SEA LEVEL RISE, SEASONAL TIDES AND THE DECADAL CHANGE IN SEA LEVEL IN CHESAPEAKE BAY

by

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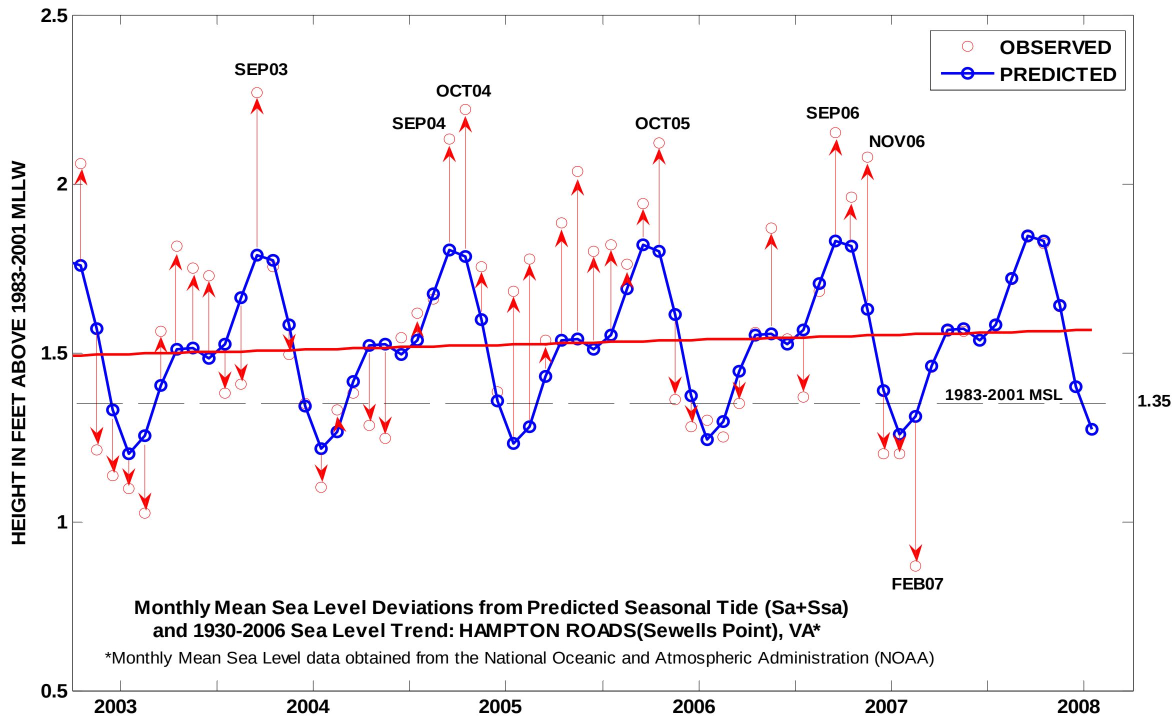
Residents of the tidewater region in Maryland and Virginia are not only familiar with the daily rise and fall in water level that we call the *astronomical tide* but are also keenly aware of *storm tides* that cause extreme flooding in low-lying coastal areas. Storm tides are water levels made higher by superposing the astronomical tide and a *storm surge*, the increase in water level due to the effects of a storm such as a hurricane, tropical storm or an extratropical storm more commonly referred to as a *northeaster*. All of these storms can quickly raise water levels and produce a damaging surge through a combination of low atmospheric pressure and wind stress acting on the surface of the water.

Although government computer models frequently give a surge height forecast for an impending storm via the media, what we witness as the storm passes is a high water mark on a sea wall or a building or a recording made by a tide gauge. The peak in water level observed using any of these methods is the storm tide. But to understand how storm tides reach the heights they do, researchers are now studying two additional contributing elements besides the storm surge and the astronomical tide. One of these is the *sea level trend* – a linear rise in water level that amounts to about 4.3 mm per year (1.4 feet per century) at Hampton Roads in lower Chesapeake Bay. Most of us are quite aware of the issue of sea level rise in the context of global climate change. However, you may not be aware of the second contributor - a long-term cyclical change in water level on a time scale varying between years and tens of years. The *decadal change in sea level*, as it is known, is being investigated at tide stations with monthly mean sea level (mmsl) values spanning several decades. Two Chesapeake Bay stations provide good examples.

Monthly Mean Sea Level and the Seasonal Tide at Hampton Roads - Astronomical tide predictions for tide stations in the United States usually include a pair of tidal constituents referred to as the solar annual (Sa) and solar semi-annual (Ssa) constituents with periods of one year and one-half year, respectively. Together they predict the *seasonal tide*. Although the Sa and Ssa constituents have a celestial origin like other tidal constituents, most of their amplitude is determined by seasonal cycles of heating and cooling that lead to thermal expansion and contraction of the ocean water column over these same periods. Because the heating and cooling varies from year to year, seasonal tides vary as well and deviations from predicted mmsl are commonly observed. What makes these deviations unusual is the fact that they are not all random but contain some interesting variations of their own.

The graph shown on the next page illustrates the behavior of the seasonal tide at Sewells Point in Hampton Roads, Virginia. Note that mmsl predictions always start the year at a low in January and reach their highest level in September. Observed mmsl values during the four years from 2003 through 2006 included large positive deviations during September and October, months closely associated with hurricanes and tropical storms (e.g., hurricane ISABEL in SEP03 and tropical depression ERNESTO in SEP06). Values after FEB07 are unknown at time of writing.

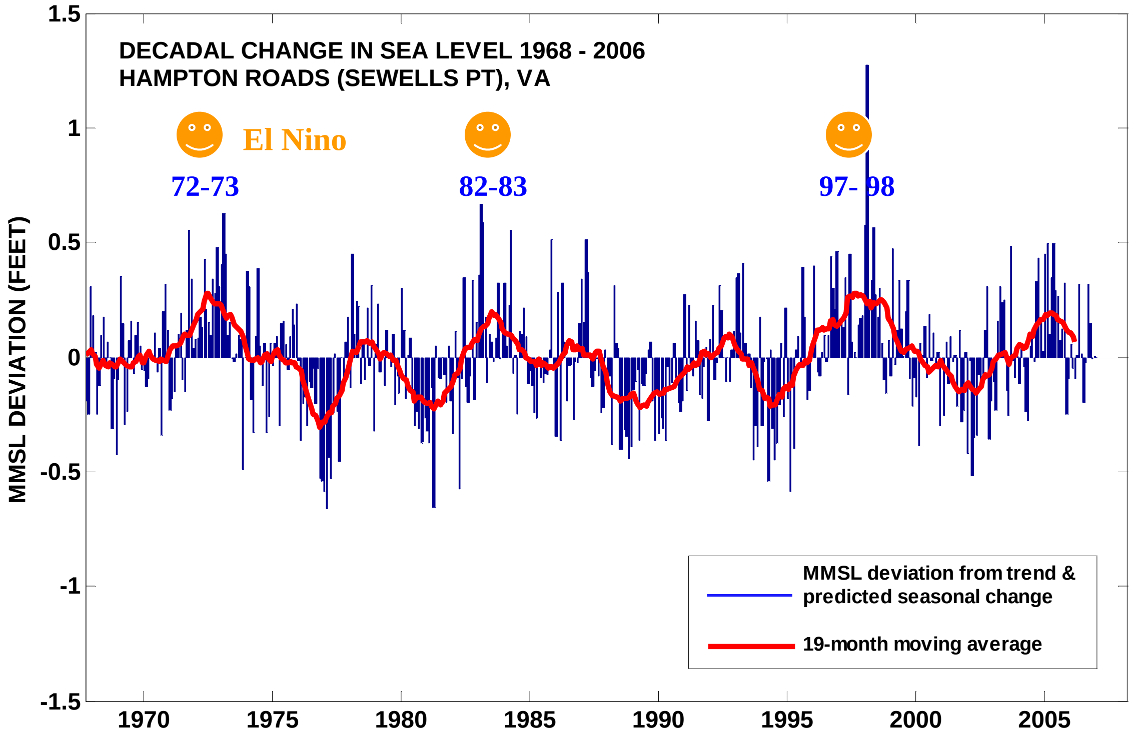


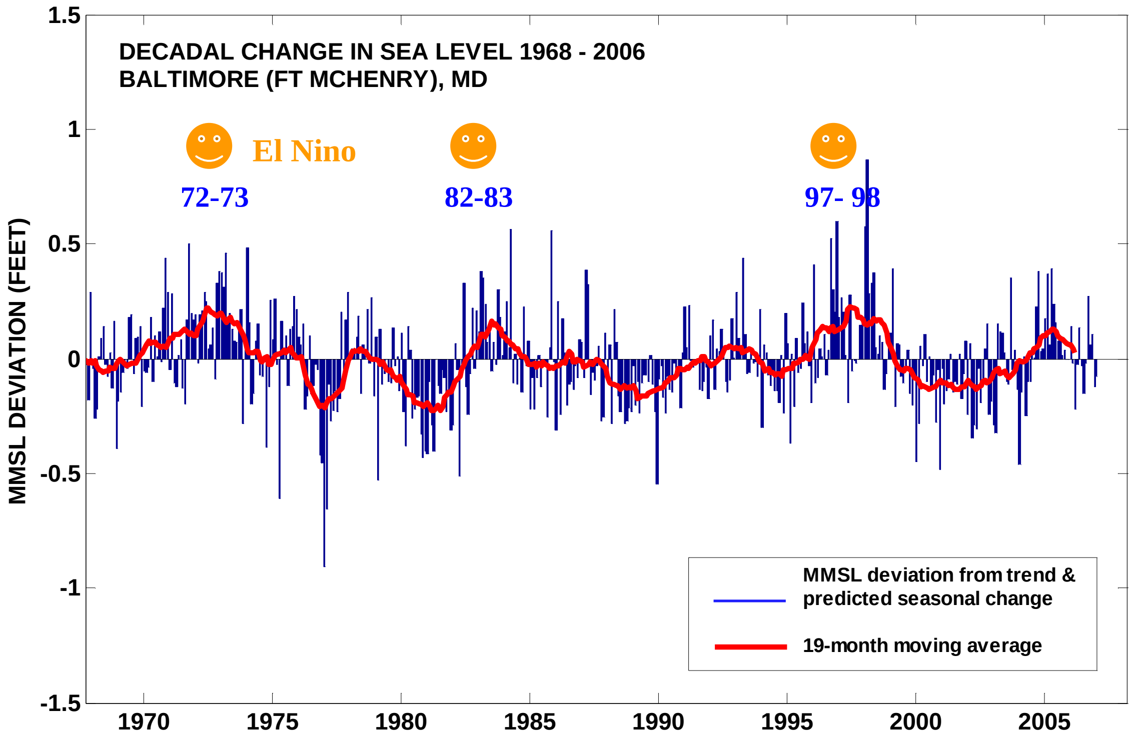
Notice the mmsl deviations or *mmsl anomalies* in the above graph. They reveal an unusual pattern in the years 2004-2005: from SEP04 through OCT05, all of the anomalies are positive, most of them strongly so. If you have ever heard someone say "the tides seem higher than usual this month", you are now seeing the reason. Unfortunately, the next hurricane may see it as well.

Also shown in the above graph is the position of the tidal datum of Mean Sea Level (MSL) for the 1983-2001 National Tidal Datum Epoch. As NOAA has determined it, MSL lies fixed (until NOAA calls for another Epoch) at 1.35 feet above Mean Lower Low Water (MLLW). The difference in elevation between an observed mmsl and the tidal datum of MSL is called the *sea level anomaly*. Notice that all the components of the sea level anomaly - the sea level trend, the seasonal tide varying about the trend as well as the observed mmsl values themselves - are all going up relative to MSL as time advances.

<u>The Decadal Change</u> - To visualize the decadal change in sea level, another graph is required like the one above but longer in length with both the sea level trend and the seasonal tide removed. This results in a busy-looking graph with many vertical blue lines as shown on the next page. However, after a little smoothing (using a 19-month moving average), the heavy red line reveals a quasi-periodic cycle representing the decadal change in sea level. For the time series utilized at Hampton Roads, these cycles have an average period of between 5 and 6 years.

What causes the decadal change? There is no clear answer at present but there is a degree of association with a global scale ocean-atmosphere event known as El Niño. Three of the most recent El Niño events in 1972-1973, 1982-1983 and 1997-1998 matched decadal highs at Hampton Roads. Similar cycles are seen at Baltimore, MD, but with slightly smaller amplitude.


DECADAL CHANGE IN SEA LEVEL 1968 - 2006
HAMPTON ROADS (SEWELLS PT), VA
El Nino
72-73
82-83
97- 98
MMSL DEVIATION (FEET)
MMSL deviation from trend & predicted seasonal change
19-month moving average
1.5
1
0.5
0
-0.5
-1
-1.5
1970
1975
1980
1985
1990
1995
2000
2005


DECADAL CHANGE IN SEA LEVEL 1968 - 2006
BALTIMORE (FT MCHENRY), MD
El Nino
72-73
82-83
97- 98
MMSL DEVIATION (FEET)
MMSL deviation from trend & predicted seasonal change
19-month moving average
1.5
1
0.5
0
-0.5
-1
-1.5
1970
1975
1980
1985
1990
1995
2000
2005

Implications for the future – A good implication may be that major hurricane activity appears to be less frequent during El Niño events. This could mean that decadal highs in the future will contribute mainly to storm tides associated with storms of lesser intensity. On the other hand, hurricane ISABEL arrived in Virginia waters during one of the higher monthly mean sea levels recorded in recent years at Hampton Roads (the sea level anomaly for September 2003 was approximately 0.91 feet above 1983-2001 MSL). In contrast to this, the moving average reflecting the decadal cycle (red curve in the above graphs) was near zero in the latter months of 2003. Nevertheless, it could be useful to know when we are entering a period of decadal highs in sea level and to compare this with previous cycles. It's relatively easy to obtain this information from tide stations with long records.