SUBMARINE GROUNDWATER DISCHARGE: UNDERSTANDING FLUX SIGNATURES IN THERMAL INFRARED DATA IN PORT JEFFERSON AND STONY BROOK HARBORS, LONG ISLAND, NEW YORK

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Introduction

Submarine groundwater discharge (SGD), comprised of both fresh (meteoric) water and recirculated seawater (Moore, 1999), diffusely discharges from the Upper Glacial Aquifer of Long Island into the surrounding coastal waters. In many instances SGD is considered a major non-point source of nutrients to a given body of water (Howarth 2008) and may have much higher nitrogen and phosphorous concentrations then rivers, matching river nutrient inputs on a regional scale (Slomp et al. 2004). LaRoche et al. (1997) proposed SGD to be a driving mechanism for the onset of harmful algal blooms in Long Island Sound, thus it is important to quantify SGD fluxes to aid in the improvement of coastal zone management plans. Natural geochemical tracers such as 222-Radon (Burnett et al. 2001) and Radium (Moore et al. 1996) can be used to quantify SGD, while thermal infrared imagery (TIR) obtained *via* helicopter has been used to located areas of SGD (Johnson et al. 2008). Both of these methods are used in this study to characterize the distribution of SGD along the shores of Port Jefferson and Stony Brook Harbors. A second objective of this study is to link SGD flux determined from in-situ geochemical measurements to aerially measured groundwater/surface water temperature and spatial distributions. Initial results indicate TIR imagery to be a useful tracer of SGD for Long Island, with the best viewing window to occur in August (during low tide, clear, cloud free day), when there is maximum temperature contrast between groundwater and surface water. Results show that SGD is unevenly distributed along the shore of Port Jefferson Harbor.

Methods

A FLIR Systems T640 TIR camera (pixel-to-pixel thermal accuracy 0.1 K, absolute accuracy ~2K, 8 in. pixel resolution at 1,000 ft.) coupled with a helicopter was used to take aerial TIR images of Port Jefferson Harbor (**Figure 1**) during August 2012, October 2012, and of both Port Jefferson and Stony Brook Harbor during February 2013, when temperature contrast between surface water and discharging water was expected to be greatest. For the February flight, in-situ conductivity temperature (CT) loggers were deployed at two locations in Stony Brook Harbor and at one location in Port Jefferson Harbor for ground-truth measurements.

Images are georeferenced to existing orthorectified visible imagery in the image processing program ENVI. Aerial images are mosaicked in ENVI, creating an entire harbor-shoreline rectified image. A preexisting USGS DEM of the harbors is used to mask out temperature data above mean sea level (0 meters). Plume areal extent can be calculated in ENVI and ArcGIS by creating a cumulative histogram of pixel temperatures within a user-defined polygon, which surrounds the plume. Strong breaks in slope near the base or top of the histogram (depending on whether the plume temperature is colder or warmer than the surrounding surface waters) can be used to define the boundary of the plume, also known as the "inflection point" technique (Danielescu et al. 2009).

^{222}Rn and Ra isotopes ubiquitously exist in aquifer sediments and are several orders of magnitude greater within groundwater compared to seawater (Burnett et al. 2001, Moore et al. 1996). Because these species are inert in water and have comparable half-lives to groundwater residence time (Moore et al. 1996), they can be used as natural geochemical tracers to determine the total fraction of SGD. A shoreline ^{222}Rn survey was conducted in August 2012 in Port Jefferson Harbor, using two RAD-7 machines (Durridge Co.) connected in parallel aboard a research vessel. A tidal survey was conducted in October 2012 at Centennial Beach (**Figure 1**) to measure the changes of ^{222}Rn concentration with changing tidal stage. Water samples were collected for ^{224}Ra analysis in February 2013, the day following the TIR flight, at select locations in Stony Brook Yacht Club and Centennial Beach, and analyzed following the methods outlined by Beck et al. (2008).

Results

The shoreline ^{222}Rn survey (**Figure 1**) showed the highest concentrations of ^{222}Rn to occur near the areas of greater near-shore gradients (eastern coastline) in Port Jefferson Harbor. ^{222}Rn concentrations appear low along the western shoreline of Port Jefferson and lowest in the center of the harbor, suggesting minimal diffusive sediment and advective input. Over a tidal cycle (**Figure 2**), the highest concentrations of ^{222}Rn were measured at low tide, as expected. Previous studies have shown a similar inverse-correlation between tidal stage and SGD (Burnett et al. 2006, Paulsen et al. 2001).

^{222}Rn concentrations can be converted into SGD by assuming a box model approach (Burnett et al. 2003). Input terms of ^{222}Rn include diffusive flux from sediments, advective movement of the water column and production by ^{226}Ra decay (parent isotope). Losses to be accounted for include radioactive decay of ^{222}Rn, advective loss and atmospheric evasion. Using these gain and loss terms, an excess ^{222}Rn flux can be calculated (dpm/m^3), which can be converted into SGD (cm/d) by using the fresh groundwater inventory of ^{222}Rn.

The flux of SGD from the tidal cycle data (max 10.8 cm/d) is markedly lower than seepage meter estimates (~100 cm/d, C. Young, personal communication), suggesting that the ^{222}Rn concentrations measured are indicative of mostly the fresh-fraction of SGD, as opposed to both fresh and recirculated seawater measured from a seepage meter. This matches well with estimates suggesting that the freshwater component of SGD is approximately 9-10% of the total flux (Bokuniewicz 1980). In addition, the ^{222}Rn measurements integrate SGD over the water column area, while seepage meters measure point discharges.

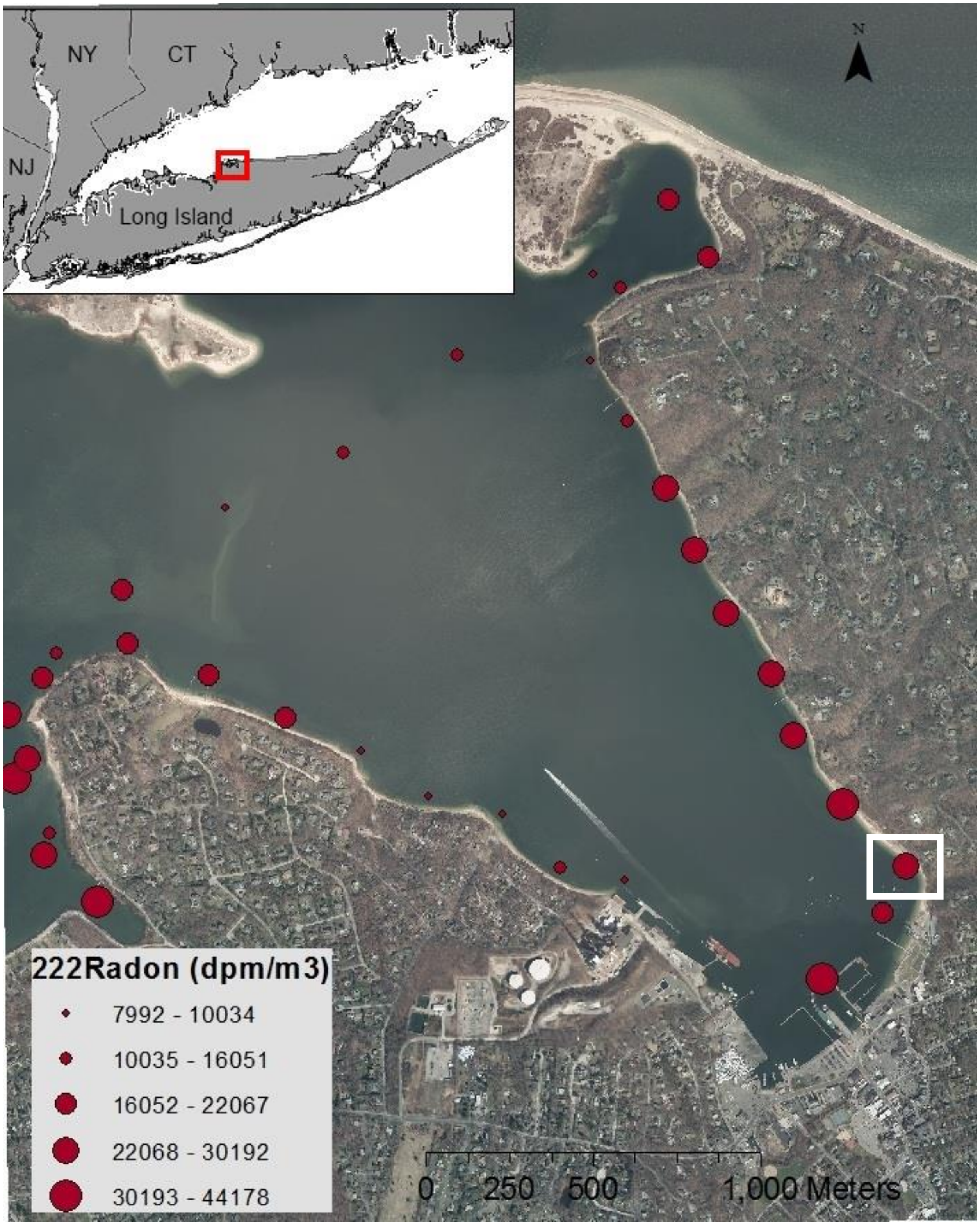

Figure 1- August 2012. Continuous ^{222}Rn survey in Port Jefferson Harbor, NY. Red points are RAD-7 measurements of ^{222}Rn concentration measured over the entire water column (disintegrations per minute/m^3). Figure inset is a map of Long Island, New York. Port Jefferson Harbor indicated by red box. Centennial Beach located within the white box of the main figure.

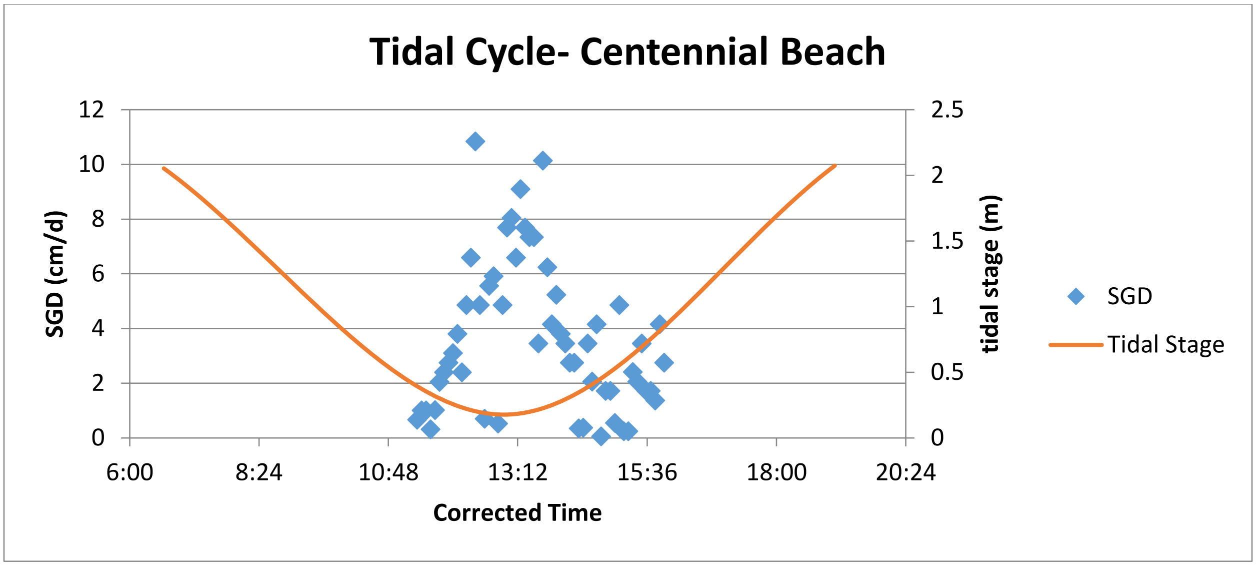

Figure 2- October 2012. Tidal cycle data for Centennial Beach, Port Jefferson Harbor, NY. ^{222}Rn concentrations converted into cm/day. Overall trend shows inverse-correlation between SGD and tidal stage.

TIR imagery has proven to be a useful indicator of groundwater discharge locations. In October, discharge at low tide can be clearly observed in the TIR data in areas of cool, wet sand (**Figure 3**), where groundwater is mixing with the distinctly different surface waters. For the August and October data, the ^{222}Rn concentrations confirm the presence of SGD observed in the TIR images. CT-loggers for the February flight confirm the observed temperatures in the TIR imagery. For the February data, ^{224}Ra activities for Stony Brook Yacht Club (54 dpm/100 L) and for Centennial Beach (11 dpm/100 L) indicate the presence of SGD and are comparable to previous estimates using short lived Ra isotopes (C. Heilbrun, personal communication). Comparison of harbor bathymetry data to a harbor mosaic shows no apparent correlation between the temperature anomalies and bathymetry.

The inflection point technique for groundwater discharge cumulative area at Centennial Beach (**Figure 4**) closely resembles results from the Danielescu et al. (2009) study. Further work is needed in order to create more inflection points for other SGD locations, which can be used to calculate the cumulative areal extent of the groundwater discharge zone relative to the surface water. The eventual goal of the plume area calculations are to determine whether there is a positive linear relationship between increased ^{222}Rn concentrations with increased SGD area. Because ^{222}Rn concentrations only change relative to the change in the hydraulic head of the aquifer (although diffusive sediment input and wind-induced mixing can affect total concentration), it is likely that changes seen in the water's thermal signatures are due to changes in the discharge of groundwater and are not mere temperature anomalies related to other factors (e.g. bathymetric depth).

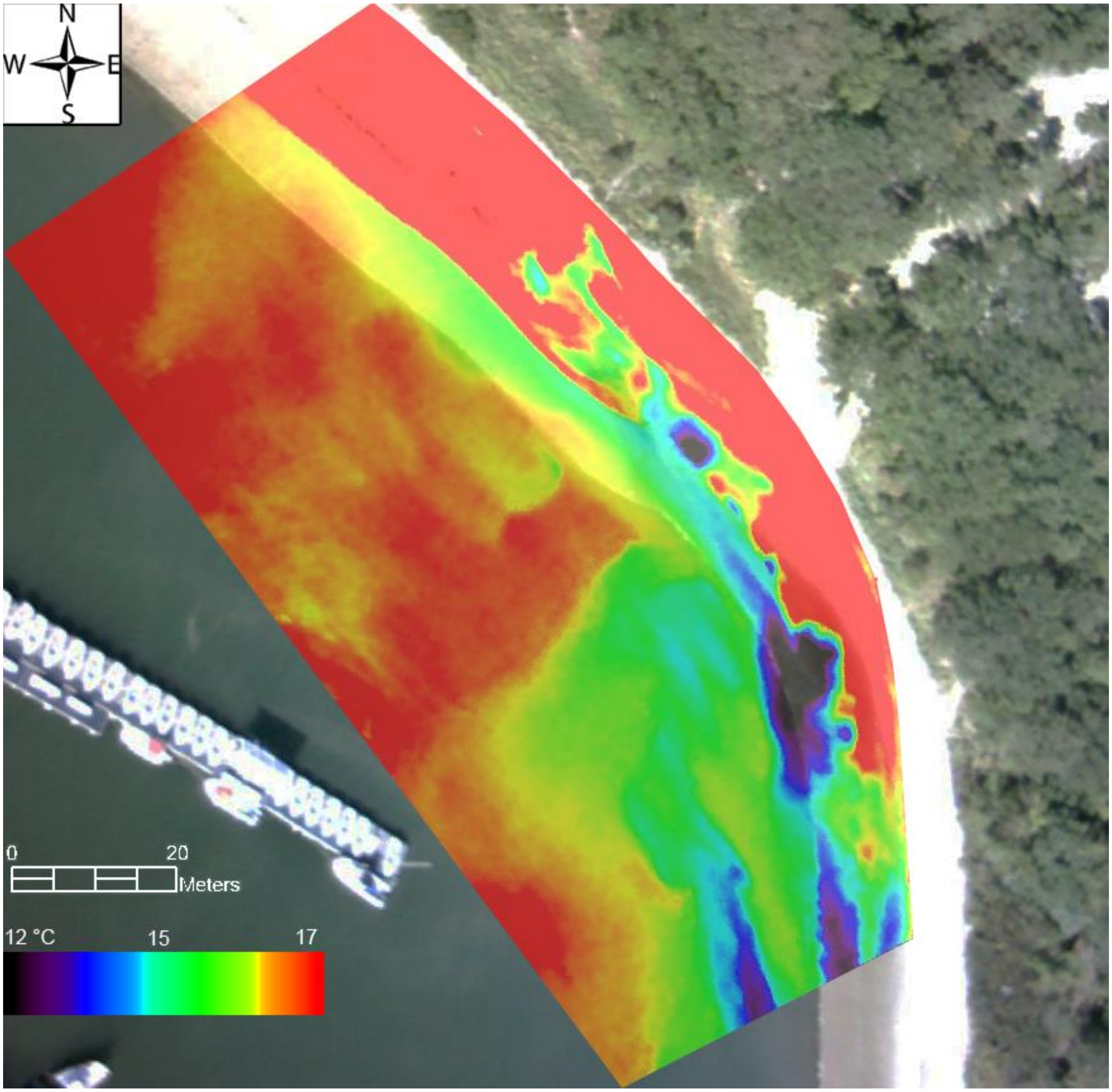

Figure 3- October 2012. Centennial Beach, Port Jefferson Harbor, NY. Thermal data (degrees Celsius) overlaying visible imagery of the study site. Thermal data has been excluded from parts of the image to allow for a better visualization of the study site. Cold locations (black and purple) indicative of groundwater discharge in the wet sand. Wet and dry sand indicated in visible portion of the image.

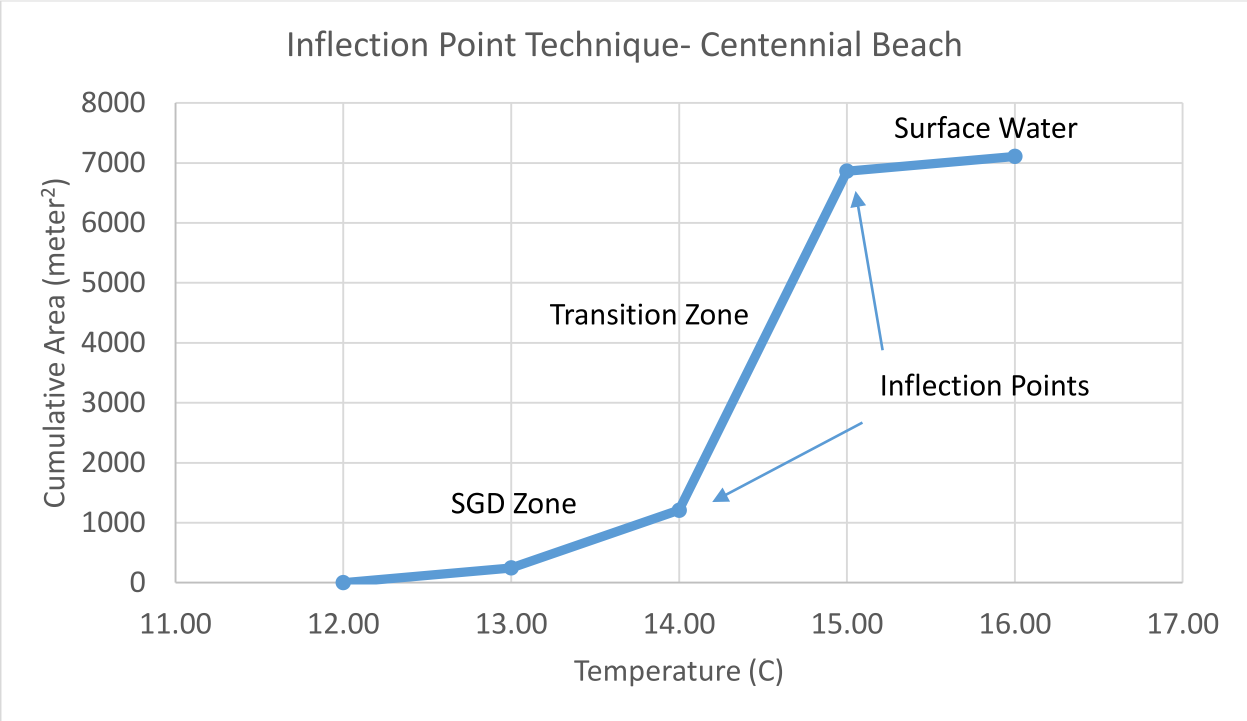

Figure 4- Inflection point technique for a SGD plume at Centennial Beach, Port Jefferson Harbor, NY (October 2012). SGD area is the integral of the curve under the first inflection point.

Based on these three flights, it is recommended to perform TIR surveys with minimal wind in order to prevent mixing of the water column, which reduces the thermal contrast between surface water and groundwater. Performing flights during the summer is recommended as opposed to the winter, because snow melt can potentially runoff into the surrounding waters, diluting the overall thermal contrast. Flights should always be flown at low tide in order to maximize SGD signal.

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