National Wetlands Newsletter, Vol. 38, No. 1, Copyright © 2016 Environmental Law Institute ® Washington, D.C., USA

Radar Remote Sensing of the Louisiana Wetlands to Study Delta Formation and Marsh Status

The National Aeronautics and Space Administration (NASA) has been collecting images of Louisiana's Gulf Coast since 2009, which has greatly supported research on various wetlands topics such as land changes and delta formation. New technology developed by NASA and the Jet Propulsion Laboratory, California Institute of Technology has allowed for data collection with many beneficial implications for future research in coastal regions.

By Dr. Cathleen E. Jones

In June 2009, the National Aeronautics and Space Administration (NASA) began a multi-year campaign to study the Mississippi River Delta of Louisiana, acquiring baseline images covering the southeastern corner of the state from Avery Island to offshore of the Birdfoot Delta (Figure 1). The campaign used what was at the time the newest member of the NASA Airborne Science Program's instruments, a high-resolution, low-noise, 1.27 GHz radar—the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR). The UAVSAR Gulf of Mexico campaign has continued through 2015 with the baseline images from June 2009 reacquired one to three times per year. The initiation of acquisitions in 2009 was fortuitous, allowing imaging of conditions prior to a number of significant events that

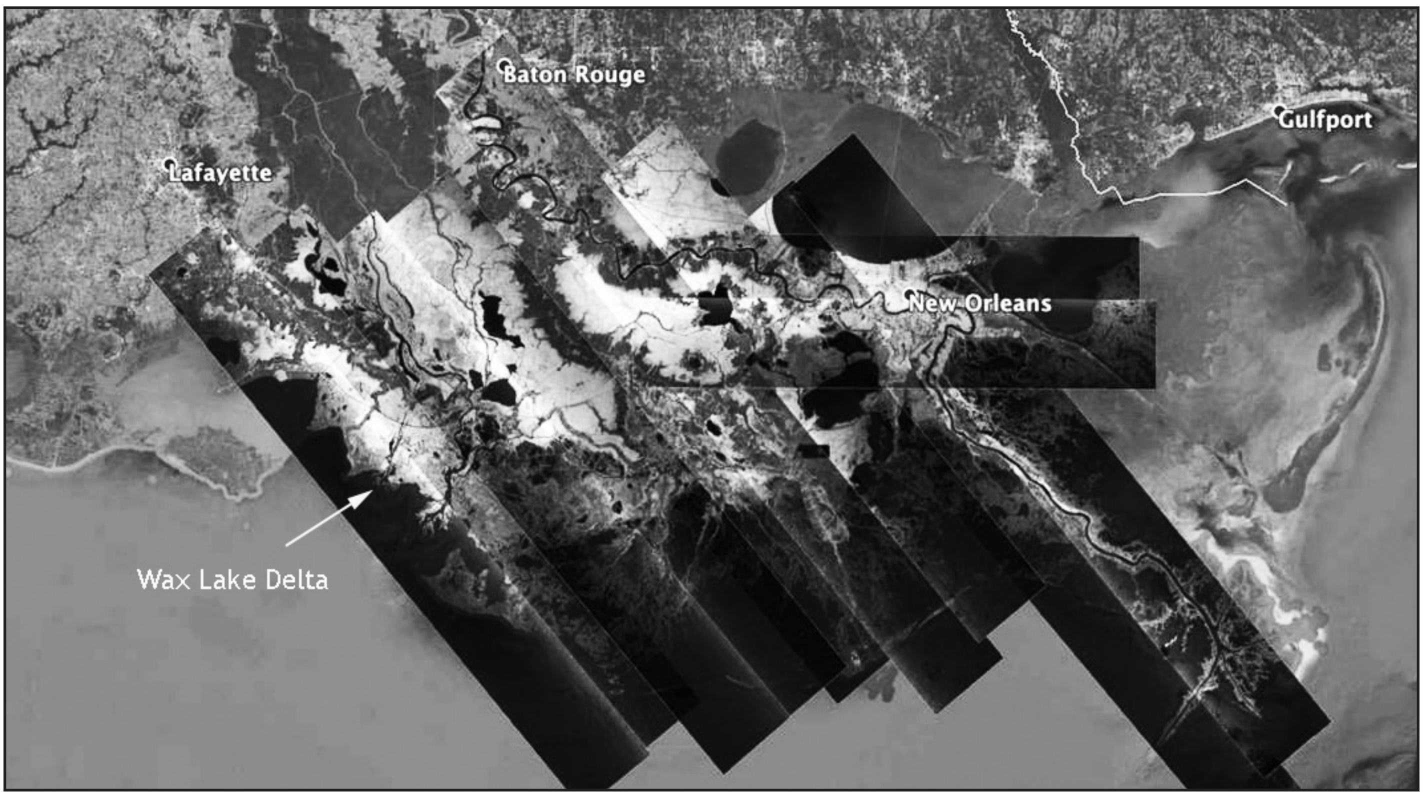

Figure 1: View of the southeastern corner of Louisiana, with overlain UAVSAR image swaths showing the extent of coverage. Background image provided by Google Earth.

occurred in the area, in particular, the *Deepwater Horizon* (DWH) oil spill in April-July 2010, the historical high-water conditions during the Mississippi River flooding of spring 2011, and the formation of the Bayou Corne sinkhole in August 2012. The data, originally acquired to support a study of subsidence across the Mississippi River Delta (Blom et al. 2011), has proven to be a treasure trove, supporting a much broader range of studies, from the ecology of Louisiana's coastal wetlands and post-DWH impact to the marshlands in Barataria Bay, to sinkhole precursor detection, oil spill monitoring, and delta formation.

Despite the instrument name, UAVSAR is standardly flown on a customized C-20A (Gulfstream III), a manned aircraft, and derives the name from the fact that its pod-based design supports being flown on large UAVs. Figure 2 shows the instrument pod installed on the aircraft, hanging from the fuselage near the leading edge of the wings. Instead of simply being a payload instrument, portable between disparate platforms, UAVSAR is an unusual combination of instrument and aircraft. Its automatic radar controller provides information about the C-20A's location, measured with Differential Global Positioning System (dGPS), and a platform-specific precision autopilot system controls the aircraft to maintain a highly accurate and repeatable flight track (Hensley et al. 2009). The aircraft is able to maintain and repeat a planned flight track within a five-meter radius tube, with typical performance significantly better, at the one- to two-meter level. This repeat track capability enables the data to be used for Interferometric Synthetic Aperture Radar (InSAR), which is a method of measuring surface deformation with sub-centimeter accuracy (Klees & Massonnet 1998). Interferometry cannot detect elevation change on open water because of the rapidly altering, small-scale capillary waves on the water surface. However, it can be used to determine water elevation change in areas with vegetation exposed above the water surface through double-bounce scattering. For example, the radar pulses forward scattering first from the water, then from the vegetation, and then back towards the radar antenna. Although UAVSAR was originally designed specifically for solid earth studies that require InSAR (e.g., studying earthquake faults and volcano growth), it also has the capability to transmit and receive electromagnetic radiation in both horizontal and vertical polarization. This full-polarization capability is often used for vegetation studies, and is of particular importance for studies of wetland ecosystems.

UAVSAR's most recent return to southern Louisiana in May 2015 included acquisitions for a new study investigating delta formation processes, with the Wax Lake Delta as the natural testbed. The Wax Lake Delta, located on the Gulf Coast southwest of Morgan City, Louisiana (see Figure 1), is one of a few naturally growing river deltas in the United States. The subaqueous delta began to form at Wax Lake after the U. S. Army Corps of Engineers cut an artificial channel to divert water from the Atchafalaya River to the Gulf Coast in 1941, intended to reduce flooding in Morgan City. Sediment carried by the river settled out as the water slowed upon reaching the one- to two-meter-deep bay at the coast, slowly building in elevation, with the new land first exposed around 1973. The delta has been continuously growing in elevation and extent since. It is becoming a near-classic site for studying natural delta formation owing to the fact that the Wax Lake Outlet Canal, although initially man-made, has never been leveed or dredged. This delta is evolving without influence from the suite of engineering modifications that are altering the vast majority of deltas worldwide, causing them to experience a loss of the sediment influx needed for natural land-building (Syvitski et al. 2009). In the face of reduced sediment influx, many deltas, including the Mississippi Delta, are experiencing land loss

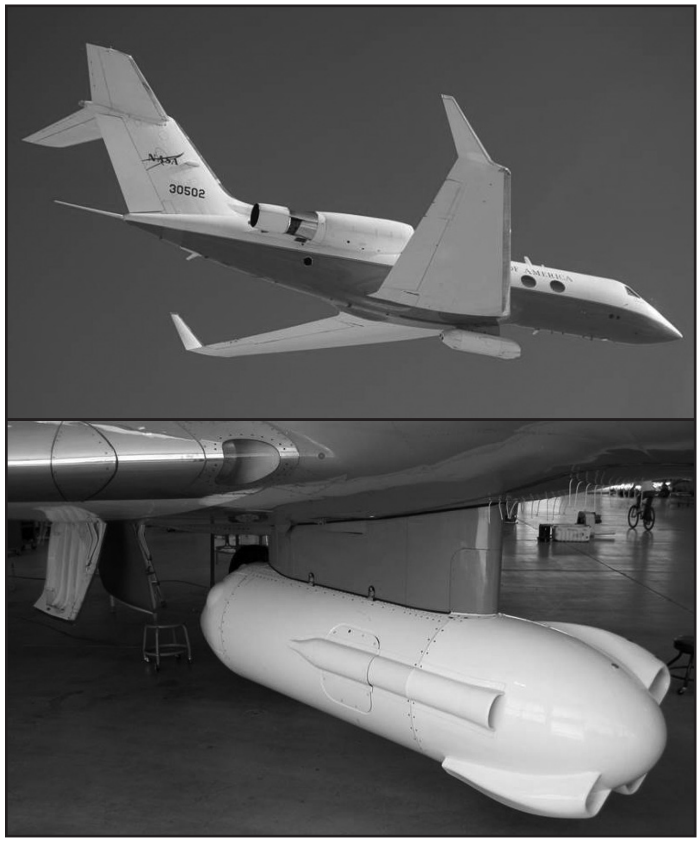

Figure 2: (*Top*) C-20A (Gulfstream III) in flight. Image provided courtesy of the Armstrong Flight Research Center. (*Bottom*) The inlets on the front of the pod enable the electronics to be ambient air-cooled so that the pod can be ported to an uninhabited aerial vehicle. Photo credit: Dr. Cathleen E. Jones

from a combination of subsidence and sea-level rise, often exacerbated by a variety of other influences, such as wetland health degradation from saltwater and storm surge incursion along man-made canals. Effective remediation of deltaic land loss requires an understanding of the underlying sediment transport and deposition processes (Wright 1977) to better model man-made diversions that could sustain land-building (Allison et al. 2014; Bentley et al. 2014). The Wax Lake Delta is currently the site of a National Science Foundation center, the Delta Dynamics Collaboratory, led by the University of Texas at Austin.

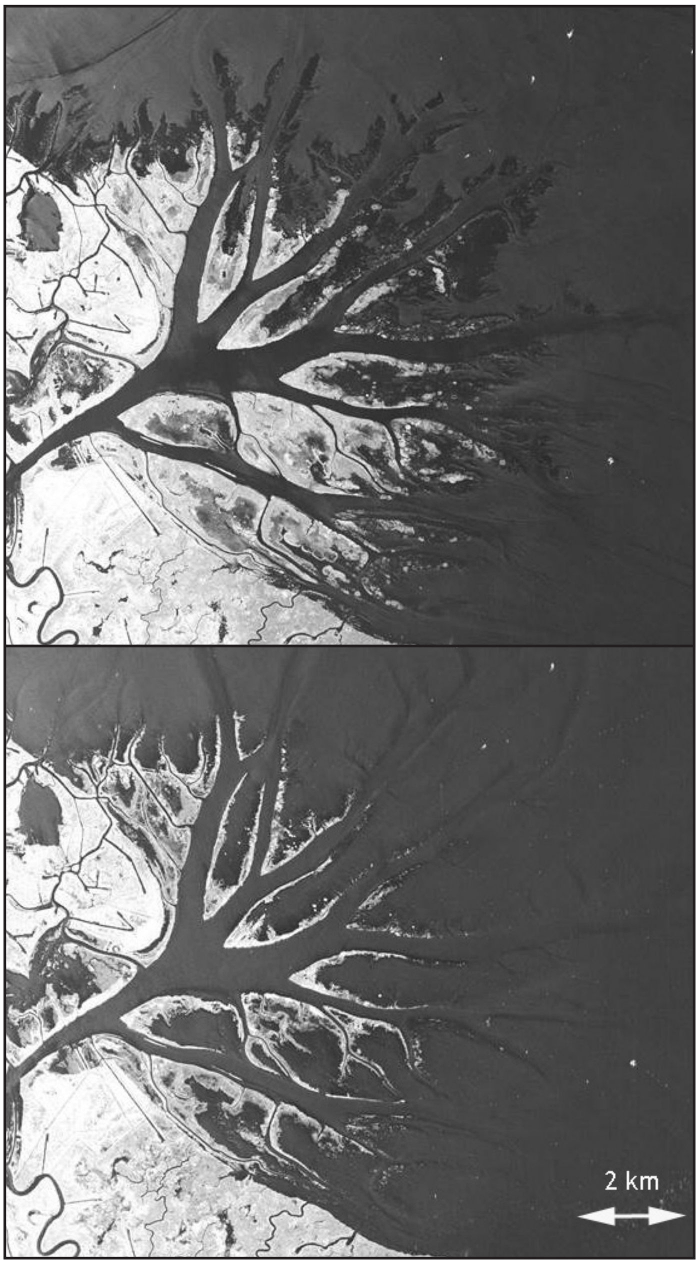

Figure 3: Two UAVSAR radar images of the Wax Lake Delta, Louisiana, with the upper image acquired on June 23, 2013, and the lower image acquired on April 4, 2013. The difference in the images is primarily due to different tidal and river outflow conditions. In the lower image, acquired during spring floods, the underwater channels can be seen extending seaward from the delta front. The radar intensity is sensitive to the bathymetry through changes in the small-scale surface capillary waves that indicate areas of faster flowing water. UAVSAR images provided courtesy of NASA/JPL-Caltech.

The NASA remote sensing study of the Wax Lake Delta was motivated by observation of the planform (view from above) bathymetry in the submerged portion of the Wax Lake Delta in UAVSAR images that are part of the time series acquired for the Mississippi River Delta subsidence study (Figure 3). This type of measurement is typically made using time-consuming and labor-intensive boat-based bathymetric sonar surveys, so the ability to observe submarine channel growth in shallow seas remotely, based on radar backscatter from the water-surface roughness, would be a significant boon to scientists studying delta morphology and dynamics. River deltas evolve naturally by self-organized flow of water and suspended sediment through a network of branching channels separated by islands built up from the deposited sediments. The branches change location to follow the maximum flow gradient, frequently altering their path following overtopping of the natural levees during a high-water event such as a major flood or storm. In a normal, uneventful year, the channels can grow in length offshore by approximately 100 meters, so the delta is continuously growing and changing. Water-surface elevation gradients and the bathymetry of the channels and the prodelta (the part of the delta that is always submerged, located seaward of the subaerial islands) are critical factors in understanding water and sediment flux through a delta, and are key to better modeling of deltas' response to climate change, information which, from the engineering perspective, is badly needed to sustain the world's endangered deltas.

NASA's Wax Lake Delta initiative, spearheaded by researchers at the California Institute of Technology and the Jet Propulsion Laboratory, California Institute of Technology (JPL-Caltech), brought together three of NASA's newest airborne instruments. The campaign occurred on May 5-11, 2015, during the high water of the year's Mississippi River spring floods, and images were acquired during different parts of the tidal cycle to capture changes with river stage and with the tides, both of which influence development of the Wax Lake Delta. UAVSAR was accompanied by the Airborne Surface Water and Ocean Topography (AirSWOT) and the Airborne Visible/Infrared Imaging Spectrometer-Next Generation (AVIRIS-NG) in a combined campaign that made use of the three instruments' complementary and unique advanced remote sensing capabilities. AirSWOT is an airborne calibration/validation and science support radar altimeter/interferometer for the Surface Water and Ocean Topography (SWOT) mission, a major NASA Earth satellite mission scheduled for launch in 2020 that will measure water-surface elevations near-globally both in the oceans and in many medium-to-large lakes and rivers. AirSWOT is used to measure water-surface gradients in the Wax Lake Canal and through the bifurcating channels of the delta. UAVSAR is used to measure planform bathymetric change from previous years, water level change across the tidal cycle within the islands of the delta, and to develop and test inversion algorithms to obtain bathymetry and water-surface currents along the delta front and the shallow waters surrounding the Wax Lake Delta. Extensive ground surveys to obtain ground validation data on water levels, currents, and vegetation status were made simultaneously in the delta and the nearby marshes, in collaboration with the NSF Collaboratory. The AVIRIS-NG instrument also acquired images of the delta, nearby wetlands, and coastal ocean, which will be used to study how vegetation modifies the water and sediment flow through marshes and the deltaic islands. At this point, analyses of all the instruments' data acquired in May 2015 are ongoing.

This newest study of the Wax Lake Delta is only one in a long list of work enabled by NASA's acquisition of the time series of repeated UAVSAR images of the southeastern corner of the state of Louisiana. To date, the most extensive usage of the data sets is associated with the direct and long-term impact of the DWH oil spill. In June 2010, during the middle of the spill, an extended three-day UAVSAR campaign was launched to image nearly the entire U.S. Gulf of Mexico coastline, from Key West, Florida, to Corpus Christi, Texas, with spatially comprehensive acquisitions of the coastal and inland wetlands of Louisiana (Jones et al. 2011). The acquisition plan was designed to capture a snapshot of conditions prior to oiling, to be used as a pre-spill baseline should oil from DWH make landfall anywhere along the coast, so that impact and recovery could be tracked in the years following the catastrophe. Oil had made landfall in some areas by the time the campaign got underway, however images had been acquired a year previously in the most extensively oiled areas, which were located along the Louisiana southeastern Gulf Coast and within Barataria Bay (Ramsey et al. 2011). The analysis of the UAVSAR data for wetland impact has been led by the United States Geological Survey (USGS) National Wetlands Research Center, where researchers have looked at correlations between oiling, the polarized radar backscatter, and various other influencing factors, including freshwater diversions intended to keep oil from further intruding into the inland marshes (Ramsey et al. 2015). Through a combination of fieldwork and radar remote imaging, it was determined that oil reached areas inland from the most heavily oiled shorelines in northeastern Barataria Bay not apparent in visual surveys (Ramsey et al. 2014), and the USGS researchers are now continuing research into the possible long-term impact to vegetation and marsh islands.

The original goal of the UAVSAR campaign, measurement of subsidence of the Mississippi River Delta, is still being pursued, with results showing anthropogenic subsidence in the urban and industrialized areas along the river. The next challenge will be extending the measurements into the wetlands, where it is likely to need installation of radar targets collocated with water-level gauges and in situ measurements to help determine the relative contributions from all the factors influencing subsidence. Perhaps, the most serendipitous outcome of the multi-year Gulf of Mexico UAVSAR campaign was observation of precursory ground movement that occurred at least a month before catastrophic collapse of a solution-mined cavern within the Napoleonville salt dome (Jones & Blom 2014), and tracking of the expansion of the collapse surface feature for nearly three years post-formation (Jones & Blom 2015). The movement was not discovered in the radar interferograms until after the collapse occurred, but is the only reported use of InSAR to detect ground movement prior to collapse in a wet, vegetated environment, which is a challenging environment for applying the technique. Other sinkhole precursors have been detected in very dry environments (Paine et al. 2012; Nof et al. 2013; Intrieri et al. 2015). This unexpected observation suggests that InSAR could be used in some cases to monitor areas like Florida for insipient sinkhole formation, especially since the environment of Florida bears much closer resemblance to Louisi-

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ana than to the dry deserts of Texas, Arizona, and Israel's Dead Sea area, all sinkhole-prone areas previously studied.

NASA continues to develop and launch satellite missions that can provide long-term observations of wetlands around the globe. Both SWOT and NASA-ISRO Synthetic Aperture Radar (NISAR), the mission for which UAVSAR serves as a science testbed, are planned with 2020 launch dates. NISAR, a joint mission by NASA and the Indian Space Research Organization (ISRO), is planned to image nearly the entire land mass of the Earth using an L-band SAR with similar capabilities to UAVSAR, providing repeat images for InSAR every eight days. Looking forward to the future, additional airborne campaigns and Earth-observing space missions for coastal and ocean applications can be planned based on the small-scale studies, like those described here, enabled with NASA's airborne instruments. ■

Acknowledgements

This research was carried out in part at JPL-Caltech under contract with NASA. I want to thank my many colleagues who participated in the UAVSAR campaigns, and most particularly, my Co-Principal Investigator in the Wax Lake Delta study, Michael Lamb of Caltech. The UAVSAR data are courtesy of NASA/JPL-Caltech.

NASA has an open access policy for science data acquired with NASA spaceborne missions and Airborne Science Program instruments. The NASA UAVSAR data are available free of charge through the Alaska Satellite Facility (https://www.asf.alaska.edu/) and through the UAVSAR website (http://uavsar.jpl.nasa.gov/cgi-bin/data/pl).

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