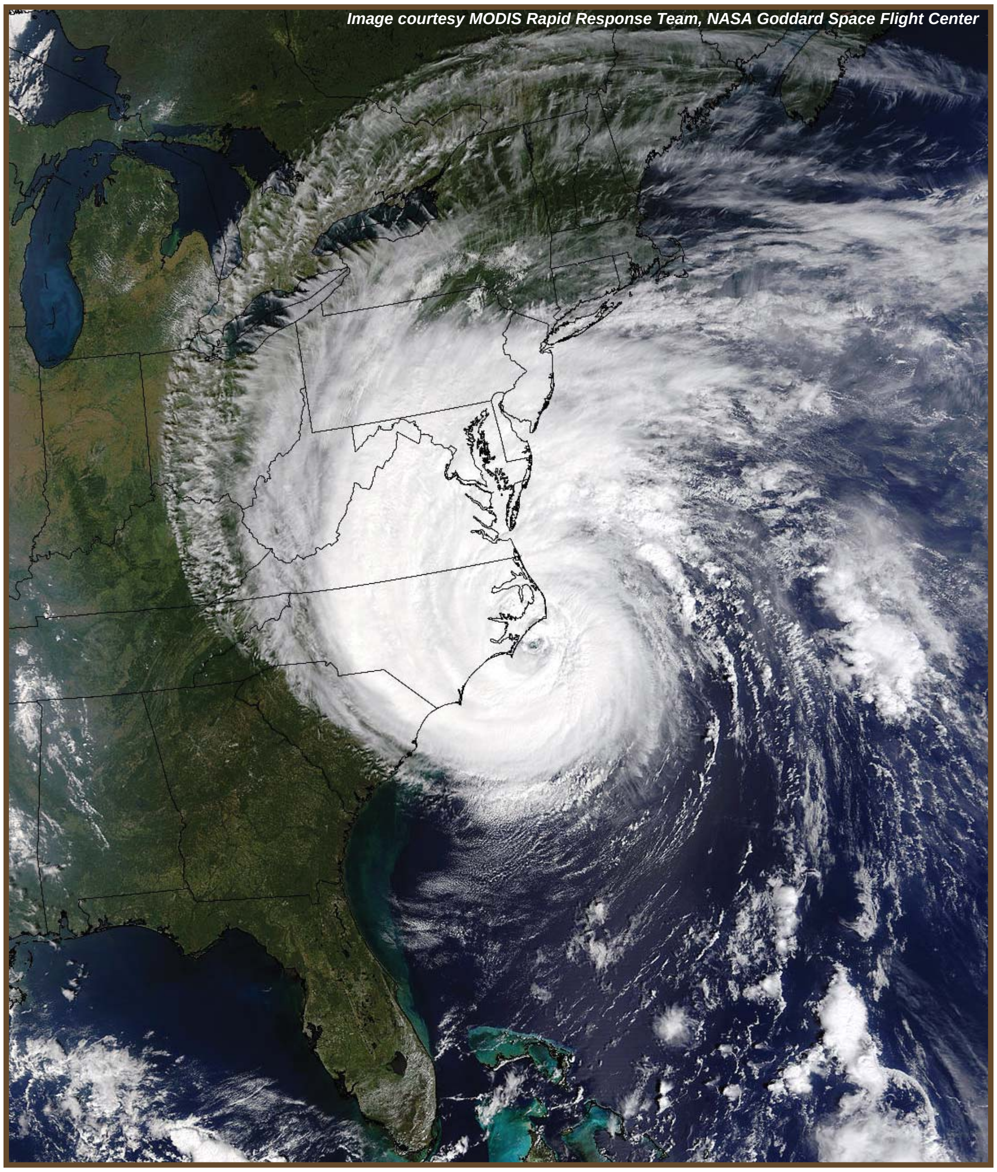
HURRICANE ISABEL AND SEA LEVEL RISE

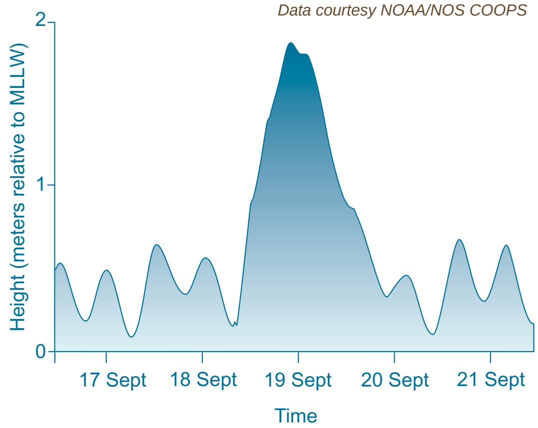
On Thursday September 18, 2003, Hurricane Isabel made landfall between Cape Lookout and Cape Hatteras on North Carolina's Outer Banks. A massive Category 2 hurricane, Isabel's strong winds and tidal surge resulted in widespread flooding, damage and power outages from North Carolina to New York.

Sea level in the Chesapeake Bay has risen by approximately 30 cm or 1 ft in the last 100 years. This is due to a combination of worldwide trends, such as global warming, and local factors like land subsidence and groundwater extraction.

Hurricane Isabel caused more flooding and damage than would normally be expected of a Category 2 hurricane and this may be partly attributable to local sea level rise. Chesapeake Bay sea level is continuing to rise at nearly double the global average which suggests that the effects of tropical storms and hurricanes like Isabel may increase in severity in the future.



Hurricane Isabel crossing the east coast of the USA on Thursday September 18, 2003.

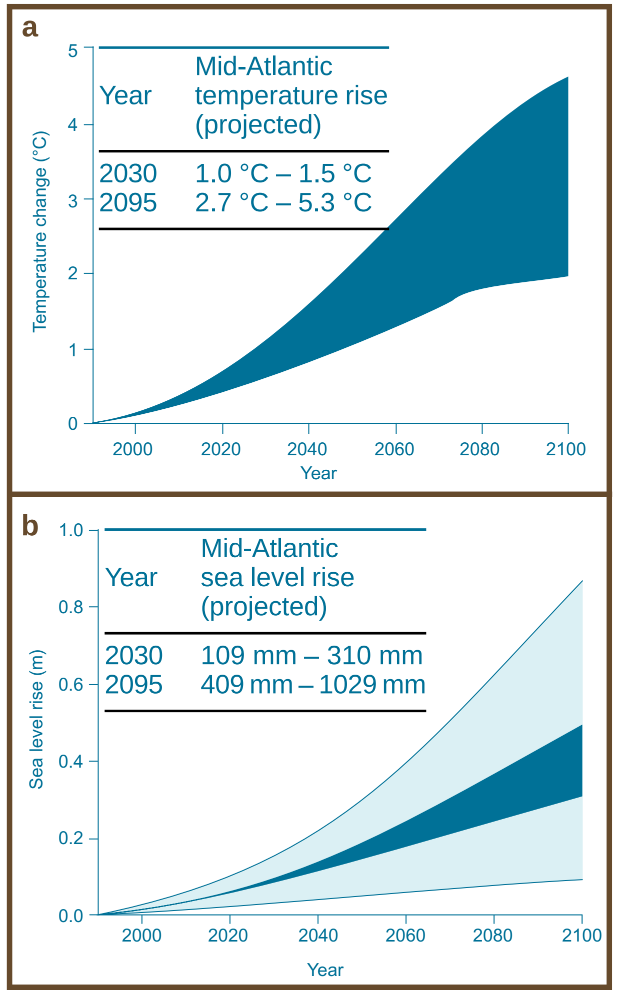


Sea level height at Cambridge, Maryland, with the storm surge from Hurricane Isabel clearly visible.

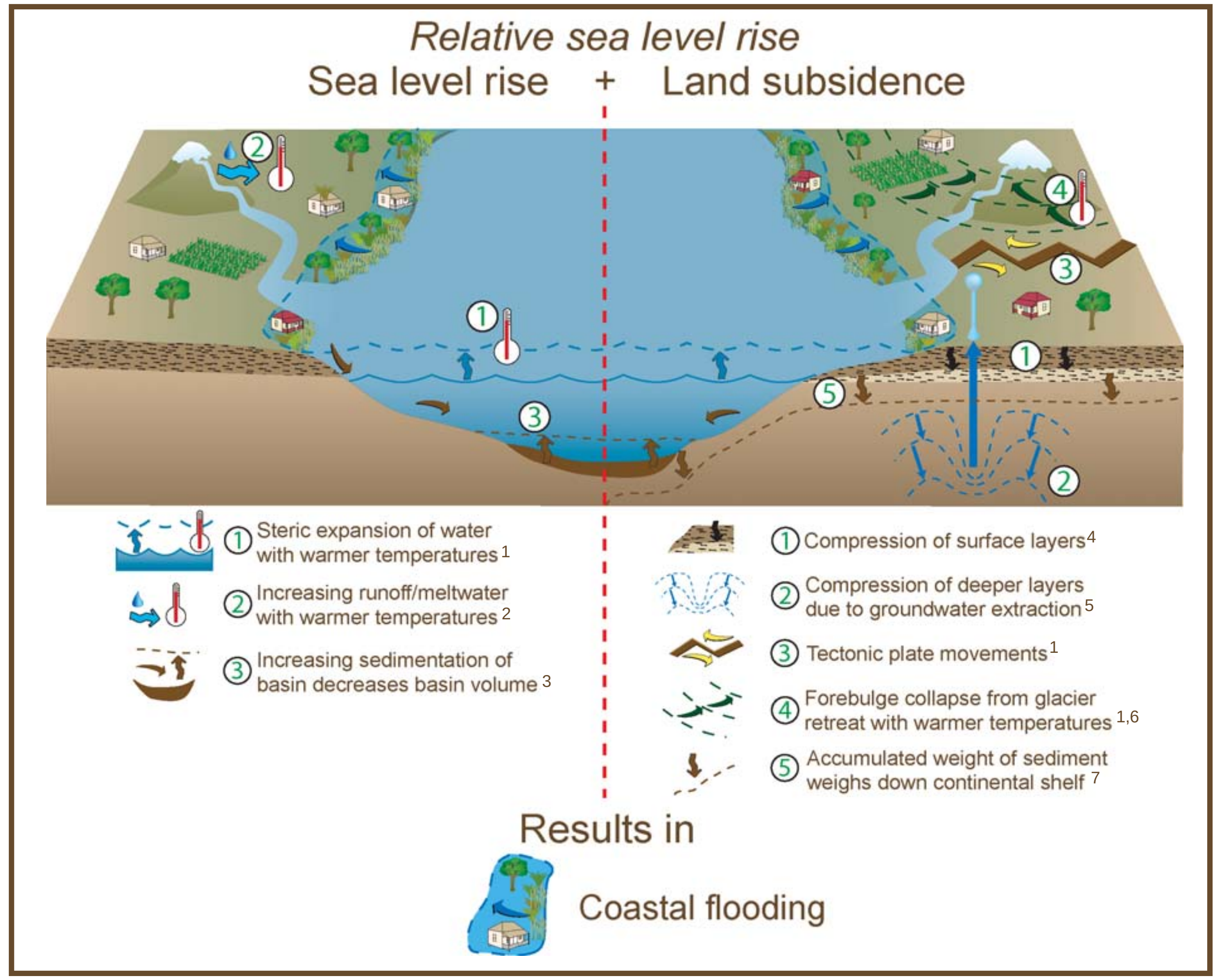
Post-Isabel flooding in Cambridge.

Flooding in Annapolis.

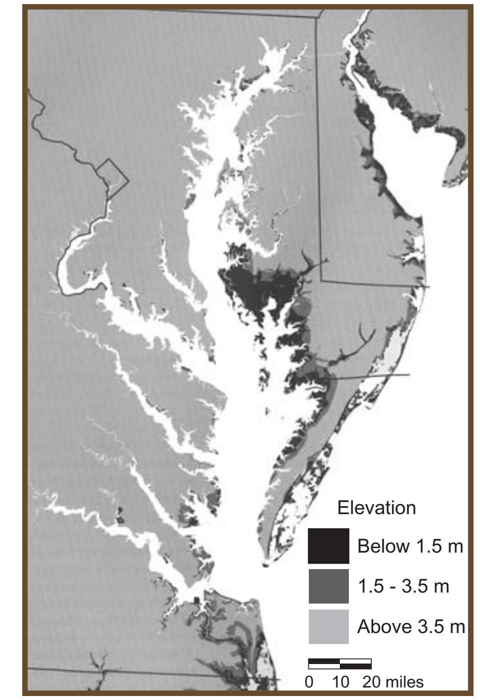
RELATIVE SEA LEVEL IS RISING AND INCREASES RISK OF HURRICANE DAMAGE



*Figures showing the projected future rise in **(a)** global temperature and **(b)** global sea level. The light blue shaded area shows sea level rise including uncertainty in land-ice changes, permafrost changes and sediment deposition. Data courtesy IPCC and Pennsylvania State University.*



Conceptual diagram depicting factors contributing to relative sea level rise.

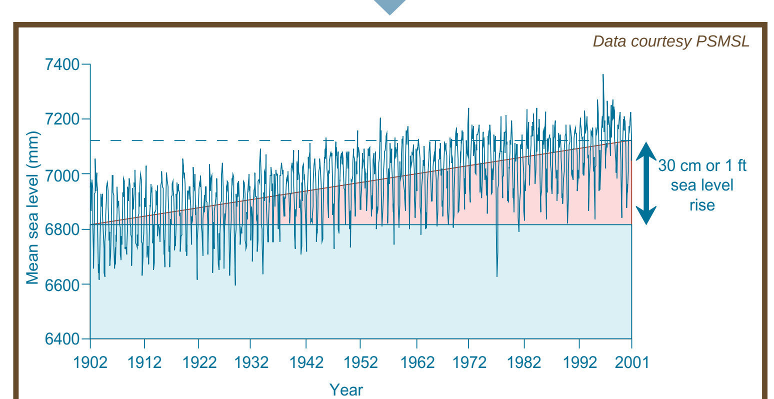


Map showing areas of low elevation adjacent to Chesapeake Bay which may be vulnerable to flooding with further sea level rise.[3]

***(a)** The last remnant of Sharp's Island at the mouth of the Choptank River, ca. 1950. This island, which was around 700 acres in the late 17th century, disappeared in the 1950s.[1]*
***(b)** Eroding marsh shoreline on the Chesapeake Bay.*

Relative sea level rise is a combination of **sea level rise** and **land subsidence.** Global warming can affect sea level in two ways. **Steric expansion** is the thermal increase of water volume. Warmer temperatures also result in **more runoff and meltwater** from melting ice sheets. Sea level rise is also affected by **sedimentation of the basin** which decreases the basin volume. **Surface layers such as peat tend to compact and subside** as they age, and deeper layers are subject to **subsidence due to groundwater extraction,** which compresses the clay bed of aquifers. **Plate tectonics** can affect sea level by causing uplift or subsidence of plates. **Postglacial forebulge collapse** occurs during glacial retreat in times of warmer global temperatures. The weight of glaciers deforms the earth's crust, creating a forebulge peripheral to the ice load. During glacial retreat, this forebulge begins to collapse and subside. **Accumulated sediments** at river mouths may compact and cause downwarp of the region.

Global, or eustatic sea level is inevitably affected by global warming. Although sea level has been rising for thousands of years, the rate of sea level rise during the 20th century has been nearly 2 mm per year, which is an order of magnitude higher than the average from the past several millennia.[1] Rising sea level has global consequences because of its potential to change ecosystems and habitability of coastal regions, where an increasing proportion of the world's population lives. Increasing sea level can result in coastal erosion, exacerbated flooding and storm damage, inundation and loss of wetlands and other low-lying areas, salt intrusion into aquifers and surface waters, and higher water tables.[1] The higher sea surface temperatures resulting from global warming may also result in an increase in the frequency and intensity of tropical storms such as hurricanes.[3] The net result of sea level rise in the Chesapeake Bay is an increase in the area vulnerable to flooding caused by hurricanes and tropical storms such as Isabel, which is evidenced by the widespread flooding and damage that it caused.



Monthly sea level data from the last 100 years at Baltimore, showing a rise in sea level of about 30 cm, or 1 ft.

Relative sea level rise in the Chesapeake Bay has accelerated over the last 200 years. Tide gauges indicate that the rate of sea level rise in the Chesapeake Bay in the last century (~ 3.1 – 3.5 mm/year) is almost double the global average (~ 1.8 – 2.0 mm/year), resulting in a sea level rise in the Chesapeake Bay of approximately 30 cm or 1 ft in the last 100 years (see figure, bottom left).[1,6] This is due to a combination of global (eustatic) sea level rise, and local, or isostatic factors such as geologic land subsidence and groundwater extraction.[6] The east coast of the USA, from New York City to Georgia, lies astride the collapsing postglacial forebulge created by the Laurentide ice sheet which formerly covered Canada.[8] Chesapeake Bay exhibits a wide range of impacts from sea level rise. Bay islands are disappearing, cliffs are eroding and marshland is being inundated. Chesapeake Bay islands are generally less than 1 m elevation, and many are suffering from erosion and submergence, and Sharps Island at the mouth of the Choptank River has been completely drowned (see photo, above right).[1] To the north, Poplar Island has lost more than 90% of its land, and is currently the focus of a restoration effort using dredge spoil to raise its elevation.[1] The Blackwater National Wildlife Refuge near Cambridge on the Bay's Eastern Shore lost around 2,000 hectares, or one-third of its total marsh area between 1938 and 1988.[1] Erosion may also contribute to the decline of submersed aquatic vegetation (SAV), through an increase in water turbidity due to suspended sediments.[6]

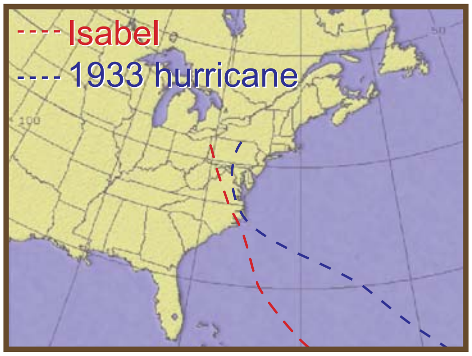
MORE FLOODING FROM ISABEL THAN 1933 STORM

On August 23, 1933 an unnamed hurricane crossed the coast at Nags Head, North Carolina. Like Isabel, it was a Category 2 hurricane at landfall and set the benchmark by which other Chesapeake storms are measured.

Isabel and the 1933 hurricane were very similar in terms of minimum pressure, maximum sustained wind speed, tidal surge and storm track (see table, below and map, right).

	1933 hurricane	Hurricane Isabel 2003
Min. pressure (" Hg)	28.26"	28.26"
Max. sustained wind	98 mph	98 mph
Tidal surge in Potomac River (feet above MLLW)	11.1'	11.3'

Comparison of statistics at landfall from the unnamed hurricane of 1933, and Hurricane Isabel. Data courtesy NOAA and UniSys Weather.



Comparison of the storm tracks of Hurricane Isabel and the 1933 hurricane. Map courtesy NOAA SSD.

Although Isabel's tidal surge was only slightly higher than the 1933 hurricane, anecdotal reports suggest that the flooding from Isabel was more severe than the 1933 storm, possibly as a result of the relative sea level rise of nearly one foot since then. [9,10,11]

With a rate of relative sea level rise of almost double the global average, Chesapeake Bay will feel the effects of global sea level rise more acutely than other regions. Global warming is expected to be accompanied by an increase in the frequency and intensity of tropical storms such as hurricanes and this combined with relative sea level rise suggests that the aftermath of Isabel may foreshadow the effects of these storms in the future.

Erosion damage at the UMCES Chesapeake Biological Laboratory in Solomons after the 1933 hurricane. Image courtesy Calvert Marine Museum Archives.

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*The **I**ntegration and **A**pplication **N**etwork (IAN) is a collection of scientists interested in **solving**, not just studying environmental problems. The intent of IAN is to inspire, manage and produce timely syntheses and assessments on key environmental issues, with a special emphasis on Chesapeake Bay and its watershed. IAN is an initiative of the faculty of the University of Maryland Center for Environmental Science, but will link with other academic institutions, various resource management agencies and non-governmental organizations.*

PRIMARY OBJECTIVES FOR IAN

- **Foster** problem-solving using integration of scientific data and information
- **Support** the application of scientific understanding to forecast consequences of environmental policy options
- **Provide** a rich training ground in complex problem solving and science application
- **Facilitate** a productive interaction between scientists and the broader community

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