

Tides, Sea Level Rise, and Storm Surge: A Miami Perspective

Brian McNoldy
Senior Research Associate

UNIVERSITY OF MIAMI

ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

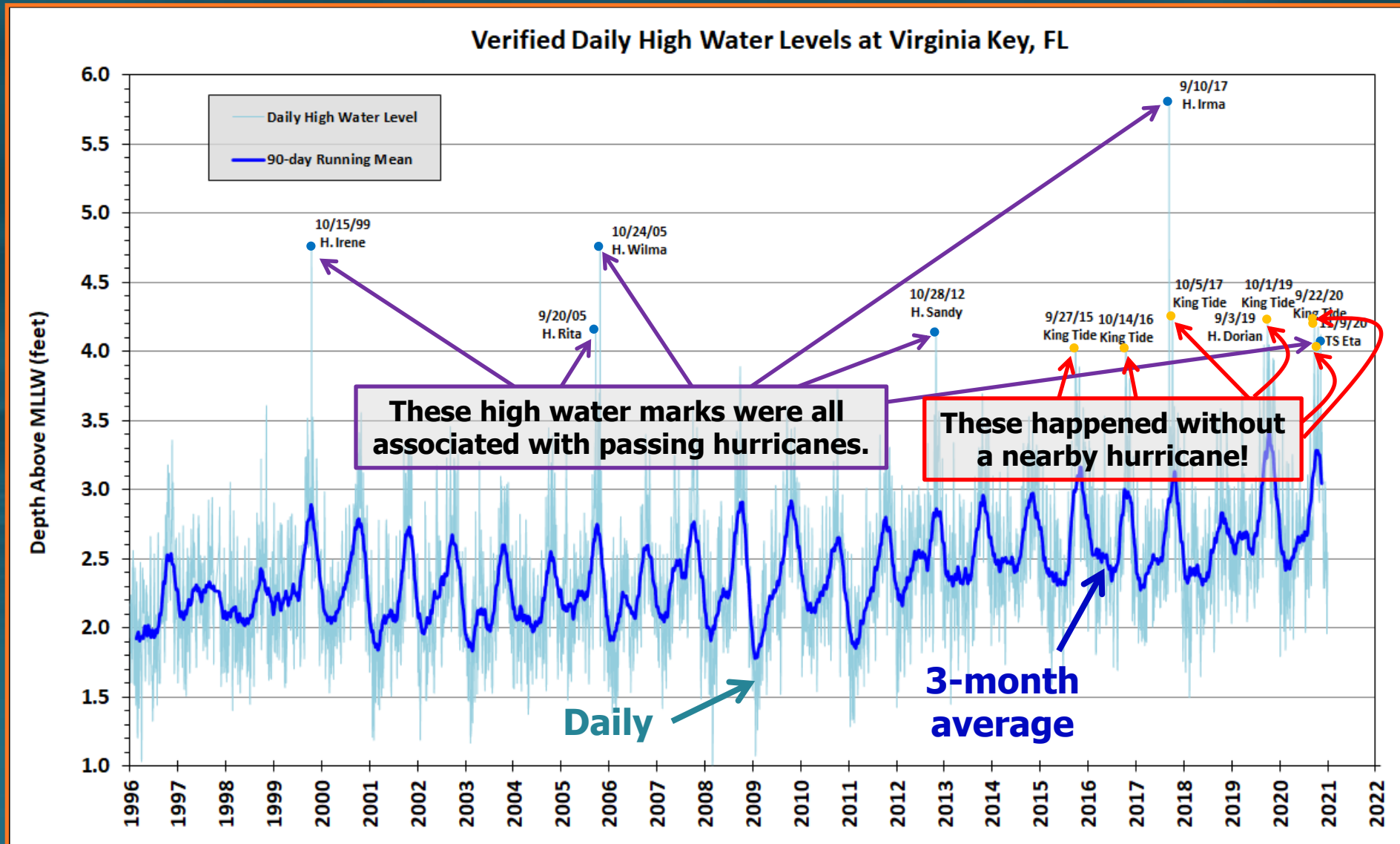


The
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TWC Speaker Series
September 30, 2021

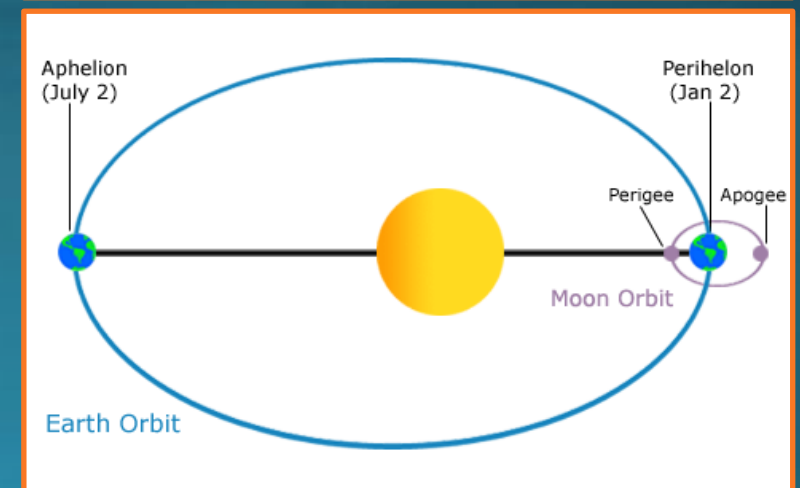
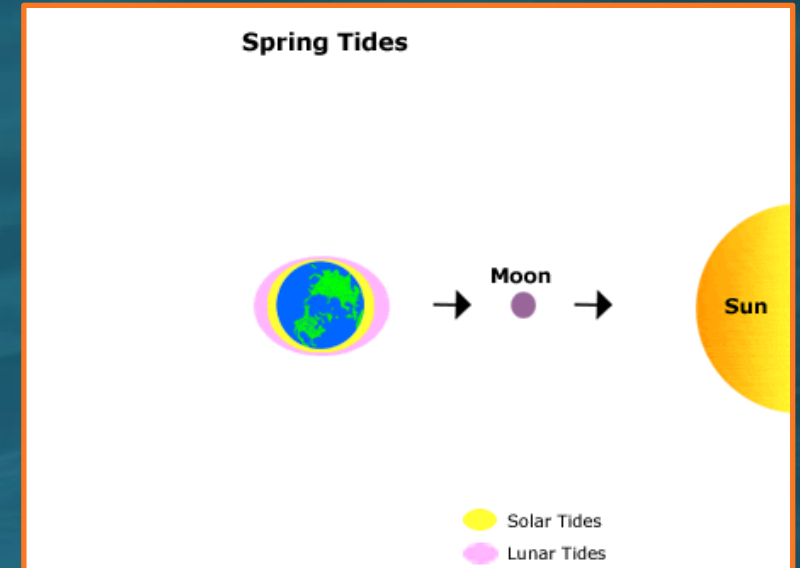


Daily Data & High Water Marks



What Factors Influence Tides?

- Phase of the moon
 - Full and new moons exert greater tidal pull on oceans
- Earth's proximity to the moon
 - Moon's elliptical orbit means once/month it's closer to Earth, producing greater tidal forces
 - "perigee" vs "apogee"
- Earth's proximity to the sun
 - Earth's elliptical orbit means once/year (January) it's closer to the sun, producing greater tidal forces
 - "perihelion" vs "aphelion"
- Lunar Nodal Cycle
 - Precession in the moon's orbital plane causes an 18.6-year cycle in mean sea level. This can be significant enough to not ignore.

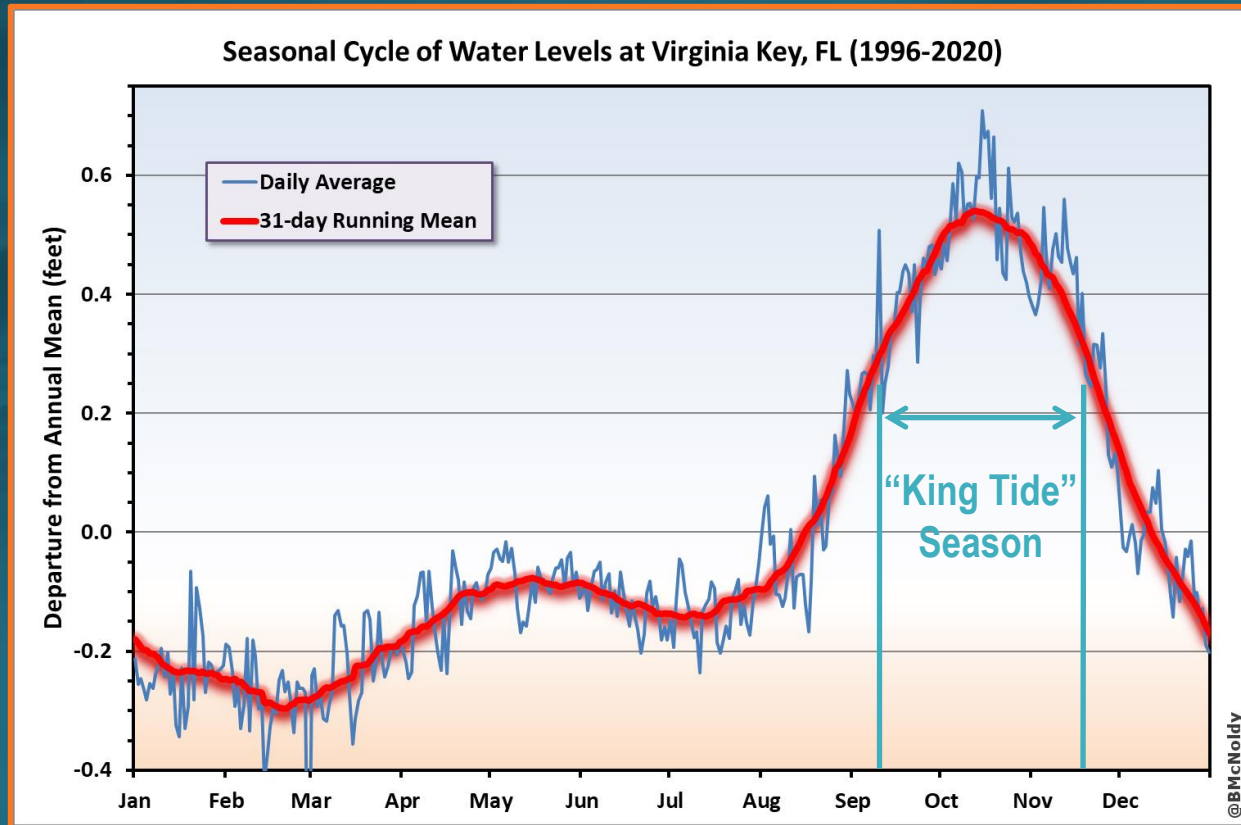


What Factors Influence Tides?

- Persistent wind direction
 - Strong onshore winds push water onto land
- Ocean temperature
 - Warm water expands more than cooler water
- Atmospheric pressure
 - Low pressure allows sea level to bulge up
- Strength of the Florida Current and Gulf Stream
 - Reduced transport allows water to pile up along U.S. east coast
- All of these have an average/climatological influence which is included in tide predictions... but *specific events and anomalies are not*

Average Seasonal Cycle of Sea Level in Southeast Florida

- For the reasons just outlined, water levels are naturally lowest in Jan-Feb-Mar and highest in Sep-Oct-Nov in the area

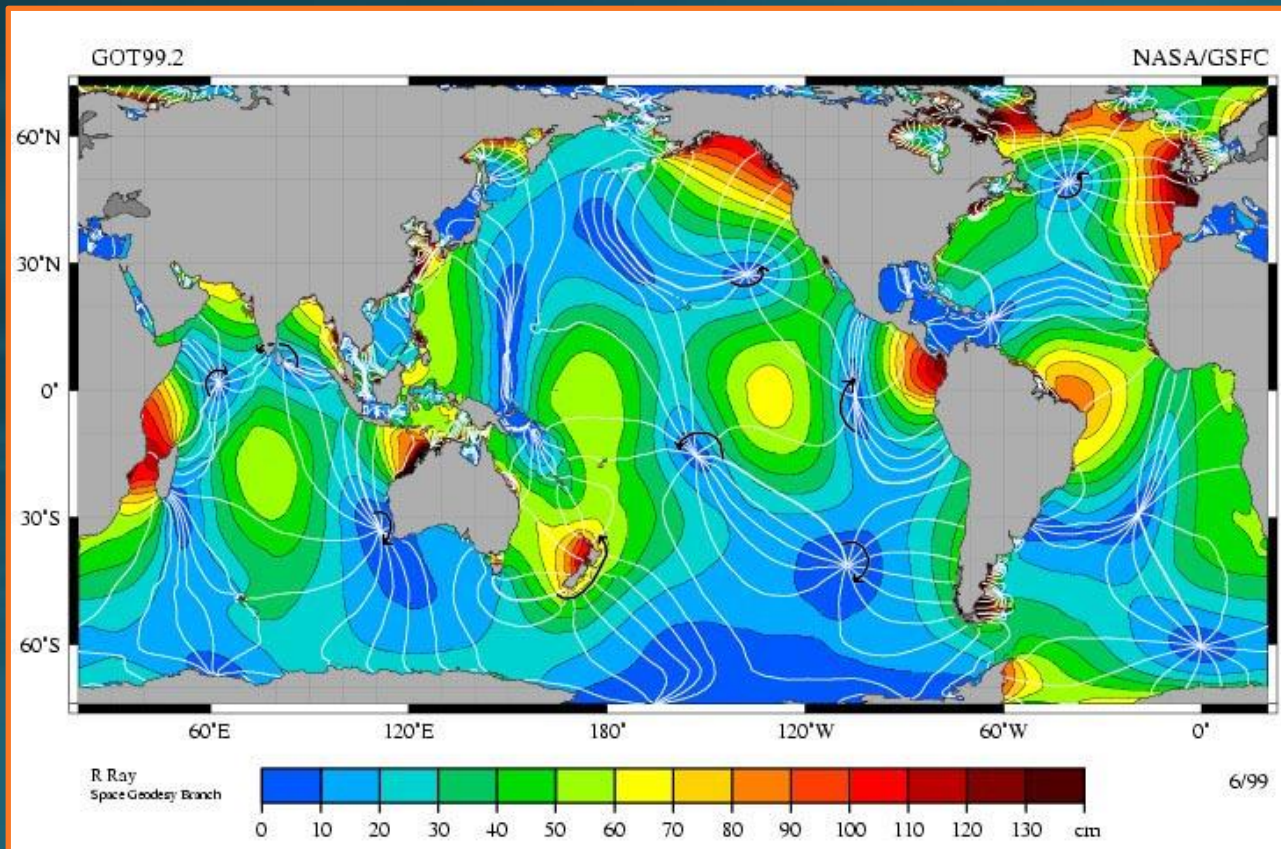


~10 in (25 cm)

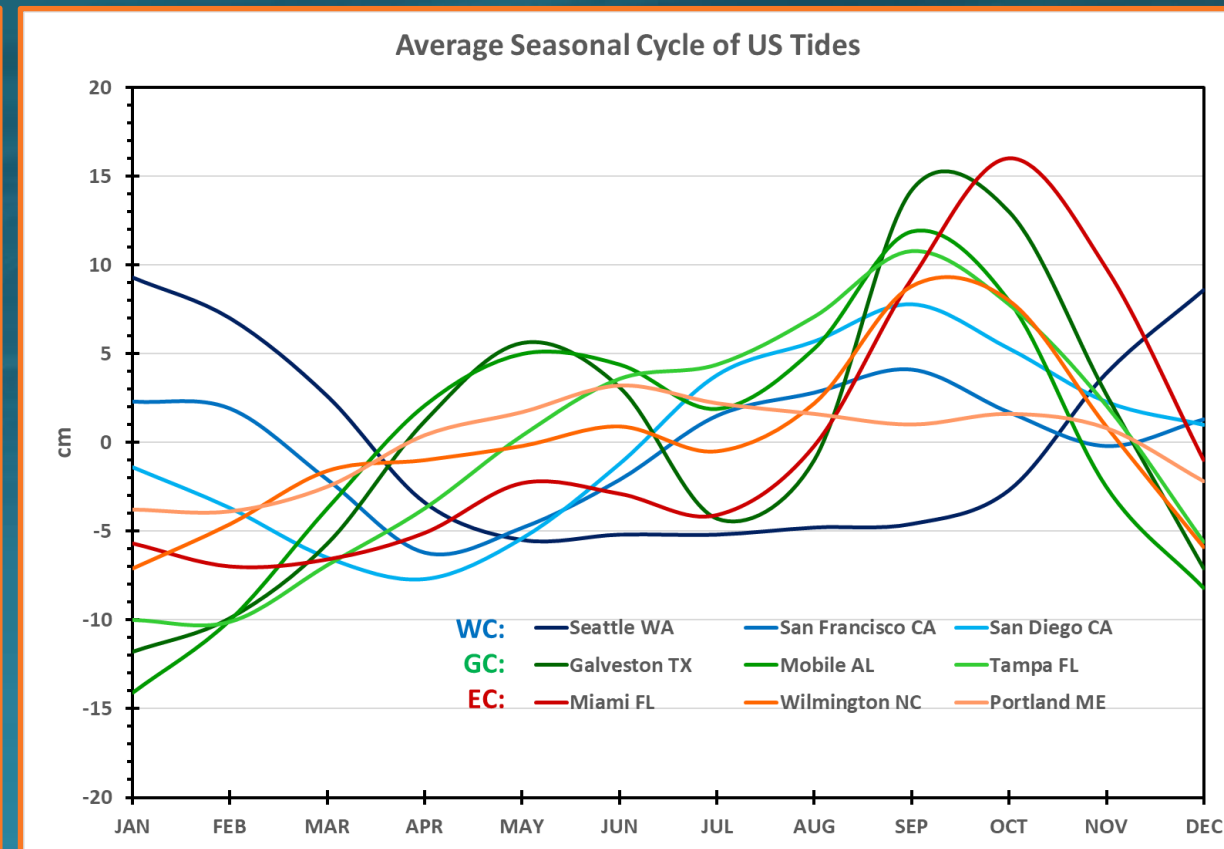
But, Not the Same Everywhere!

- Tidal ranges have distinct daily and annual variations

DIURNAL

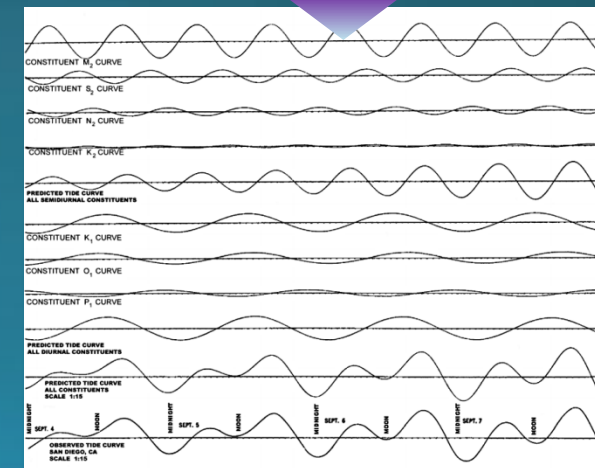
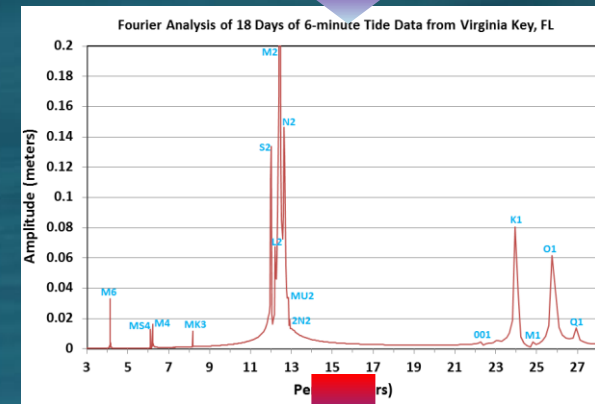
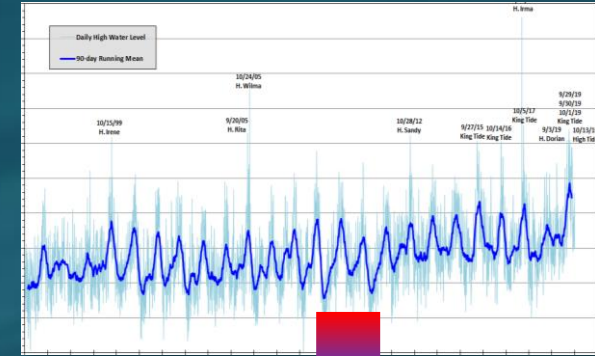


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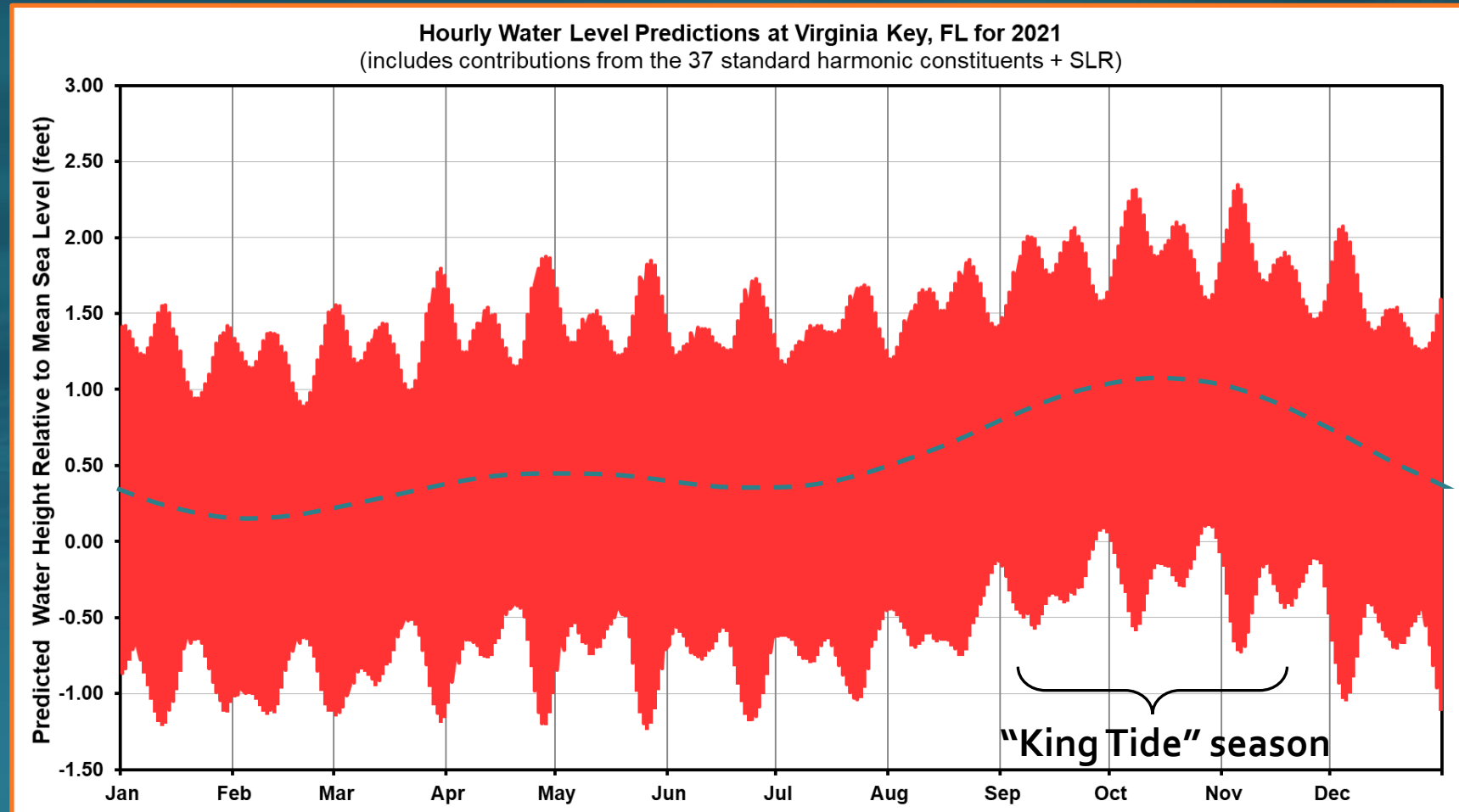
What Tide Predictions Are... and Are Not

- Tide predictions rely on a long time series of actual tide observations at a location.
 - A Fourier decomposition is performed to produce a list of sinusoidal components (“harmonic constituents”), each with a phase, frequency, and amplitude
 - These components are added together to arrive at a reconstructed total water level relative to a vertical datum of choice
- *NOAA’s tide predictions are not like weather forecasts...* they are essentially astronomy + climatology.



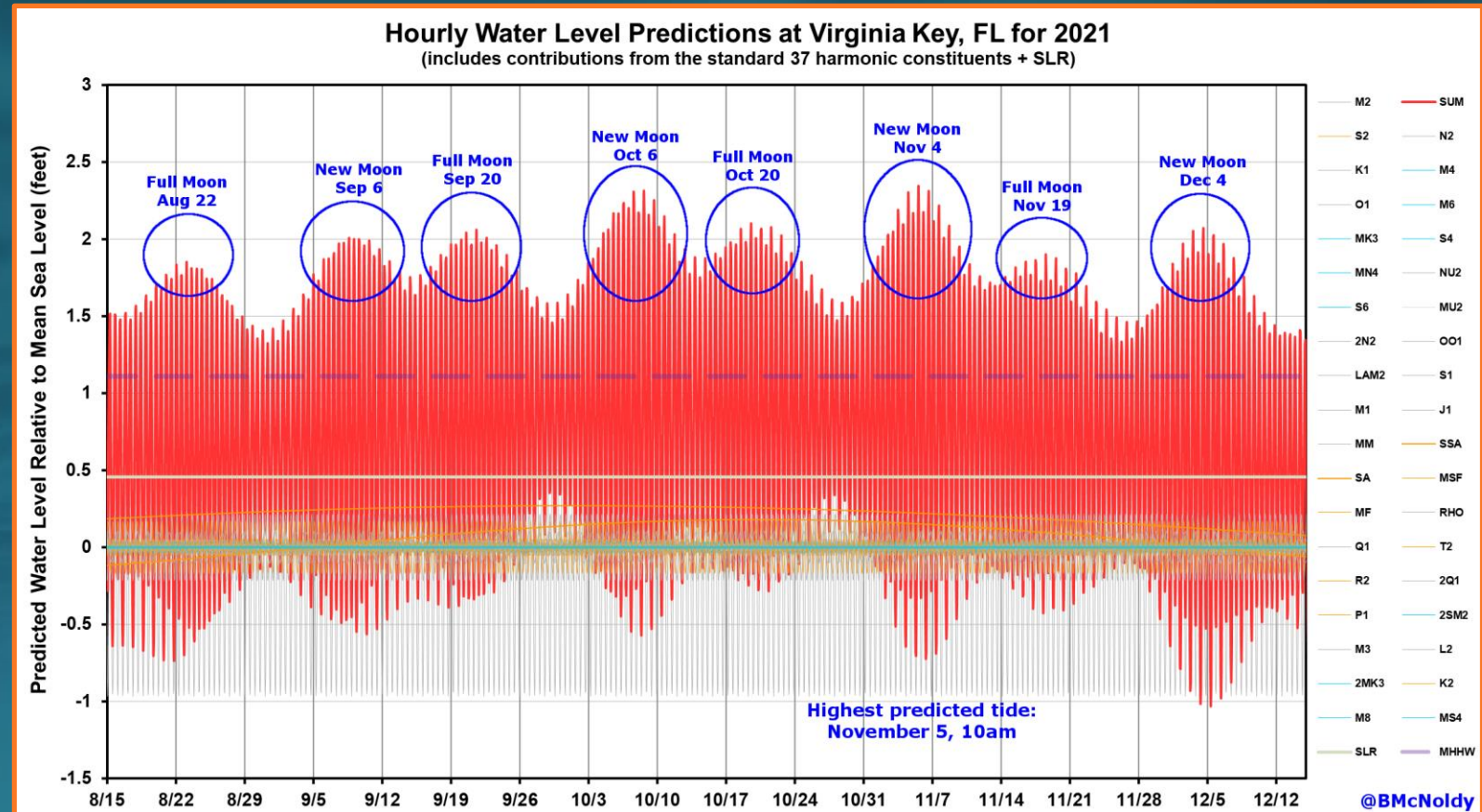
2021 Tide Predictions for Southeast Florida

- Water level shown relative to the 1983-2001 epoch mean sea level (MSL) at this location
- I add 5.5 in (13.9 cm) to that to adjust to 2018-2020 MSL
- Mean seasonal cycle peaks ~Oct 15... highest predicted tide of the year will *typically* occur near the full or new moon closest to that date



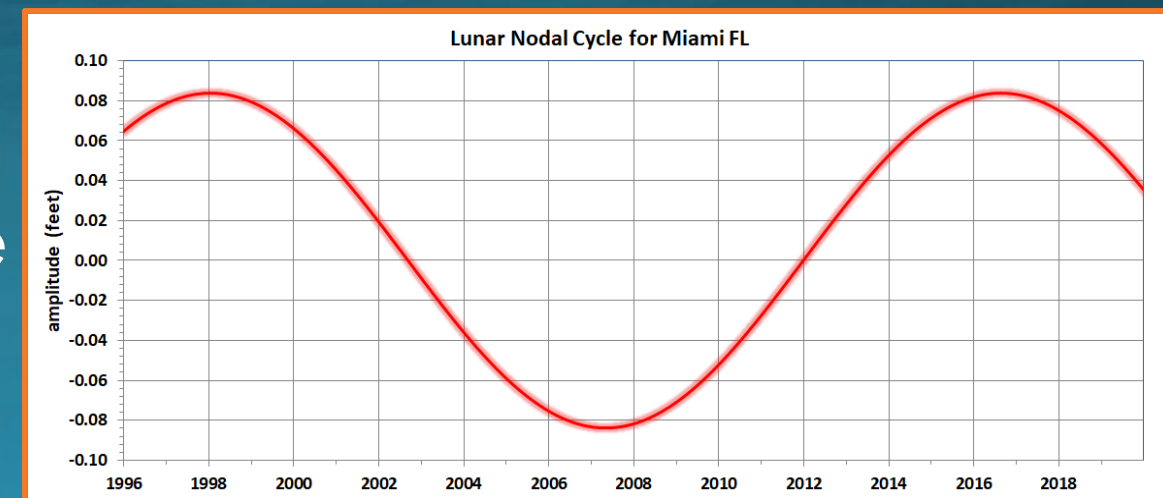
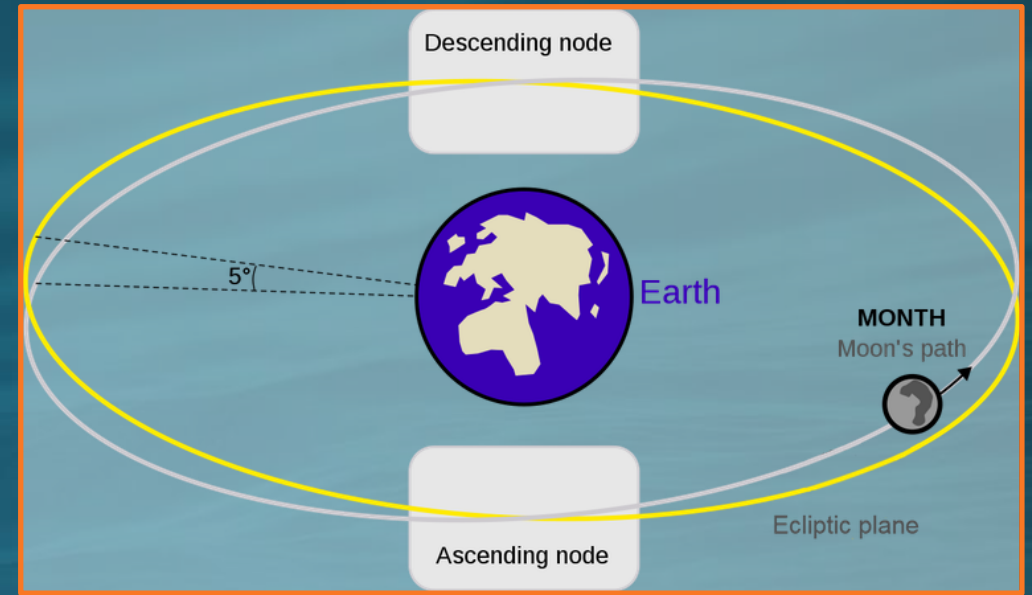
Zooming In

- This chart shows just 4 months from the previous chart, with the various harmonic constituents plotted separately, plus a 5.5-inch (13.9 cm) offset for sea level rise.



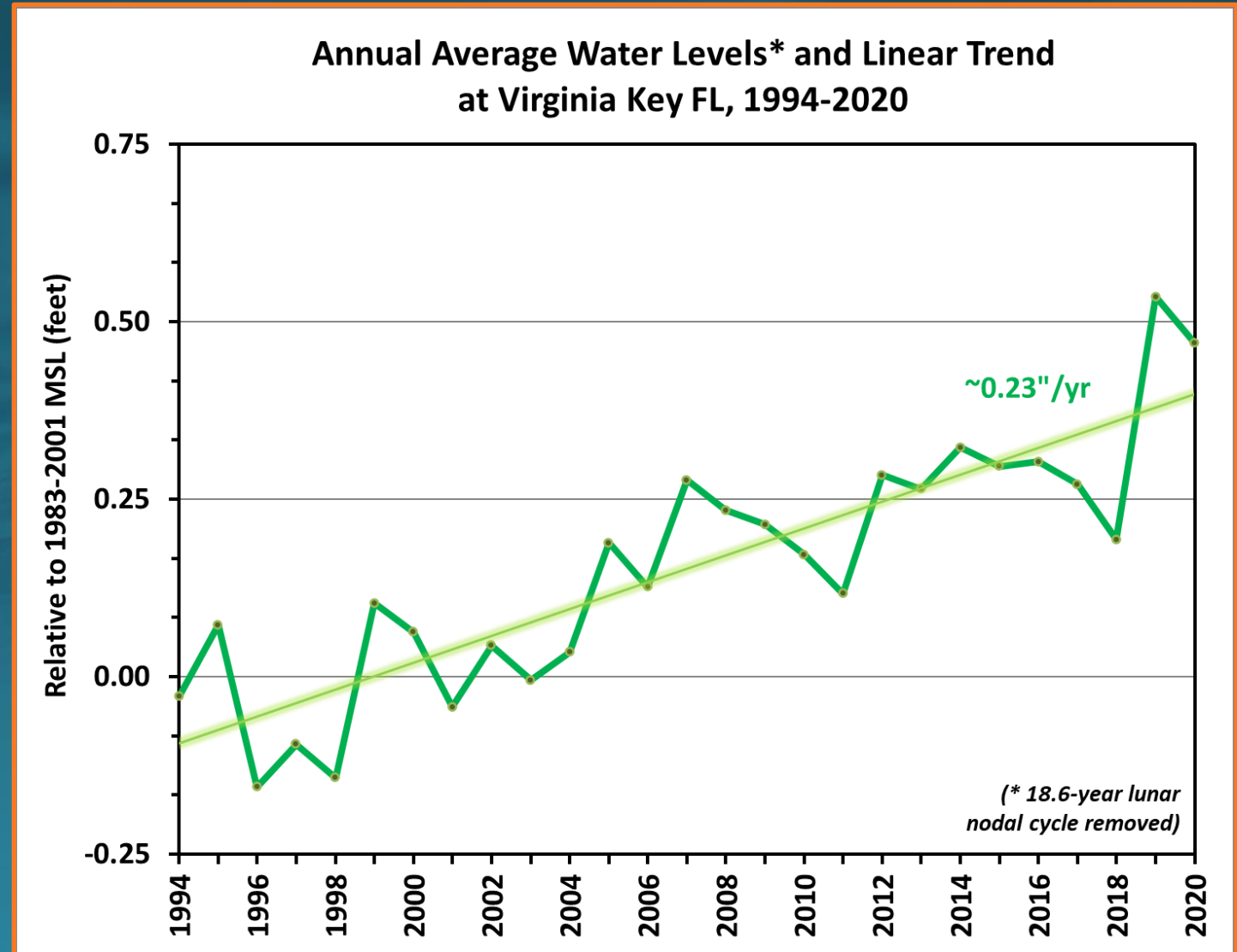
18.6-year Lunar Nodal Cycle

- Moon's orbital plane is tilted relative to Earth's, tilt varies $\pm 5^\circ$
- The planes intersect at "nodes"
- Moon's orbital plane precesses over a period of ~ 18.6 years.
- Discovered 5000+ years ago, published nearly 300 years ago
- The [mis]alignment has an impact on global sea levels, though not the same everywhere
 - In Miami area, it's ± 1 inch (2.5 cm)



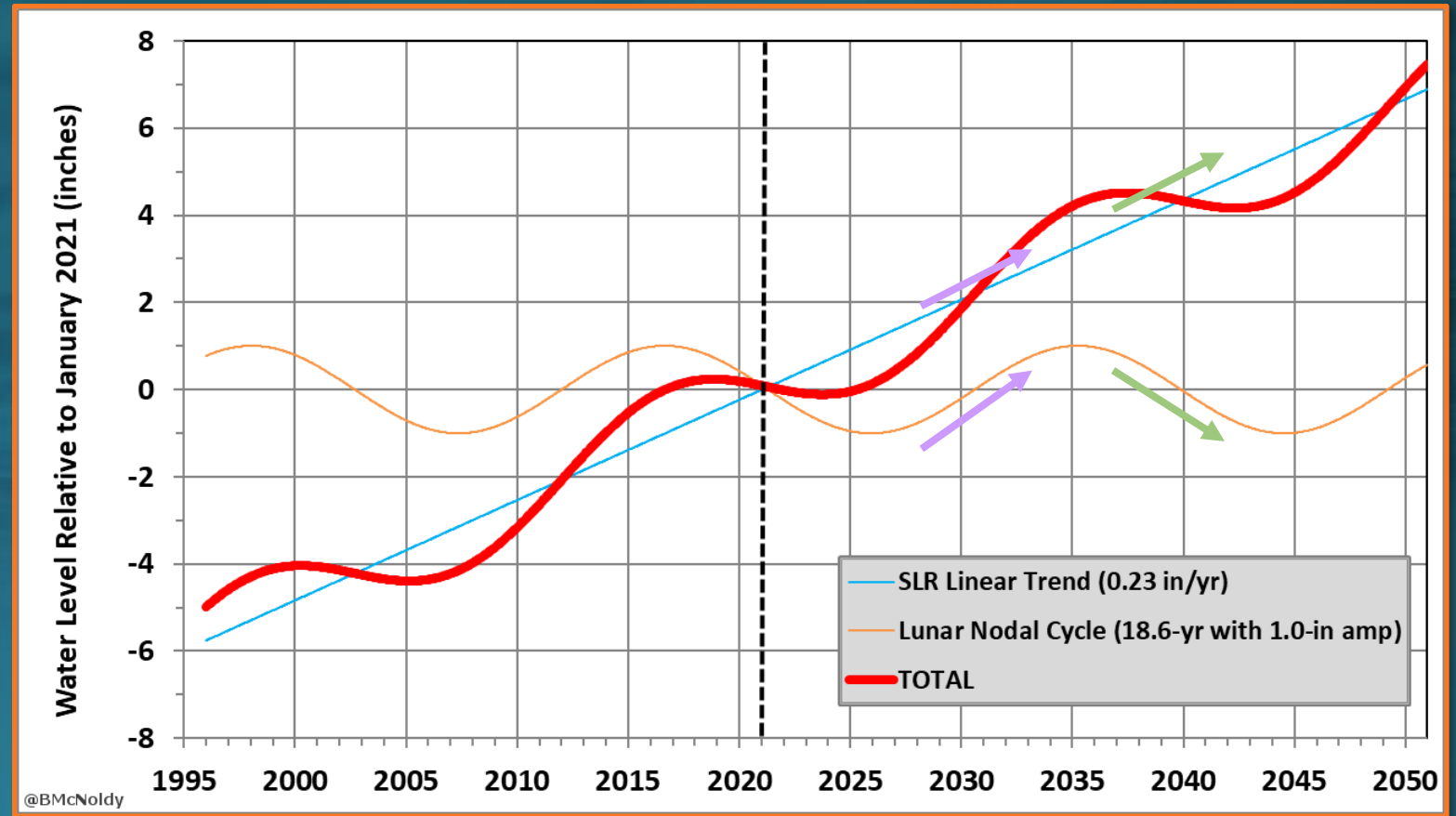
Sea Level Rise

- Now that we understand some of the natural variations, we can remove the major cycles and look at the remaining trend (linear for simplicity)
- There are ups & downs in the annual averages, but overall trend is definitely UP
 - **~0.23 in/yr** (0.58 cm/yr)



“Apparent” Sea Level Rise

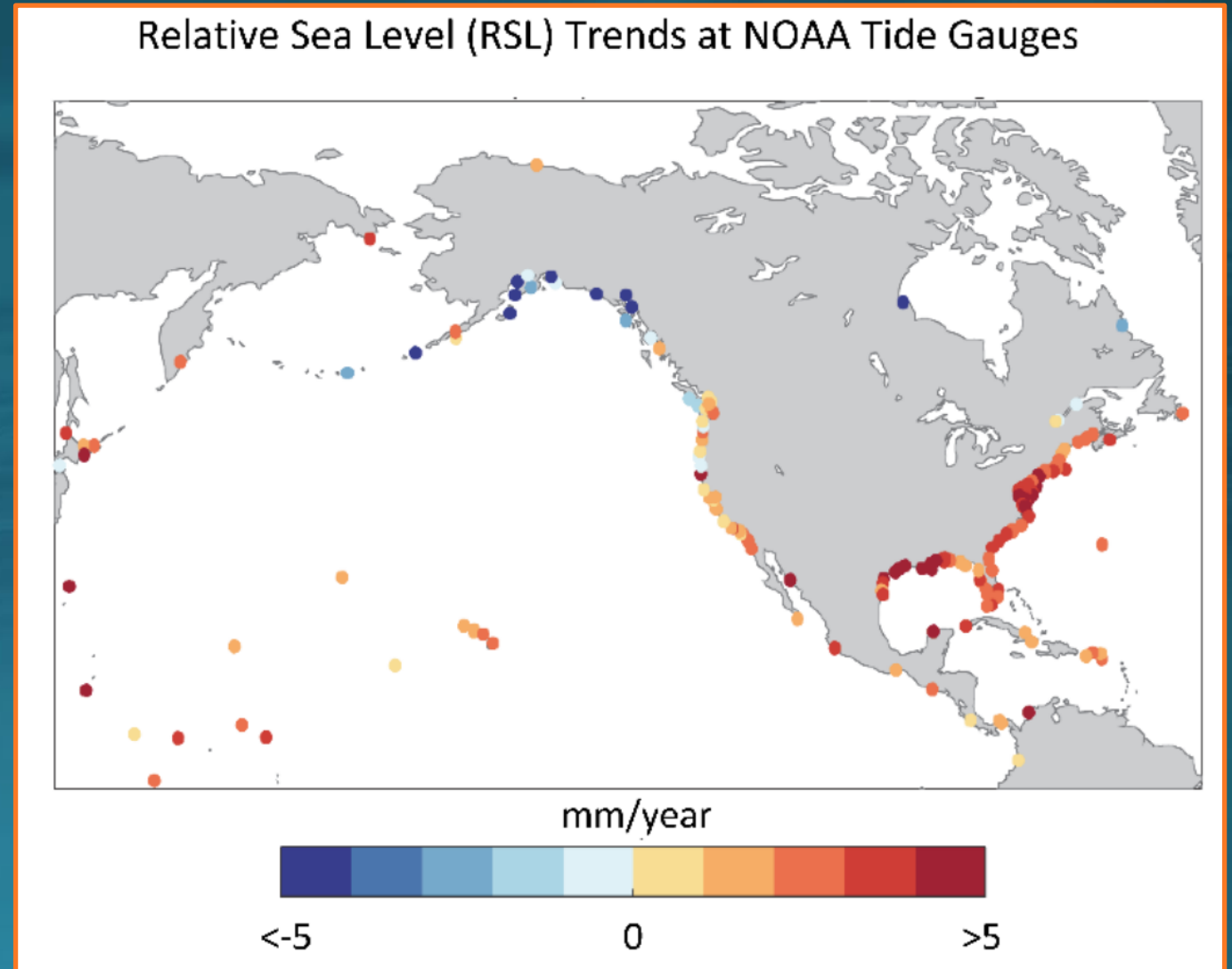
- Recall the 18.6-year *lunar nodal cycle*...
 - Here, the peak slope of the **oscillation** roughly matches the simple linear rate of **sea level rise**!
 - During **upward phase**, it ~ doubles SLR
 - During **downward phase**, it ~ negates SLR
 - Their sum is a very crude representation of the **observed water level** (ignoring the certain future acceleration of SLR)



@BMcNoldy

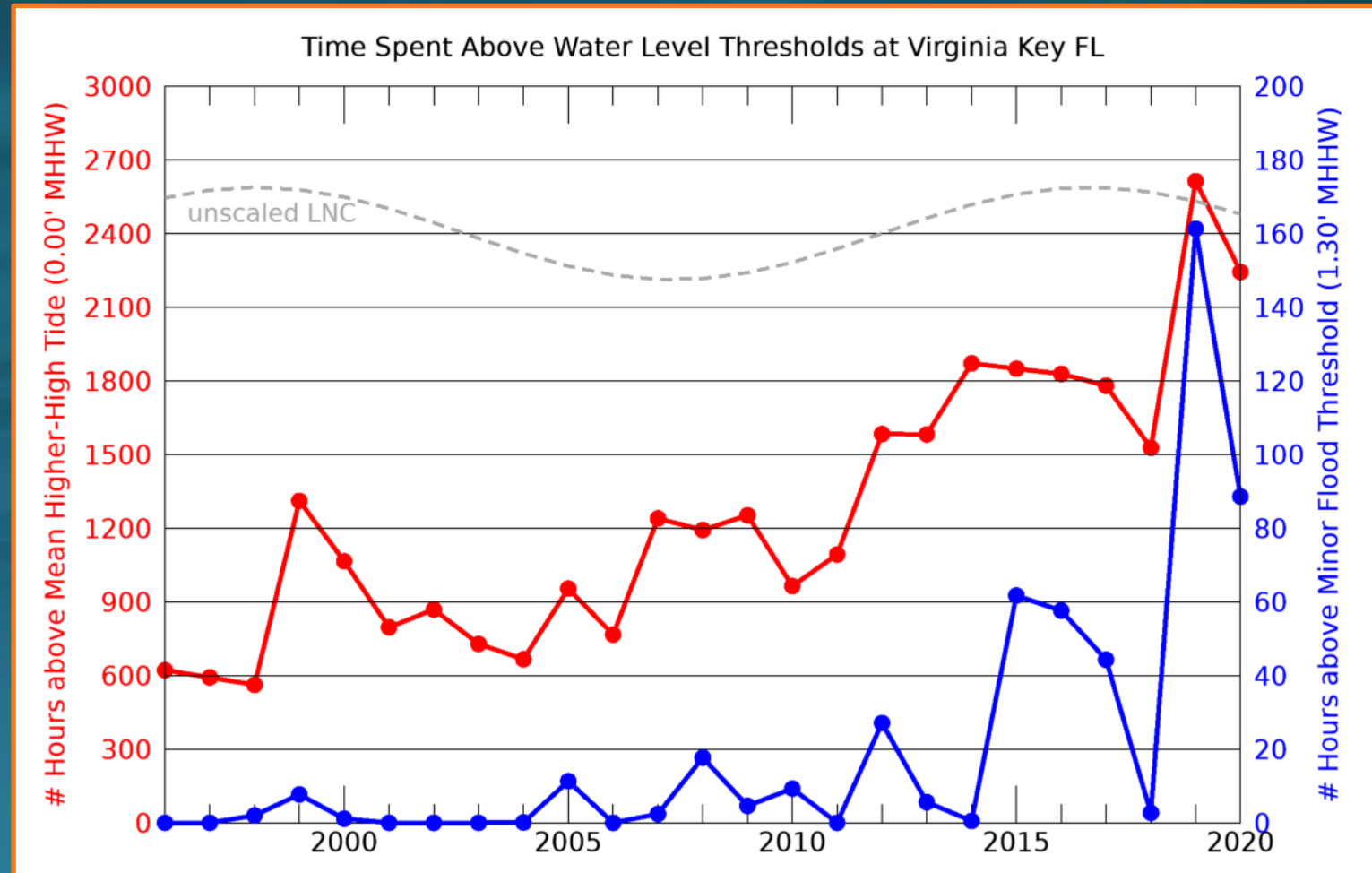
SLR Trend Varies by Location

- There is significant variability in the rate of sea level rise
- The global average trend is +0.14 in/yr (3.6 mm/yr), but U.S. Gulf coast and east coast are more rapid
- High latitudes can be negative because of glacial rebound



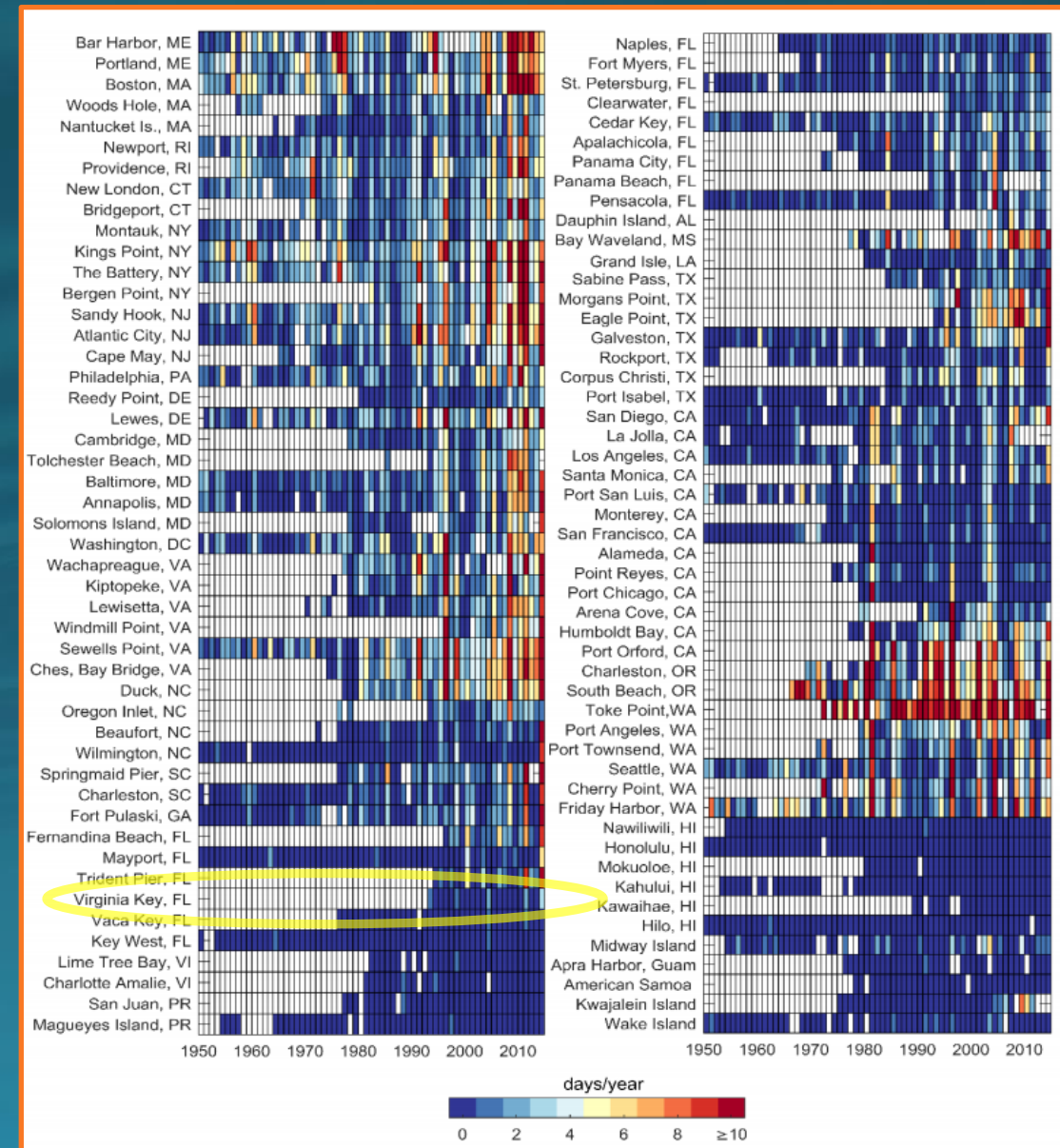
High Tide Flooding

- “sunny-day flooding”
- “nuisance flooding”
- When low-lying areas experience tidal inundation... no rainfall needed
- From the tide gauge measurements, we can add up the number of hours the water level spends above certain thresholds each year
- Almost never above the “minor flood threshold” two decades ago, but 160 hours in 2019!



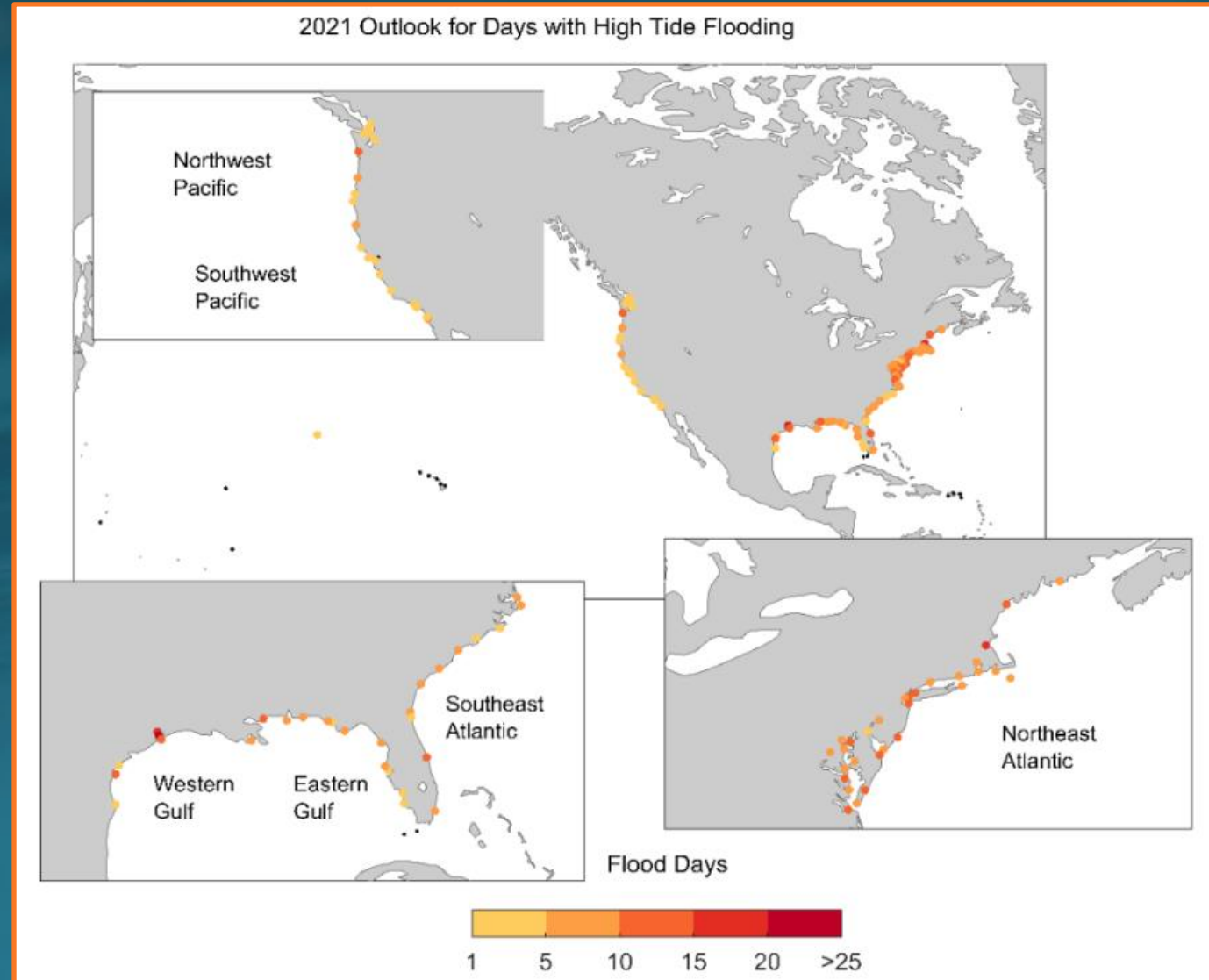
Not Just Miami...

- This chart shows the number of days per year with high tide flooding (HTF) at all U.S. tide gauge locations from 1950-2017.
- What was once observed occasionally in a few locations is now observed everywhere and at greater frequency



NOAA (Sweet et al., February 2018)

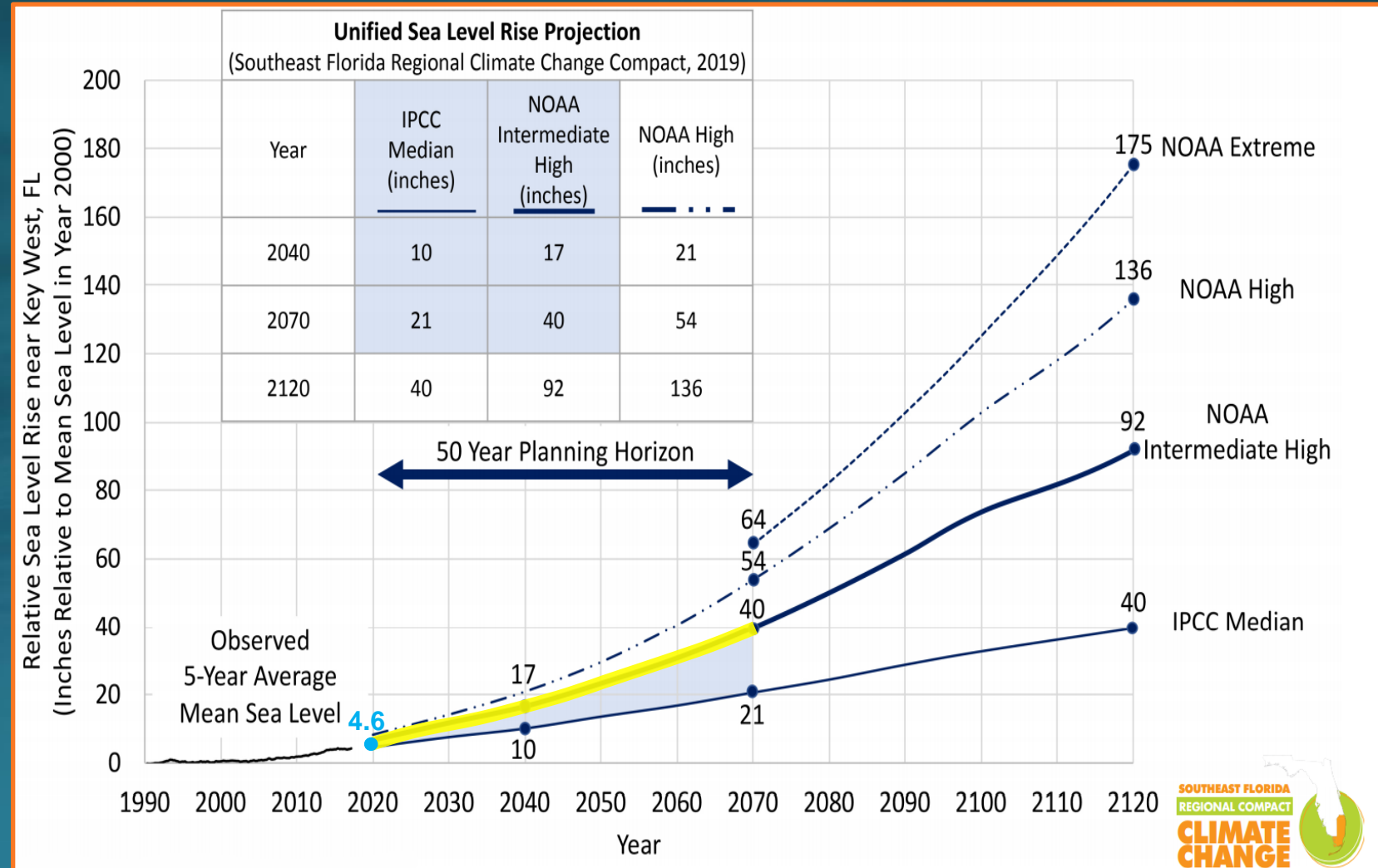
HTF Forecast for this season...



NOAA (Sweet et al., July 2021)

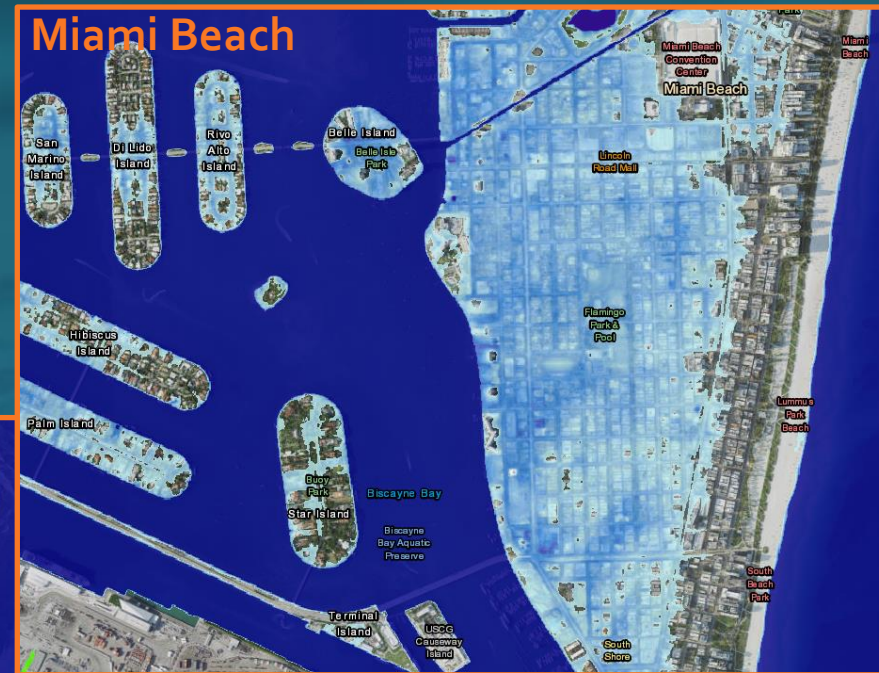
Sea Level Rise Projections

- Using NOAA's "Intermediate High" SLR curve adjusted to south Florida, we could see:
 - ~1 ft (31cm) in 20 years
 - ~3 ft (91cm) in 50 years
- What does an extra 3 feet of water look like around here?



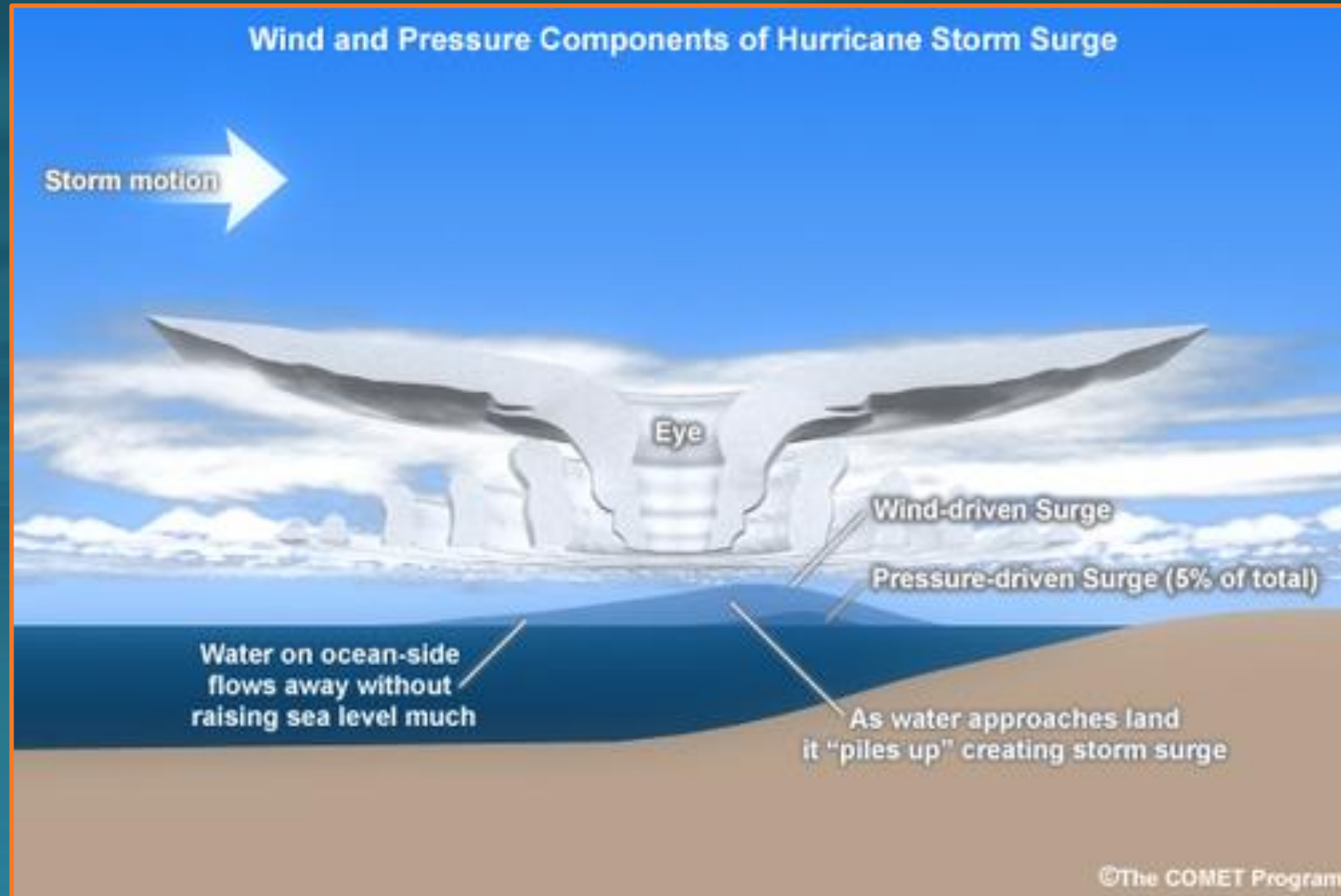
Mapping the Future

- Some local examples at high tide with an additional 3 feet (91 cm) of SLR (~50 years):



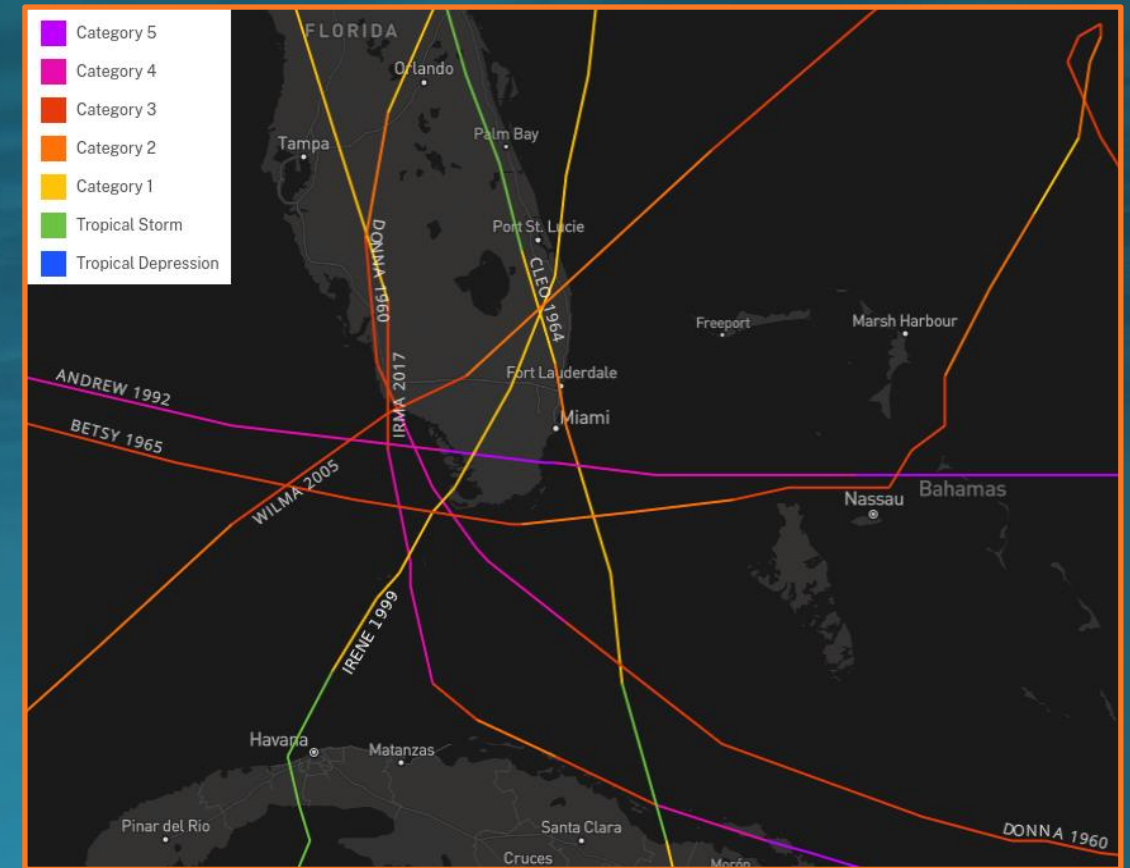
Storm Surge

- The rise in water level (sometimes very rapid) caused by a storm.
 - ~95% of total surge driven by onshore winds
 - ~5% of total surge caused by lowered pressure...
1 cm/mb (0.39 in/mb)
- Depends on hurricane's speed, direction, size, intensity, as well as local topography/bathymetry ... no easy relationship to just the intensity (Saffir-Simpson category).



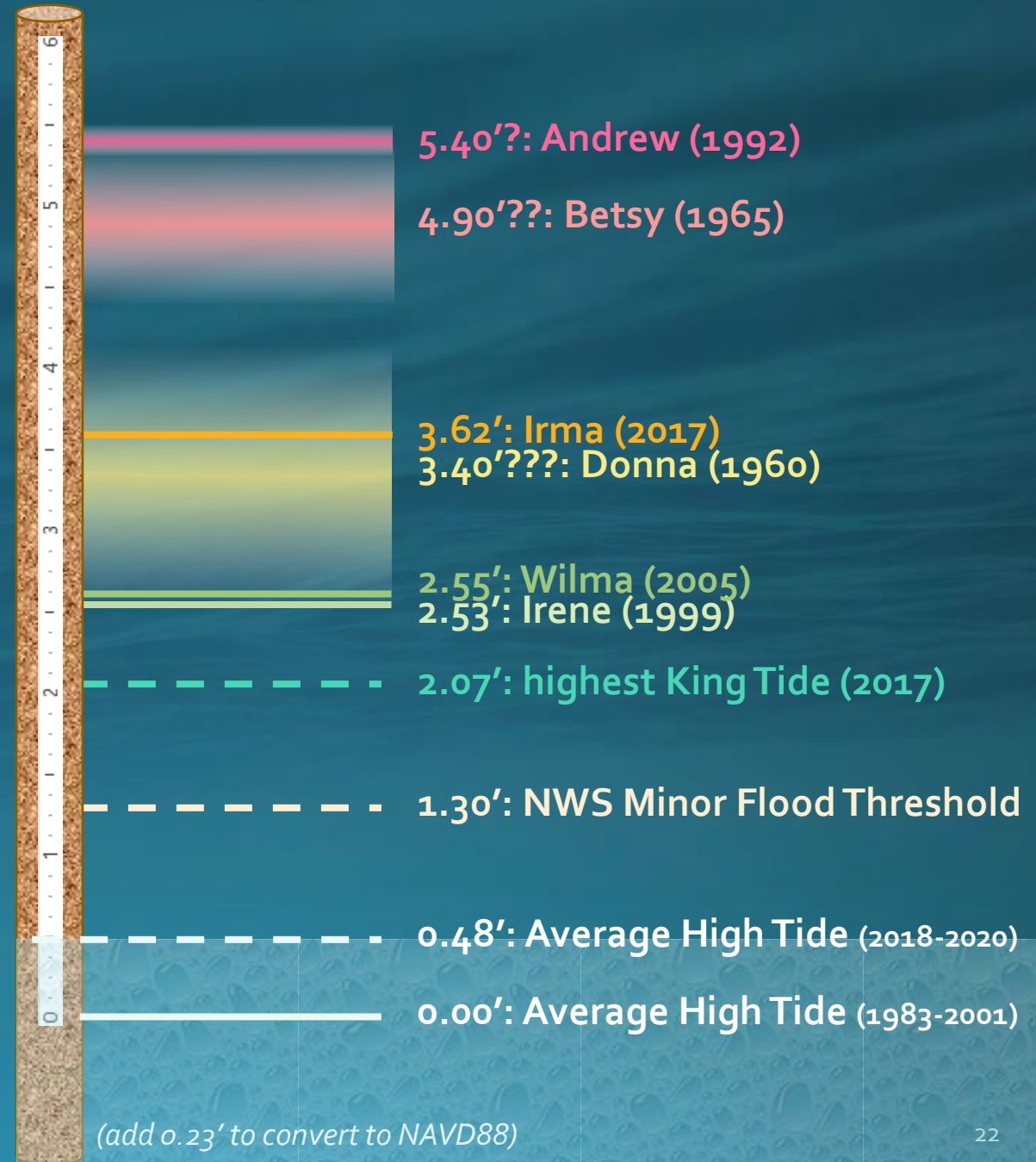
RSMAS Hurricane History

- Although the Univ. of Miami “Marine Laboratory” was established in 1943, the campus on Virginia Key has its origins in 1951.
 - Just missed Category 4 Hurricane King in 1950 by a year, which was a direct hit and would have been very destructive
 - We have a long history of hurricane encounters in Miami, but since 1951, a handful [likely] generated notable storm surges at Virginia Key:
 - Donna (Sep 10, 1960)
 - Cleo (Aug 27, 1964)
 - Betsy (Sep 8, 1965)
 - Andrew (Aug 24, 1992)
 - Irene (Oct 15, 1999)
 - Wilma (Oct 24, 2005)
 - Irma (Sep 10, 2017)

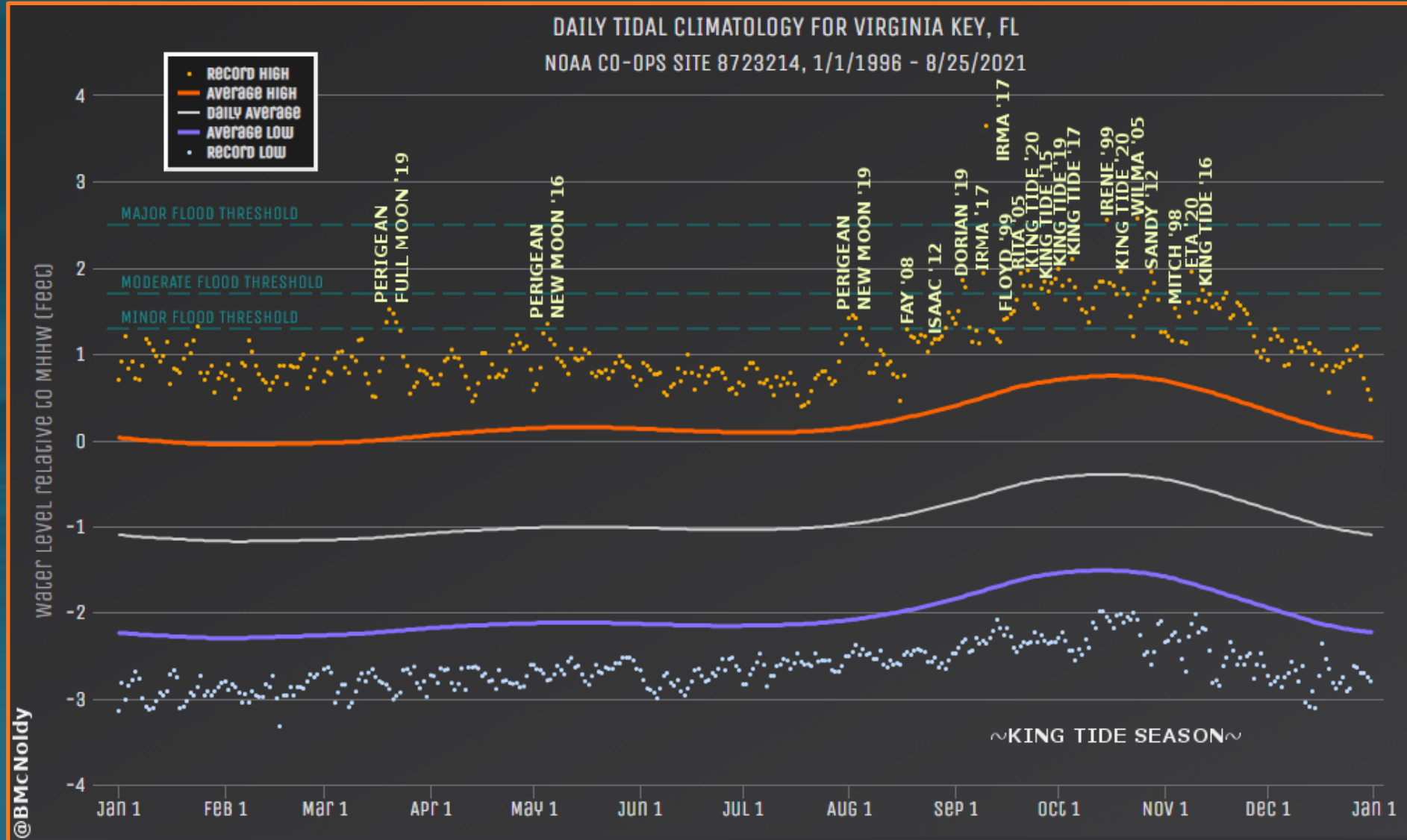


Storm Tide

- Storm tide is the total water level... regular astronomical tide plus storm surge
- Timing matters: flooding will be worse if storm surge arrives at high tide vs low tide (2.2 ft difference here)
- Unfortunately, we don't have reliable water level measurements or high water marks from all of those storms at the RSMAS campus, but I was able to use measurements or create estimates for most...



The Record-setters (since 1996)



Summary

- Sea level has risen ~6.2 inches (~15.8 cm) in the past 27 years in Miami area... or an *average rate of 0.23 in/yr (5.8 mm/yr)*. An additional 3 feet of SLR is possible/likely in the coming 50 years.
- Significant high water events used to only be associated with passing or landfalling hurricanes... but lately, some high tides are comparable
- Natural cycles influence “*apparent*” sea level rise, but *actual* sea level rise continues and is influenced by global and regional factors
- Sea level rise is responsible for “*nuisance flooding*” now, but it is a ***slow-motion crisis*** on a global scale
- Hurricanes are low-frequency high-impact events that can inundate a coastal area with several feet of water in a matter of hours
- Sea level rise provides an increasing baseline upon which storm surge acts