Observations and Projections of Sea Level Rise in Miami

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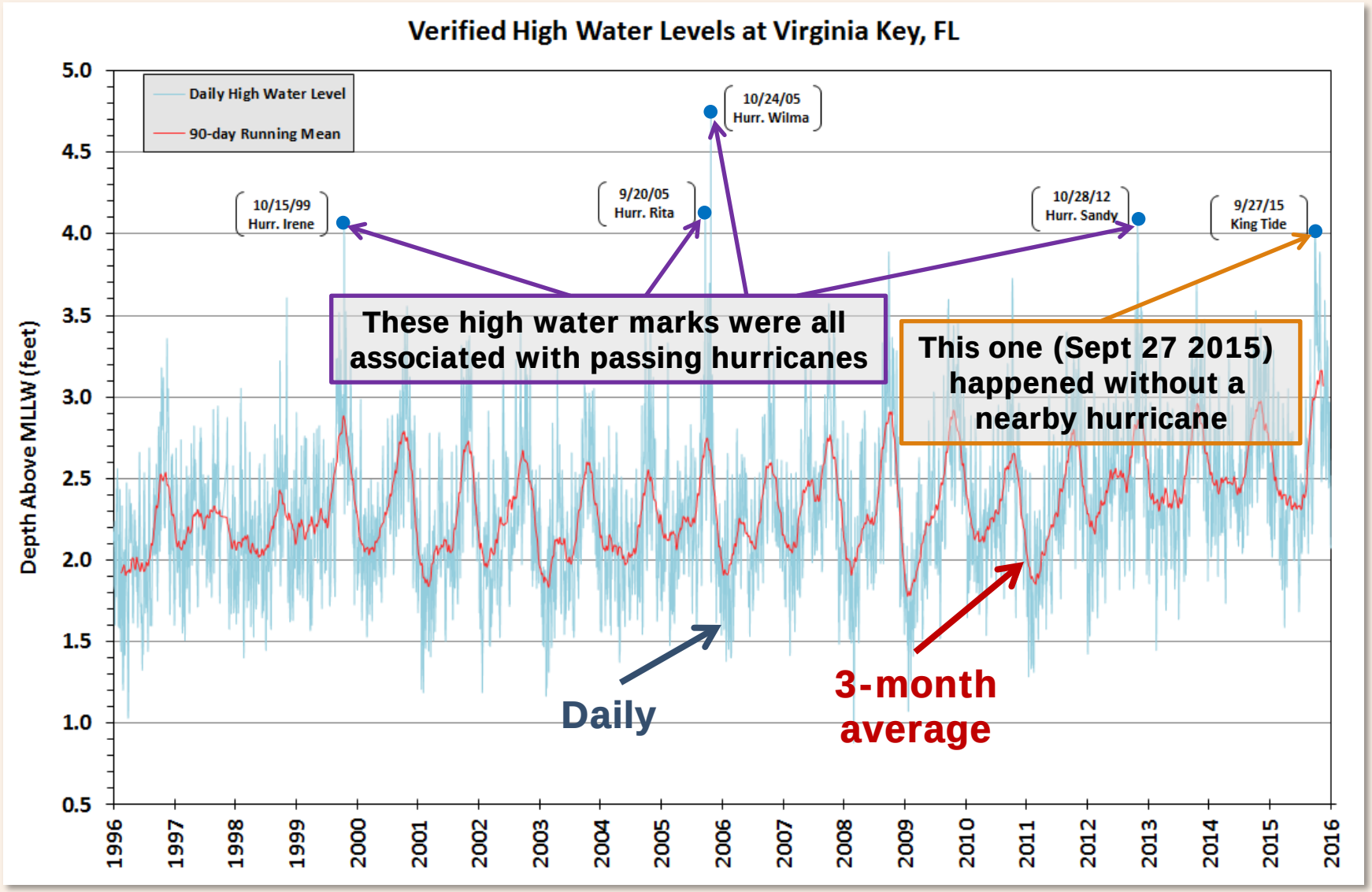
MDPL MIAMI DESIGN PRESERVATION LEAGUE

Before We Get to Sea Level Rise . . .

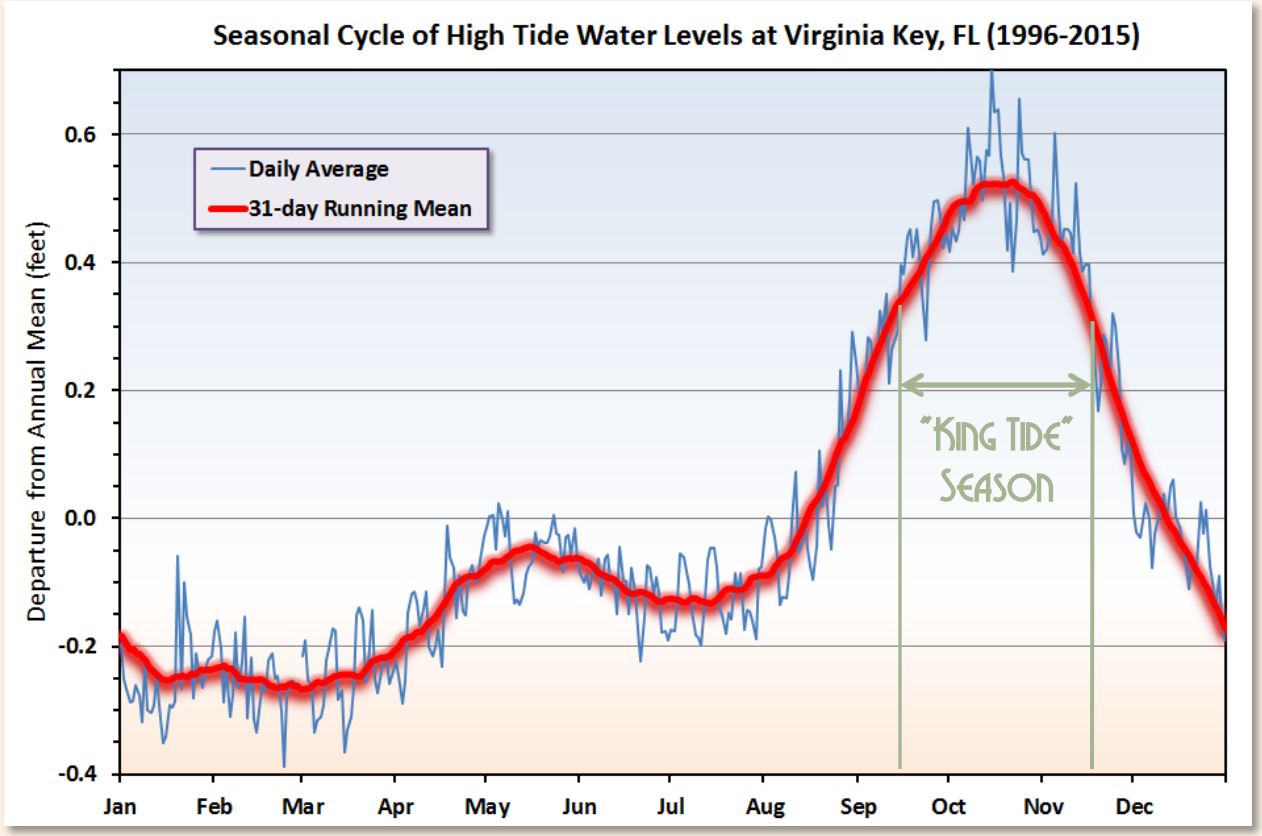
- Tides are complicated!
  - Large natural variations throughout the year and even across multiple years
  - What does the normal seasonal cycle look like here?
  - What factors influence the normal seasonal cycle of tide levels?
- Verified data from a tide gauge on Virginia Key available online from 1996-present
  - Only active long-term gauge in the area... Miami Beach (1932-1980) and Haulover Pier (1982-1992)
  - Not a very long record, but long enough to see recent trends

20 Years of Sea Level Measurements



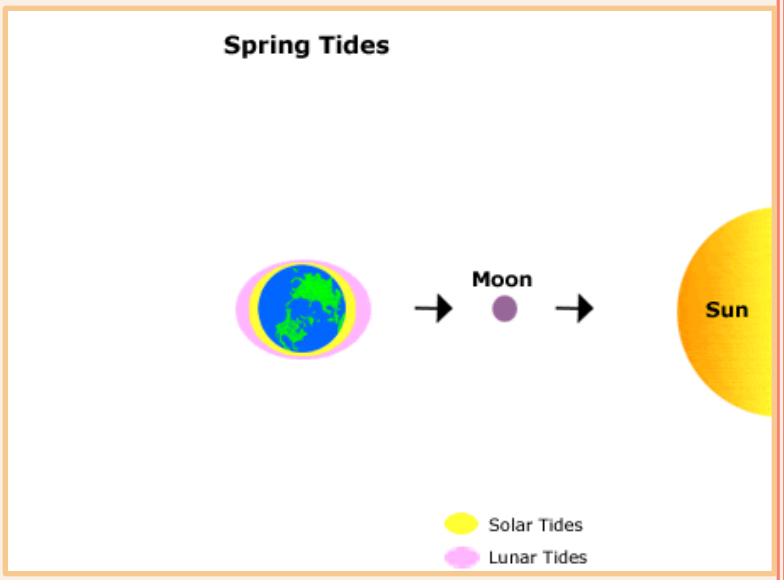
Average Seasonal Cycle of Sea Level in Southeast Florida

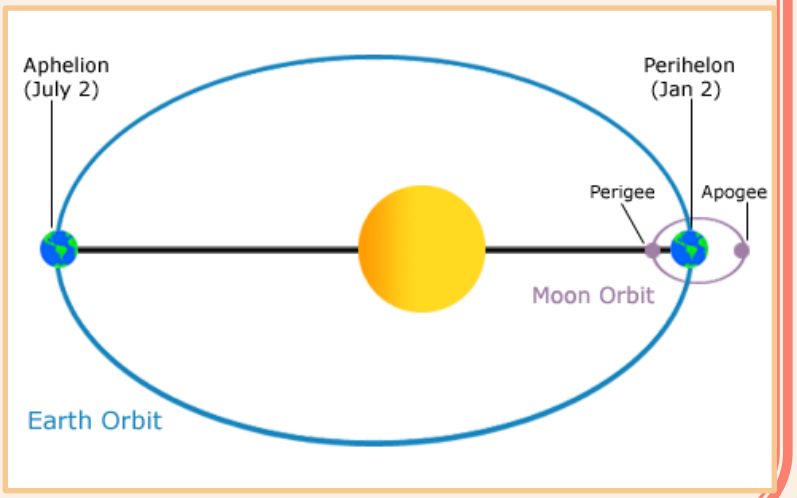
- Not all high/low tides are equal... water levels are naturally lowest in JFM and highest in SON. Why??



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



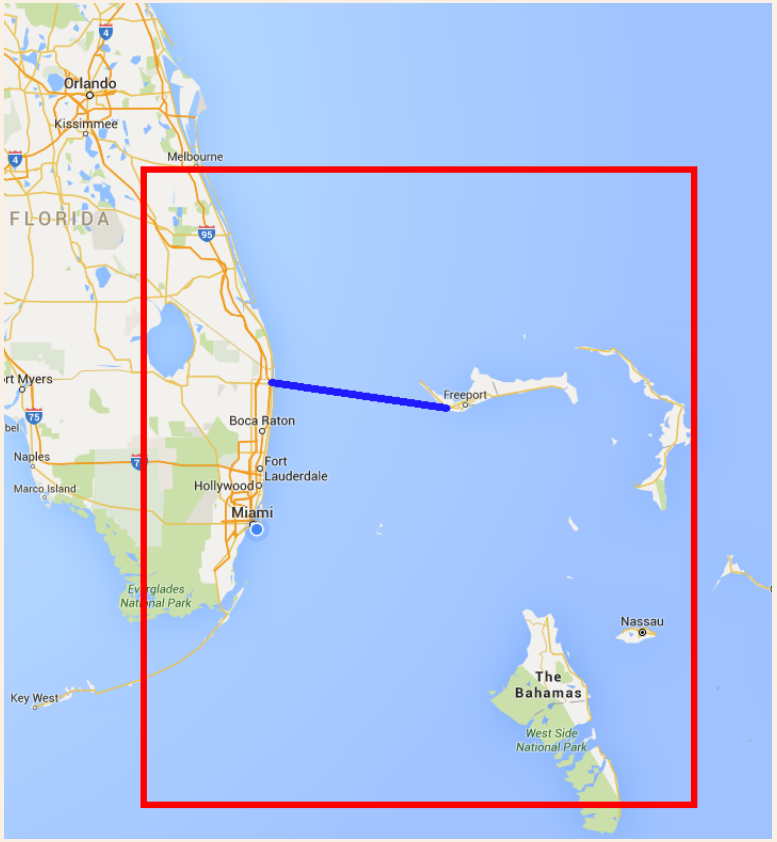


What factors influence sea level?

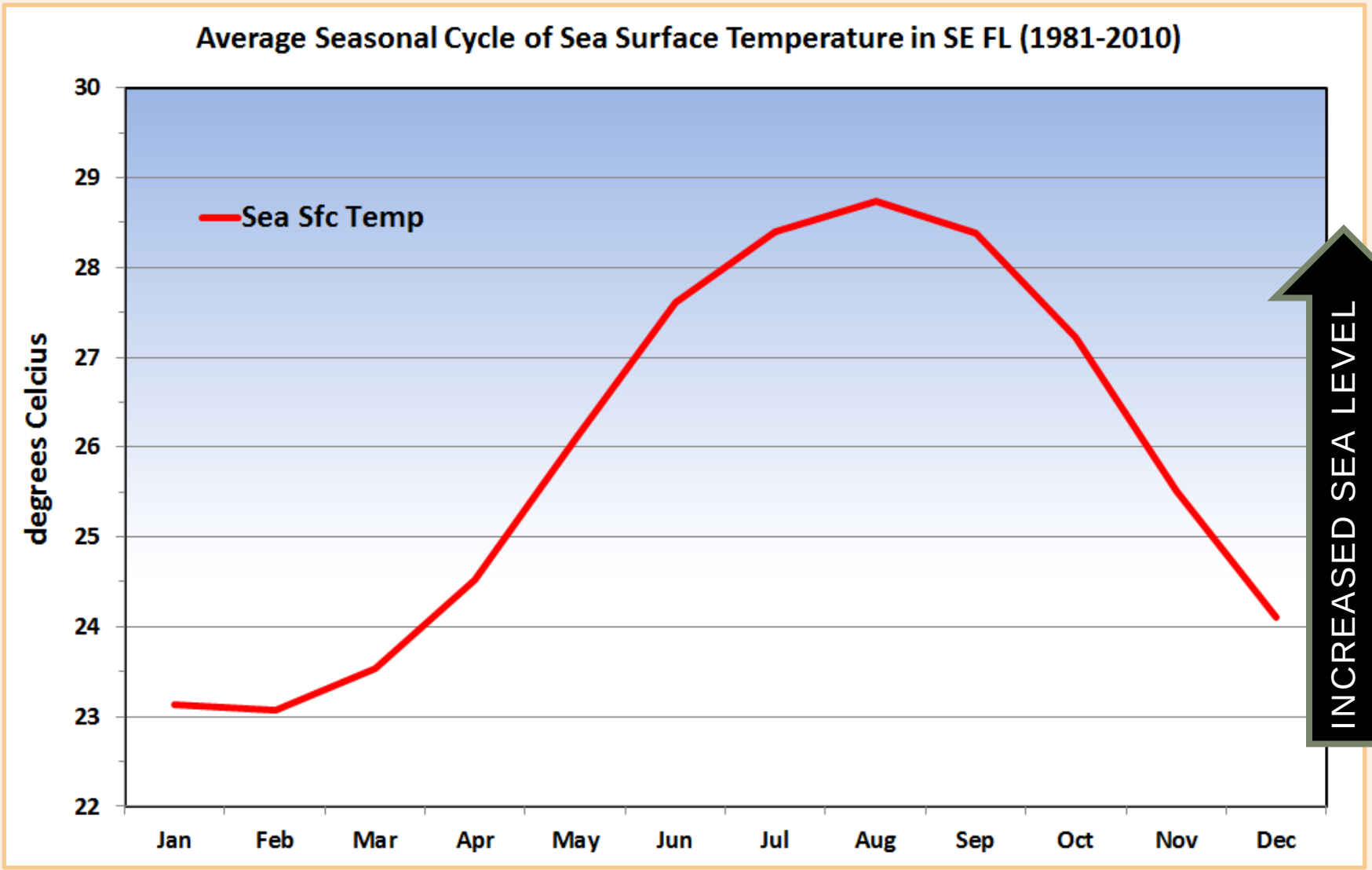
- Persistent wind direction
  - Strong onshore winds push water onto land
- Ocean temperature
  - Warm water expands more than cooler water
- Atmospheric pressure
  - Low pressure allows sea level to bulge up (rise)
- Locally, the strength of the Gulf Stream (and Florida Current) plays a role
  - Reduced transport allows water to pile up along U.S. east coast
- Etc, etc, etc

Climatology of Various Factors

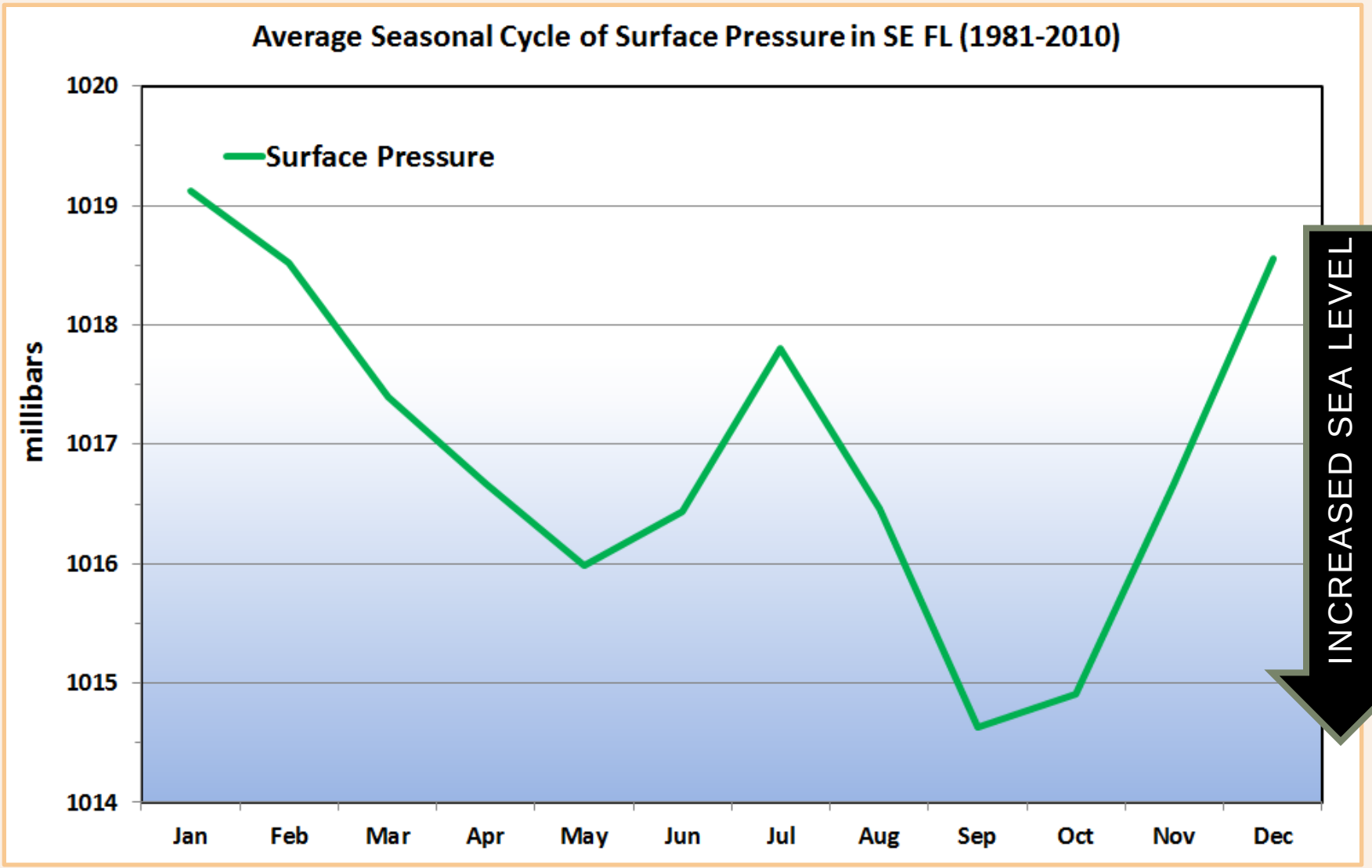
- Monthly averages of sea surface temperature, surface pressure, and wind in regional area (red outline) from 1981-2010
- Monthly average of Florida Current transport derived from voltage induced in submarine cable (blue line) from 1982-2009



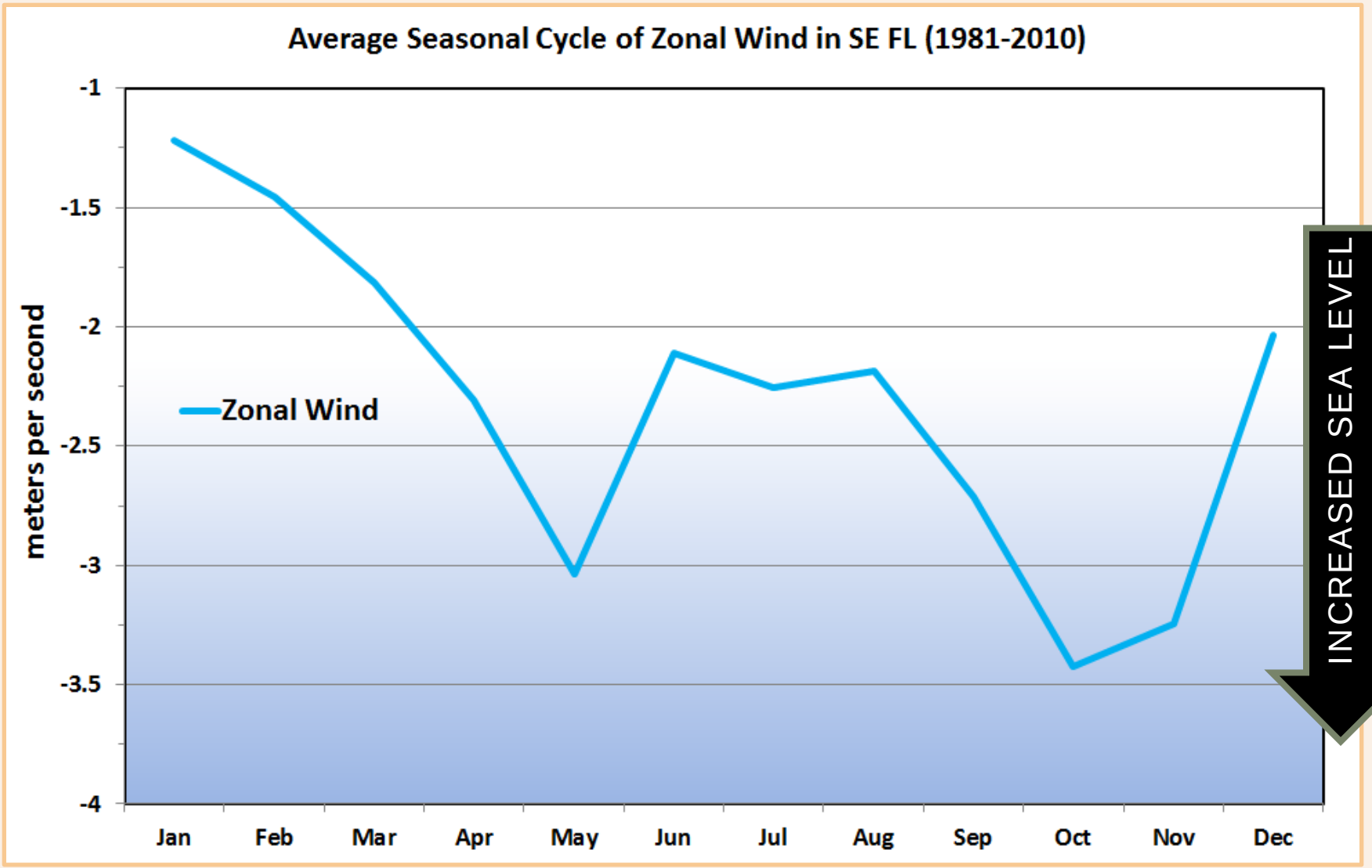
Sea Surface Temperature



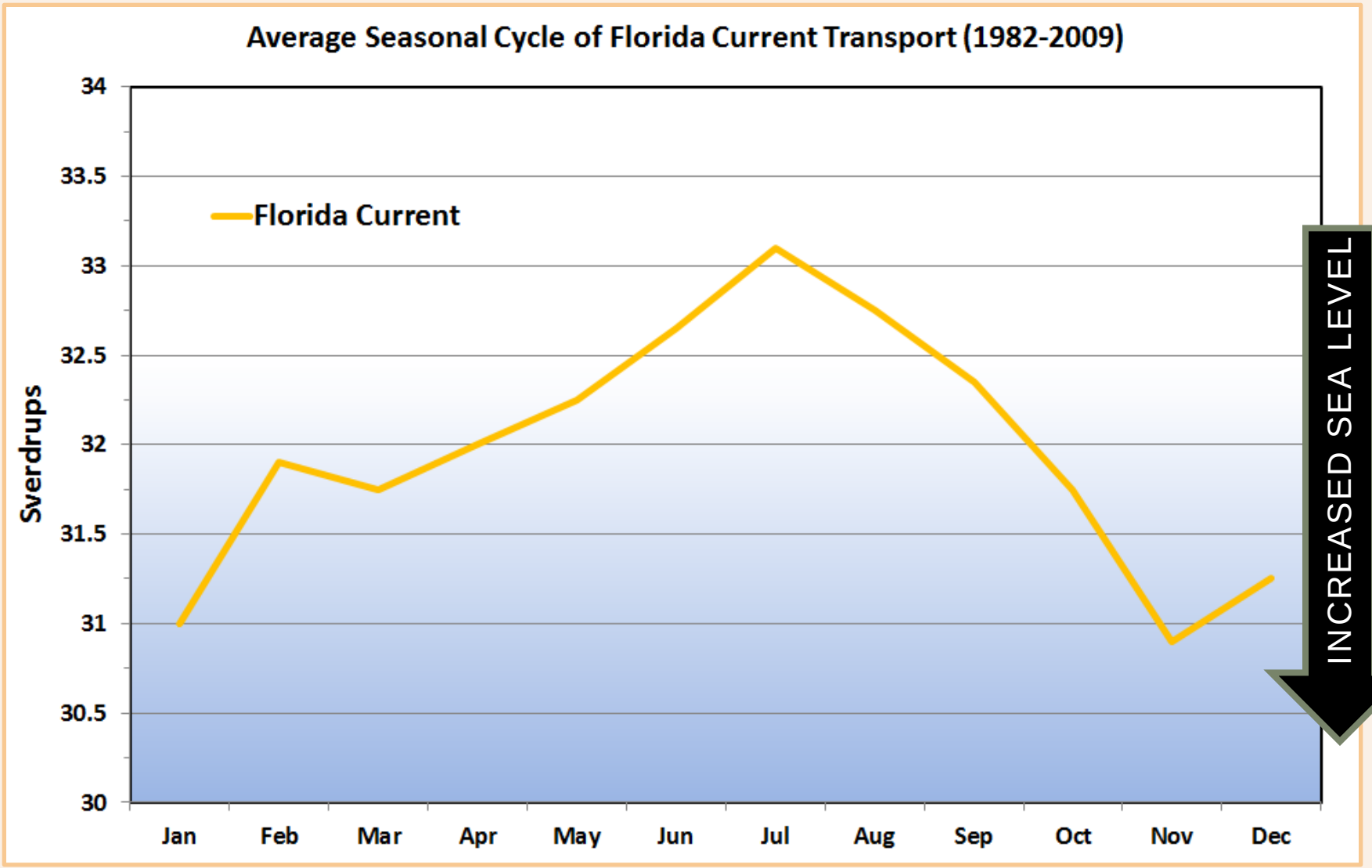
Surface Pressure



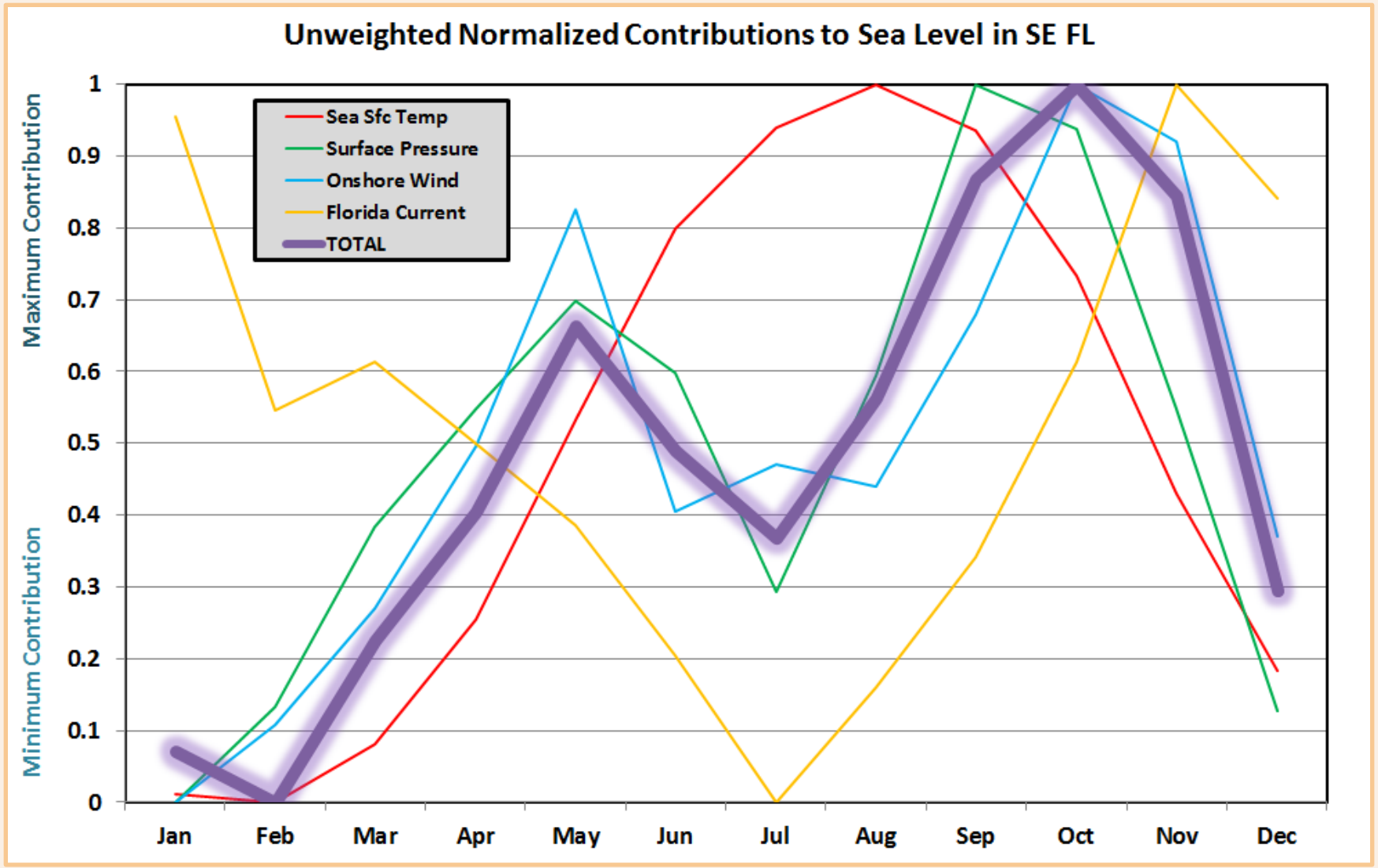
Zonal (Onshore) Wind



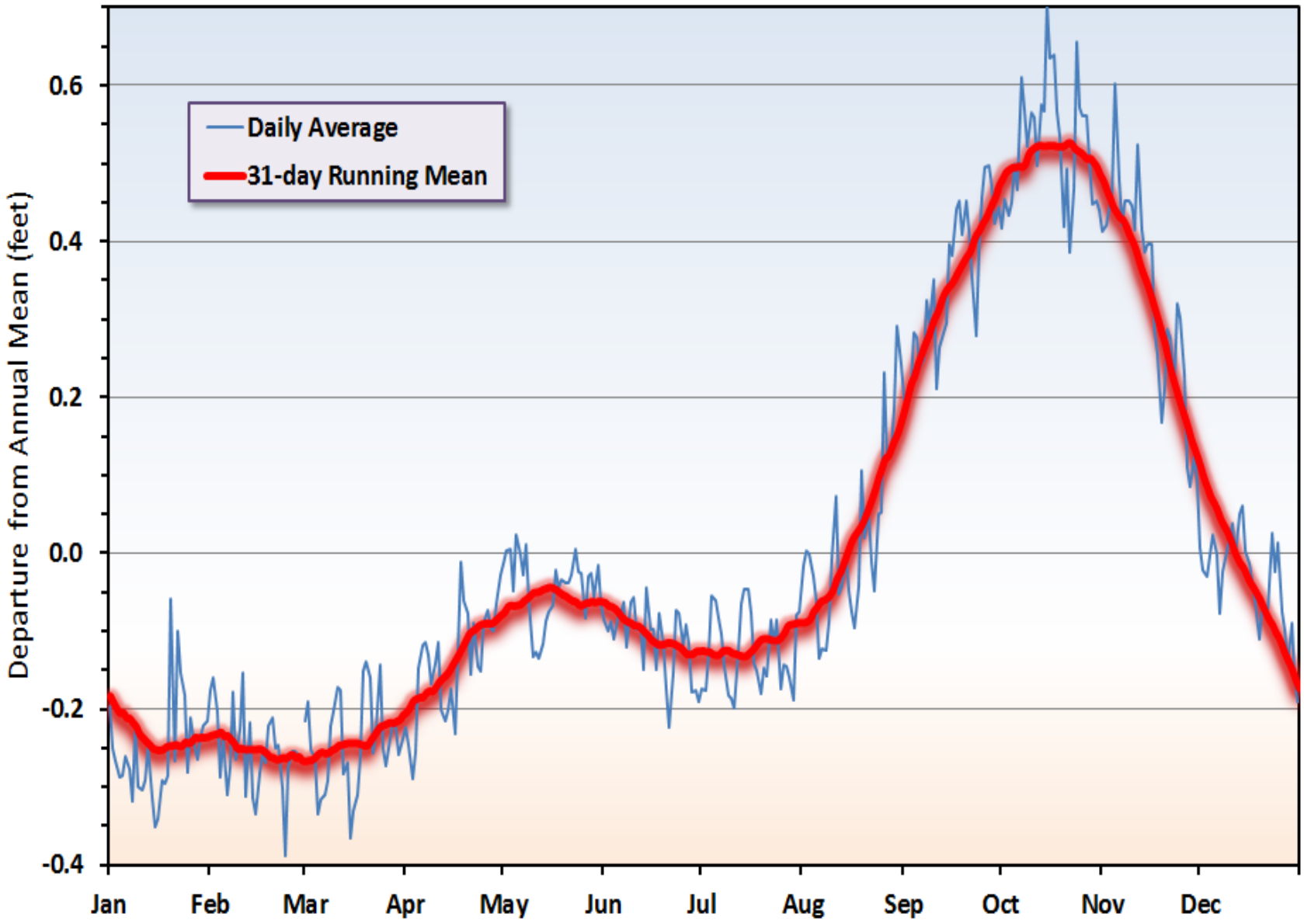
Florida Current Transport



Unweighted Normalized Sum of All Four Components

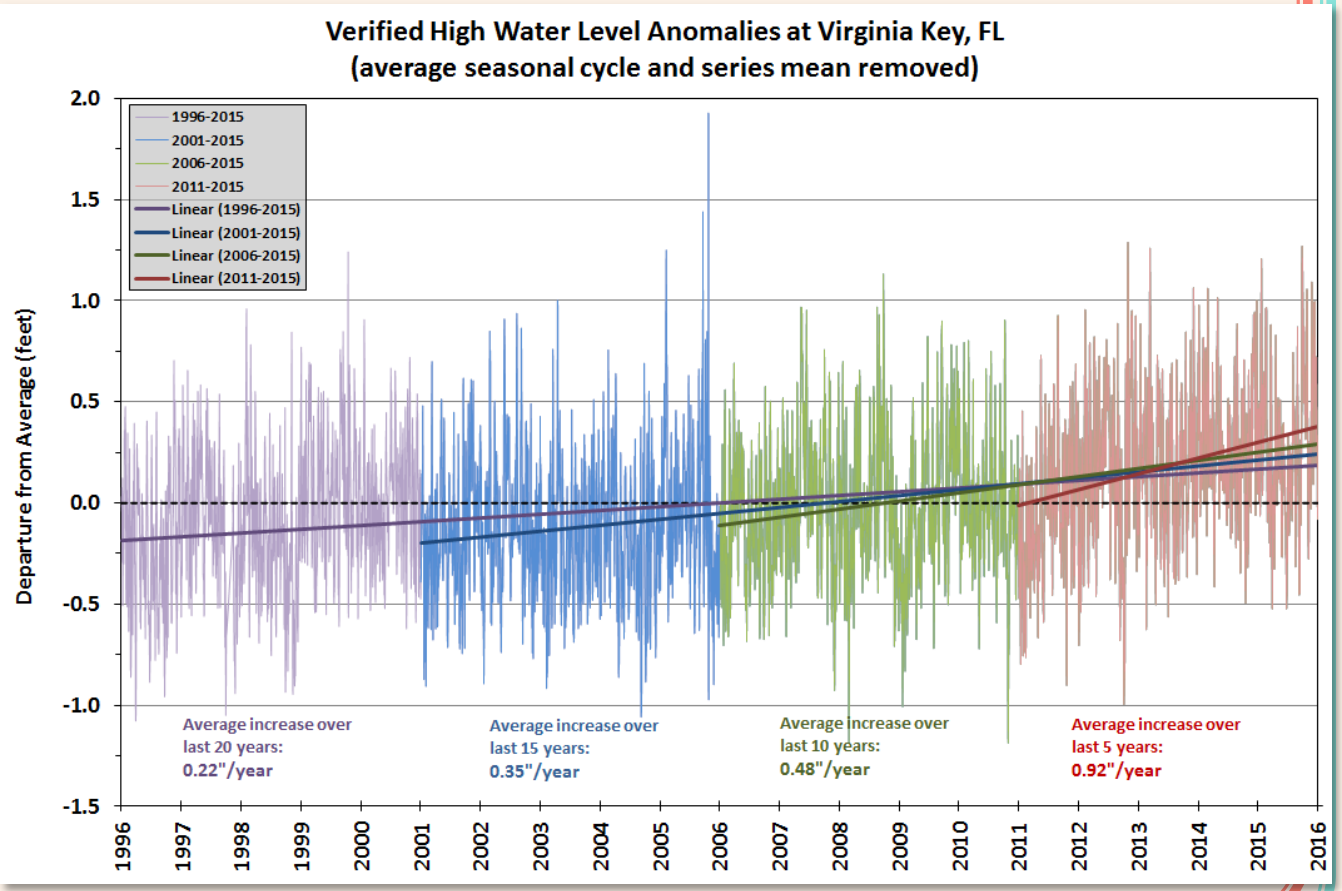


Seasonal Cycle of High Tide Water Levels at Virginia Key, FL (1996-2015)



Moving On to Sea Level Rise

- Now that we understand some of the natural variations, we can remove the average seasonal cycle from the daily data and look at remaining trends
- Linear trends through past 20, 15, 10, and 5 years show increasing rates of sea level rise
- Data are still very noisy... not fit well by linear trends, should not rely too heavily on exact rates from these trend lines

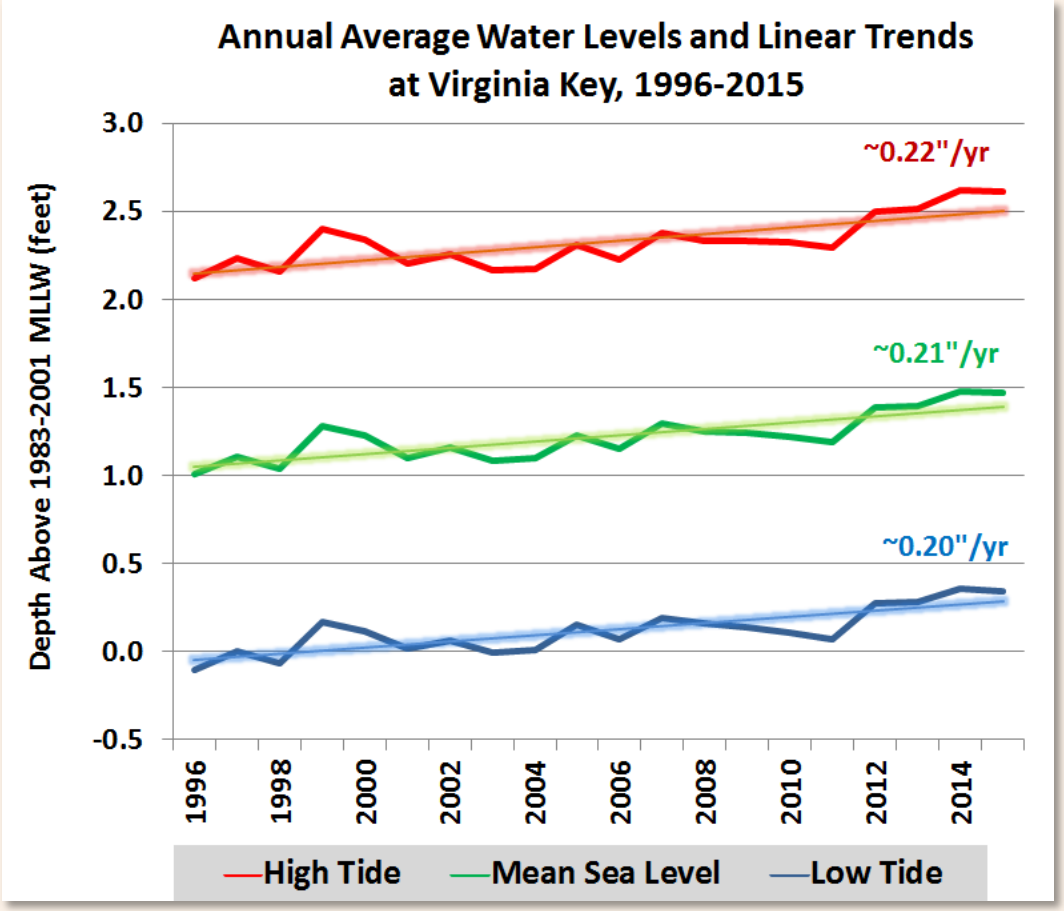


Rates of Sea Level Rise are Increasing, but…

- Linear trends of noisy time series have to be used with caution!!!
  - ESPECIALLY with relatively short periods
  - 20-year trend (0.22”/yr): probably pretty reliable, but more years would be better
  - 5-year trend (0.92”/yr): likely not accurate
  - (if sea level rose 4” in past 20 years, it didn’t rise 5” in past 5 years!)
- *Longer time series allows for higher confidence in linear trend line, but cannot account for accelerating rates*

A BETTER ESTIMATE OF TRENDS?

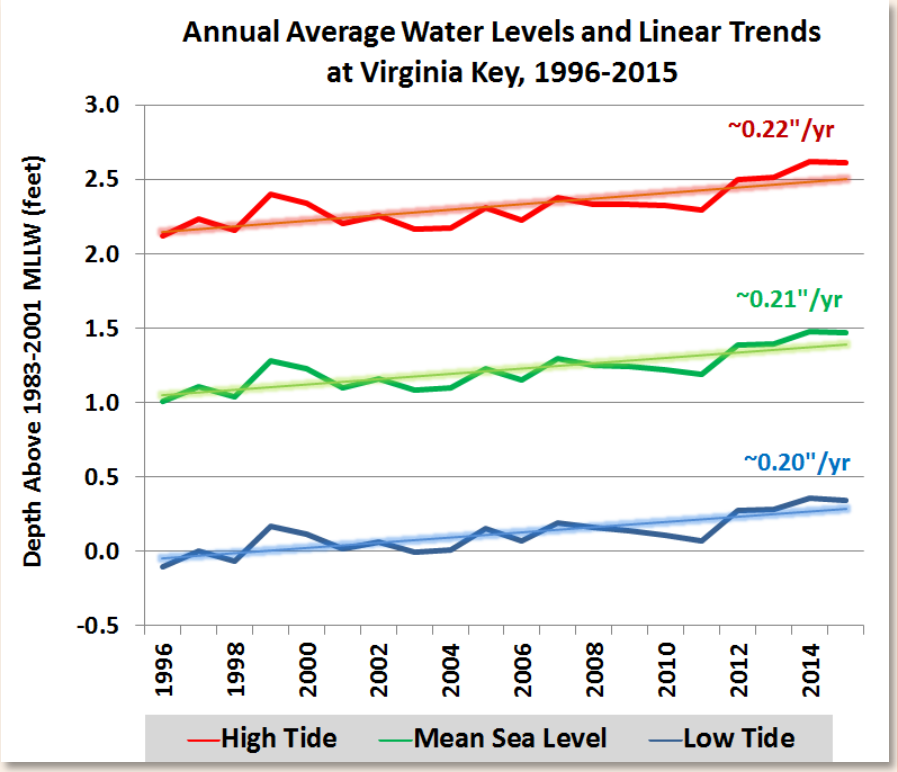
- Use the same data, but calculate *annual averages* rather than daily values to remove noise
- 20-year trend still ~0.21”/year!
- Confidence of ~4.2” of SLR in past 20 years increases



What about the short-term trend?

- To eliminate year-to-year variability, and dependence on specific endpoints, average past five 5-year trends of each time series (total of 15 linear trends of recent data)

	Average Trend
2011-2015	+0.64 “/yr
2010-2014	+0.71“/yr
2009-2013	+0.47 “/yr
2008-2012	+0.21 “/yr
2007-2011	-0.22 “/yr
Average Recent Trend	**0.36 “/yr**



- *It appears that the recent trend is nearly twice that of the 20-year trend*

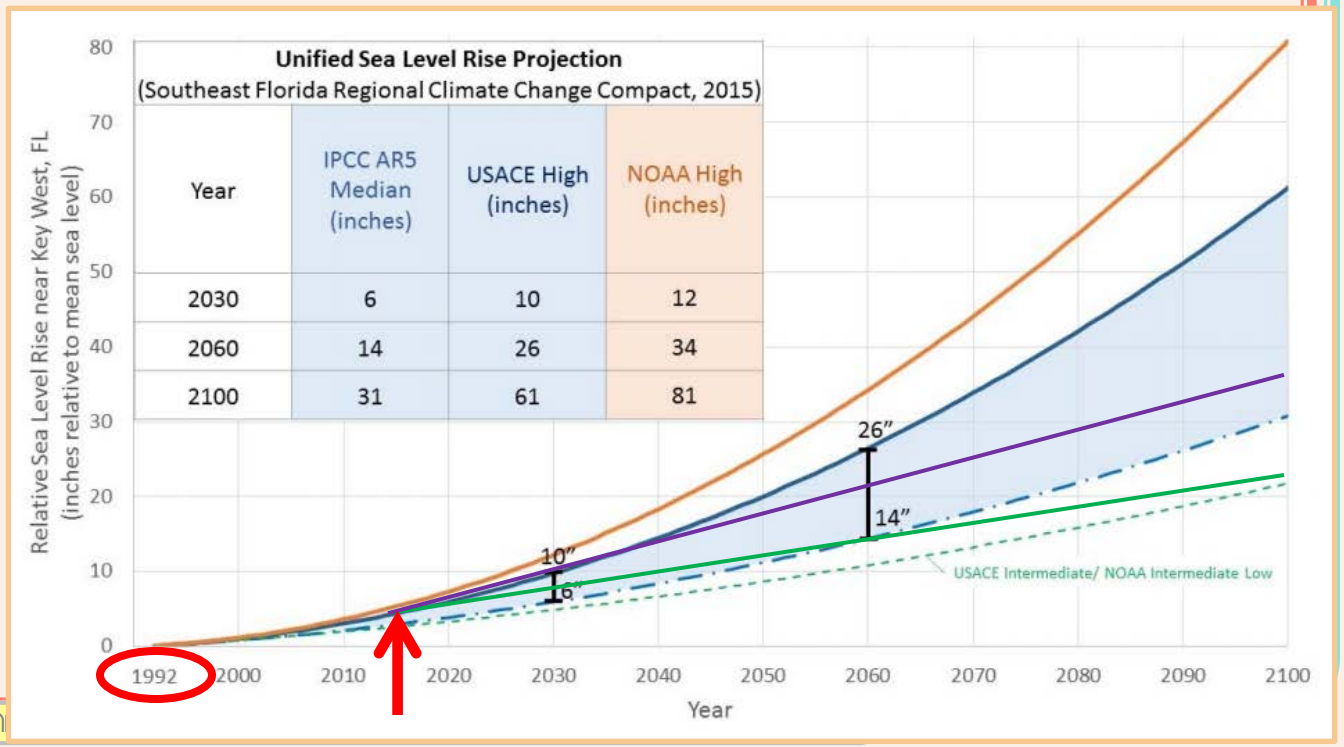
Other Historical Local Estimates

- Archaeologist Bob Carr & Team (2015)
  - At least 12” of SLR in past ~150 years
  - Digging downtown near Miami River
    - “But when Carr started to piece together where the 1860s-era bricks were found — about a foot below the water table — and what he knew about construction, he came to a surprising conclusion: the artifacts provided proof that sea level in the area had risen more than a foot in the last century. Neither the bricks nor coconut palms would have existed on submerged land.” Miami Herald
- Maul & Martin paper in *Marine Geodesy* (2015)
  - ~7.5” in past 82 years
  - Combined the adjusted data records from Miami Beach, Haulover Pier, and Virginia Key to create 82-year time series of annual mean sea level... linear trend is 0.092 ± 0.005 “/yr

Sea Level Rise Projections from 2015 Levels

	2030	2050	2070	2100
Linear 0.21"/yr	3.2"	7.4"	11.6"	17.9"
Linear 0.36"/yr	5.4"	12.6"	19.8"	30.6"
IPCC AR5 Median	1"	6"	13"	26"
USACE High	5"	15"	29"	56"
NOAA High	7"	20"	39"	76"

** Using a 0.21"/yr trend, sea level has risen ~5" since 1992 in this region, which is the baseline year for values in this chart (from the 2015 SFRCC Report)*



Uncertainty increases with time

- Natural variability is not known perfectly
- Effects of existing greenhouse gases on global climate and sea level are not known perfectly
- Future global greenhouse gas emission scenarios to be determined
- Catastrophic ice loss is unpredictable
- Climate models have inherent errors that grow with time
- *Projections are based on expert interpretation of many of the most trusted models and most probable climate change scenarios*

What *is* Certain?

- *Sea levels are rising at increasing rates*, and all of south Florida is extremely vulnerable to the effects
- Tidal ("nuisance", "clear-sky") flooding will become more frequent and affect more areas
- A higher baseline sea level will exaggerate impacts from storm surge and heavy rain events
- Adaptation (or even relocation) is a long-term, complex, and costly process that cannot wait until infrastructure is underwater!
- ***Sea level rise is a slow-motion crisis*... hard to get people motivated or even convinced**

Questions?

- My RSMAS blog post on sea level rise:
  - http://www.rsmas.miami.edu/blog/2014/10/03/sea-level-rise-in-miami/
- My WaPo blog post on nuisance flooding:
  - https://www.washingtonpost.com/news/capital-weather-gang/wp/2015/10/20/during-autumn-king-tides-nuisance-flooding-becomes-chronic-flooding-in-miami-area/
- Tide gauge data from Virginia Key:
  - http://tidesandcurrents.noaa.gov/waterlevels.html?id=8723214
- 2015 SFRCC Unified Sea Level Projection report:
  - http://www.southeastfloridaclimatecompact.org/wp-content/uploads/2015/10/2015-Compact-Unified-Sea-Level-Rise-Projection.pdf