Coastal Subsidence along Eastern seaboard and Gulf of Mexico

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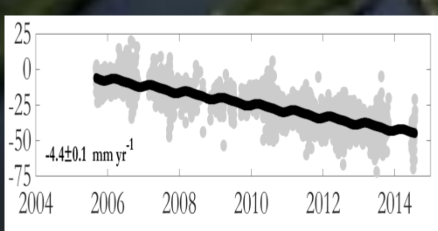
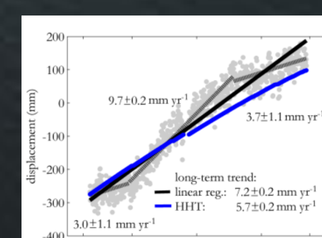


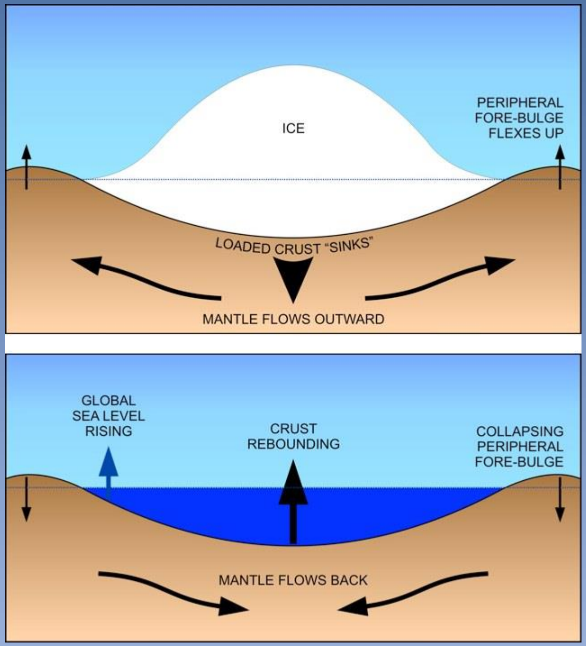


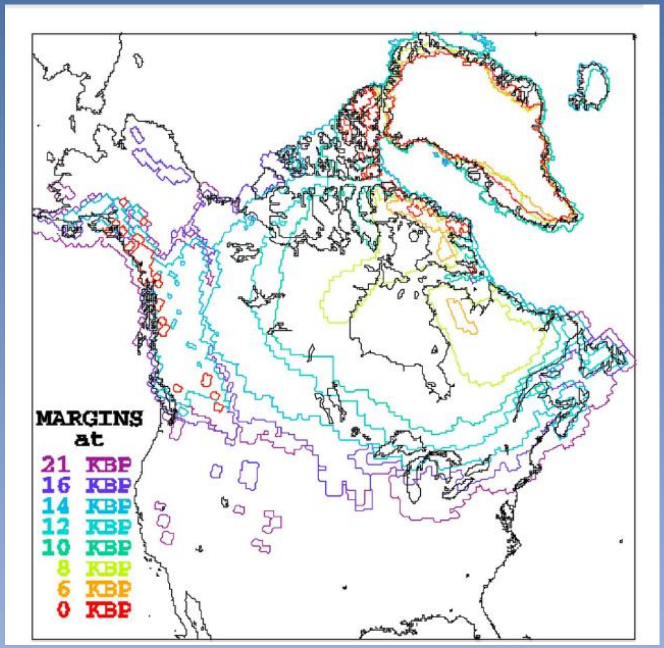
Coastal Flood Exposure

- Future risk reflects both sea level rise and coastal subsidence
- Natural and human-made causes
- This talk focuses on coastal subsidence
- Compare two independent data bases: Geological RSL (last 4 Ka) and GPS (last decade)

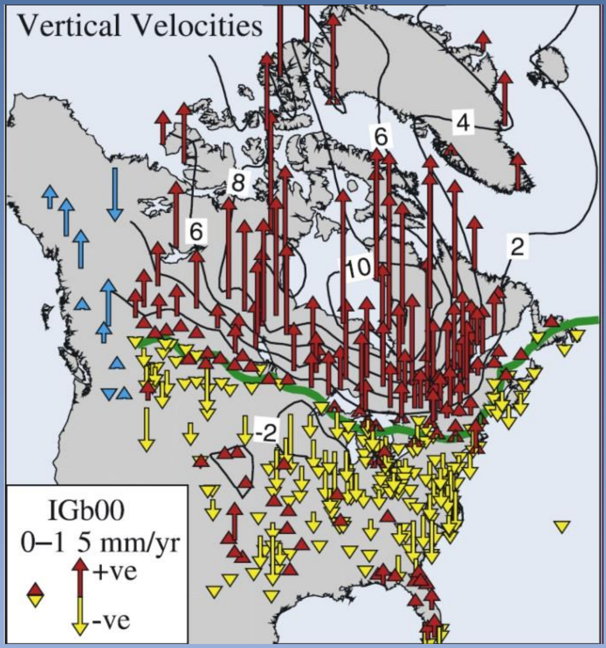
East Coast Subsidence Background

Glacial Isostatic Adjustment (GIA)





Deglaciation isochrons for the Laurentide, Cordilleran, and Innuit ice sheet complexes (Peltier et al., 2015)



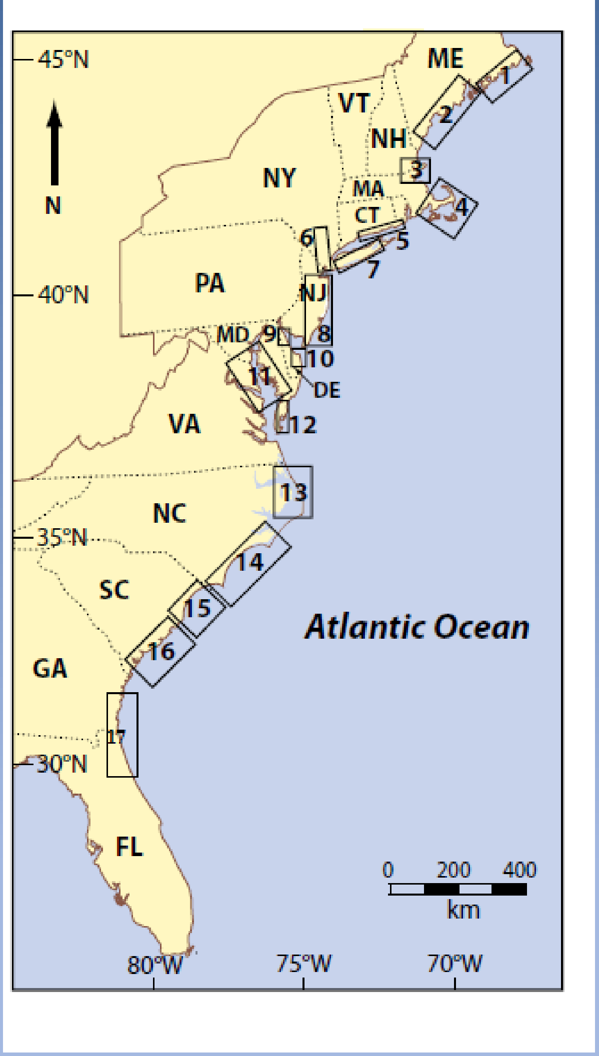
Current deformation measured with GPS (Sella et al., (2007).

Subsidence measurements

- Late Holocene Rate of Relative Sea Level [Engelhart and Horton, 2012; Kemp el al., 2014]:

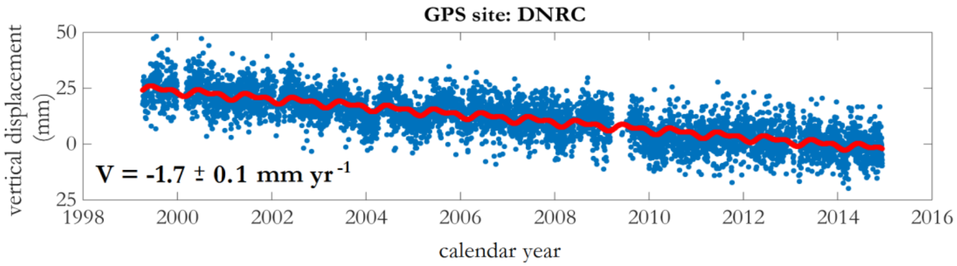
- Tectonic activity along passive margin of Eastern seaboard assumed to be negligible.
- Effect of sediment compaction minimized by using basal peat samples.
- RSL trends reflect spatially-variable land motion primarily dominated by GIA.

- Rates of RSL change for 17 regions for the last 4 ka after removing RSL change since A.D. 1900 based on measurements from nearest reliable tide gauge.

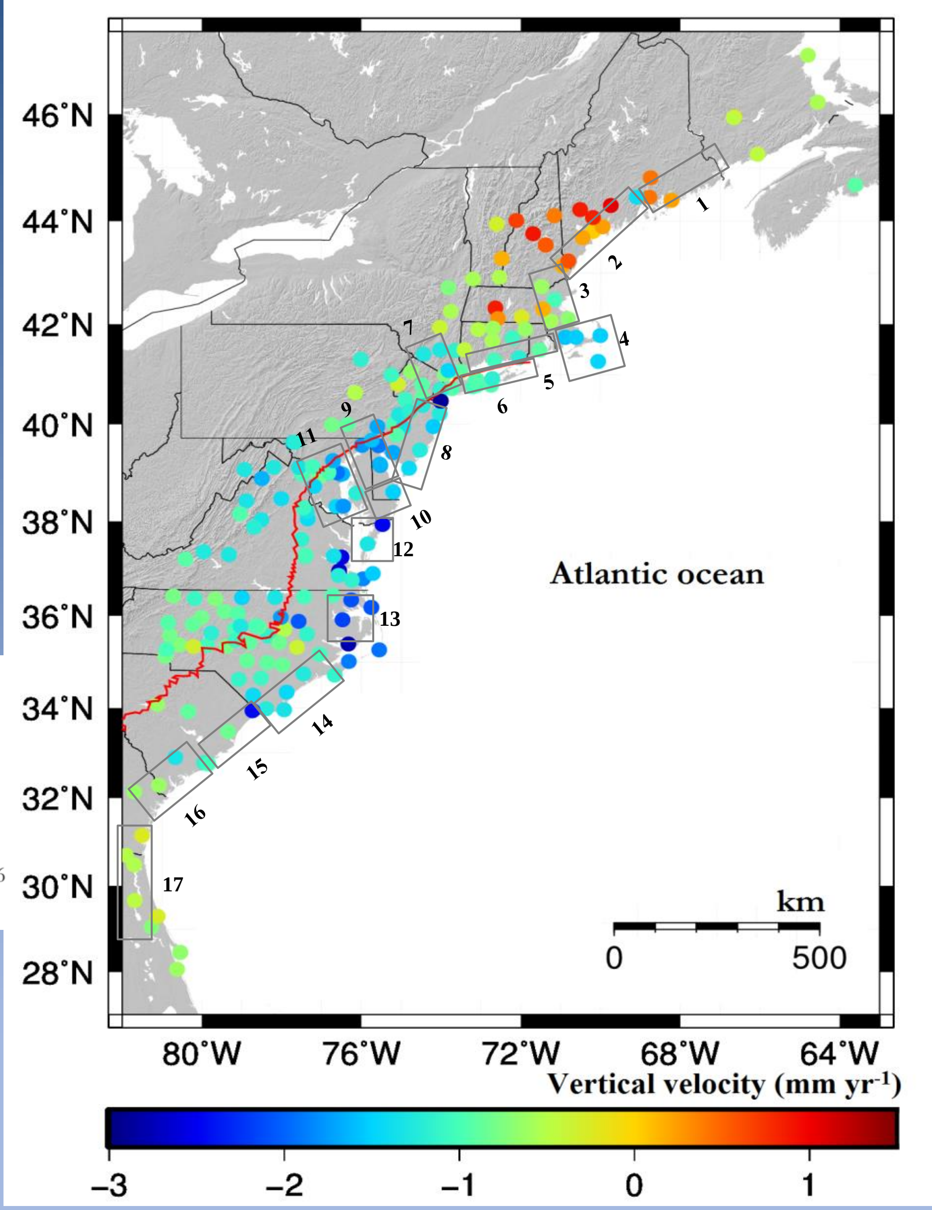


Land vertical motion from GPS

- GPS stations with nearly continuous observations 4 - 18 years.
- More than 70 stations record data > 10 years.
- Raw data processed with GIPSY/OASIS II (V. 6.2
- Uncertainty estimates incorporate time-correlated noise.

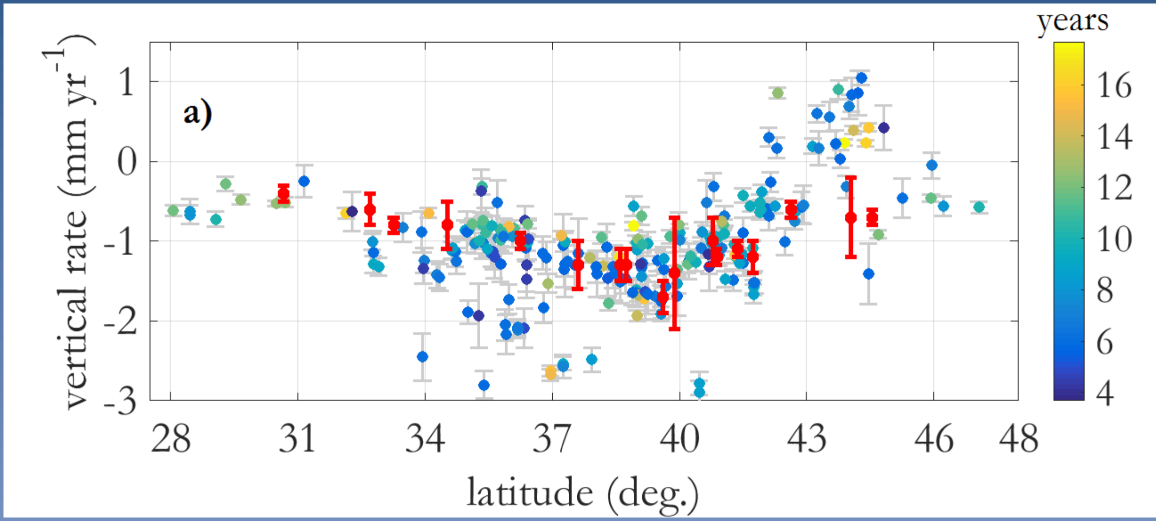


GPS vertical time series, Dover, Delaware.



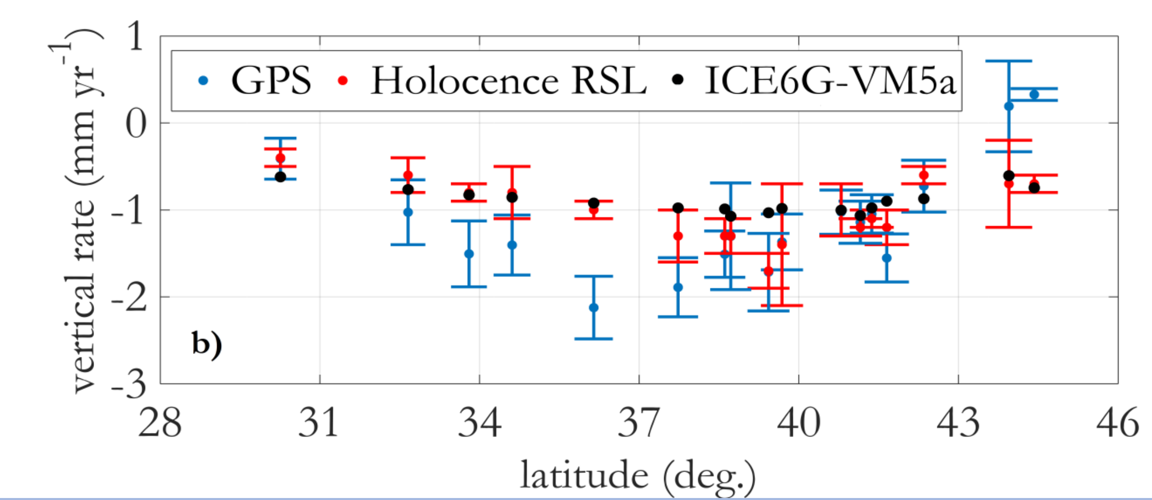
➢ GPS vs. Geologic rates

- ➢ **Pattern of subsidence dominated by ongoing GIA (collapse of proglacial forebulge).**



- ➢ **good agreement between GPS and geologic rates.**

GPS rate is averaged for all stations in the 17 regions.



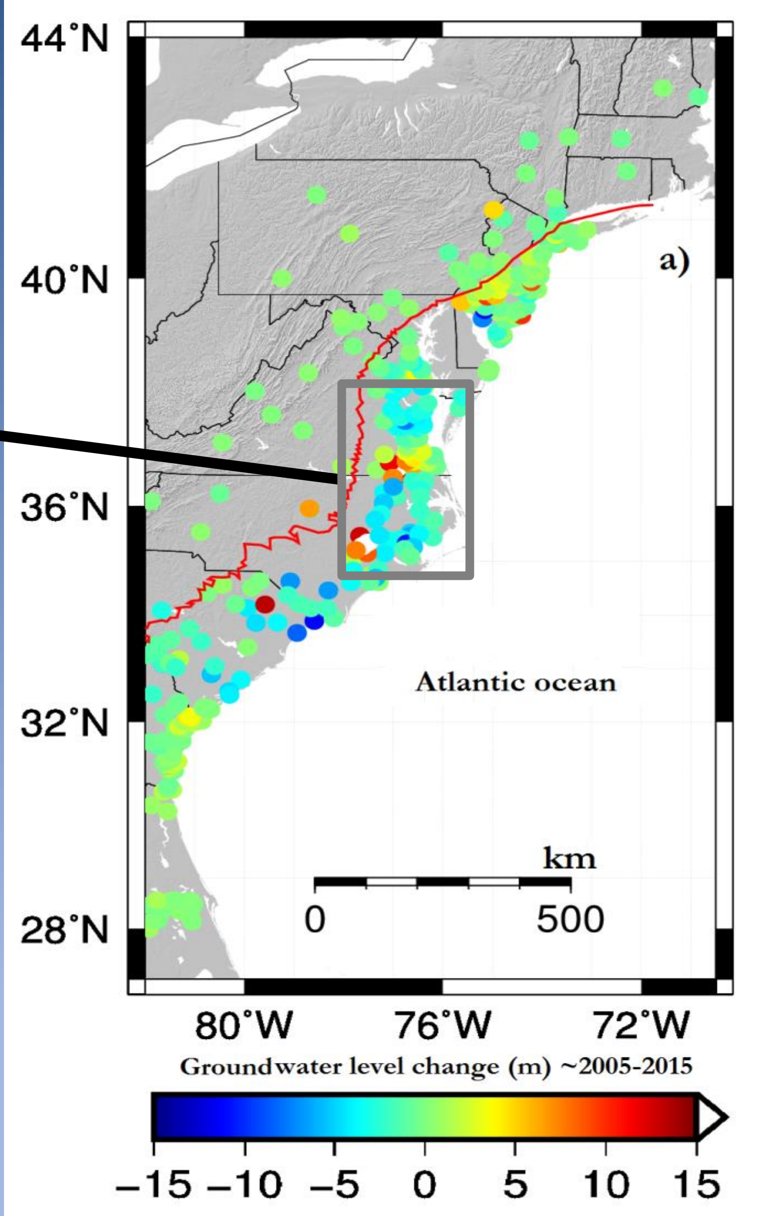
- ➢ **Exceptions are:**

- **GPS subsidence, 38º N - 32.5º N (Virginia to South Carolina) are double the geologic rate.**

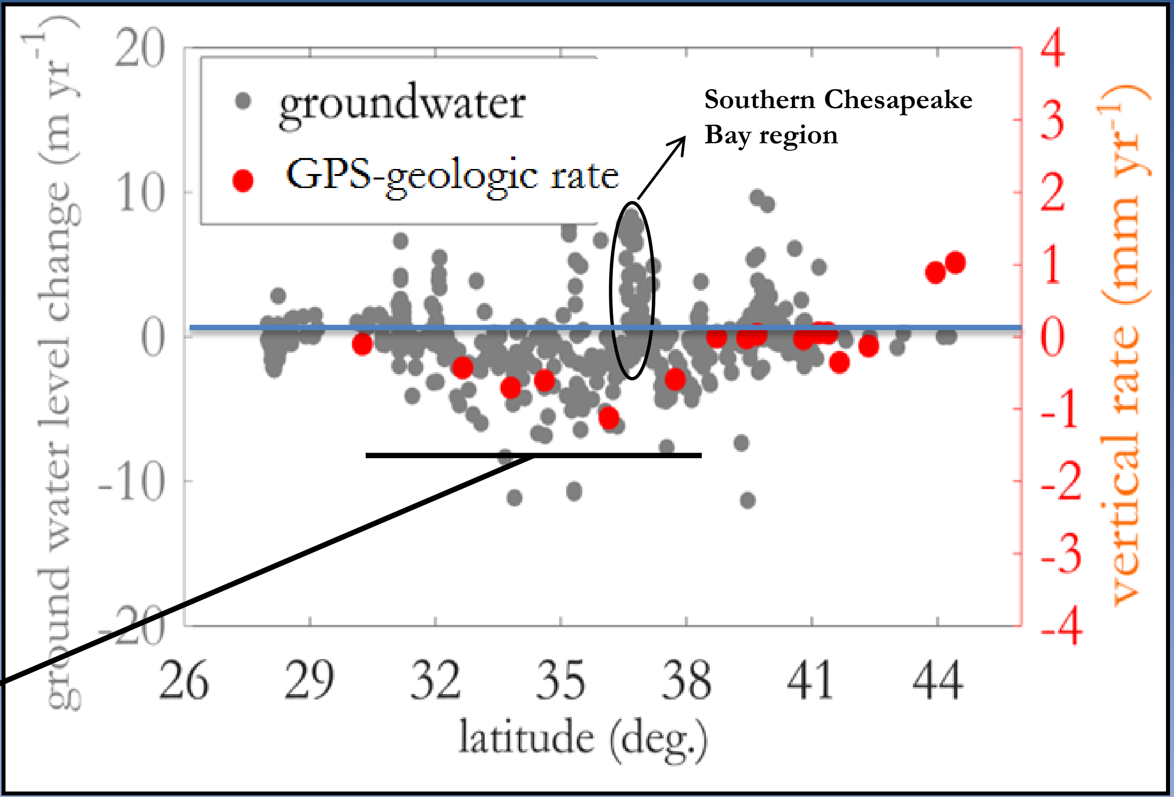
➢ Effects of groundwater withdrawal

➢ Average trend in groundwater level since 2005.

We test whether areas experiencing rapid subsidence correlate with areas of intense groundwater extraction.

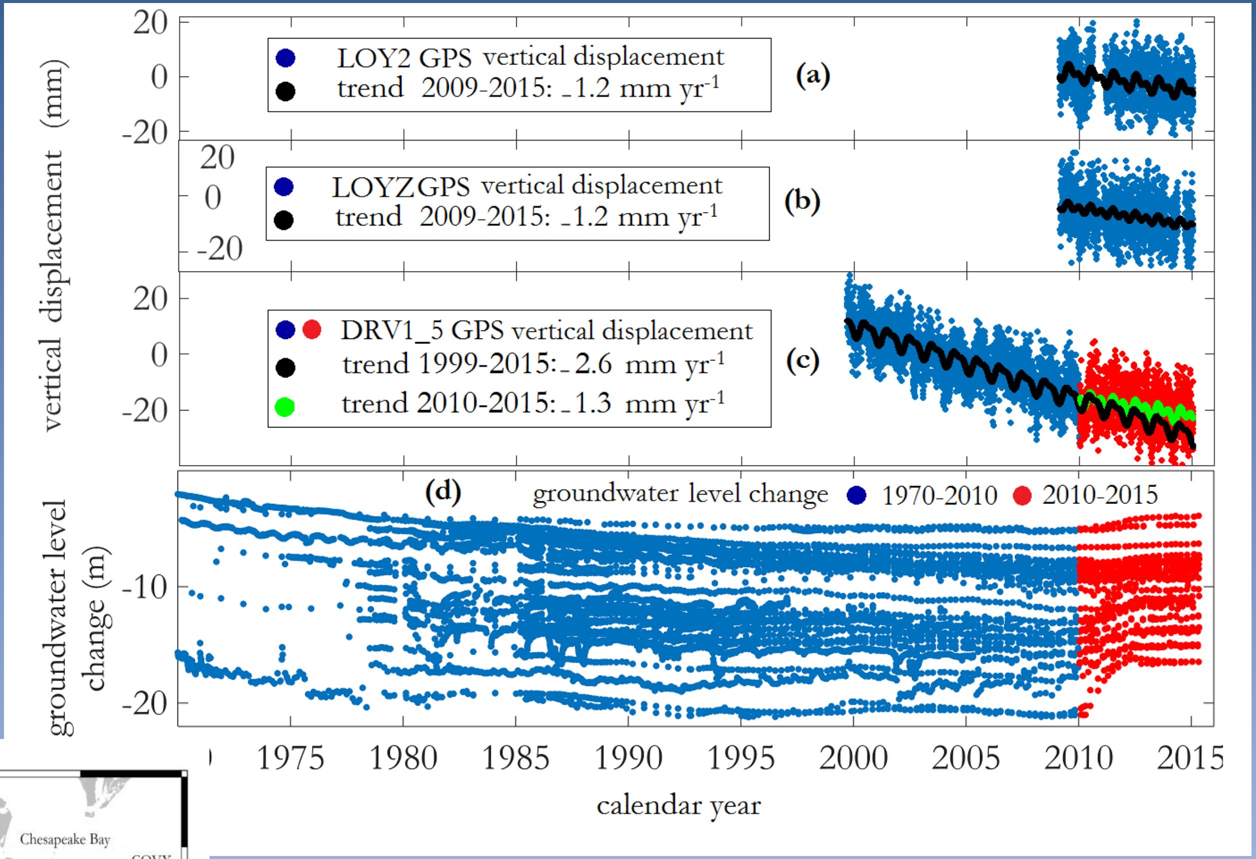


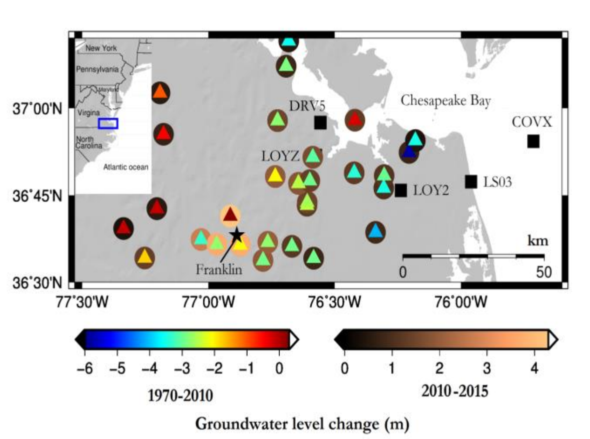
GPS rates corrected for GIA (GPS rate minus geologic rate) versus average trend in groundwater level changes.



Note correlation between rapid subsidence and groundwater depletion. GPS subsidence rates are double the geologic rates, suggesting that excessive groundwater extraction drives rapid land subsidence.

GPS vs. groundwater South of Chesapeake Bay





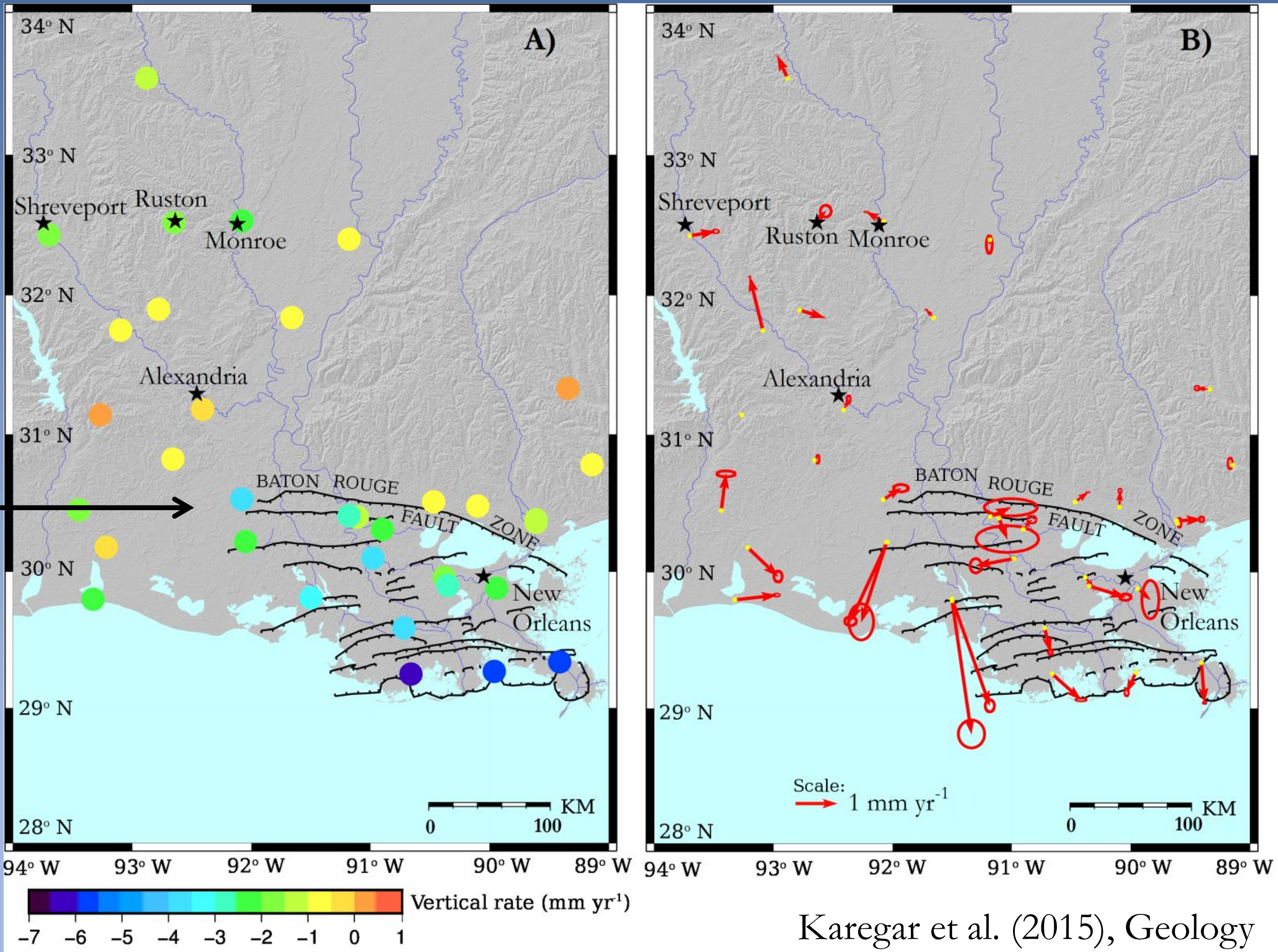
Summary

- Installation of more than 130 new cGPS stations in eastern coastal NA since 2006 represents a significant improvement in our ability to precisely define present-day vertical motions in this region, improving our ability to understand and predict RSL variations and long-term flood hazard.
- Comparison of present-day land vertical motions estimated from GPS with rates of late Holocene RSL rise indicates substantial agreement in most areas.
- Subsidence of Eastern seaboard of NA continues with constant rate with GIA as the main deriver.
- Exceptions are related to areas of recent excessive groundwater extraction in Virginia (38° N) and South Carolina (32.5° N). Tide gauge records, therefore, should be used with caution for studying sea level rise in this region.

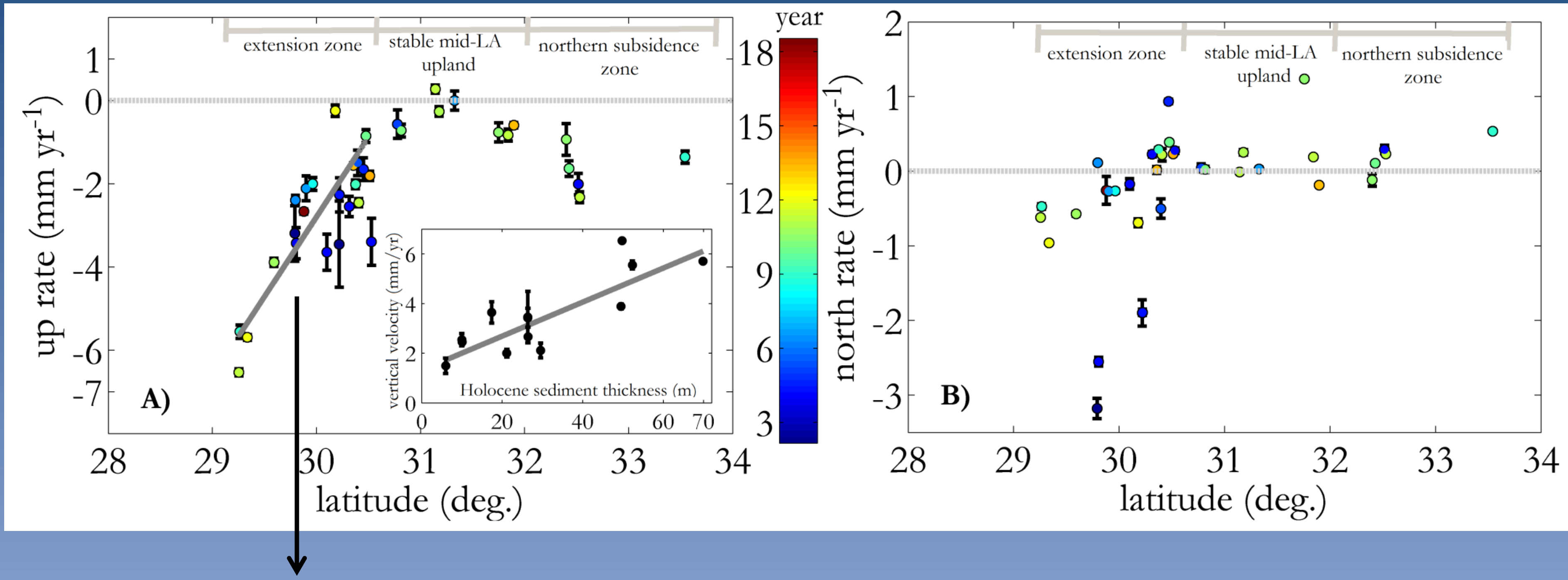
Three-dimensional surface velocity field for the Mississippi Delta

GPS observations:

Geomorphic boundary



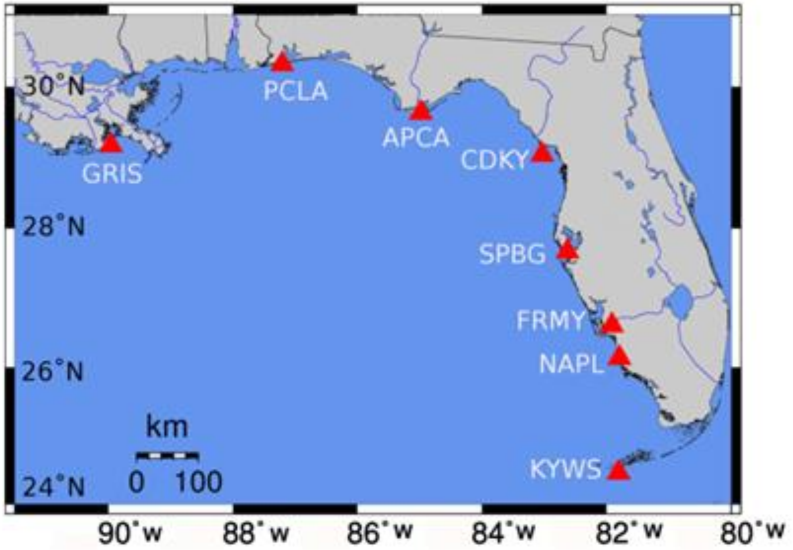
Karegar et al. (2015), Geology



Regional pattern in subsidence:

- Sediment loading
- Sediment compaction

Tide gauge data:



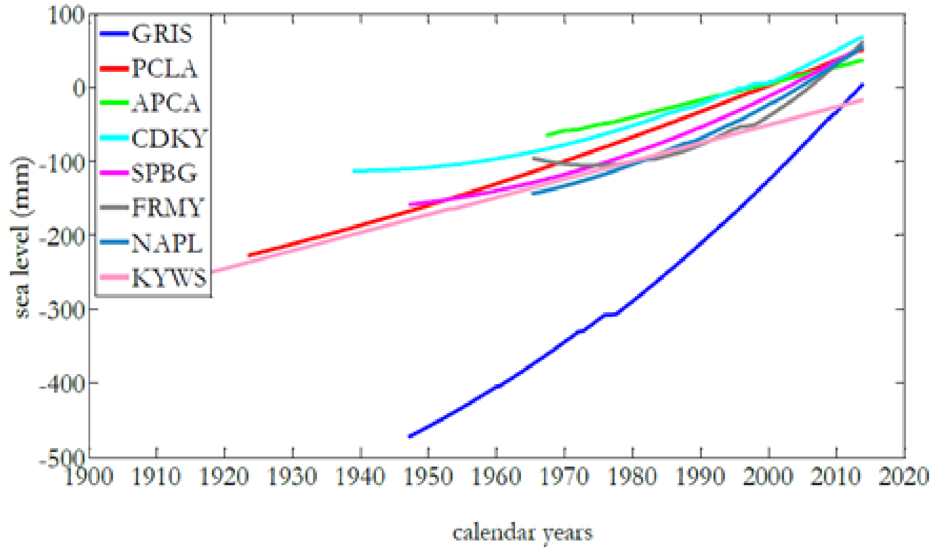


Table DR2.1. Average relative sea level rise rates and accelerations from HHT.

tide gauge stations	length (year)	[a]mean RSL rate (mm yr^{-1})	[b]mean RSL rate after 1990 (mm yr^{-1})	[c]mean RSL acceleration (mm yr^{-2})	[d]vertical displacement (mm yr^{-1})
Grand Isle (GRIS)	66.9	7.3± 0.4	9.1± 1.2	0.007	-5.6±0.2 (GPS)
Pensacola (PCLA)	90.5	3.1±0.6	3.6± 3.1	0.001	-1.0±0.2 (GPS)
Apalachicola (APCA)	46.5	2.2±1.1	2.3±1.2	0.000	-1.1 (GIA)
Cedar Key (CDKY)	75.1	2.5± 0.3	4.0±3.4	0.005	-0.9 (GIA)
St. Petersburg (SPBG)	66.9	3.2±0.6	4.6±2.2	0.005	-0.9 (GIA)
Fort Myers (FRMY)	48.6	3.4±0.7	6.0±3.2	0.021	-1.1±0.1 (GPS)
Naples (NAPL)	48.7	4.1±0.6	5.2±1.1	0.008	-1.9±0.1 (GPS)
Key West (KYWS)	100.9	2.4±0.7	2.4±1.2	0.000	-1.1±0.1 (GPS)

Note. a. Average relative sea level rise rates over entire period. *b.* Average relative sea level rise rates after 1990. *c.* Average relative sea level rise acceleration over entire period. *d.* Land vertical motion from continuous GPS measurements at nearby station or GIA model. Note that the relative sea level rates and accelerations are obtained from the trend (*r*) of HHT analysis (Figure B5).

Time-variable subsidence in Grand Isle, Southern Louisiana

Fluid withdrawal:
(water; oil and gas production)

Plot of tide gauge data at Grand Isle, Louisiana referenced to Pensacola, Florida (gray dots) and comparison between average long-term subsidence rate (black line) and change of rate (dash line) obtained from linear regression (reg.) analysis, compared to Hilbert-Huang transform (HHT) analysis (blue line).

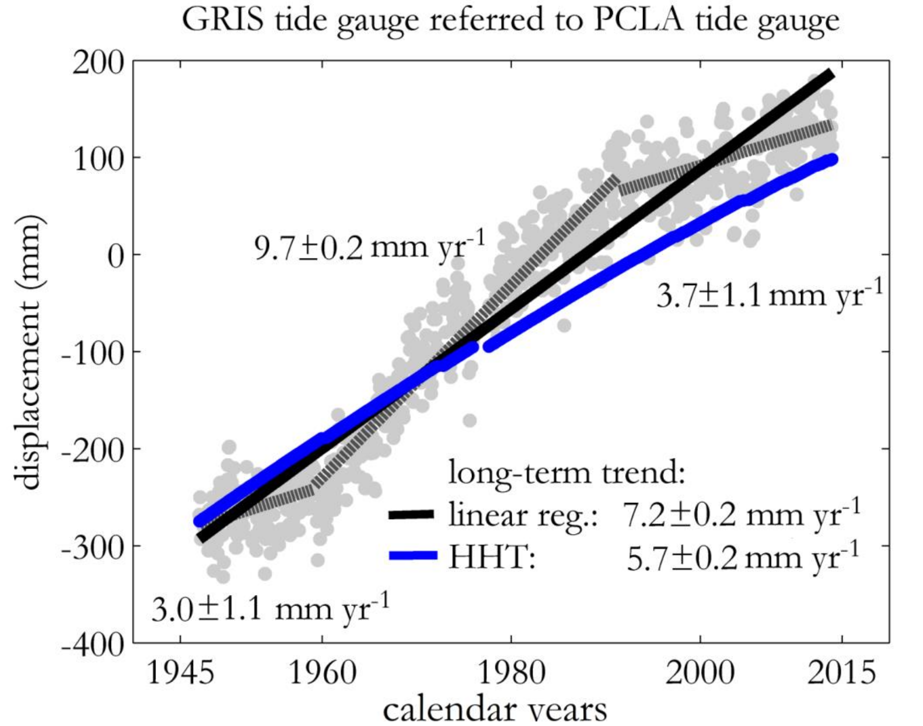


TABLE 1. COMPARISON OF SUBSIDENCE RATE AT GRAND ISLE RELATIVE TO THREE DIFFERENT REFERENCE STATIONS FROM LINEAR REGRESSION AND HILBERT-HUANG TRANSFORM

Tide gauge	Rate from linear regression (mm yr^{-1})				Rate from HHT (mm yr^{-1})	Rate from GIA (mm yr^{-1})
	A.D. 1947–1959	1959–1994	1994–2014	1947–2014	1947–2014	
Grand Isle-Pensacola	3.0 ± 1.1	9.7 ± 0.2	3.7 ± 1.1	7.2 ± 0.2	5.7 ± 0.2	1.1
Grand Isle-St. Petersburg	1.2 ± 2.9	8.5 ± 0.9	3.5 ± 1.4	6.7 ± 0.3	5.7 ± 0.3	0.9
Grand Isle-Key West	1.7 ± 6.7	8.6 ± 0.4	3.9 ± 1.0	6.9 ± 0.2	5.8 ± 0.2	0.7

Note: The subsidence rate (here positive) is calculated by subtracting listed monthly tide gauge record from Grand Isle tide gauge record. The average subsidence rate is computed using linear regression analysis and residual of Hilbert-Huang transform (HHT) analysis. Uncertainties are 1σ and accounts for colored noise using the Allan variance of rates method (Hackl et al., 2011). The glacial isostatic adjustment (GIA) related subsidence rate is from the model ICE-5G v1.3 (Peltier, 2004).

Summary

- The current rate of relative sea-level rise (combined effect of land subsidence and sea-level rise) along parts of the coastal delta is ~8–9 mm/yr.
- Most tide gauge stations have recorded sea-level-rise acceleration after A.D. 1970.
- The agreement between the subsidence rate obtained from a decade of GPS measurements and those estimated from multidecadal tide gauge records using the HHT method indicates that continuous GPS measurements adequately measure subsidence of the delta.