Towards a New Baseline of Vertical Land Motions in the Chesapeake Bay Using GNSS and InSAR

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January 20, 2023

Abstract

Relative sea-level rise is a major coastal hazard affecting about half the population of the United States. The Chesapeake Bay is characterized by the fastest rate of sea-level rise along the Atlantic coast of North America, in part because of land subsidence. Previous studies have quantified a range of land subsidence rates in the Chesapeake Bay (˜1-4 mm/yr) from various measurement techniques that contribute to high rates of relative sea-level rise. In this study, we present progress towards developing a new vertical land motion map for the Chesapeake Bay region to provide more robust constraints on estimates of relative sea-level rise. We are using a combination of GNSS observations and InSAR interferograms. Available continuous GNSS data in the region that span November 2014 - September 2020 are processed with GAMIT-GLOBK to align temporally with available Sentinel-1 InSAR satellite data. We are using an approach that combines the two geodetic observations to provide a new solution of vertical land motions for the Chesapeake Bay. Additionally, this project is collecting new campaign GNSS observations across the Chesapeake Bay each fall for 5 years, beginning in 2019. We will also present about the 2020 and planned 2021 campaign GNSS observations, which will ultimately be incorporated into our new map of vertical land motions for the region. The impacts of this work will be improved flooding and inundation hazard maps, as well as updated projections for municipal flood mitigation planning that will be created using the new dataset.

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Land and Labor Acknowledgement

Virginia Tech

Department of Geosciences

American Geophysical Union Meeting 2021

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Jonathan Weiss, NOAA Pacific Tsunami Warning Center

Overview

- Introduction
- Objective
- Data & Methods
- Results
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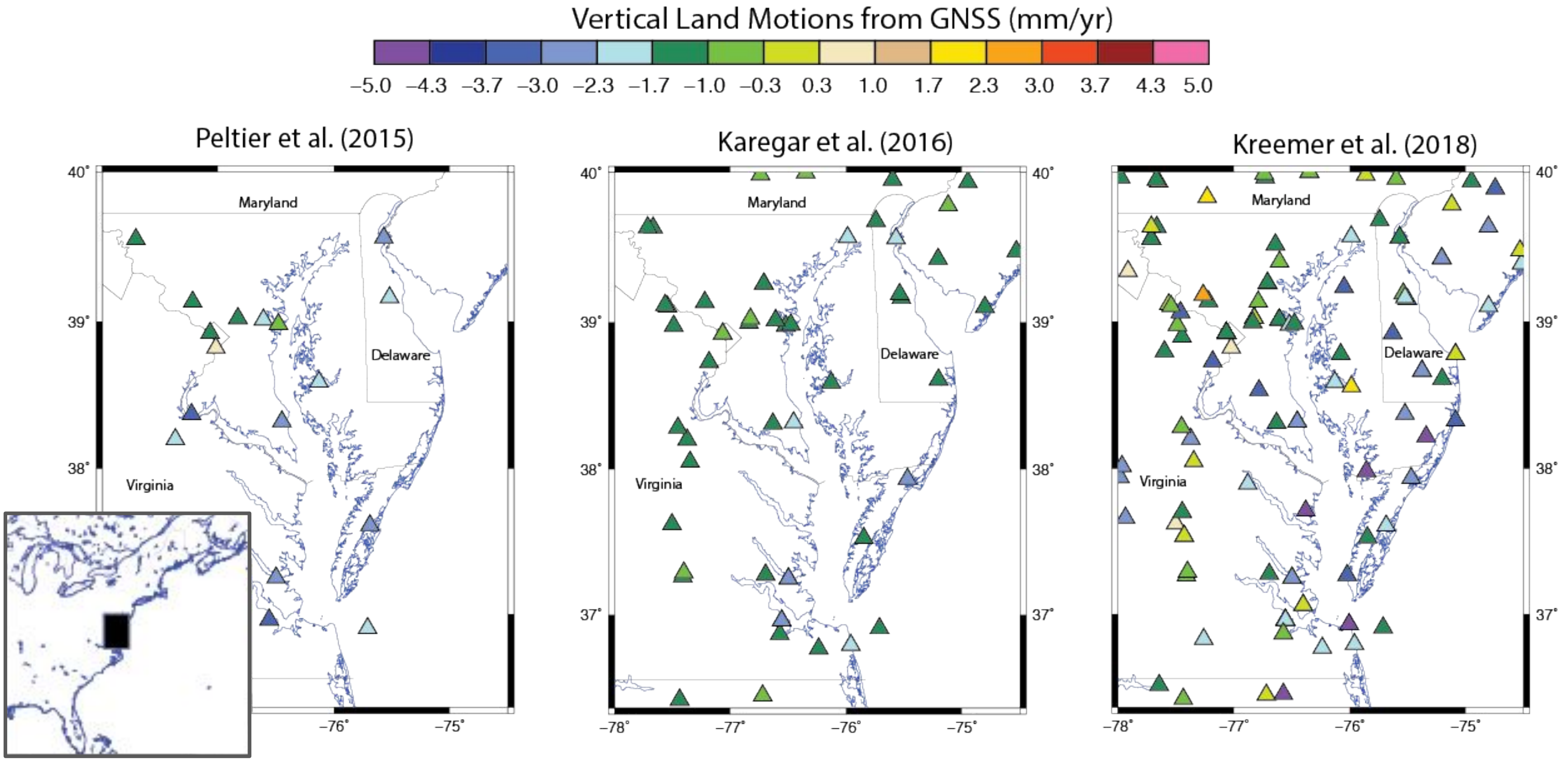
Several techniques suggest subsidence in the Chesapeake Bay

GNSS observations



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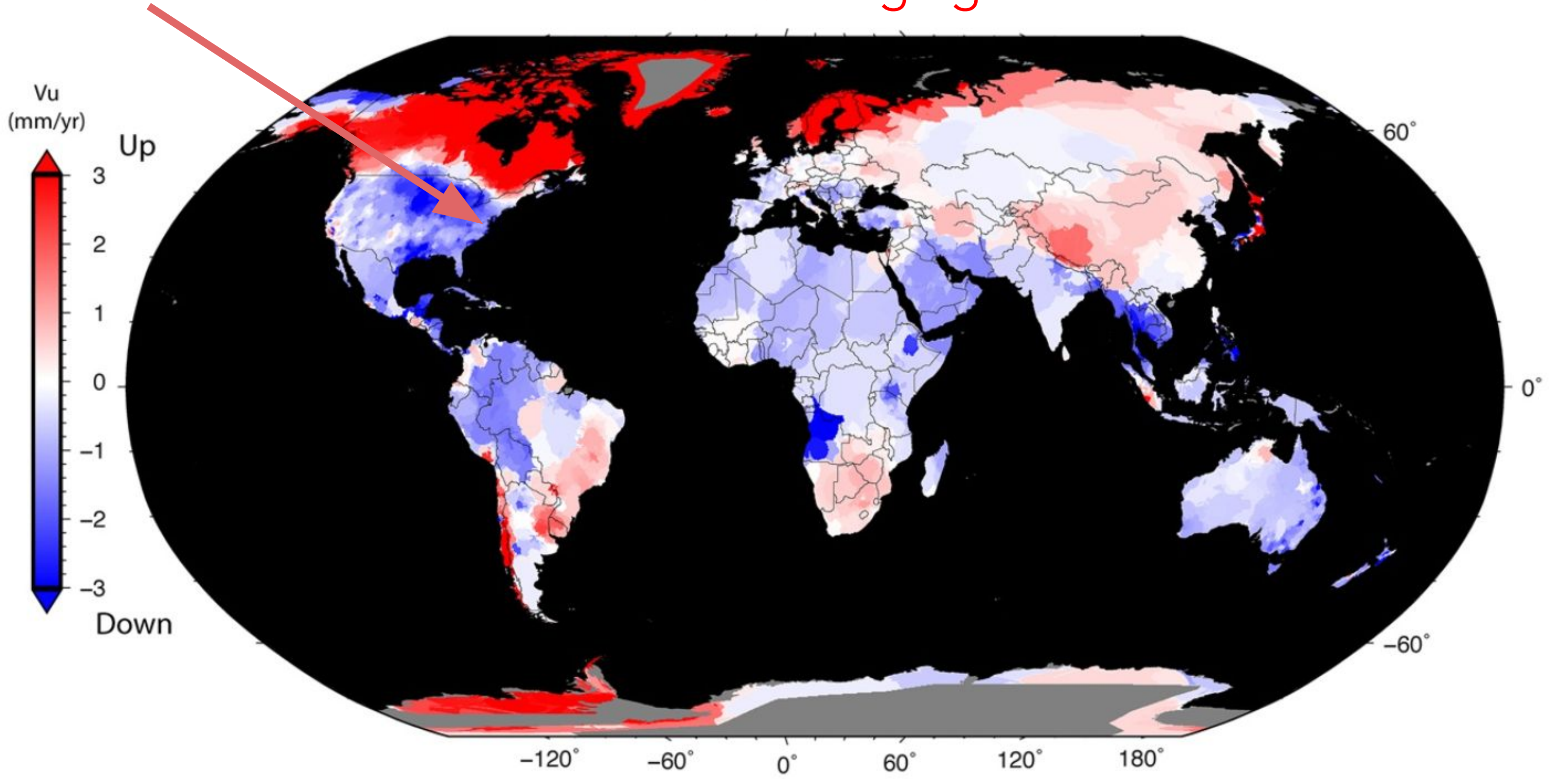
GPS Imaging



Hammond et al. (2021), JGR

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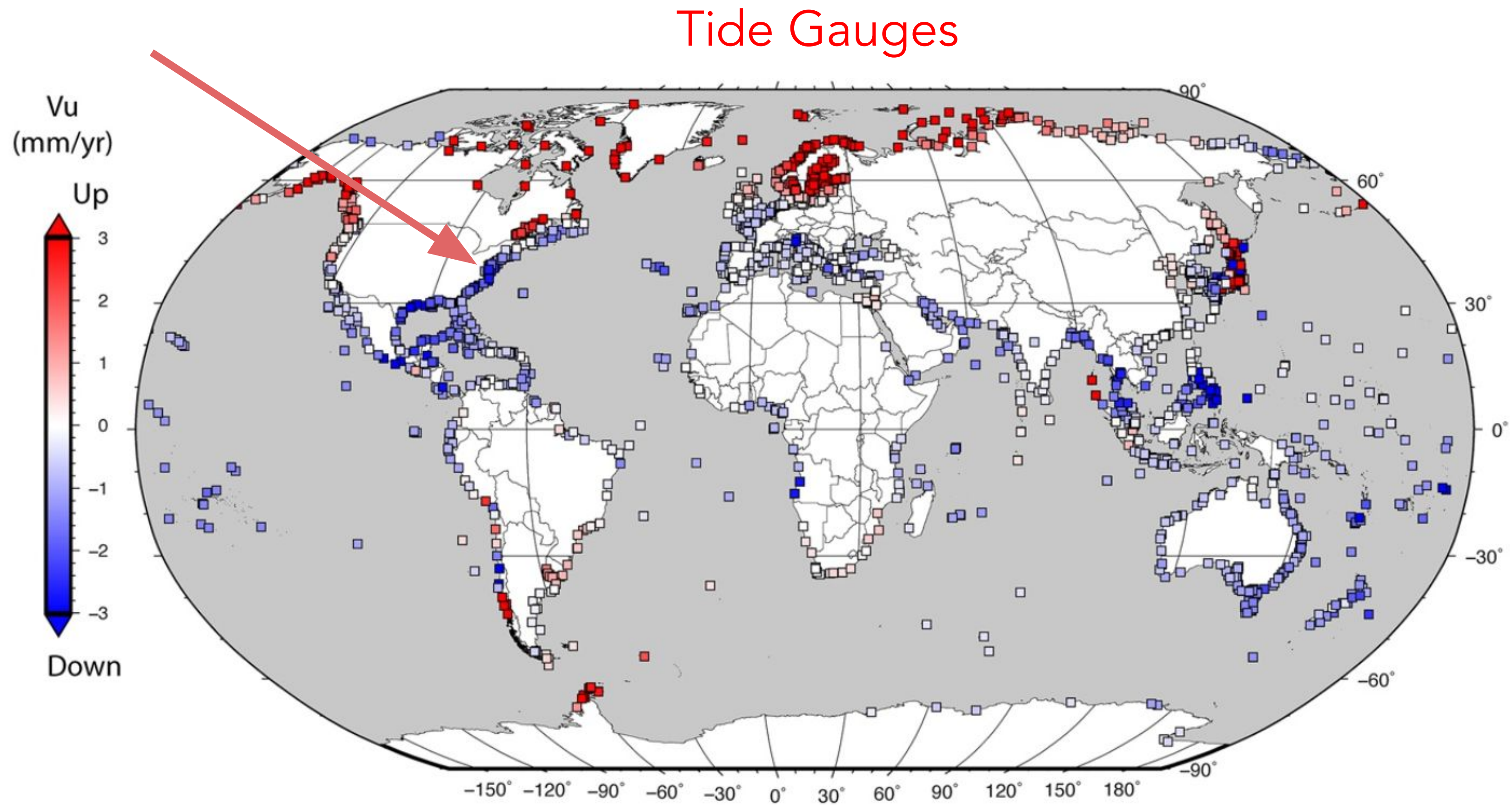

Hammond et al. (2021), JGR based on Holgate et al. (2013)

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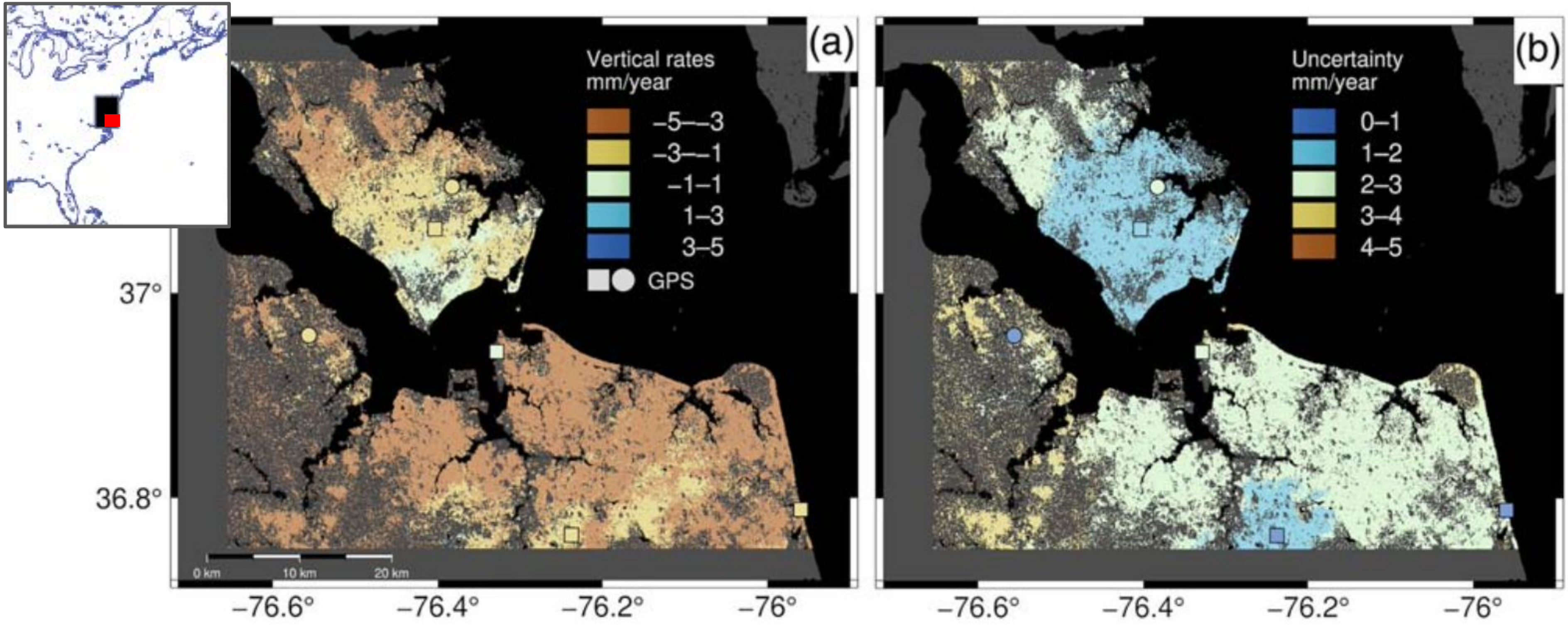
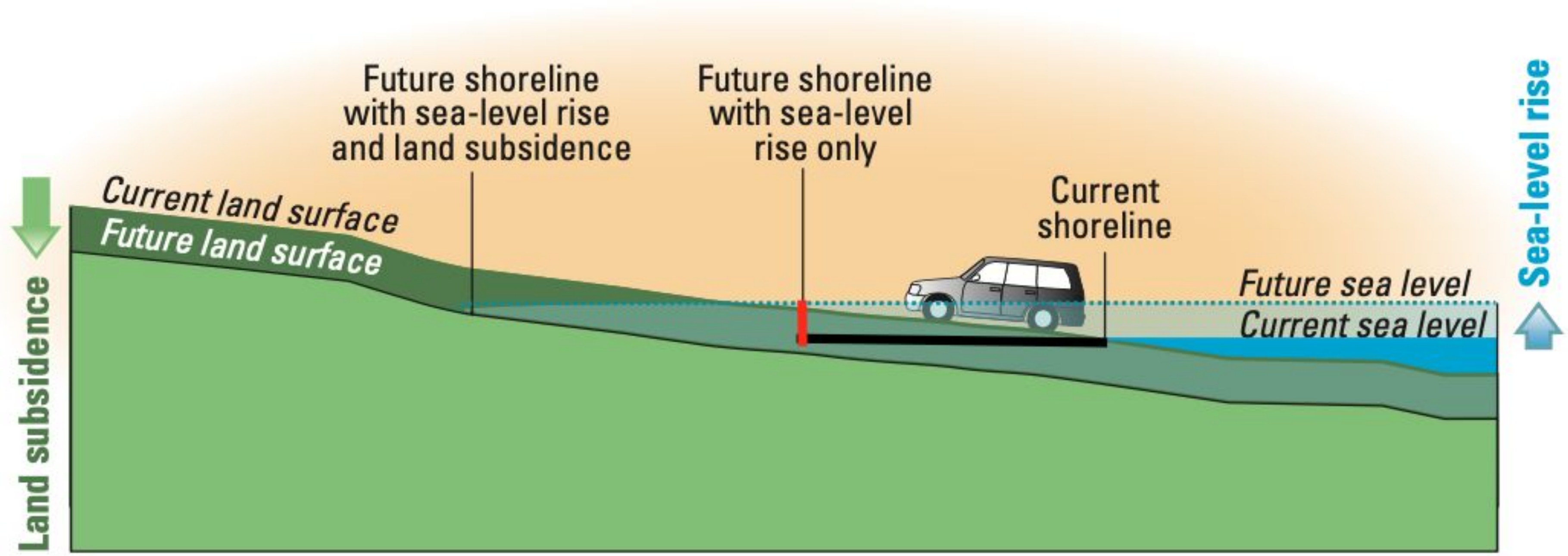
InSAR



Buzzanga et al. (2020), GRL

Land subsidence influences rates of relative sea-level rise



Eggleston and Pope (2013) USGS Report Circular 1392

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Our objective is to develop a new estimate of vertical land motions across the Chesapeake Bay using a combination of InSAR and GNSS data.

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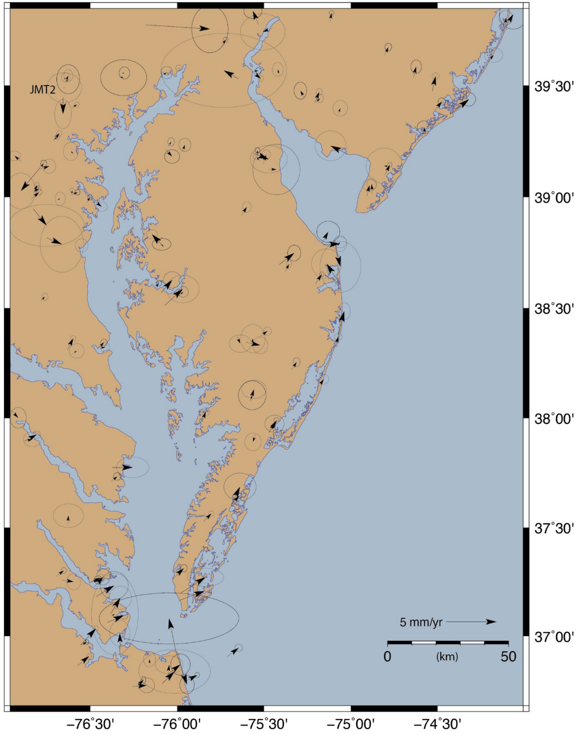
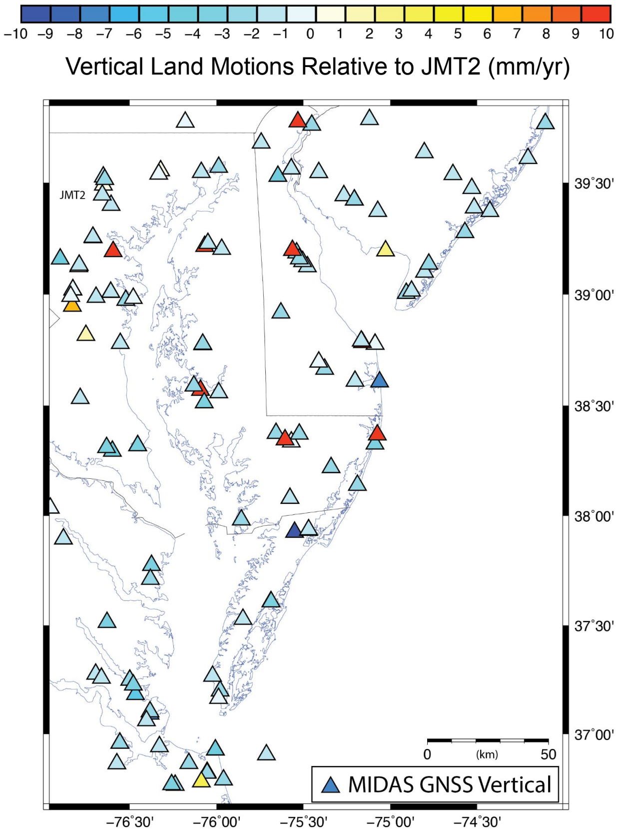
Horizontal and Vertical GNSS Velocities

- MIDAS solution obtained from the National Geodetic Laboratory in Nov. 2021
- Blewitt et al. (2016), JGR
- Local reference frame: site JMT2
- Outliers with horizontal rates greater than 10 mm/yr removed
- Timespan: 1995 - 2021

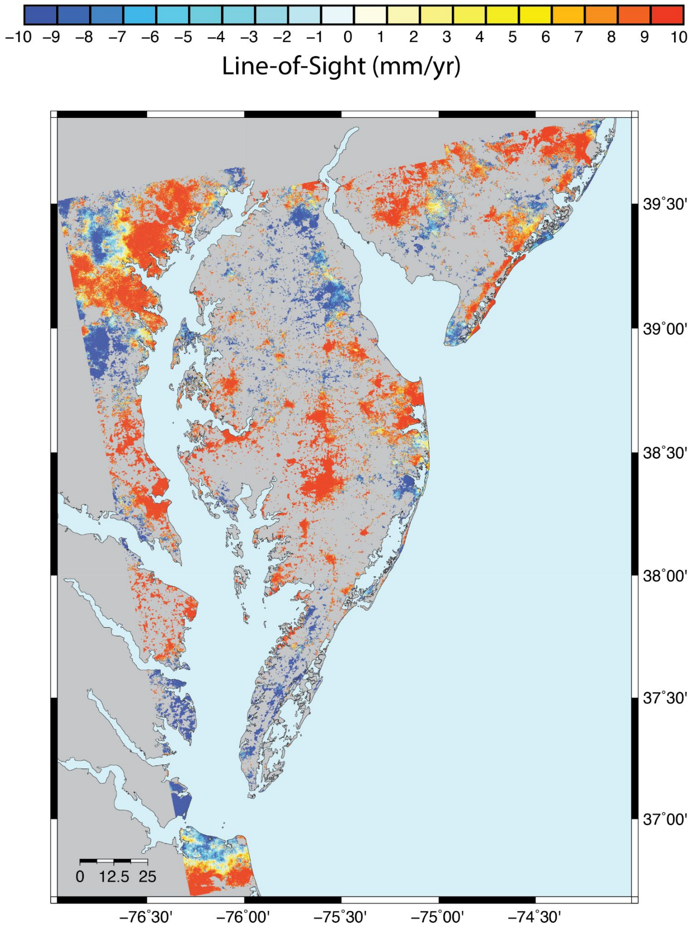
Horizontal Velocities Relative to JMT2 (mm/yr)





InSAR Line-of-Sight (LOS) Observations

- Sentinel-1 C Band
- 217 images of ascending data (paths 04 and 106)
- Processed with the wavelet-based InSAR approach of Shirzaei et al. (2017)
- Timespan: 2 July 2016 - 9 October 2020
- Local reference frame: LOS value at JMT2



3D Velocity Inversion Based on Blackwell et al. (2020)

Step 1: Project GNSS Ve and Vn onto InSAR LOS

$LOS_{GNSS} = C_n V_n + C_e V_e$

$C_n = \sin(\theta)*\cos(\alpha\text{-}270)$
$C_e = \sin(\theta)*\sin(\alpha\text{-}270)$
$C_u = \cos(\theta)$

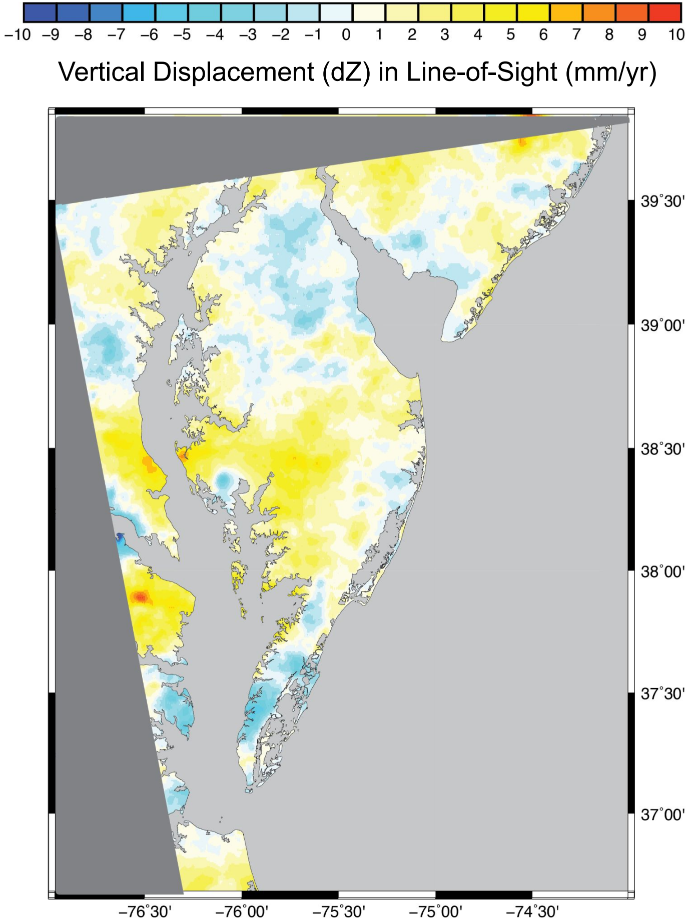
θ = SAR incidence angle (33°)
α = SAR heading angle clockwise from N (347°)

Step 2: Interpolate LOS_{GNSS} to InSAR resolution (70 m)

Harmonic spline (local max/min occur at data points)

Step 3: Calculate vertical displacement

$dZ = (LOS - LOS_{GNSS})/C_u$



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$dZ = (LOS - LOS_{GNSS})/C_u$

Step 4: Locate dZ near GNSS

$dZ_{@GNSS}$

Step 5: Calculate Vertical residual

$dZ_{residual} = U_{GNSS} - dZ_{@GNSS}$

Step 6: Apply an affine transformation to align the InSAR-based dZ and GNSS reference frames

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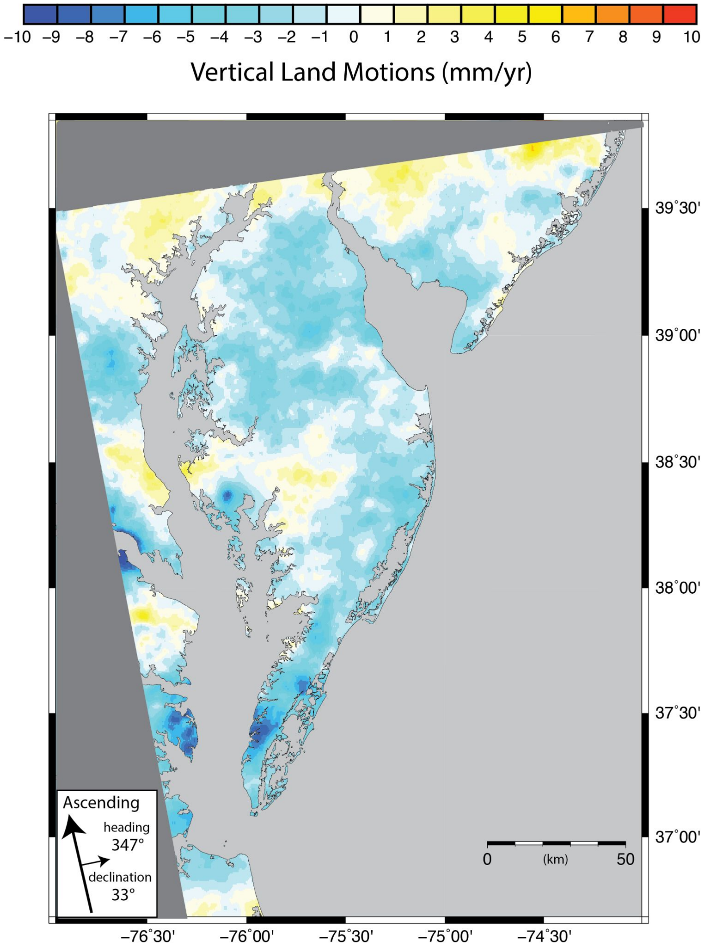
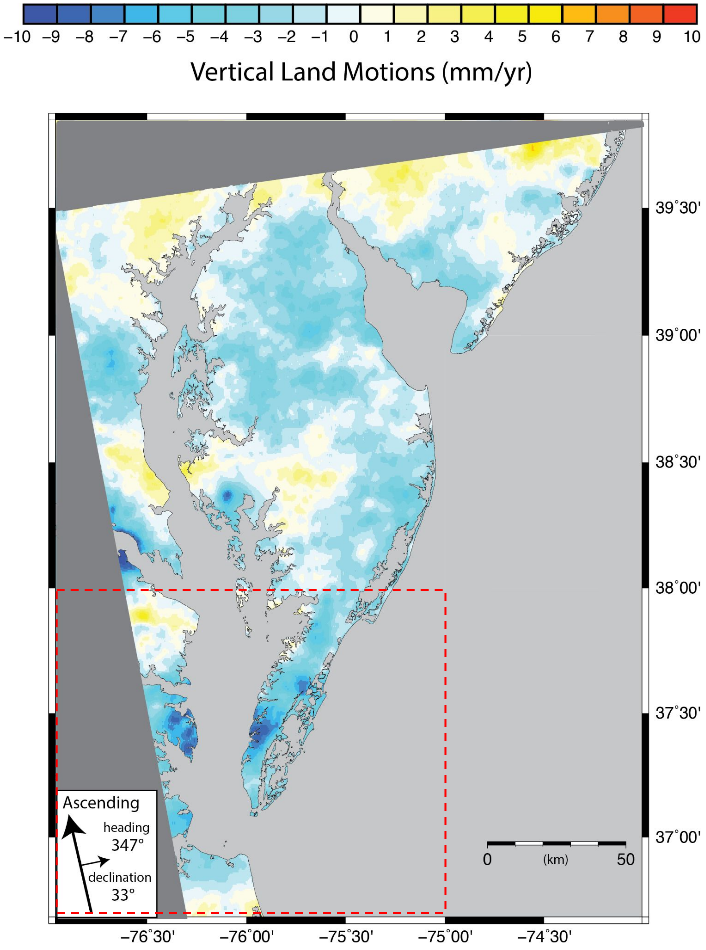
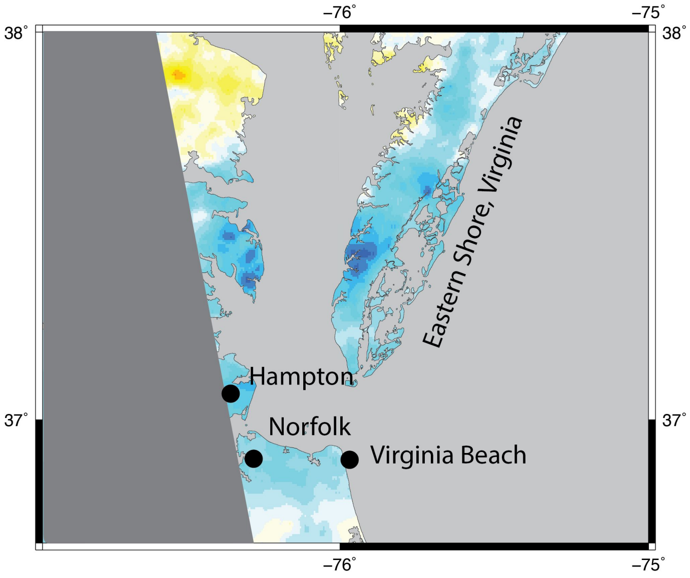
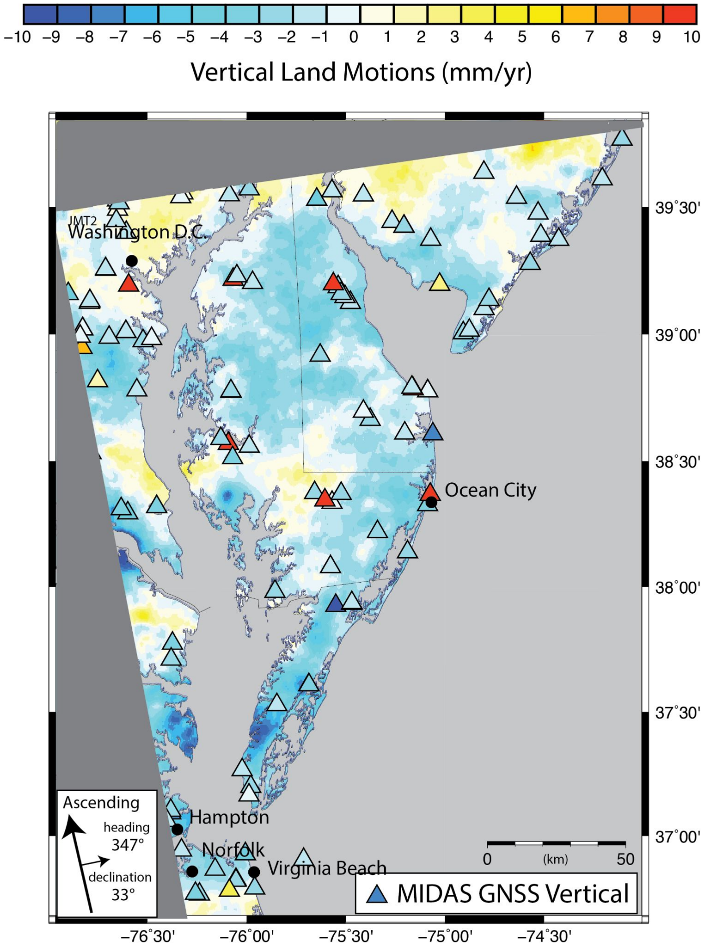


- VLM ranges from -21.75 to 12.01 mm/yr with an average subsidence rate of -1.62 mm/yr
- Uplift is present in the central Chesapeake Bay

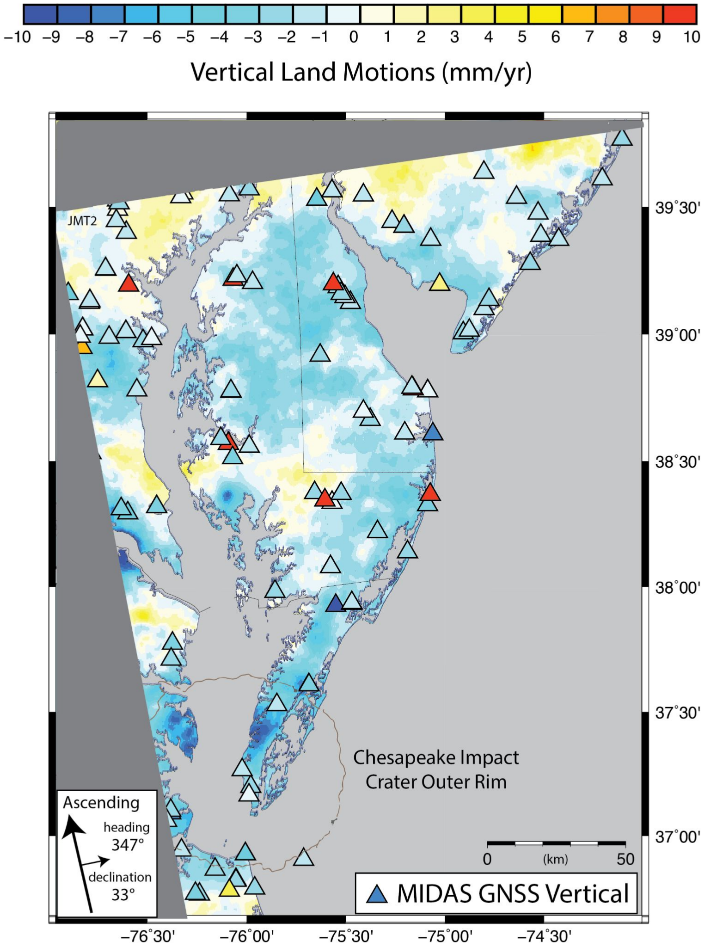


- VLM ranges from -21.75 to 12.01 mm/yr with an average subsidence rate of -1.62 mm/yr
- Uplift is present in the central Chesapeake Bay
- Faster subsidence is present in the southern Chesapeake Bay





- VLM compares well to GNSS vertical rates in some areas, particularly near Hampton, Norfolk, and Virginia Beach, Virginia.
- A few GNSS stations have significantly faster rates of uplift than the combined solution, like near Ocean City, Virginia



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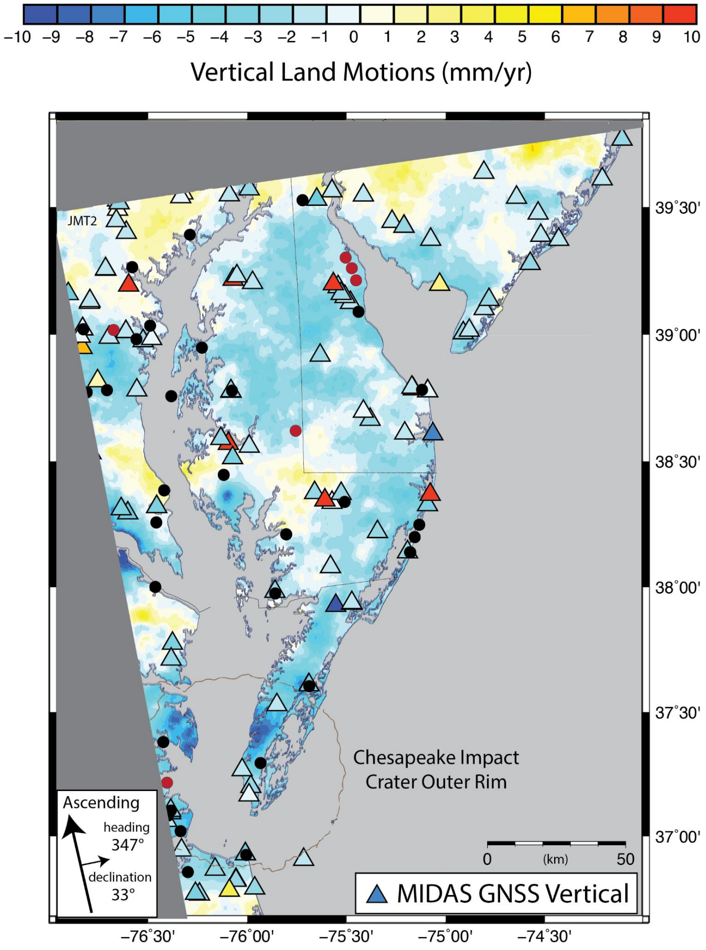
- A few GNSS stations have significantly faster rates of uplift than the combined solution, like near Ocean City, Virginia
- More pronounced subsidence exists within the 35 Ma Chesapeake Impact crater outer rim



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- A few GNSS stations have significantly faster rates of uplift than the combined solution, like near Ocean City, Virginia
- More pronounced subsidence exists within the 35 Ma Chesapeake Impact crater outer rim
- This team is actively collecting new episodic GNSS data at benchmarks across the region annually from 2019 - 2023 towards producing a revised baseline VLM solution

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Summary

- We have calculated vertical land motions of the Chesapeake Bay by applying the approach of Blackwell et al. (2020) for ascending data to combine InSAR and GNSS data

- Widespread subsidence averaging -1.62 mm/yr (range -21.75 to 12.01) is detected although the InSAR LOS data and GNSS velocities cover different time spans.

Summary

- We have calculated vertical land motions of the Chesapeake Bay by applying the approach of Blackwell et al. (2020) for ascending data to combine InSAR and GNSS data
- Widespread subsidence averaging -1.62 mm/yr (range -21.75 to 12.01) is detected although the InSAR LOS data and GNSS velocities cover different time spans.

Future Work

- Align the timeframes of GNSS observations and InSAR data
- Evaluate uncertainties of the combined InSAR and GNSS solution
- Continue observing benchmarks with GNSS in the Chesapeake Bay annually until at least 2023
- Develop new vertical land motion maps based on the episodic GNSS data and compare with continuous GNSS solutions
- Develop VLM products that are valuable to stakeholders of the Chesapeake Bay
- Detailed comparison of VLM results with land-use metrics, population density, etc.