Gulf Coast Subsidence: Integration of Geodesy, Geophysical Modeling, and Interferometric Synthetic Aperture Radar Observations

Ronald Blom [1], Bruce Chapman [1], Roy Dokka [2*], Eric Fielding [1], Brian Hawkins[1], Scott Hensley[1], Erik Ivins [1], Cathleen Jones[1], Joshua Kent [2], Zhen Liu[1], Rowena Lohman [3], Yang Zheng[1]

1. NASA/Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
2. Louisiana Spatial Reference Center and Center for GeoInformatics
Louisiana State University
Baton Rouge, LA 70803
3. Department of Earth and Atmospheric Sciences
Cornell University, Snee Hall,
Ithaca, NY 14850
***deceased**

Cornell University

Jet Propulsion Laboratory
California Institute of Technology

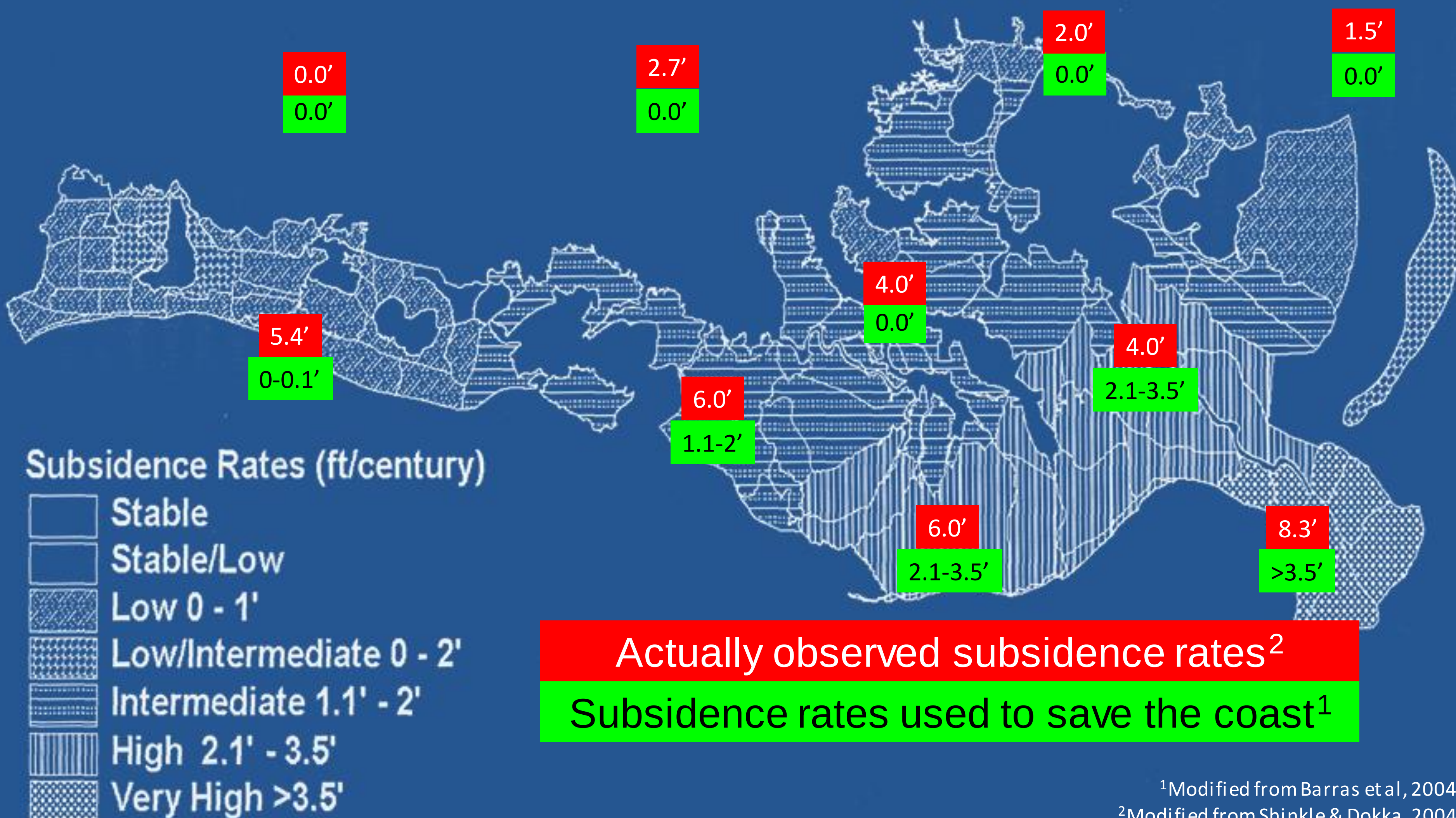
Gulf Coast Subsidence

- Hurricanes Katrina, Rita, and Ike focused attention on the vulnerability of the Gulf Coast to hurricanes
- Well recognized components of this vulnerability are sea level rise and wetland loss
- Wetland loss is attributed primarily to interruption of the natural processes of sediment delivery & distribution
- In addition, subsidence due to a multiplicity of factors including: sediment compaction, sediment oxidation, fluid extraction, ***and the crustal response to <u>sediment load</u> and <u>~130 m rise in sea level</u>.***
- Precise geodetic measurements of current subsidence, and a geophysical understanding of crustal response would aid in monitoring and prediction of future subsidence
- InSAR can potentially provide maps of subsidence
- Better prediction will protect lives and infrastructure


463

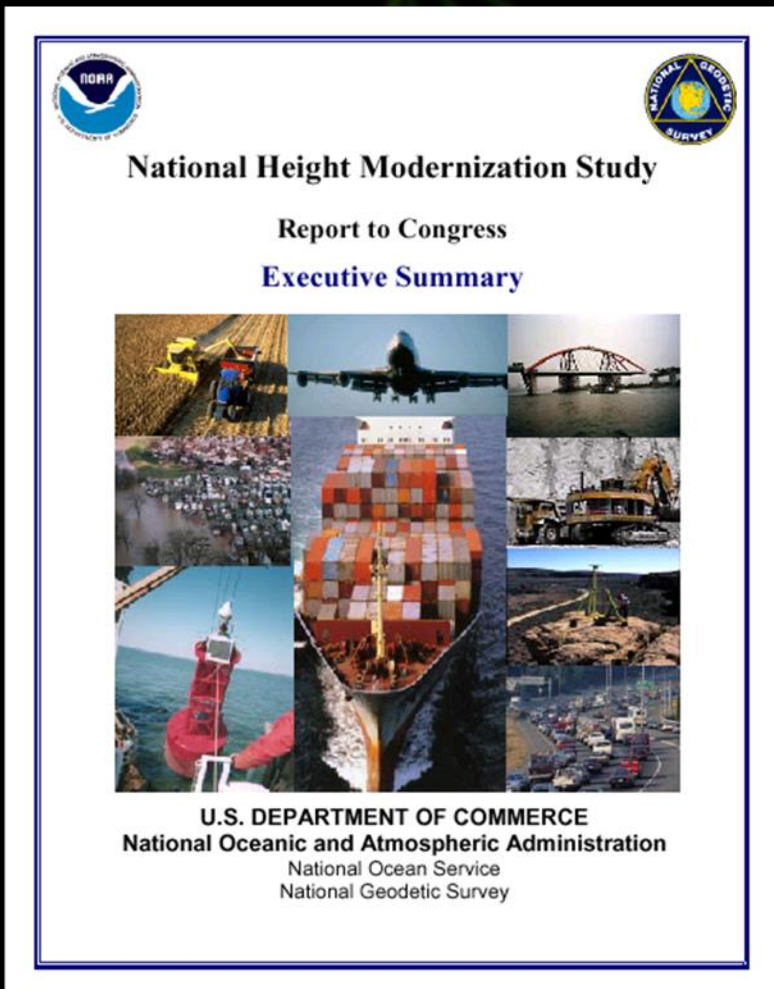

MISS LISA
ST. PETER

Past efforts to mitigate erosion and restore Louisiana's coast failed to consider actual subsidence rates



[1] Modified from Barras et al, 2004
[2] Modified from Shinkle & Dokka, 2004

A Report to Congress



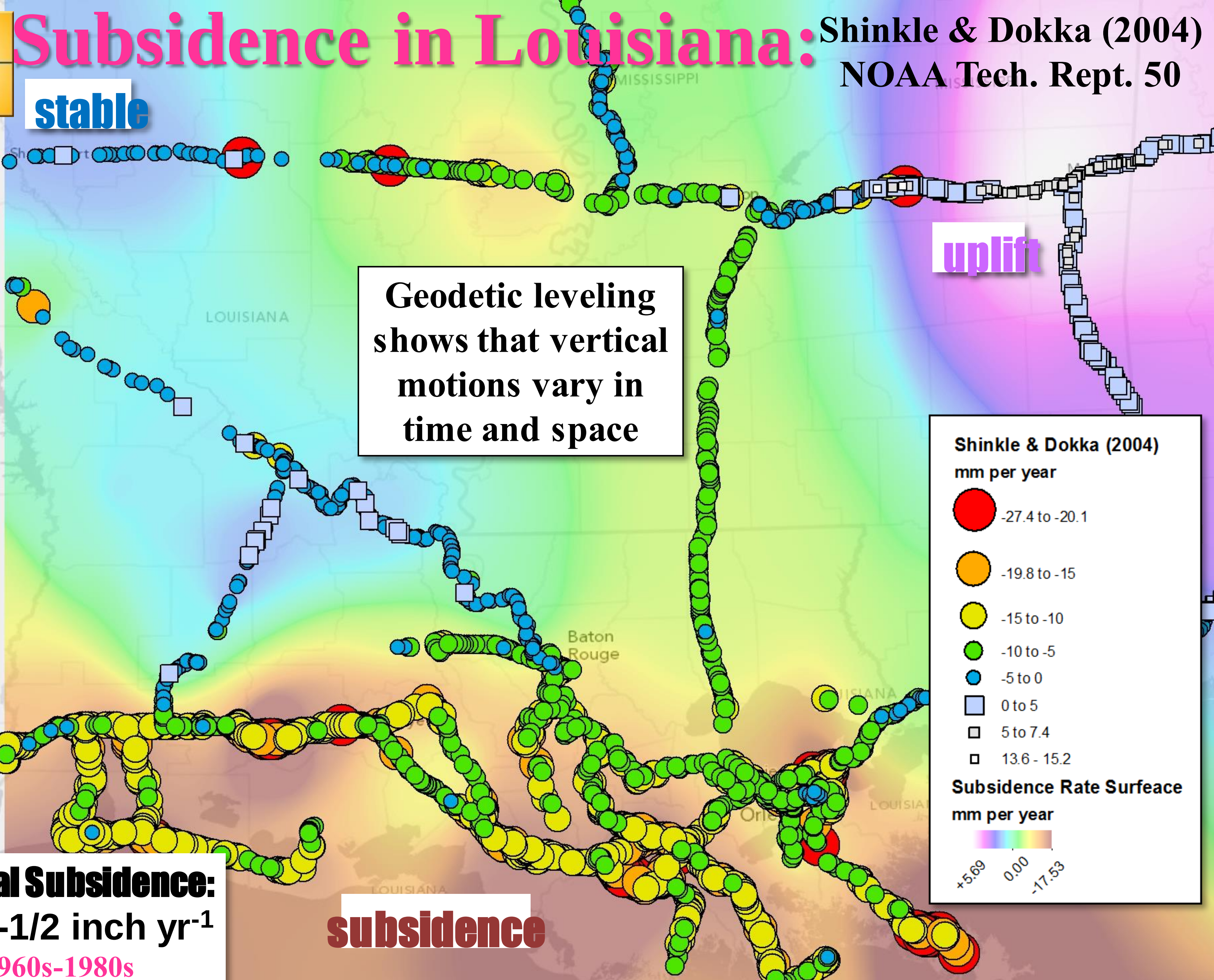
NOAA told the U.S. Congress in 2001 that the system used to measure elevations in LA was,

" inaccurate and obsolete and unable to support public safety."

Accurate elevations were not restored until 10/2005.

Subsidence in Louisiana:

Shinkle & Dokka (2004)
NOAA Tech. Rept. 50



Geodetic leveling shows that vertical motions vary in time and space

Coastal Subsidence:
avg. -1/2 inch yr^{-1}
1960s-1980s

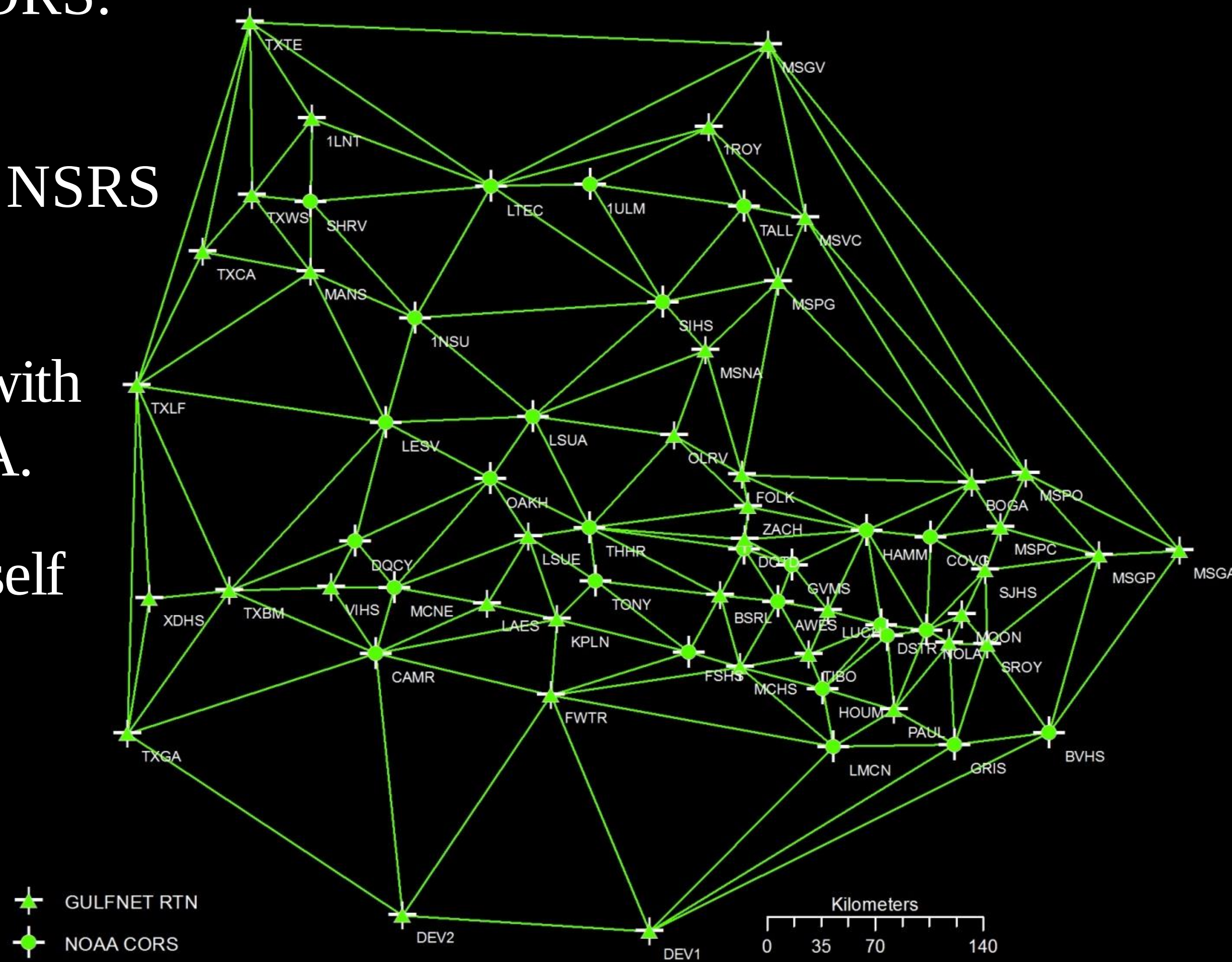
Existing Partnerships

The C4G has Partnerships at all Levels of the Public Sector

- **Academia:**
  - LSU Earth Scan Lab
  - LSU Southern Regional Climate Center
  - LSU GCCETR
  - LSU AgCenter
  - Louisiana Sea Grant Program
  - CIT/NASA Jet Propulsion Lab
- **Local & Regional:**
  - South Lafourche Levee District
  - Greater Lafourche Port Commission
  - Jefferson, Terrebonne Parish
  - Plaquemines Parish
  - Parish
- **State Agencies:**
  - LA Dept of Agriculture
  - LA Dept. of Transportation & Development
  - LA Division of Administration
  - LA Governor's Office of Homeland Security & Emergency Preparedness
  - Louisiana National Guard
- **Federal:**
  - Federal Emergency Management Agency (FEMA)
  - NASA: Michaud Assembly Facility
  - U.S. Army Corps of Engineers: New Orleans District (USACE)
  - NOAA – National Geodetic Survey (NGS)
  - NOAA – National Weather Service (NWS)
  - U.S. Department of Agriculture (USDA)
  - U.S. Geological Survey (USGS)
  - Congressional Delegation

C4Gnet: Real-Time Network

- Based on LSU CORS.
- The most reliable component of the NSRS in Louisiana.
- Partially created with funds from FEMA.
- Maintained with self generated funds.



Last Geodetic Words from Dokka

Dokka, R. K., 2011, The Role of Deep Processes in Late 20th Century Subsidence of New Orleans and Coastal Areas of Southern Louisiana and Mississippi. JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, B06403, doi:10.1029/2010JB008008, 2011

- Deep set monuments (upper Pleistocene) show subsidence 8-50 times higher than previous estimates
- In addition to subsidence/compaction in Holocene sediments
- These observations contradict the current geological paradigm that asserts that natural compaction of Holocene sediments is the major cause of subsidence. Full accounting of the total late 20th century subsidence must include shallow and deep-seated components
- Also, significant groundwater extraction component for shallow component
- Late 20th century subsidence in eastern New Orleans dominated by mainly anthropogenic factors
- Current hurricane protection and coastal restoration planning are based on long, time-averaged subsidence rate estimates that do not reflect current motions established by geodetic methods

Interdisciplinary research task involving multiple institutions to study:

1. **What subsidence is expected from crustal loading?**

- Modeling (Ivins): Effects of sediment loading plus ocean loading of 130 meters sea level rise

2. **What subsidence is observed today?**

- Geodetic Observations (LSU-C4G)

3. **What can observed via InSAR?**

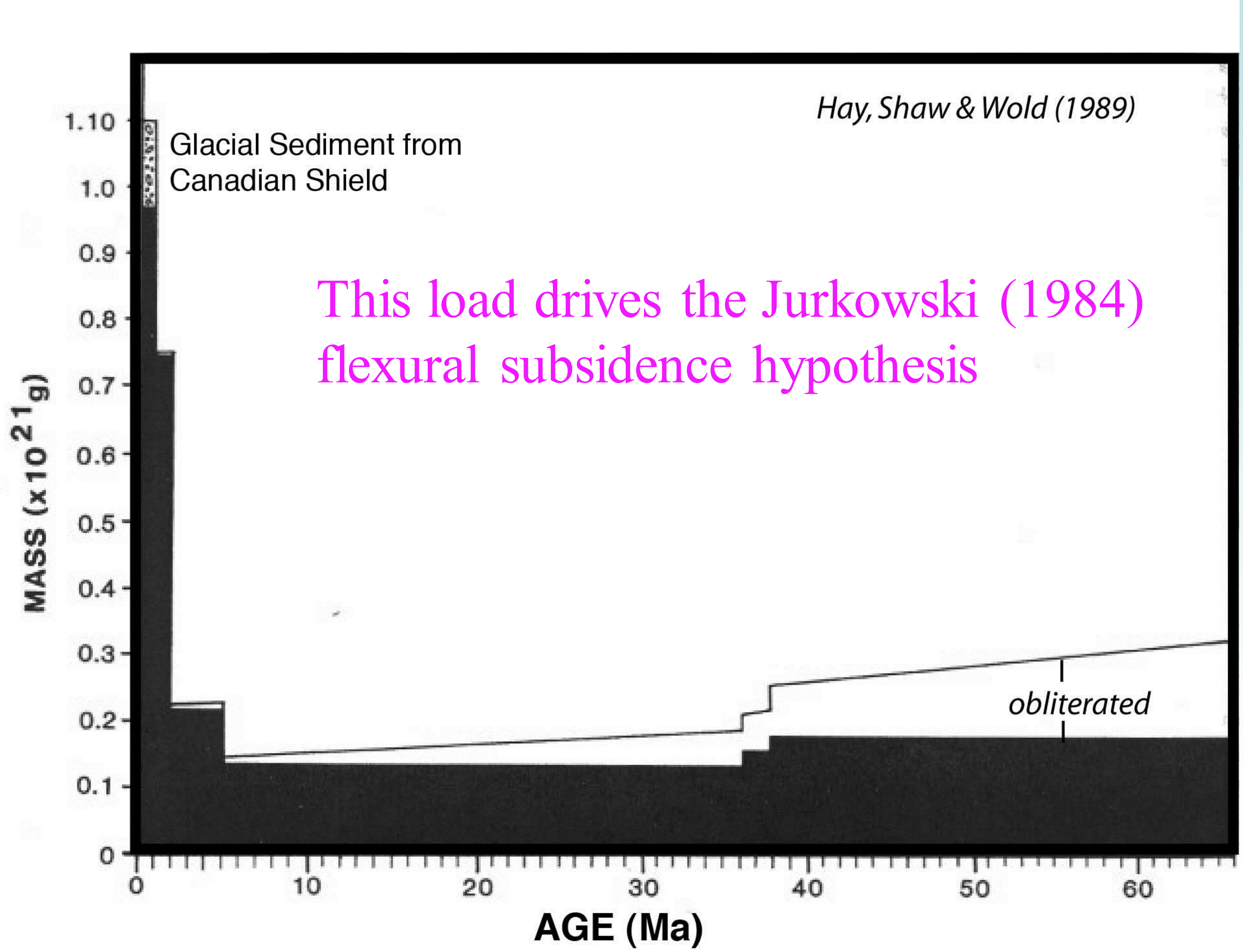
- Satellite InSAR data (Chapman, Fielding, Liu, Lohman)
- UAVSAR InSAR data (Chapman, Fielding, Hawkins, Hensley, Jones, Zheng)

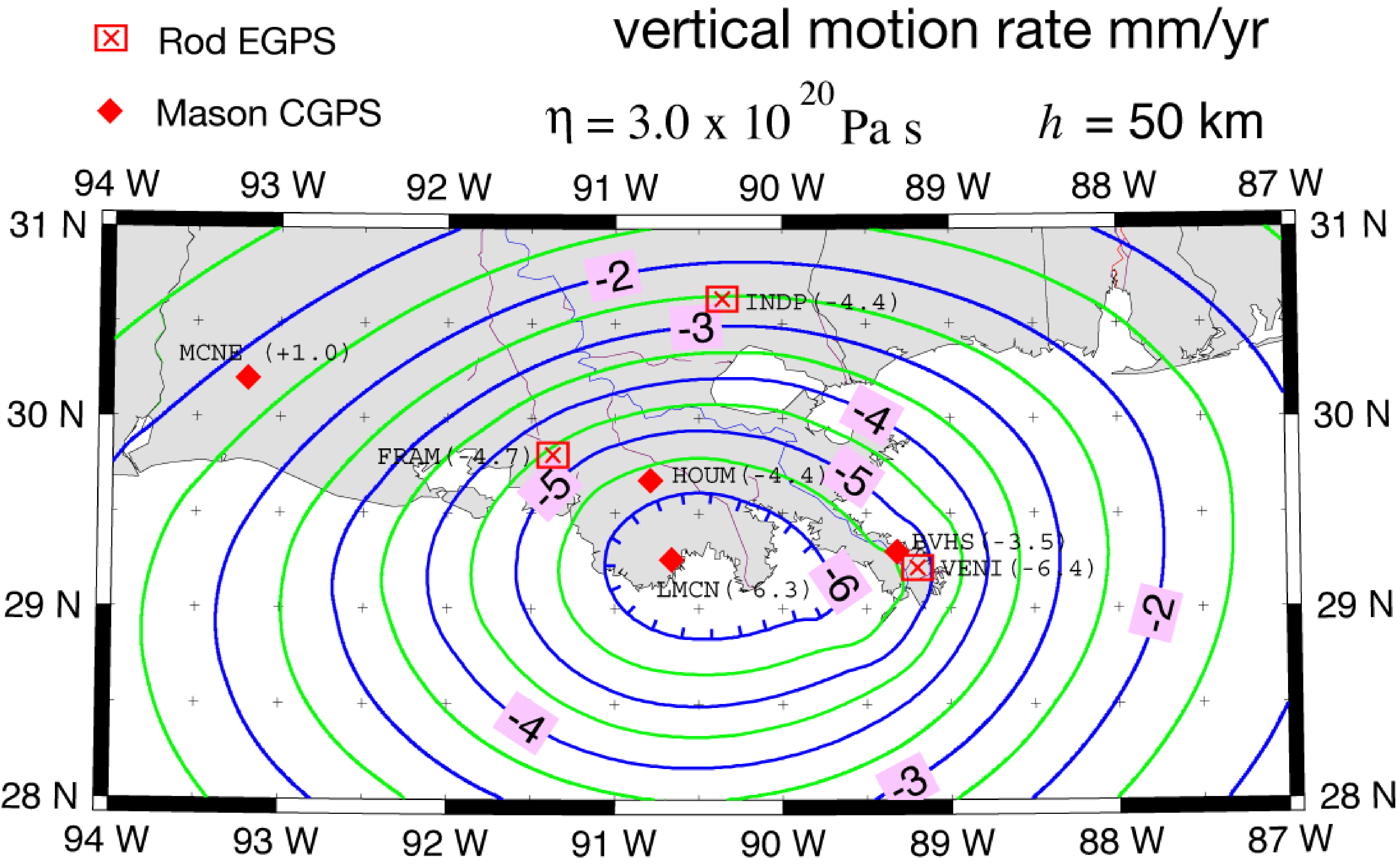
Integration of these 3 methods would provide:

A geophysical basis for understanding and predicting subsidence

A mechanism for subsidence mapping/monitoring

Since the first Glacial Maximum in North American (2.4 Ma) Gulf sediment deposition rate has increased nearly ten-fold

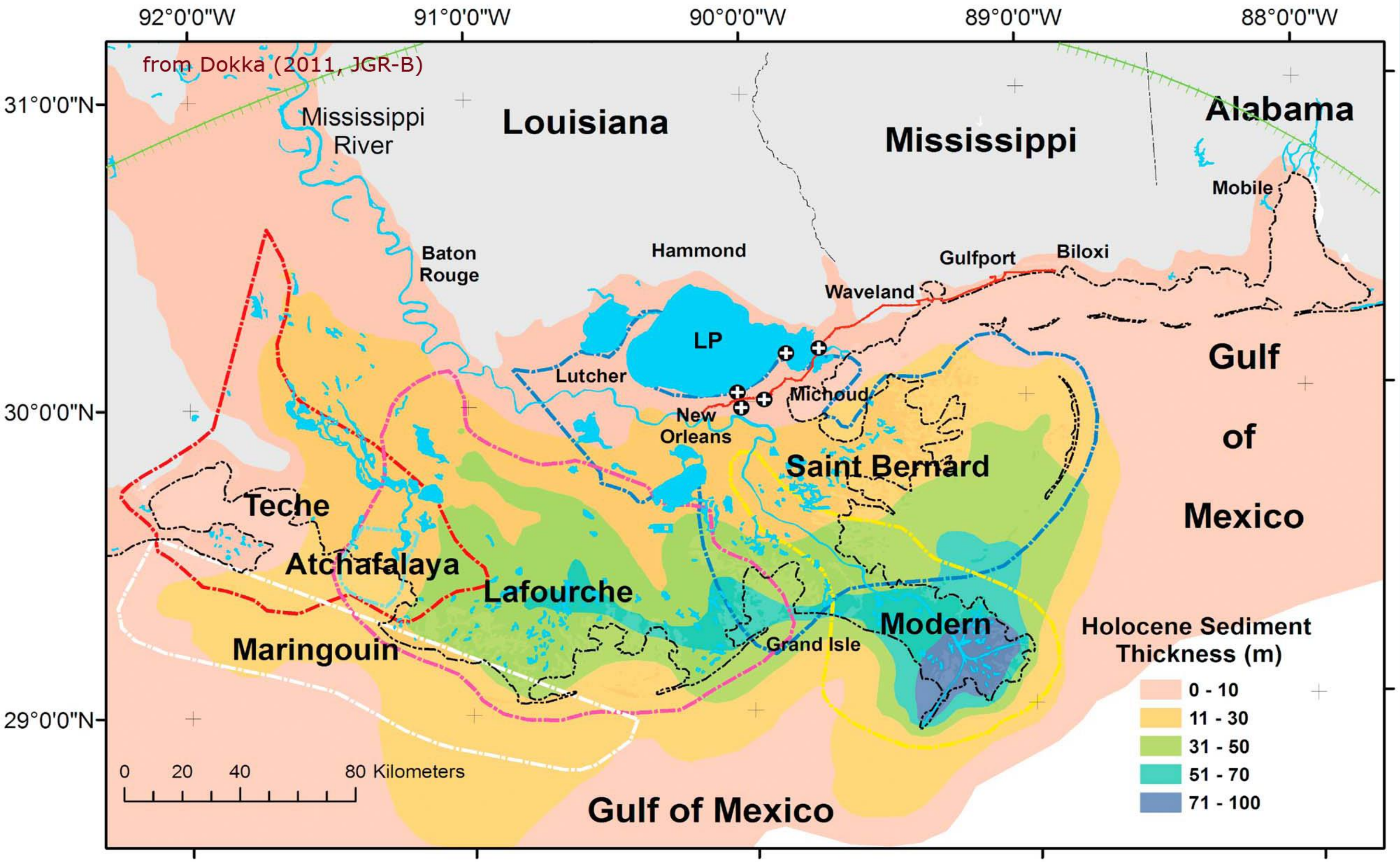




Ivins, E.R., R.K. Dokka & R.G. Blom, Post-glacial sediment load and subsidence in coastal Louisiana, *Geophys. Res. Lett., 34,* L16303, doi: 10.1029/2007GL030003, 2007.

New Sediment Load Map

- **Revised sediment load thickness history (Coleman et al, 1998; Kulp 2000)**
- **Load from Mississippi Fan included (Simms et al., 2007)**



Revised load and GPS data lead to revised load 'background' subsidence model

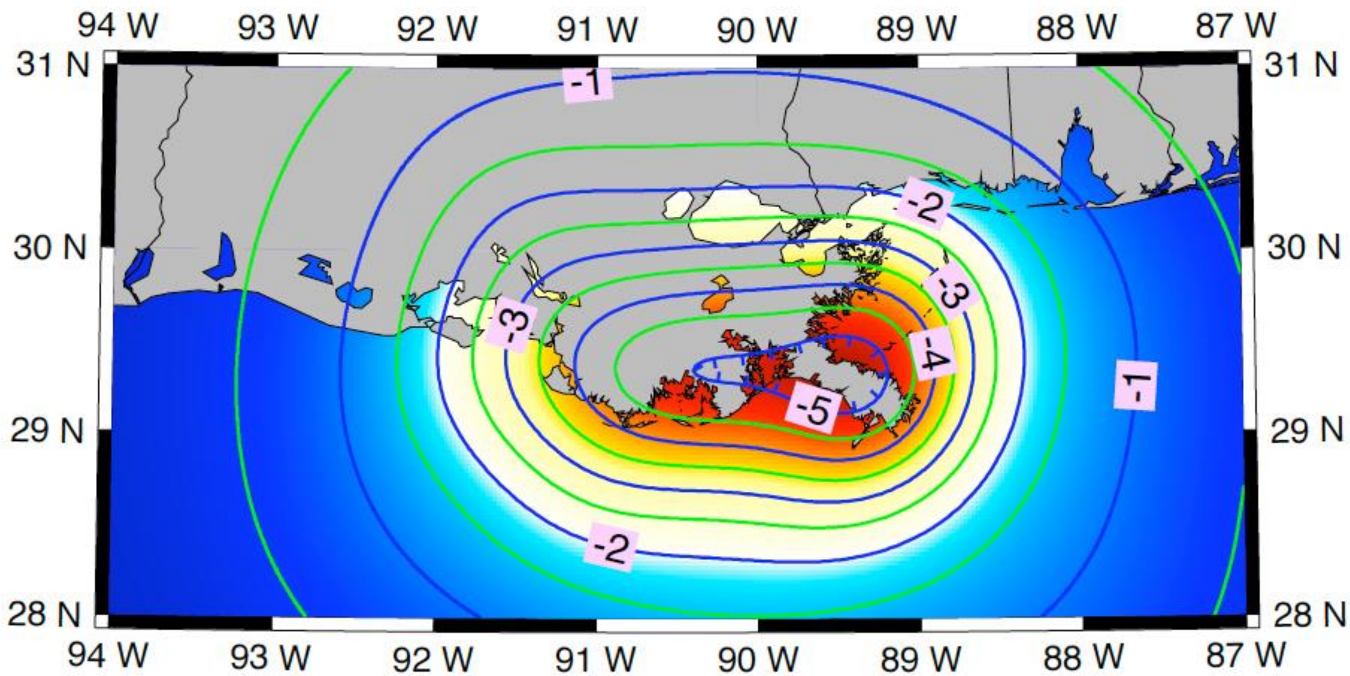


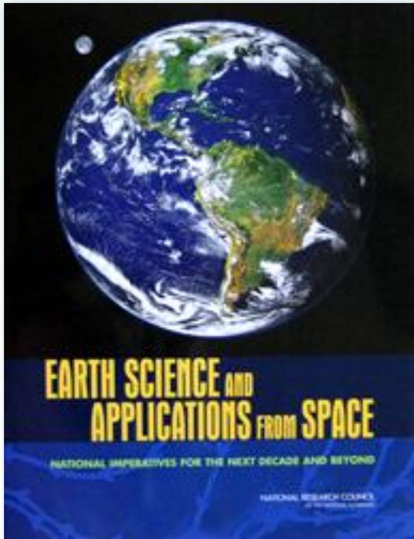
Figure X. Sediment load assumes thicknesses shown in Figure 1a (Dokka and Ivins 2011) with timing as inferred from a compilation of sources summarized in Table 1 of Ivins et al. (2007). Lithospheric thickness is 45 km. Model viscosity is $\eta_{u.\ mantle} = 2.0 \times 10^{20}$ Pa s and an elastic rigidity of dry clay (From Helgarud et al. 1999). The load assumes sediment deposition during over the Holocene and at the present-day .

Revised Holocene Sediment load

- Refined data provided by Dokka (2011).
- Fitting of Ivins et al., 2007 model to new and more precise GPS data (unpublished).
- New model provides 'background' regional subsidence model for examination of detailed vertical motion data from 20th Century (fluid withdrawal, compaction, growth faults, land use, etc. (Dokka, 2011).
- Dokka, R. K. (2011), The role of deep processes in late 20th century subsidence of New Orleans and coastal areas of southern Louisiana and Mississippi, *J. Geophys. Res.*, 116, B06403, doi:10.1029/2010JB008008.
- Series of models to be published-requires access to geodetic data at LSU.

Radar Interferometry-InSAR

- **In**terferometric **S**ynthetic **A**perture **R**adar technique can provide geographically comprehensive Earth surface deformation measurements
- Although much exciting science has been done with available radar data, existing radar satellites have not been designed expressly for InSAR measurements, and have serious shortcomings with regards to sampling interval, scene decorrelation, satellite tasking, cost of data etc.
- Accordingly, **systematic** InSAR observations of volcanoes, earthquakes, ice, subsidence, and other phenomena has not been possible
- In 2007 the National Research Council recommended a sequence of missions to NASA to satisfy critical data needs
- ***D***eformation, ***E***cosystems ***S***tructure, and ***Dyn***amics of ***I***ce
- **NRC** indicated **DESDynI** launch in 2017
- Now **E**arth **R**adar **M**apper- studies underway-launch?



The Gulf coast: A VERY challenging environment for InSAR

Satellite data considerations

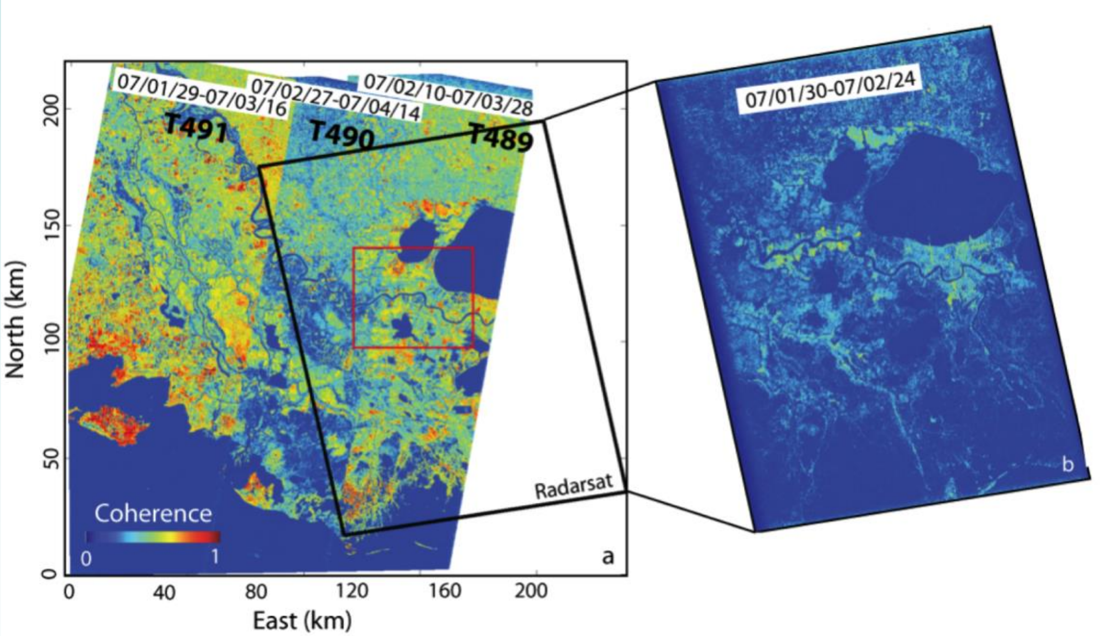
- Most existing satellite data is C-Band ~ 5.6 cm wavelength
- Data from European ENVI Sat, Canadian RadarSat
- Short wavelength decorrelates due to vegetation and other surface changes between data acquisitions-standard InSAR methods not useful
- "Point scatterer" methods can be used where suitable targets exist, buildings, bridges, etc. Dixon et al 2006 Nature paper on New Orleans used this method Natural terrain more difficult
- To capitalize on the long time series available only from the C-band systems, one of us (Lohman-Cornell) is developing an improved point scatterer technique
- Basic concept is to find and track scatterers in data sets over time, increases number of points

- Japanese ALOS satellite PALSAR is L-Band ~23 cm wavelength, much less decorrelation but limited data availability, long repeat interval (46 days), 2006 launch
- ALOS failed in 2010, new mission to be launched in December 2013, 14 day repeat, interferometry capable

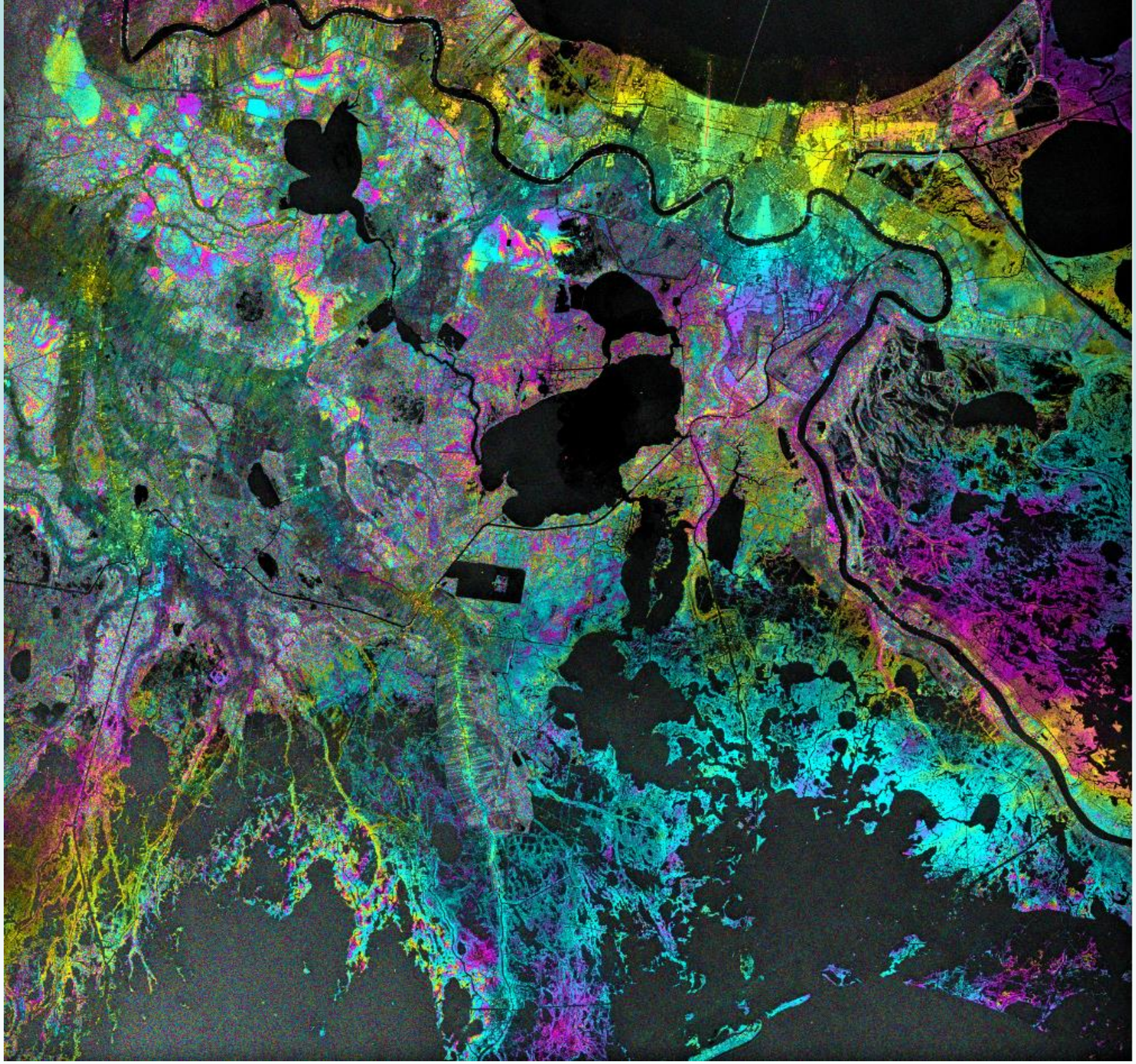
The Gulf coast is a VERY challenging environment for the InSAR technique

Most existing data is C-Band ~ 5.6 cm wavelength-data “decorrelates” due to vegetation and other changes between data acquisitions-standard methods not useful

Japanese ALOS satellite PALSAR is L-Band ~23 cm wavelength, much better



Comparison of coherence between L-Band interferograms in early 2007 and similar time interval using C-band data (black box in (a), b). C-band data shows very little coherence after just 26 days. L-band data maintains useable coherence over longer time spans.



- Preliminary improved point scatter technique RADARSAT interferogram covering New Orleans-(02/05/2006-03/25/2006, R. Lohman)
- High coherence in urban areas, wetlands, along levees
- Technique development may permit useful time series in the Gulf

UAVSAR

UAVSAR is an L-band fully polarimetric InSAR capable radar employing an electronically scanned antenna designed to support a wide range of science investigations.

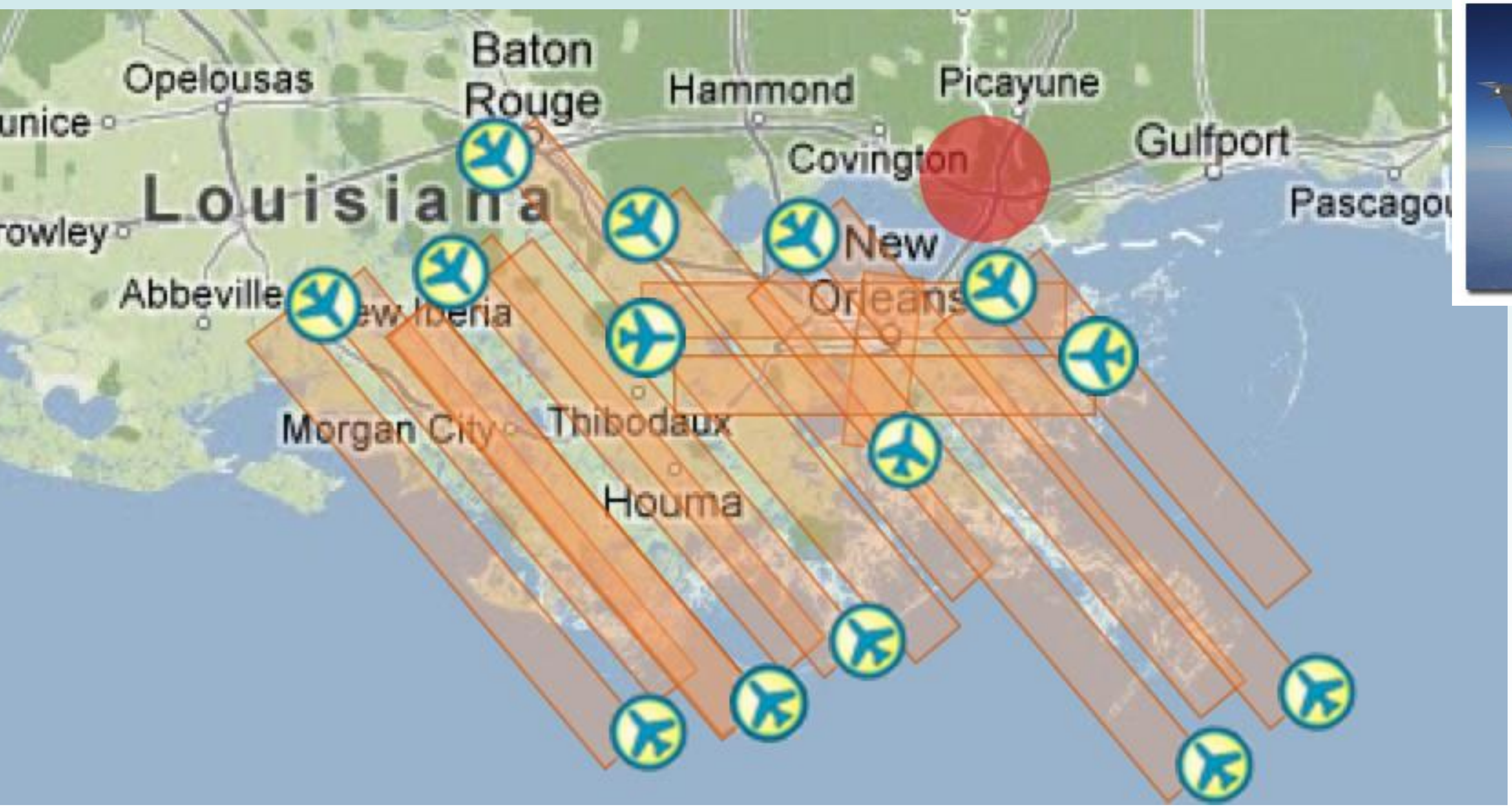
The UAVSAR design incorporates:

- **A precision autopilot developed by NASA Dryden that allows the platform to fly repeat trajectories that are mostly within a 5 m tube.**
- **Compensates for attitude angle changes during and between repeat tracks by electronically pointing the antenna based on attitude angle changes measured by the INU.**

Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz
Bandwidth	80 MHz
Resolution	1.67 m Range, 0.8 m Azimuth
Polarization	Full Quad-Polarization
ADC Bits	2,4,6,8,10 & 12 bit selectable BFPQ, 180Mhz
Waveform	Nominal Chirp/Arbitrary Waveform
Antenna Aperture	0.5 m range/1.5 azimuth (electrical)
Azimuth Steering	Greater than ±20° (±45° goal)
Transmit Power	> 3.1 kW
Polarization Isolation	<-25 dB (<-30 dB goal)
Swath Width	> 23 km

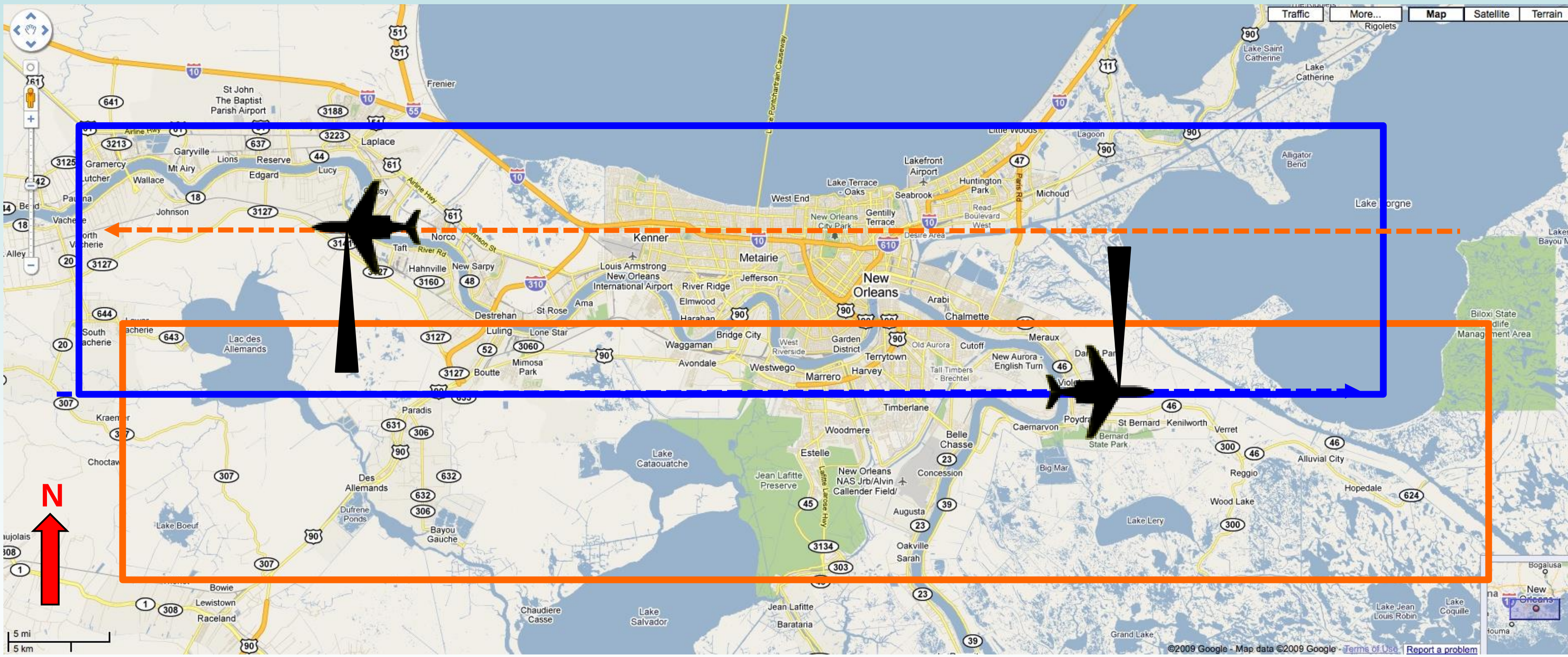
UAVSAR

- UAVSAR is an airborne radar interferometer developed by JPL for NASA
- We have requested UAVSAR fly a portion of the Gulf coast
- Data acquisitions July, Sept 09, Jan 10, June 11, Jul 12, Oct 12, Apr 13
- While data quality is excellent, interferometry challenging

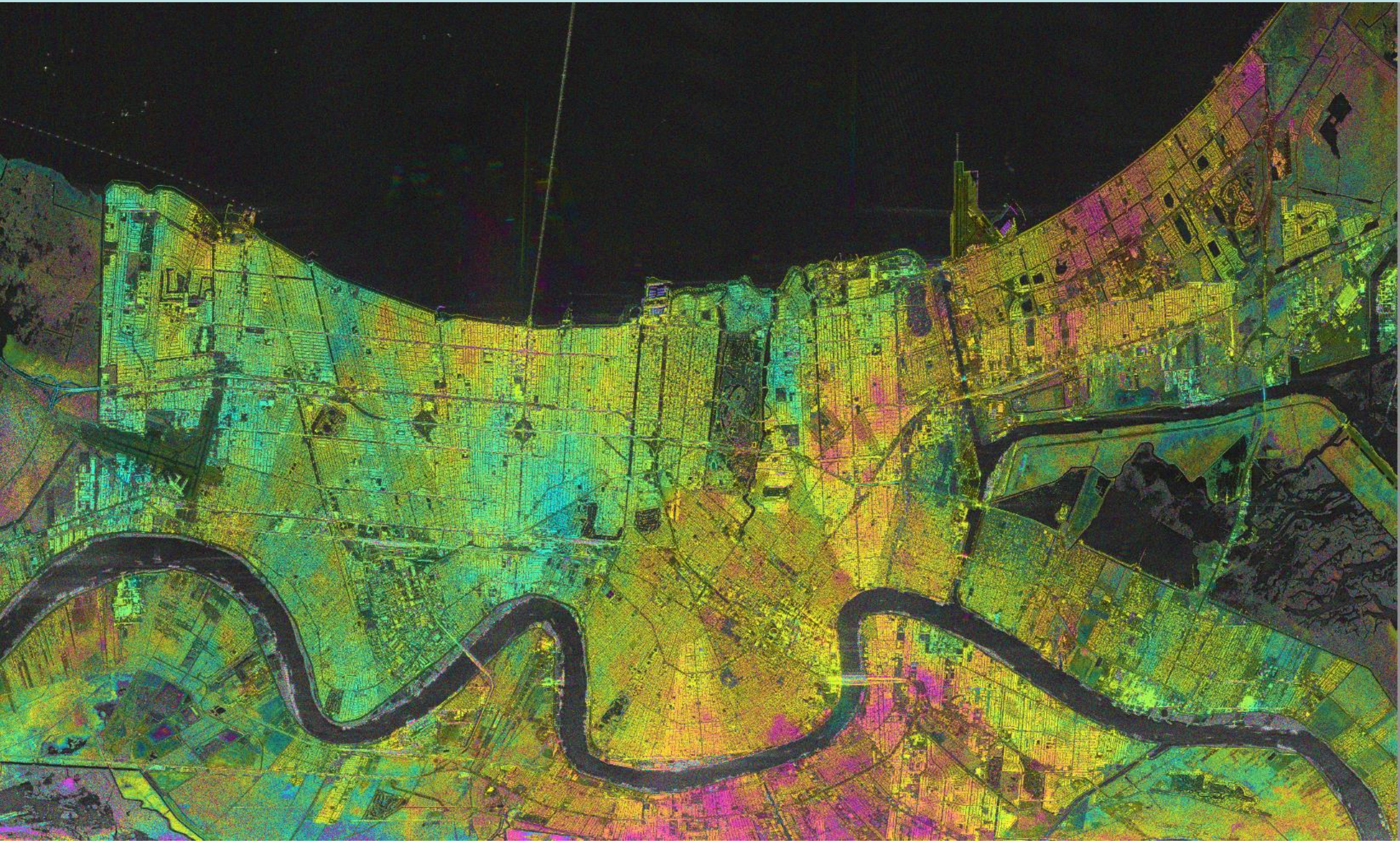


New Orleans UAVSAR Observations

- Repeat pass data were collected on multiple headings (including 90˚ and 270˚) on June 16 and September 3 of 2009 yielding a 79 day repeat period.

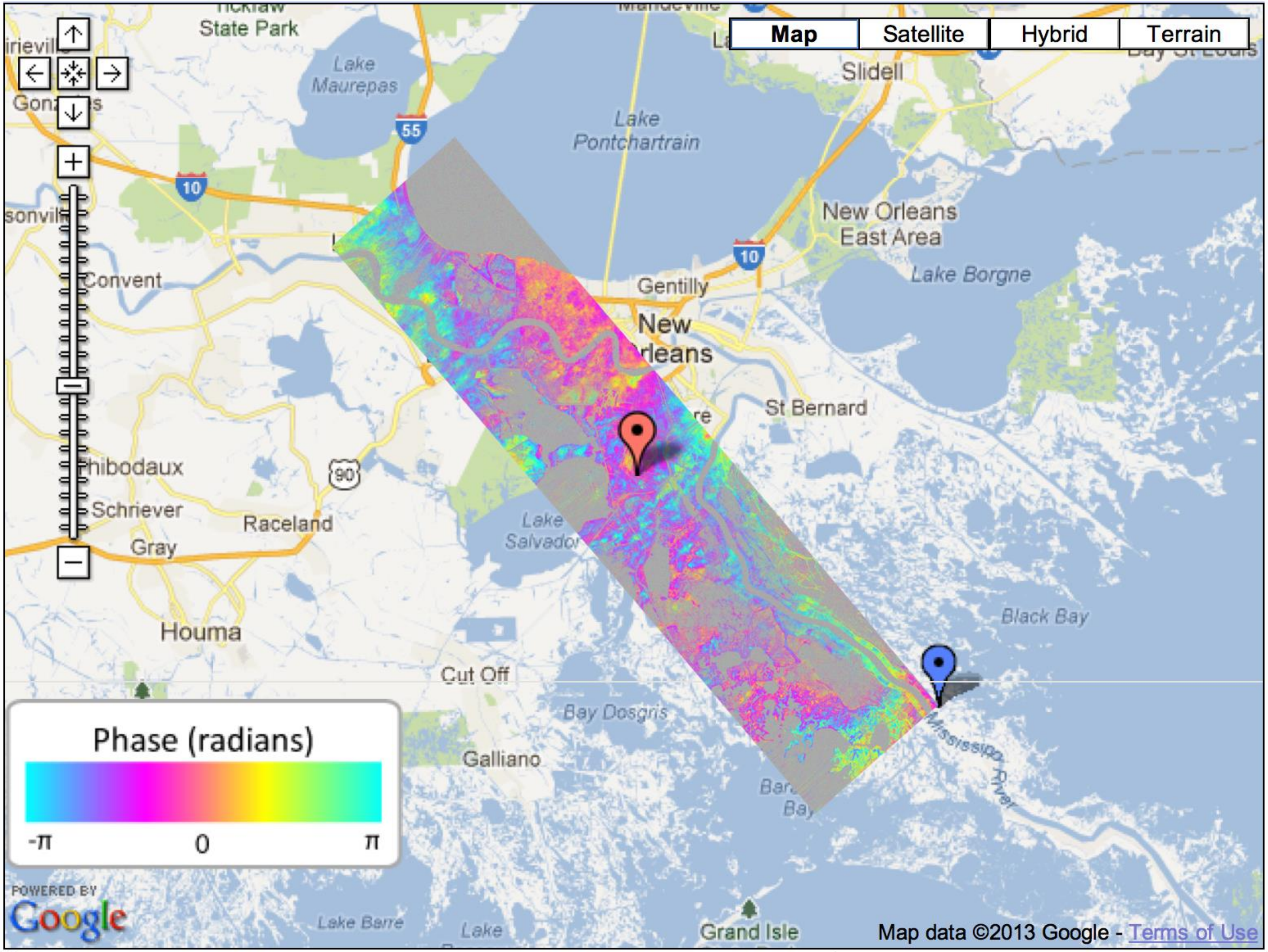


79 Day UAVSAR Interferogram



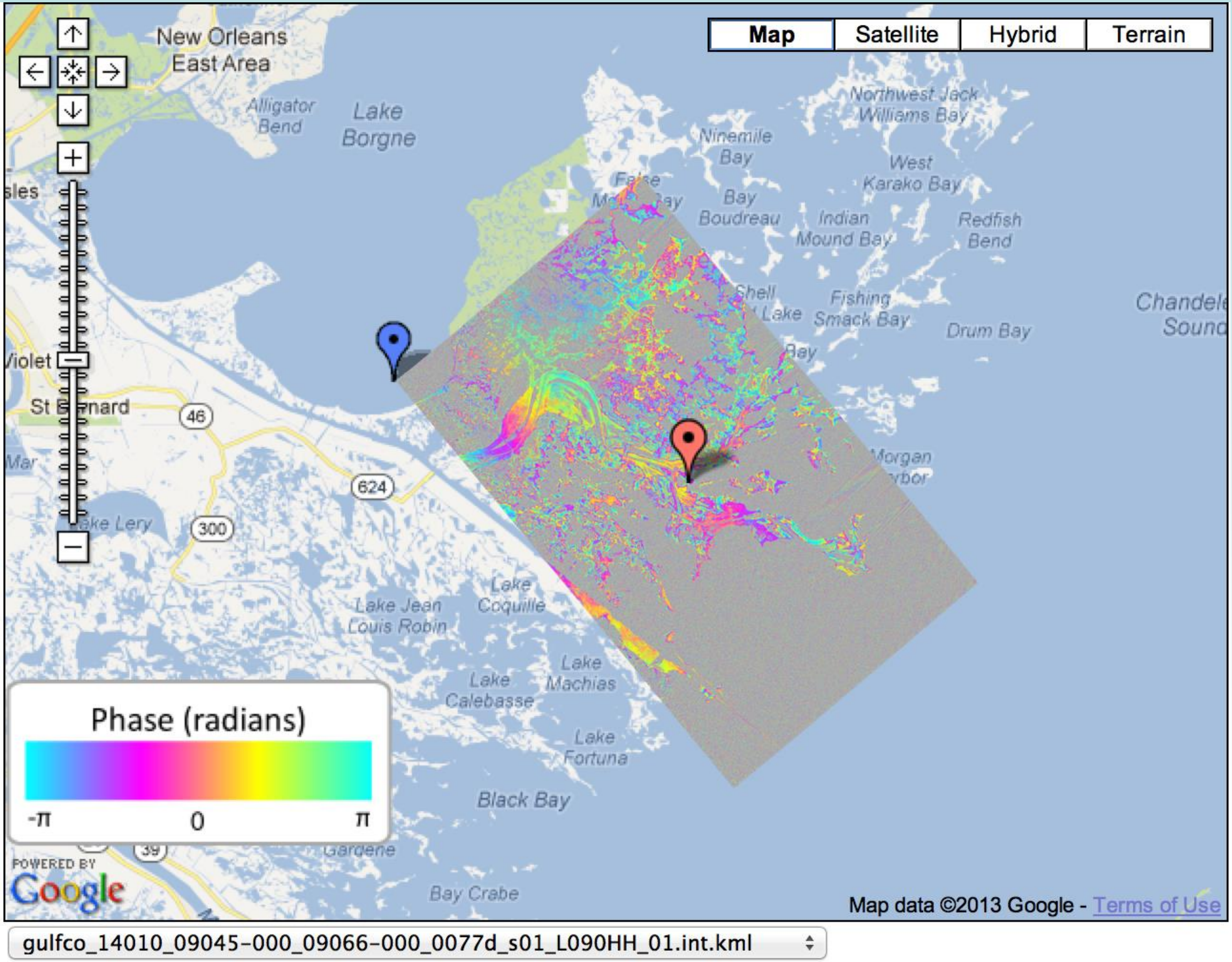
77 Day UAVSAR Interferogram

RPI Image of Gulf Coast, LA

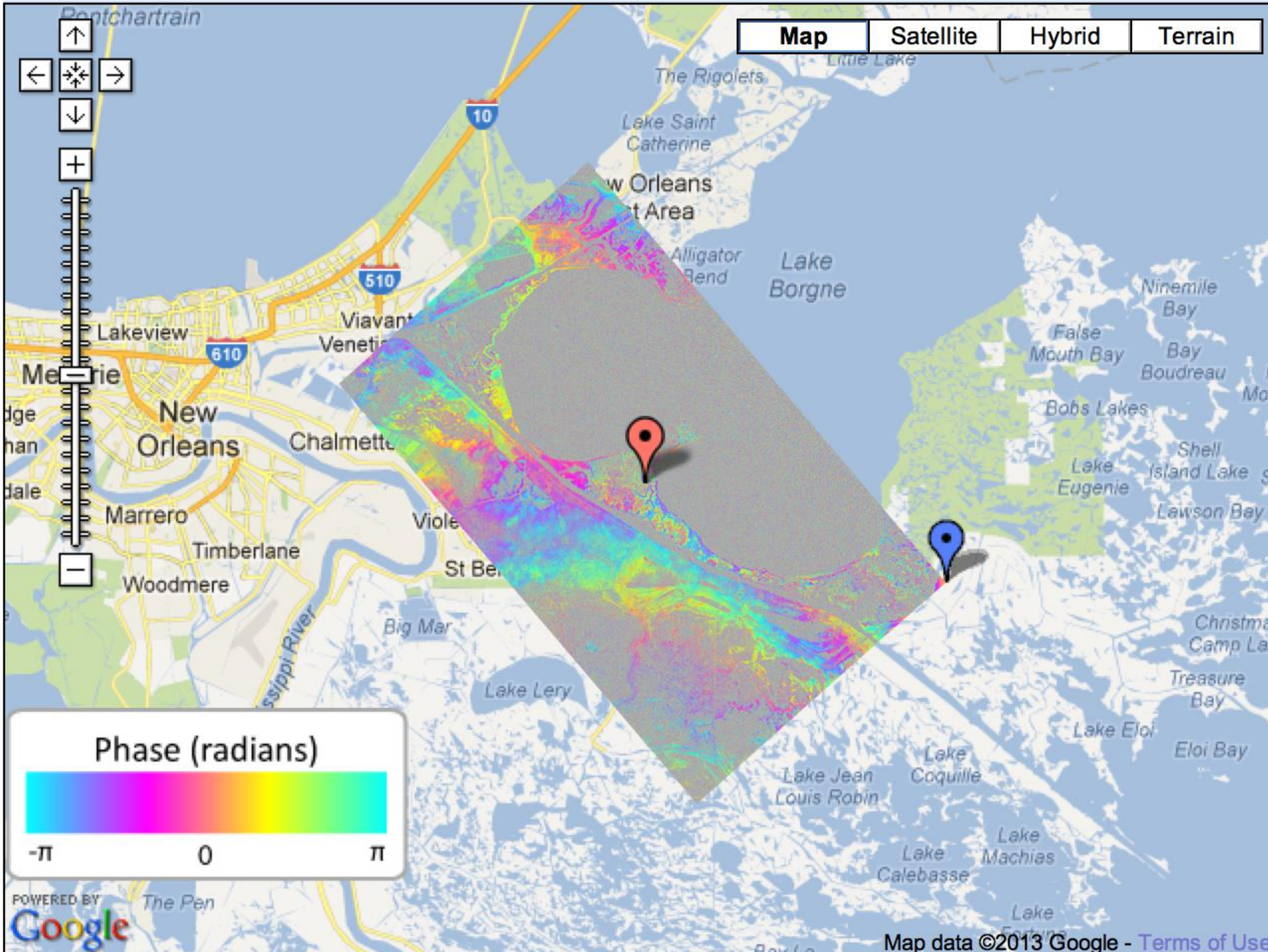


gulfco_32017_09045-001_09066-003_0077d_s01_L090HH_01.int.kml

77 Day UAVSAR Interferogram

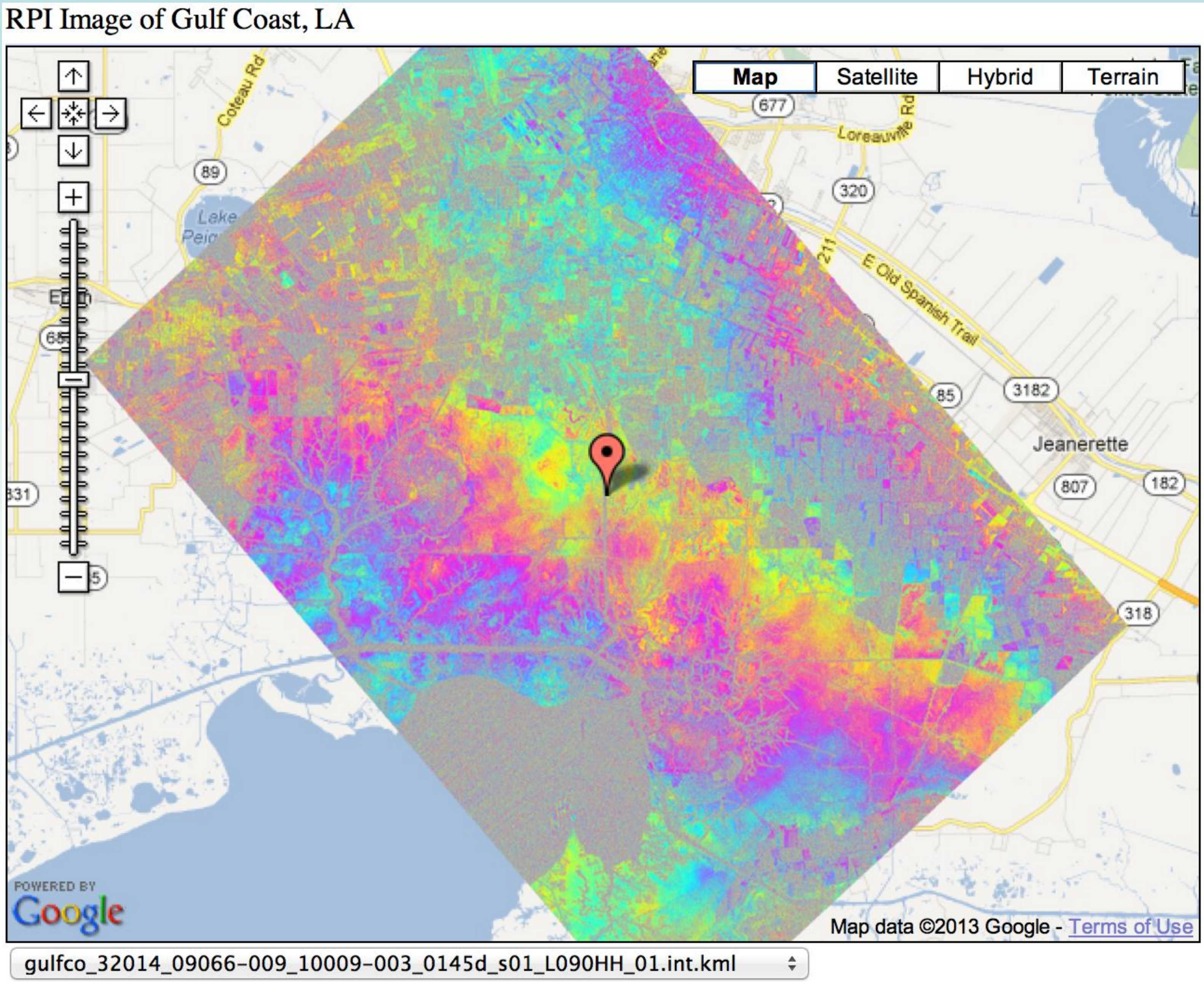


RPI Image of Gulf Coast, LA

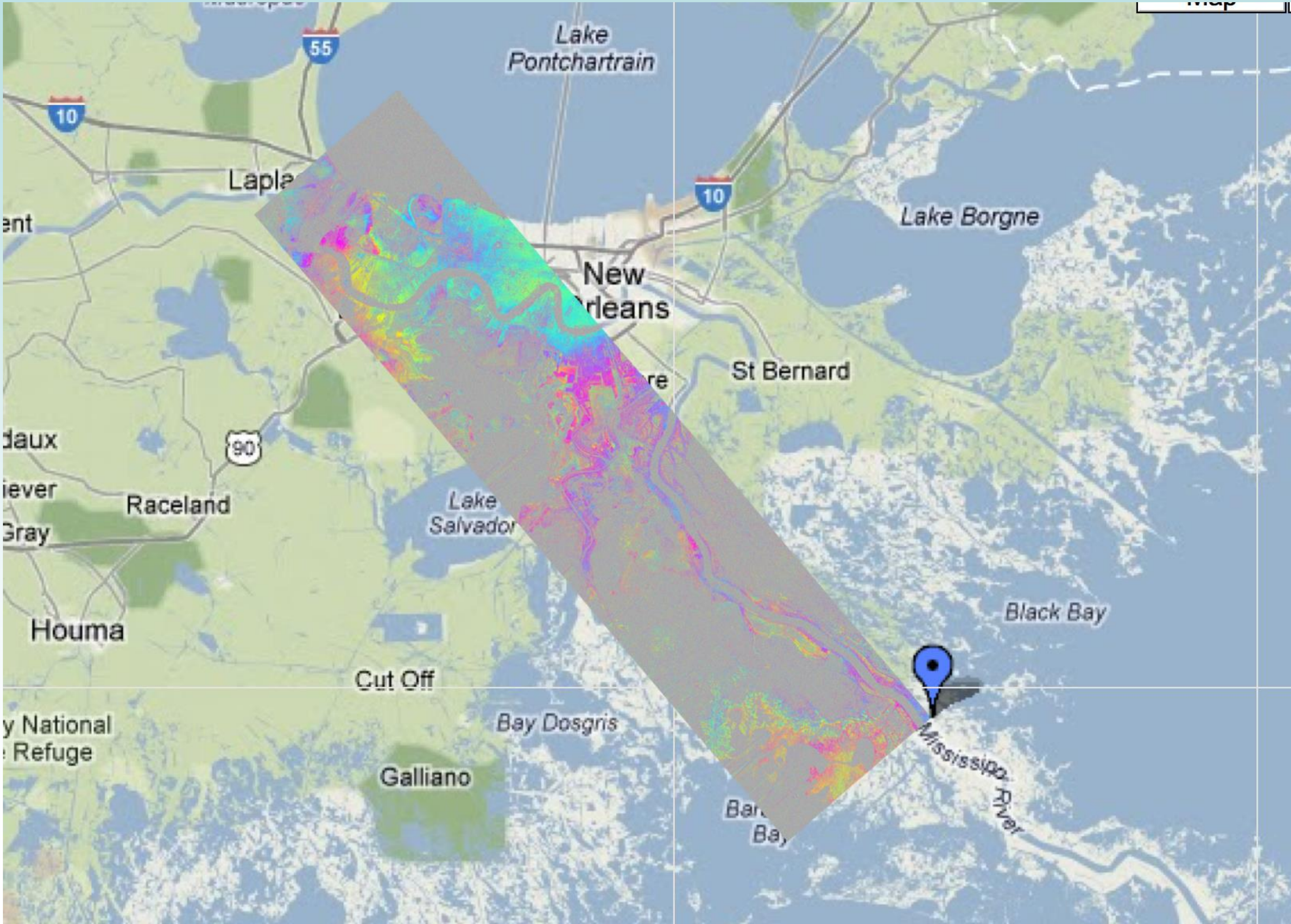


gulfco_32010_09045-001_09066-001_0077d_s01_L090HH_01.int.kml

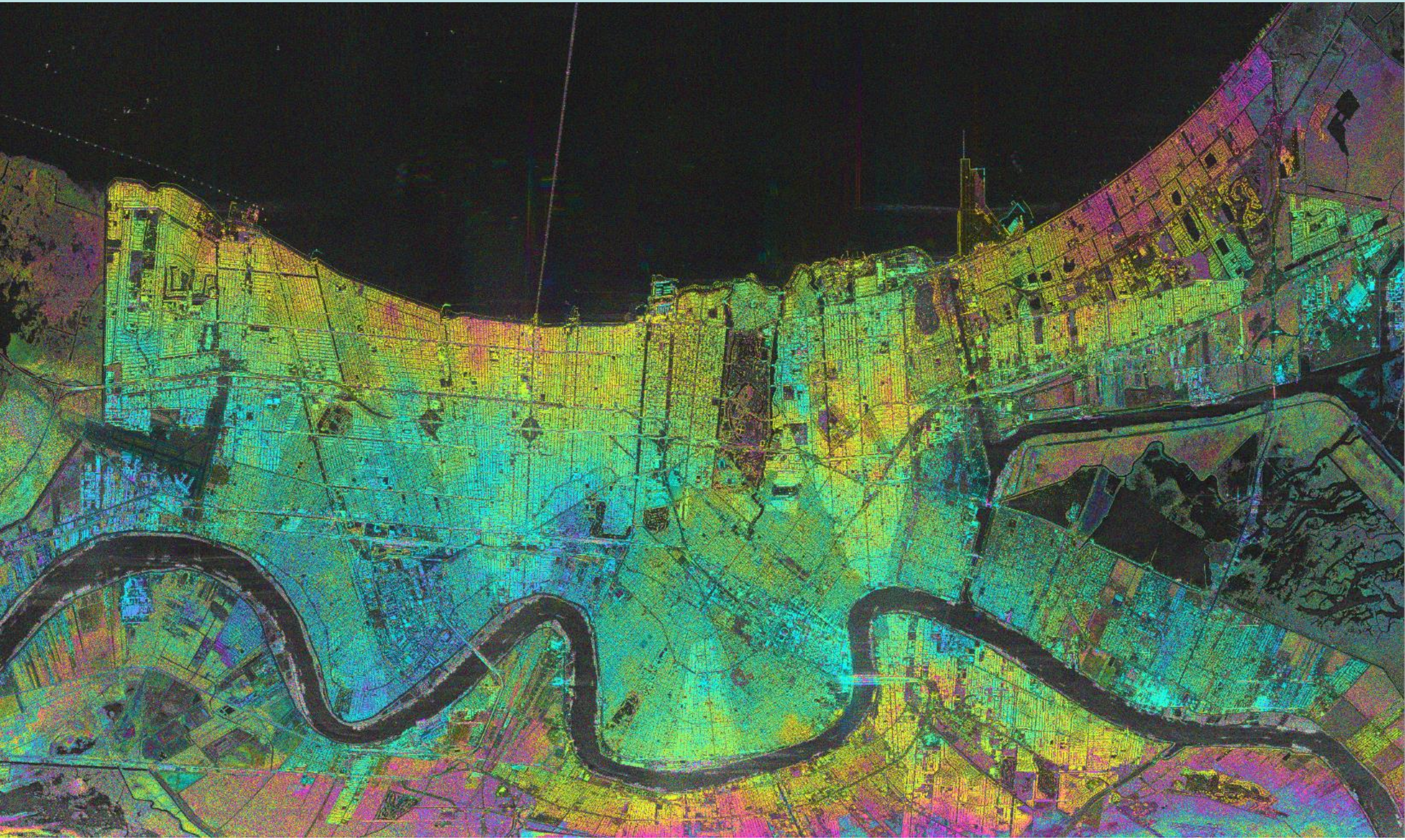
145 Day UAVSAR Interferogram



371 Day UAVSAR Interferogram

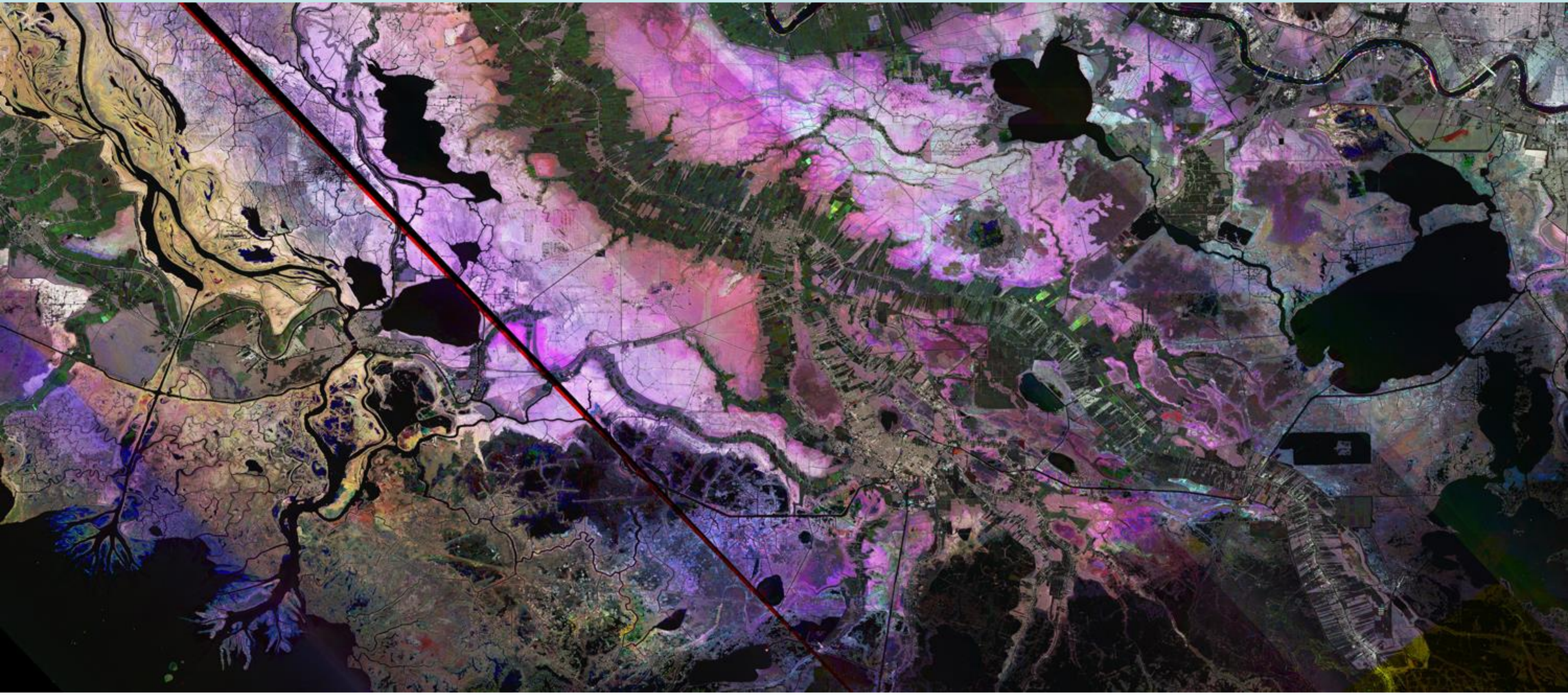


223 Day UAVSAR Interferogram

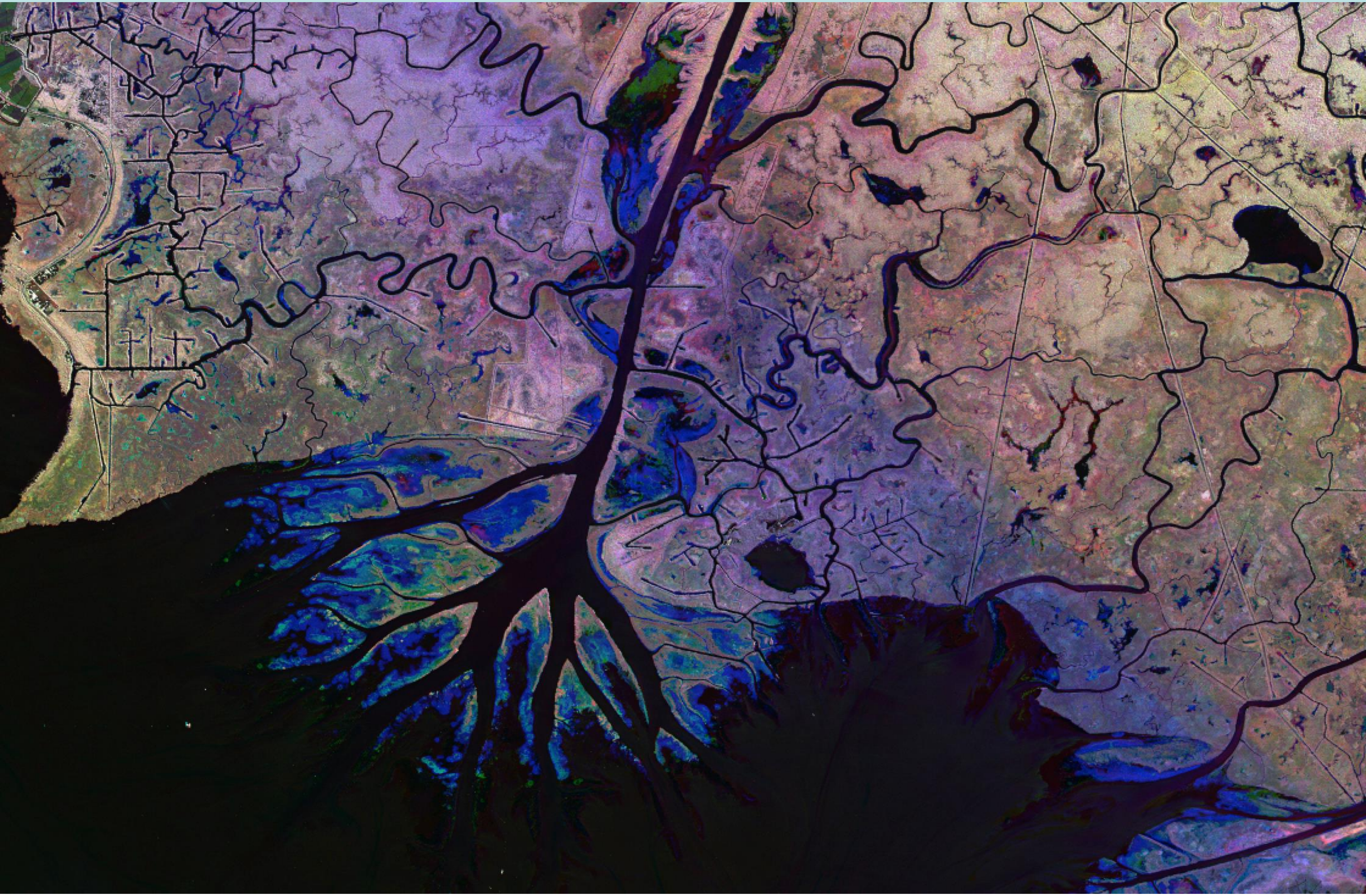


Gulf Coast Subsidence

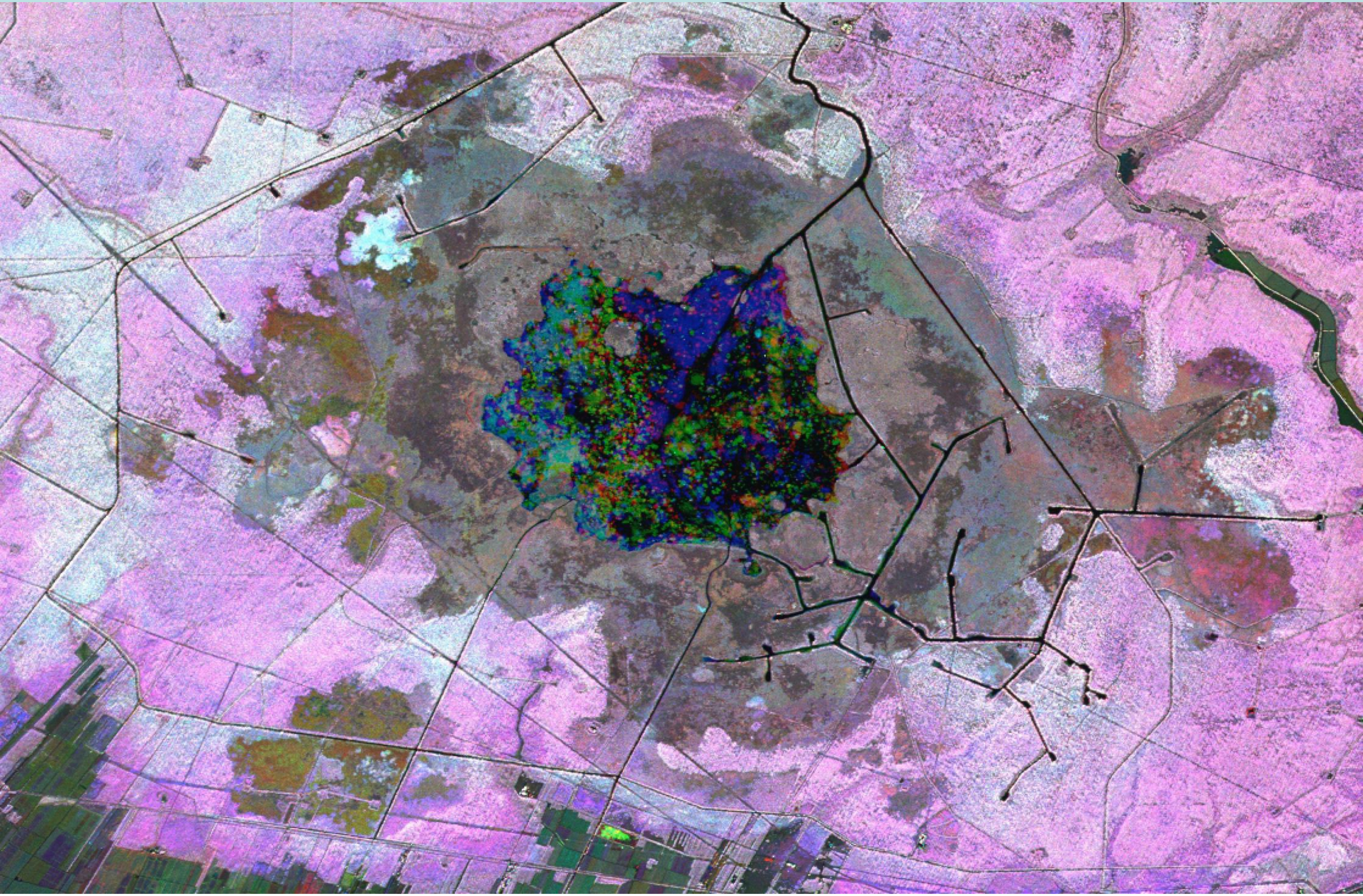
- So now we have some RPI data-how to interpret?
- How to separate subsidence features from dominant water/veg etc?
- Examine context through larger scale mosaics of UAVSAR image swaths
- Start with slant range data
  - Compensate for range dependent backscatter variations
  - Still in progress
- Project to ground range and mosaic
- Following from Bruce Chapman



L-HH June 2009, June 2011, July 2012

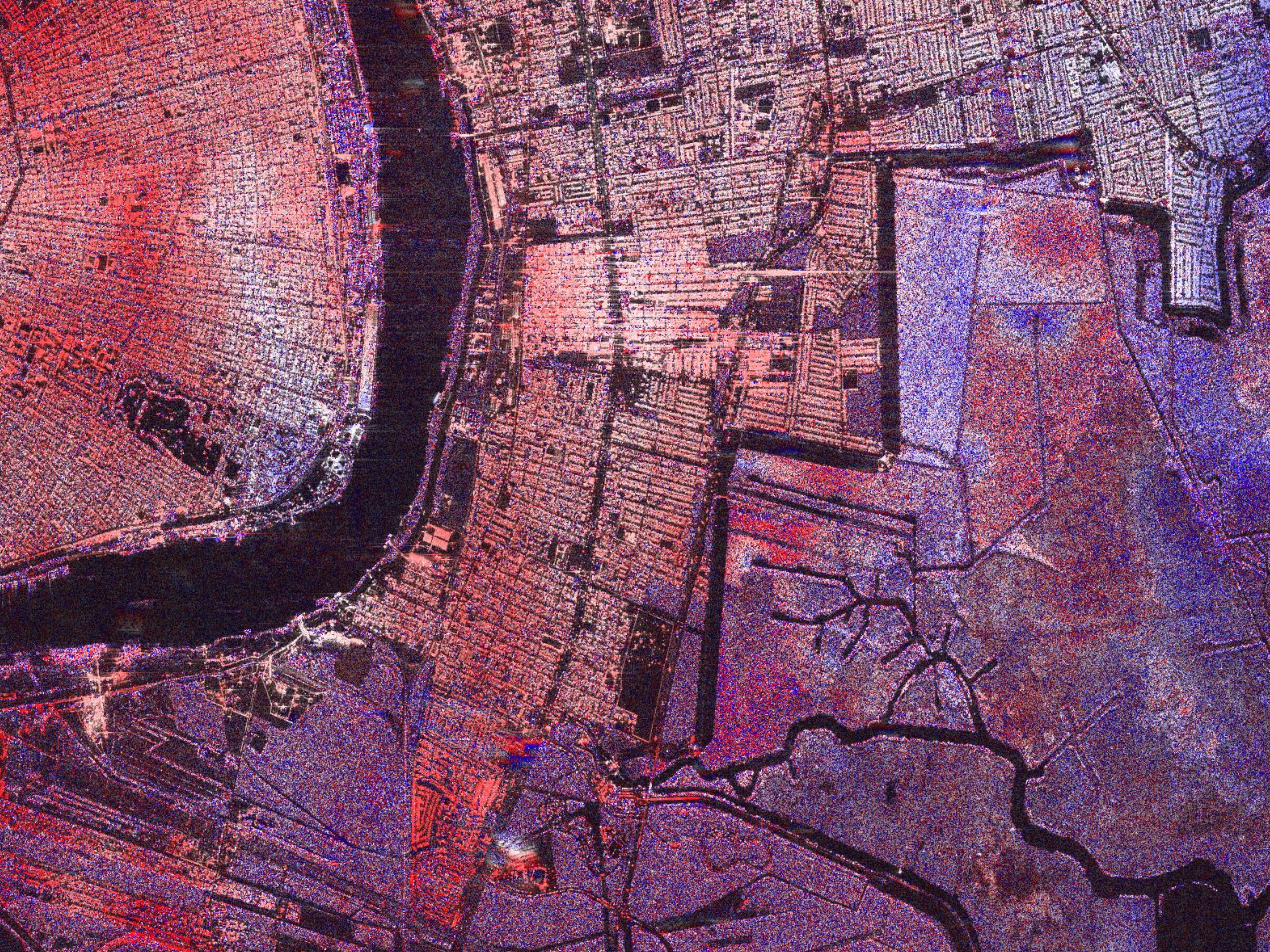


L-HH June 2009, June 2011, July 2012



L-HH June 2009, June 2011, July 2012

Flight 12053 to 12115 unwrapped phase-
July 2 - Oct 26 2012-Red = down
Courtesy Cathleen Jones



Summary

Geophysical modeling

- Load driven bedrock subsidence varies spatially, range 2-7 mm per year
- This is in addition to sea level rise of ~ 3mm/ yr, wetland loss, compaction, and other subsidence factors
- Geophysical model predicts pattern and amplitude seen in geodetic data
- Model being refined, but general conclusions are geophysically inescapable

Geodesy

- Geodetic techniques provide precise POINT positions
- Continuous GPS provides temporally continuous record
- Geodetic data constrains geophysical model

InSAR

- InSAR technique can provide geographically comprehensive temporal snapshots of deformation in map form
- UAVSAR showing great promise with new/refined processing, esp short repeat intervals
- Interferograms must be tied to a geodetic datum
- **DESDynI-Earth Radar Mapper like satellite could provide this data**