Water Levels at Virginia Key: Past, Present, and Future

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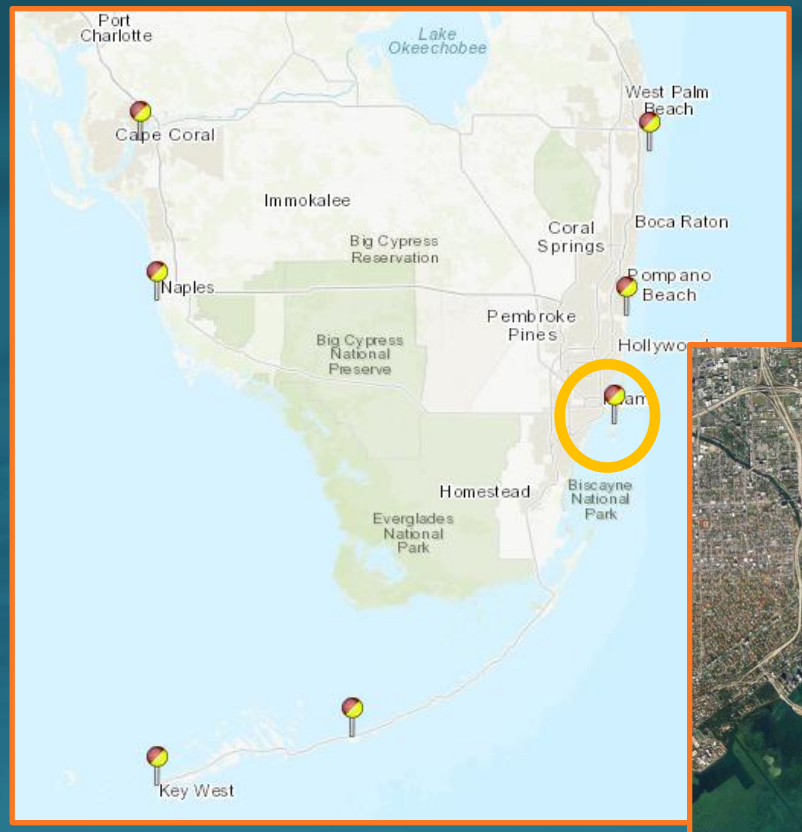
COMPASS Seminar
September 3, 2021

High tide: October 3, 2017

Station History & Location

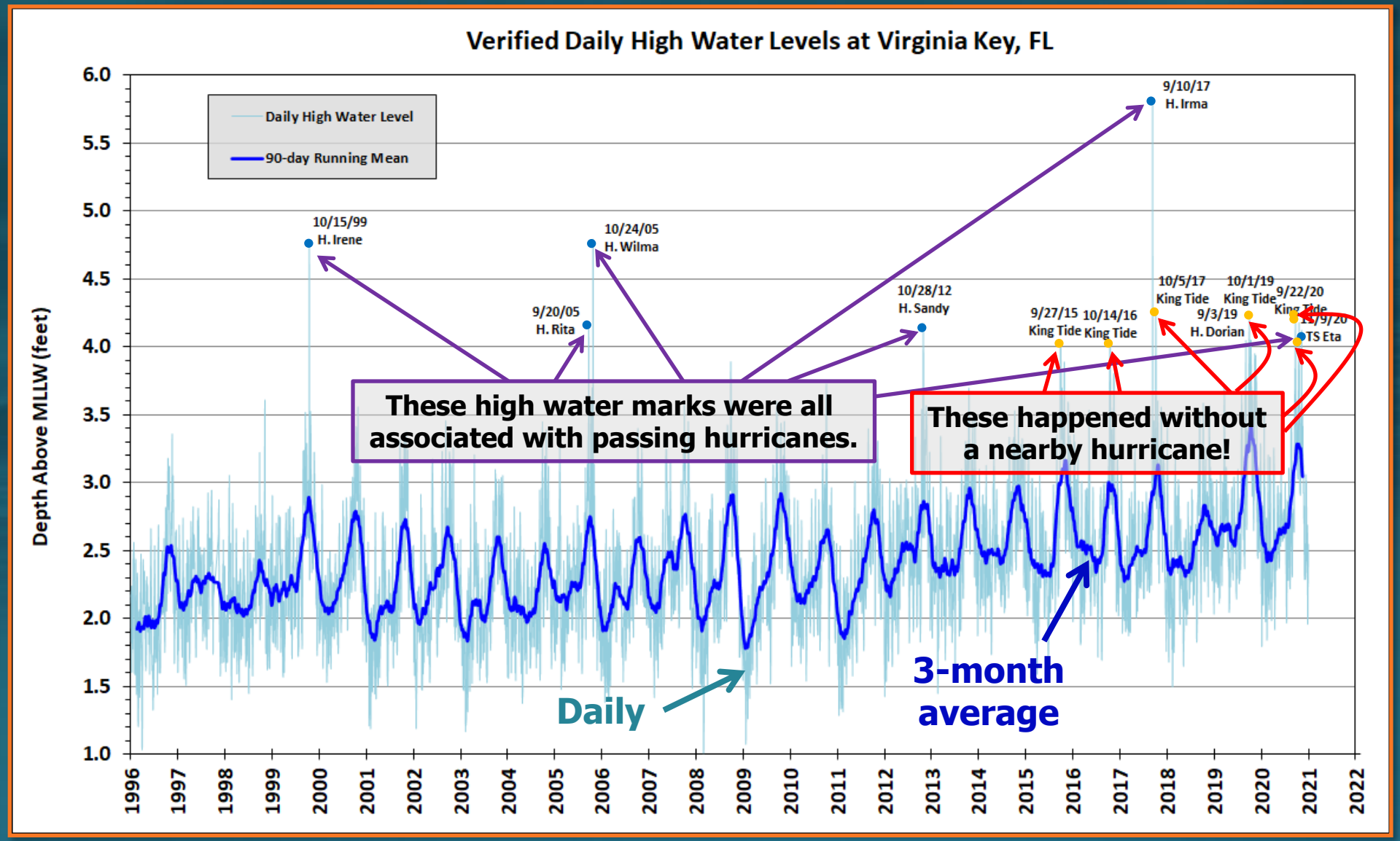
- NOAA CO-OPS installed and monitors tide gauge on Virginia Key since 1994
  - Verified hourly and high/low data since 1994
  - Verified six-minute data since 1996
- Station is located at end of dock on the UM Rosenstiel School campus



NOAA CO-OPS tide gauges in south Florida

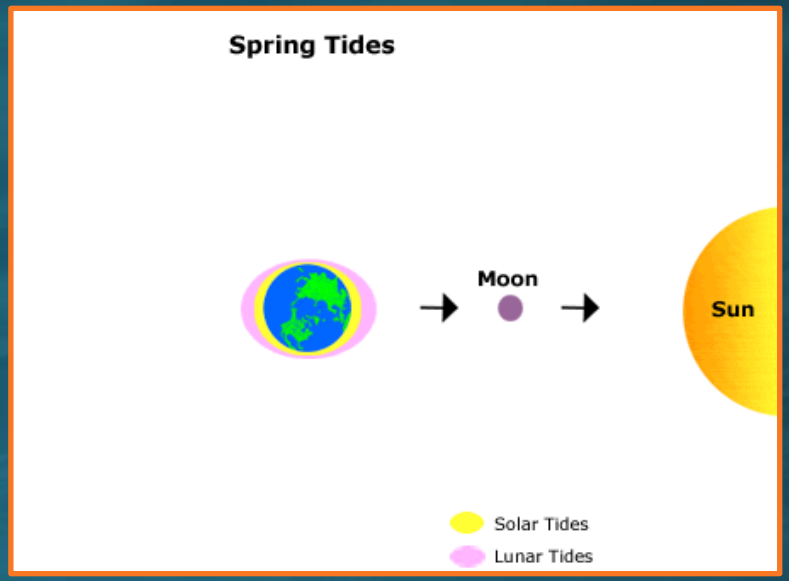
Virginia Key area

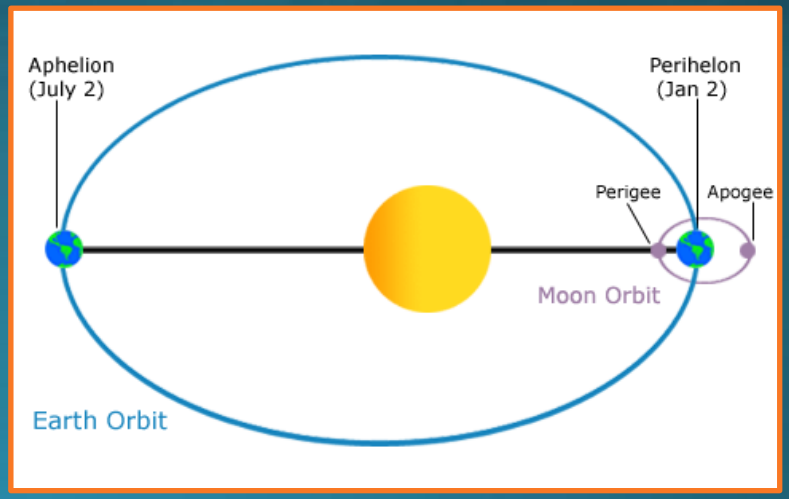
Daily Data & High Water Marks



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
- Earth's proximity to the sun
  - Earth's elliptical orbit means once/year (January) it's closer to the sun, producing greater tidal forces
- 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.



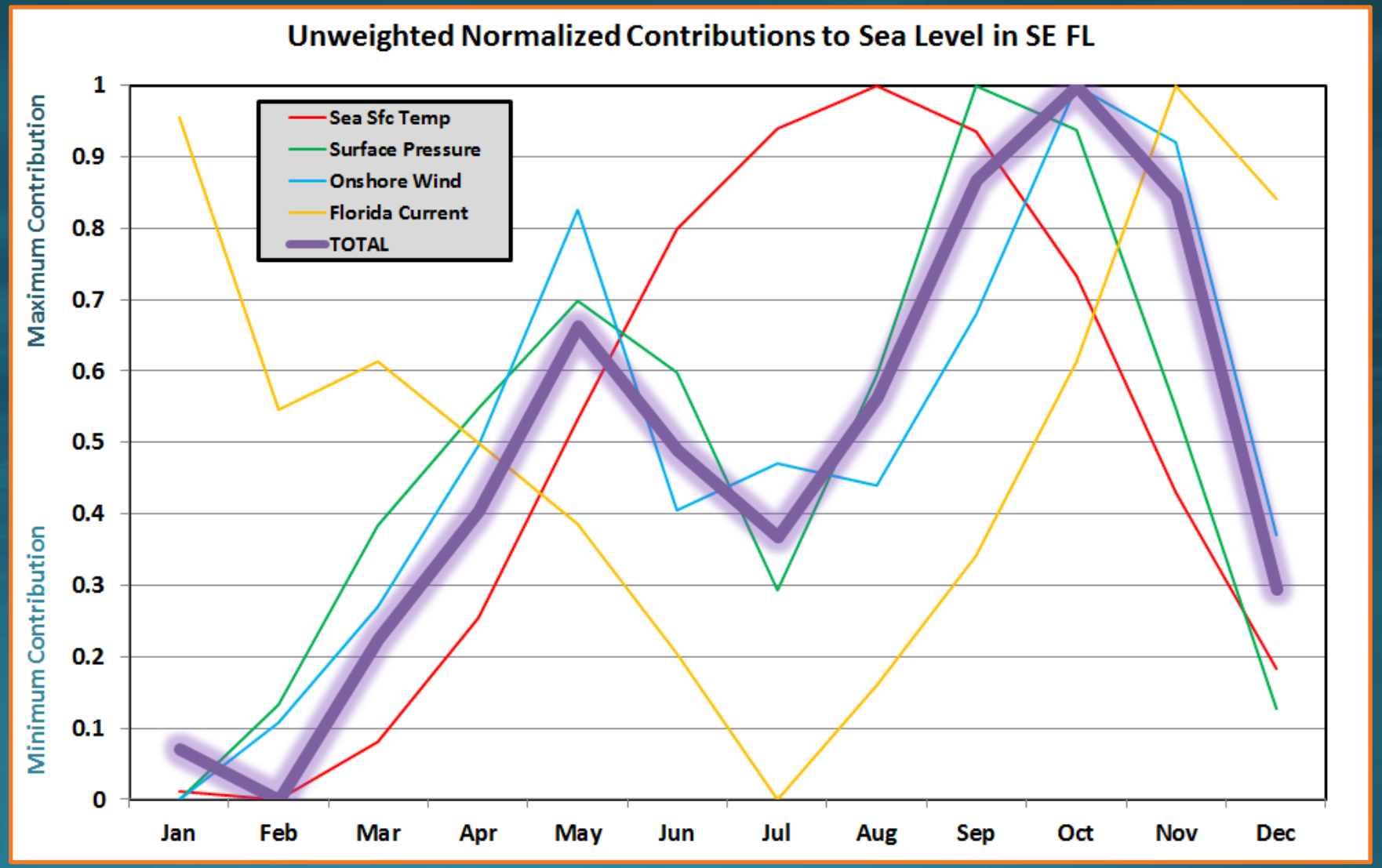


What Factors Influence Tides?

- 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
- Locally, the strength of the Florida Current plays a role
  - 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*

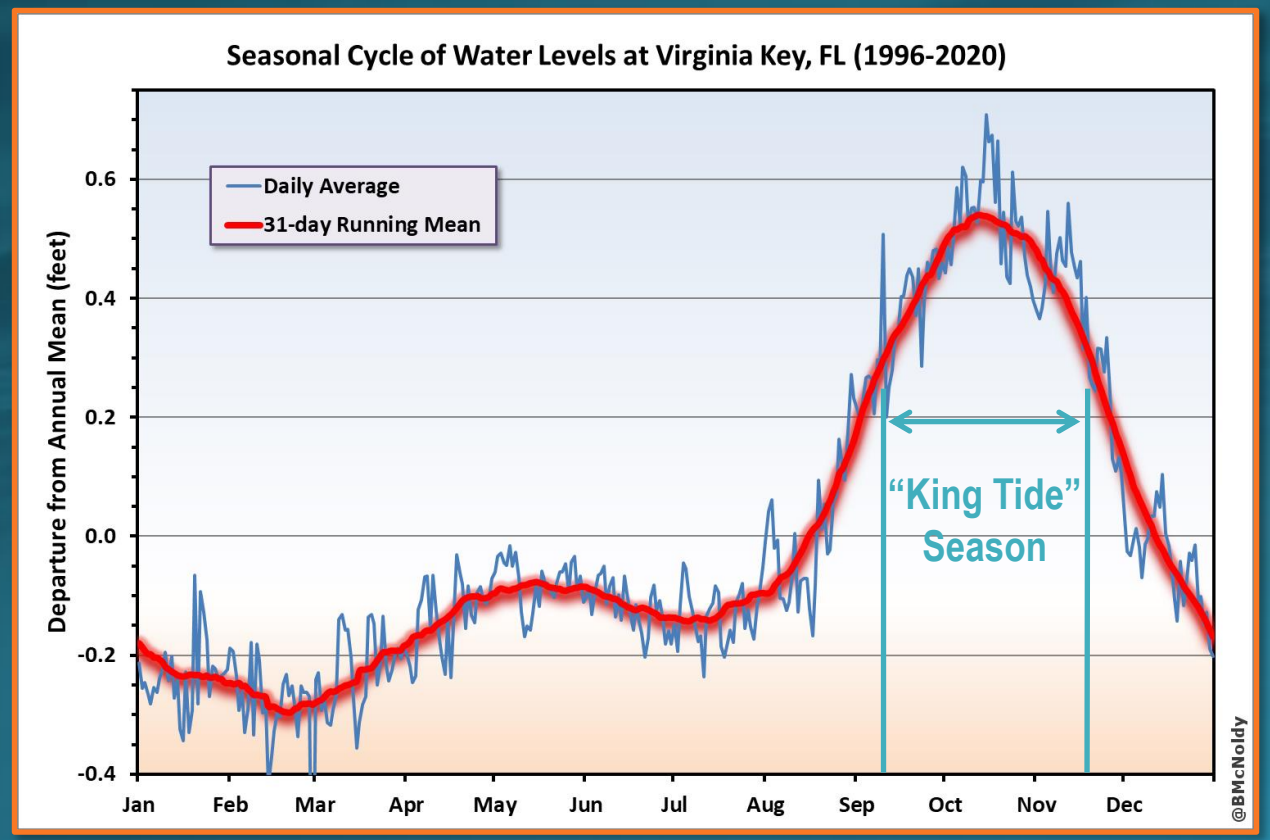
Key Seasonal Cycles

- Calculate crude monthly seasonal cycle of those 4 variables
- Orient the sign of each by its contribution to local sea level
- Normalize each
- Average these 4 basic normalized curves together…



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 here



~10 in (25 cm)

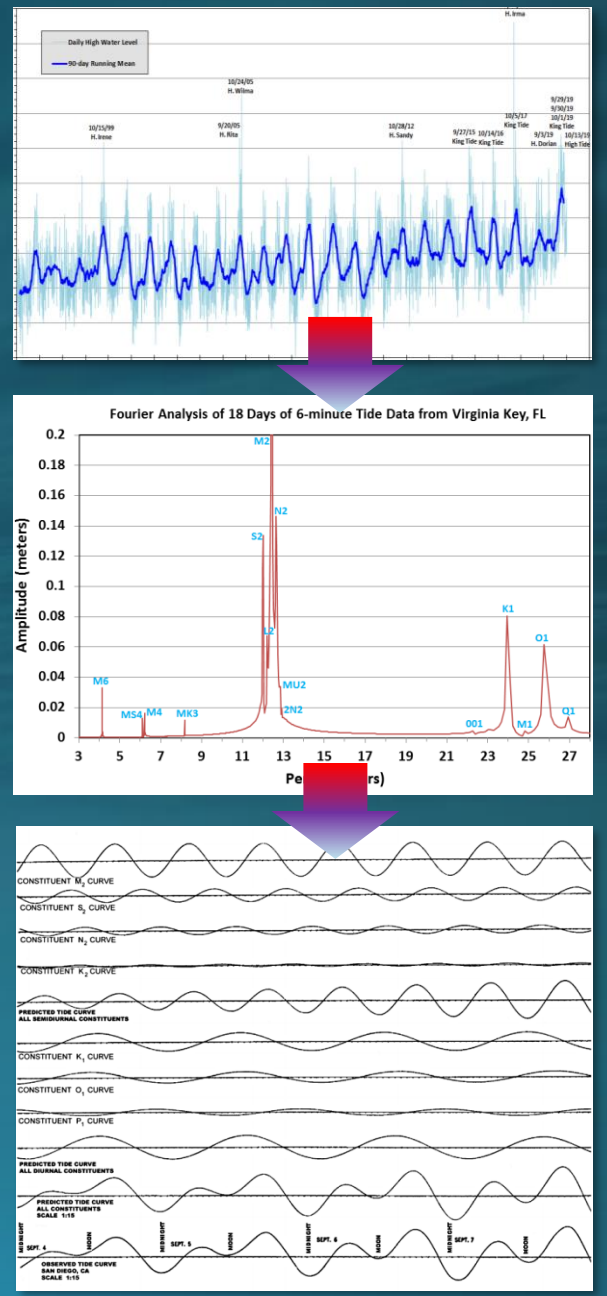
What Tide Predictions Are… and Are Not

- 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 datum of choice:

$$h(t) = H_0 + \sum_{i=1}^{n} f_i H_i \cos[a_i t + (V_0 + u)_i - \kappa_i]$$

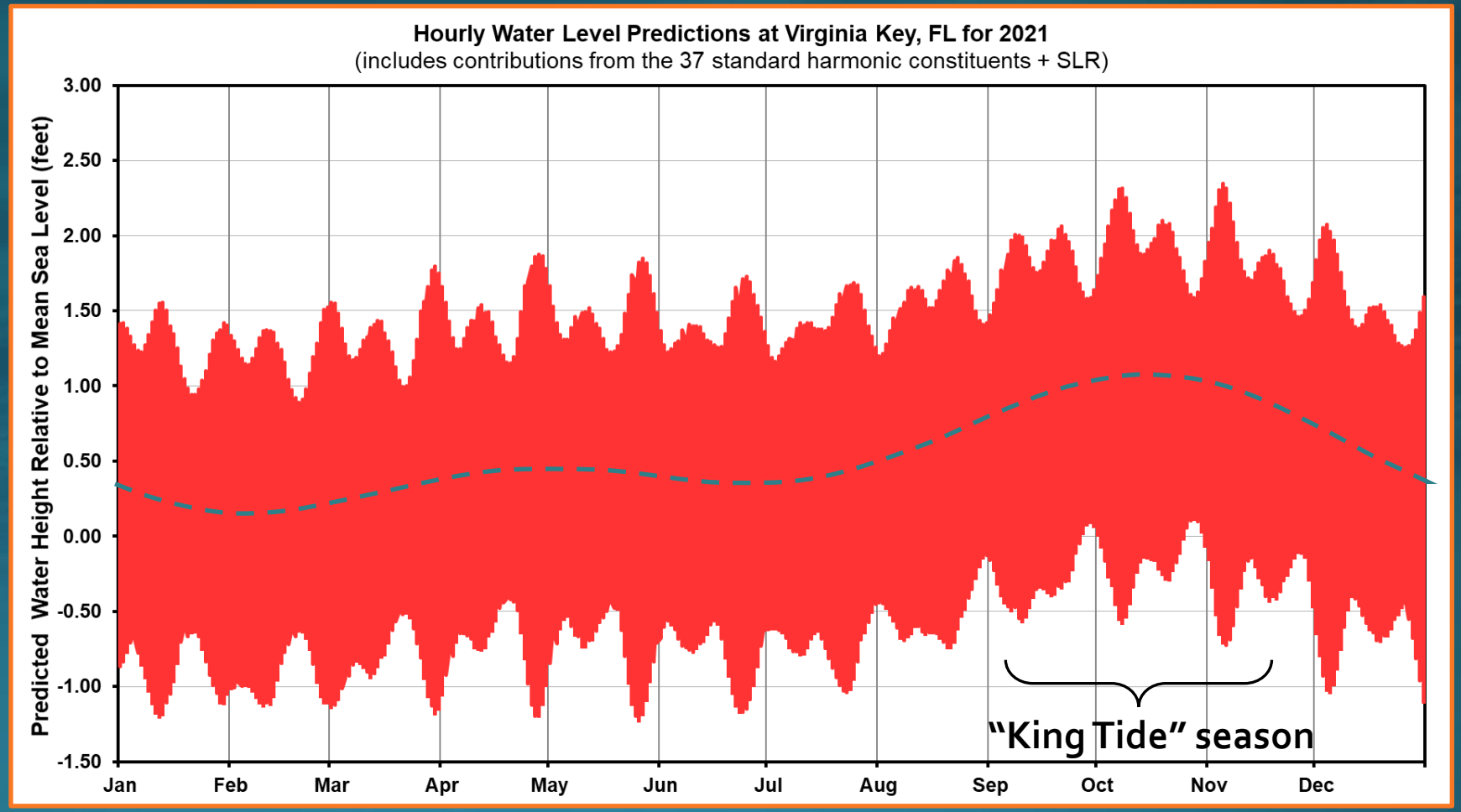
[The higher n is, the more accurately the time series can be reproduced]

- *NOAA's tide predictions are not like weather forecasts*… they are essentially astronomy + climatology.



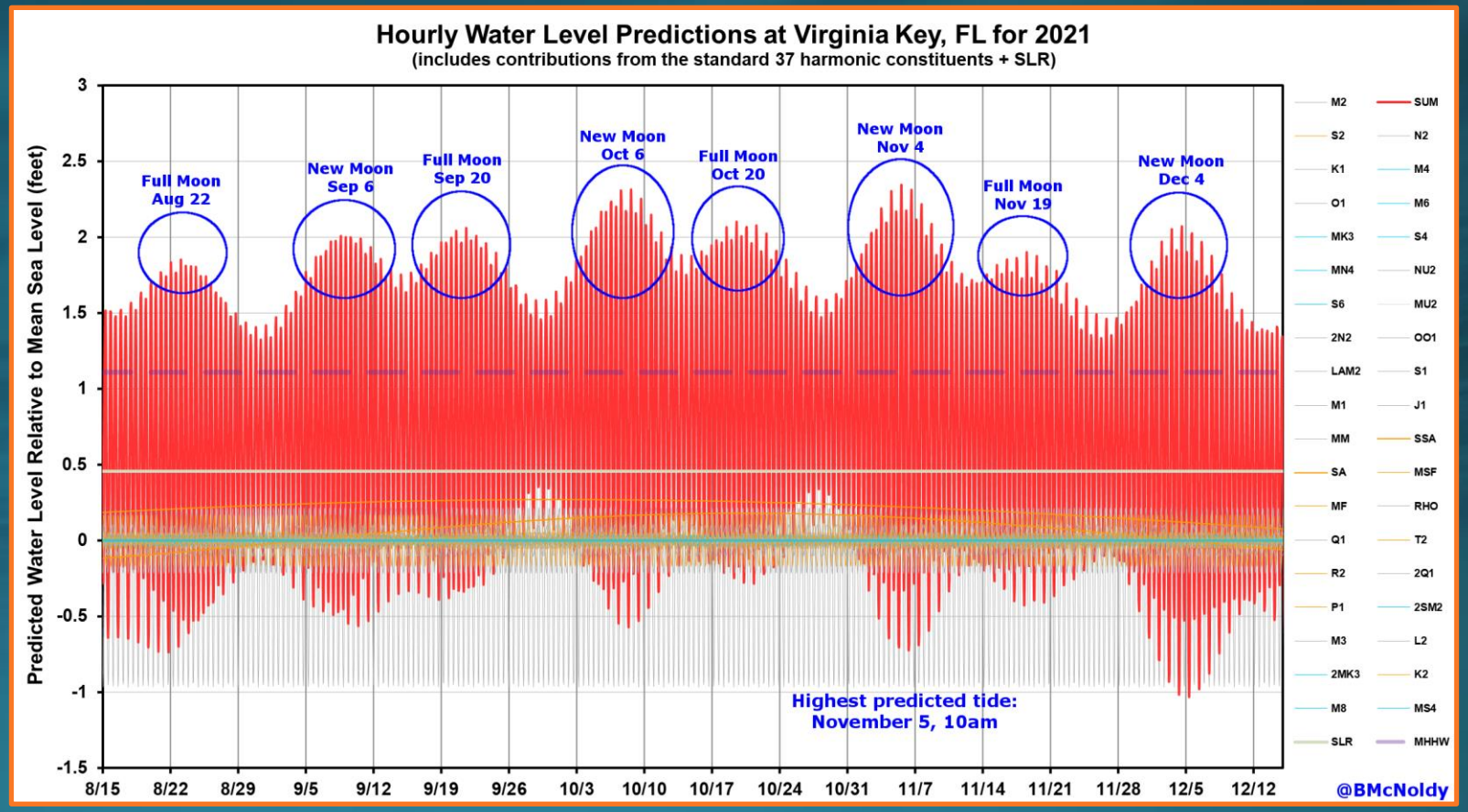
2021 Tide Predictions for Southeast Florida

- 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



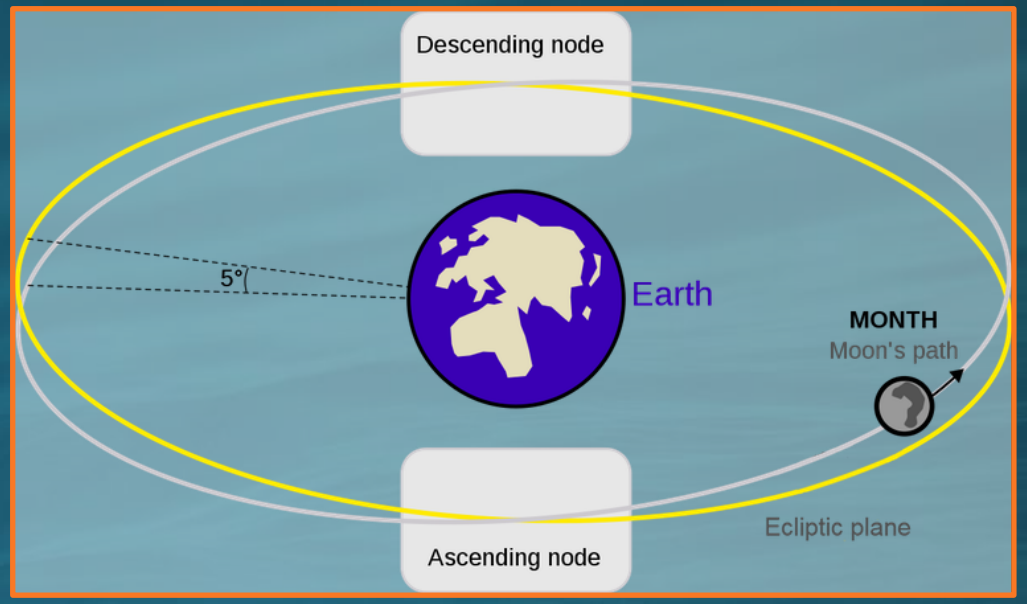
Zooming In

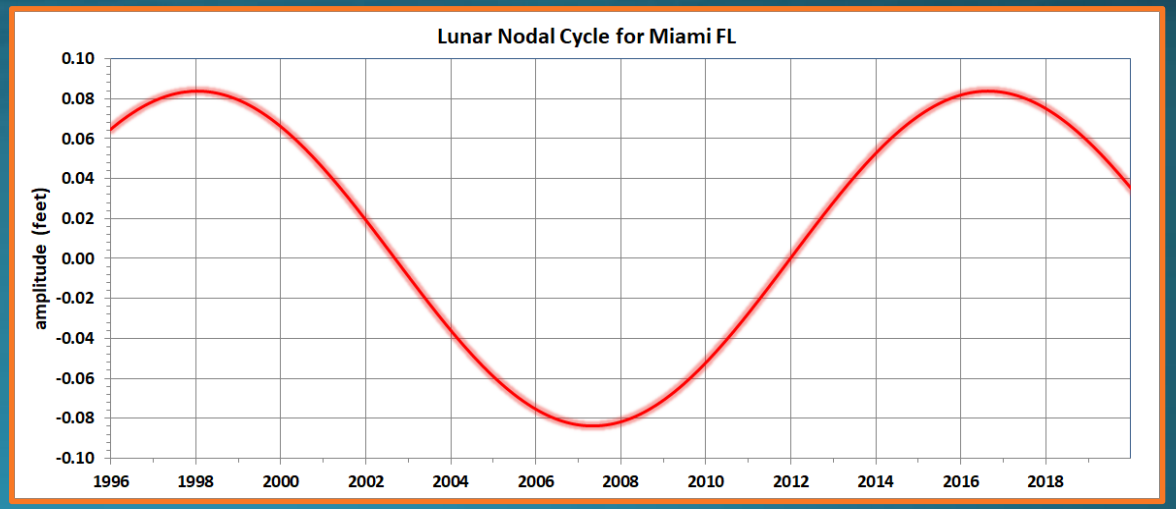
- This chart shows just 4 months from the previous chart, with the various harmonic constituents plotted separately, plus a 5.5-inch (13.9 cm) offset for sea level rise.



18.6-year Lunar Nodal Cycle

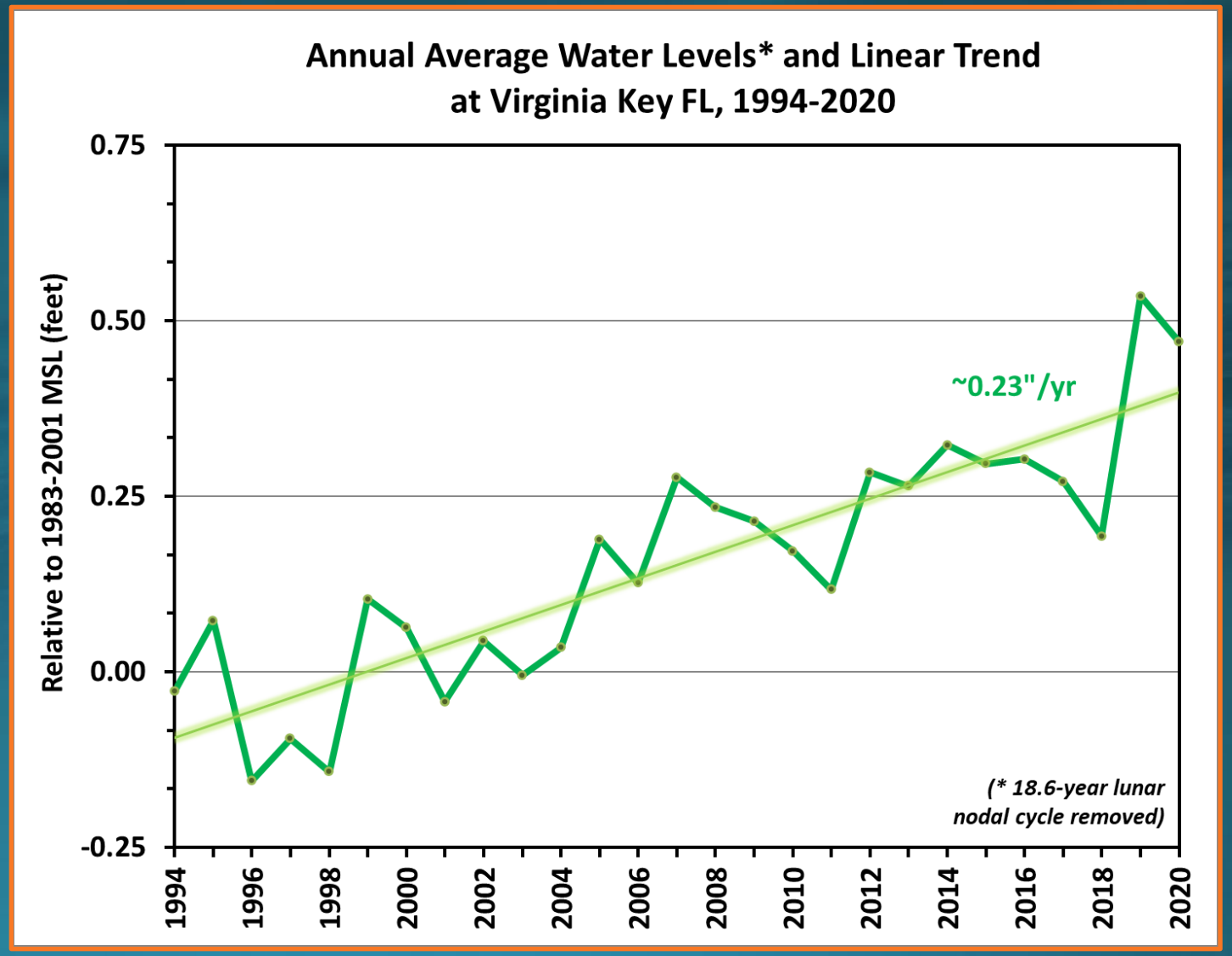
- Moon's orbital plane is tilted relative to Earth's, tilt varies +/- 5°
- The planes intersect at "nodes"
- Moon's orbital plane precesses over a period of ~18.6 years.
- Discovered 5000+ years ago, published nearly 300 years ago
- The [mis]alignment has an impact on global sea levels, though not the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





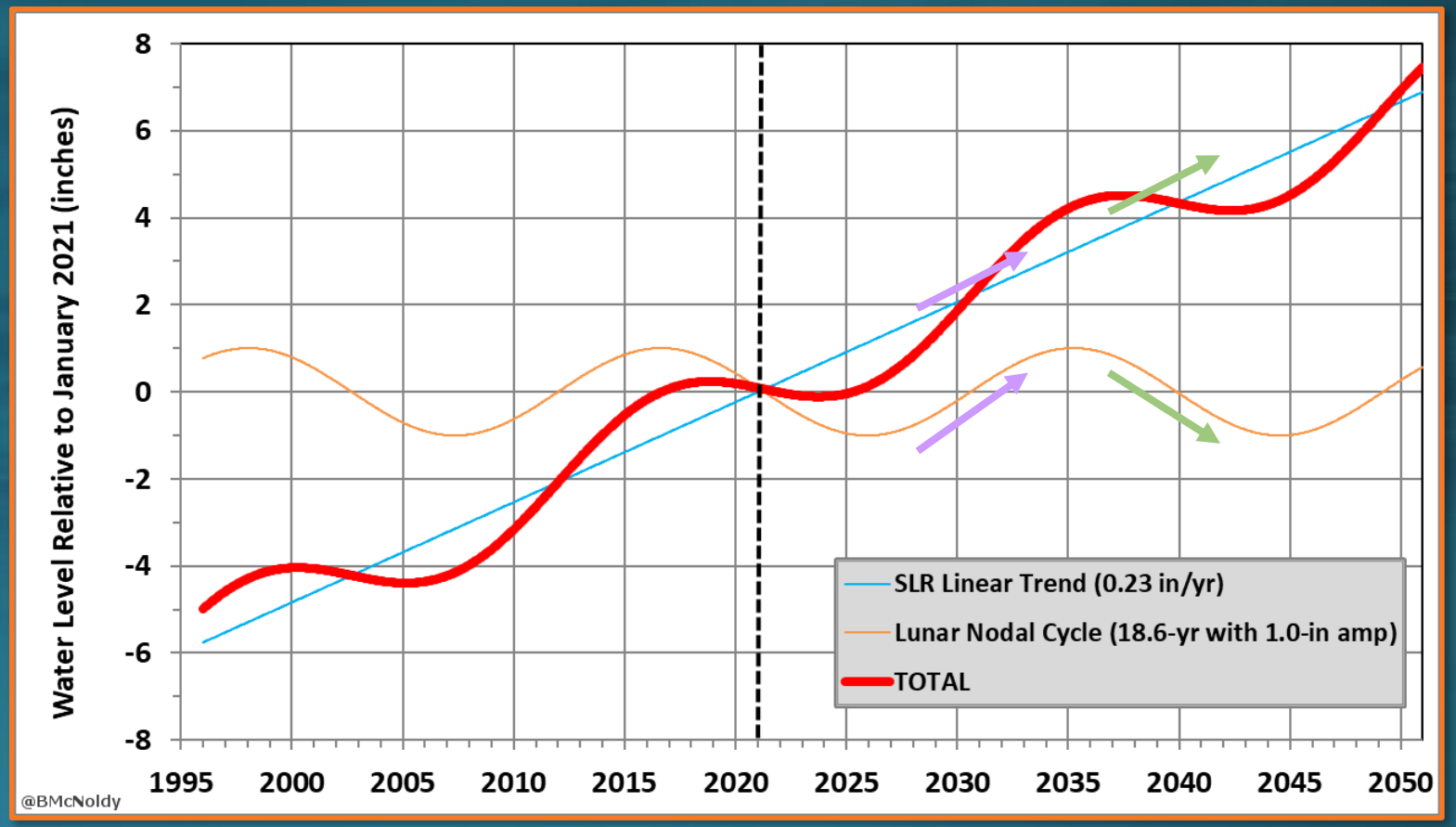
Local Sea Level Rise

- 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)



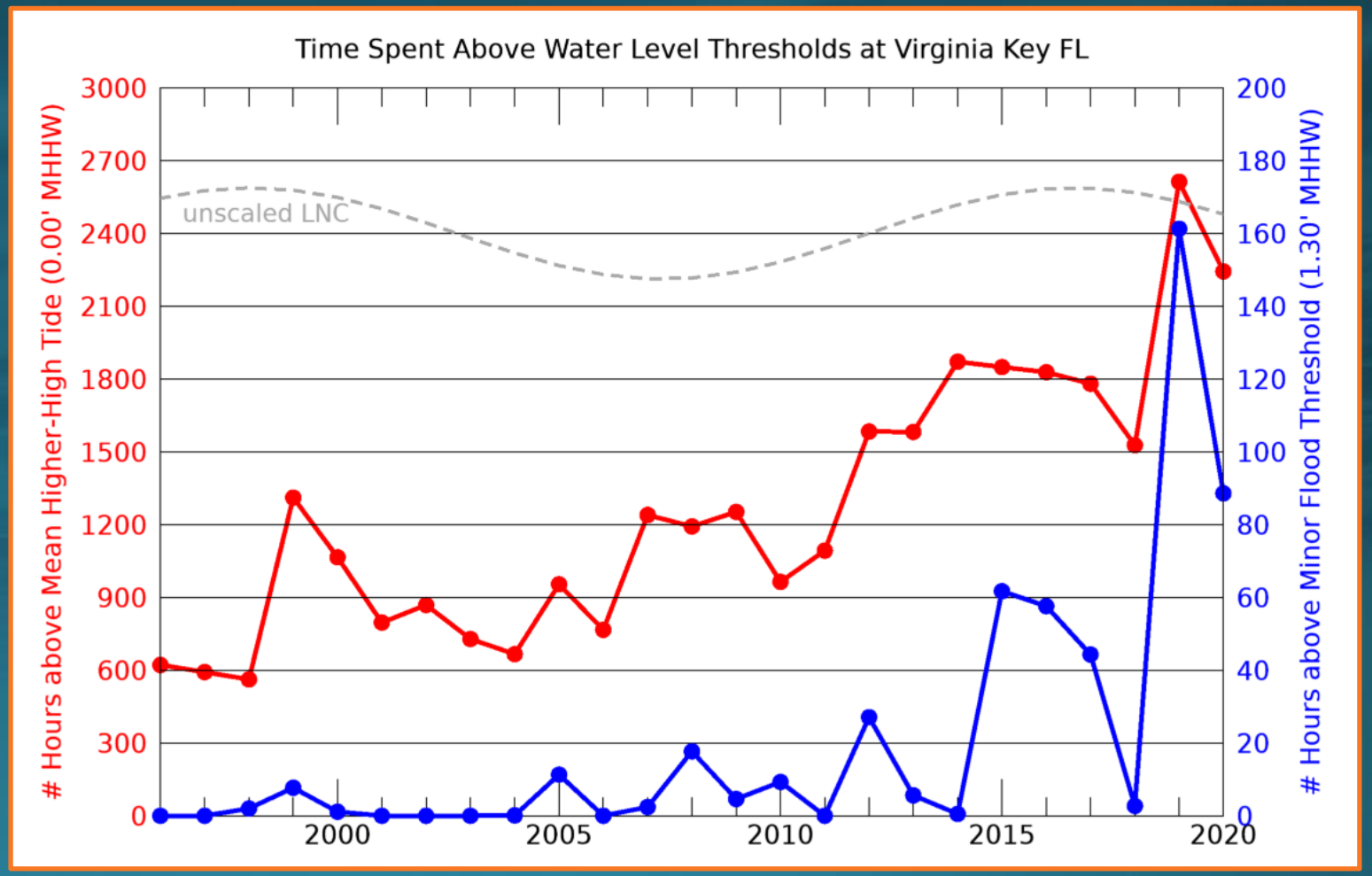
"Apparent" Sea Level Rise

- 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)



“Nuisance Flooding”

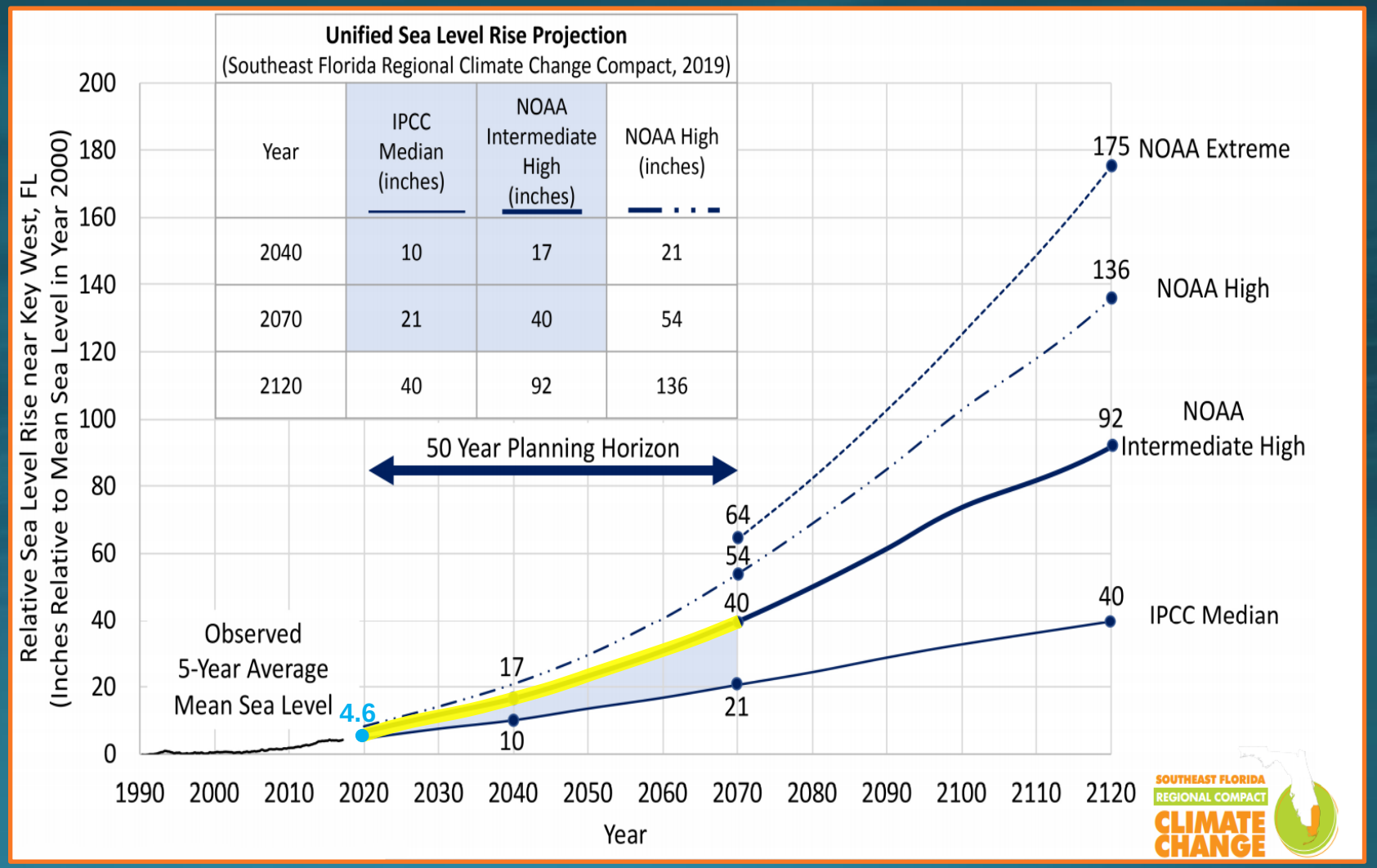
- “sunny-day flooding”
- When low-lying areas flood during the highest tide… no rainfall needed
- From the tide gauge measurements, we can add up the number of hours the water level spends above certain thresholds each year
- Almost never above the “minor flood threshold” two decades ago, but 160 hours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



Sea Level Rise Projections

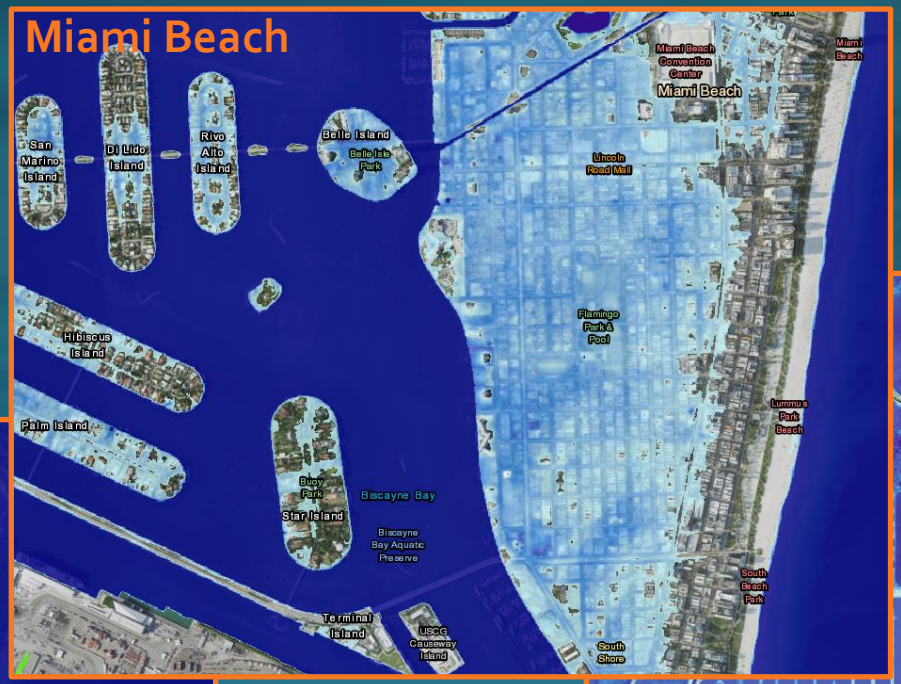
- Using NOAA's "*Intermediate High*" SLR curve adjusted to south Florida, we could see:
  - ***~1 ft (31cm) in 20 years***
  - ***~3 ft (91cm) in 50 years***

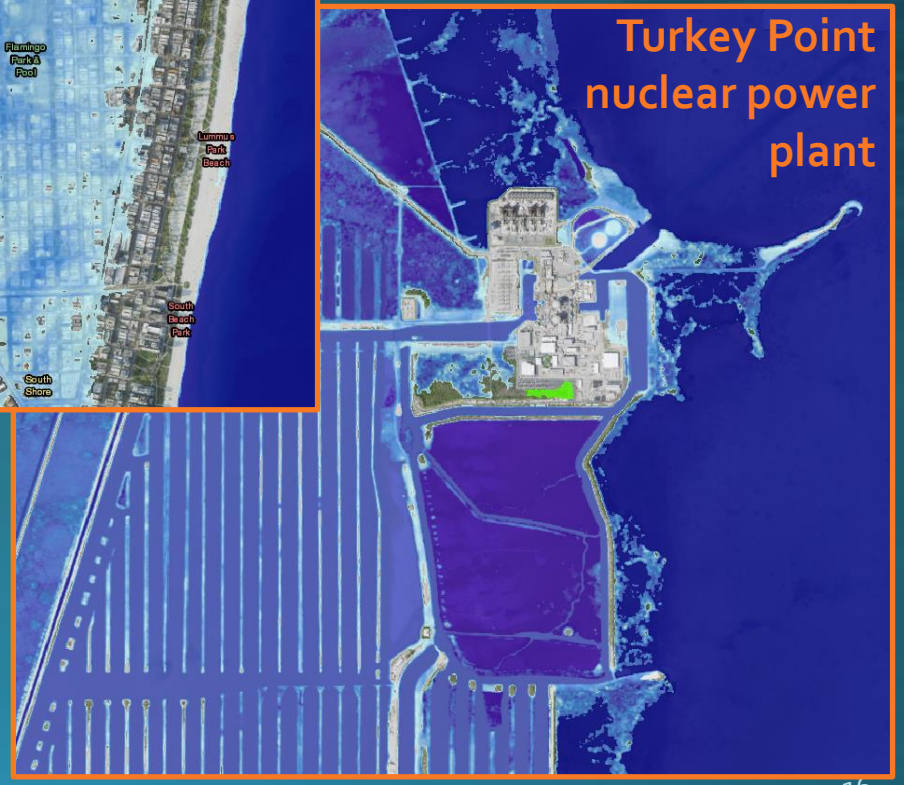
- What does an extra 3 feet of water look like around here? ……



Mapping the Future

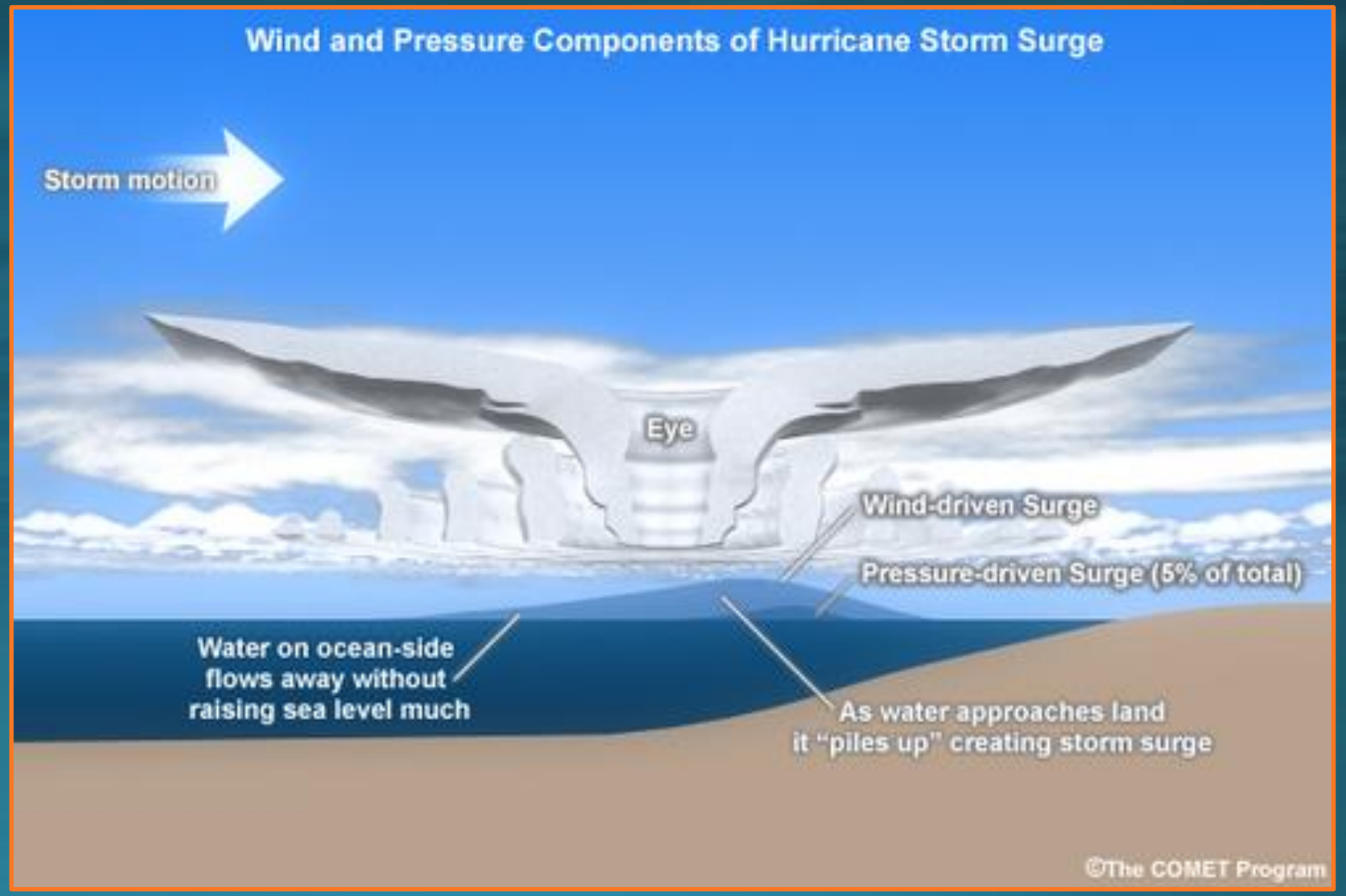
- Some local examples at high tide with an additional 3 feet (91 cm) of SLR (~50 years):





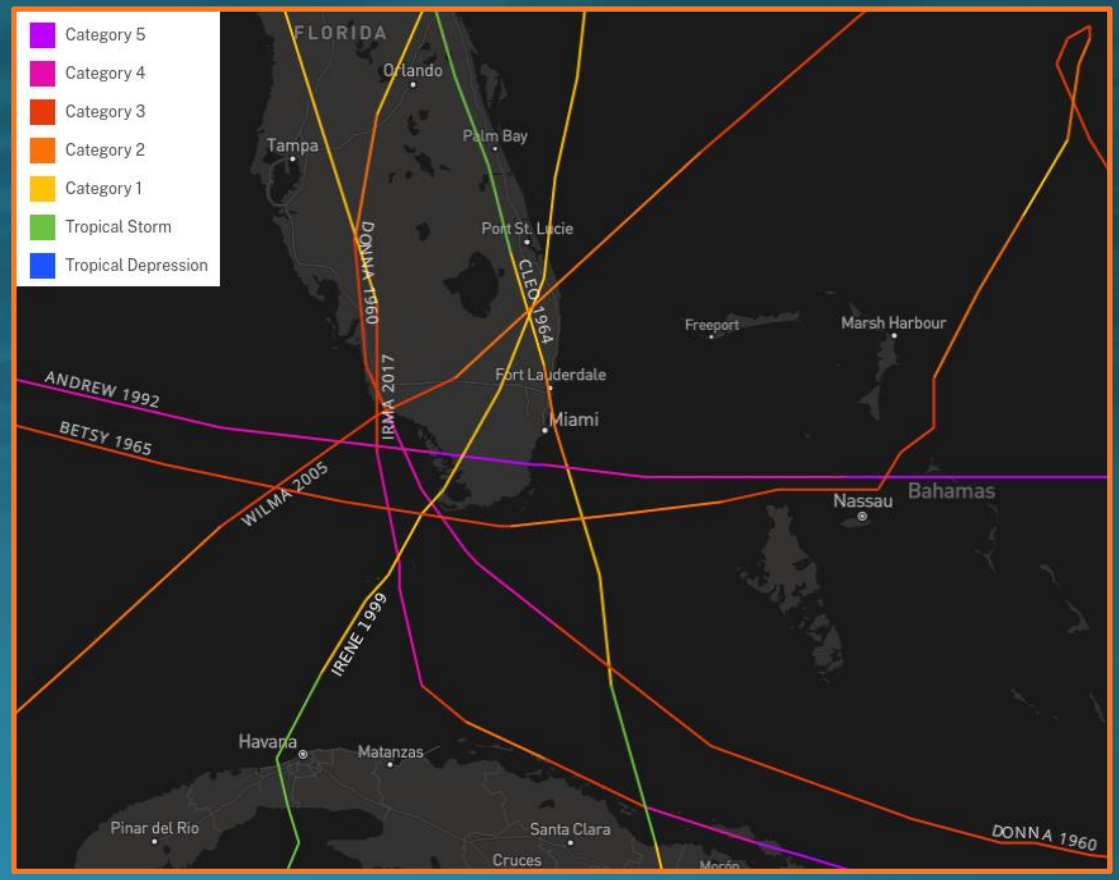
Storm Surge

- 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).



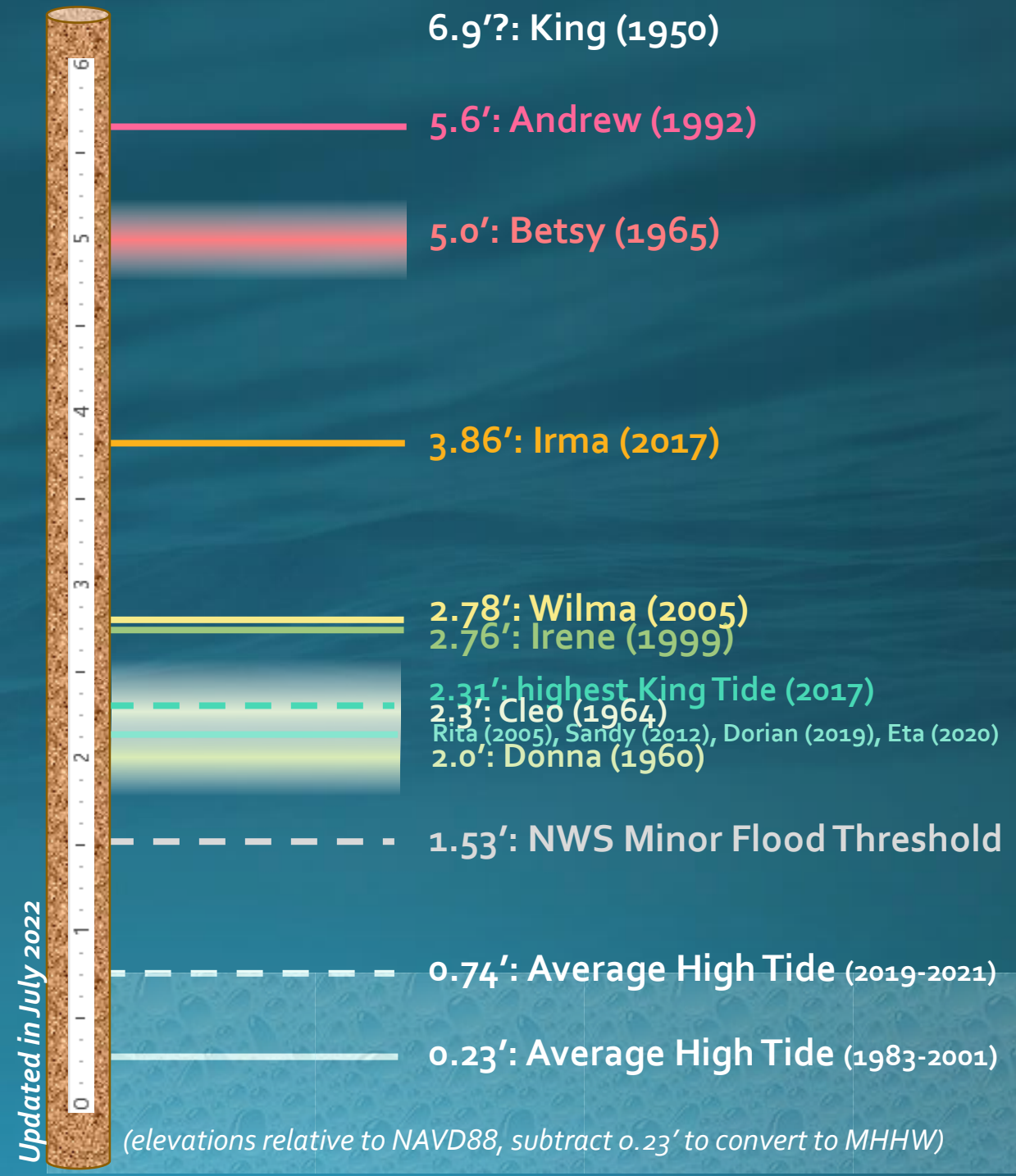
Local Hurricane History

- Although the UM 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 here 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:
    - 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)

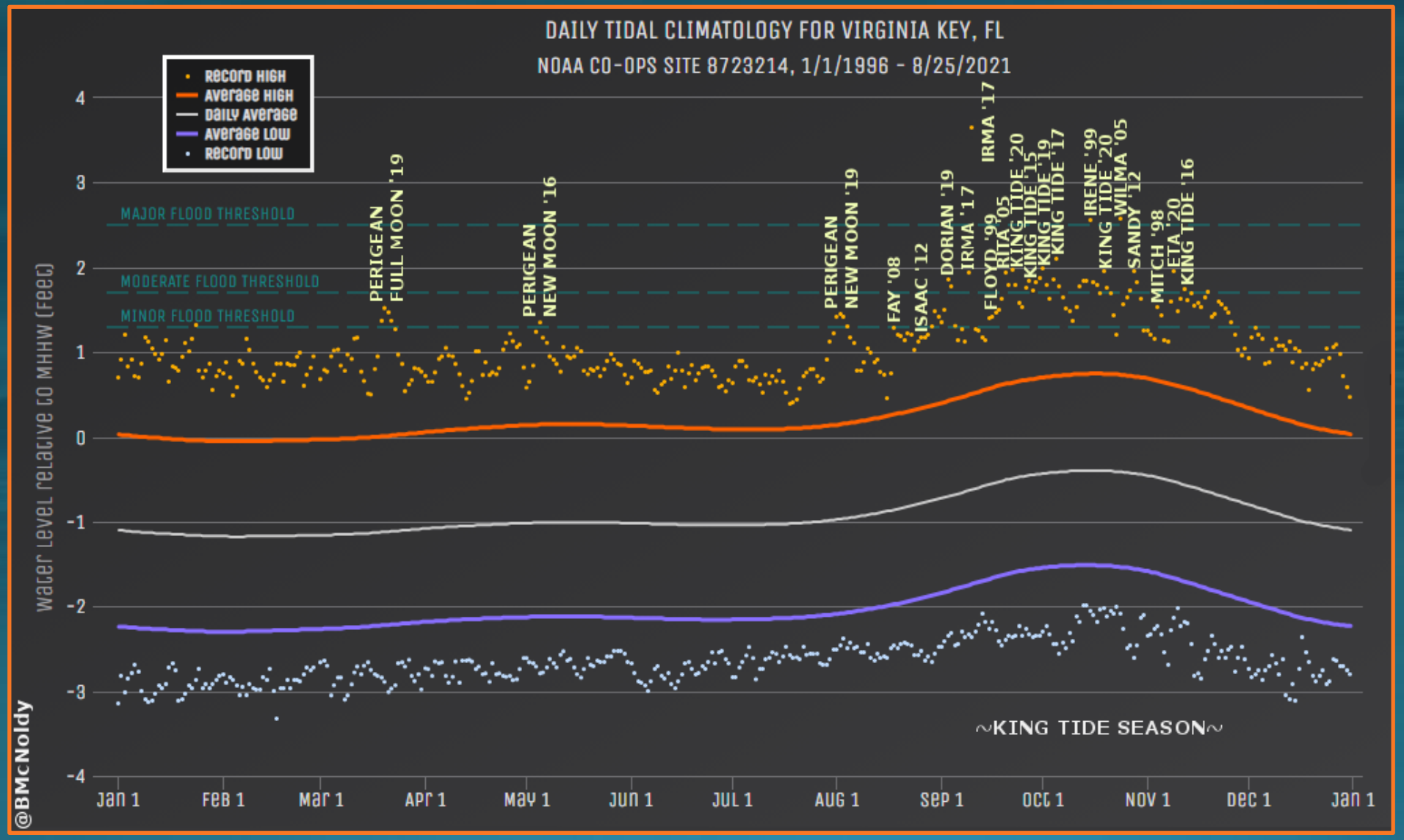


Storm Tide

- 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 Rosenstiel School campus, but I was able to use measurements or create estimates for them…



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 the area with several feet of water in a matter of hours
- Sea level rise provides an increasing baseline upon which storm surge acts
- VK climatology & records: http://bmcnoldy.rsmas.miami.edu/vk/