The Race to the Top: Is Sea Level Rise Accelerating Due to Global Climate Change?

E. Christa Farmer, Ph.D.
Hofstra University
Geology Department

AAARI
9 March 2007

Roaring Glacier, Prince William Sound, Alaska, June 21, 2005

The Problem:

- In 1990, 23% of the world's population (1.2 billion people) were living within 100km distance and 100m elevation of the oceans (Church, *Eos*, 23 Jan 2007).

- Sea level has risen ~17 inches over the last century, mostly due to melting of continental ice sheets, and rates have recently increased (Miller and Douglas, *Nature*, 2004; Church et al., *J. Climate*, 2004).

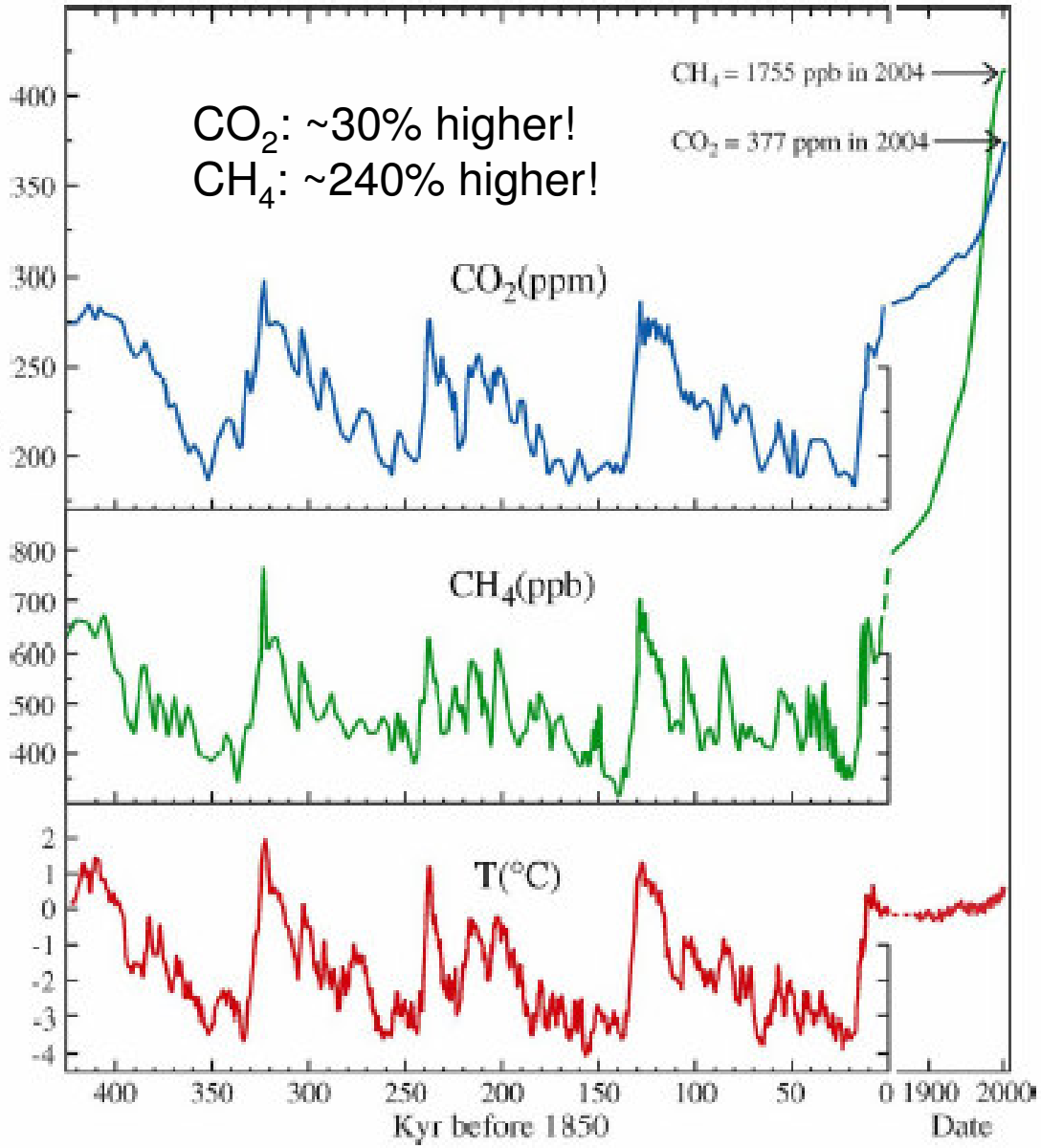
- Concentrations of greenhouse gases are rising to levels never seen in the last 500,000 years, with implications for future sea level rise (Hansen, 2005).

- What can we expect to see in the next 100 years?

Human Influence on Climate:

In the last ~150 years of burning fossil fuels, we have raised atmospheric greenhouse gas concentrations far above what they have ever been for at least 500,000 years.

CO_2,CH_4 and estimated global temperature (Antarctic $\Delta T/2$ in ice core era) 0 = 1880-1899 mean.

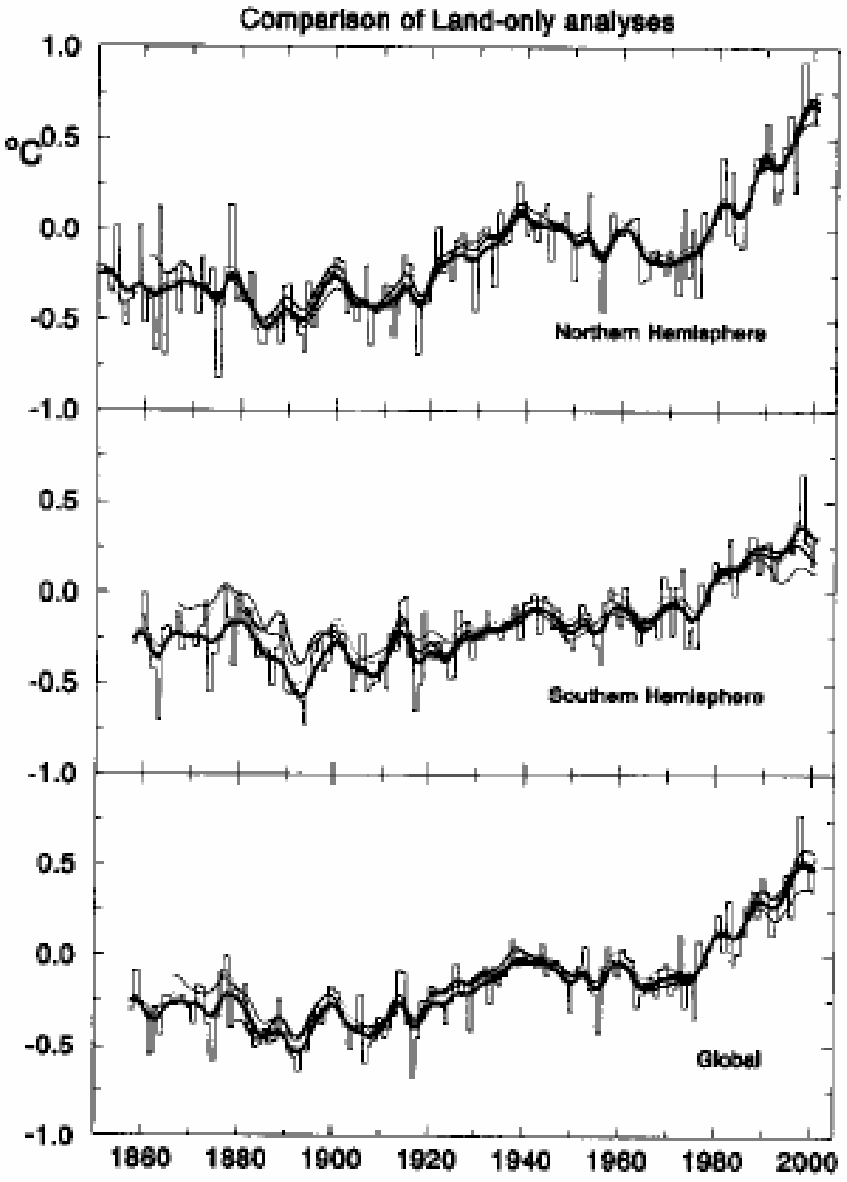


Source: Hansen, *Clim. Change*, 68, 269, 2005.

“Global Warming”

- global average temperature trend: ~+1ºC (~+1.8ºF) over the last ~100 years

- larger trend in Northern Hemisphere because more land surface there



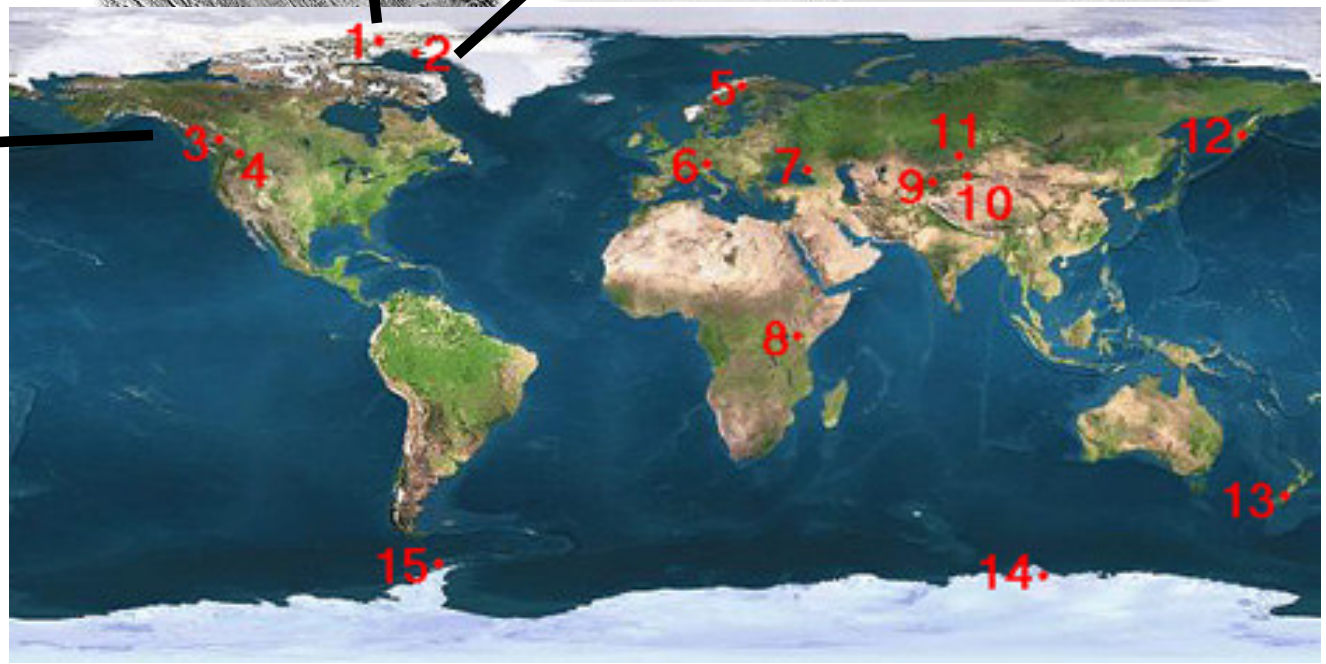
Jones & Moberg, 2003, Journal of Climate

Glaciers today:

White Glacier, Canada

Greenland Ice Sheet

Peyto Glacier, Canadian Rockies



http://www.glacier.rice.edu/land/5_warmice.html#anchor996447

Geologic perspective:

- Fifty million years ago (Eocene):
  - CO_2 levels may have topped 1000 parts per million by volume (ppmv)
  - sea levels were about 50 meters higher than those today

- CO_2 levels gradually decreased:
  - marine organisms fixed carbon through photosynthesis
  - then buried it by sinking into ocean basins

- This allowed ice sheets to develop in Antarctica starting 30 to 40 million years ago

- By 3 to 4 million years ago:
  - CO_2 probably dropped to or below preindustrial level of ~290 ppmv
  - permanent ice sheets appeared in Northern Hemisphere

- As subsequent glaciations came and went, CO2 concentration and temperature were tightly linked:
  - When both went down, ice sheets grew and sea levels sank, lower than today's by more than 100 meters.
  - When both went up, there were relatively stable warm periods with high sea levels.

Kennedy & Hanson, 2006, Science

Natural Climate Variability:

Notice pattern of high values about every 100,000 years: these are ice ages, when ice covered much of high latitudes.

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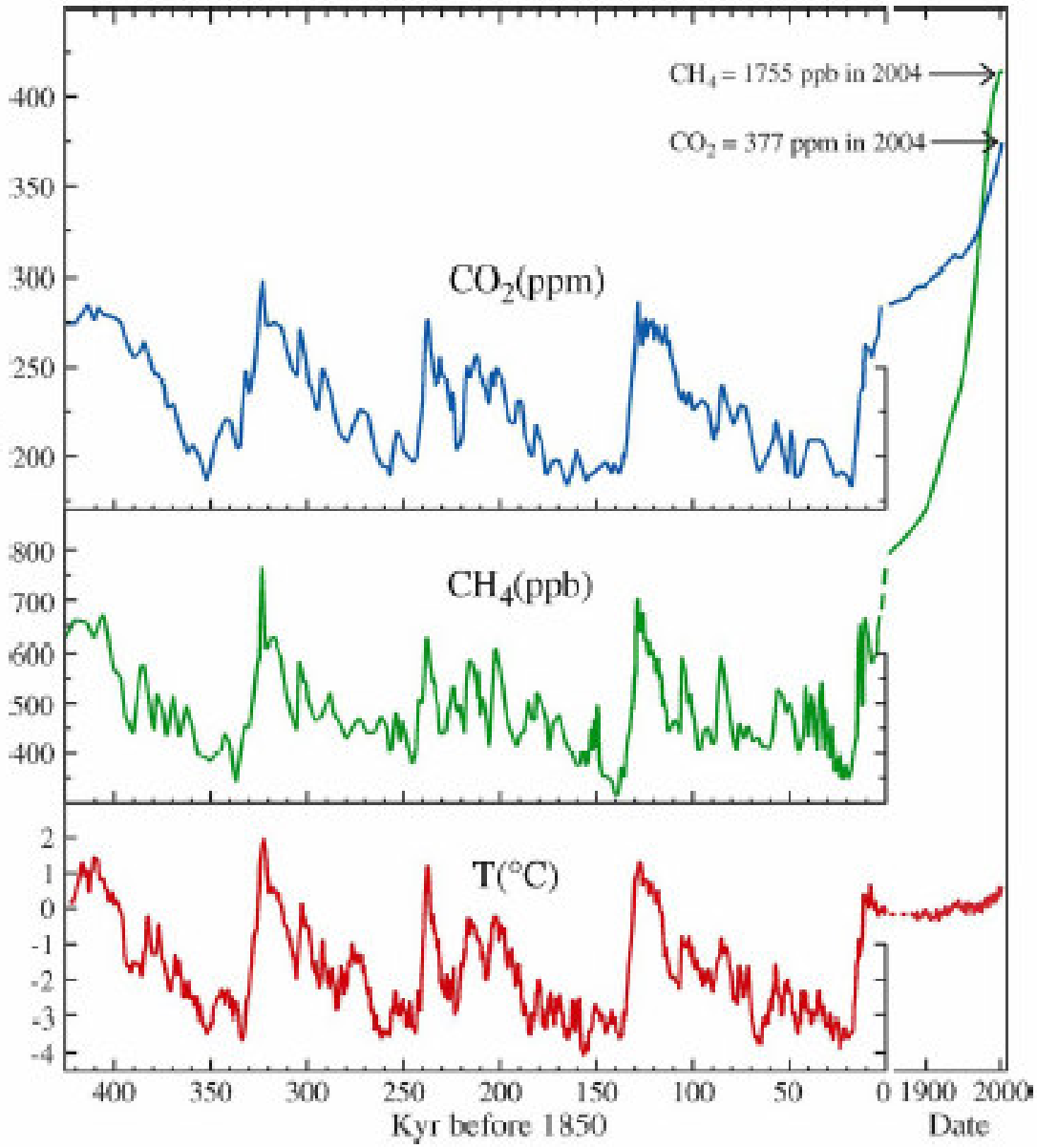
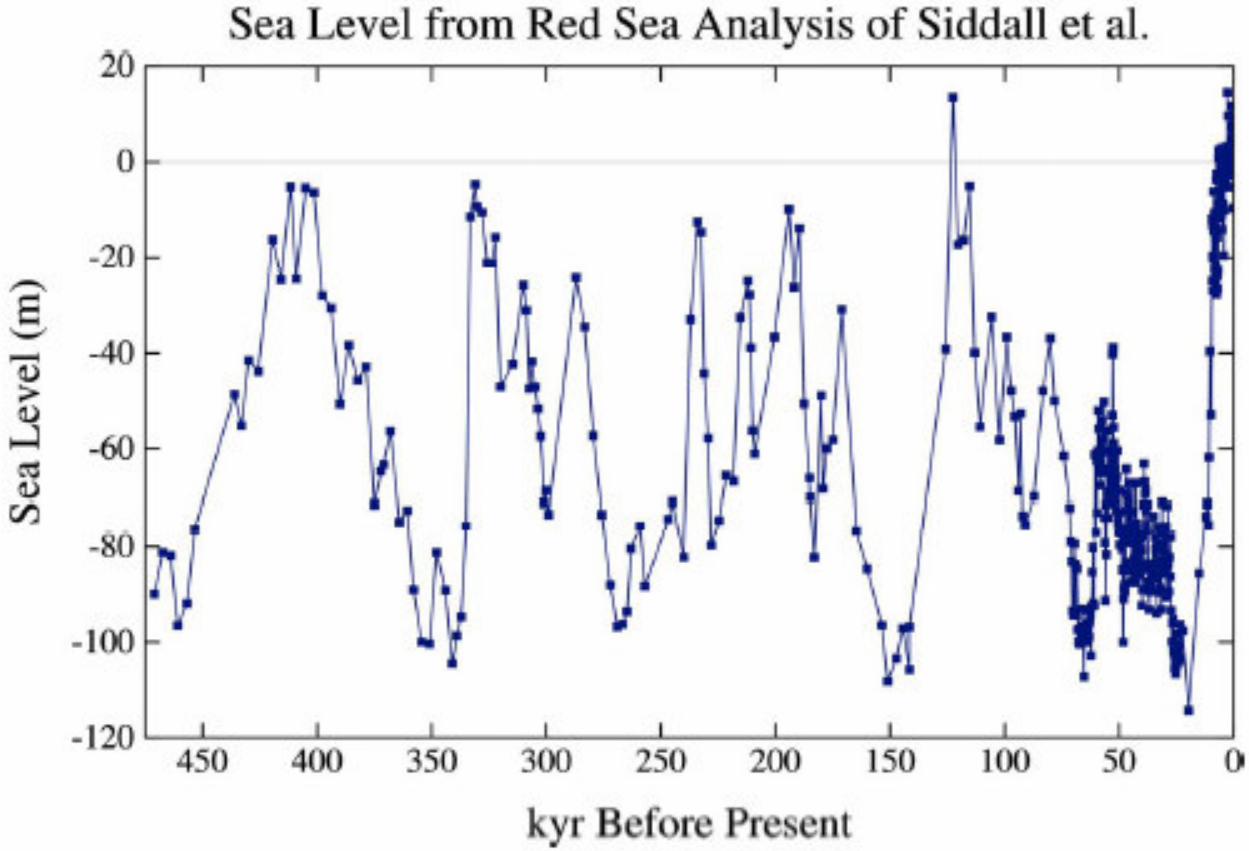


Source: Hansen, *Clim. Change*, **68**, 269, 2005.

Sea level rise in geologic record:

- calculation of sea level from residence time of Red Sea waters and estimates of sill depth
- sea level changes in concert with ice ages about every 100,000 years
- maximum rates of sea level change: 35m at 2cm/yr



Global sea level extracted, via a hydraulic model, from an oxygen isotope record for the Red Sea over the past 470 kyr (concatenates Siddall's MD921017, Byrd, & Glacial Recovery data sets; AMS radiocarbon dating).

Source: Siddall et al., *Nature*, **423**, 853-858, 2003.

20th Century Sea Level Rise:

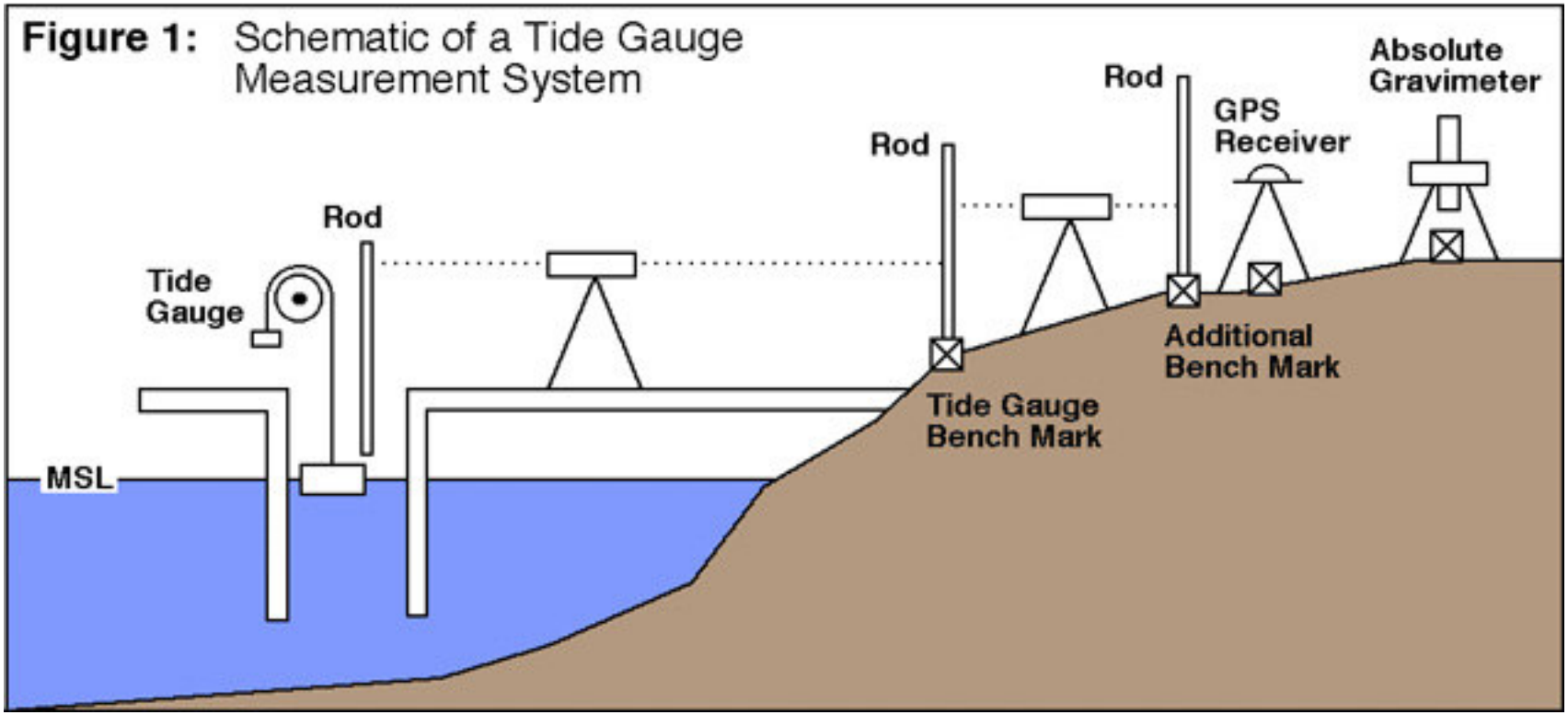
- Estimated from tide gauges:
  - 1.5-2 mm/year

  (~17cm, or ~7 inches, in 100 years)

- Estimated from satellites:
  - 1.8 mm/year (+/- 0.3)

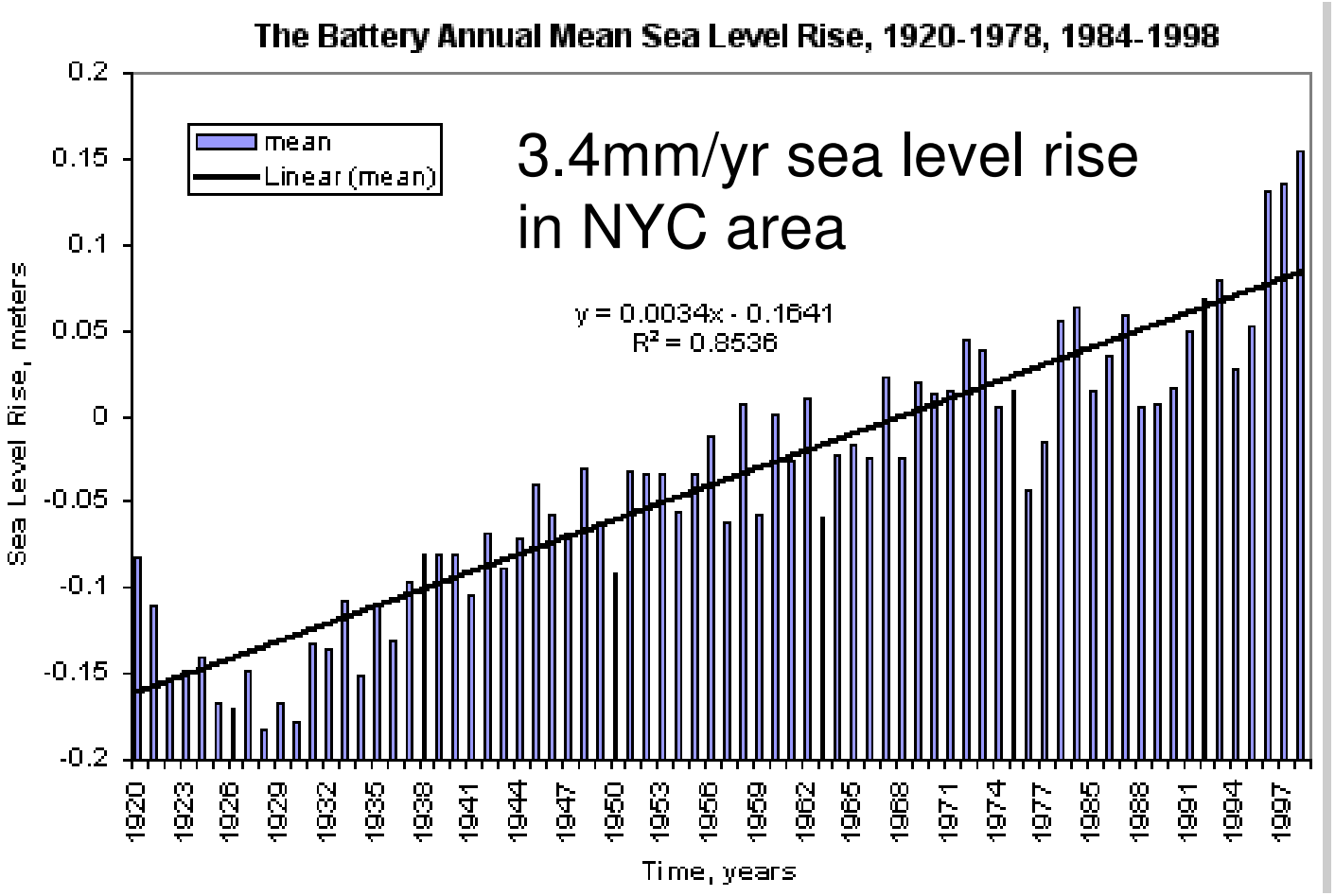
- Believed mostly to be due to mass increases:
  - primarily melting of continental ice sheets

Miller and Douglas, *Nature*, 2004; Church et al., *J. Climate*, 2004



http://sealevel.colorado.edu/tidegauges.html

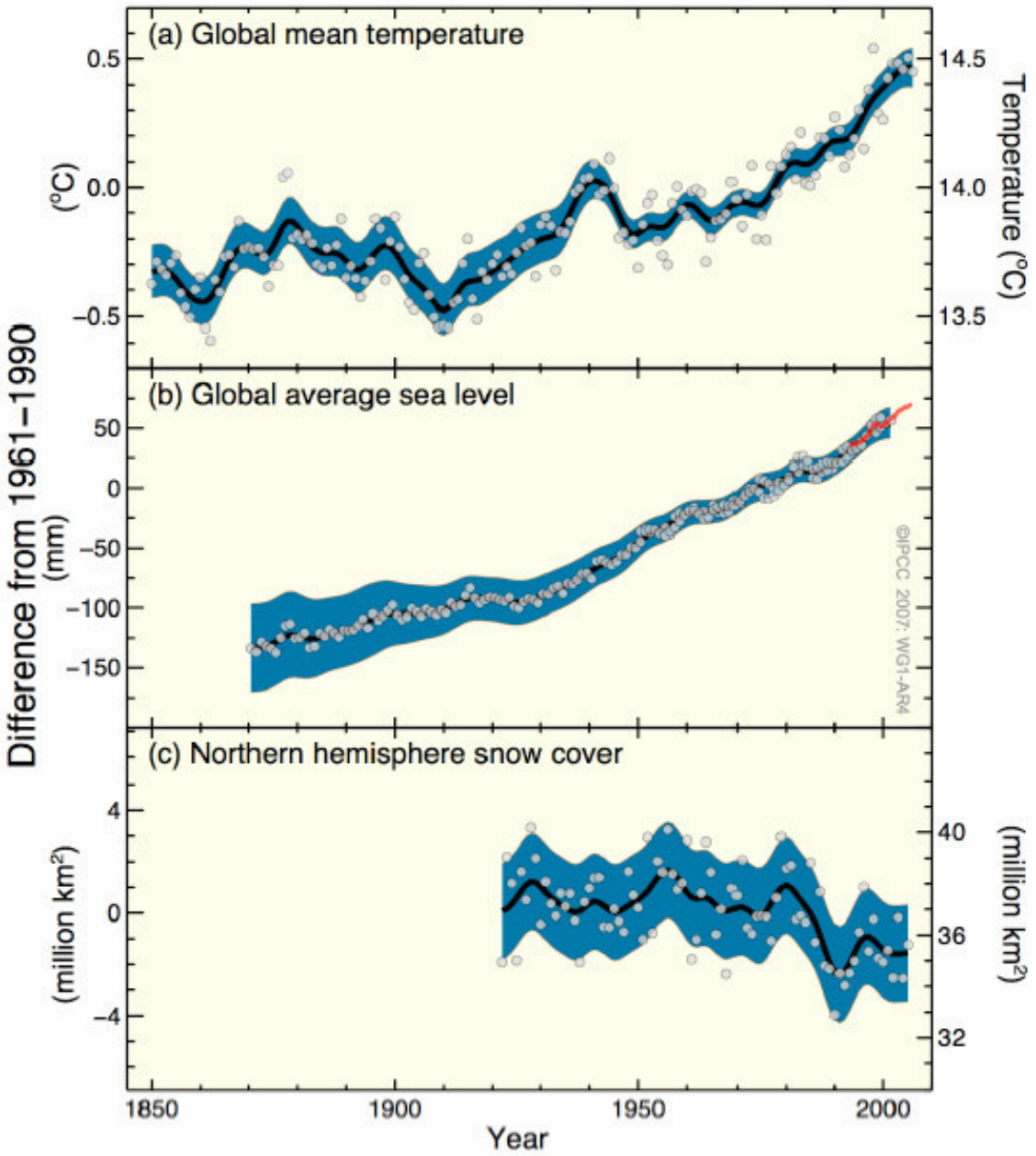
Metro East Coast Assessment:



http://metroeast_climate.ciesin.columbia.edu/coastal.html

20th Century Sea Level Rise:

- for sea level: white circles indicate tide gauge data, red line indicates satellite data



Intergovernmental Panel on Climate Change, Assessment Report 4, Feb 2007

21st Century Sea Level Rise:

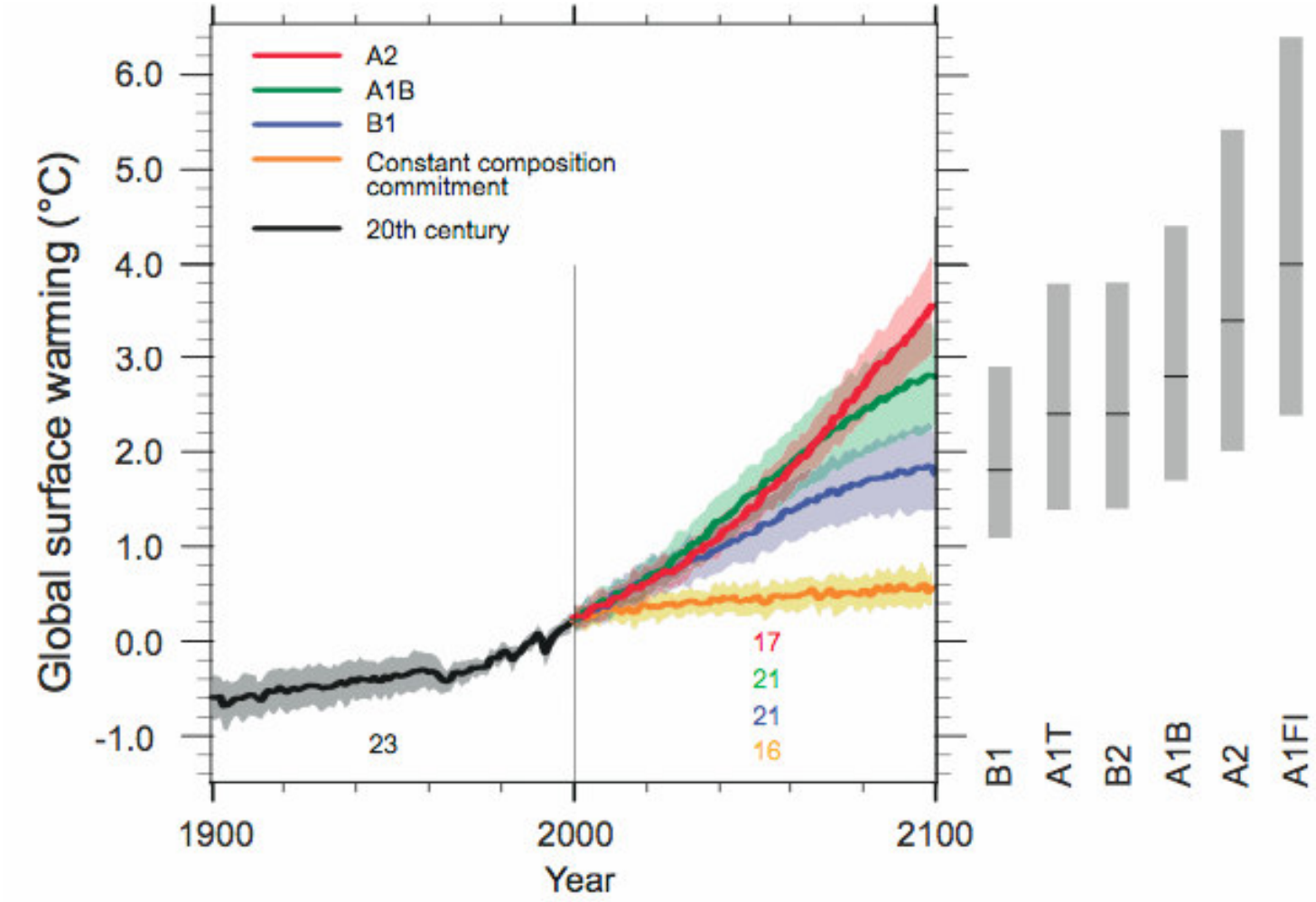
- Beginning in 1992, sea level rising at a rate of 3.2 mm/yr
  (Compared to 1.5-2mm/year for last century)
  Not sure whether this is an acceleration of sea level rise, or decadal variability

- Thermal expansion of the ocean accounts for about half of sea level rise in satellite record, but only a quarter of change in last century:
  Under-sampling of ocean temperatures or recent enhanced climate change?

- Glacier melt rates during the last decade approximately double those of past several decades…

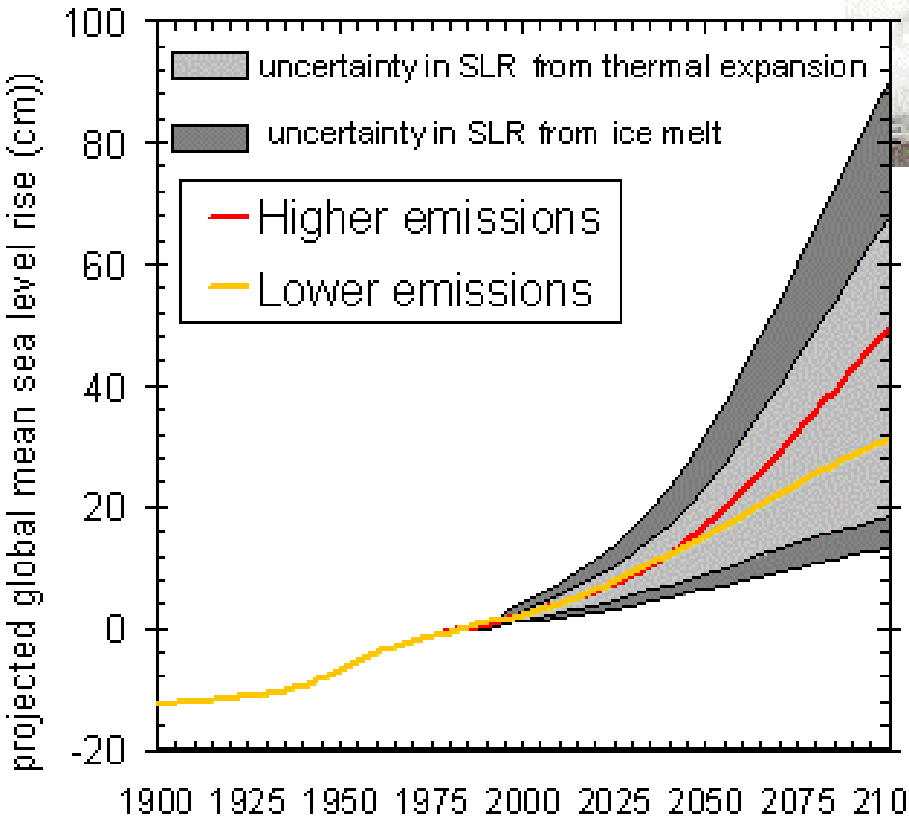
Church, *Eos*, 23 Jan 2007, report on World Climate Research Program workshop on sea level rise

Possible future climate change:



Intergovernmental Panel on Climate Change, Assessment Report 4, Feb 2007

Predicted
Sea-Level Rise



Higher: 8-33 inches

Lower: 4-21 inches

These estimates do not include the potential for additional increases due to more rapid melting of major polar ice sheets.

NE Climate Impacts, Hayhoe et al. 2007 (consistent with IPCC predictions)

Future possibilities for continued sea level rise:

- expansion of the oceans from global warming
  - with stabilization of greenhouse gas emissions in 2100, sea level would still rise 0.3-0.8m by 2300 due to thermal expansion

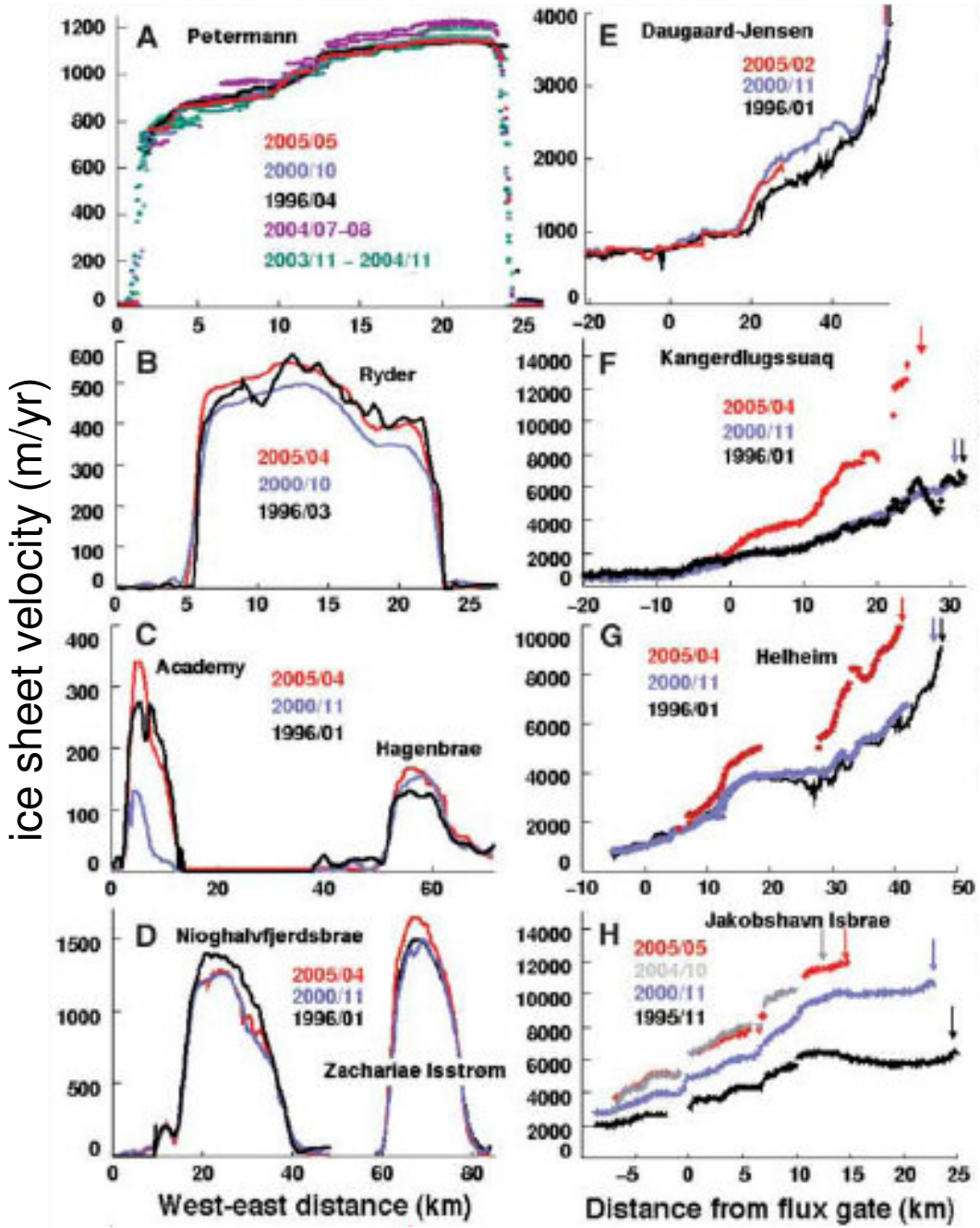
- melting of land-locked ice:
  - Greenland (~7m sea level rise, would probably take ~1000 years)
  - Antarctica (not projected to melt right away)
  - smaller glaciers and ice caps (~0.2m sea level rise)

- climate surprises??
  - faster melting of ice sheets due to feedbacks?
  - geologic record indicates changes in sea level rise ~10 times higher than what we've seen in last 100 years!

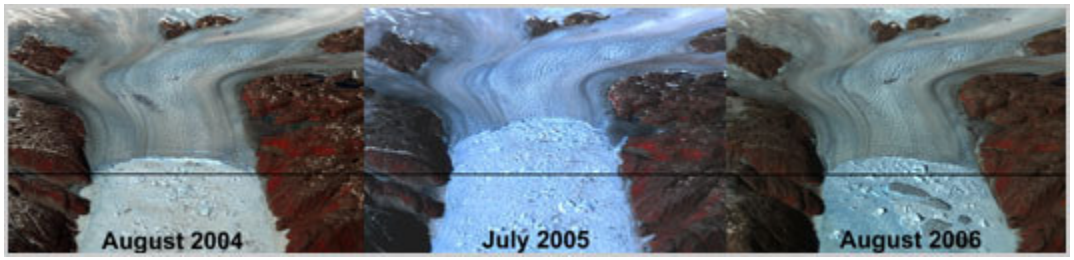
Climate Surprise? Rignot & Kanagaratnam 2006: glaciers speed up!

- Black line = 1996
- Blue line = 2000
- Red line = 2005

("flux gate" is location where thickness of ice sheet is well known)



Howat et al. 2007: glaciers slow!



- "Between 2004 and 2005, Greenland's Helheim Glacier seemed to be collapsing. It's seen here in a view looking up the glacier from the sea. Its "calving front," where icebergs break off, was just above the black line in the 2004 satellite image, at left. By 2005, the glacier had retreated so that the calving front was 3 miles closer to the interior of Greenland. But then the retreat abruptly reversed in 2006 as the glacier expanded and the calving front advanced back to near the earlier position. (Photo: Ian Howat)"

  http://tierneylab.blogs.nytimes.com/2007/02/12/greenland-redux/

Climate Surprises:

- no one is sure whether glaciers will speed up their melting in the future…

- geologic records indicate much faster levels of melting are possible

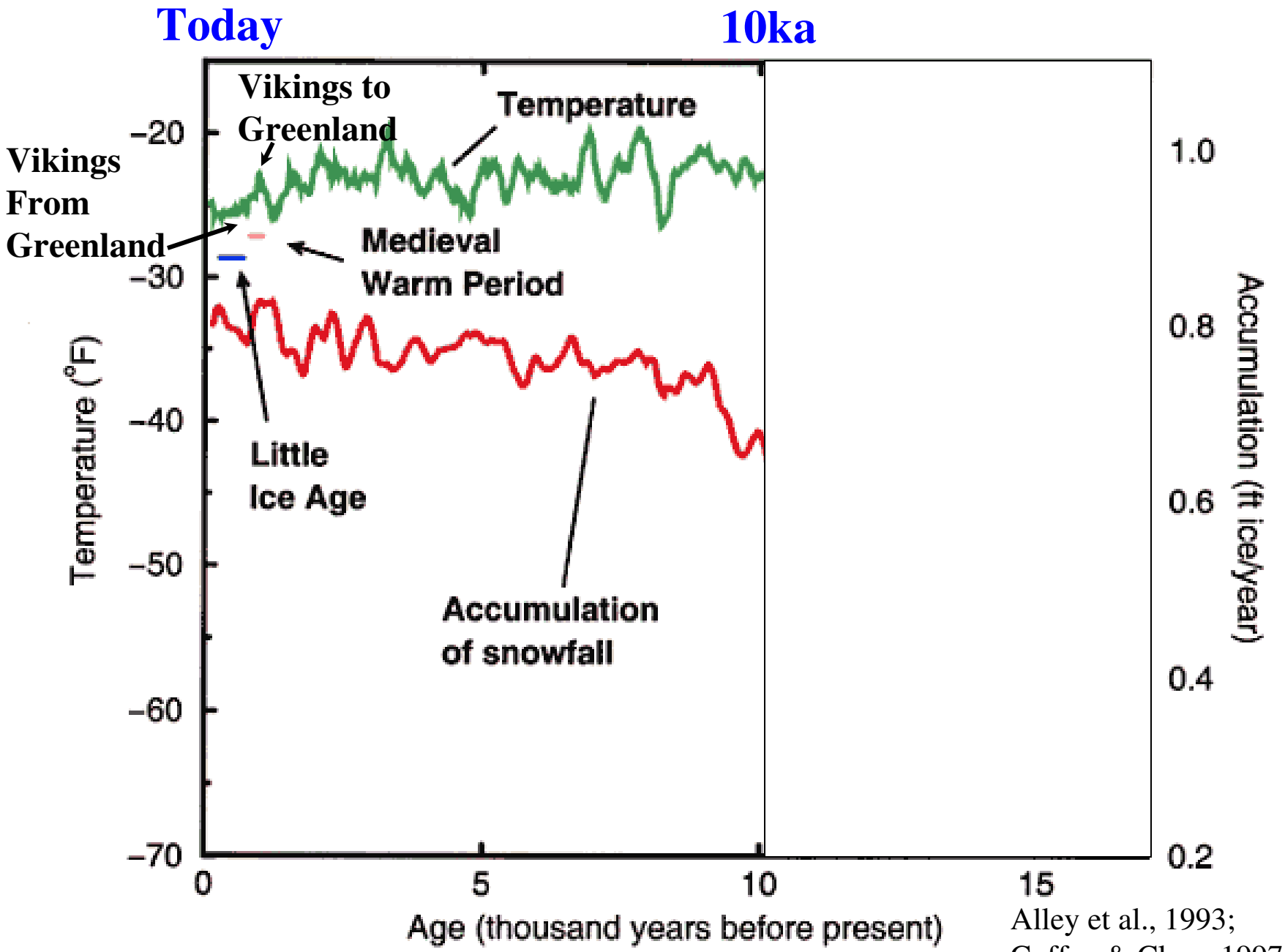
  (compare 2cm/yr in geologic record with 2mm/yr in instrumental record of last 100 years)

More climate surprises:

- climate system is full of feedbacks which enable nonlinear changes

- “Younger Dryas” at end of last glacial period is a prime example…

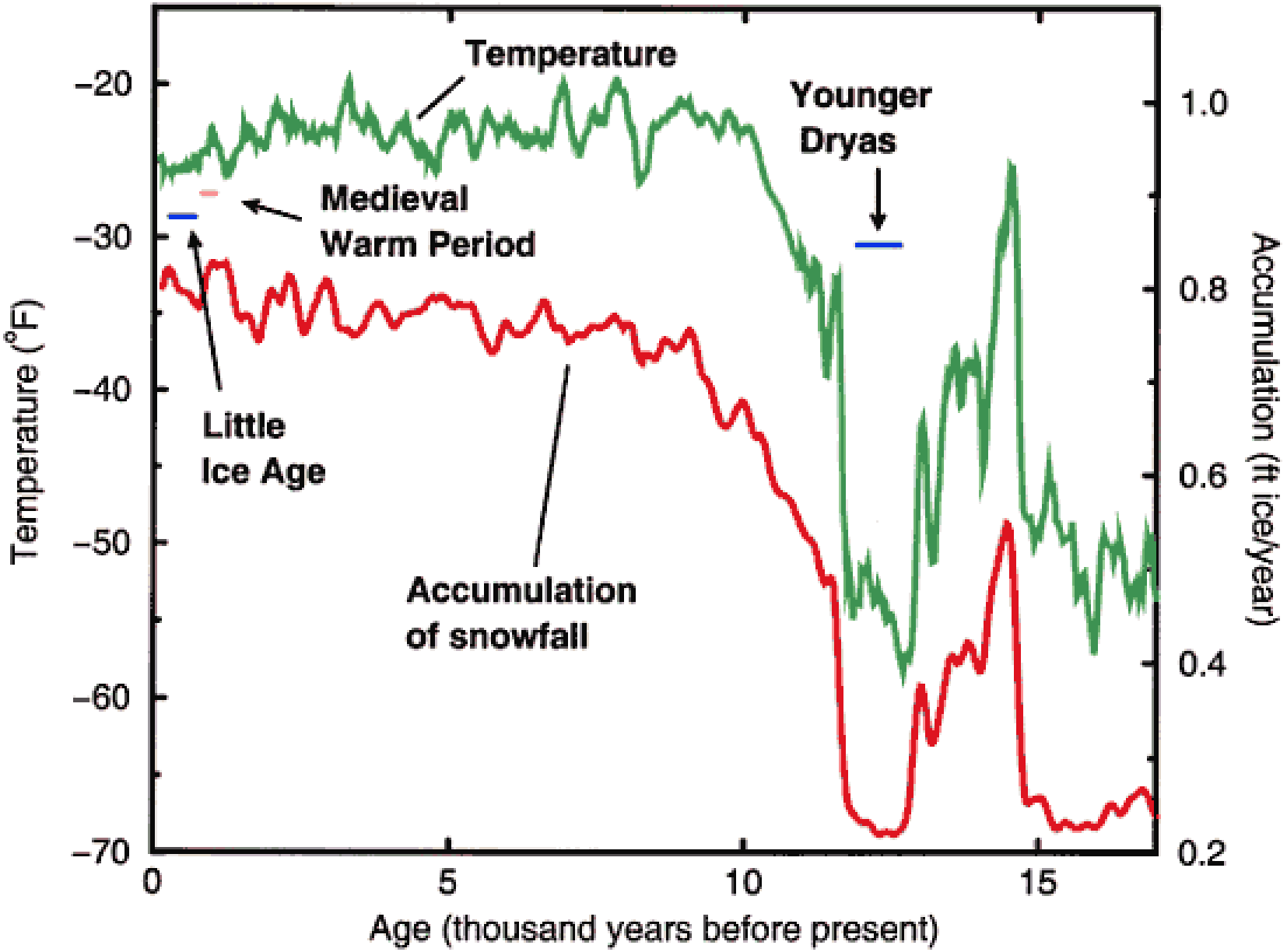
Central Greenland Climate GISP2, NSF



Alley et al., 1993;
Cuffey & Clow, 1997

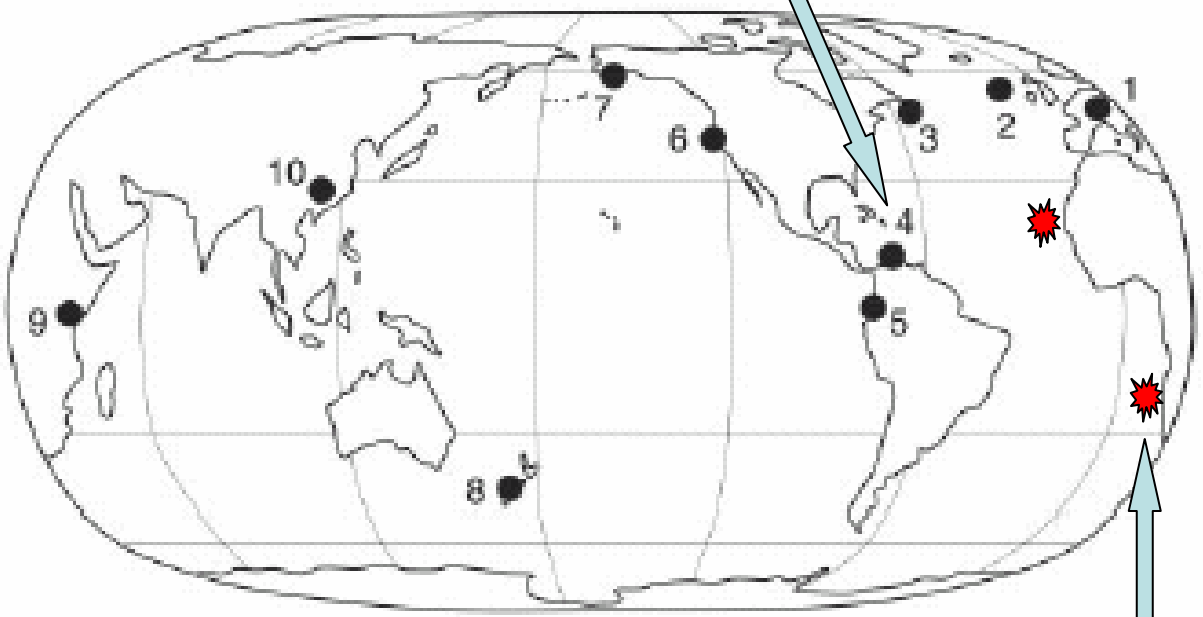
Central Greenland Climate

GISP2, NSF

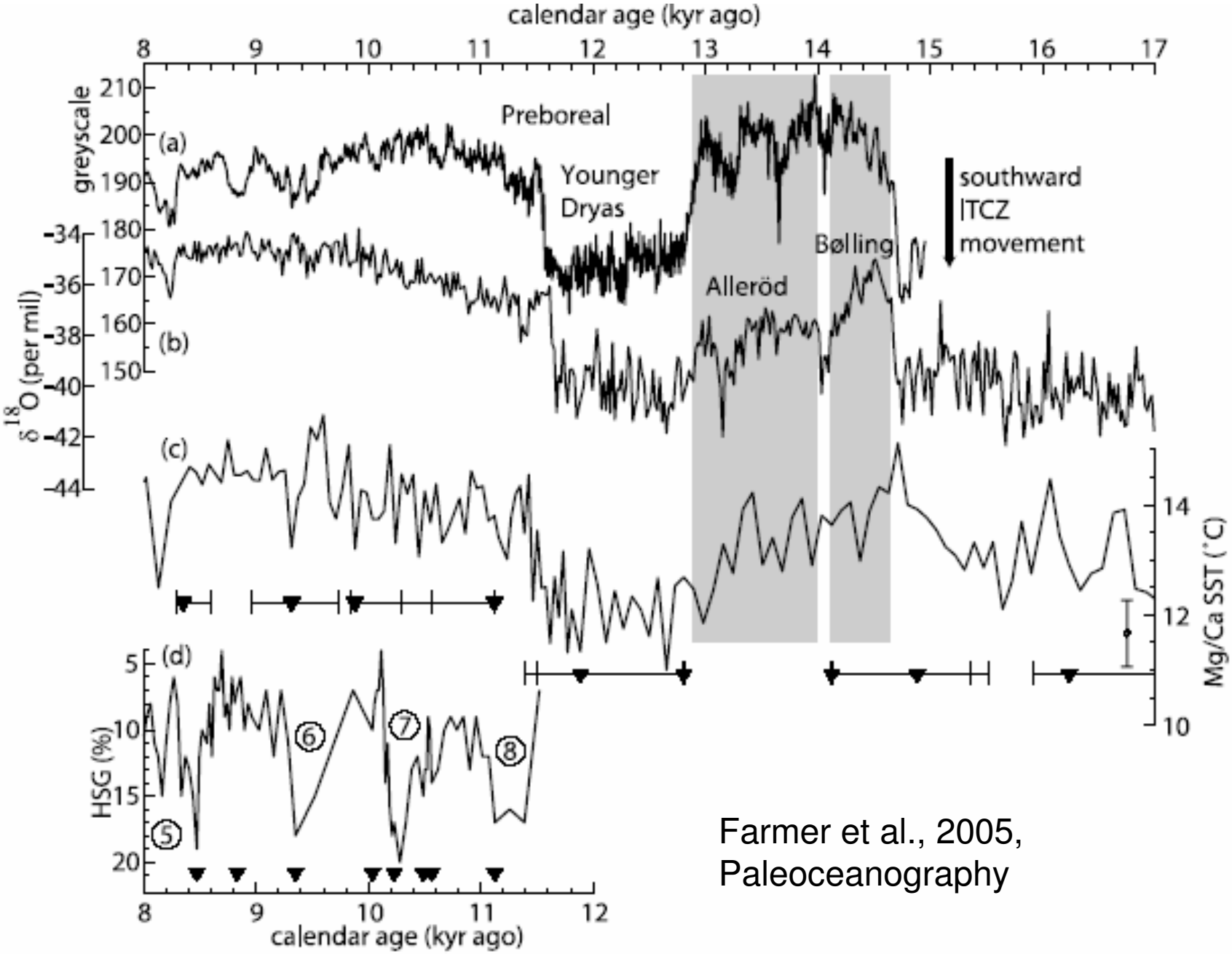


How global was the Younger Dryas?

- seems to be everywhere but Antarctica?
- but need more data from Southern Hemisphere...



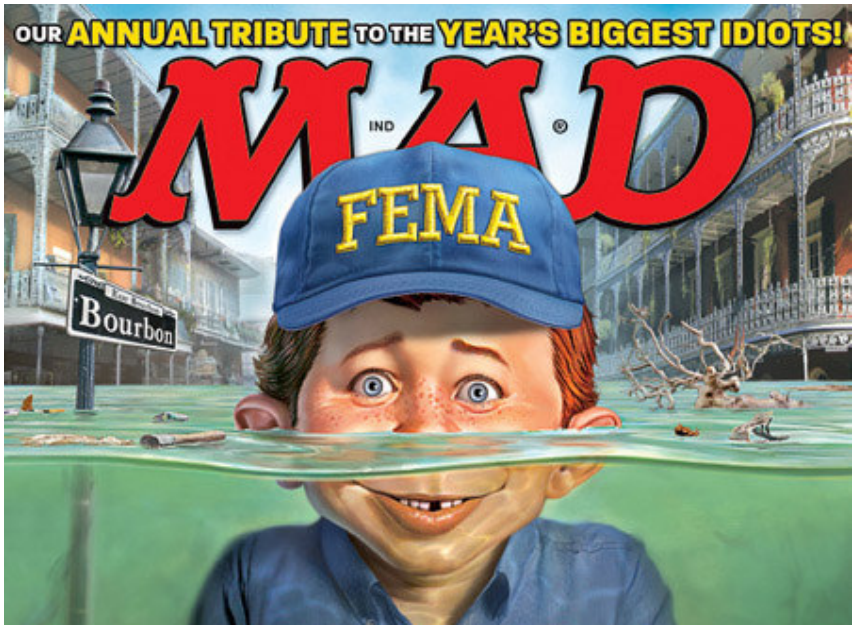
locations of well-dated Younger Dryas climate records (Broecker, 2003)



Farmer et al., 2005, Paleoceanography

Summary:

- atmospheric greenhouse gas concentrations have risen 30-240% in the last century or so
- global temperature has gone up almost 2°F in last century
- sea level is rising 3.2mm/yr in this century (~2mm/yr last century)
- sea level has risen 35m at 2cm/yr in geologic record
- greenhouse gases will continue to rise unless significant actions taken to change energy use patterns

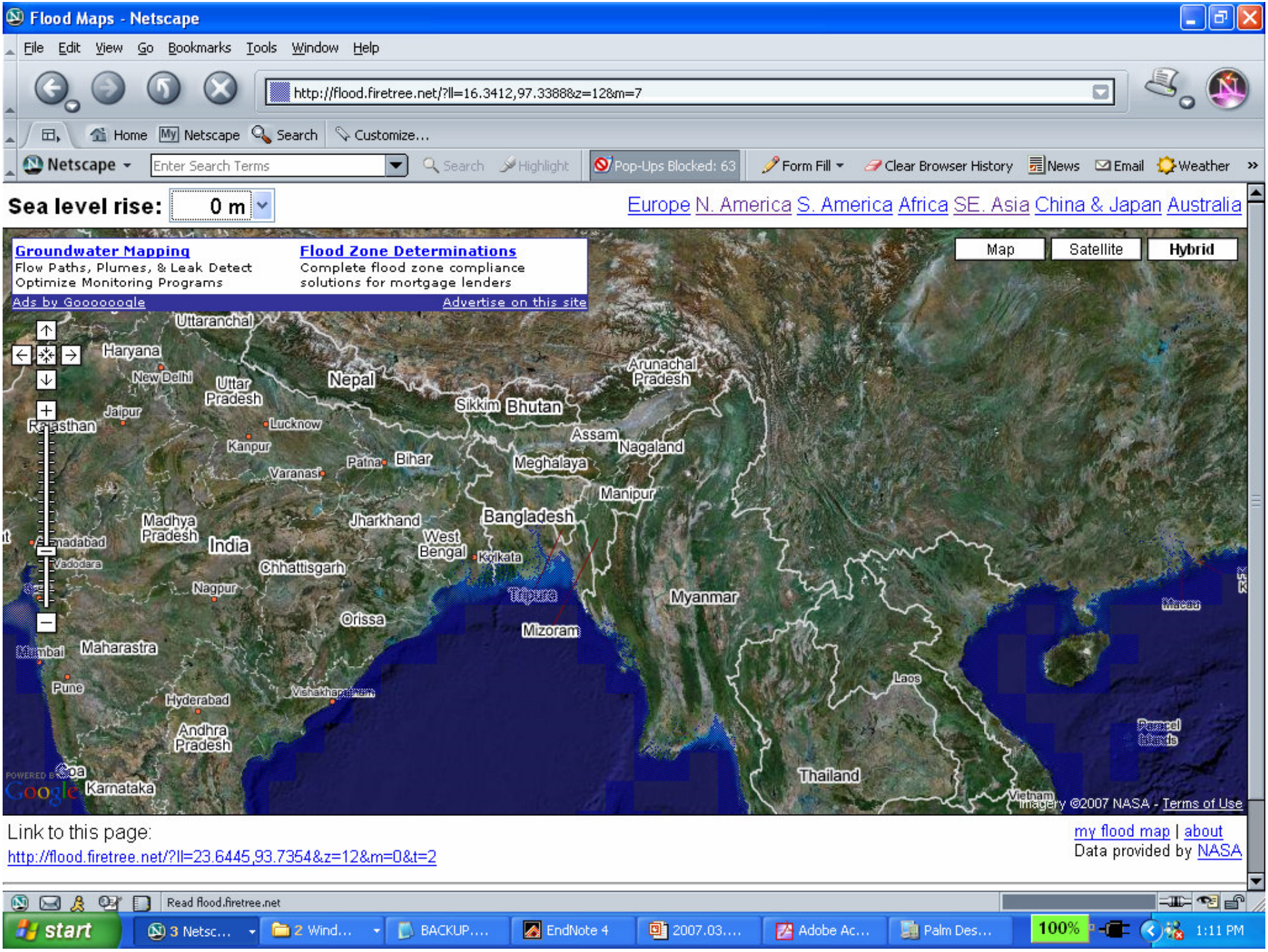


- current predictions of 4-33 inches of sea level rise in this century do not take into account possibility that glacier melt will increase substantially
- climate system is capable of significant surprises with global extent ("Younger Dryas" involved changes in deep ocean circulation)

Let's assume ~1m (~3ft) sea level rise:

- not unlikely in next 100-200 years
- what would this mean for low-lying areas of the world?
- internet tool for imagining impact:

  http://flood.firetree.net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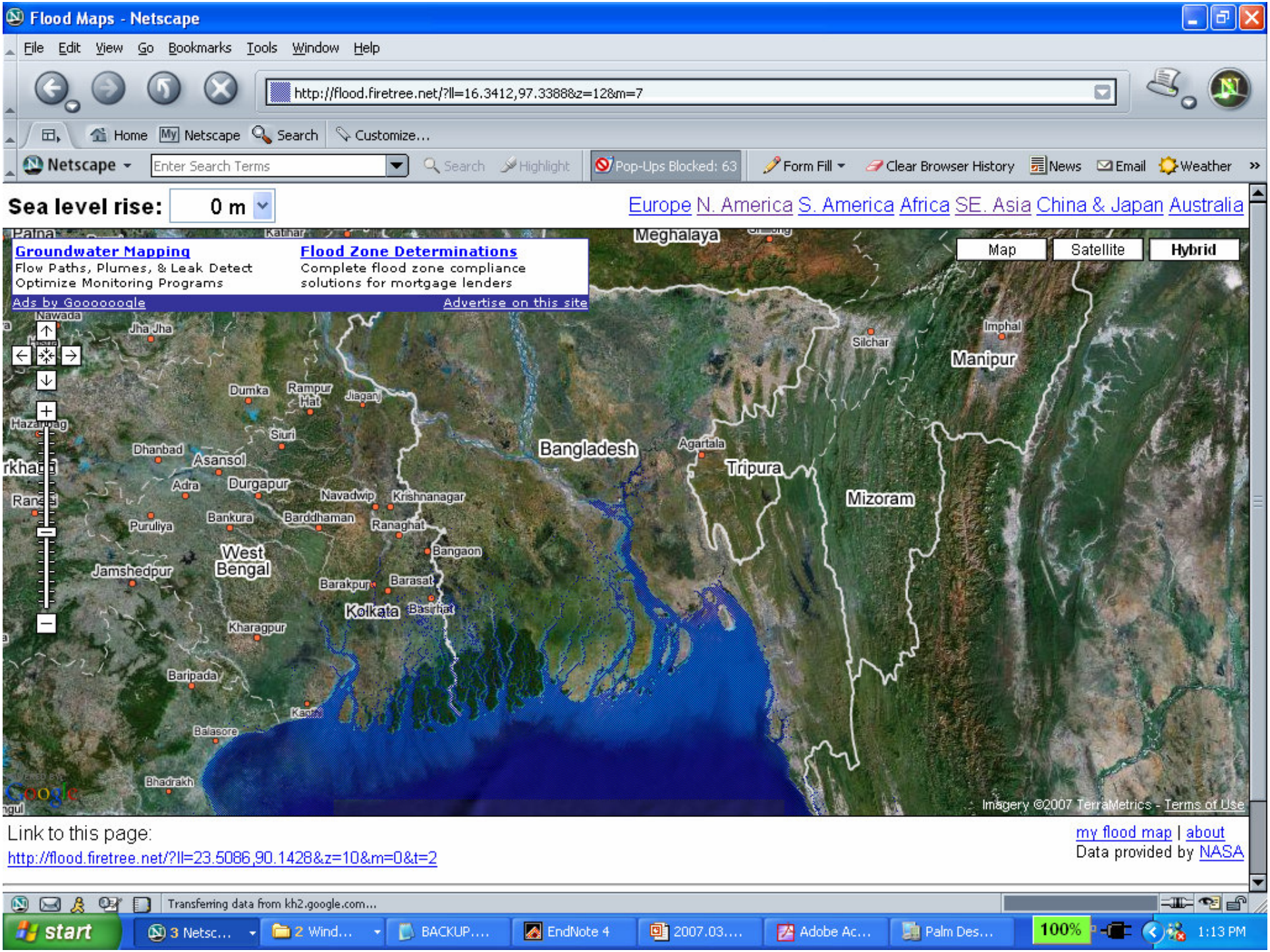
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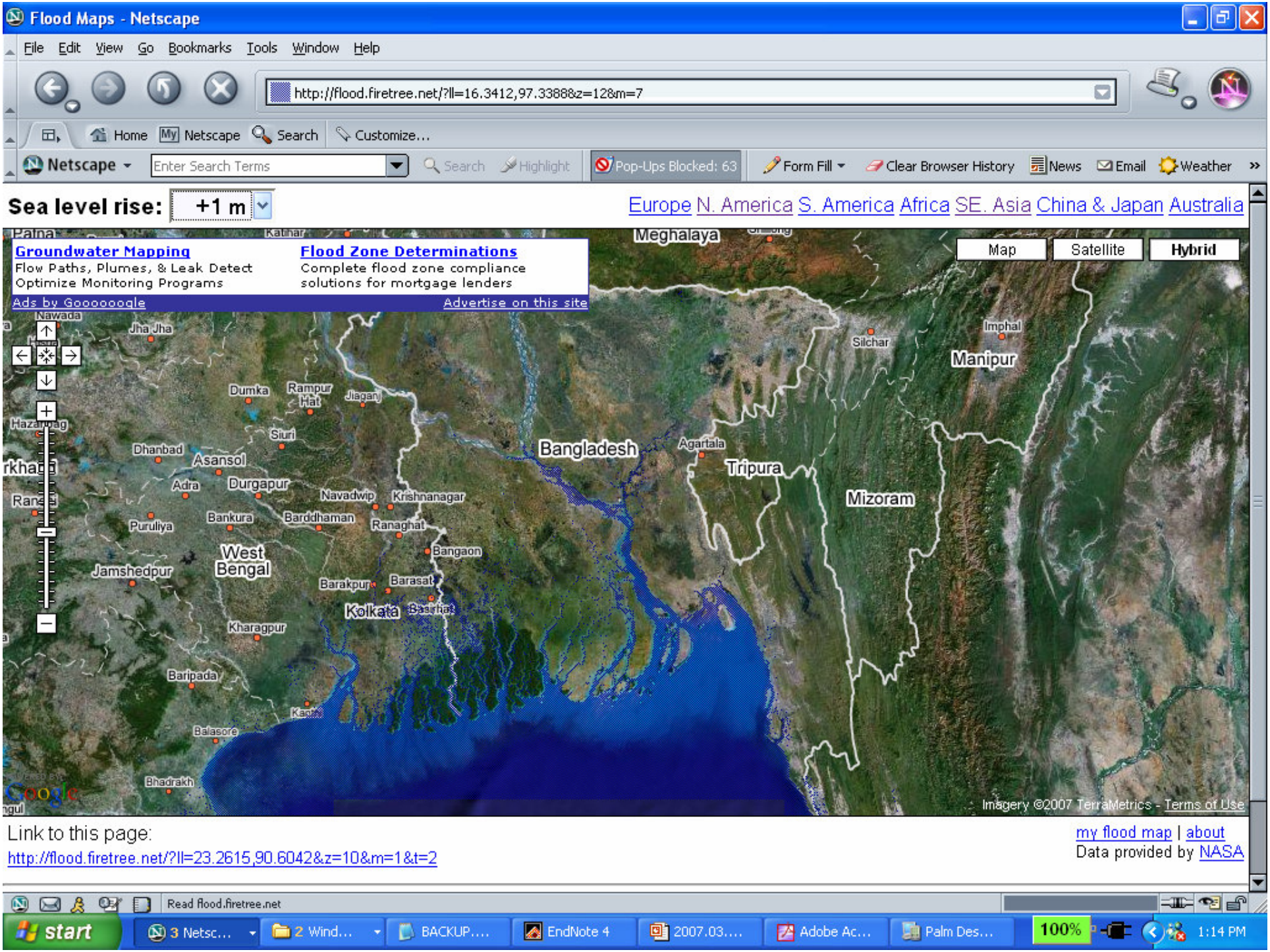
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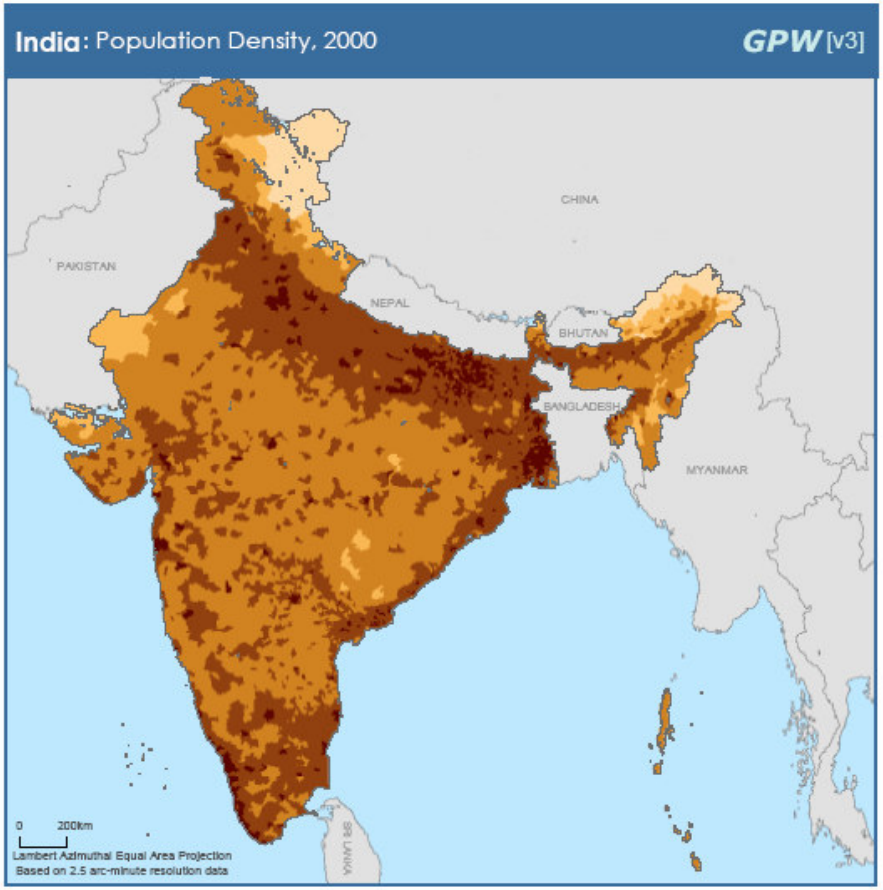
Population Densities:

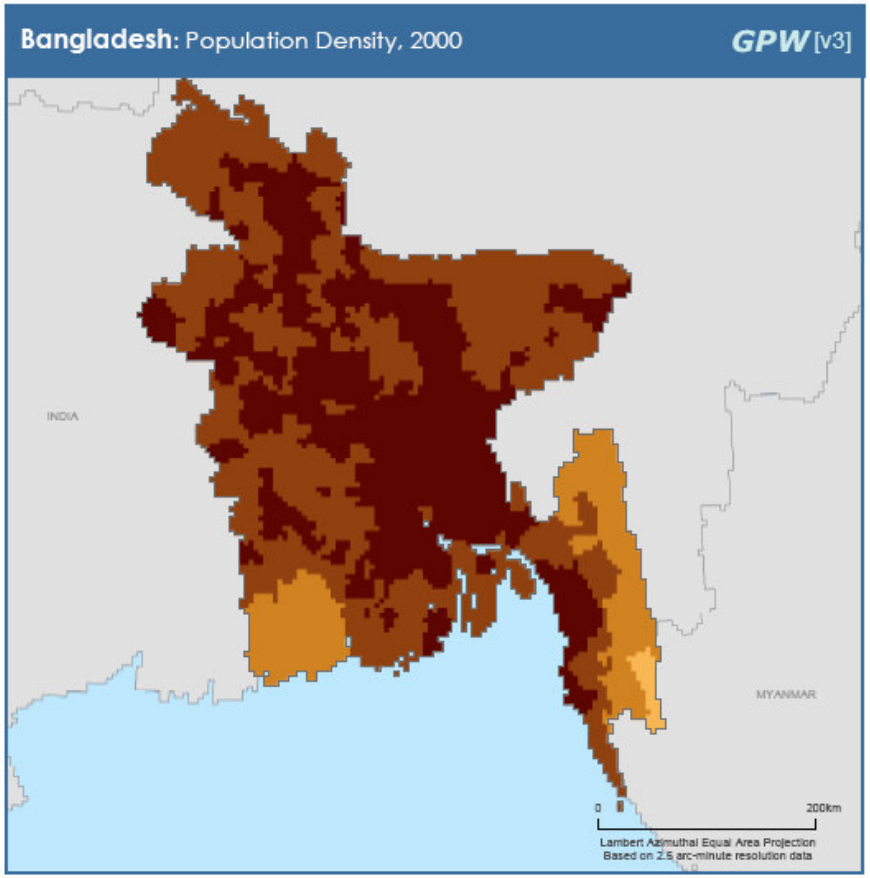


Gridded Population of the World

Persons per km^2

- 0
- 1 - 4
- 5 - 24
- 25 - 249
- 250 - 999
- 1,000 +

NOTE: National boundaries are derived from the population grids and thus may appear coarse.



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Population Density:

- population density of NYC and Long Island comparable to that of Bangladesh and Eastern India

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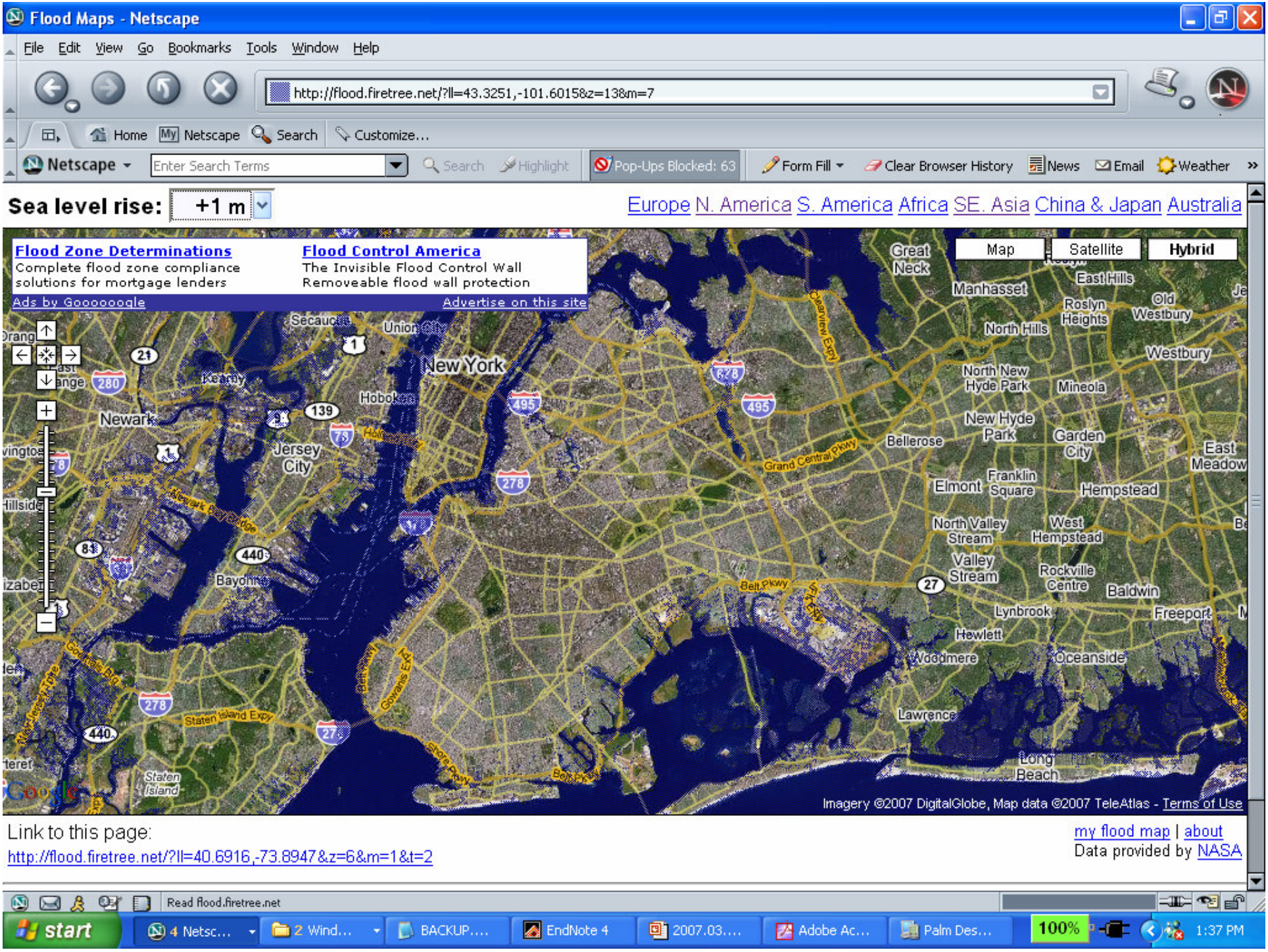
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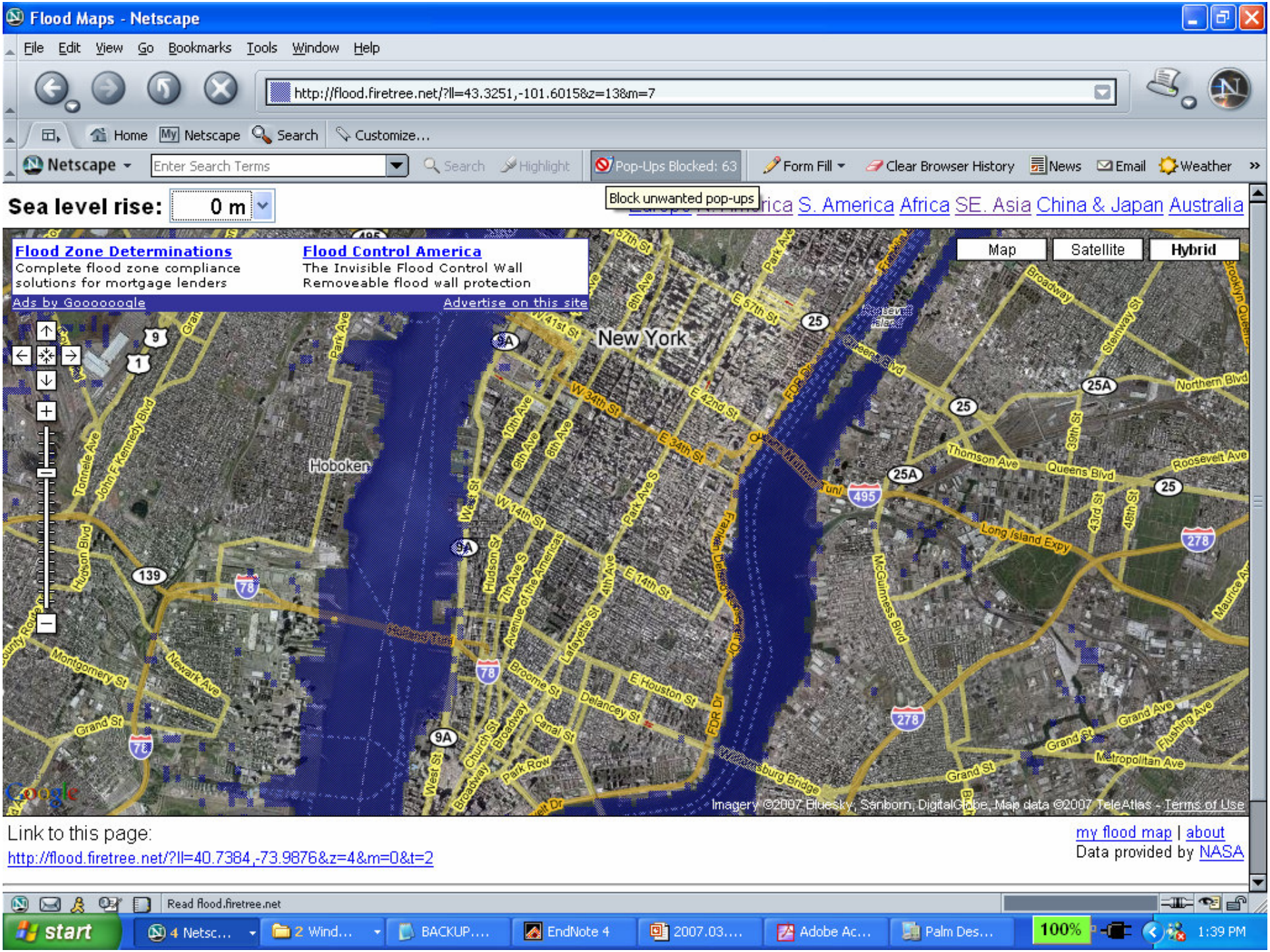
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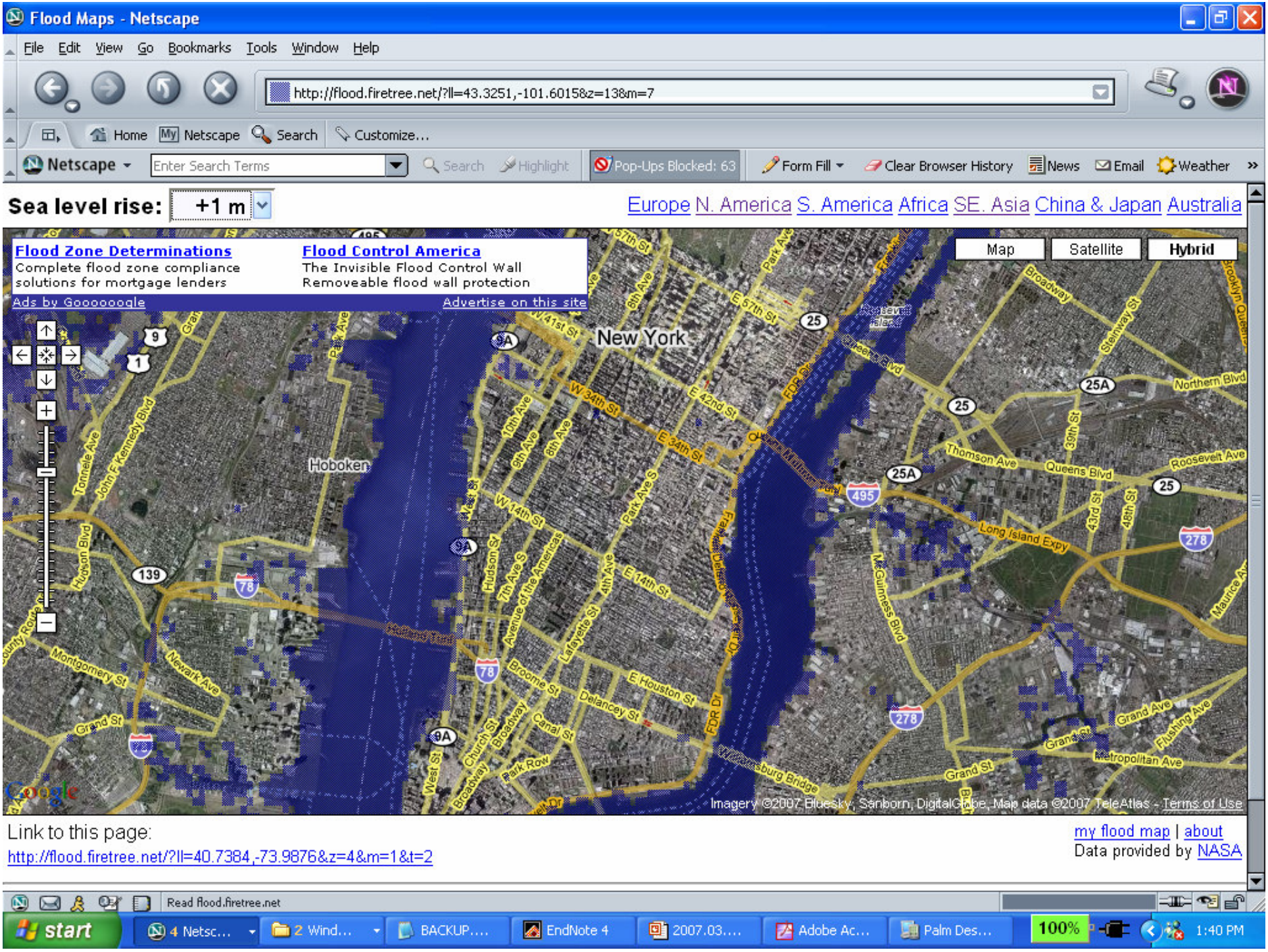
Flood Maps - Netscape
File Edit View Go Bookmarks Tools Window Help
http://flood.firetree.net/?ll=43.3251,-101.6015&z=13&m=7
Home Netscape Search Customize...
Netscape Enter Search Terms Search Highlight Pop-Ups Blocked: 63 Form Fill Clear Browser History News Email Weather
Sea level rise: +1 m
Europe N. America S. America Africa SE. Asia China & Japan Australia
Flood Zone Determinations
Complete flood zone compliance solutions for mortgage lenders
Flood Control America
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