Comparison of daily, monthly (lunar), yearly, decadal, quarter-century, half-century, and centurial shoreline change rates at the Kennedy Space Center, Cape Canaveral, Florida, USA

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Summary

The Kennedy Space Center (KSC) is North America's premier spaceport and provides crucial access to space for both government and private entities. The National Aeronautics and Space Administration (NASA) facilities are clustered along a 12 km active shoreline at Cape Canaveral, Florida, USA, with the entire NASA and US Space Force station (SF) shoreline stretching over 32 km (Figure 1). Several Launch Complexes (LC's) including the modern heavy lift facilities are only a few tens of meters from the active shoreline and are imminently threatened by continued sea level rise and ongoing coastal erosion. The space center was built on the northern part of Cape Canaveral. Images collected in 1943 show that Apollo Heavy Lift Launch Complexes were built in swales on ground that was at or below sea level with Launch Complex 39B constructed on a paleo inlet (Figures 2 and 3). Today the Heavy Lift Launch Complexes are ~220 meters from the shoreline with the area between the complexes retreating at the highest rates along the cape (Figure 4). To better understand the intersection of environmental concerns, limited budgets for shoreline protection, and sheltering critical infrastructure; NASA, The

University of Florida, United States Geological Survey (USGS), National Park Service (NPS) and contractors have and continue to conduct numerous studies to characterize and understand the shoreline evolution and rates of change at KSC. This project aims to better understand and visualize the temporal and spatial variability of change along the NASA shoreline beyond a simple point to point solution.

Workflow

In order to address the complexities of coastal change dynamics at Cape Canaveral, multiple data types were collected to produce both visual based shorelines (VBS) and datum based shorelines (DBS) for the period of 1875 through to 2023. Previous studies were conducted to better understand the complex relationship between VBS and DBS and how to integrate these fundamentally different data types into a single cohesive data set. VBS proxies result in higher uncertainty than techniques using high precision topographic mapping instruments such as Light Detection and Ranging (LiDAR) or Global Positioning System (GPS), which have only been available since the 1990s. While DBS techniques can be more desirable for coastal change studies due to the decrease in uncertainty, the economic trade offs of DBS are high, with an increased cost, and high sampling frequency. Additionally, remotely sensed imagery provides insight into geomorphic evolution and system dynamics that may be difficult to extract from current DBS survey methods. Therefore, geomorphic clues from remotely sensed imagery combined with knowledge of coastal morphology and DBS surveys can minimize uncertainties in using VBS proxies.

In order to understand the full breadth and scale of shoreline change ranging from daily to centurial spans, both VBS and DBS must be used in conjunction with each other. In the Cape Canaveral KSC study area, combining these methodologies can provide insight into the daily, monthly (lunar), annual, quarter-century, half-century, and centurial shoreline change and change rates which have direct application to understanding impacts on critical infrastructure located along the coast. The daily shoreline response to the local wave climate (2009-2012) has been documented via DBS data leveraging 17 dGPS surveys. Monthly and annual shoreline change, and shoreline change envelopes (SCE) were studied by conducting 60 dGPS surveys on the full moon lunar cycle from 2009 to 2014. Annual shoreline change rates were also studied using remotely sensed satellite and aerial imagery to compare and bridge the change from DBS to VBS. Additionally, more than 50 image sets ranging in age from 1943 to 2023 were analyzed to investigate and document decadal, quarter century, half century, and centurial shoreline position change and shoreline change envelope.

Results, Observations, Conclusions

The results of this study show that leveraging both VBS and DBS together allows for a comprehensive understanding of coastal change and SCE through a variety of impactful spatial and temporal scales. Daily shoreline change is generally on the order of meters to a decimeter of change, with storm adjustments showing both retreat and rebound occurring on the order of one or two tidal cycles. The threshold for permanent shoreline change is reached at an offshore significant wave height of ~3m based on measurement data and storm surveys. The monthly SCE through the entire study area averages around 3.5m seaward with a maximum of ~15m seaward while the decadal change rate average is ~2.5m/yr seaward with a maximum of ~5m/yr. The centurial average change rate for the entire area is effectively zero with the maximum of ~2m/yr (Figure 5).

These data also suggest, that the Cape can be divided into four distinct regimes of coastal change: the *North Section* characterized by a single tall dune and a relatively high slope that shows very little variability; the *Overwash Zone* that is characterized by no dune, medium slopes, and medium positional variability and general retreat, the *False Cape Region* characterized by multiple low dunes, low slope, high variability and general growth, and the *South Section* characterized by multiple dunes, and medium positional variability (Figures 5 and 6). These different regions have been and will further guide coastal management decisions and space center infrastructure planning. The results from this study can be used to assist with management decisions of mitigation and restoration projects, as well as providing more accurate and science-based timelines for the expected life and repeat interval for these efforts.

Acknowledgements

We wish to acknowledge Peter Adams and John Jaeger of the University of Florida Geomorphology and Sedimentary Labs for their continued reviews and support of this project.

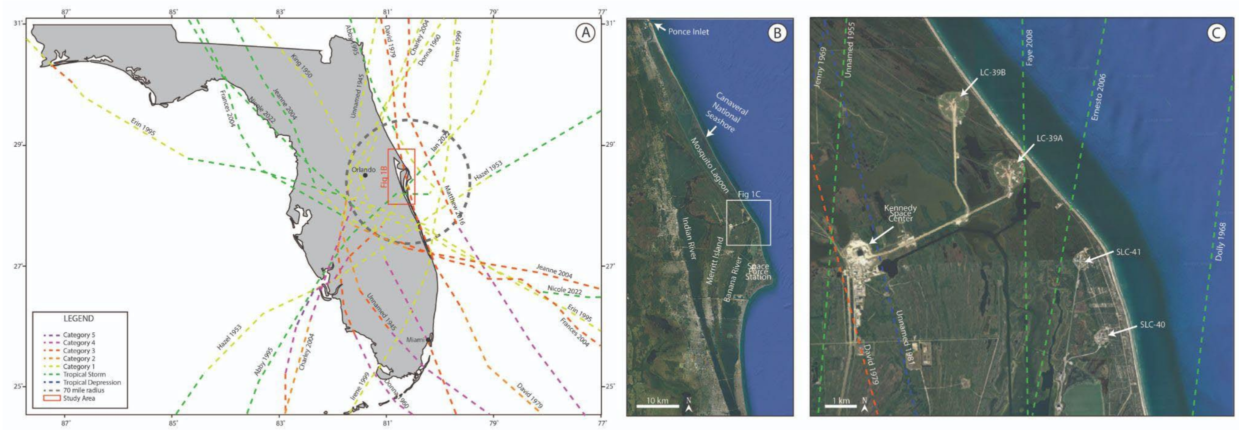

Figure 1: Kennedy Space Center study area showing the shoreline, key LC's and paths of major tropical storms.

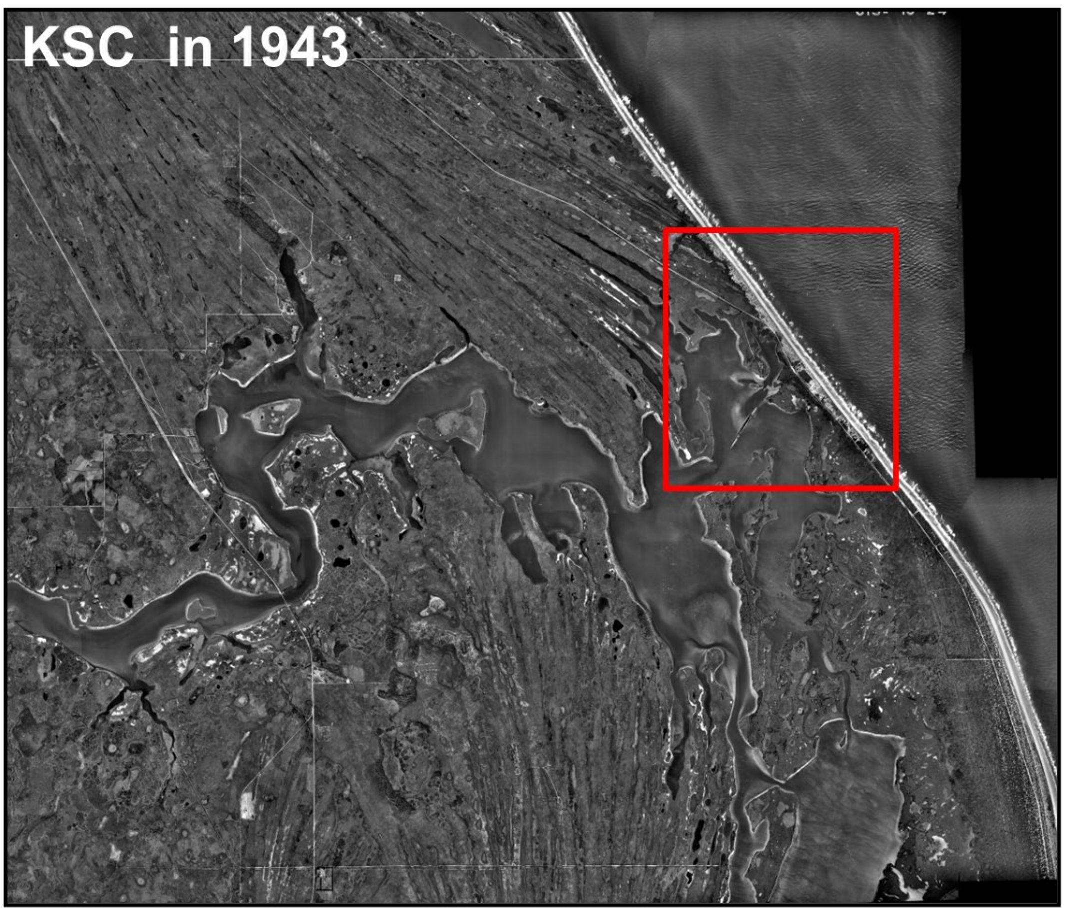

Figure 2: NHAP aerial image taken in 1943 during the Space Center search phase, before construction of the Space Center, showing the area of the future Apollo Launch Complex 39-A.

Figure 3: NHAP 1943 image with the LC-39A Apollo and current Heavy Lift Launch Complex ghosted over the paleo tidal inlet.

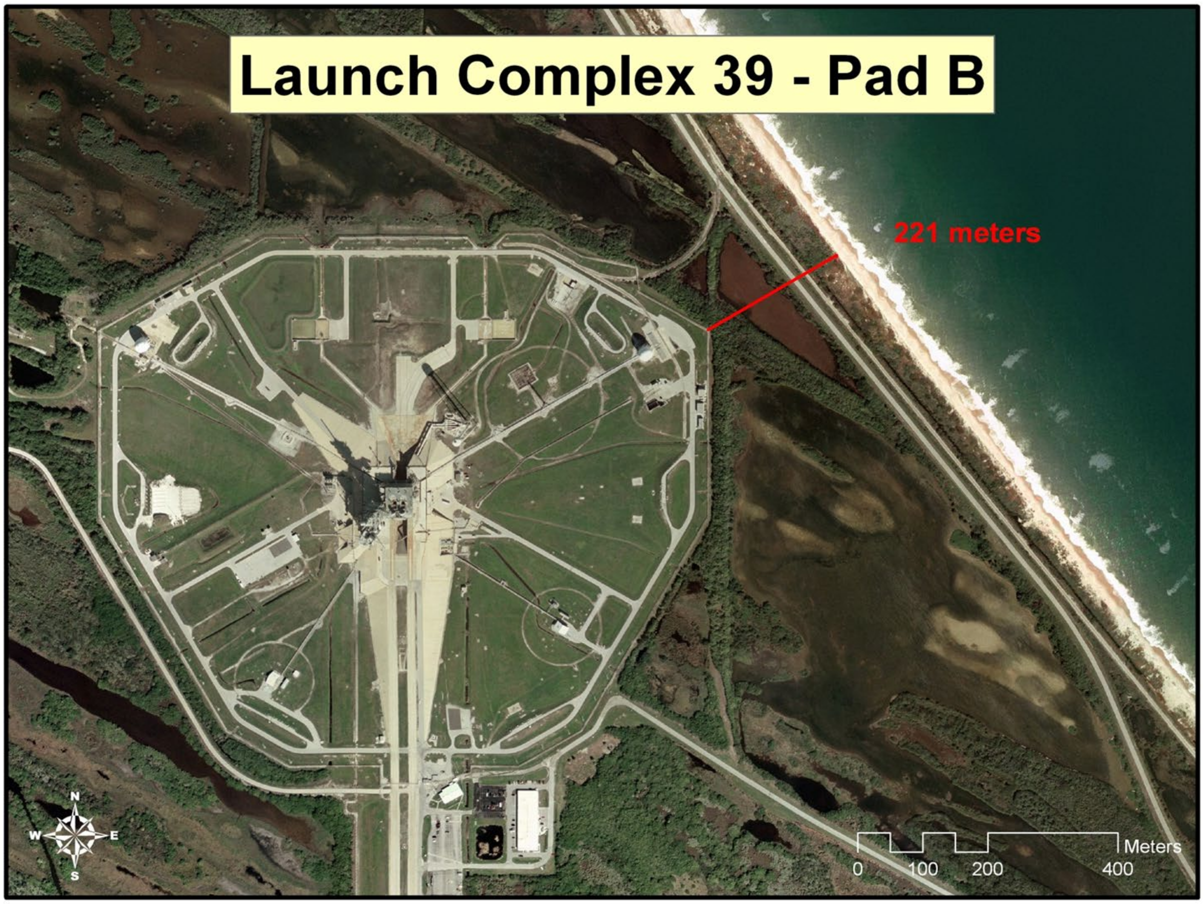

Figure 4: 2007 IHA image of LC-39 Pad B (Artemis) with proximity of the shoreline clearly delineated. Wetlands to the east and east southeast below sea level.

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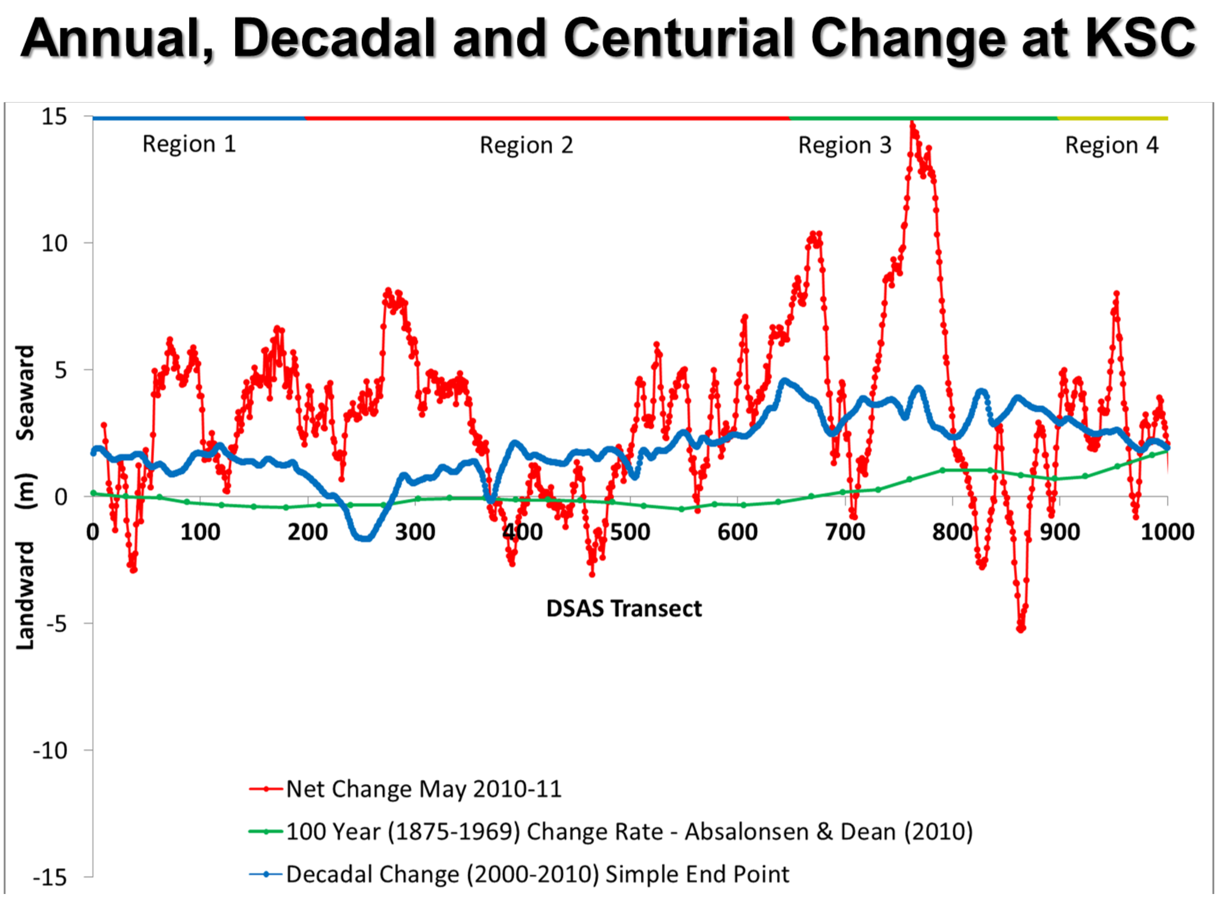

Figure 5: Annual, Decadal, and centurial shoreline change amplitude measured at NASA, Cape Canaveral, Fl, showing the four distinct coastal change regions that can be interpreted from these data.

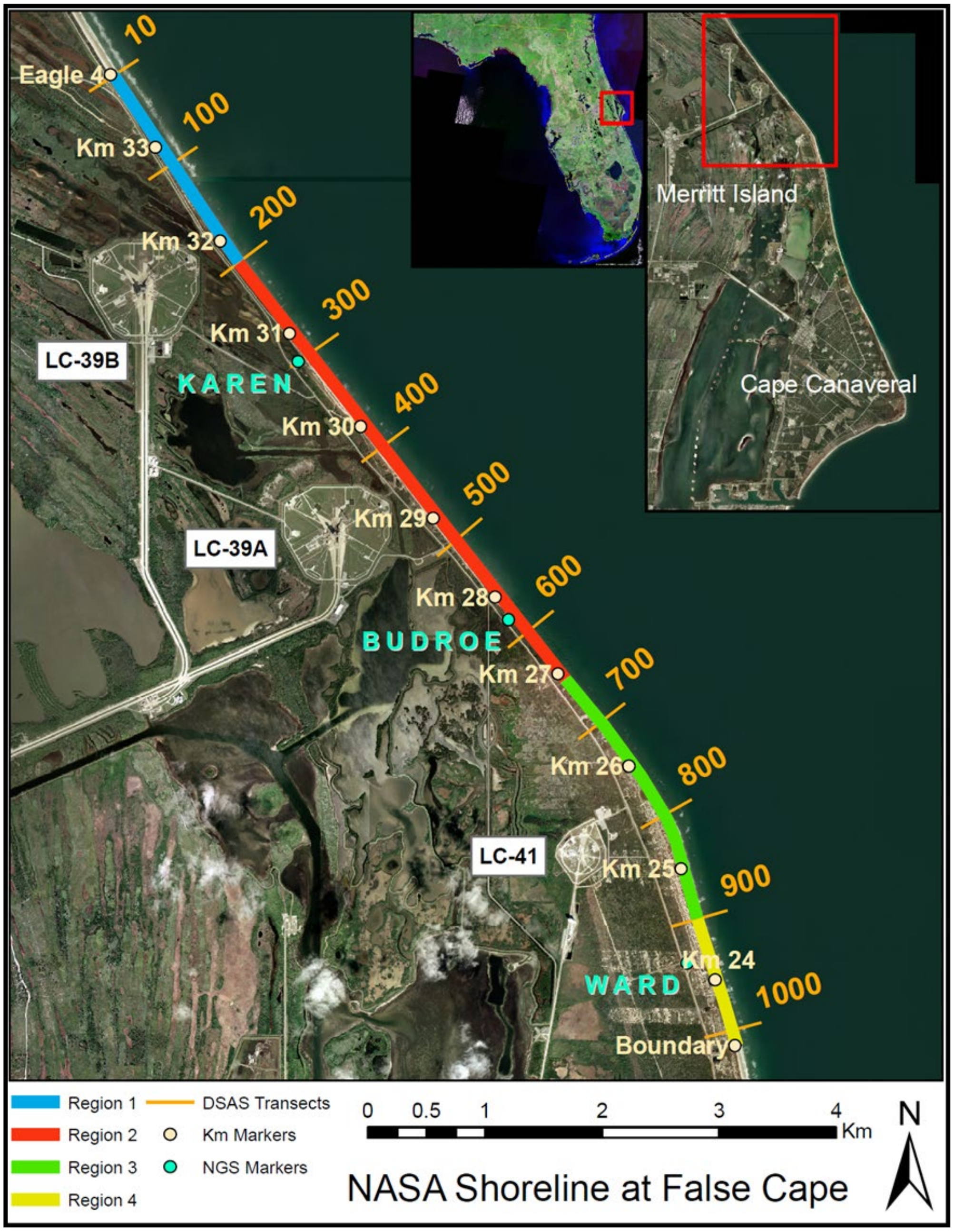

Figure 6: 2007 IHA image with the four zones of differing coastal response delineated.