



# POLAR EXPLORER


As a polar explorer you and your team will be collecting evidence of changes occurring throughout the world that might connect our polar regions to changing sea level. Record your evidence, then work with your team to analyze the data and develop a hypothesis to convince your colleagues to 'FOCUS ON THE POLES' when studying the Earth System!

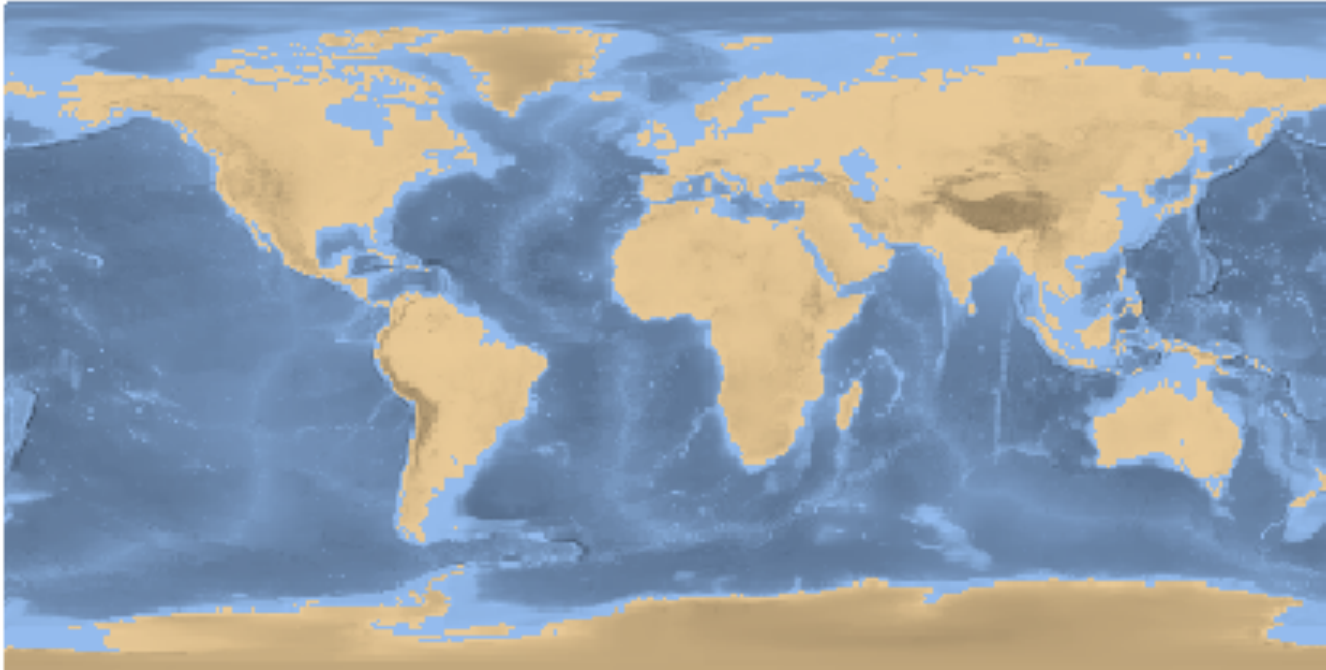
EXPLORING SEA  
LEVEL RISE



Developed by: Margie Turrin,  
mkt@ldeo.columbia.edu

POLAR  
PARTNERSHIP

 **Note:** Pages with this mark have data to record on your worksheet.



EXPLORING SEA  
LEVEL RISE

What makes  
sea level  
change?

Is Greenland's  
Ice Sheets  
Changing  
Now?

Is Antarctica's  
Ice Sheets  
Changing  
Now?

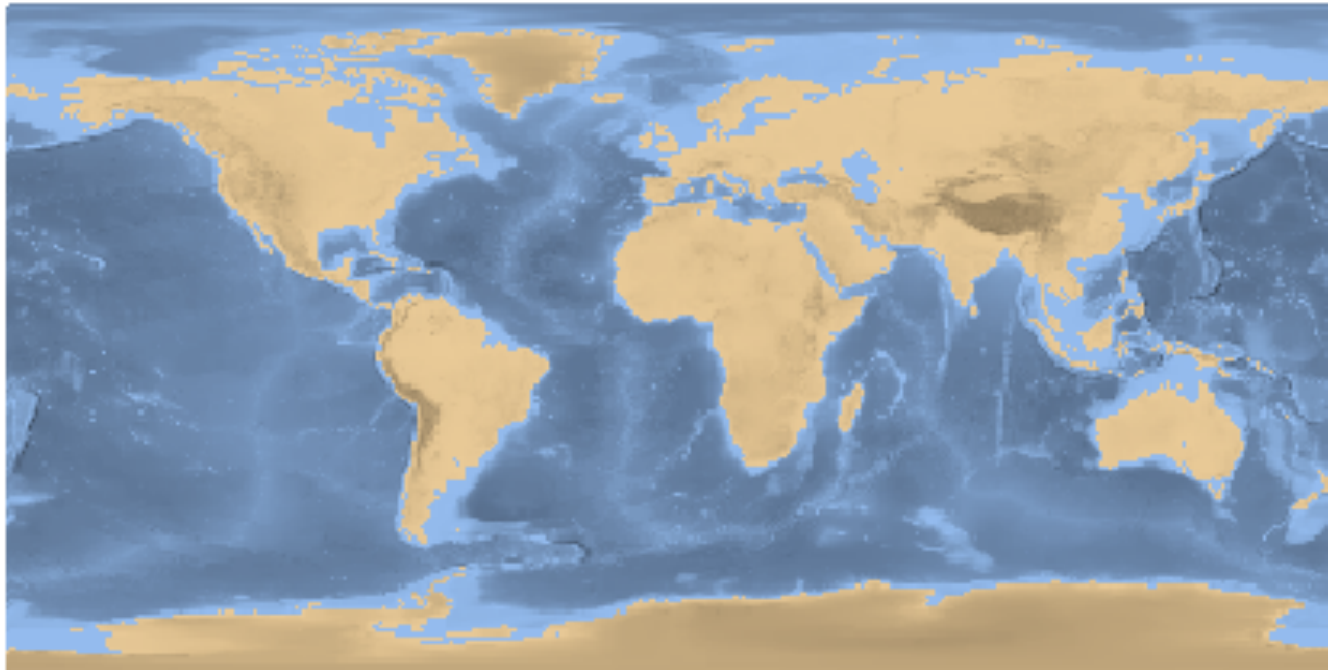
How Fast Can  
Sea Level  
Change?

How Much Ice  
Is There At  
the Poles?

Is There A  
Critical  
Tipping Point?

What Can I  
Do?

## WHAT CAUSES GLOBAL SEA LEVEL TO CHANGE?



EXPLORING SEA  
LEVEL RISE

### PART 1

What makes  
sea level  
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Is Greenland's  
Ice Sheets  
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Is Antarctica's  
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How Fast Can  
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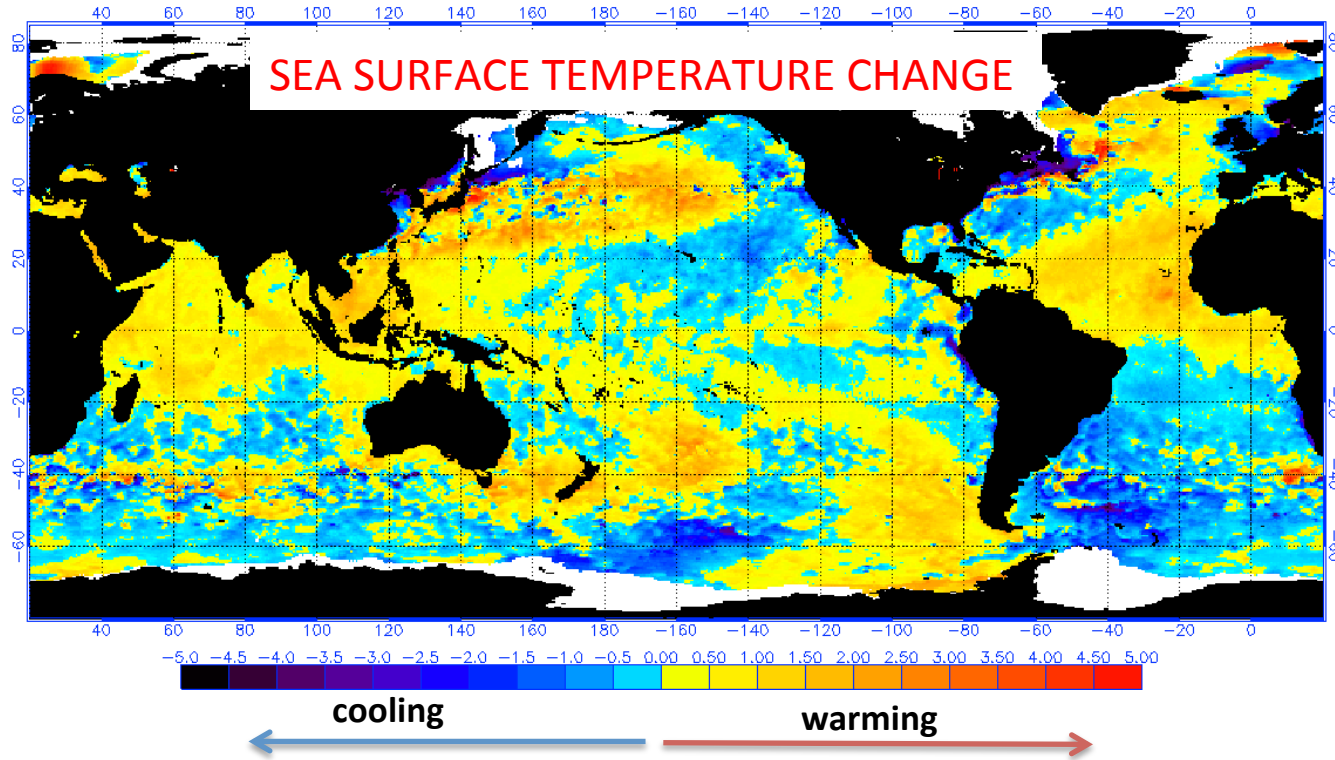
How Much Ice  
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## HOW MUCH HAS THE OCEAN SURFACE WARMED?

NOAA/NESDIS 50 KM GLOBAL ANALYSIS: SST Anomaly (degrees C), 4/1/2013  
(white regions indicate sea-ice)



<http://www.ospo.noaa.gov/Products/ocean/sst/anomaly/index.html>

EXPLORING SEA  
LEVEL RISE

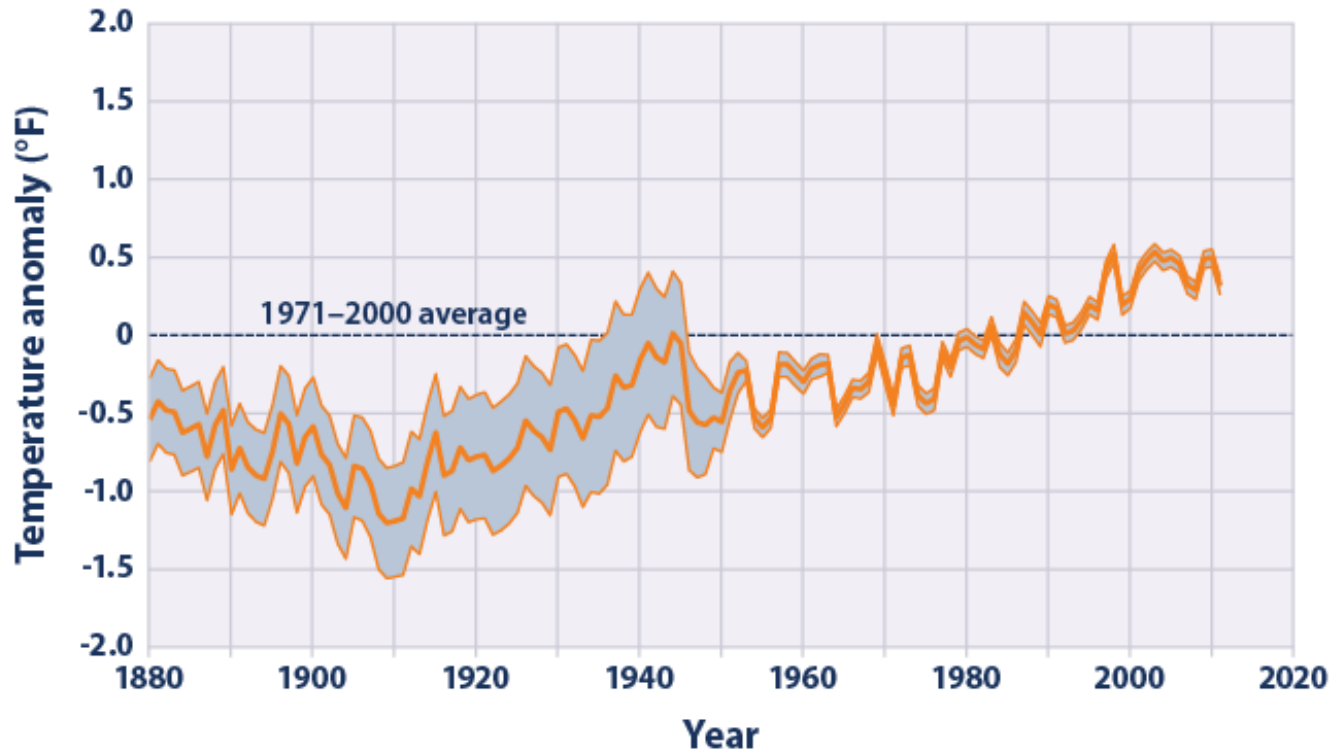
**'Science Fact':** A warming ocean expands in size causing sea level to rise, and begins to melt glacial ice.

What makes sea level change?	Oceans are Warming: Expanding & melting ice
Is Greenland's Ice Sheets Changing Now?	Atmosphere is warming: Melting polar ice
Is Antarctica's Ice Sheets Changing Now?	Warm Water Expands in the ocean
How Fast Can Sea Level Change?	Melting polar Ice from warm ocean and air is adding to the ocean
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## SEA SURFACE TEMPERATURE CHANGE

Average Global Sea Surface Temperature, 1880–2011



Data source: NOAA (National Oceanic and Atmospheric Administration), 2012. Extended reconstructed sea surface temperature (ERSST.v3b). National Climatic Data Center. Accessed April 2012. [www.ncdc.noaa.gov/ersst/](http://www.ncdc.noaa.gov/ersst/). <http://www.epa.gov/climatechange/science/indicators/oceans/sea-surface-temp.html>

EXPLORING SEA  
LEVEL RISE

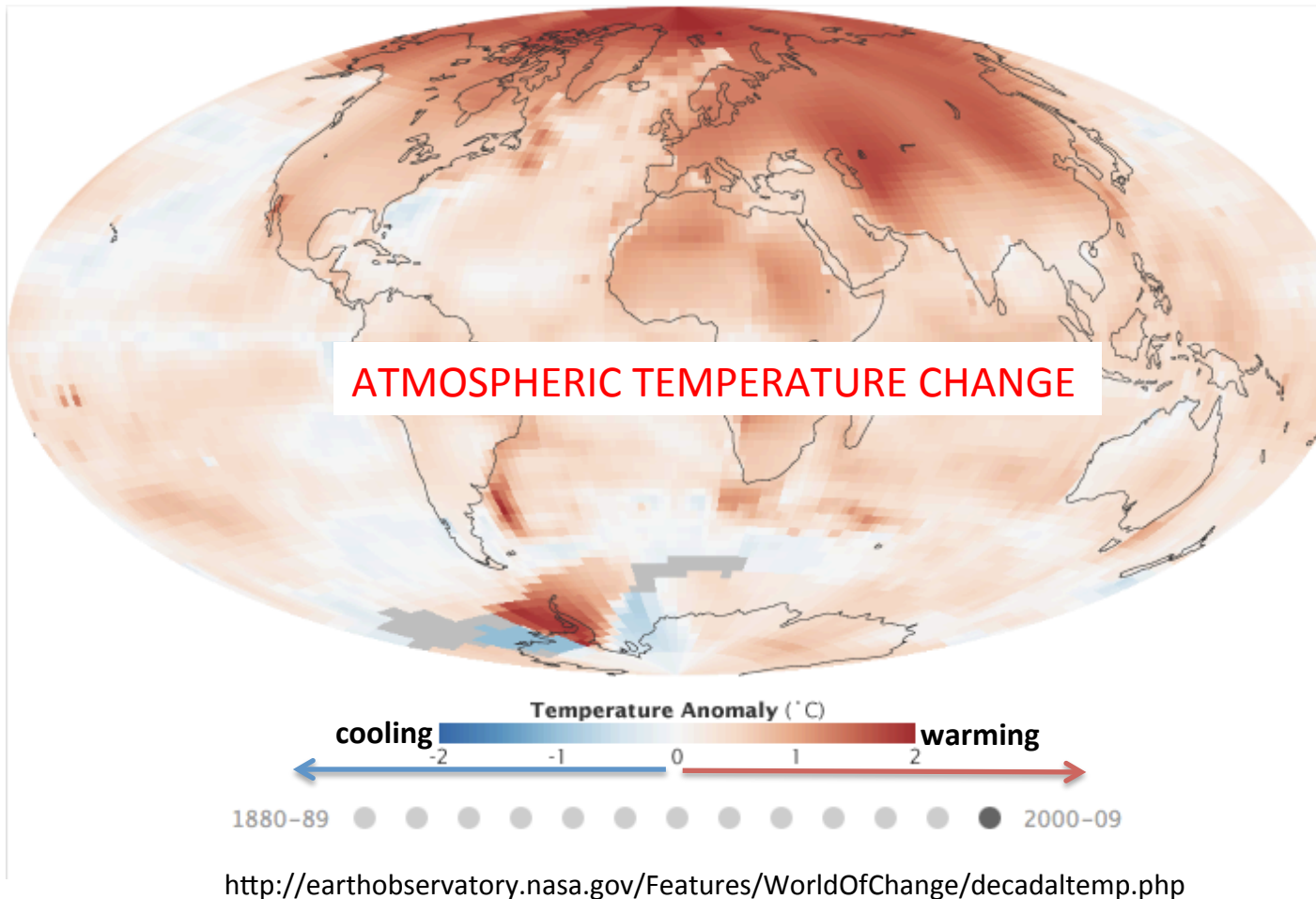
**RECORD: HOW MUCH HAS THE SURFACE OF THE OCEAN WARMED FROM 1880-2011?**

**Note: 'Anomaly'** is often the way scientists measure change. It measures differences compared to the average for a period of time.

What makes sea level change?	<b>Oceans are Warming: Expanding &amp; melting ice</b>
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# HOW MUCH HAS THE ATMOSPHERE WARMED?



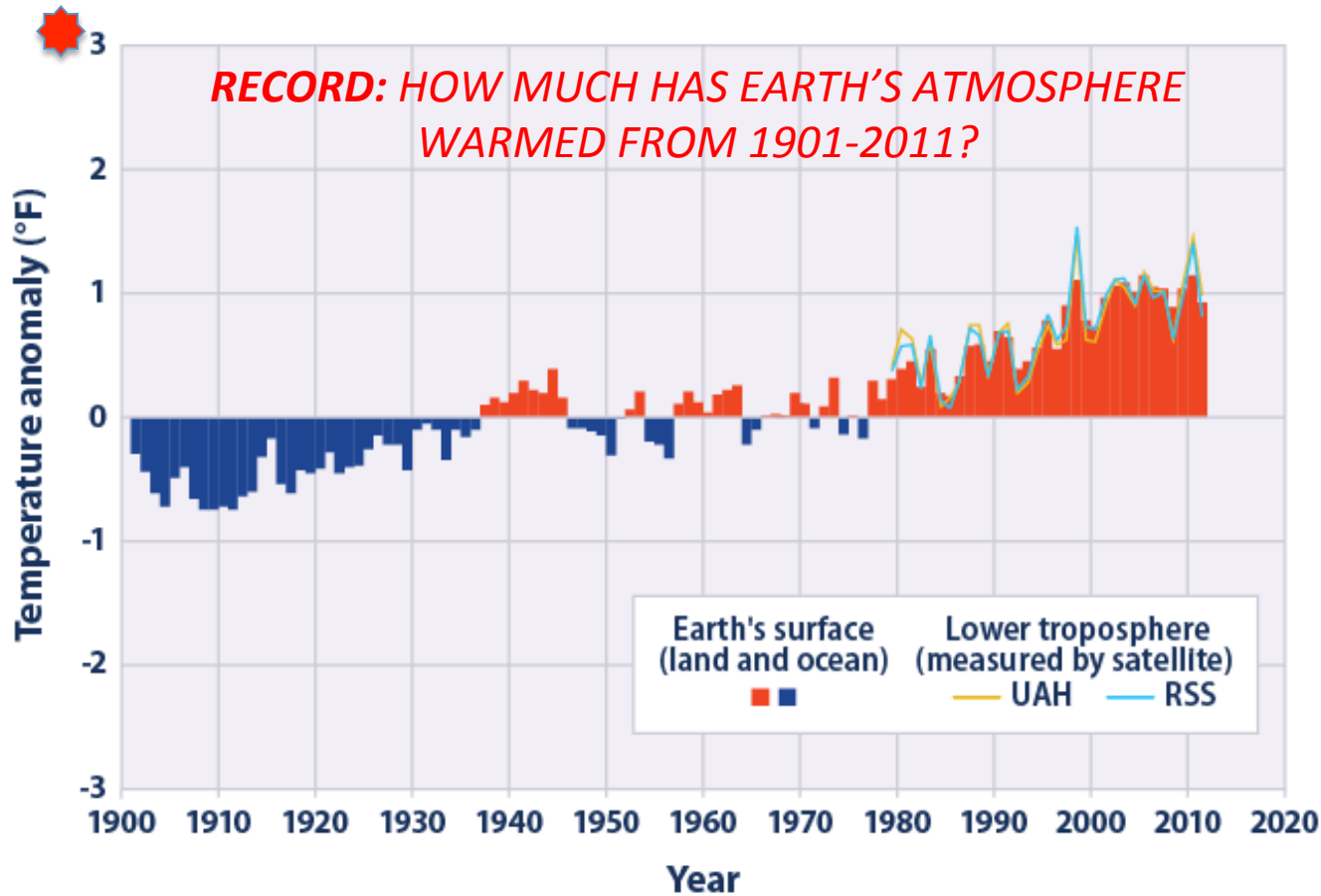
<http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php>

**EXPLORING SEA LEVEL RISE**

**‘Science Fact’:** A warming atmosphere warms the global oceans and begins to melt glacial ice.

What makes sea level change?	Oceans are Warming: Expanding & Melting ice
Is Greenland’s Ice Sheets Changing Now?	<b>Atmosphere is warming: Melting polar Ice</b>
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## Temperatures Worldwide, 1901–2011



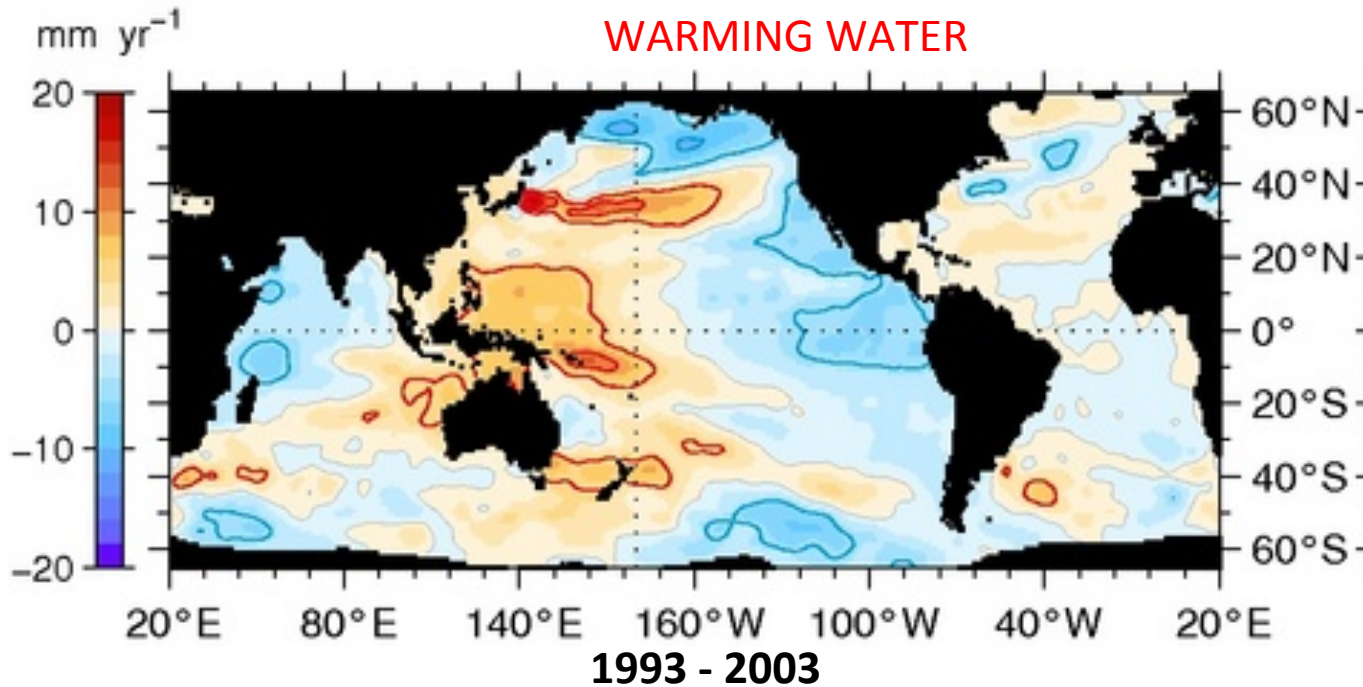
Data source: NOAA (National Oceanic and Atmospheric Administration), 2012. National Climatic Data Center. Accessed April 2012. [www.ncdc.noaa.gov/oa/ncdc.html](http://www.ncdc.noaa.gov/oa/ncdc.html)  
<http://www.epa.gov/climatechange/science/indicators/weather-climate/temperature.html>

### EXPLORING SEA LEVEL RISE

Note: Earth's surface data from land-based weather stations and sea surface temperature measurements. Lower troposphere measurement (atmosphere layer closest to the Earth) by satellite.

What makes sea level change?	Oceans are Warming: Expanding & Melting ice
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## THERMAL EXPANSION OF THE OCEAN FROM WARMING WATER



Like a hot air balloon water expands as it warms. This is called ‘thermal expansion’. Above black is land, colors are ocean water expansion from warming from 1993 to 2003. Temperature varies throughout the ocean causing the differences in the expansion.

[http://www.cmar.csiro.au/sealevel/sl\\_drives\\_longer.html](http://www.cmar.csiro.au/sealevel/sl_drives_longer.html)

### HOW MUCH HAS THE OCEAN EXPANDED FROM WARMING?

EXPLORING SEA LEVEL RISE

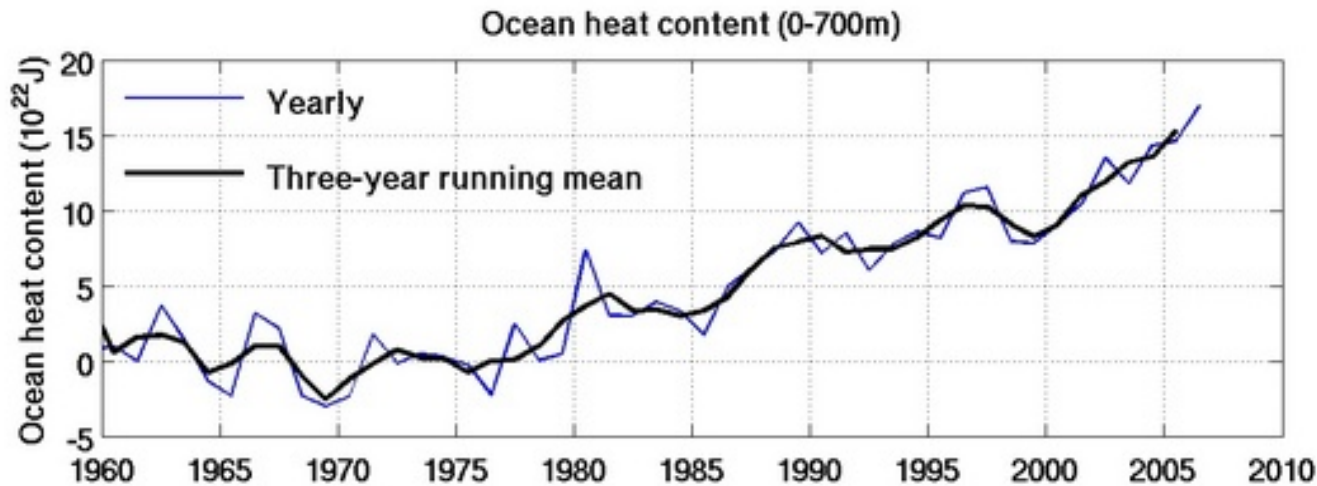
‘Science Fact’: Water **EXPANDS** as it warms and **shrinks** as it cools. A warming ocean expands in size causing sea level to rise.

What makes sea level change?	Oceans are Warming: Expanding & Melting ice
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## Ocean heat content (0-700m of depth)



[http://www.cmar.csiro.au/sealevel/sl\\_drives\\_longer.html](http://www.cmar.csiro.au/sealevel/sl_drives_longer.html)

**RECORD: HOW MUCH HAS THE OCEAN WARMED & EXPANDED 1960-2007?**

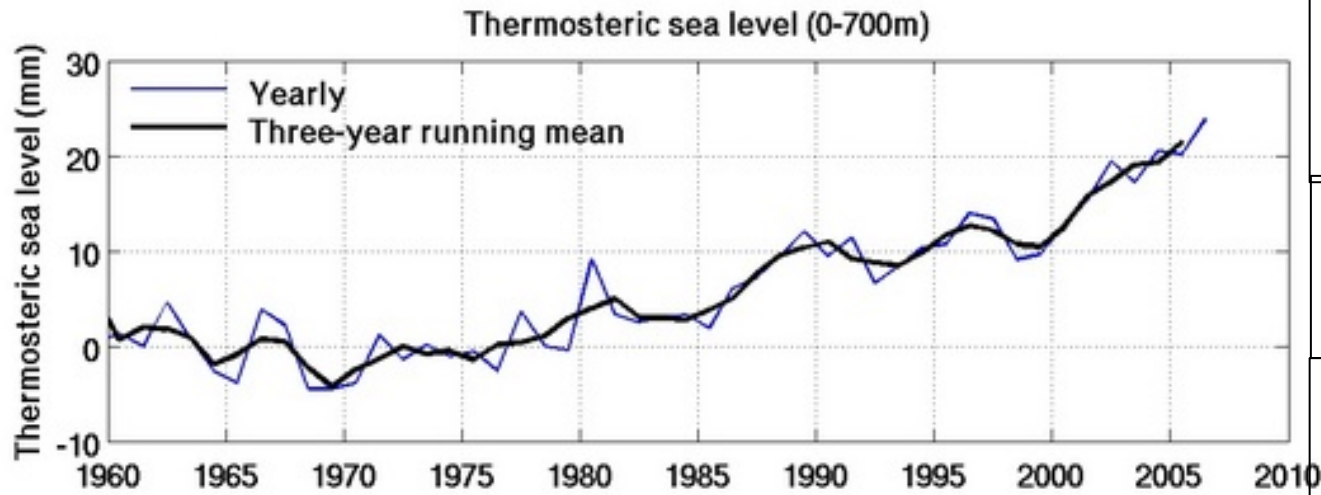
\*Heat in Joules. In water 4.184 Joules = 1 calorie.  
1 calorie is the heat needed to raise 1 gram of water 1°C.

EXPLORING SEA  
LEVEL RISE

What makes sea level change?	Oceans are Warming: Expanding & Melting ice
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Is Antarctica's Ice Sheets Changing Now?	<b>Warm Water Expands in the ocean</b>
How Fast Can Sea Level Change?	Melting polar Ice from warm ocean and air is adding to the ocean
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## Ocean Expansion (0-700m of depth)



[http://www.cmar.csiro.au/sealevel/sl\\_drives\\_longer.html](http://www.cmar.csiro.au/sealevel/sl_drives_longer.html)

***RECORD: HOW MUCH HAS THE OCEAN WARMED & EXPANDED 1960-2007?***

\*Thermosteric is change in sea surface height from expansion/contraction from temperature change

What makes sea level change?

Oceans are Warming: Expanding & Melting ice

Is Greenland's Ice Sheets Changing Now?

Atmosphere is warming: Melting polar Ice

Is Antarctica's Ice Sheets Changing Now?

**Warm Water Expands in the ocean**

How Fast Can Sea Level Change?

Melting polar Ice from warm ocean and air is adding to the ocean

How Much Ice Is There At the Poles?

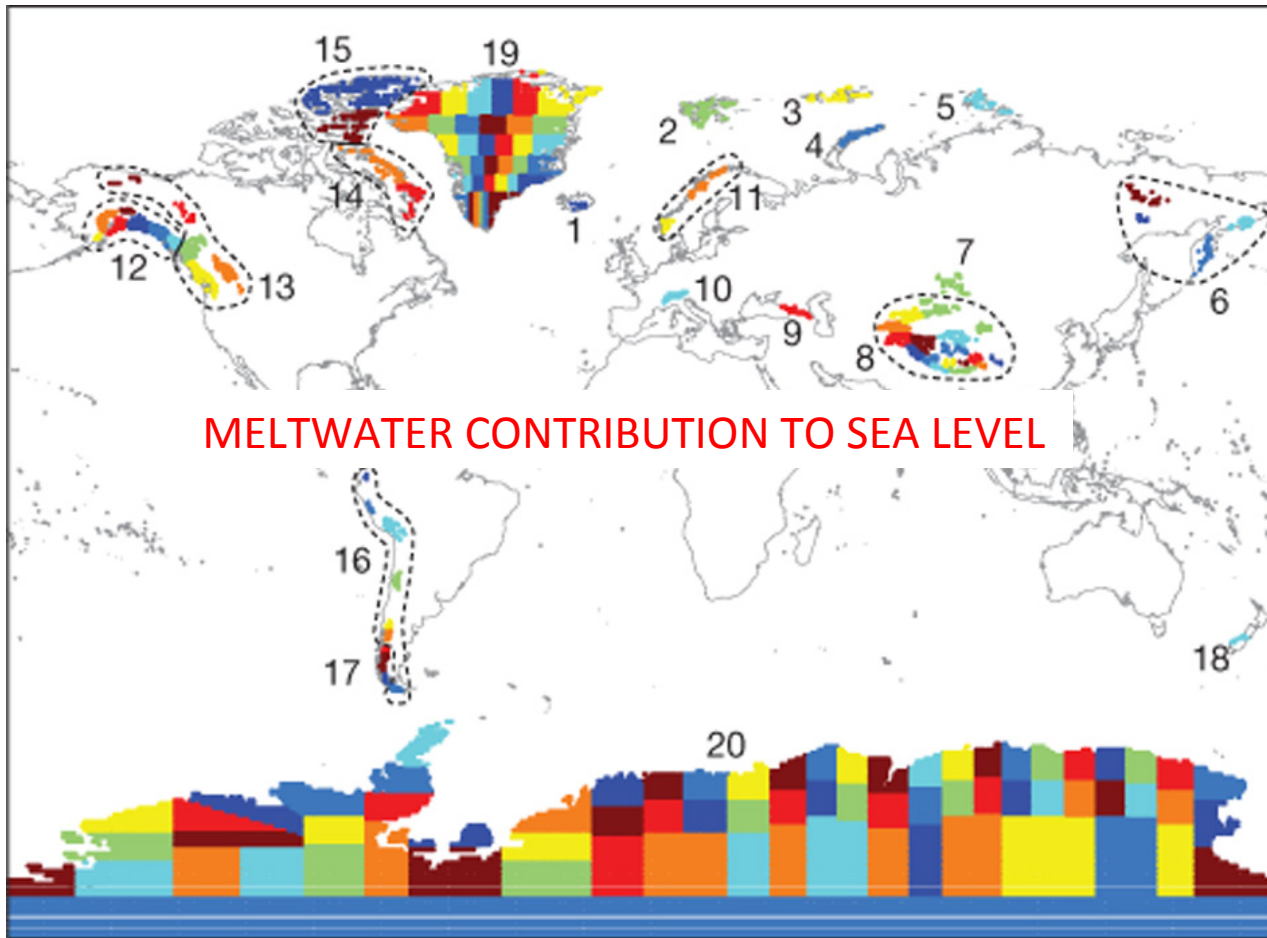
Is There A Critical Tipping Point?

Does Melting Sea Ice Contribute to Sea Level?

What Can I Do?

EXPLORING SEA LEVEL RISE

POLAR PARTNERSHIP



Glaciers and Ice cap meltwater contribution areas, from Jacob et al Nature paper, 2012

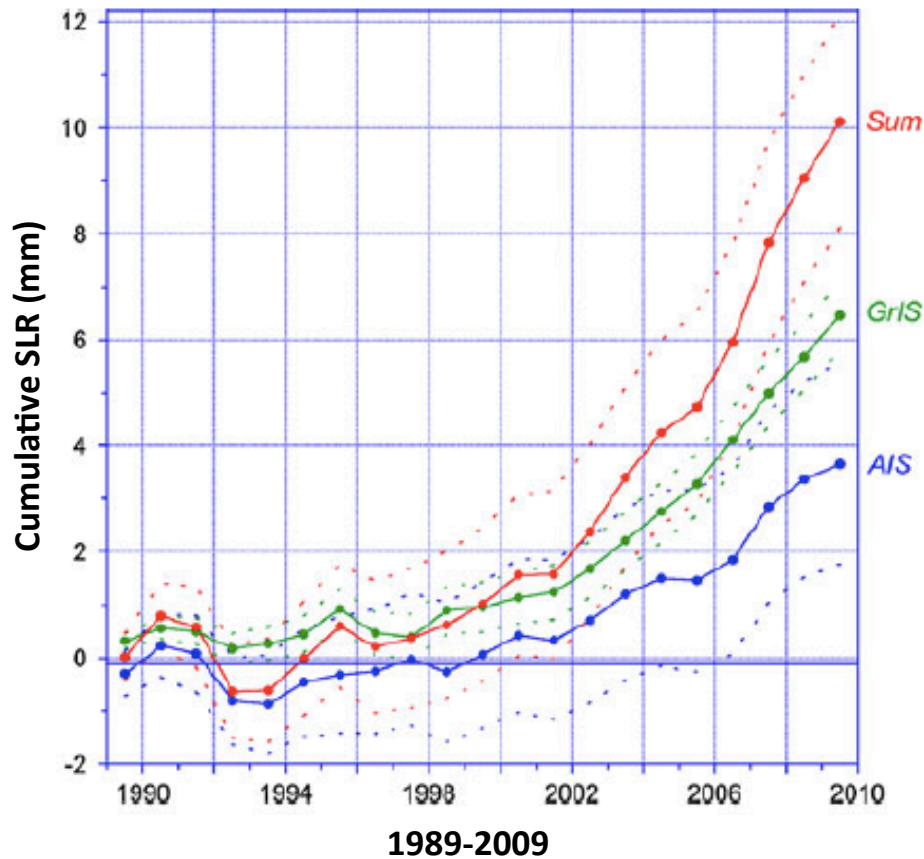
**HOW MUCH MORE WATER IS IN THE OCEAN FROM MELTING POLAR GLACIERS?**

EXPLORING SEA LEVEL RISE

**‘Science Fact’:** Melting ice from the Earth’s glaciers adds to the oceans causing sea level to rise.

What makes sea level change?	Oceans are Warming: Expanding & Melting ice
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# YEARLY POLAR MELTWATER CONTRIBUTIONS TO SEA LEVEL



Sea level rise contributions from the Ice Sheets. Antarctica (AIS-blue). Greenland (GrIS-green). Red is the sum. Dashed lines outline uncertainty.

<http://link.springer.com/content/pdf/10.1007%2Fs10712-011-9137-z.pdf>

EXPLORING SEA LEVEL RISE

**RECORD: HOW MUCH WATER IS BEING ADDED TO THE OCEANS FROM POLAR GLACIERS?**

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Sea Ice Extent  
Dec 2012

## DOES MELTING SEA ICE CAUSE SEA LEVEL TO CHANGE?

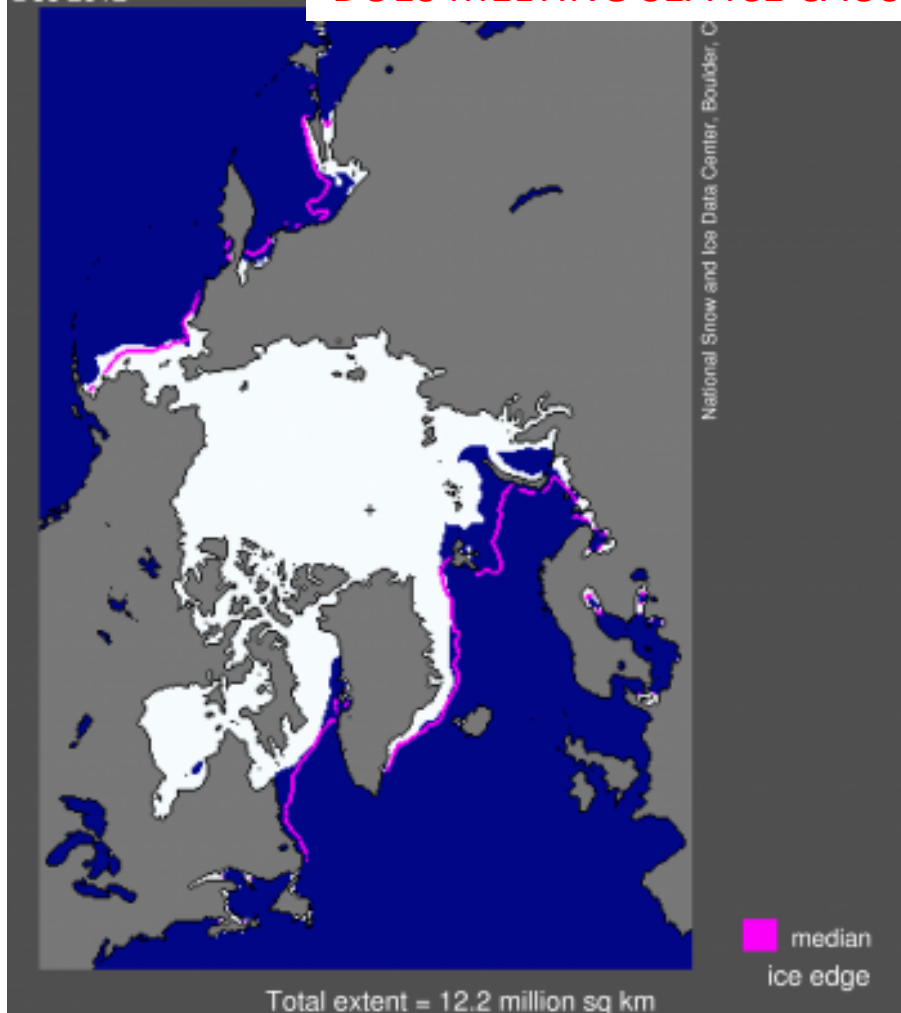


Image from NSIDC

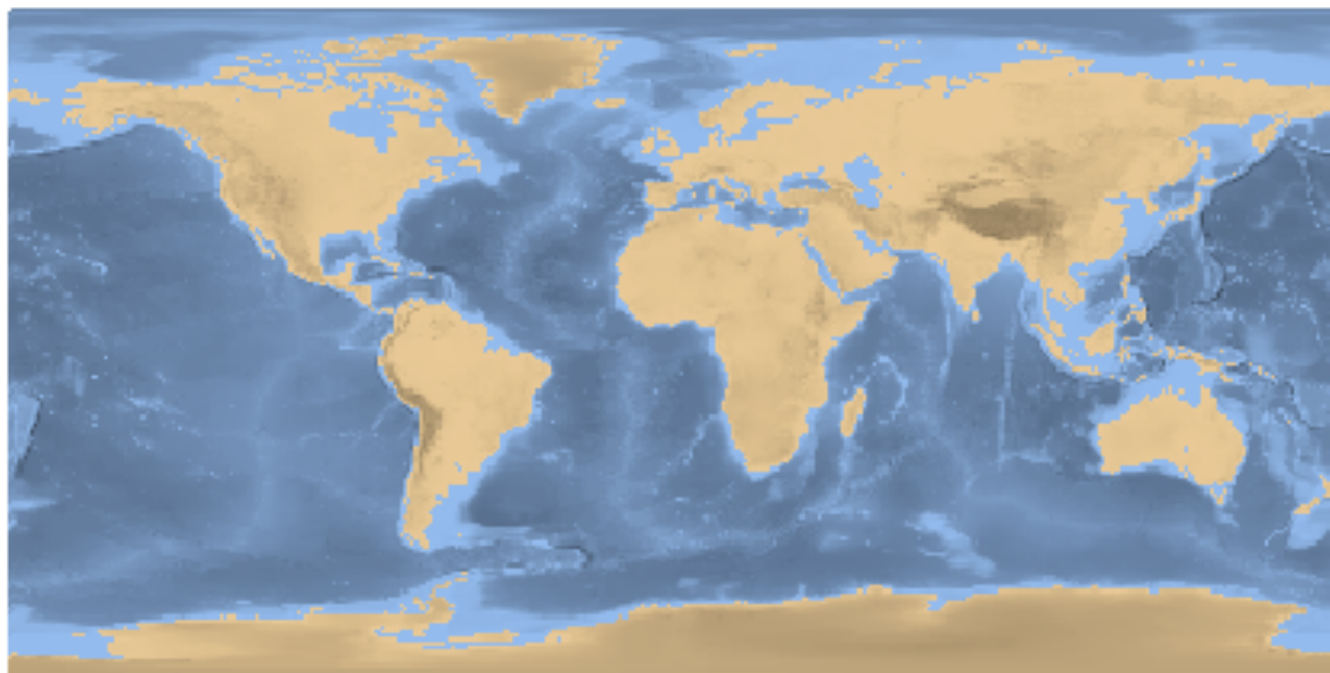
EXPLORING SEA  
LEVEL RISE

**‘SCIENCE FACT’:** Not Directly. In the image above sea ice is white and land is grey. Sea ice already floats directly in the ocean so as it melts it does not add new volume to the ocean.

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***SO WHAT MAKES GLOBAL SEA  
LEVEL CHANGE?***



***TIME TO EXAMINE YOUR EVIDENCE AND FINISH THIS SECTION OF  
YOUR WORKSHEET TO FIND OUT WHAT MAKES SEA LEVEL CHANGE &  
IF YOU FOUND A POLAR CONNECTION!***

**EXPLORING SEA  
LEVEL RISE**

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How Fast Can  
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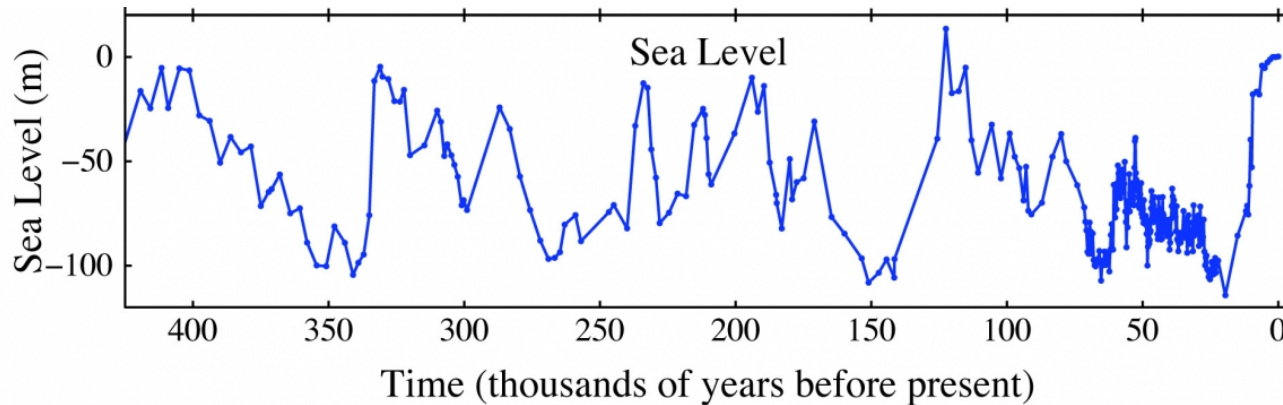
How Much Ice  
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the Poles?

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What Can I  
Do?

**HOW FAST CAN SEA LEVEL CHANGE?  
WORK BACK THROUGH TIME TO FIND OUT!**

SEA LEVEL DATA CALCULATED FROM THE LAKE VOSTOK, ANTARCTIC ICE CORE



Edited chart from NASA scientist Dr. James Hansen.  
<http://www.johnenglander.net/t-co2-sl-420kyr-chart>

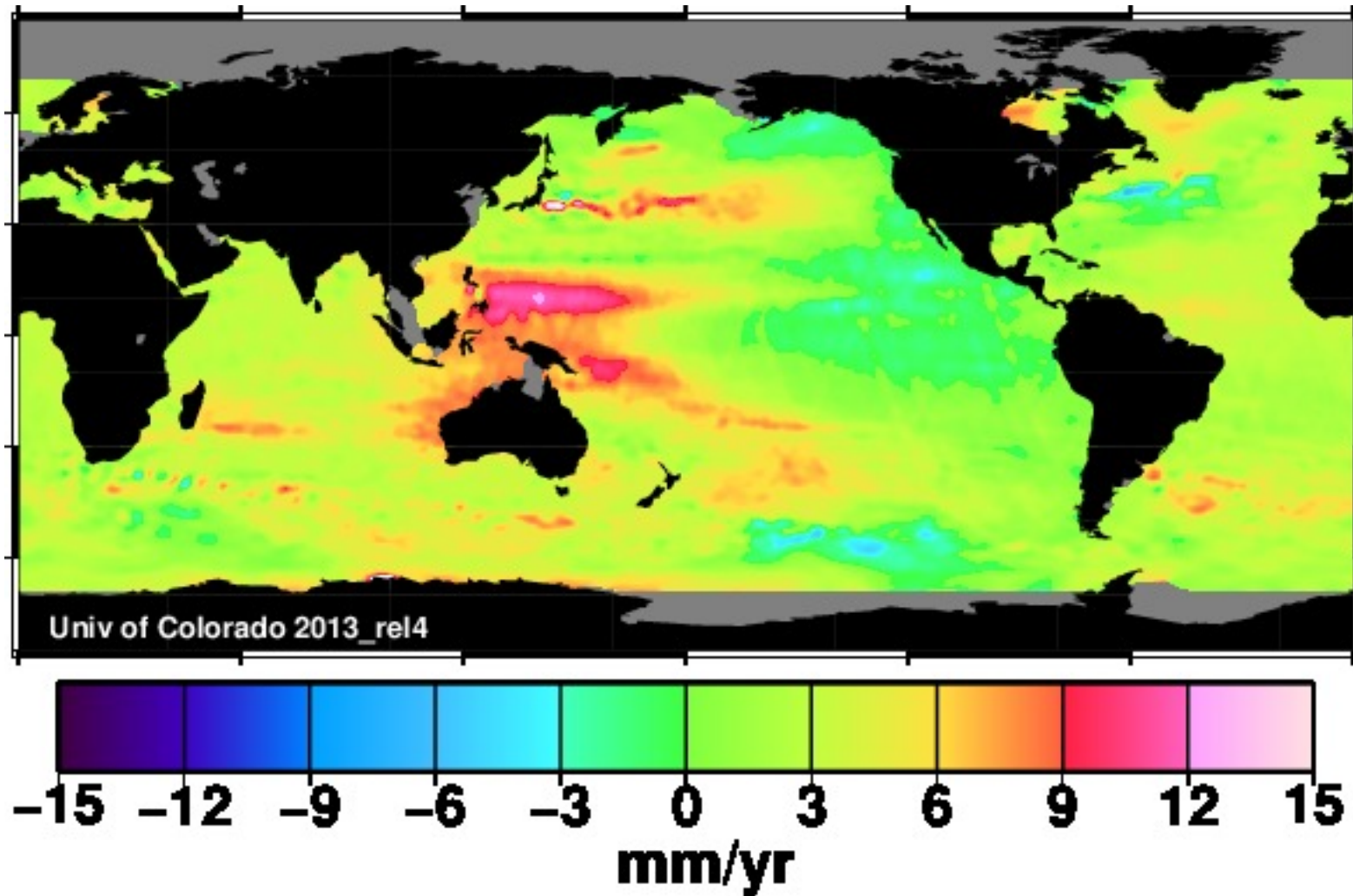
The Earth's Climate has changed throughout its history. We know this from ice cores taken from Antarctica and Greenland. Data from the Vostok core shows the ~100,000 year fluctuation between glacial and interglacial periods with water moving between the oceans and glacial ice changing sea level as it moved.

How Fast Can Sea Level Change?

**PART 2**

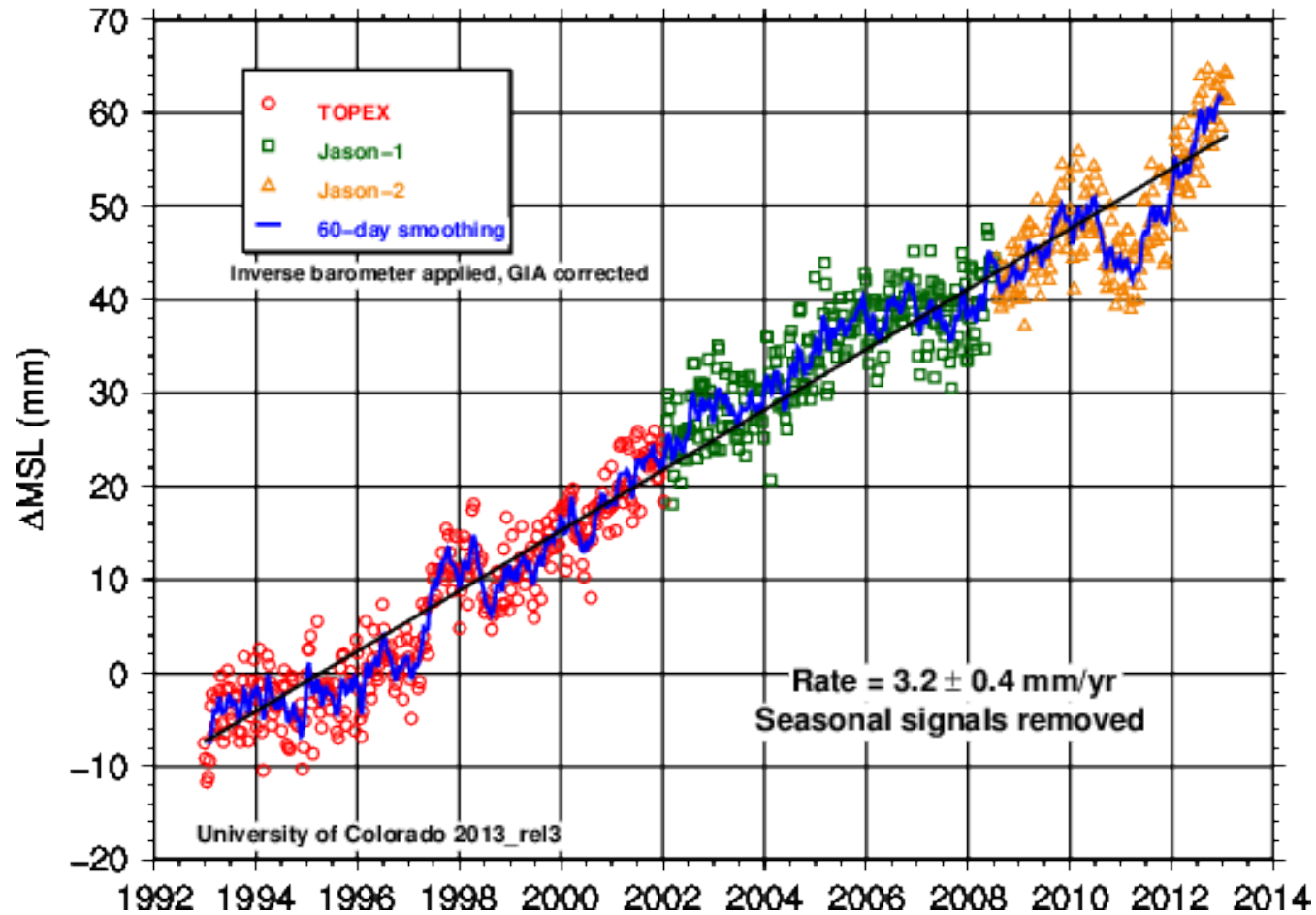
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- What Can I Do?

# Sea Level Trend Map 1993 - 2012 period



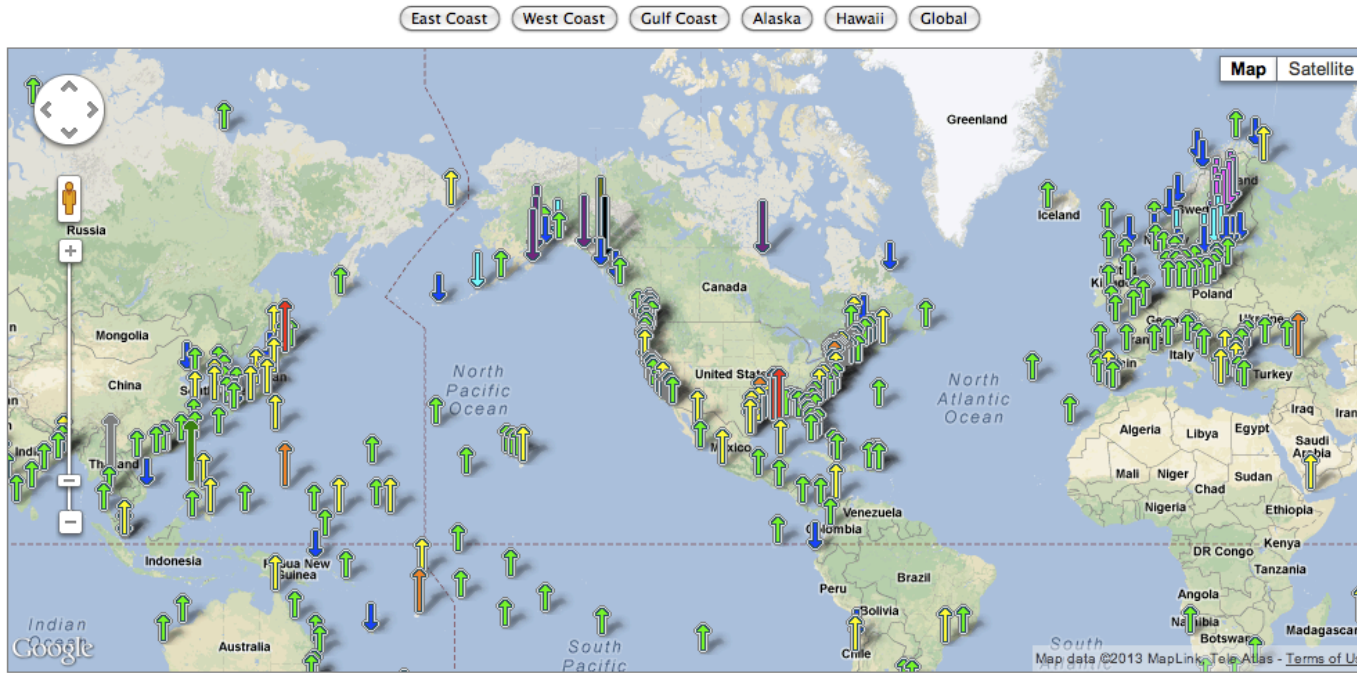
<http://sealevel.colorado.edu/content/map-sea-level-trends> - (Colorado Univ)

## 2013\_rel3: Global Mean Sea Level Time Series (seasonal signals removed) - $3.2 \pm 0.4$ mm/yr

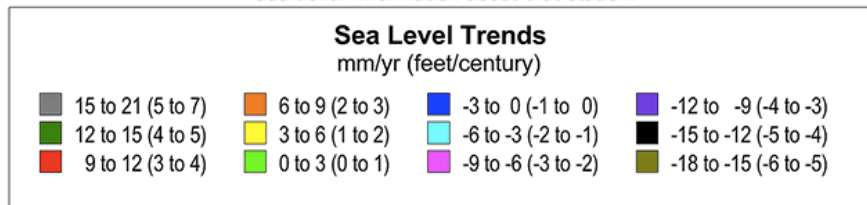


<http://sealevel.colorado.edu/content/global-mean-sea-level-time-series-seasonal-signals-removed> - can get ascii file

## CURRENT SEA LEVEL WITH TRENDS



The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.



Use NOAA's Sea Level Online to see trends for a location close to you:  
<http://tidesandcurrents.noaa.gov/sltrends/index.shtml>

What makes sea level change?	Current Sea Level
Is Greenland's Ice Sheets Changing Now?	Sea Level in Human History
Is Antarctica's Ice Sheets Changing Now?	Last Ice Age 95,000 to 20,000 yrs. ago
How Fast Can Sea Level Change?	Last Warm Period ~125,000 yrs. ago
How Much Ice Is There At the Poles?	Future Sea Level 50/100/1000
Is There A Critical Tipping Point?	
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How Fast Can Sea Level Change?

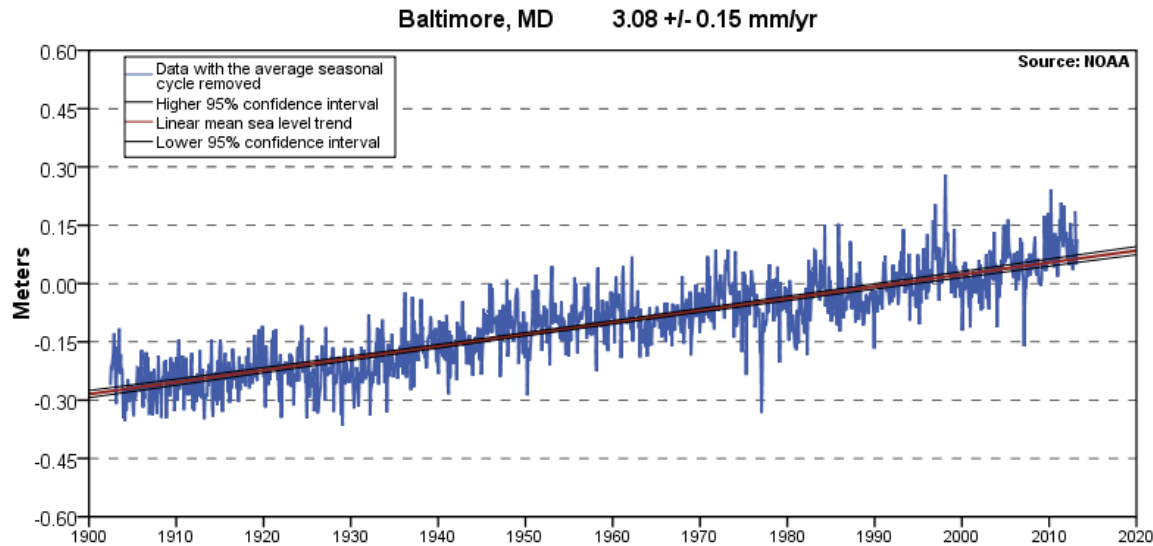
LOCATE: WHAT IS HAPPENING ON THE COASTAL AREA CLOSE TO YOU ?





## RECORD: CURRENT SEA LEVEL WITH TRENDS

### Mean Sea Level Trend 8574680 Baltimore, Maryland



The mean sea level trend is 3.08 millimeters/year with a 95% confidence interval of +/- 0.15 mm/yr based on monthly mean sea level data from 1902 to 2006 which is equivalent to a change of 1.01 feet in 100 years.

### BALTIMORE, MARYLAND

<http://tidesandcurrents.noaa.gov/sltrends/index.shtml>

How Fast Can Sea Level Change?

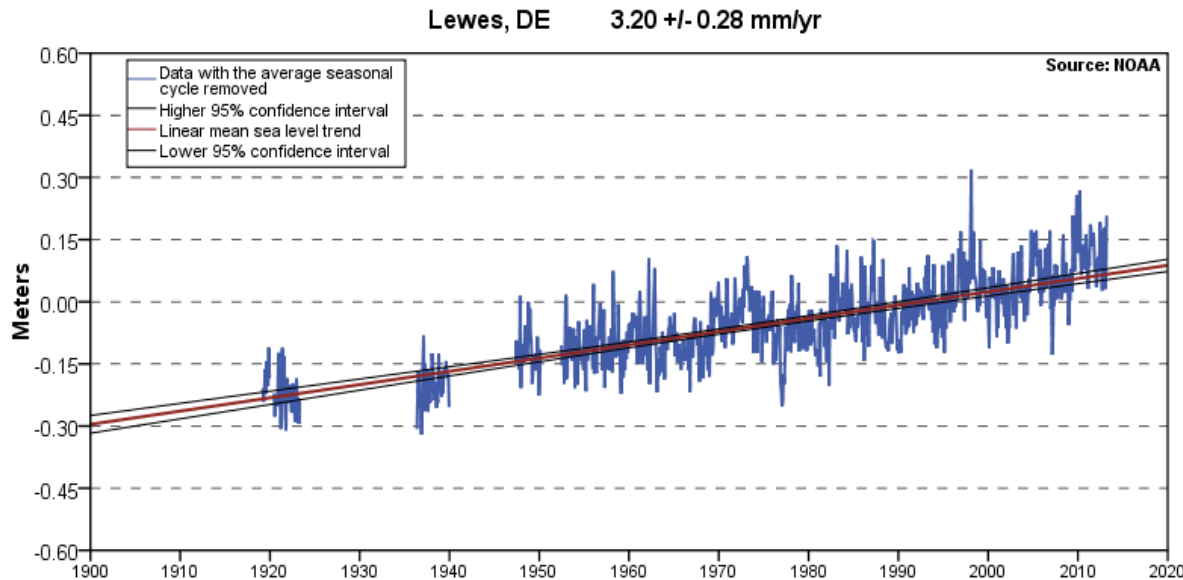
**‘Science Fact’:** Sea Level does not change the same in every location. There are local conditions that cause it to vary from site to site.

What makes sea level change?	Current Sea Level
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Is Antarctica’s Ice Sheets Changing Now?	Last Ice Age 95,000 to 20,000 yrs. ago
How Fast Can Sea Level Change?	Last Warm Period ~125,000 yrs. ago
How Much Ice Is There At the Poles?	Future Sea Level 50/100/1000
Is There A Critical Tipping Point?	
What Can I Do?	



## RECORD: CURRENT SEA LEVEL WITH TRENDS

### Mean Sea Level Trend 8557380 Lewes, Delaware



The mean sea level trend is 3.20 millimeters/year with a 95% confidence interval of +/- 0.28 mm/yr based on monthly mean sea level data from 1919 to 2006 which is equivalent to a change of 1.05 feet in 100 years.

### LEWES, DELAWARE

<http://tidesandcurrents.noaa.gov/sltrends/index.shtml>

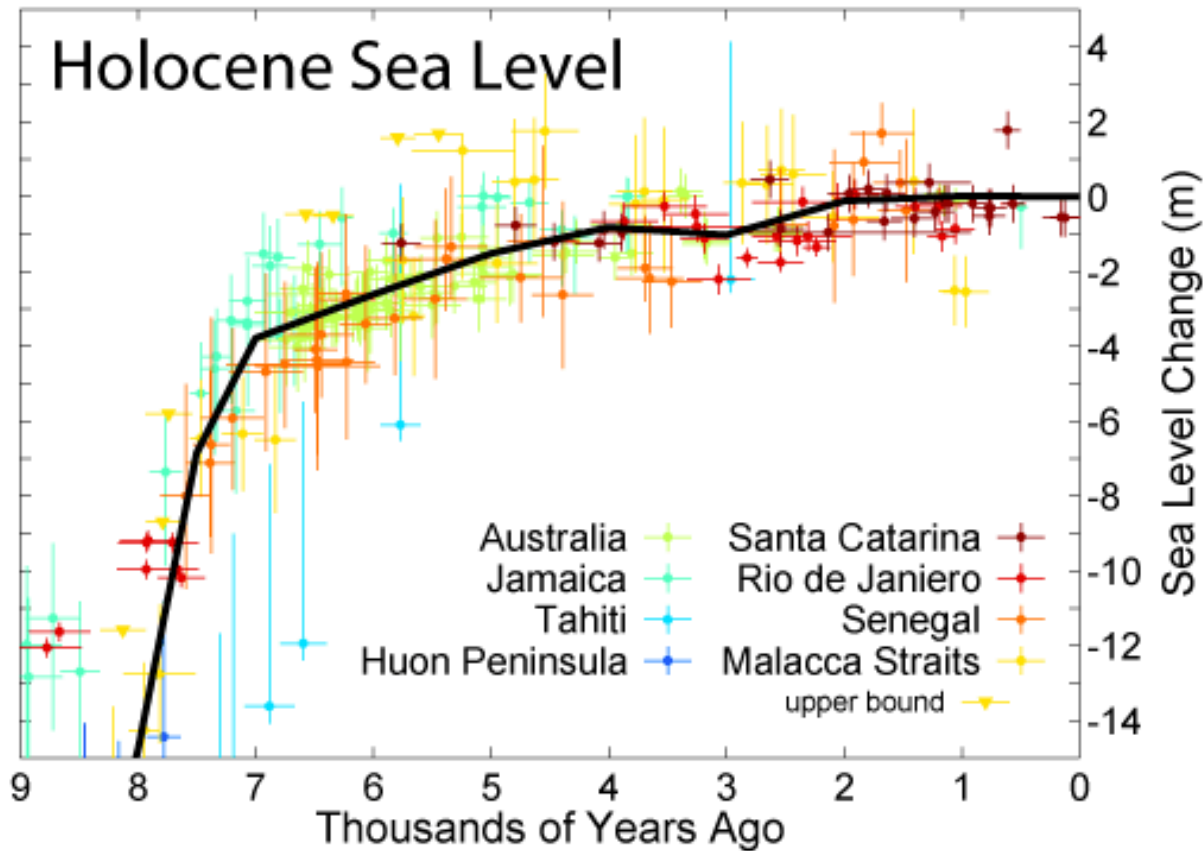
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## SEA LEVEL RISE LAST 8000 YEARS



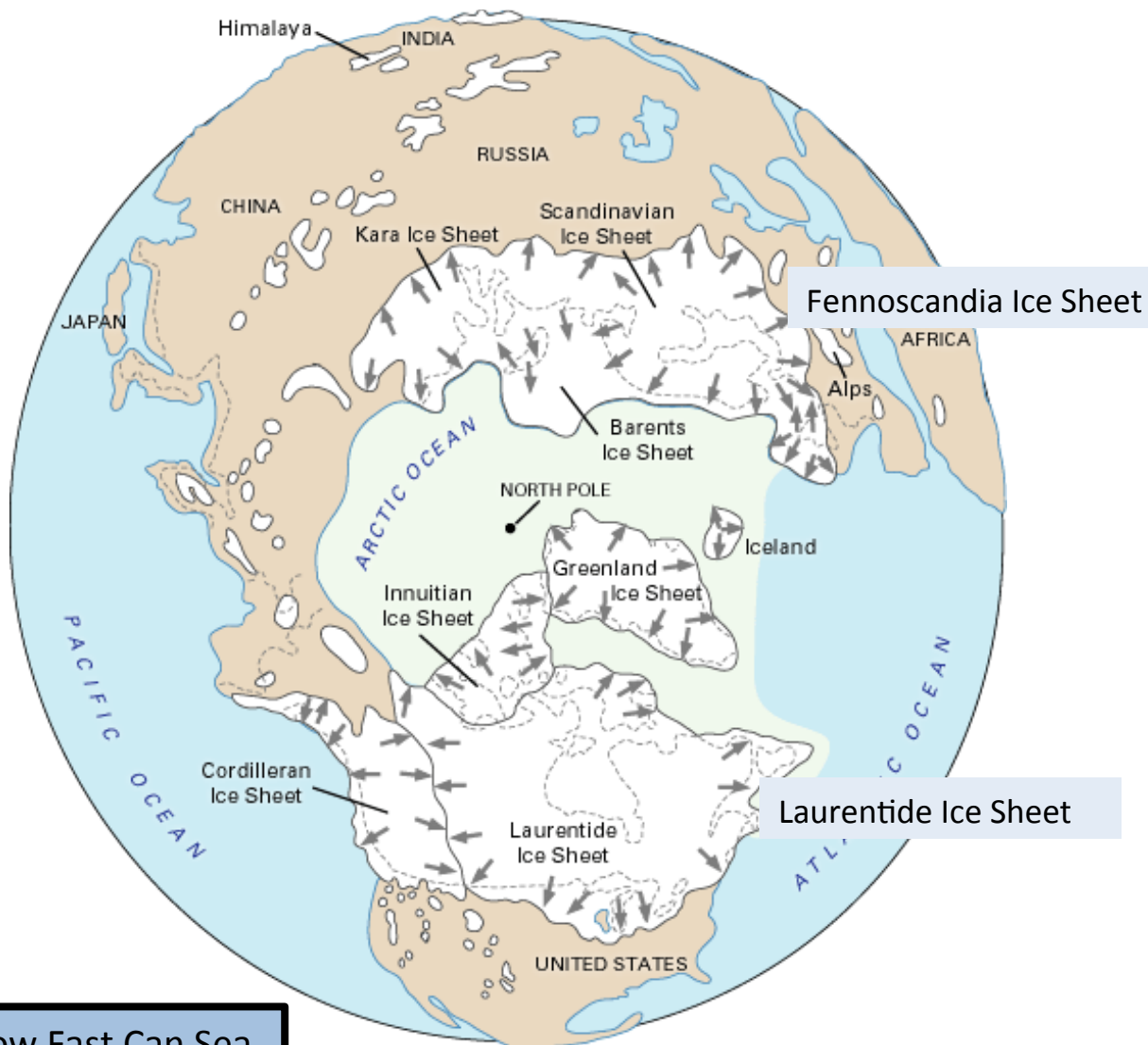
Use the **black trend line** for sea level rise. From 8000 to 7000 years sea level rose significantly, then slowed considerably after that point.

How Fast Can Sea Level Change?

**Note:** In a graph showing a time-period of thousands of years changes at the level of the last century are not evident.

What makes sea level change?	Current Sea Level
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**DURING THE LAST GLACIAL MAXIMUM (LGM) ICE COVERED THE NORTHERN HEMISPHERE & SEA LEVEL WAS MORE THAN 120 M LOWER THAN PRESENT**



How Fast Can Sea Level Change?

Ocean water was frozen into major ice sheets in North American and northern Europe and Asia.

What makes sea level change?	Current Sea Level
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**LAST GLACIAL MAXIMUM (LGM) - OUR COASTLINE & BEACH WAS FURTHER AWAY DURING THIS COLD ICE PERIOD!**

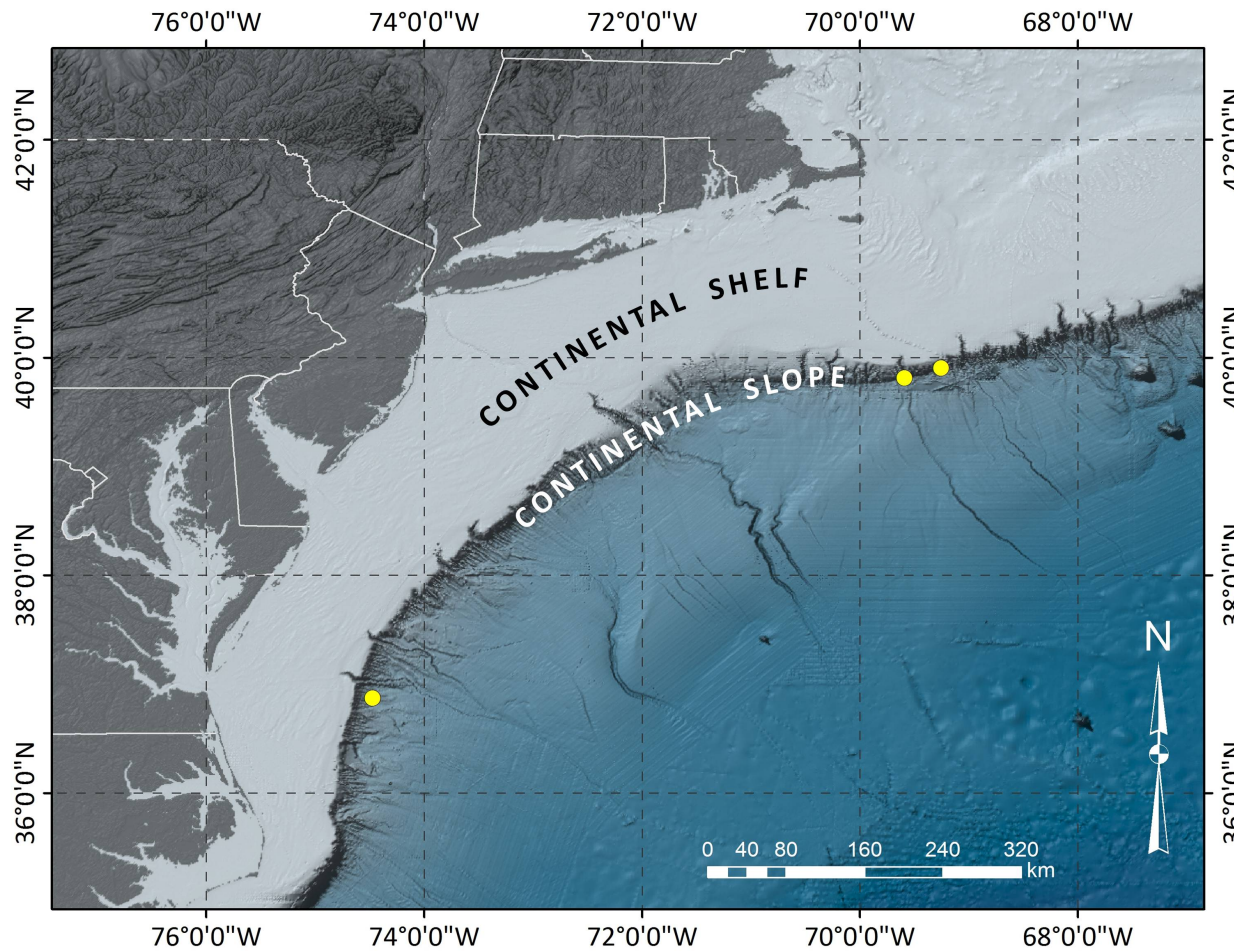


Image from NOAA

Oceans were smaller as the water was frozen into ice sheets. The Continental Shelf (above) shows us the shoreline from that period. At the last glacial maximum sea level was more than 120 m below present.

How Fast Can Sea Level Change?

What makes sea level change?	Current Sea Level
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**RECORD:** HOW MUCH DID GLOBAL SEA LEVEL RISE AT THE END OF THE LAST GLACIAL MAXIMUM (LGM).

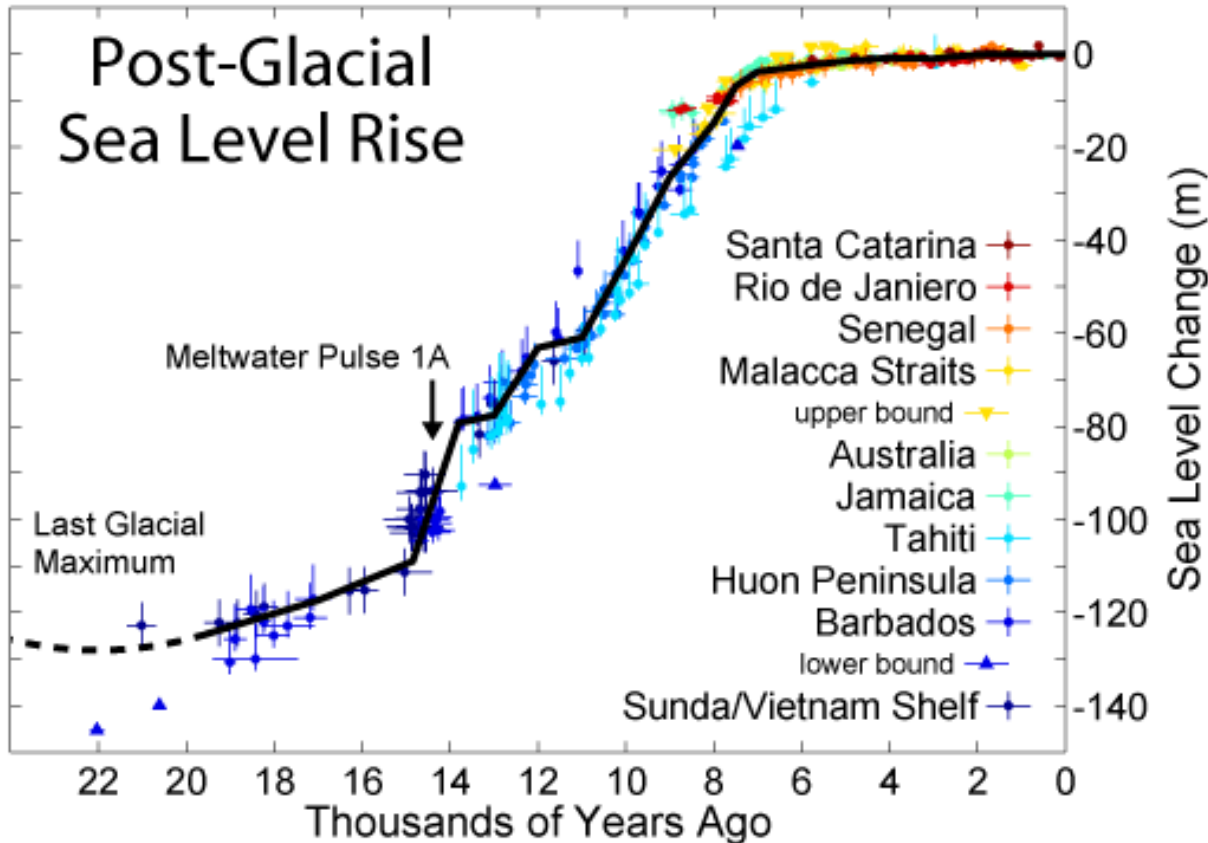


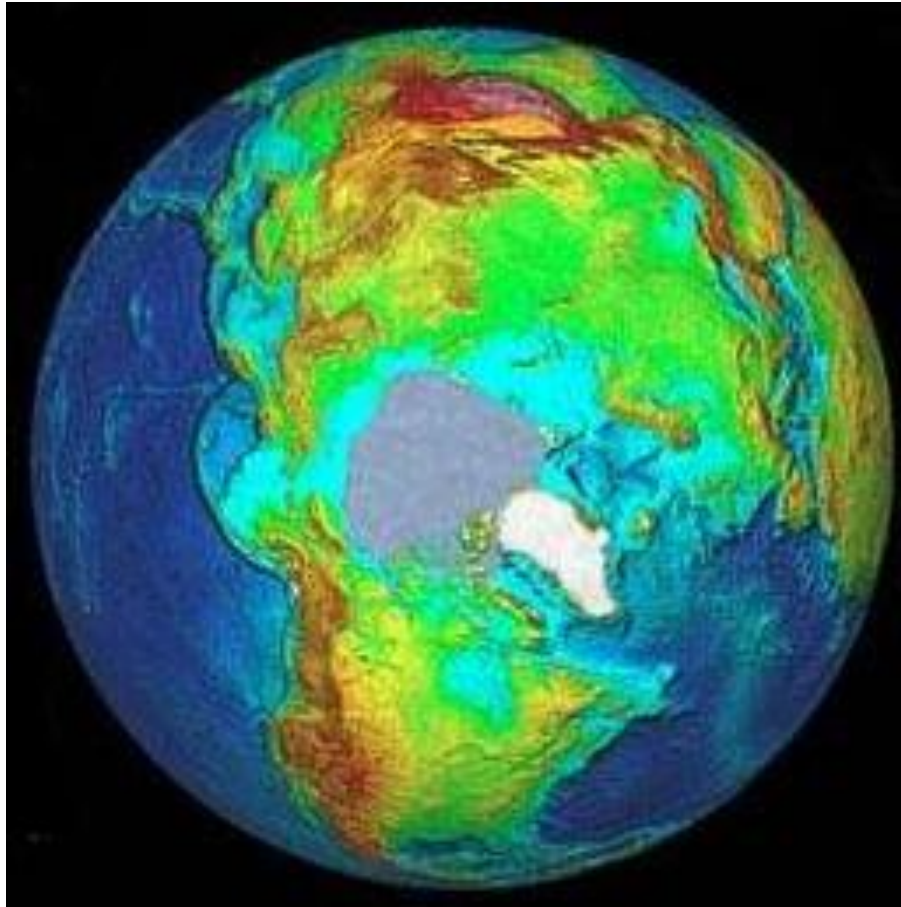
Figure prepared from published data by Robert A. Rohde

~21,000 years ago following the end of the Last Glacial Maximum the ice sheets started to melt causing sea level to rise over thousands of years.

How Fast Can Sea Level Change?

What makes sea level change?	Current Sea Level
Is Greenland's Ice Sheets Changing Now?	Sea Level in Human History
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How Fast Can Sea Level Change?	Last Warm Period ~125,000 yrs. ago
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EARTH HAS HAD **WARM INTERGLACIAL PERIODS** WHEN SEA LEVEL WAS HIGHER. ~125,000 YEARS AGO THE EARTH WAS IN THE LAST INTERGLACIAL, A PERIOD CALLED 'THE EEMIAN'.



<http://www.ncdc.noaa.gov/paleo/pubs/clark2009/clark2009.html>

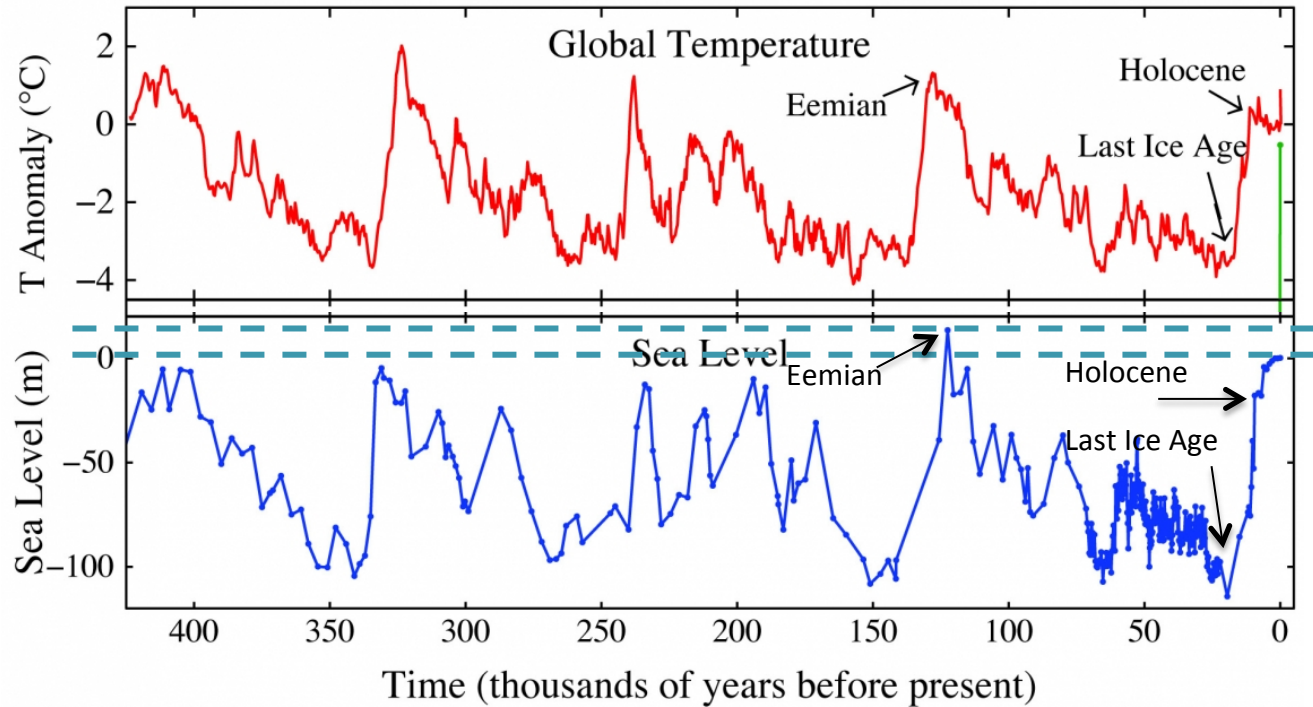
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<b>How Fast Can Sea Level Change?</b>	<b>Last Warm Period ~125,000 yrs. ago</b>
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How Fast Can Sea Level Change?

TEMPERATURES WERE 3-5 DEGREES C WARMER MELTING ICE & SEA LEVEL INCREASED.



**RECORD: IN THE EEMIAN THE HIGHER GLOBAL TEMPERATURES CAUSED SEA LEVELS TO RISE ~8M HIGHER THAN TODAY**



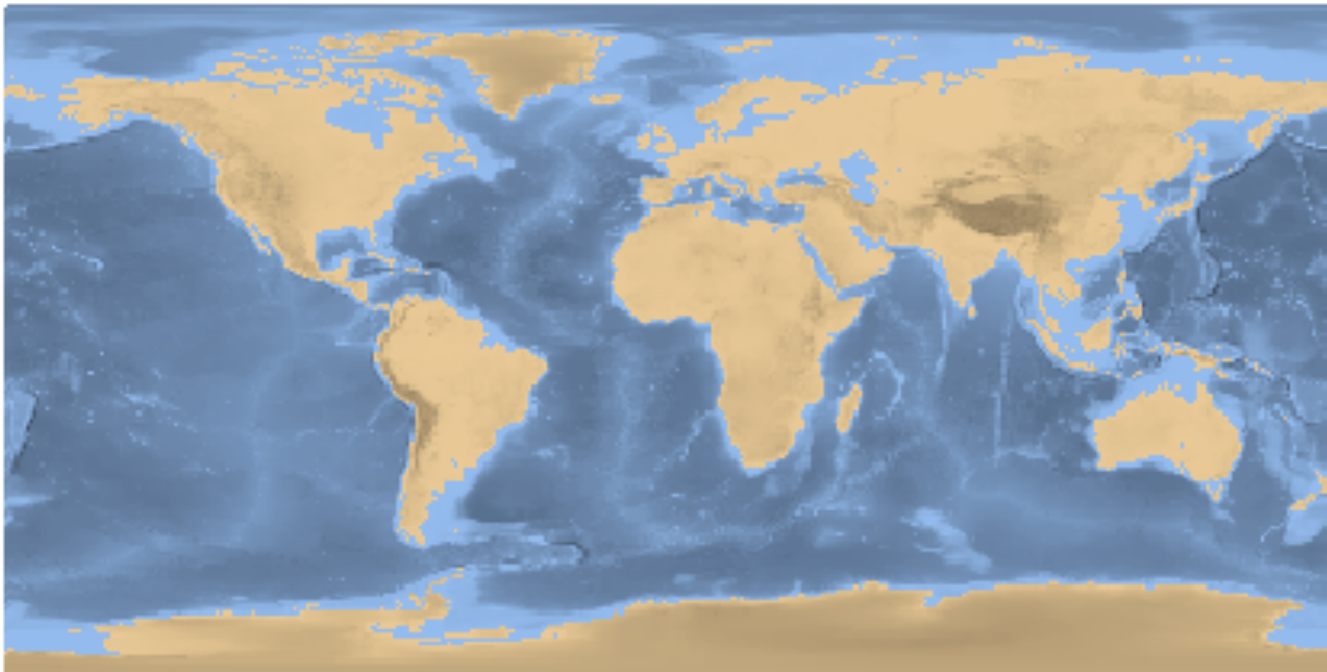
Edited chart from NASA scientist Dr. James Hansen, based on proxy oxygen isotope data.  
<http://www.johnenglander.net/t-co2-sl-420kyr-chart>

Locate the Eemian in the sea level section and use the dashed lines to estimate and record sea level height at the Eemian and at the present.

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How Fast Can Sea Level Change?

## WHAT MIGHT SEA LEVEL BE IN THE FUTURE?



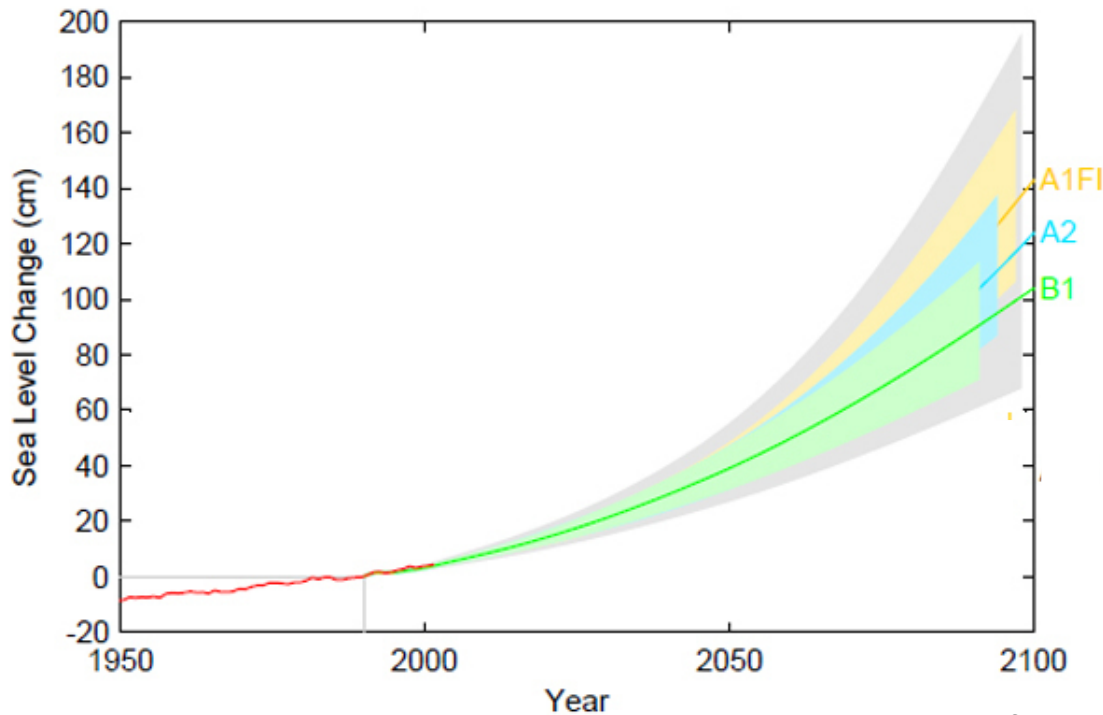
What will sea level be in 2050, 2100, 3000? In the last 100 years sea level has gone up ~ 12 inches on average. Will it continue to rise at that same rate (linear projection), or will it accelerate or slow?

What makes sea level change?	Current Sea Level
Is Greenland's Ice Sheets Changing Now?	Sea Level in Human History
Is Antarctica's Ice Sheets Changing Now?	Last Ice Age 95,000 to 20,000 yrs. ago
<b>How Fast Can Sea Level Change?</b>	Last Warm Period ~125,000 yrs. ago
How Much Ice Is There At the Poles?	<b>Future Sea Level 50/100/1000</b>
Is There A Critical Tipping Point?	
What Can I Do?	

How Fast Can Sea Level Change?



**RECORD:** WHAT MIGHT SEA LEVEL BE IN 2050 , 2100, 3000. IN THE REMEMBER IN THE LAST 100 YEARS IT HAS GONE UP GOBALLY AN AVERGE OF 12 INCHES. WILL THIS CHANGE IN THE NEXT 100 YEARS?



There have been projections done by many scientists about future sea level. Will the rise be at the same rate (linear)? accelerate? slow down? The chart shows a set of projections from the IPCC, an international group of scientists selected to study and report on our changing climate. Select one of the 3 projections to record on your chart and analyze.

Source: Advancing the Science of Climate Change, 2010, National Research Council.

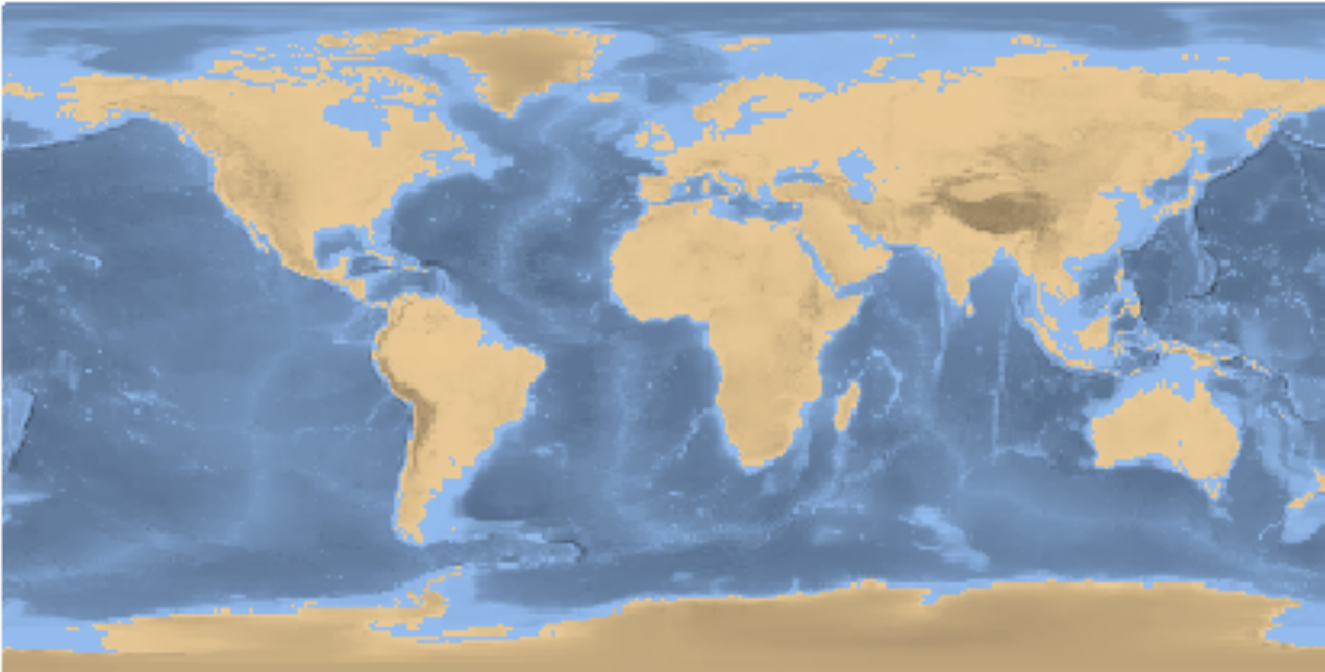
**How Fast Can Sea Level Change?**

Note: Graph based on the 2007 IPCC reported projection of sea level rise, edited to add ice sheets. Three different projections are included (labels on right). Gray area is uncertainty. Red line is annual global sea level rise over the past half century.

What makes sea level change?	Current Sea Level
Is Greenland's Ice Sheets Changing Now?	Sea Level in Human History
Is Antarctica's Ice Sheets Changing Now?	Last Ice Age 95,000 to 20,000 yrs. ago
<b>How Fast Can Sea Level Change?</b>	Last Warm Period ~125,000 yrs. ago
How Much Ice Is There At the Poles?	<b>Future Sea Level 50/100/1000</b>
Is There A Critical Tipping Point?	
What Can I Do?	



**HOW FAST HAS SEA LEVEL CHANGED IN THE PAST  
AND HOW FAST COULD IT CHANGE IN THE FUTURE?**



***TIME TO EXAMINE YOUR EVIDENCE AND FINISH THIS SECTION  
OF YOUR WORKSHEET TO FIND OUT HOW FAST SEA LEVEL CAN  
CHANGE & IF YOU FOUND A POLAR CONNECTION!***

What makes  
sea level  
change?

Is Greenland's  
Ice Sheets  
Changing  
Now?

Is Antarctica's  
Ice Sheets  
Changing  
Now?

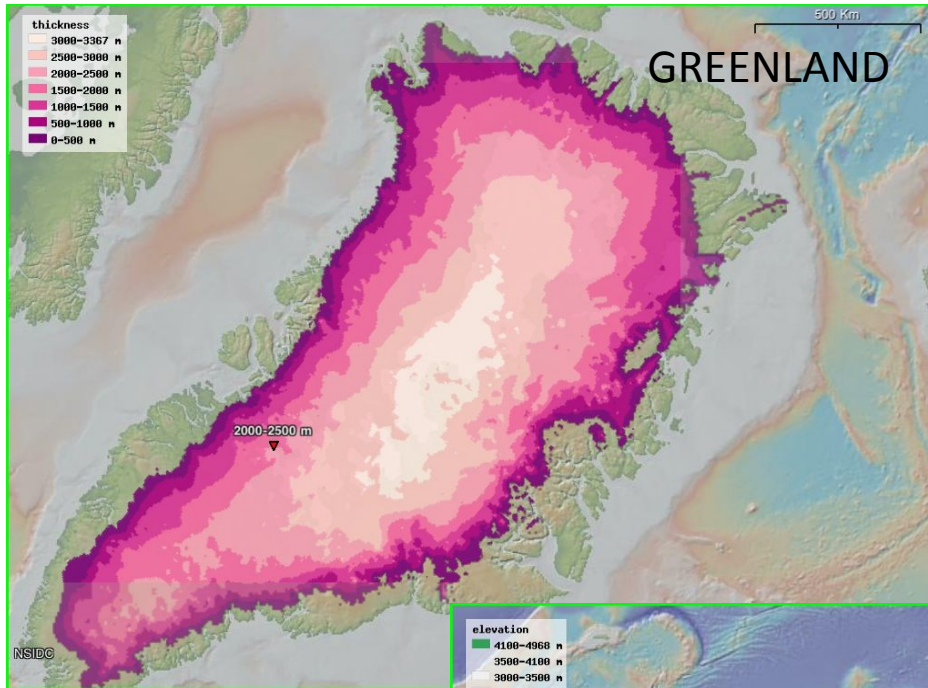
**How Fast Can  
Sea Level  
Change?**

How Much Ice  
Is There At  
the Poles?

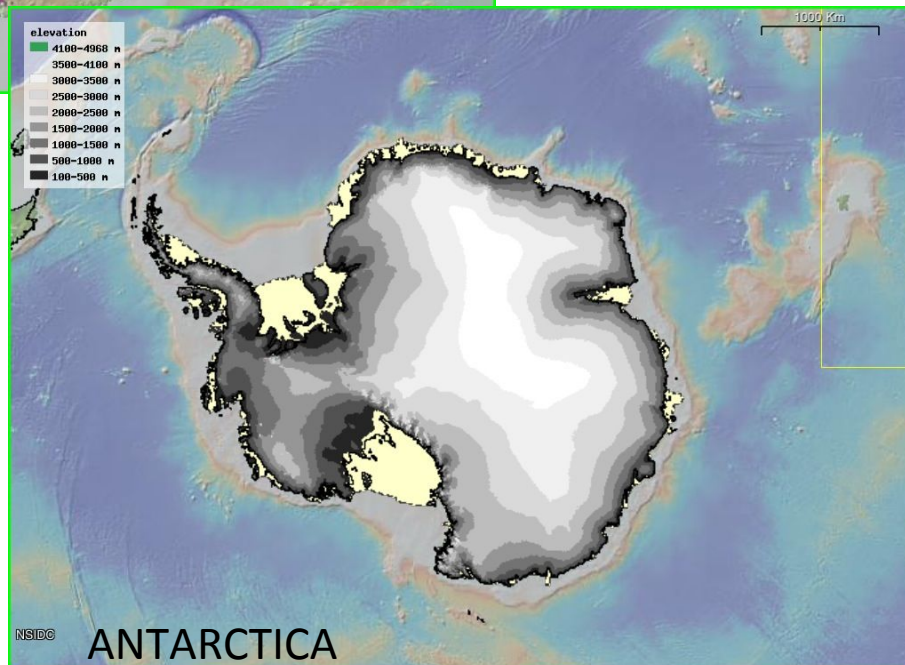
Is There A  
Critical  
Tipping Point?

What Can I  
Do?

How Fast Can Sea  
Level Change?



SO JUST HOW MUCH ICE IS THERE AT THE POLES?



How Much Ice is There at the Poles?

### PART 3

What makes sea level change?

Is Greenland's Ice Sheets Changing Now?

Is Antarctica's Ice Sheets Changing Now?

How Fast Can Sea Level Change?

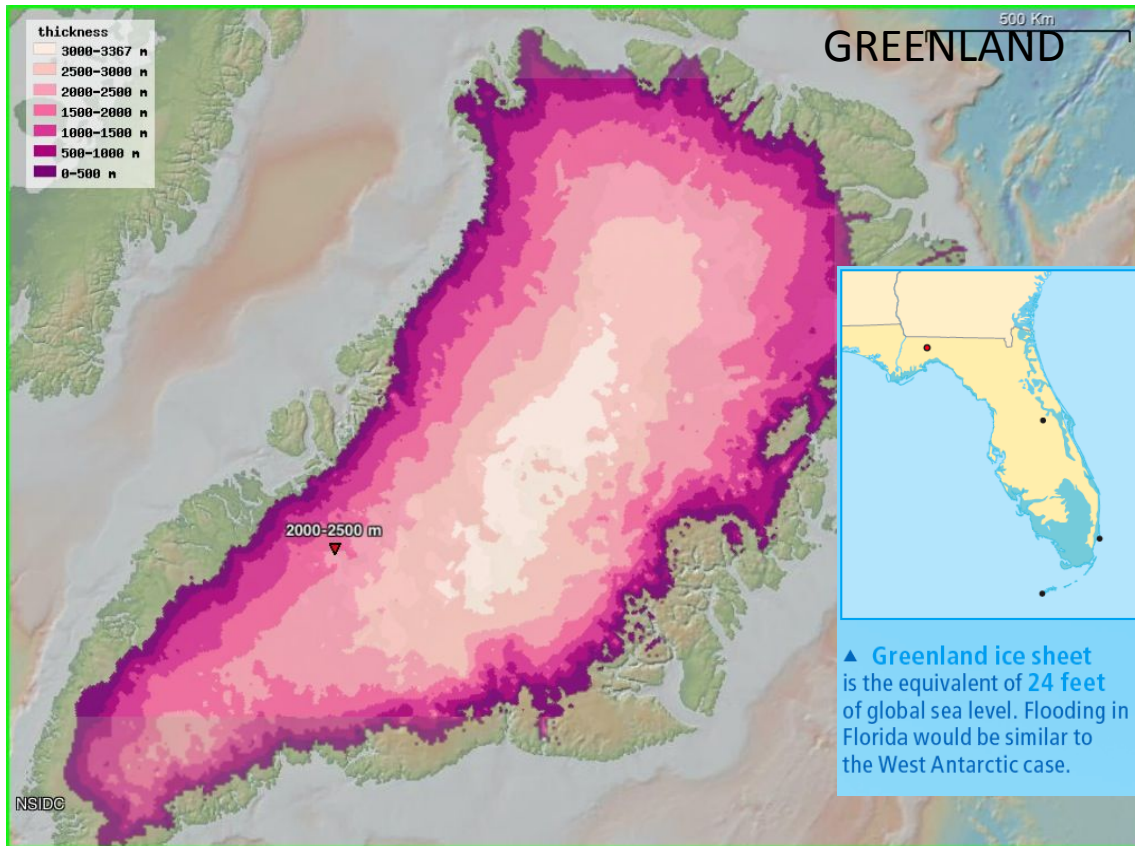
How Much Ice Is There At the Poles?

Is There A Critical Tipping Point?

What Can I Do?



**RECORD: HOW MUCH ICE IS IN GREENLAND'S ICE SHEET?  
7 M (~24 FT) OF SEA LEVEL RISE!**



The Greenland Ice Sheet holds the equivalent of 7m (24 ft.) of sea level rise throughout the world's oceans. If all that ice were added to the ocean the tip of Florida would be under water (see inset map).

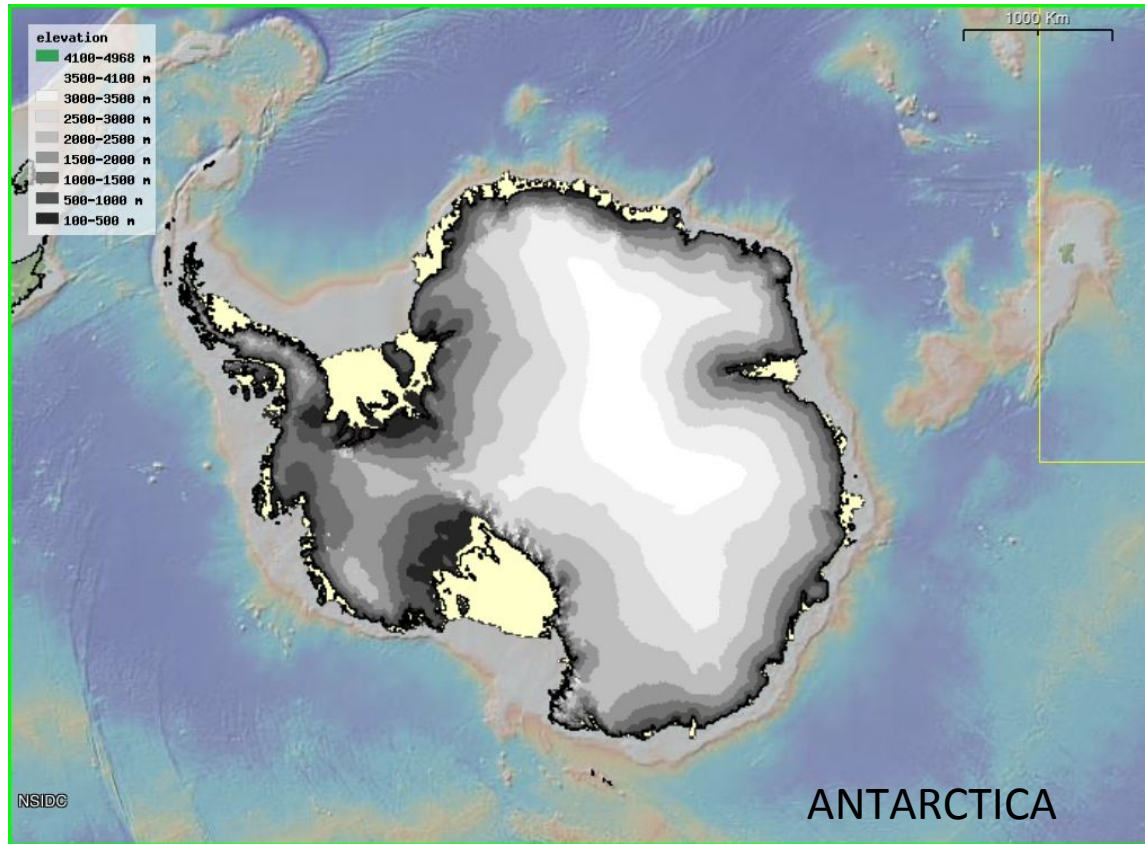
Inset box from R. Bell, Scientific American, The Unquiet Ice, 2008.

How Much Ice is There at the Poles?

What makes sea level change?	Feet of Sea Level Rise in Greenland Ice Sheet
Is Greenland's Ice Sheets Changing Now?	Feet of Sea Level Rise in W. Antarctic Ice Sheet
Is Antarctica's Ice Sheets Changing Now?	Feet of Sea Level Rise in E. Antarctic Ice Sheet
How Fast Can Sea Level Change?	
How Much Ice Is There At the Poles?	
Is There A Critical Tipping Point?	
What Can I Do?	



## WEST AND EAST ANTARCTICA



West Antarctica

East Antarctica

What makes sea level change?

Feet of Sea Level Rise in Greenland Ice Sheet

Is Greenland's Ice Sheets Changing Now?

Feet of Sea Level Rise in W. Antarctic Ice Sheet

Is Antarctica's Ice Sheets Changing Now?

Feet of Sea Level Rise in E. Antarctic Ice Sheet

How Fast Can Sea Level Change?

How Much Ice Is There At the Poles?

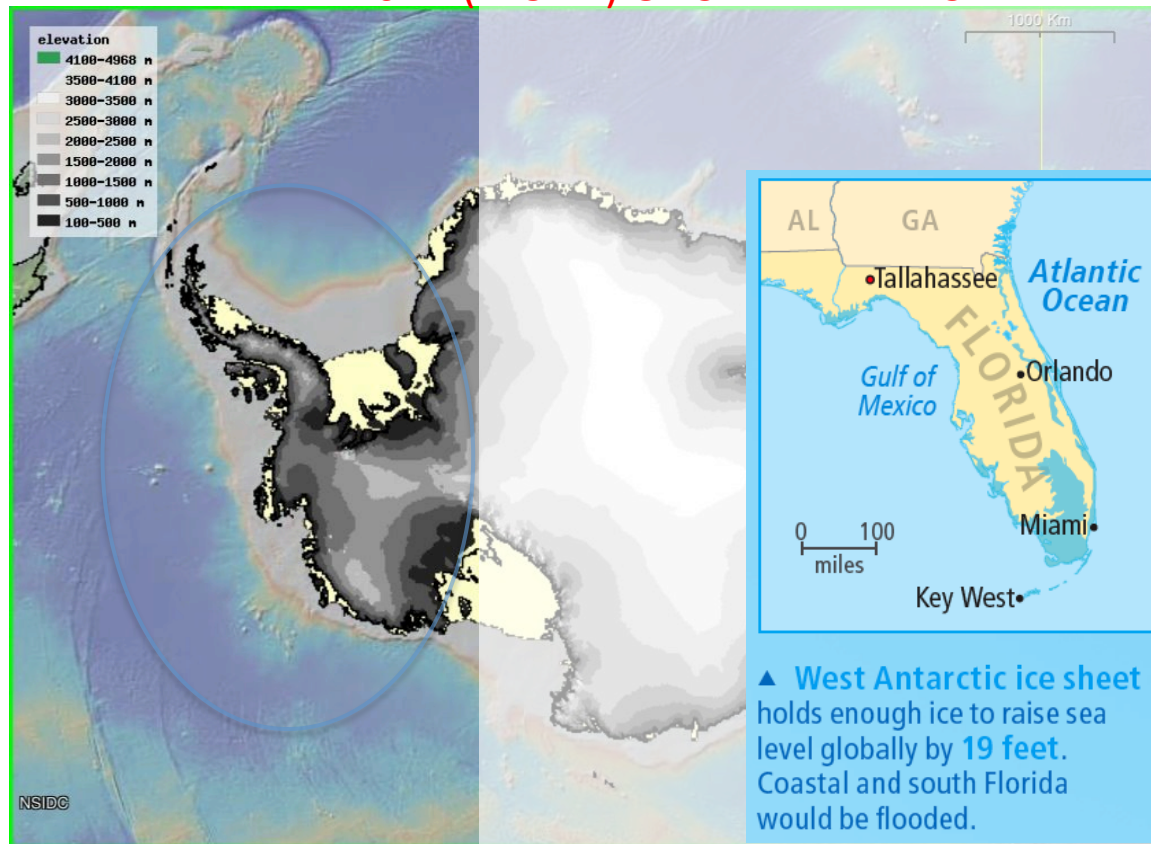
Is There A Critical Tipping Point?

What Can I Do?

How Much Ice is There at the Poles?

THE Antarctic Ice Sheet is much larger than Greenland (~ 7 times larger!) and is really two separate sections of ice – West and East.

**RECORD: HOW MUCH ICE IS IN WEST ANTARCTIC ICE SHEET = 6 M (~19 FT) OF SEA LEVEL RISE**



West Antarctica

How Much Ice is There at the Poles?

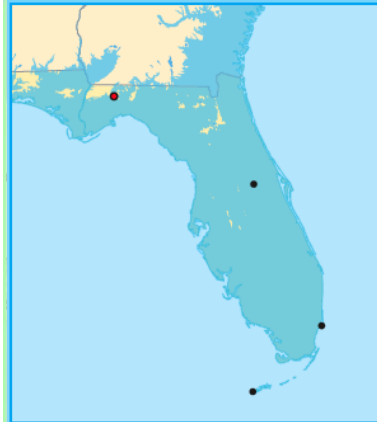
The West Antarctic Ice Sheet is close to the same size as Greenland yet some of the ice sits below sea level. Melting the ice resting below sea level will not add to global sea level so the West Antarctic Ice Sheet holds 6m (19 ft.) of sea level rise. This is enough to flood the tip of Florida (see inset).

What makes sea level change?	Feet of Sea Level Rise in Greenland Ice Sheet
Is Greenland's Ice Sheets Changing Now?	Feet of Sea Level Rise in W. Antarctic Ice Sheet
Is Antarctica's Ice Sheets Changing Now?	Feet of Sea Level Rise in E. Antarctic Ice Sheet
How Fast Can Sea Level Change?	
How Much Ice Is There At the Poles?	
Is There A Critical Tipping Point?	
What Can I Do?	

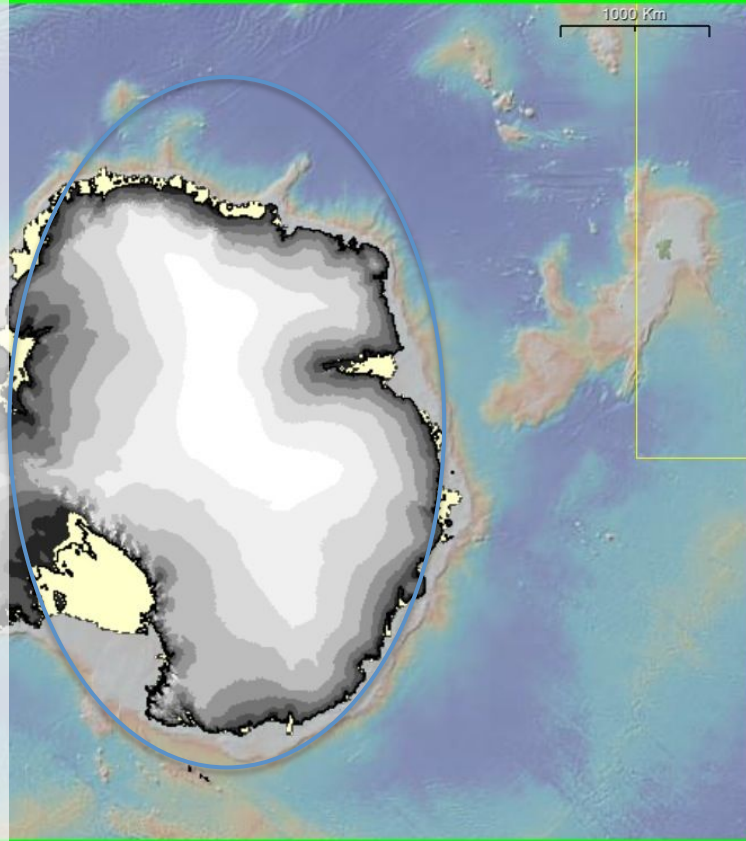




# RECORD: THE EAST ANTARCTIC ICE SHEET = 52 M (~170 FT) OF SEA LEVEL RISE



▲ East Antarctic ice sheet could raise sea level globally by 170 feet. Virtually the entire state of Florida would be underwater.



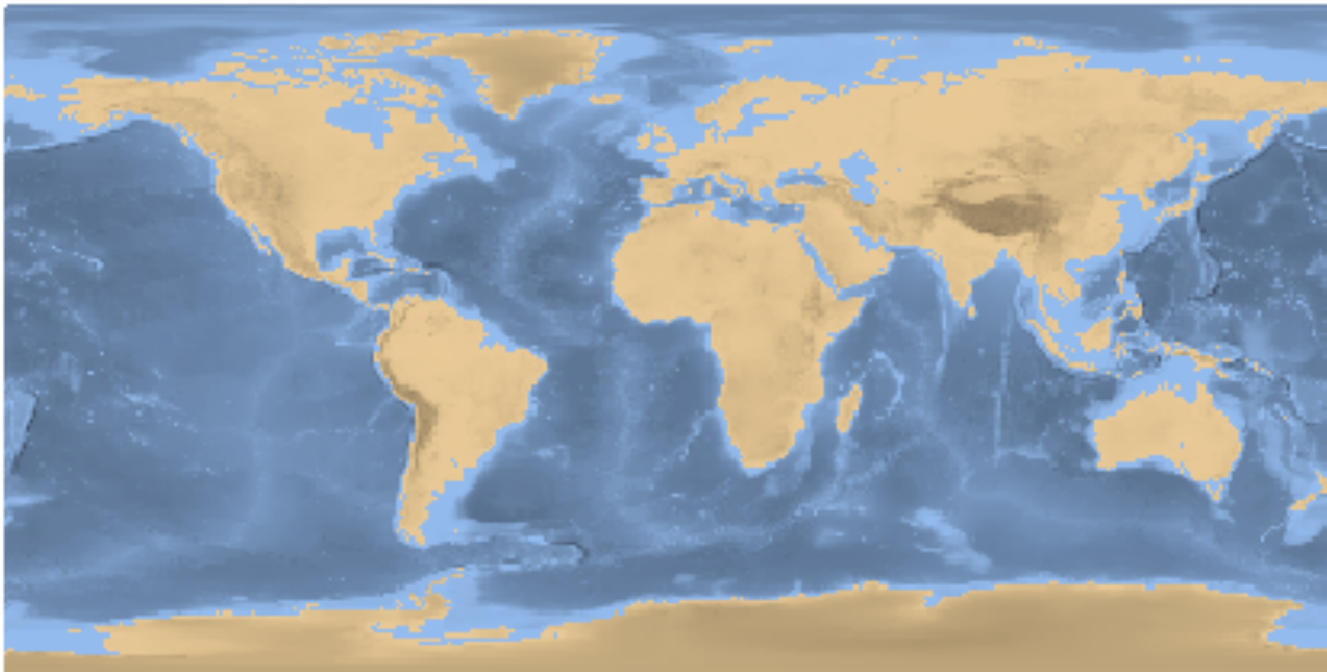
East Antarctica

The East Antarctic Ice Sheet is the largest potential contributor of sea level rise to the global oceans. It holds 52m (170 ft.) of sea level rise, an amount that would cover Florida with water (see inset).

How Much Ice is There at the Poles?

What makes sea level change?	Feet of Sea Level Rise in Greenland Ice Sheet
Is Greenland's Ice Sheets Changing Now?	Feet of Sea Level Rise in W. Antarctic Ice Sheet
Is Antarctica's Ice Sheets Changing Now?	Feet of Sea Level Rise in E. Antarctic Ice Sheet
How Fast Can Sea Level Change?	
How Much Ice Is There At the Poles?	
Is There A Critical Tipping Point?	
What Can I Do?	

**CONSIDER THE POTENTIAL! HOW MUCH ICE IS THERE AT THE POLES THAT COULD ADD TO GLOBAL SEA LEVEL?**



***EXAMINE YOUR EVIDENCE AND FINISH THIS SECTION OF YOUR WORKSHEET TO FIND OUT HOW MUCH ICE IS AT THE POLES & IF YOU FOUND A POLAR CONNECTION!***

What makes sea level change?

Is Greenland's Ice Sheets Changing Now?

Is Antarctica's Ice Sheets Changing Now?

How Fast Can Sea Level Change?

How Much Ice Is There At the Poles?

Is There A Critical Tipping Point?

What Can I Do?

How Fast Can Sea Level Change?