SEA LEVEL IS RISING:
The volume of water in the world's oceans is slowly increasing. This is causing a steady rise in sea level relative to the land, except in a few places where the land itself is rising faster relative to the earth's center. What else is disturbing sea level? Will the sea's response prove disturbing to coastal residents in turn, by boosting storm tides experienced during a hurricane for example? Hints of the answer to these and other questions can be found by examining historical sea level records. We are fortunate to have a number of these records at hand along the U.S. east coast including Virginia's coastal and estuarine regions.

WATER LEVEL DATA FROM NOAA-NOS:
The National Ocean Service (NOS), a division of the National Oceanic and Atmospheric Administration, has been in the marine data gathering business for a long time. Water (sea) level records[1] at some NOS observation stations go back a hundred years or more. Often we hear them called 'tide stations'. So why not refer to the output as a 'tide record' rather than a 'water level record'? The reason is: changes in sea level are only partly a response to the gravitational attractions of the earth, moon and sun that result in what is called the *astronomical tide*. Other variations occur at the same time that have a different origin. These *non-tidal changes* can and do have important consequences. Unfortunately, while astronomical tides can be predicted quite accurately years in advance, very little is predictable as to the 'when' and 'where' of non-tidal changes in water level. But rather than pure chaos, there is often a distinguishing feature: a characteristic period or length of time needed to complete a cycle of motion.

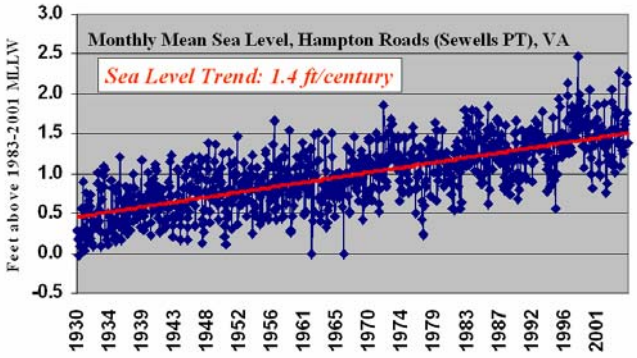
PERIODIC CHANGES IN SEA LEVEL:

[1] The NOS prefers the term *water level* to *sea level* except when referring to the datum of *mean sea level*.

Besides ruining your day when your boat runs aground during a low tide, changing sea level matters in a variety of ways. The semi-daily rise and fall due to astronomical tides drives the circulation that provides the flushing ability of a healthy estuary. In tidal wetlands, frequency of immersion plays a key role in the distribution of different types of vegetation. The Federal Emergency Management Agency (FEMA) defines flood risk zones based on expected sea level extremes during tropical storm and hurricane events.

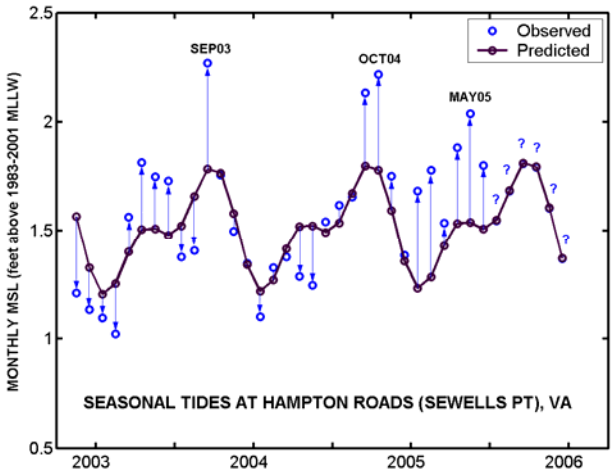
Tide prediction tables capture most, but not all, of the observed daily variation in sea level. Weather events are often responsible for the short-term discrepancy commonly seen between predicted and observed sea level over a period of days or weeks. Moving beyond this to a scale of months, we encounter a different type of change, one that is much harder to predict.

MONTHLY MEAN SEA LEVEL:
Values of monthly mean sea level (MMSL), calculated as the average water level during each calendar month, are available for many U.S. stations online at http://co-ops.nos.noaa.gov/. The figure below contains a plot of MMSL for Hampton Roads (Sewells Point), VA, over a 74 -year period from 1930 through 2004.

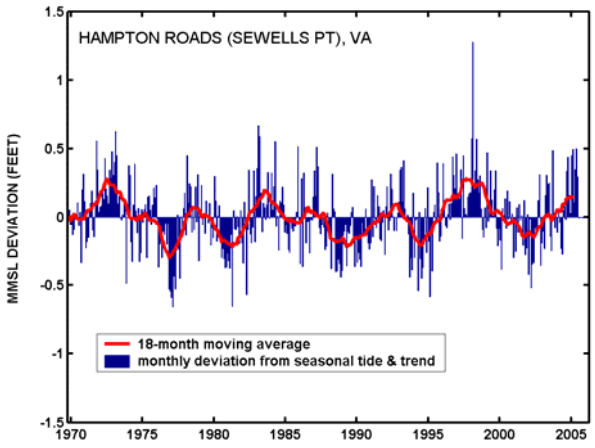


The sea level trend for Hampton Roads is positive, rising at approximately 1.4 feet per century as shown by the red line of best fit to the data. The trend alone is cause for concern as it continually adds to the sea level base that storm surge from future hurricanes will build on in combination with the astronomical tide (storm tide = storm surge + astronomical tide).

For example, during the 70 years between Hurricane Isabel (18 September, 2003) and the August 1933 hurricane, mean sea level rose at Hampton Roads by almost a foot. However, the trend tells only part of the story; the blue lines in the figure show that MMSL for an individual month can deviate either above or below the trend by as much as a foot. This deviation is not completely random but varies seasonally in an annual and semiannual cycle as shown in the next illustration.



The so-called *seasonal tide* shown by the black curve in the above figure is actually a part of the NOS tide prediction formula used at Hampton Roads and other locations. The solar annual (Sa) and solar semiannual (Ssa) tidal constituents that are derived for this purpose depend not only on solar gravity modulated by the sun's 'apparent' orbital motions as viewed from earth but on seasonal heating and cooling that leads to thermal expansion and contraction of the ocean water column as well. But even this formula does not account for all the ups and downs exhibited by the observed MMSL values shown in blue. While seasonal tide level at Hampton Roads is highest during the prime hurricane months (August through October), the MMSL value for September 2003 was about half a foot higher than predicted in that year. Quite unusual - or so I thought until I noticed that MMSL for September and October 2004, was again higher than normal. As I write this midway through 2005, I'm even more surprised to see that MMSL recorded every month thus far (except for March) is well above normal. What is causing sea level to act this way? The answer to this question may be seen in plots of the MMSL deviation from the sea level trend and the seasonal tide over several decades.



DECADAL CHANGE IN SEA LEVEL:

The last figure for Hampton Roads provides a look at what is called the decadal change in sea level. The individual MMSL deviations (shown in blue) display many ups and downs reminiscent of the stock market. Like stock market analysts, we can apply a smoothing technique, such as a moving average (MA), to see whether there is a cyclical trend. What we find after applying an 18-month MA to the Hampton Roads data is a sea level oscillation with a period of roughly 6 to 7 years (red line). Although not a guarantee of future sea level behavior, the data suggest that we may have just entered a new cycle of decadal change in our region.

Physical oceanographers are still debating the probable cause of the observed decadal cycle in sea level. Some experts have suggested that an expansive deep ocean feature known as a *Rossby wave* may be responsible. If true, decadal sea level curves should appear similar not only within Chesapeake Bay but in other parts of the country bordering the North Atlantic Ocean. This seems to be the case as shown by the examples below.

Final thought: the red line, slow-changing and muted, indicates risk; blue lines mark the possible extremes.