G51A-0136 COMBINING GEOLOGICAL, GEODETIC, AND TIDE-GAUGE DATA TO ESTIMATE COASTAL SUBSIDENCE AND FLOODING HAZARDS IN THE MACKENZIE DELTA, WESTERN ARCTIC CANADA

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Introduction

The Mackenzie Delta is the second largest on the coast of the Arctic Ocean (Fig. 1). It occupies a long-term depocentre in which >12 km of sediment has accumulated since the Cretaceous (Dietrich et al., 1985). The subaerial Holocene delta fills a glacially-scoured valley 60-100 m deep and about 50 km wide, extending NW into a deeper trough with a thick late-Quaternary sediment fill underlying Mackenzie Bay (Hill et al., 2001). The modern delta overlies an older transgressive delta wedge and flooding surface. Borehole and temperature profile data indicate that the delta had prograded to within 25 km of the modern delta front by 4500 years BP (Dallimore, 1992; Taylor et al., 1996).

Water levels and subsidence

Relative sea-level trends across the Canadian Arctic are highly variable, in part because of the strong imprint of postglacial isostatic adjustment. In many parts of the central Arctic, ongoing uplift exceeds the rate of regional sea-level rise, resulting in continued coastal emergence (Fig. 2). In peripheral areas such as the Arctic coastal plain, models and geological evidence point to ongoing subsidence, adding to relative sea-level (RSL) rise in the Beaufort-Mackenzie region (Fig. 3). Additional sources of subsidence in the Mackenzie Delta include long-term sediment loading and sediment compaction, as well as thaw subsidence where thermal changes such as deeper seasonal thaw lead to melting of excess ground ice. Compaction is reduced in ice-bonded sediments and the thickness of ice bonding varies with the depth of permafrost. On its eastern flank, the modern delta has expanded over older Pleistocene sediments with deep permafrost and ice-bonded sediments down to 700 m (Fig. 4). In contrast, the ice-bonded section in the modern delta typically extends to <60 m, overlying 20-50 m of non-bonded sediments over more compact and lithified deposits. Ice-bonding is reduced or absent in thaw taliks beneath deep lakes and channels that do not freeze to the bottom in winter. Differential compaction and subsidence resulting from variable thickness of non ice-bonded sediments may play a role in maintaining or expanding lake area on the delta plain and in promoting delta-front erosion.

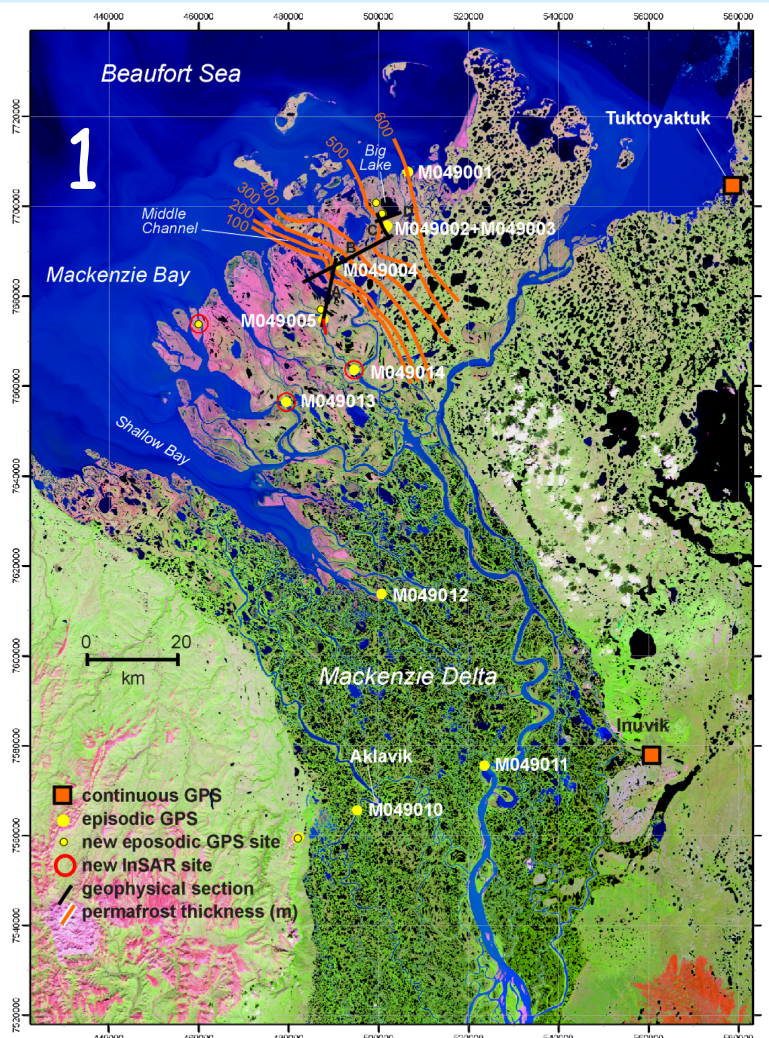

Fig. 1 (above): Landsat mosaic of the Mackenzie Delta and nearby coast, showing depths of permafrost in outer delta, locations of continuous and epoch GPS monitoring, new InSAR and GPS sites, and location of geophysical transect forming the basis for Fig. 4 (from Todd & Dallimore, 1997).

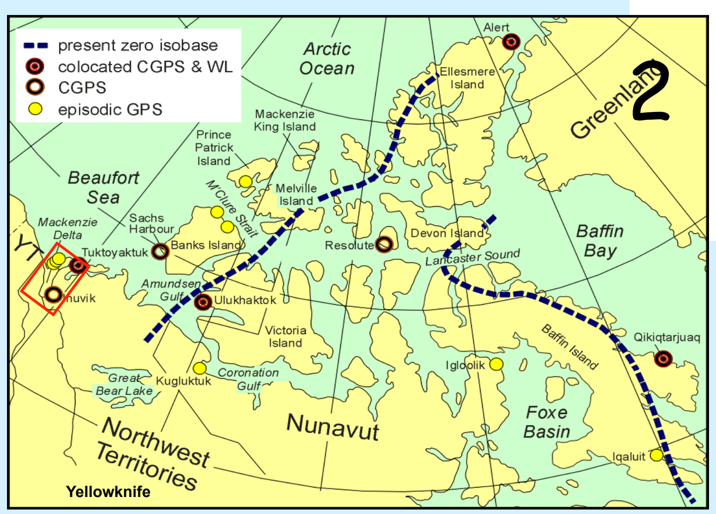

Fig. 2 (left): Network of CGPS sites with and without colocated tide gauges in the Canadian Arctic, with approximate present-day zero isobase (from Forbes et al. 2004).

Beginning in 2001, we have established an Arctic network of continuous GPS (CGPS) stations, including CGPS co-located with tide gauges at Tuktoyaktuk and Ulukhaktok, among other locations (Fig. 2). Over time, the data will enable independent measurement of vertical motion and sea-level change. GPS velocities from the North American Reference Frame (consistent with rates from JPL and SOPAC) indicate positive values (uplift) at all CGPS stations, even in the Beaufort-Mackenzie region.

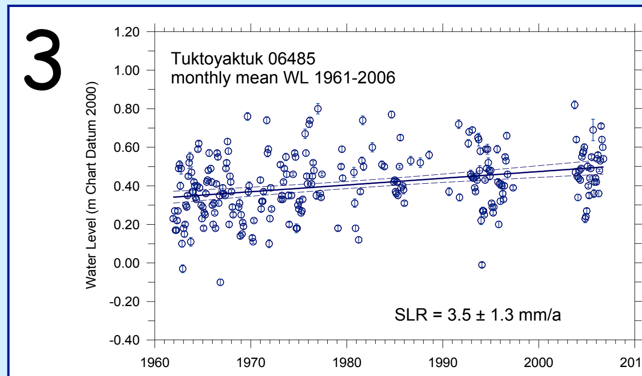

Fig. 3: Monthly mean (±2 se) WL at Tuktoyaktuk 1961-2006 (excluding months with >10% missing records). Rising RSL trend over 45 years is +3.5 ± 1.3 mm/a. If sea-level rise in the Beaufort Sea has been comparable to the global trend during this interval (Church & White, 2006), the vertical motion at Tuktoyaktuk is approximately -1.7 ± 1.8 mm/a (subsidence).

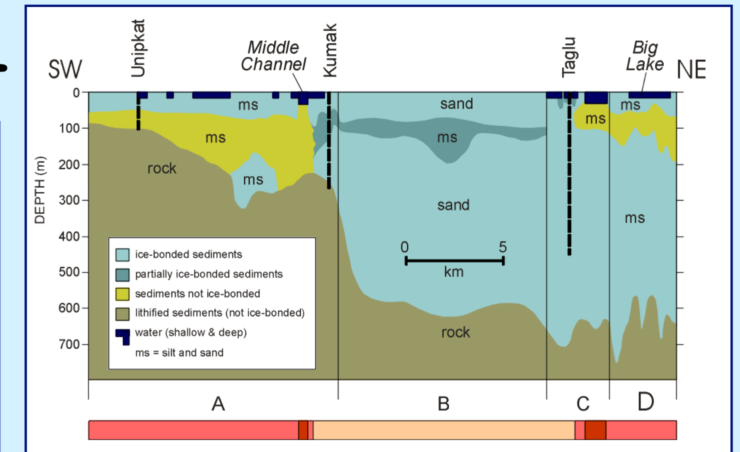

Fig. 4: Interpreted EM profile along transects shown on Landsat mosaic (Fig. 1), modified from Todd & Dallimore (1997). Note partially ice-bonded sediments, particularly along section B, and limited depth of bonding under modern delta relative to older terrain to east. Darker red in colour bar implies higher compaction potential.

Fixed monuments for episodic GPS observations have been established and occupied repeatedly in the Mackenzie Delta (Fig. 1) and we are currently developing a network of fixed reflectors for persistent-scatterer InSAR. Preliminary GPS results from the Mackenzie Delta indicate natural subsidence ranging from 0 to 14 mm/a (Fig. 5). These rates, derived from benchmarks seated at depths of 10-30 m, do not include subsidence from any expansion of the active layer and thaw of shallow ice (Kokelj & Burn, 2005). Delta subsidence combined with rising sea levels implies an increased probability of flooding at spring breakup and from storm surges in the Beaufort Sea (Marsh & Schmidt, 1993). LiDAR digital elevation models (Fig. 6) provide a basis for simulating flooding impacts from rising sea levels and differential subsidence on the delta plain.

These results are being used in the environmental review of proposed natural gas production and transportation facilities. Realistic estimates of the magnitude and spatial distribution of subsidence from all sources (and implications for flooding frequency) are required to assess the impacts of development on nesting waterfowl habitat in the Kendall Island Bird Sanctuary on the outer delta, as well as for engineering design of production facilities.

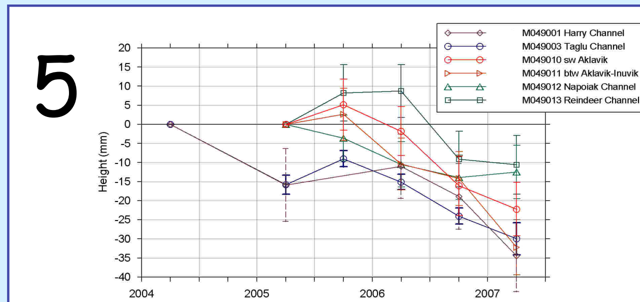

Fig. 5: Rates of subsidence from episodic GPS observations, showing modal pattern for six sites in the mid- to outer Mackenzie Delta. Rates range from 5-17 mm/a (relative to Yellowknife where uplift is ~6 mm/a), thus implying regional subsidence plus compaction of 0-11 mm/a. If we assume a regional isostatic signal of about 2 mm/a, this implies compaction+loading values as high as 8 mm/a. One site exhibits more rapid fall (14 mm/a subsidence) and a few are stable or rising.

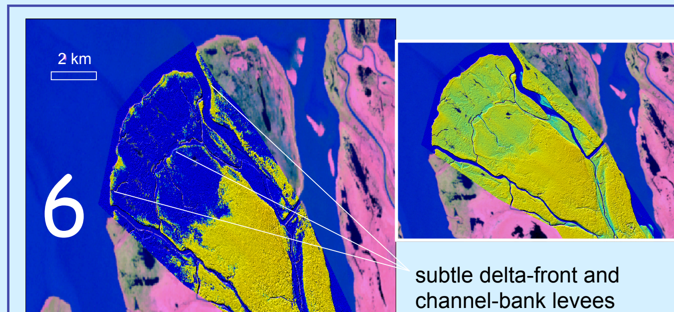

Fig. 6: Flooding of low-relief outer delta by 1 m surge, simulated using colour-classified shaded-relief image of LiDAR DEM (inset).

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