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The Tide Next Time

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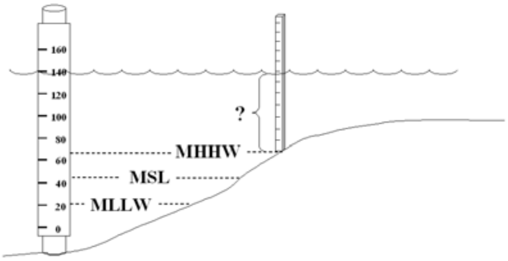
THE TIDE NEXT TIME



By John Boon
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Will sea level be higher the next time Virginia encounters a hurricane? The most likely answer is ‘yes’. See https://scholarworks.wm.edu/reports/2805 for my web article titled ***The three Faces of Isabel*** describing the role of changing sea level in shaping the ***storm tide*** produced by Hurricane Isabel on 18 September 2003. As explained in that article, a storm tide is the extreme water level that results when ***storm surge,*** the short-term change in water level due to the effects of the storm, is superposed on the everyday rise and fall of the ***astronomical tide*** that happens to be in place as the storm arrives at the coastline. Isabel’s third face emerged from the long-term change in sea level within the Hampton Roads area: the rising ***mean sea level trend* of 4.42 mm/year** or **1.45 feet/century at Hampton Roads (Sewells Point) VA** reported by the National Ocean Service, a division of the U.S. National Oceanic and Atmospheric Administration (NOAA). This trend, however, is not the only important contributor to sea level change that we will witness in the future.

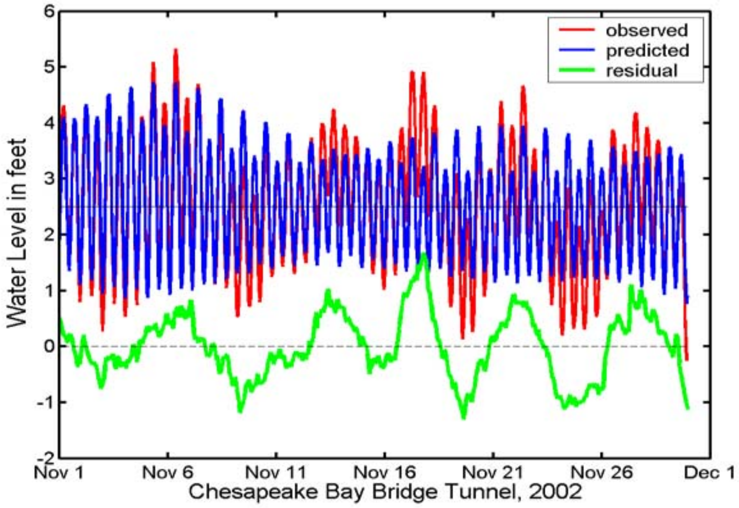
While a few millimeters of sea level rise per year relative to the land we stand on poses a very small threat in the short term, it clearly matters when we compare the storm tides produced by large and infrequent hurricanes: Hurricane Isabel and the hurricane of August 1933, for example. The latter is often cited as the storm of the century for the Hampton Roads region. In the seventy years separating these two record events, mean sea level rose by about one foot in lower Chesapeake Bay where the mean tide range is approximately two and a half feet. This fact helps to explain why the storm tides for both events were nearly identical, even though Isabel was a less powerful storm and produced a smaller storm surge. We can appreciate the change now, after the fact, but what about the future?

A QUESTION OF TIME

To establish a benchmark for the area, a large hurricane in the historical record is sometimes referred to as the 100-year storm. By that, we mean that the event has a 1-in-100 chance of occurring in any year, not that it will reoccur precisely every 100 years like a comet completing its orbit in space. Only after an extremely long period of time has passed will we actually know whether or not, on average, such storms occurred every 100 years, more or less. On the other hand, there is little or no chance that the average sea level is going to raise one foot in the space of a year. Seventy years is required for mean sea level to rise that far assuming it follows the trend we see at Hampton Roads. That certainly gives coastal zone managers a lot of time to plan adequate coastal infrastructure and prepare for future storm emergencies, but maybe not as much time as we might think. We may want to have another look at the sea level data that NOAA has collected.

DAILY CHANGE IN WATER LEVEL

Water level observations are routinely made at permanent gauging stations such as the one at Sewells Point. Although these are sometimes called tide stations, NOAA refers to the hourly values they record as water level observations because the astronomical tide accounts for only a portion of the day-to-day variation in water level that takes place. An example is given below for the Chesapeake Bay Bridge Tunnel, the location of an NOAA station at the entrance to Chesapeake Bay.



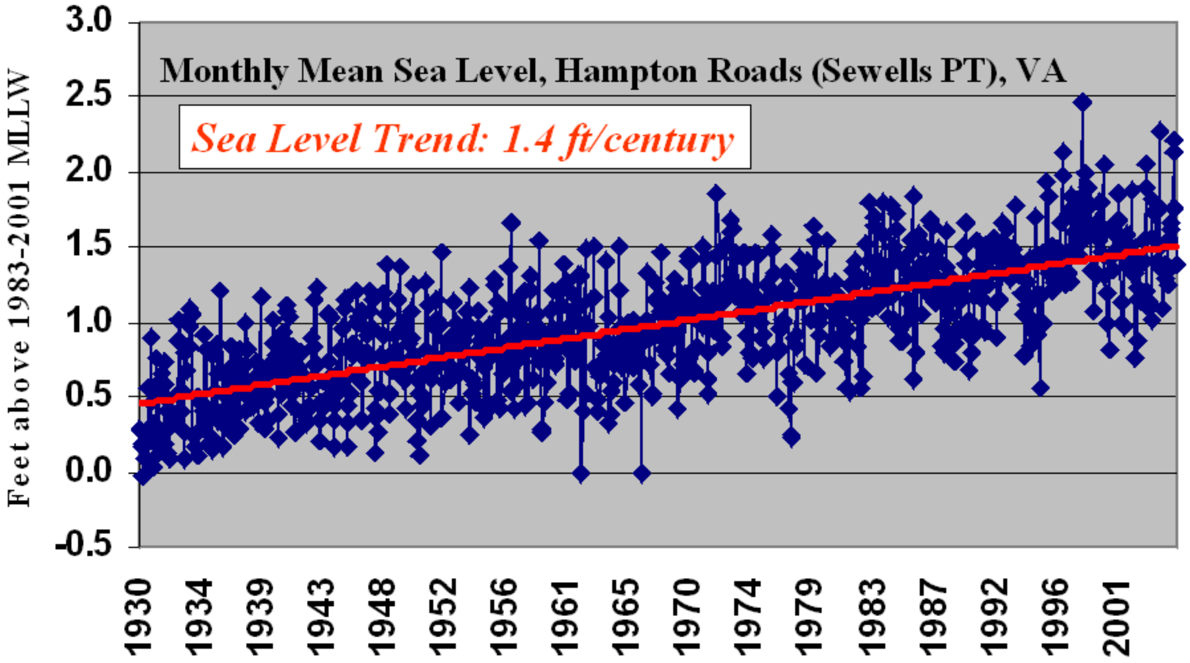
The blue line shown in the figure at right represents the predicted (astronomical) tide. By subtracting the predicted hourly tide from the observed hourly water levels (red line), we obtain the *residual* change in water level (green line). The green line in this case illustrates a common feature for our region in winter months – a *sub-tidal* oscillation with a period of approximately four to five days caused by the regular passage of ordinary winter storm systems. A nearly identical oscillation appeared throughout the lower Bay and along Virginia's Atlantic coastline during this same time interval. I hope you are impressed, as I am, by the magnitude of the sub-tidal change in water level – it can be as large as the tide itself!

It is obvious from the above that averaging water (sea) level over not just one day but tens of days is needed to get a meaningful *base elevation* – one to which both a predicted storm surge and predicted astronomical tide can be added on any given day to yield a predicted storm tide relative to the land. An average of at least one month is needed to smooth the sub-tidal changes observed in the Chesapeake Bay region. However, plotting monthly averages of sea level from one month to the next will show that the 'base elevation' is anything but stable.

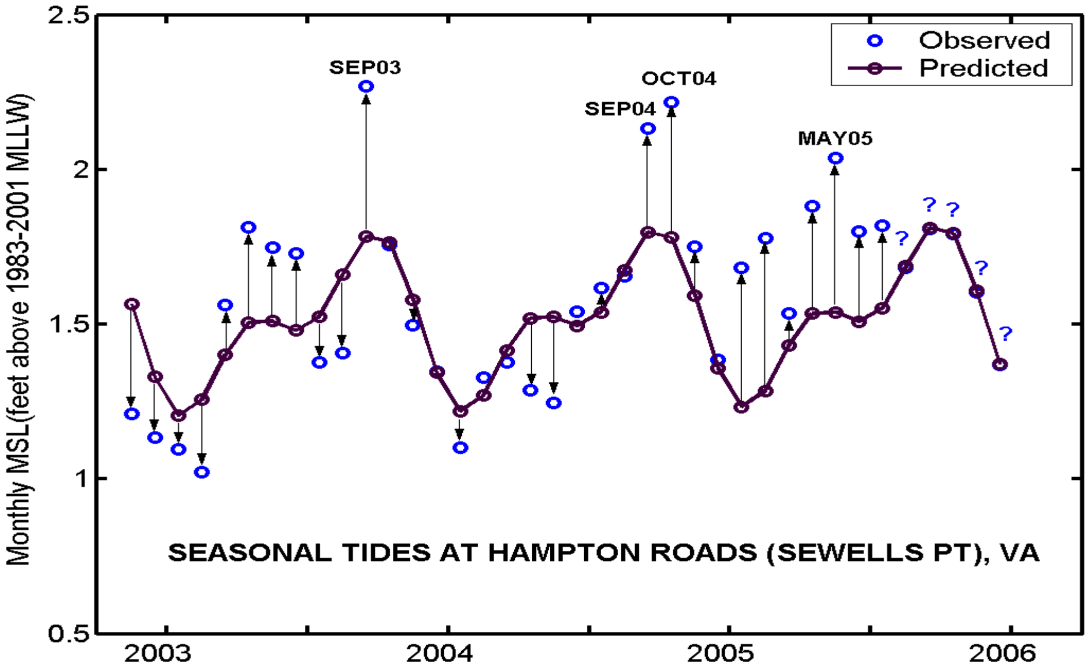
MONTHLY MEAN SEA LEVEL

It is an easy matter to find *monthly mean sea level* (mmsl) data on the World Wide Web. Both NOAA at http://co-ops.nos.noaa.gov/ and the British Permanent Service for Mean Sea Level at http://www.pol.ac.uk/psmsl/ offer a wealth of observed water levels, including monthly mean values, for many stations in the U.S. and around the world. A monthly mean in either database refers to a *calendar month* and thus a mean over a variable number of days (28-31). Some stations have sea level observations that span a hundred years or more.

To use these data to estimate a sea level trend, all of the observations must refer to a fixed vertical datum; i.e., a common reference point on land. This can be a *tidal datum* such as Mean Lower Low Water (MLLW), a datum used in the U.S. or its counterpart, Lowest Astronomical Tide (LAT) used in the U.K. and most other countries. However, both datums are nothing more than a computed offset from mean sea level, made for the express purpose of avoiding negative numbers in predictions of the astronomical tide. Mean sea level remains the central player to keep our eye on. When used as a tidal datum, mean sea level is defined by averaging hourly observations for a specific series of years that is often updated as sea level continues to change. In the U.S., a 19-year series called the National Tidal Datum Epoch is used and the latest Epoch is based on the years 1983 through 2001. To avoid negative numbers, I too have chosen to use 1983-2001 MLLW as the vertical reference for the mmsl series shown below for Hampton Roads (Sewells Point), VA:



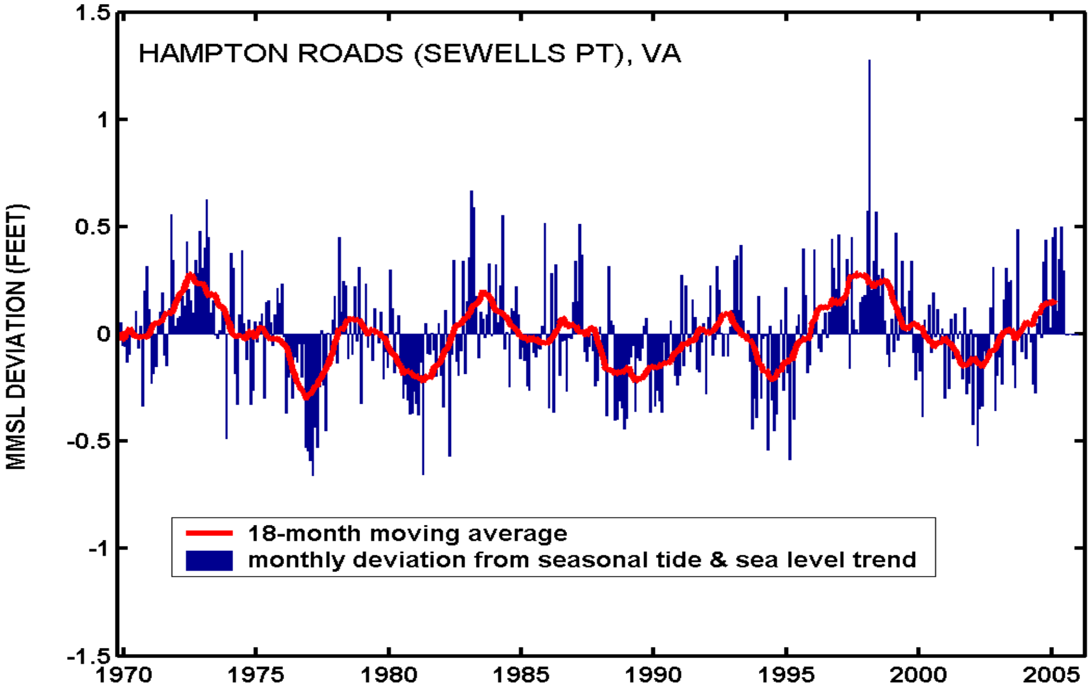
The red line of ‘best fit’ to the mmsl data yields essentially the same sea level trend (1.4 feet per century) that NOAA has reported for Hampton Roads. There is, however, quite a lot of variation about that red line. Part of it is accounted for by the so-called *seasonal tide* shown by the black curve in the next figure below. The latter is part of the NOS tide prediction formula used at Hampton Roads and other locations. The *solar annual* (Sa) and *solar semiannual* (Ssa) tidal constituents 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. However, even this formula does not account for all the ups and downs exhibited by the observed mmsl data – a fact readily apparent in the figure below.

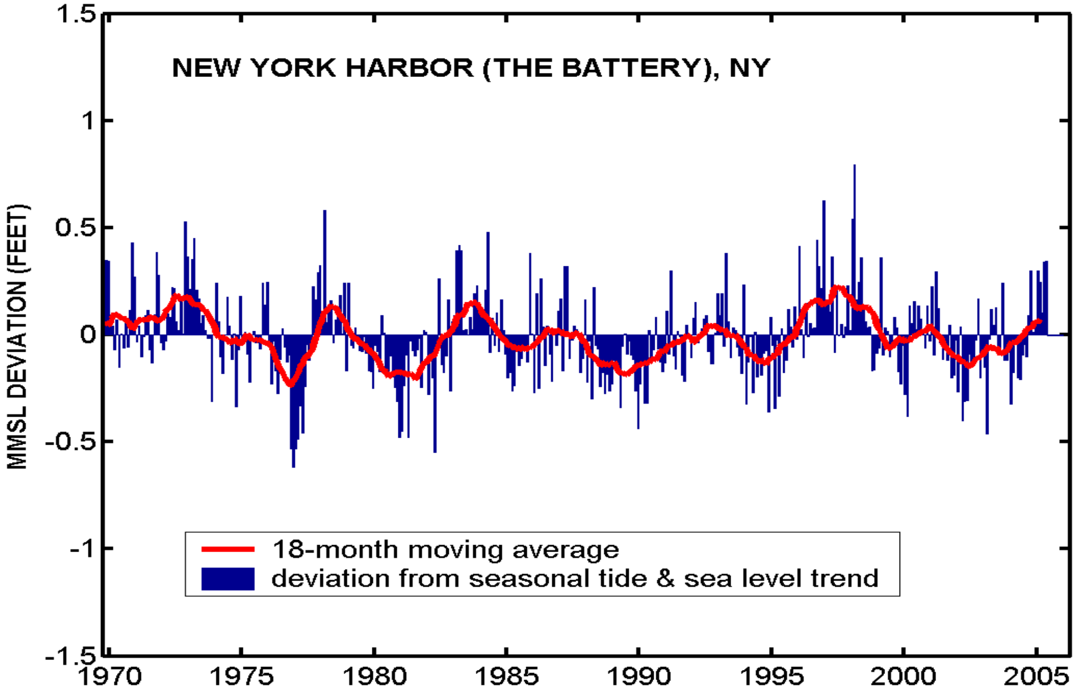


Looking at the year 2003 in the graph above, we see that mmsl was not that far off from the predicted level (black curve), sometimes rising above it and sometimes falling below it – until September when Hurricane Isabel occurred. Isabel's storm surge, in effect for 24 hours on September 18th, obviously contributed to the higher monthly mean for September but not by a lot: in fact, about 2 centimeters or less than an inch was added to the mean by the storm. Clearly, something else was responsible for mmsl being almost half a foot higher than predicted that month. An isolated occurrence? I though so, until I saw elevated mmsl values for September and October of 2004 – months with hurricanes making landfall in Florida but none in Virginia. However, what really has my attention is mmsl in the present year. As I write this in early August of 2005, I see that every month thus far, with the exception of March, has a mmsl value well above predicted. What does this mean?

DECADAL VARIABILITY IN SEA LEVEL

The exact cause is not well known but the deviations from predicted mmsl seem to be associated with a cyclical trend that is perhaps as well established in certain Atlantic coast regions, including ours, as the linear trend in sea level rise. In the two figures below, blue lines show the observed mmsl deviation from both the linear trend and the predicted seasonal tide for the last 36 years at two NOAA stations with long records: Hampton Roads, VA, and New York Harbor, NY.





The red line in each of the above figures is obtained by using an *18-month moving average* to smooth the deviations. This process reveals ***the cyclical trend: a set of oscillations in which the average cycle lasts roughly six to seven years***. While the magnitudes of the deviations seem to be slightly larger at Hampton Roads as compared to New York Harbor, the cyclical trend is very similar in terms of the *phase* or the beginning and ending periods of each cycle. Interestingly, we seem to be well into a new cycle in 2005, an observation that is consistent with the positive mmsl deviations we've seen thus far at Hampton Roads.

A POSSIBLE CAUSE

The similarity of the cyclical trends in these two widely separated locations argues for a large scale forcing mechanism – one that is not local to either coastal region. Physical oceanographers have proposed that large-scale wind systems that act over the open ocean are responsible. Press these oceanographers a little harder and the conversation may shift to topics like *baroclinic Rossby waves*, deep-ocean features that arise from large-scale wind stress patterns acting on the sea. In any case, the so-called *decadal variability in sea level* has revealed itself well enough to take advantage of the information.

THE TIDE NEXT TIME

Virginia and the Tidewater region will one day encounter another major storm such as Hurricane Isabel or the hurricane of August 1933. When that day arrives, our sea level history all but guarantees that a sea level higher than today's will be there to greet that storm. Exactly how much higher will be a question worth answering in advance and the data to do that with will be at hand as long as sea level monitoring continues. The answer can be found as the sum of three parts:

- Sea Level Trend: The amount of yearly mean sea level rise relative to the land can be predicted for any future year by simply utilizing the linear trend for the region; e.g., 0.0145 feet per year in Hampton Roads. The projected mean sea level will be expressed, as it is today, as a height above a suitable tidal datum defined by the current National Tidal Datum Epoch.
- Seasonal Tide: When added to the projected yearly mean sea level, the predicted seasonal tide for a given month will yield the projected mean sea level for the year and month above the selected tidal datum.
- Decadal Variability: The final addition is partly systematic and partly a matter of chance. The moving averages defining the cyclical trend in our region suggest that an *increase* (up to 0.5 ft.) is likely during the *positive* phase and a *decrease* (up to 0.5 ft.) is likely during the *negative* phase of an estimated 7-year cycle. This cycle deserves close and continuing study.