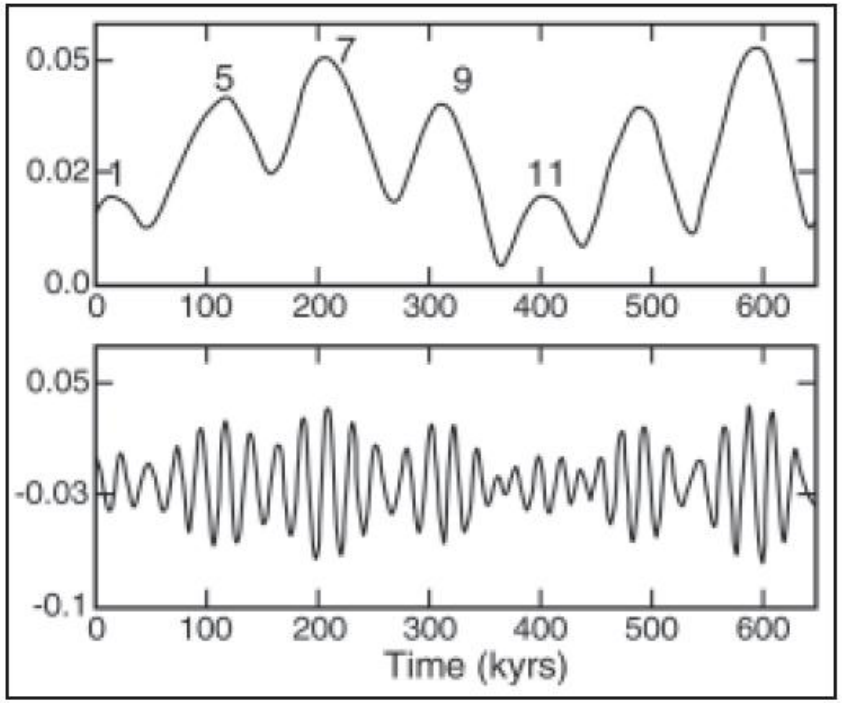
Evidence: $CaCO_3$ Compensation Depth

- CCD
  - Deeps initially
  - Then begin to rise as CO_2 returns
- Observed
  - Early Holocene
    - Shell and fragmentation weight remain high
  - Over time increased dissolution

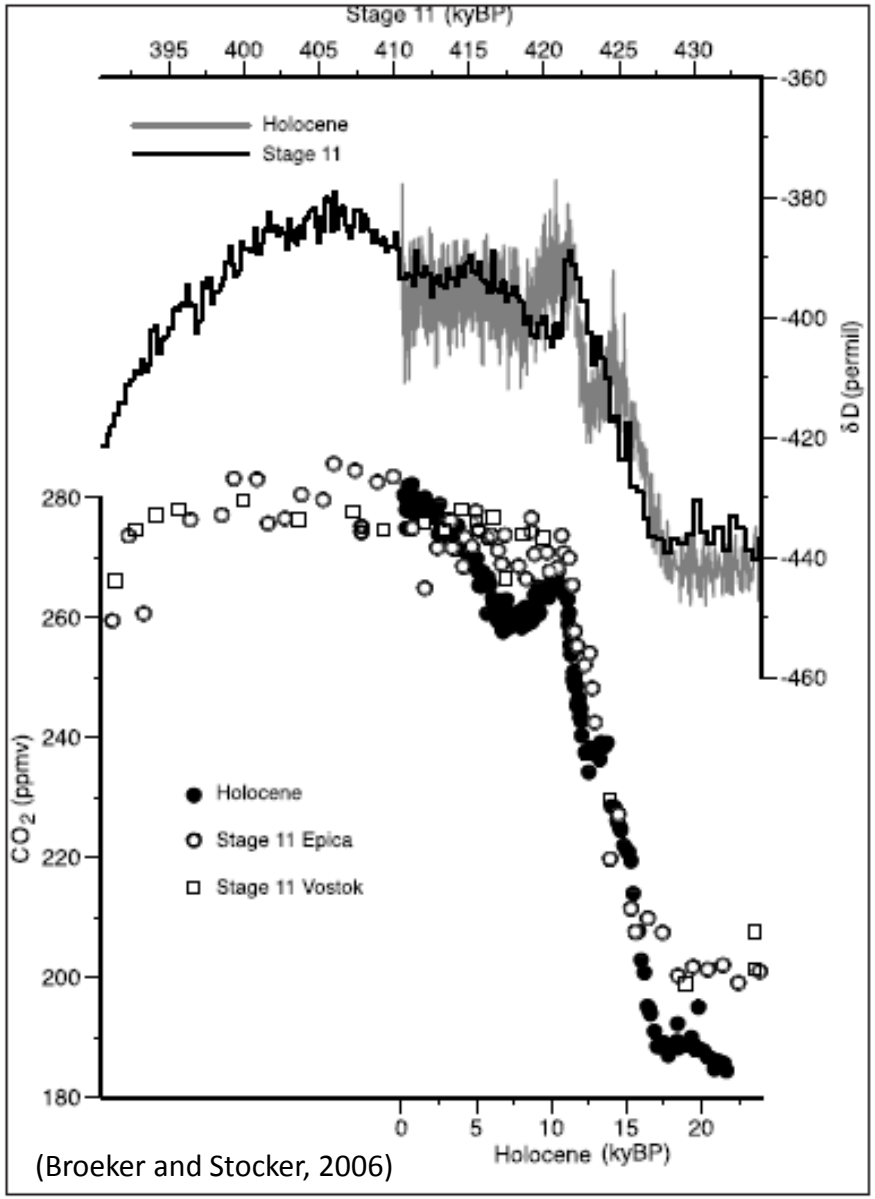


Solar Explanation

- Smaller Eccentricity (Stage 1 and 11)
  - Too weak to drive CO_2 conditions down



(Broeker and Stocker, 2006)



(Broeker and Stocker, 2006)

Questions?