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Subsidence Monitoring in Hampton Roads Using Satellites

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Collaborators

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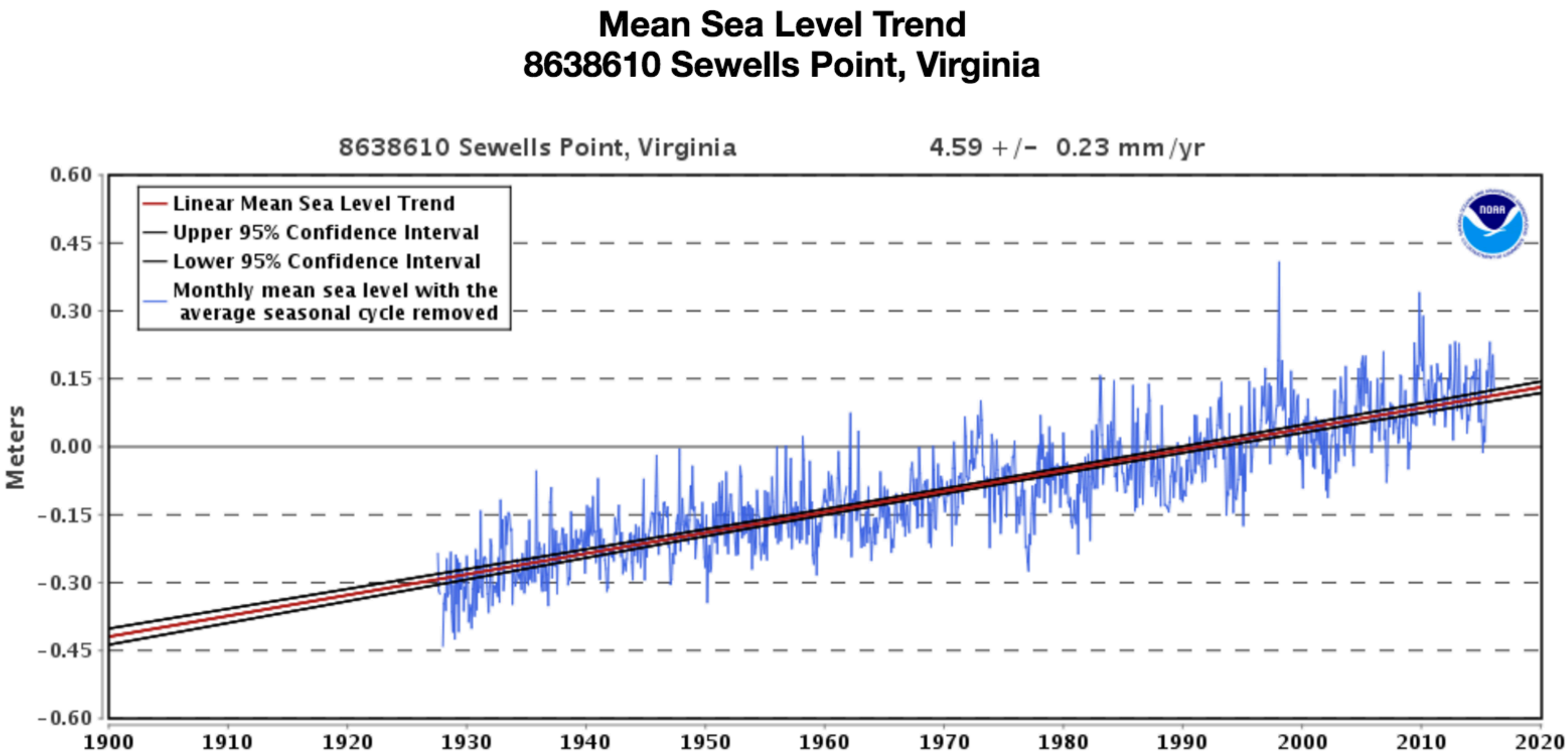
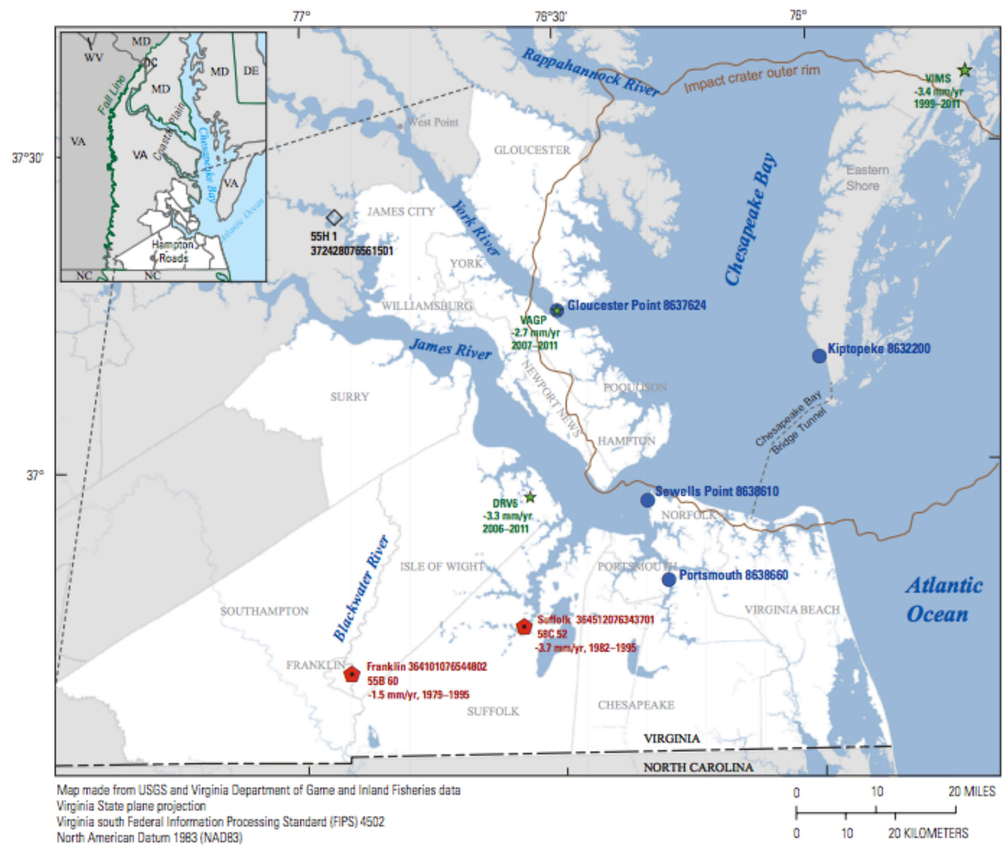
- John Murray | *NASA Langley*
- Jack Eggleston | *USGS*
- Michelle Sneed | *USGS*

Sea Level Rise in Hampton Roads

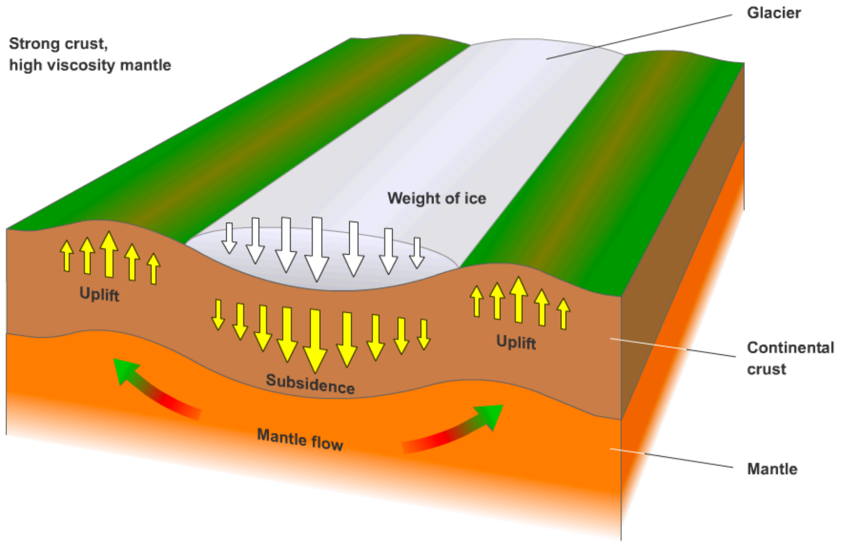


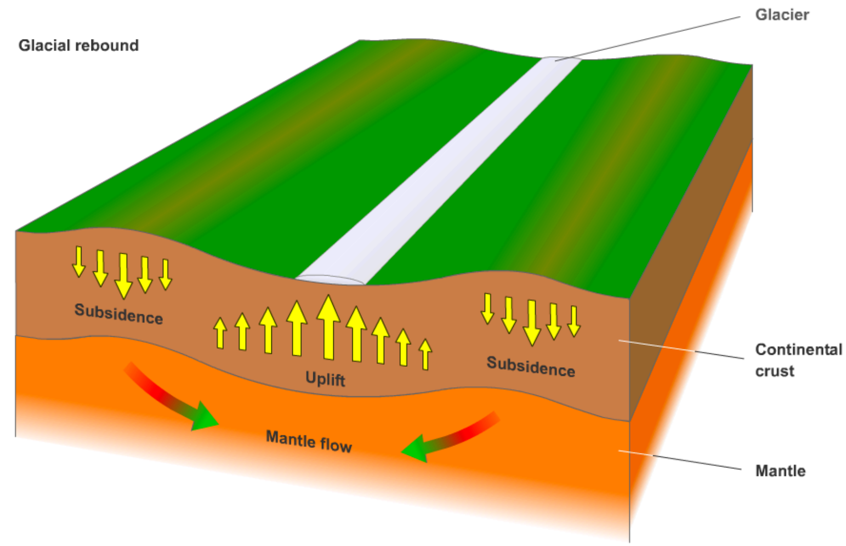
Sea Level Rise in Hampton Roads

- How much of the trend is the ocean rising, and how much of the trend is the land sinking?
  - 50% ocean rising, 50% subsidence (?).
- Three main (known) causes of the subsidence:
  - Glacial Isostatic Adjustment (Post-glacial rebound)
  - Chesapeake Bay Impact Crater
  - Groundwater Removal



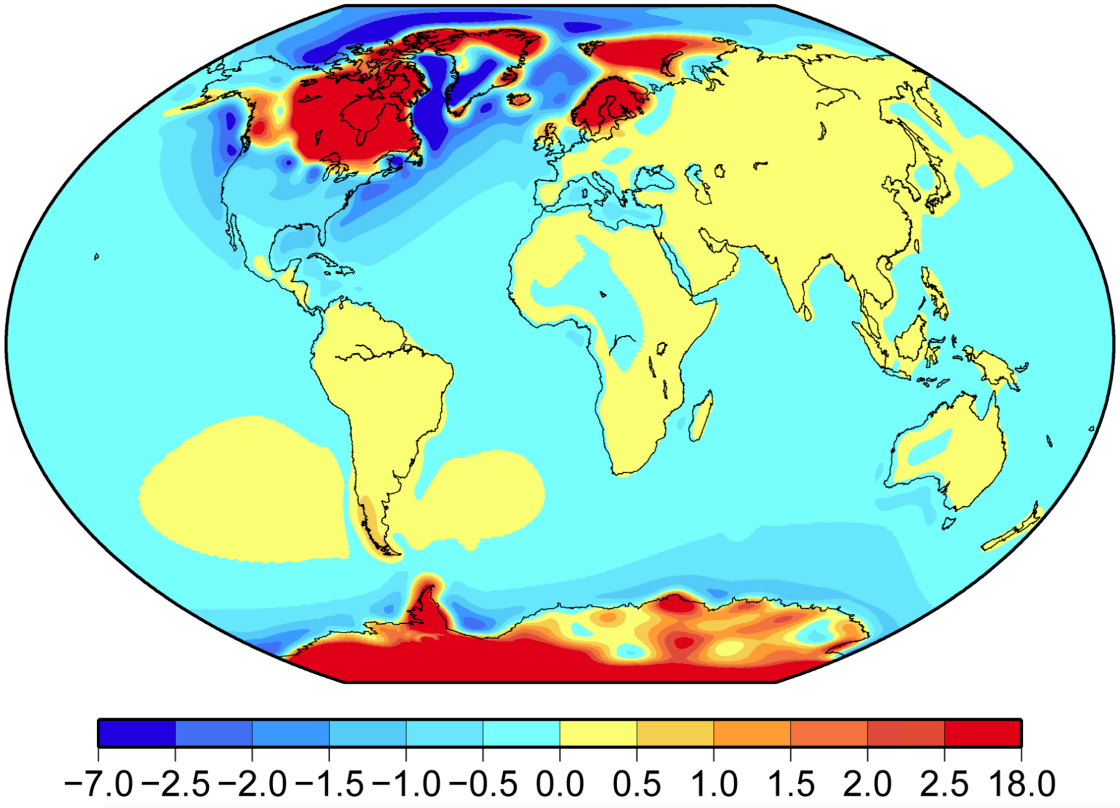
Glacial Isostatic Adjustment (GIA)



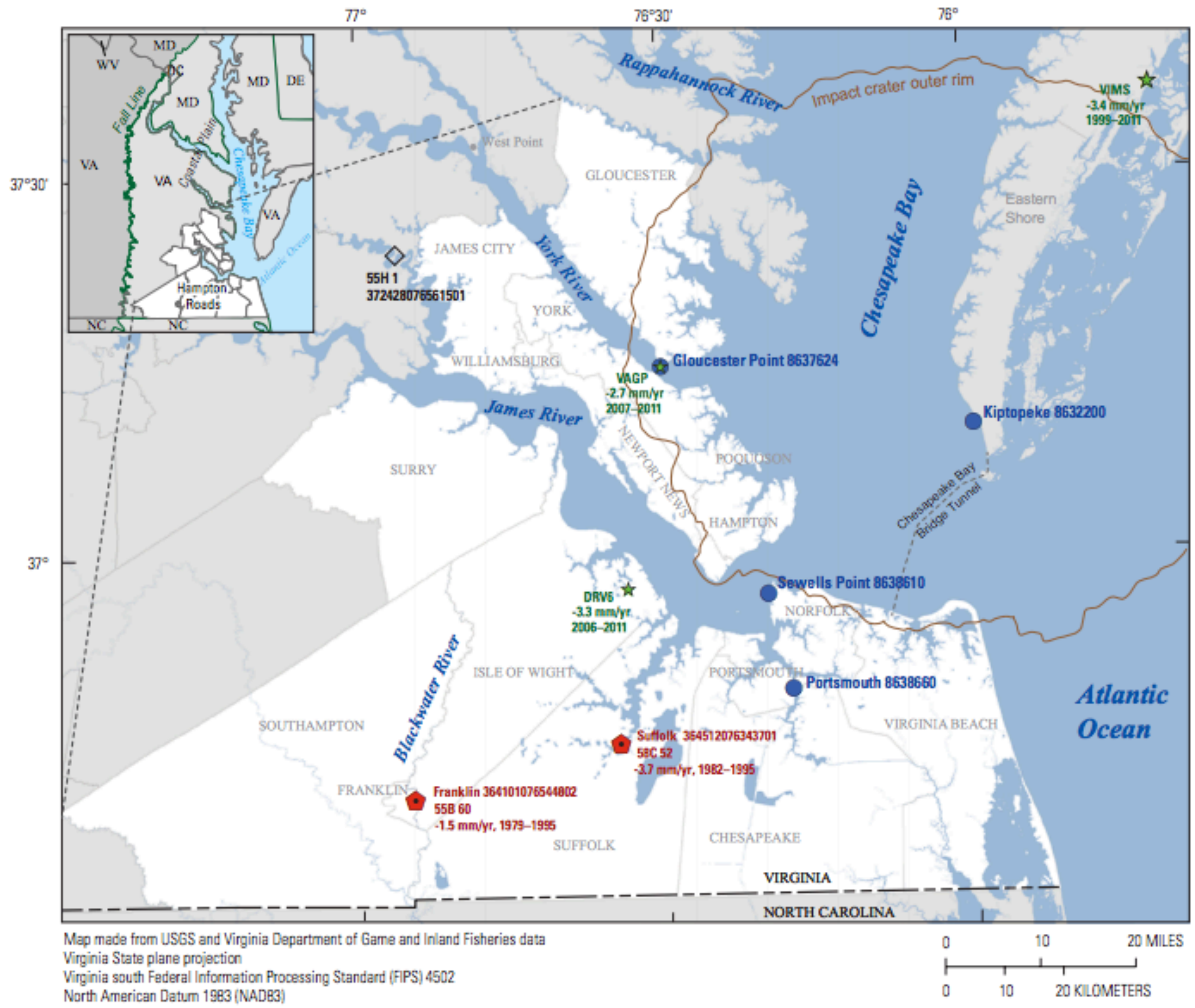


Glacial Isostatic Adjustment (GIA)

- Vertical land motion (mm/year) associated with GIA.
- Positive values indicate uplift, while negative values indicate subsidence.

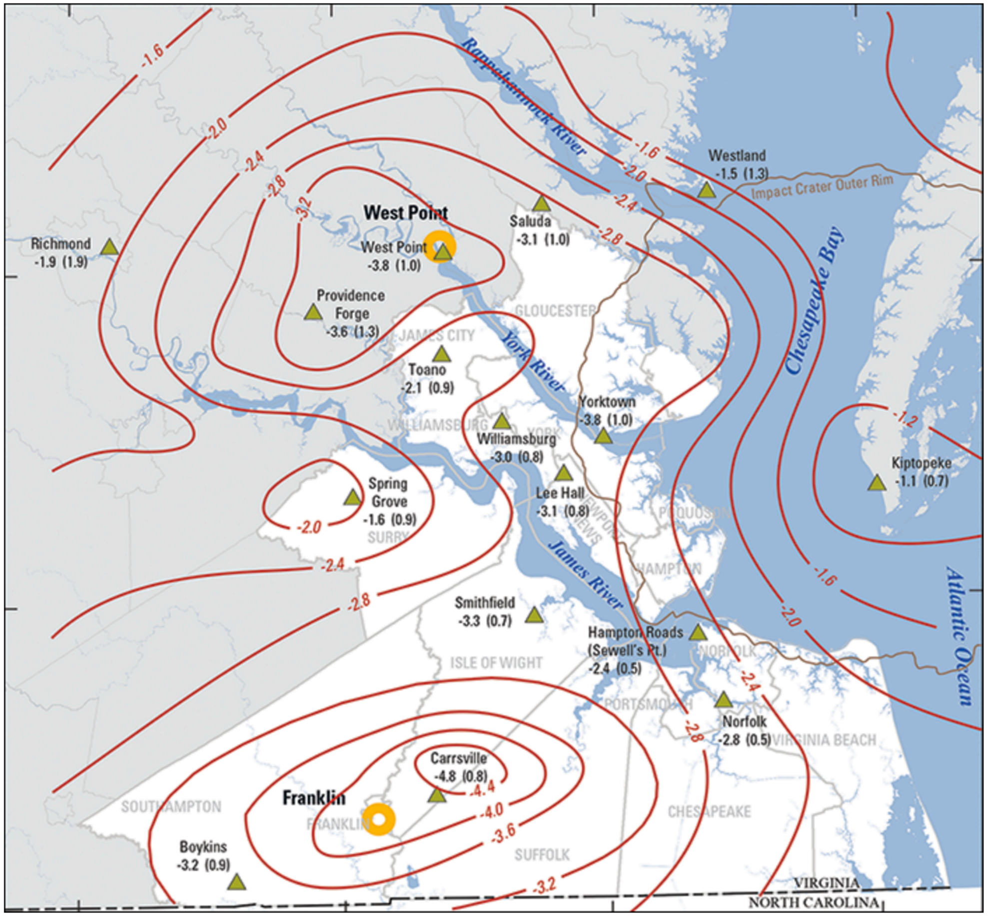


Chesapeake Bay Impact Crater



Groundwater Removal

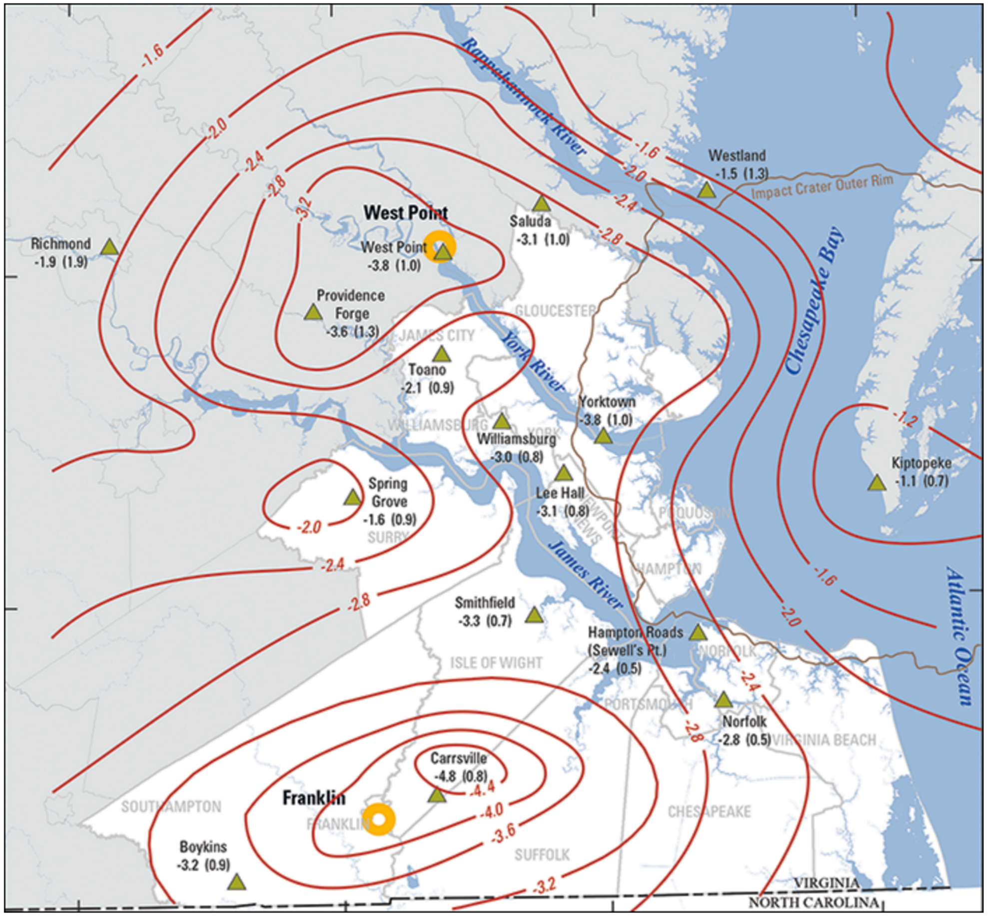
- This map shows estimates from subsidence for the time period from 1940 to 1971.
- High subsidence rates are centered near paper mills in West Point and Franklin.



Map: courtesy of the U.S. Geological Survey

Hampton Roads Subsidence

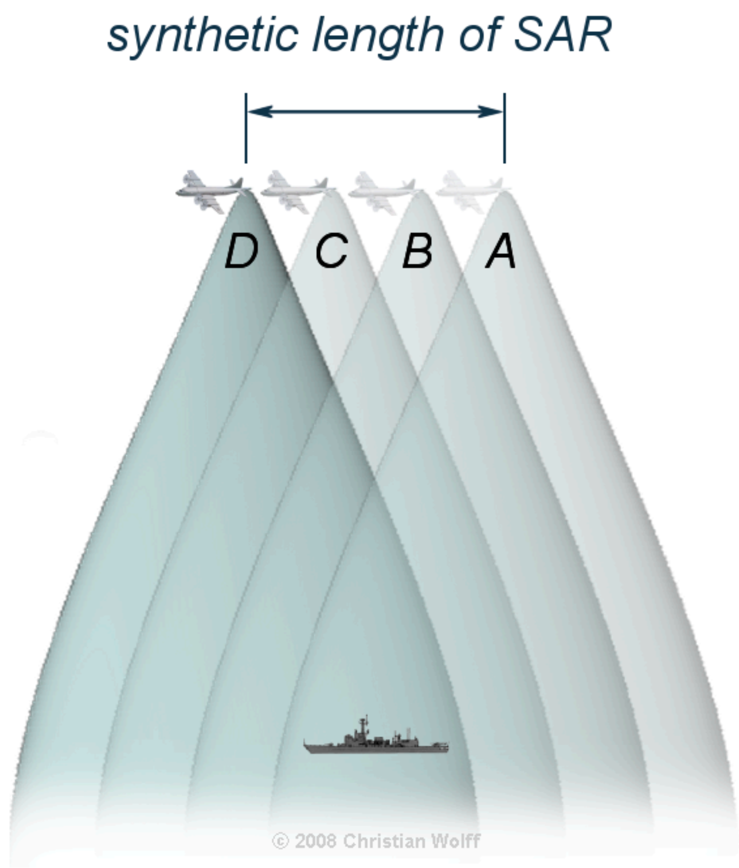
- This map shows estimates from subsidence for the time period from 1940 to 1971.
- What does the subsidence map look like now?
- Is there greater (finer-scale) spatial variability than indicated by this map?
- To answer these questions, we can use Interferometric Synthetic Aperture Radar (InSAR) analysis.



Map: courtesy of the U.S. Geological Survey

What is SAR/InSAR?

- A synthetic aperture radar (SAR) is a side-looking (active) remote sensing system which utilizes the flight path of the platform (plane or satellite) to simulate a large antenna → higher resolution imagery.
- InSAR analysis compares two (or more) SAR images of the same area, taken by the same satellite at the same vantage point, but at different times to estimate surface deformation or elevation.
  - Relies on differences in the phase of the waves returning to the satellite, which can then be converted into displacement.



What do we need to measure the rate of subsidence?

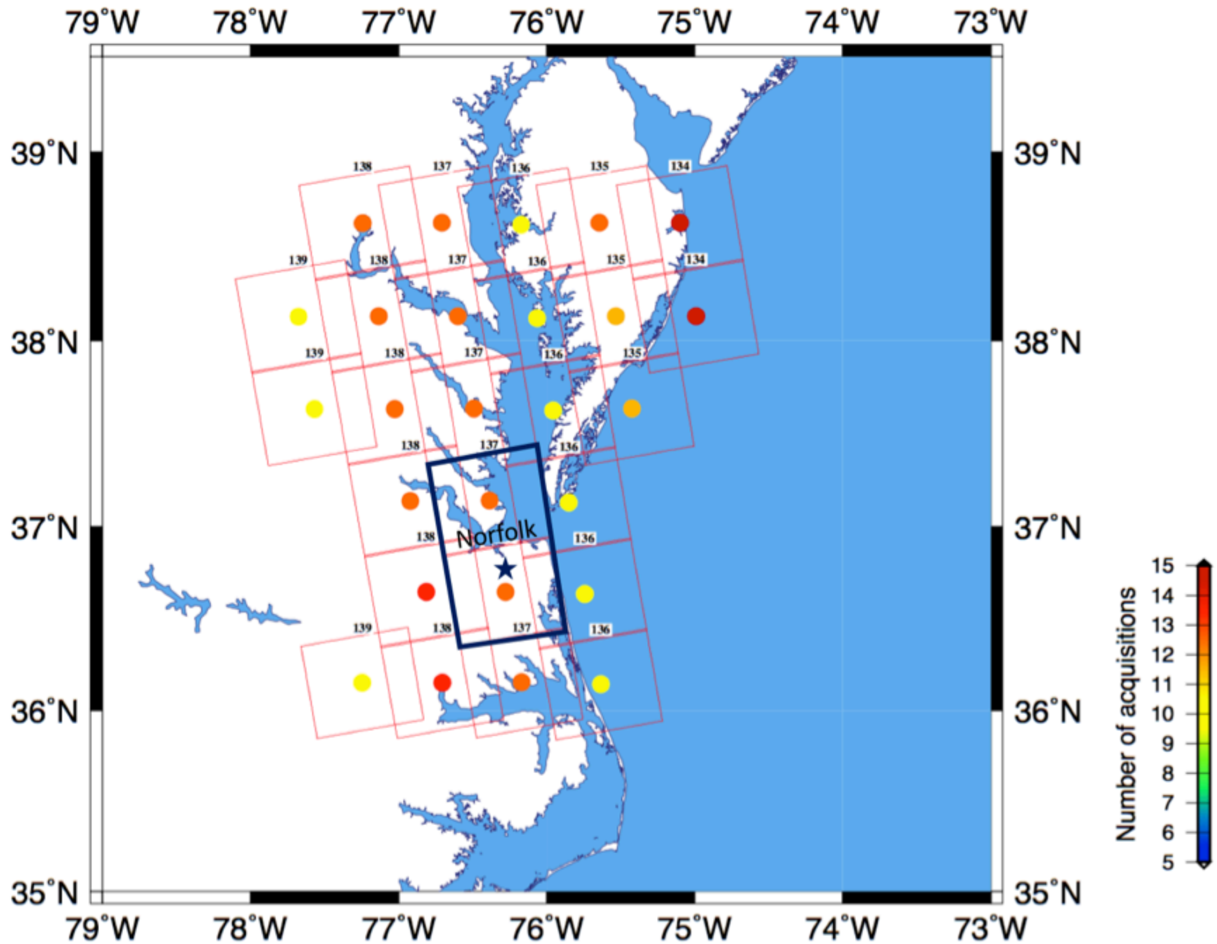
- To get accurate satellite-derived measurements of long-term subsidence in the region, we need:
  - A long record
  - Good sampling within that record (lots of data points)
  - Consistent overflights of the satellite
  - In situ measurements for calibration and ground-truthing/validation
  - Ability to correct for sources of error
    - Anything that causes a delay in the time it takes for the signal to propagate from the target to the satellite will result in error that (ideally) needs to be accounted for.

Preliminary InSAR Analysis

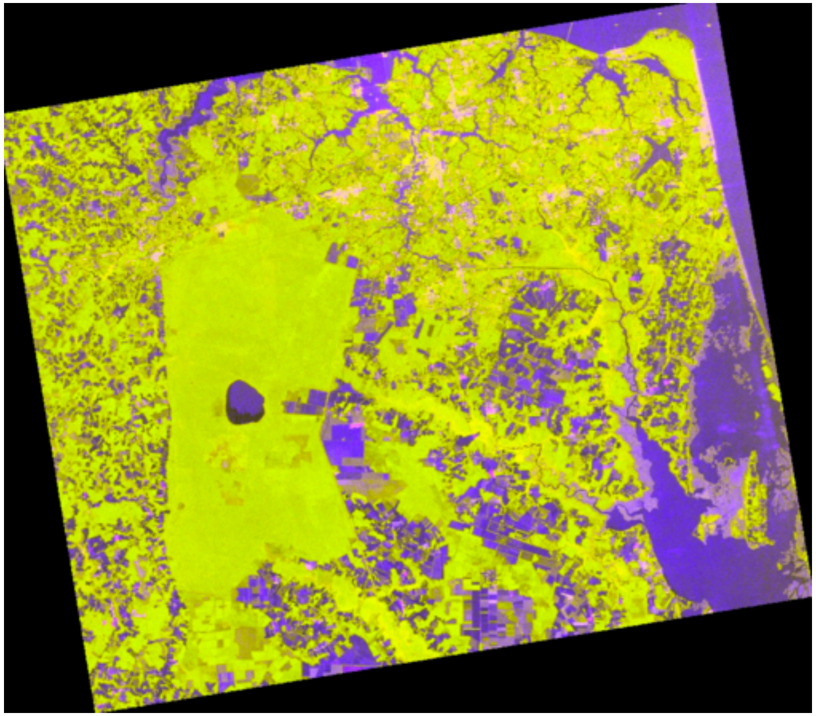
- As a starting point, we have performed a preliminary InSAR analysis for the region.
  - **Goal**: Analyze historical SAR data with a simple processing tool to compute an initial subsidence rate map.
  - Here, we are using the GMTSAR software.
- Steps:
  1. Find any SAR data coincident with Hampton Roads region.
  2. Assess the quality of this data.
  3. Estimate a subsidence map using simple InSAR analysis.

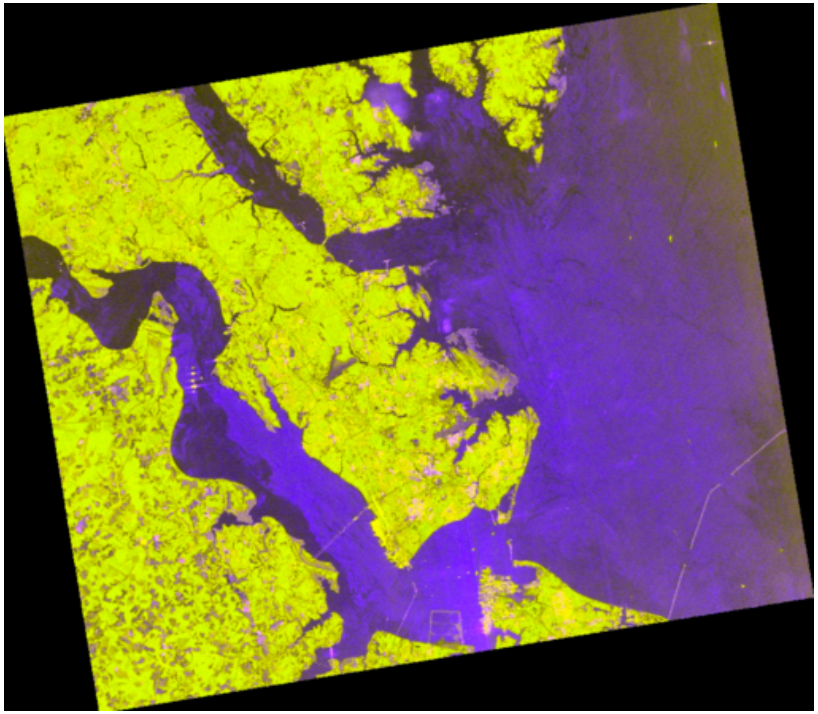
Available Data

- For historical SAR data, ERS and ALOS-1 appear to provide the best coverage of HR with the longest available time series.
- Initial analysis will use data from ALOS-1 PALSAR (Japanese satellite).
  - Data is (publicly) available over HR from 2006 through 2011.
  - Some of the available frames are shown in figure on the right, with each frame measured along multiple passes of the satellite.



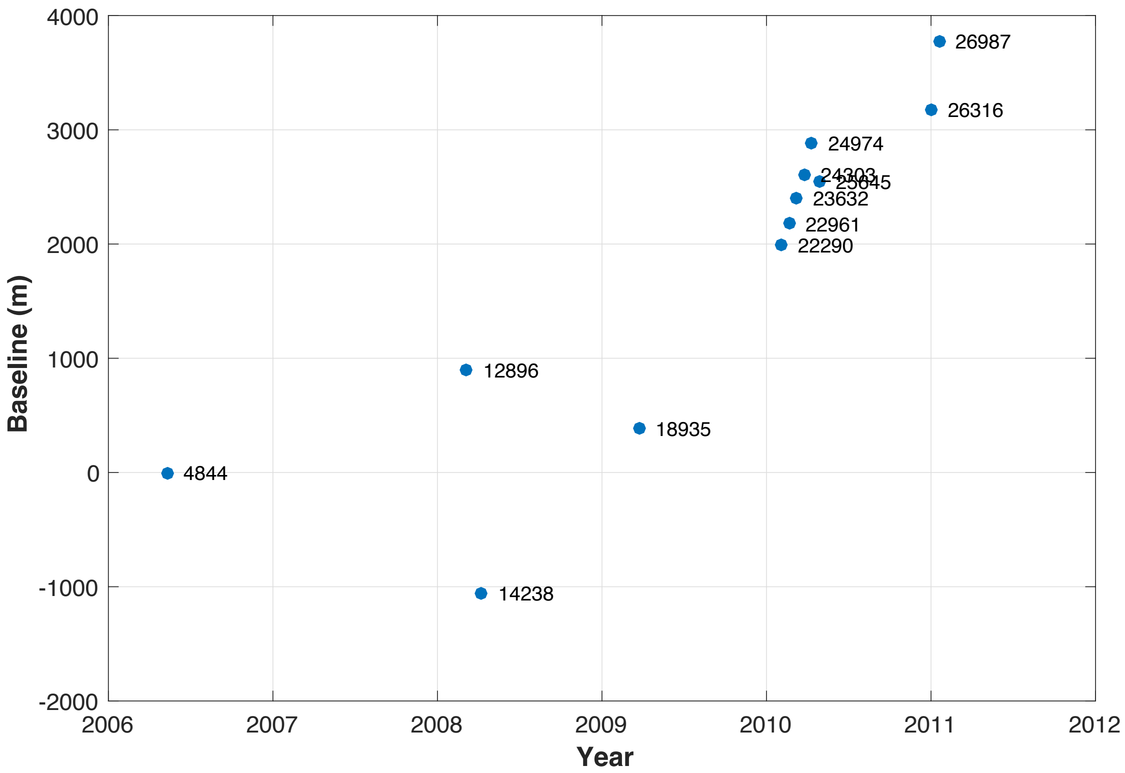
Available Data





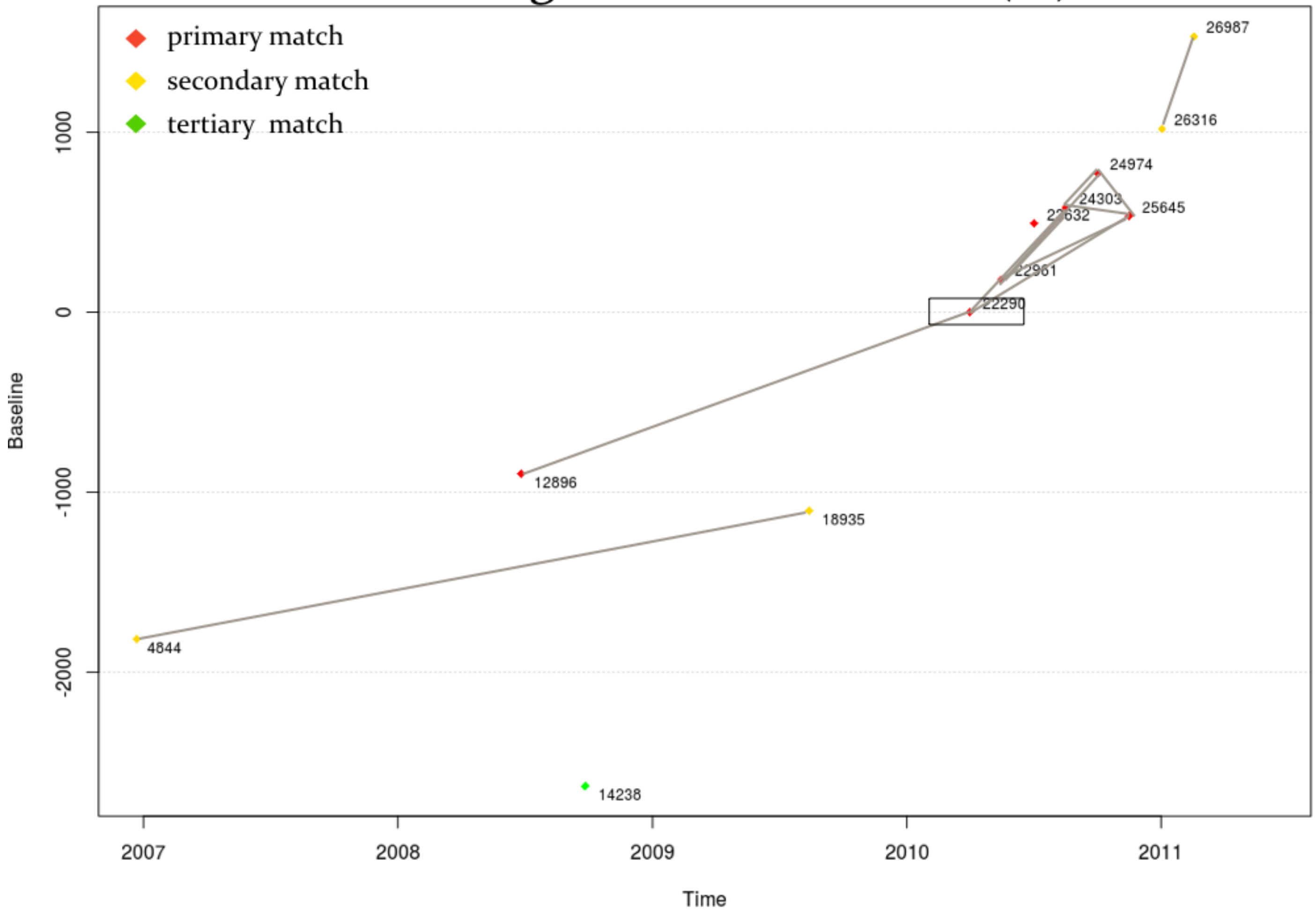
Available Data

- Satellite baseline for ALOS-1 Frame 730 (12 images available from 2006 to 2011). Critical baseline ~1000 m.



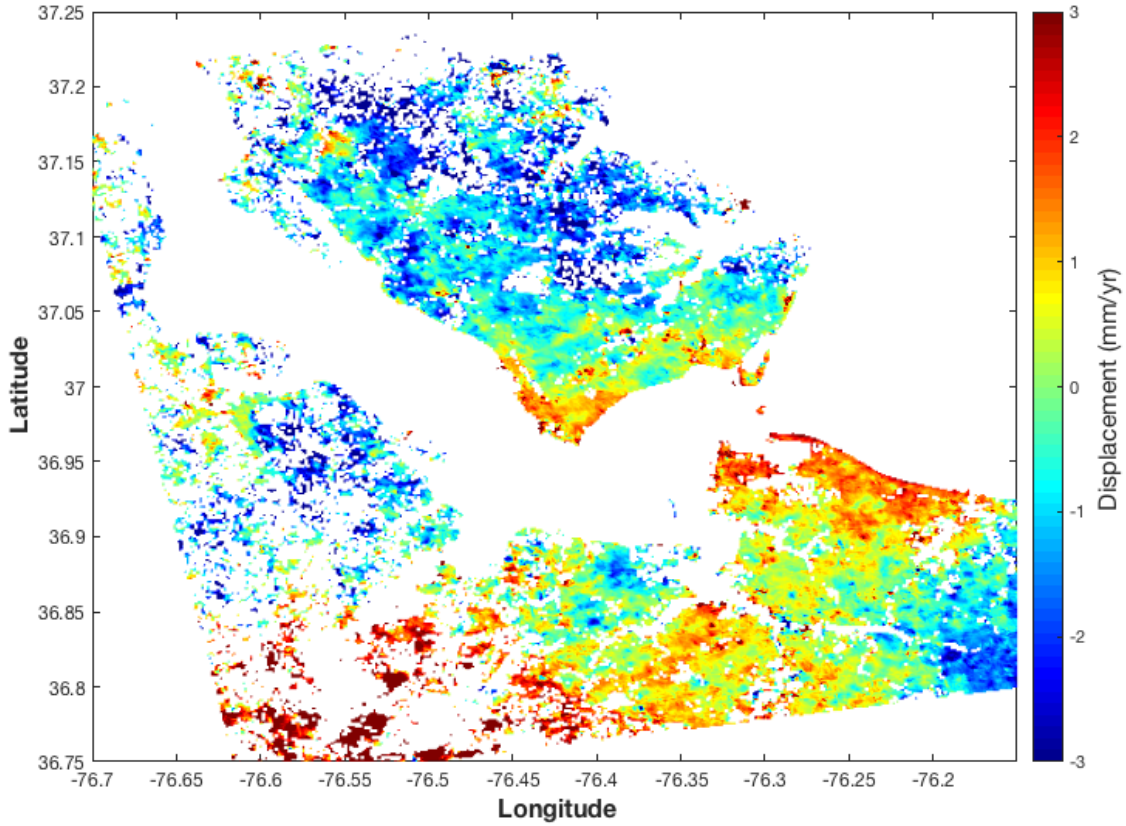
Available Data

Interferogram Pairs for Stack (12)



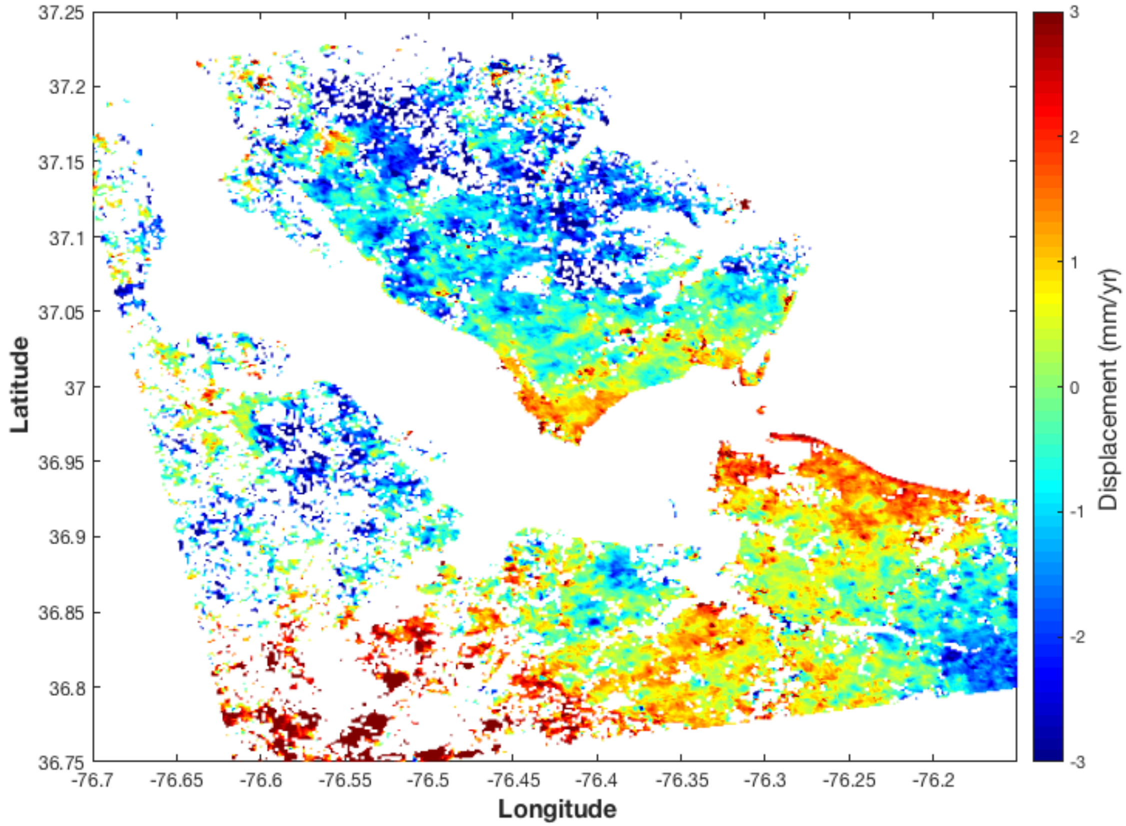
Subsidence Map

- Skipping a lot of steps….subsidence rates (mm/yr) from December 22nd, 2006 to January, 14th, 2011.
- After removing the long wavelength signals (e.g. GIA), we are left with what can be interpreted as an "anomaly" displacement map.
- This can provide information regarding what areas subsided more over this time period than others.
- It does not, however, provide information regarding absolute displacement, as the longest wavelength signals like GIA are removed → further work is needed.



Problems

- A long record
- Good sampling within that record (several data points)
- Consistent over-flights of the satellite
- In situ measurements for calibration and ground-truthing/validation
- Ability to correct for sources of error



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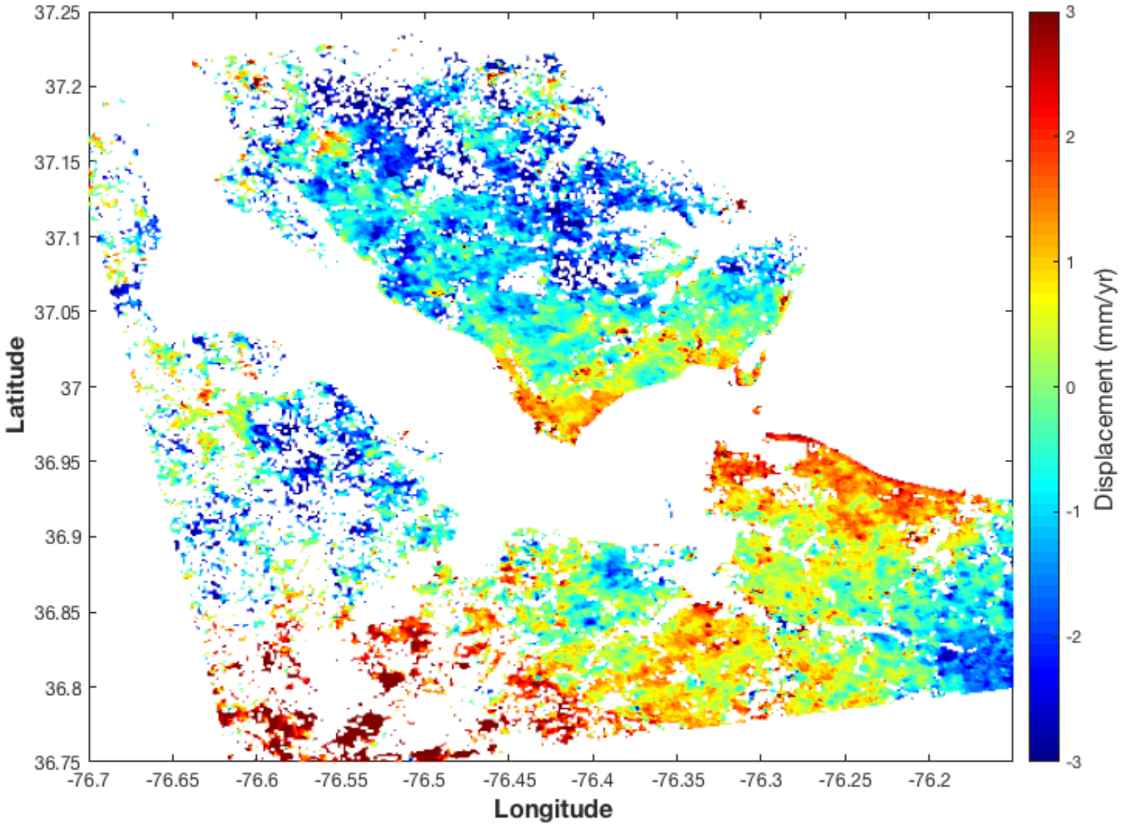


ODU/CCRFR/NASA Collaborative Subsidence Project

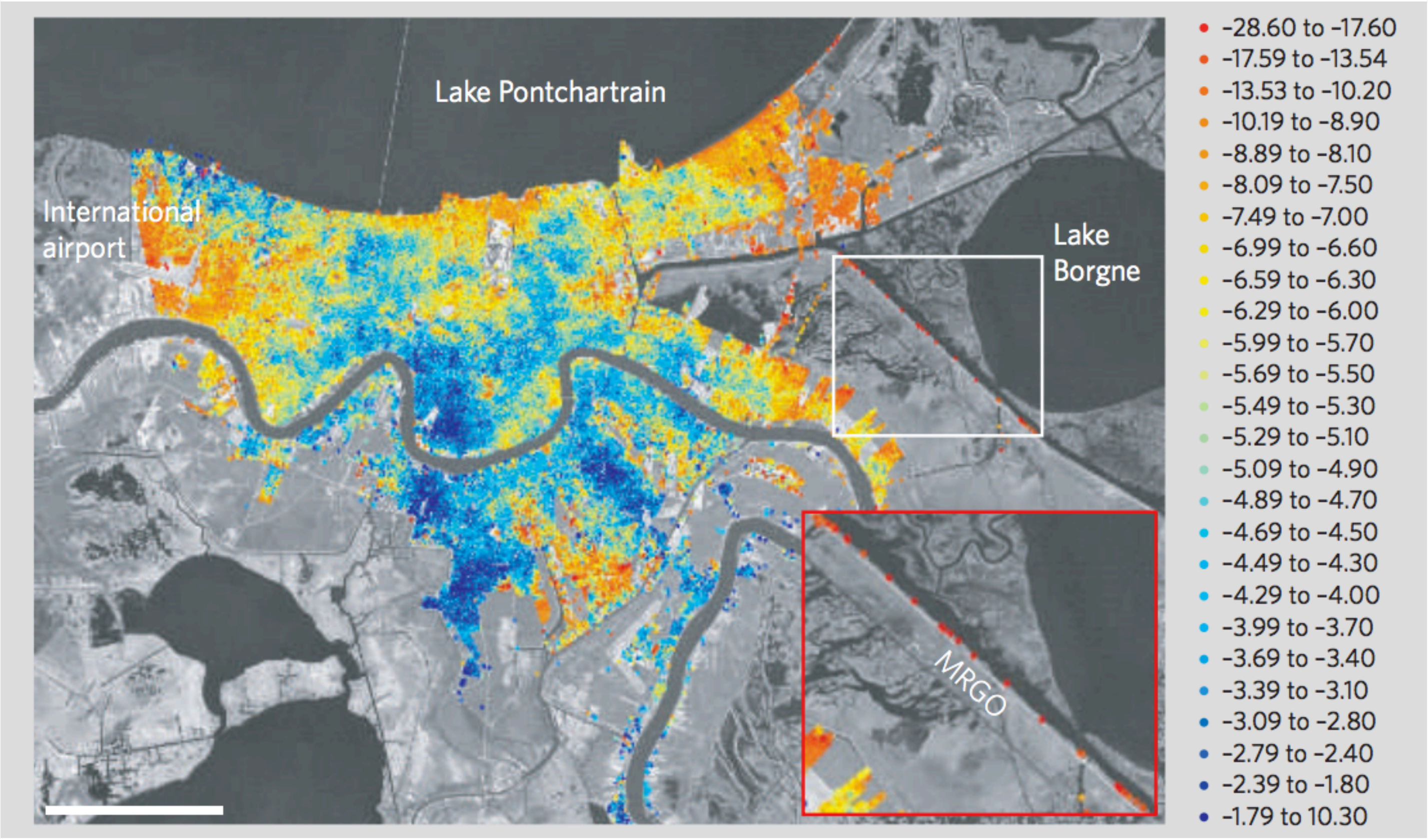
- To improve on this preliminary subsidence map, ODU, CCRFR, and NASA have formed a collaborative project designed to get the "most" out of the available data.
  - Funding will be provided jointly by the CCRFR and a NASA Rapid Response proposal.
  - InSAR experts, David Bekaert and Cathleen Jones from NASA JPL, will work with scientists at ODU to both perform state-of-the-art analysis of the available SAR data and build capacity at ODU to perform this analysis in the future.
  - John Murray (NASA Langley) will coordinate the effort between NASA JPL and ODU.
  - Will use ISCE, TRAIN, and StaMPS/MTI software to perform the analysis, with dramatically improved atmospheric correction procedures.

PHASE 1: ***September 2016-November 2016:*** Set up ISCE, TRAIN, and StaMPS/MTI capability at ODU and JPL. Preliminary analysis of ALOS data and investigate the need for ionospheric corrections. ***December 2016-February 2017:*** Produce first subsidence map with uncertainties for a sub-region within Hampton Roads (highlighted region Figure 1). Optimize StaMPS parameters for the range of land types found in the sub region, and apply tropospheric corrections using TRAIN. Ground-truth initial subsidence map where possible.
PHASE 2 follow-on: ***March 2017-May 2017:*** Extend region of study to include all of Hampton Roads. ***June 2017-August 2017:*** Produce final InSAR subsidence map with accompanying uncertainty. Provide guidance for future subsidence monitoring efforts.

Persistent Scatterer InSAR Analysis

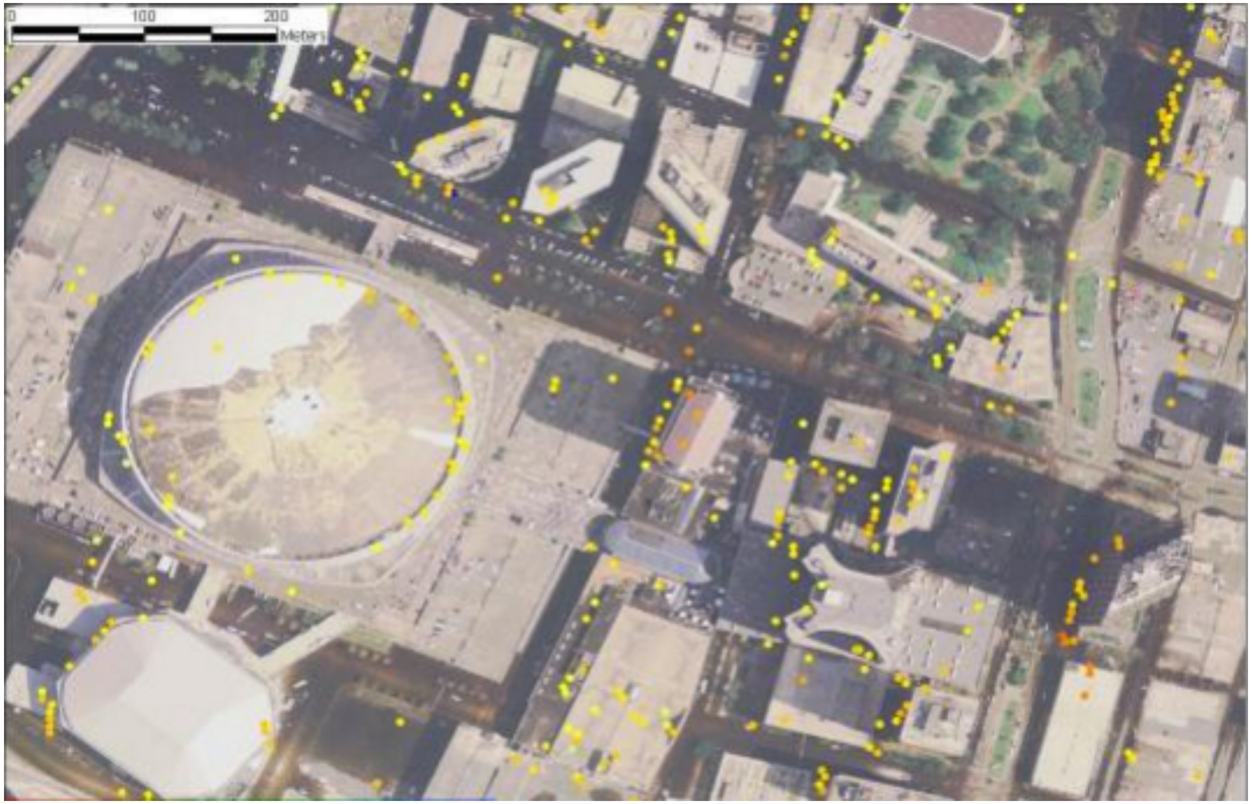
- We will use the Persistent Scatterer InSAR (PSInSAR) method to obtain higher resolution and more accurate subsidence rate maps.
- PSInSAR relies on features within the field of view that provide permanent "scattering points".
  - Features such as roof tops, bridges, dams, antennae, large rock outcrops, etc. make good persistent scatterers.
  - Using the technique (and without getting into details), the motion of each scatterer structure can be very precisely tracked and vertical land motion can be determined.
  - Technique performs better in urban areas than rural.

Persistent Scatterer InSAR Analysis



Dixon, Timothy H., Falk Amelung, Alessandro Ferretti, Fabrizio Novali, Fabio Rocca, Roy Dokka, Giovanni Sella, Sang-Wan Kim, Shimon Wdowinski, and Dean Whitman. 2006. "Space Geodesy: Subsidence and Flooding in New Orleans." Nature 441 (7093): 587–88.

Persistent Scatterer InSAR Analysis



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Summary

- By the end of the year, we will have a preliminary subsidence map for a portion of Hampton Roads (frames 720 and 730) using PSInSAR analysis that will be made publicly available.
  - By mid-2017, we will expand our analysis to the entire Hampton Roads region, releasing final subsidence maps.
  - There is a limit imposed by the data on how well we can do with what is currently available.
  - Our initial goal is to extract the best possible information regarding recent subsidence rates in Hampton Roads.
  - By the end of the project, ODU will have the capacity to perform state-of-the-art InSAR analysis.
- The work completed here will help inform how subsidence can be monitored in Hampton Roads using satellites.
  - With the coverage of SAR satellites increasing, this is a vital step towards determining how best to perform ongoing and continuous subsidence monitoring in the region.

Thanks for your time!