A Quarter-century of Tide Measurements at Virginia Key

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SCHOOL of MARINE &
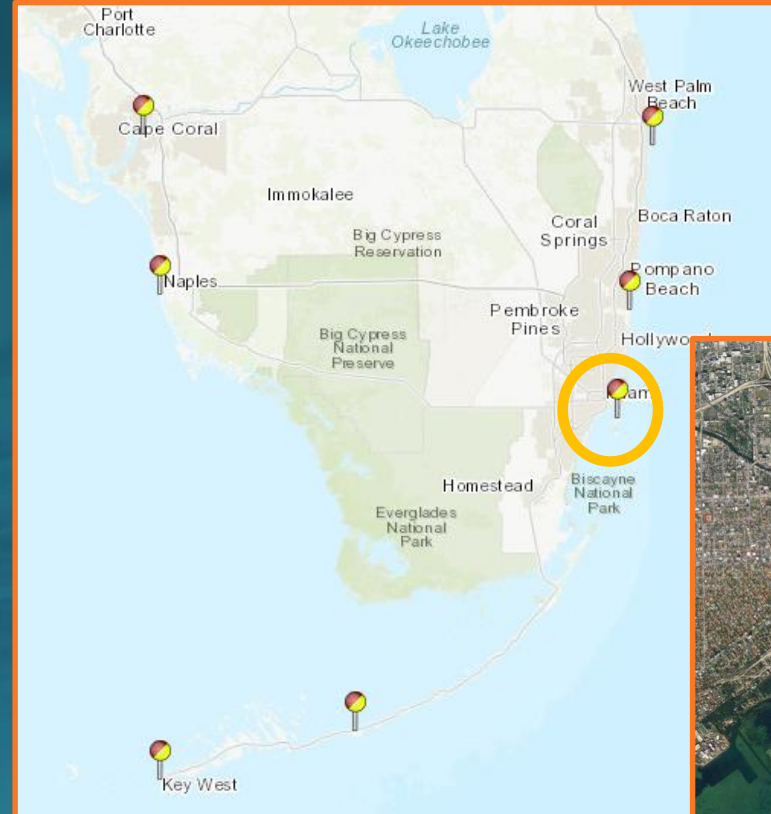ATMOSPHERIC SCIENCE

*Miami Climate Symposium*
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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
  - Preliminary real-time six-minute data since 2001
- Station is located at end of dock on the UM Rosenstiel School campus
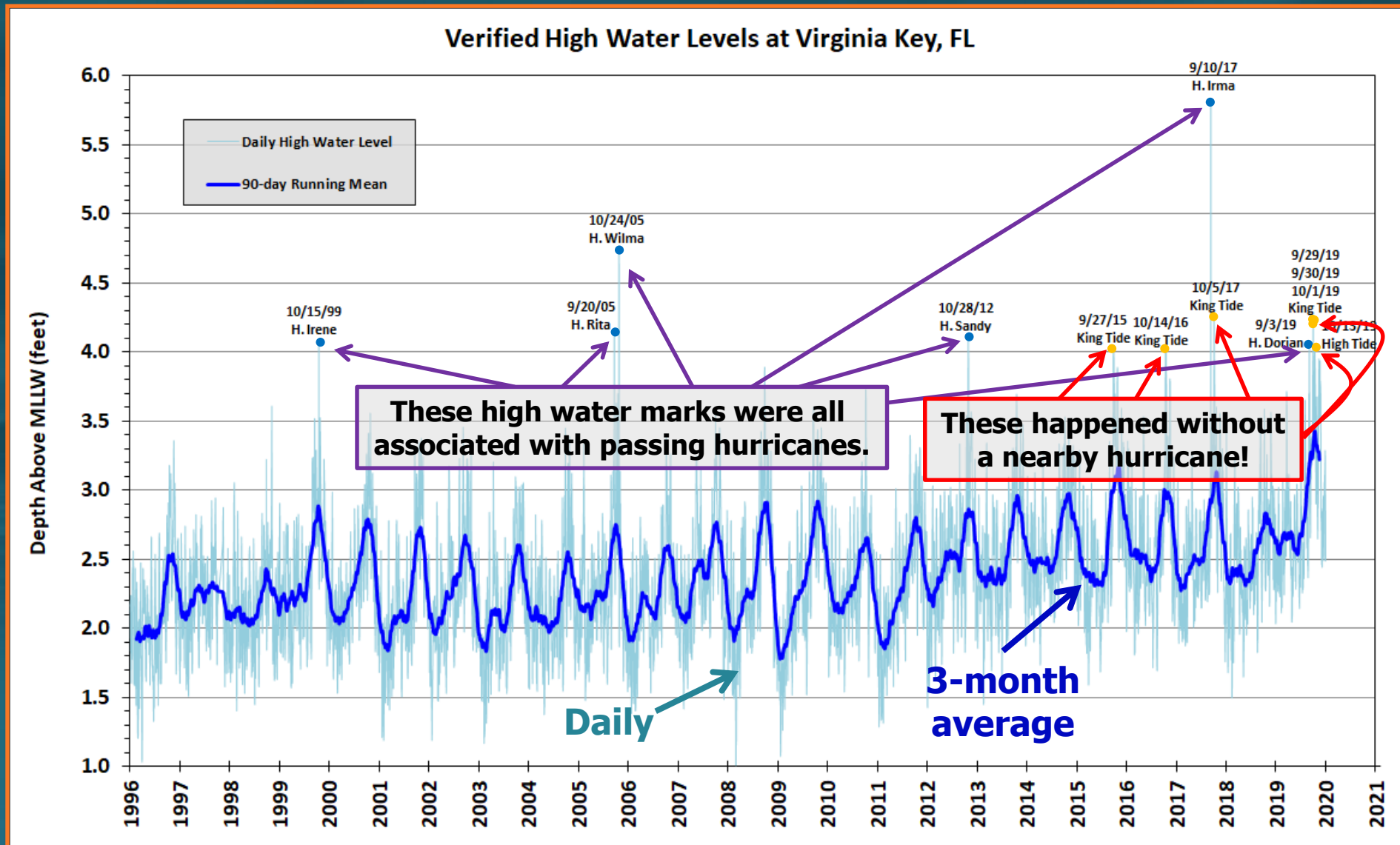

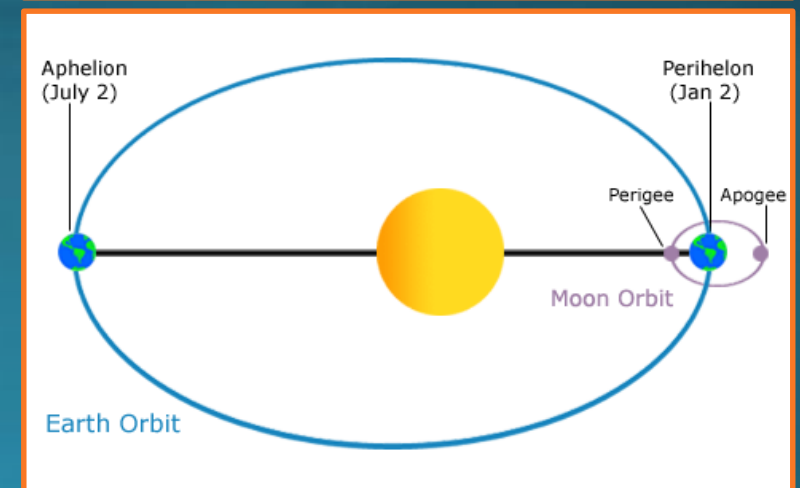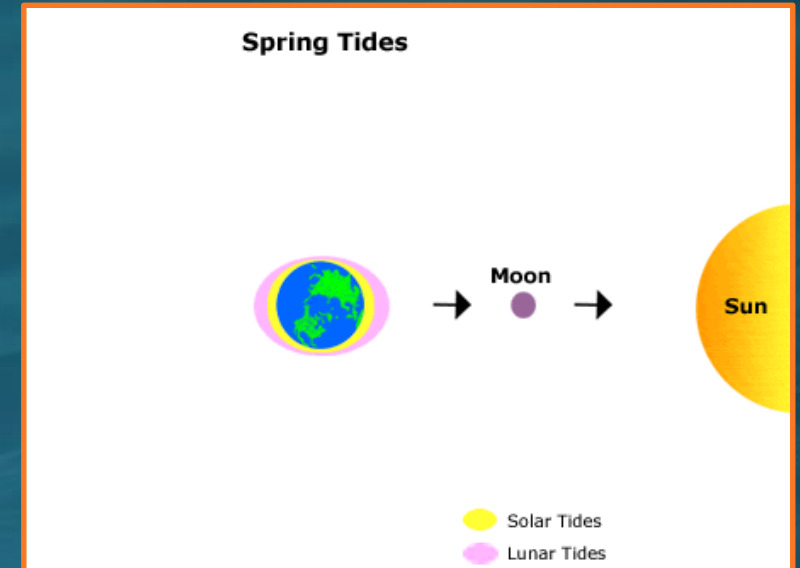NOAA CO-OPS tide gauges in south Florida

Virginia Key area
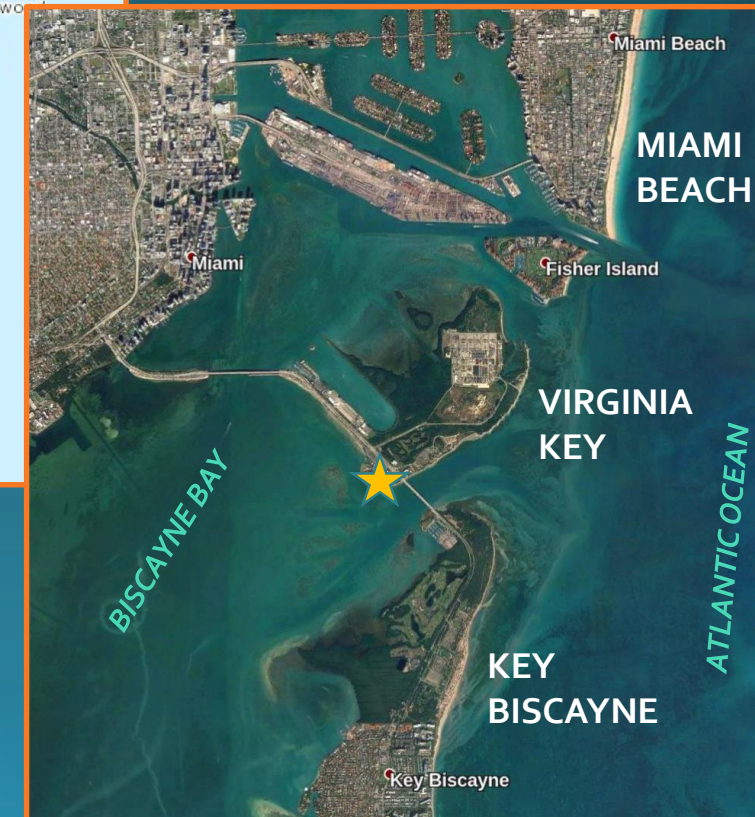
Daily Data & High Water Marks

Verified High Water Levels at Virginia Key, FL

What Factors Influence Sea Level?

- 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. Locally, this can be significant enough to not ignore.

Spring Tides

Moon → ● → Sun

Solar Tides
Lunar Tides

Aphelion (July 2)

Perihelon (Jan 2)

Perigee   Apogee

Moon Orbit

Earth Orbit

What factors influence sea level?

- 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 (rise)
- 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

Average Seasonal Cycle of Sea Level in Southeast Florida

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

**Seasonal Cycle of Water Levels at Virginia Key, FL (1996-2019)**
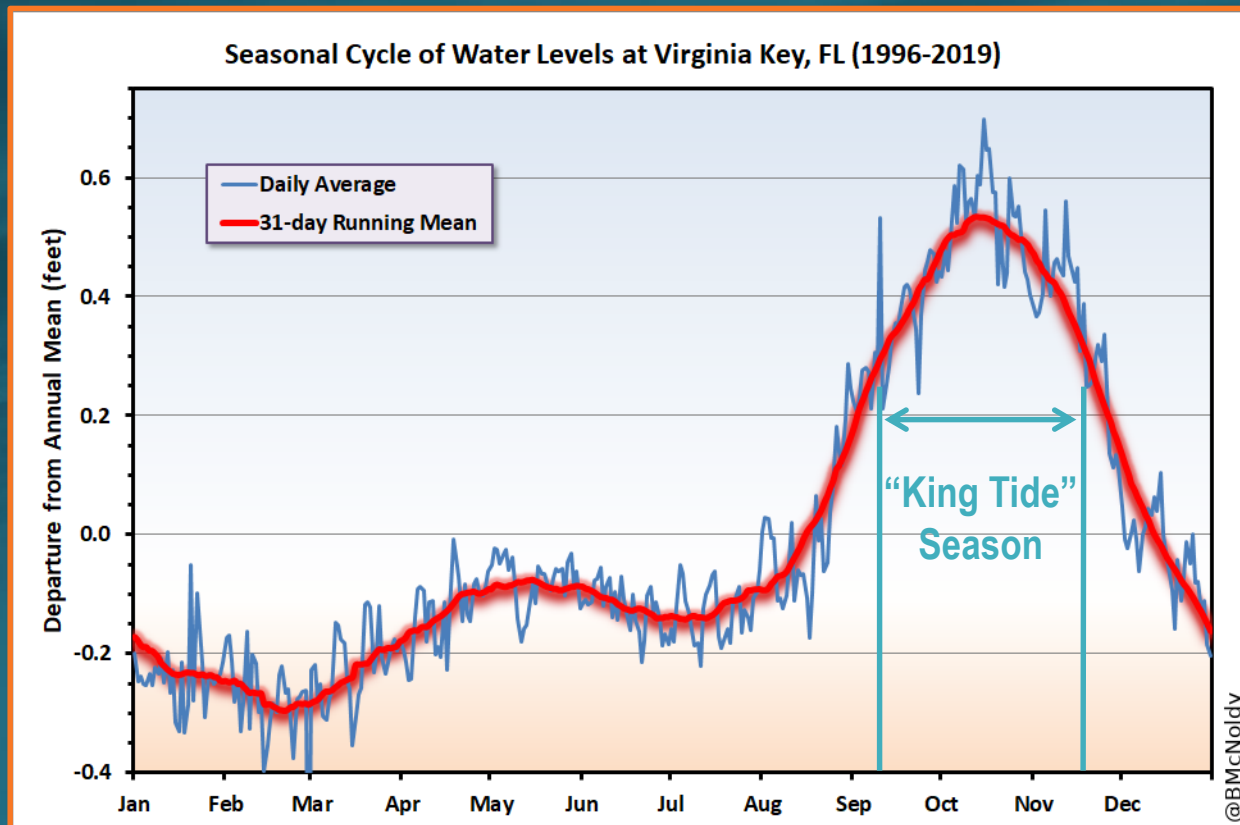
~10"

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, each with a phase, frequency, and amplitude
  - These components are added together to arrive at the total water level relative to a datum of choice:

    $$h(t) = H_0 + \sum_{i=1}^{n} f_i H_i \cos[a_i t + (V_0 + u)_i - \kappa_i]$$
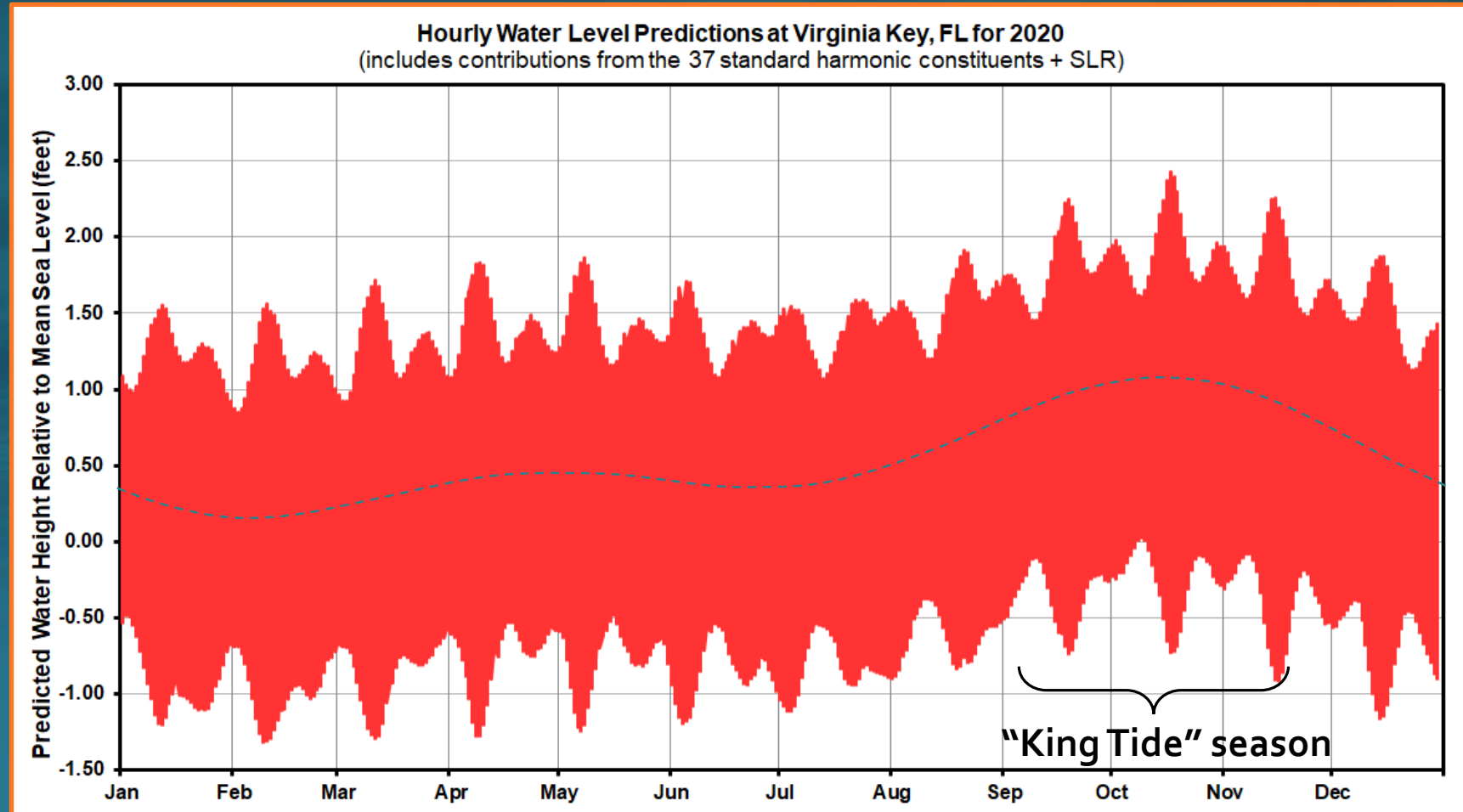
    [The higher n is, the more accurately the time series can be reproduced]

- This can be done for years in advance, and has no dependence on actual weather or ocean conditions.

- *Tide predictions are not like weather predictions…* they make no attempt to be anything beyond "climatology". The timing is typically quite accurate, but the amplitude often falls short (partly due to aging baseline).
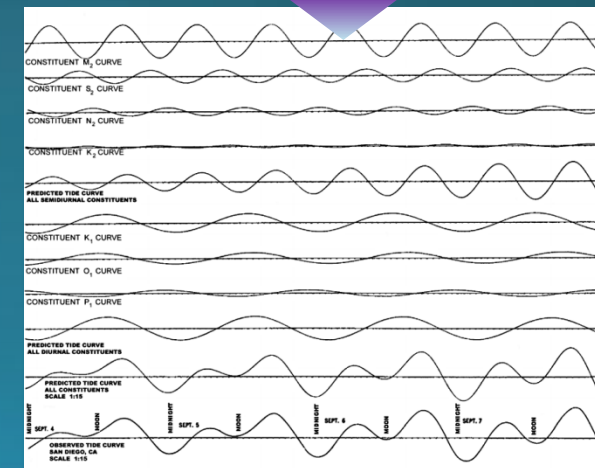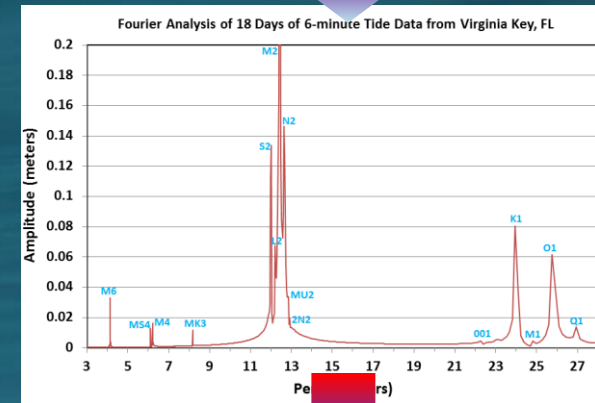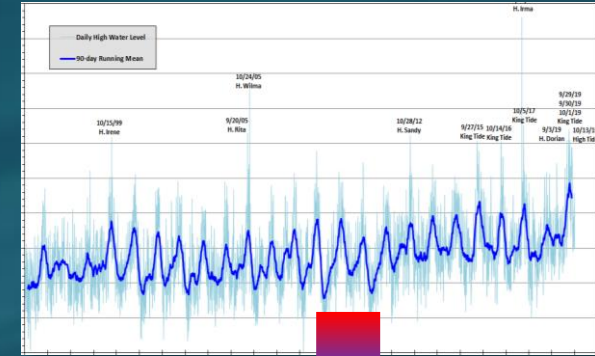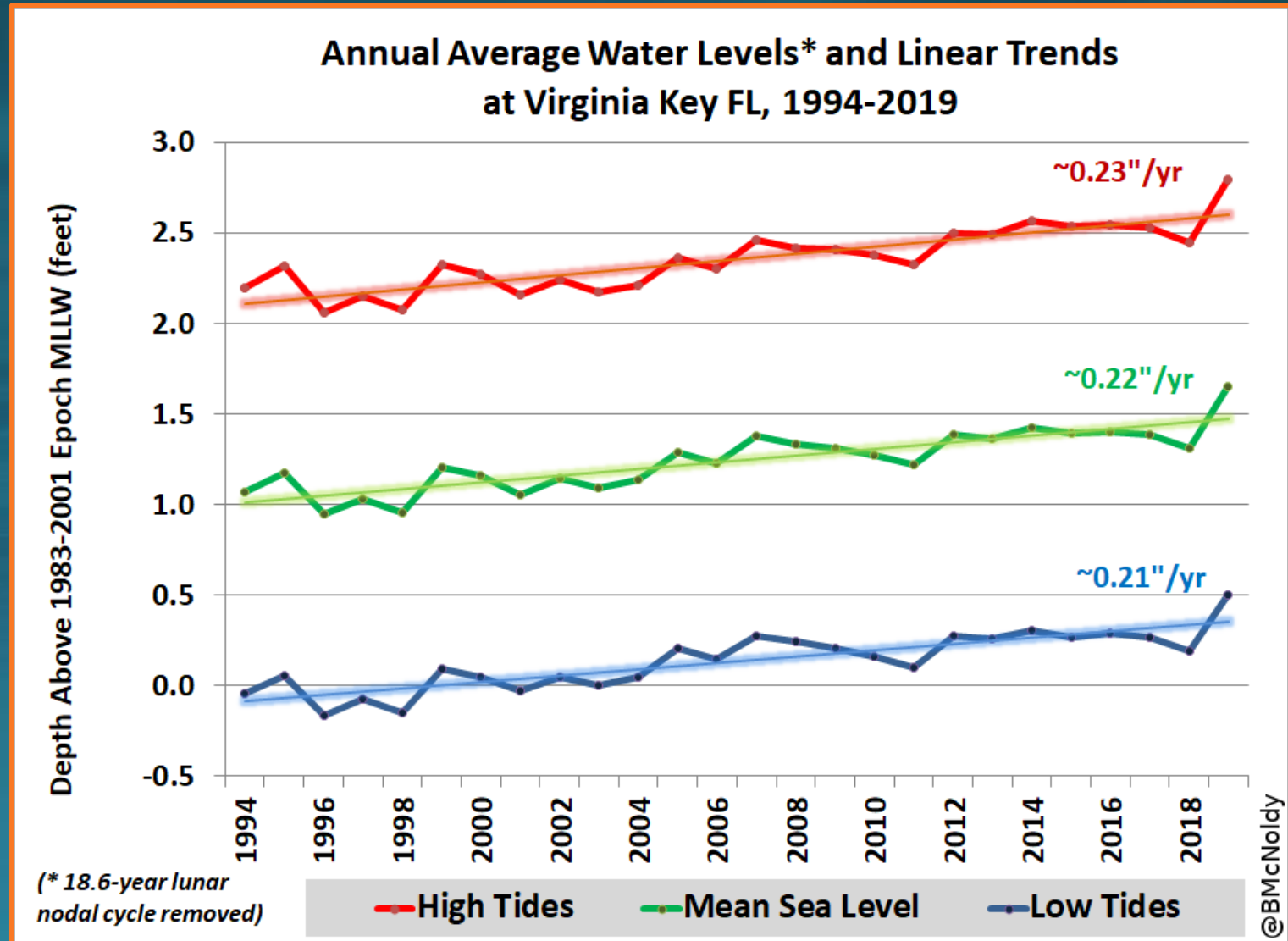
2020 Tide Predictions for Southeast Florida

- Water level shown relative to the 1983-2001 epoch mean sea level at this location

- Mean seasonal cycle peaks on Oct 15… highest predicted tide of the year will typically occur near the full or new moon closest to that date

Hourly Water Level Predictions at Virginia Key, FL for 2020
(includes contributions from the 37 standard harmonic constituents + SLR)

"King Tide" season

Moving on to Sea Level Rise

- Now that we understand some of the natural variations, we can remove the major known cycles and look at the remaining trend (linear for simplicity)

- There are ups & downs in the annual averages, but overall trend is definitely UP
  - **~0.22 in/yr** (5.6 mm/yr)

Annual Average Water Levels* and Linear Trends at Virginia Key FL, 1994-2019

~0.23"/yr

~0.22"/yr

~0.21"/yr

(* 18.6-year lunar nodal cycle removed)

High Tides — Mean Sea Level — Low Tides

@BMcNoldy

"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)
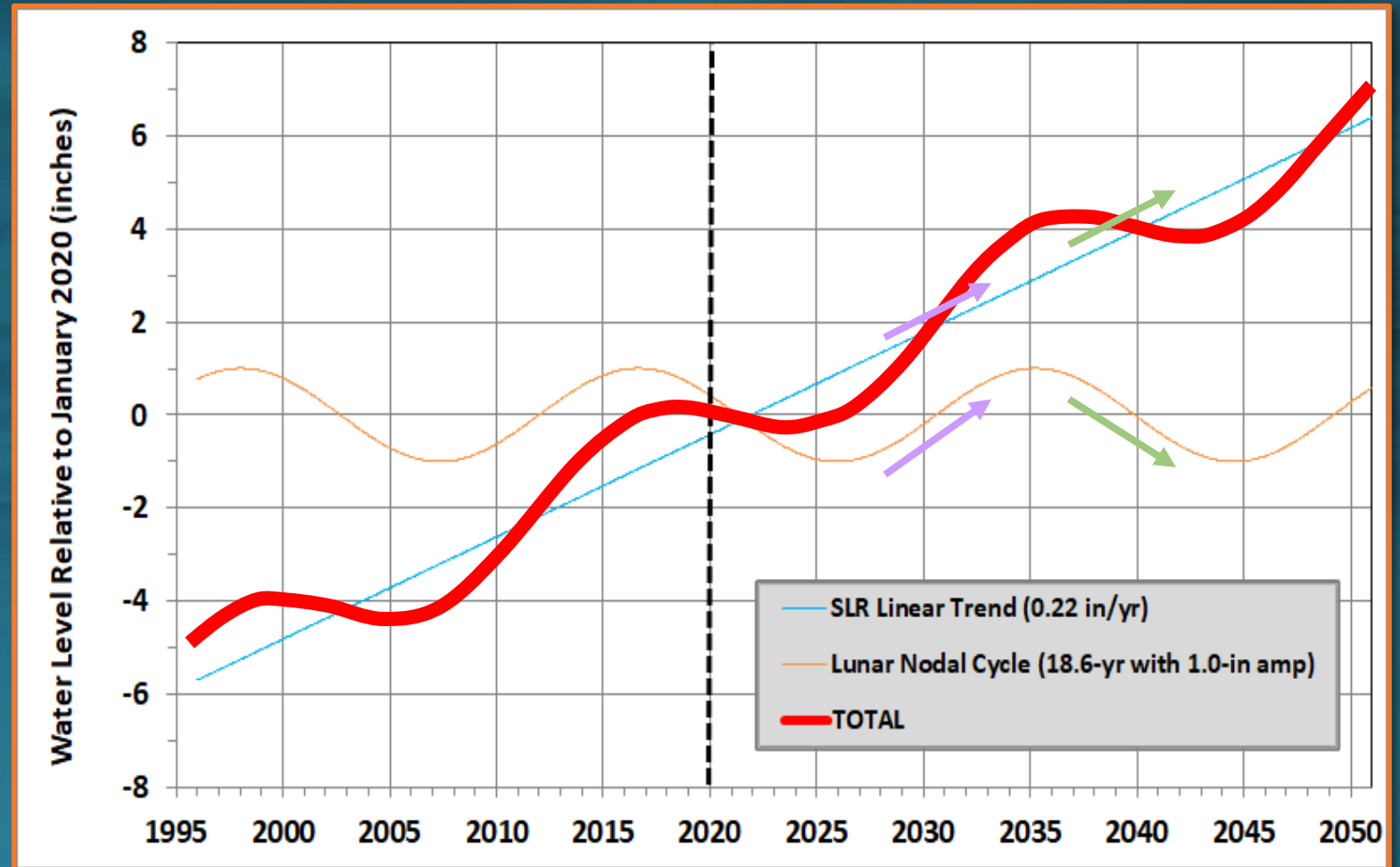
Summary

- Sea level has risen ~5.7 inches (~14.5 cm) in past 26 years in Miami area… or an average rate of 0.22 in/yr (5.6 mm/yr)
- Significant high water events used to only be associated with passing or landfalling hurricanes… but lately, some high tides are comparable
- Record high annual average water level occurred in 2019
- Natural cycles influence "apparent" sea level rise, but *actual* sea level rise continues and is influenced by global and regional factors