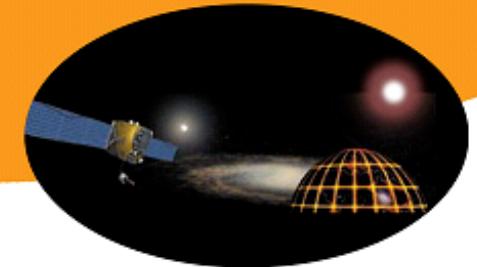




## *Earth Sciences Sector*



Canadian Spatial Reference System

# Measuring Crustal Motion and Sea Level Change in the Canadian Arctic

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Geodetic Survey Division

Natural Resources Canada

Presented at

GPS in the IPY: The POLENET Project Workshop

Dresden, October 4-6, 2006



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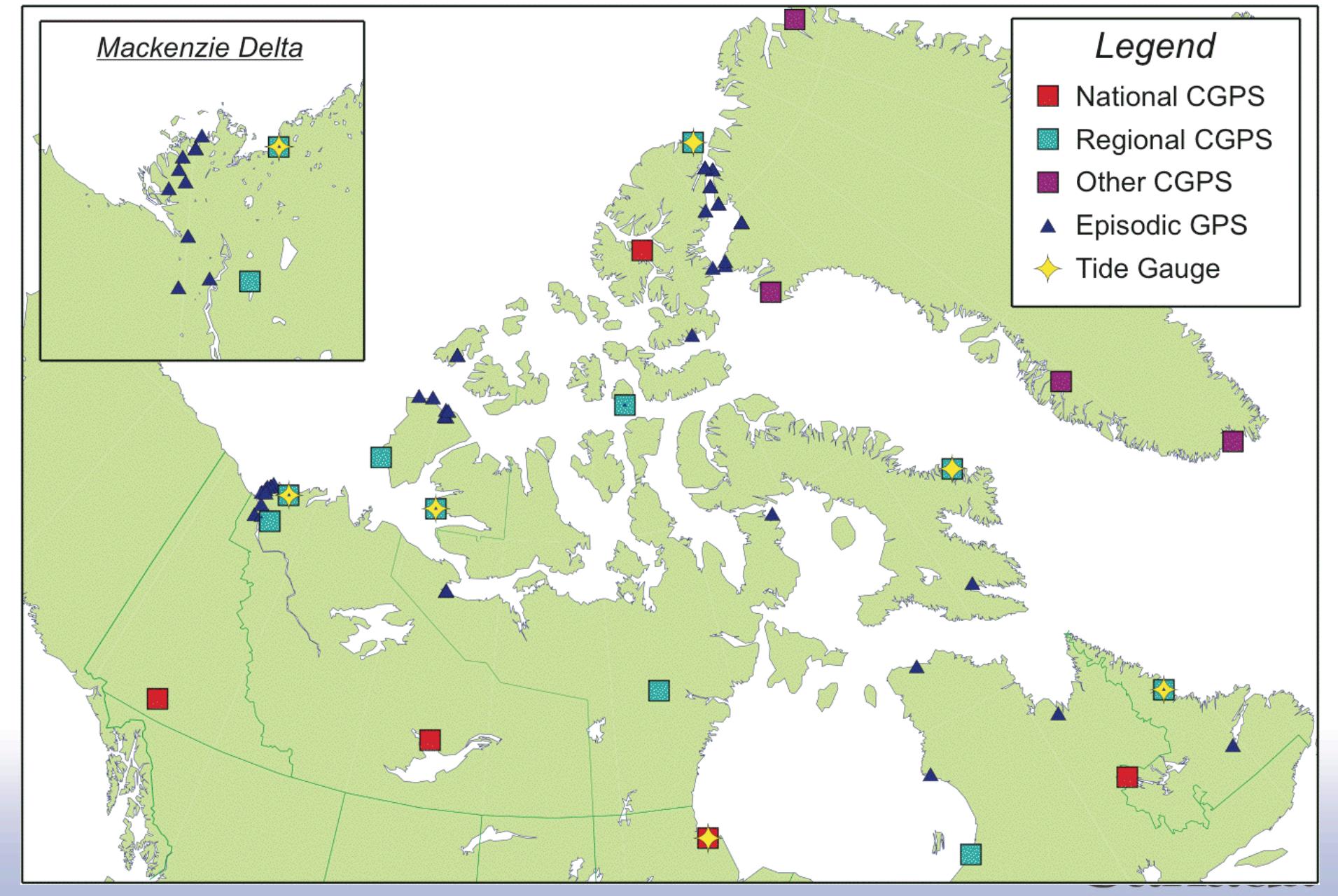
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# Abstract

A network of several continuous GPS stations co-located with tide gauges has been established in the Canadian Arctic with the aim of directly measuring changes in absolute sea level. The tide gauge data provide measurements of relative sea level with respect to the crust upon which the tide gauge is anchored. The GPS data enable us to determine the absolute vertical velocity of the crust at each tide gauge with respect to a global reference frame. Combining the two allows us to determine absolute changes in Arctic sea level with respect to the global frame. Several factors affect our ability to obtain reliable estimates from these measurements, including monumentation, various kinds of noise and systematic biases, equipment type and changes, and, most importantly, the length of the time series. Each of these factors will be discussed in relation to our experiences from the past several years. Although based only on three to five years of data, we provide some preliminary results of crustal motion and sea level change and compare these to estimates reported by others. We also estimate the level of accuracy we might expect with longer time series and discuss proposals for expanding this network in the near future.



# Canadian Arctic GPS & Tide Gauge Sites



# CGPS Time Series

## *NAREF Weekly Solutions*

- Weekly combinations of regional solutions from 2001.0
  - GSD Bernese (Can+) NGS PAGES (US CORS)
  - GSD Gipsy (Can) SIO Gamit (Prelim. PBO)
  - PGC Bernse (WCDA) MIT PBO (Official PBO)
- Solutions archived at IGS (narwww7.snx)

## *Reference Frame Definition*

- Fixed IGS orbits
- Aligned & weighted w.r.t. IGS weekly solution of date
- Common stations from IGS weekly solution used as weighted constraints (normal equation stacking)



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# CGPS Velocities

## *NAREF Cumulative Solutions*

- Weekly solutions combined at normal equation level (stacking)
- Each week aligned & weighted w.r.t. an IGS cumulative solution (IGS05P01)
- Common stations from IGS05P01 used as weighted constraints (normal equation stacking)

## *First Solution*

- Using weekly solutions from 2001 to 2004
- Solution available upon request

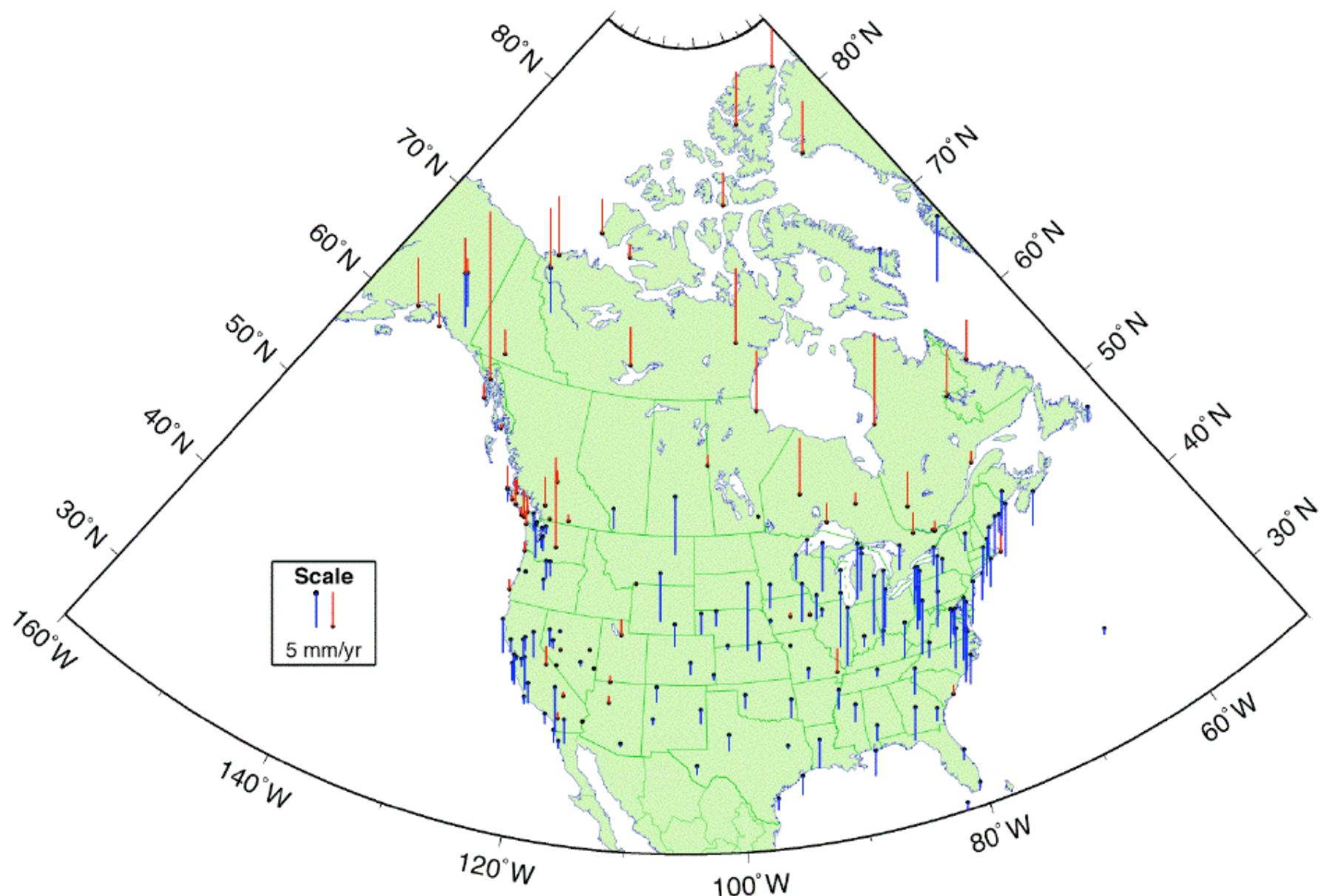


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## NAREF Vertical Velocities



# Problem 1

## *Solid Earth tide correction in Bernese 4.2*

- Error in correction
- Caused bias in time series (see plots)
- Velocities too small or too negative
- Reprocessed all GSD Bernese solutions with v5.0
- Recombinations nearly complete



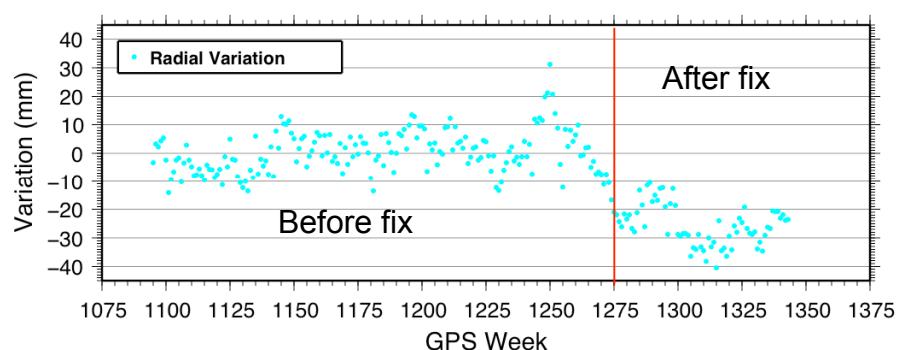
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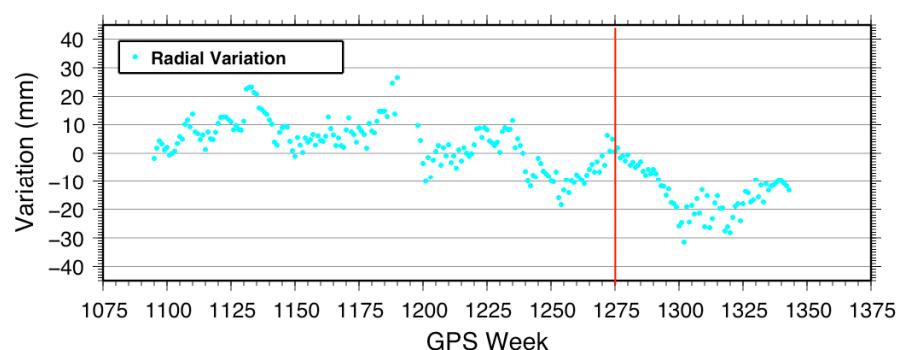
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## GSD Bernese Time Series

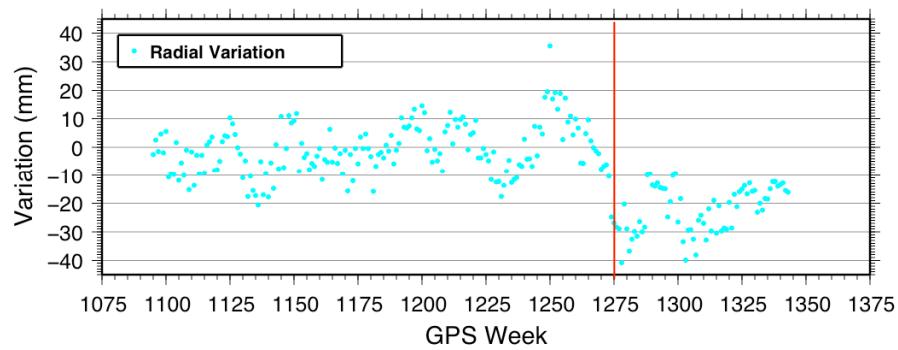
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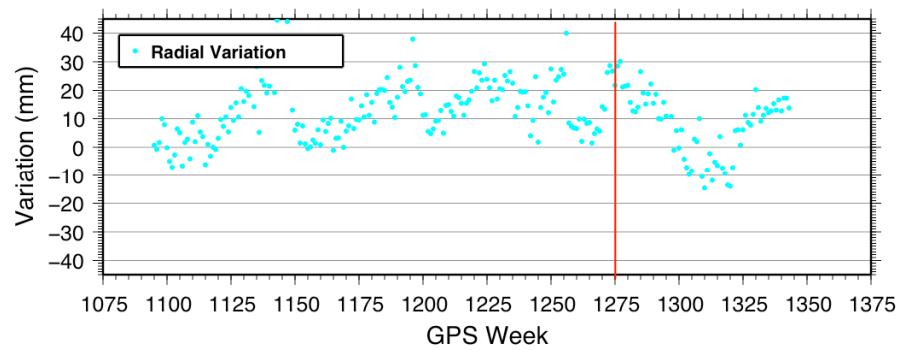
NANO



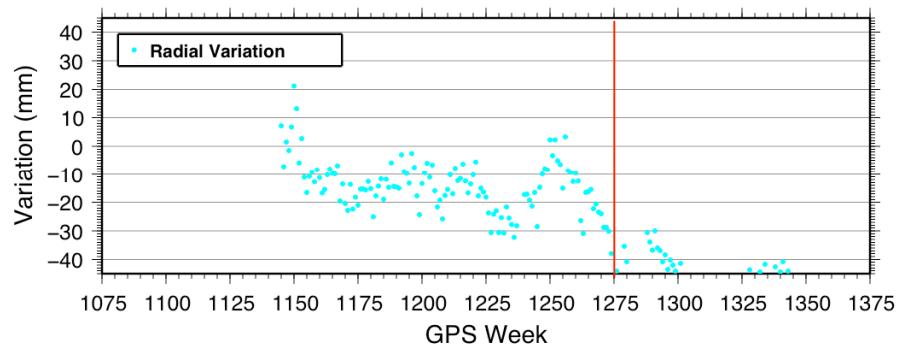
ALGO



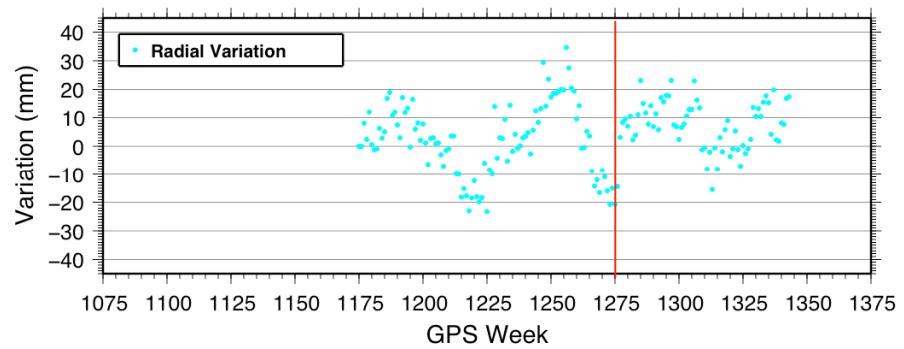
WHIT



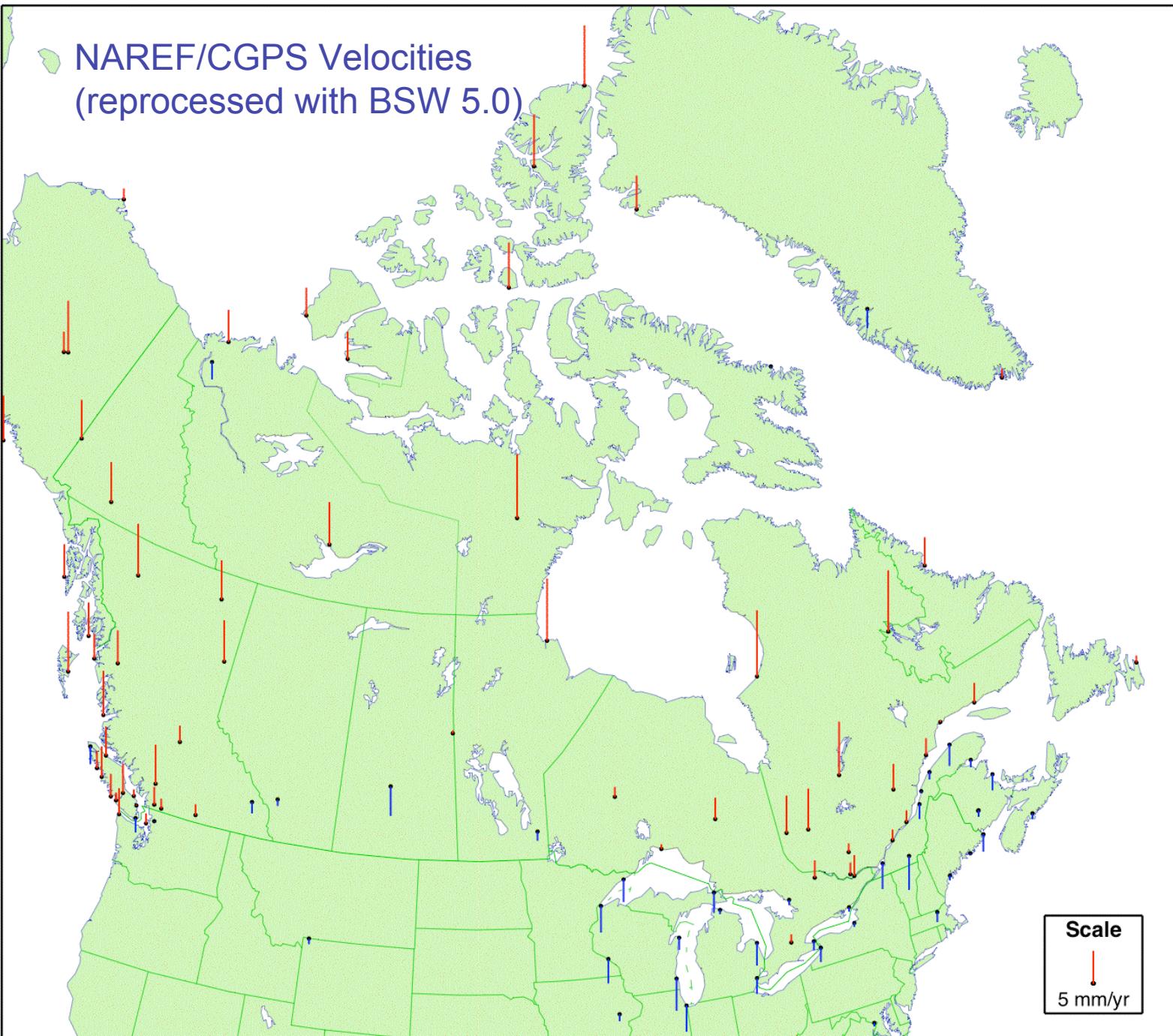
HLFX



ALRT



NAREF/CGPS Velocities  
(reprocessed with BSW 5.0)



# Problem 2

## *Effects of snow & ice*

- Snow/ice on antenna can affect PCV
- Appears as seasonal signals in time series
- Clearly evident in INVK time series
- Dome added (SCIGN dome)
- Didn't really solve problem -- ice sticking to dome

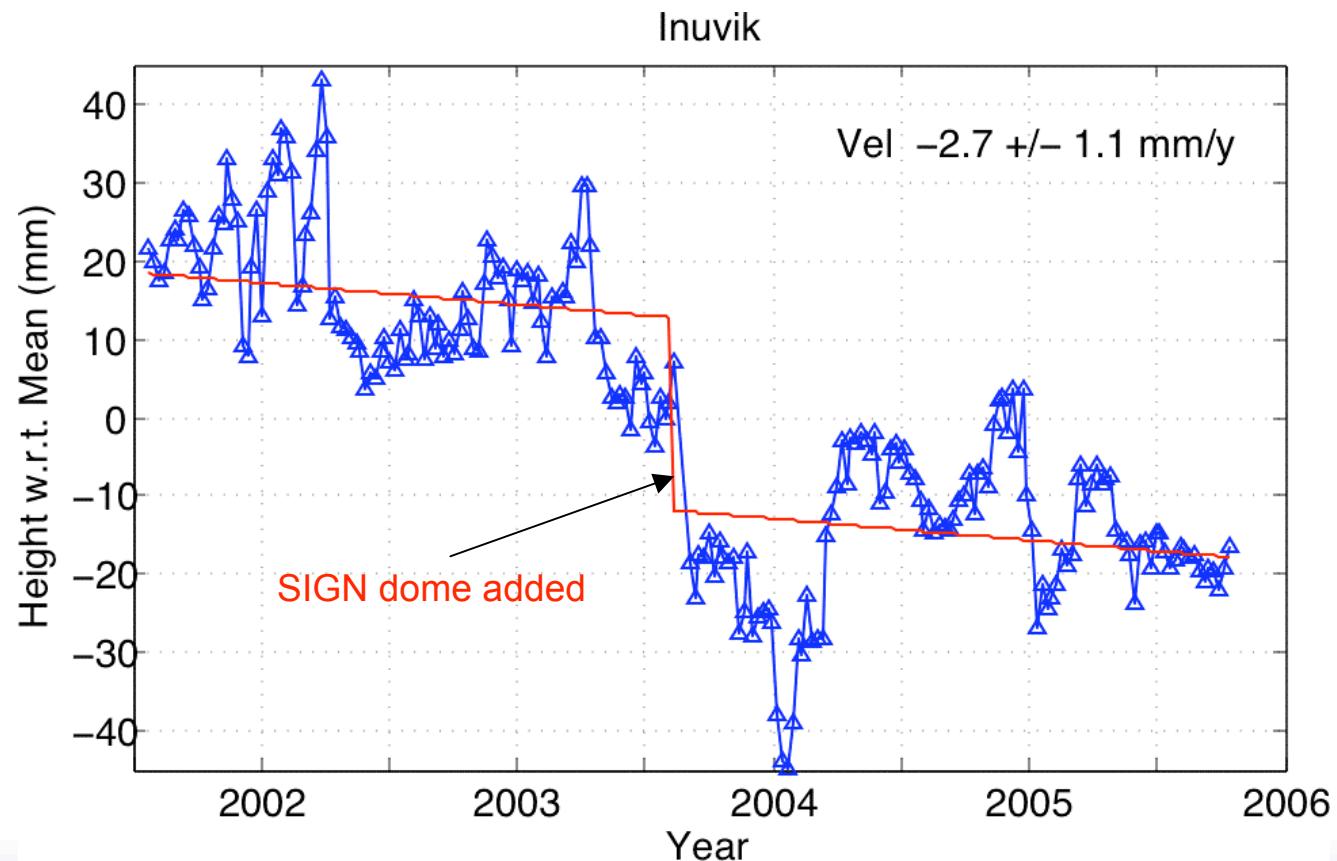


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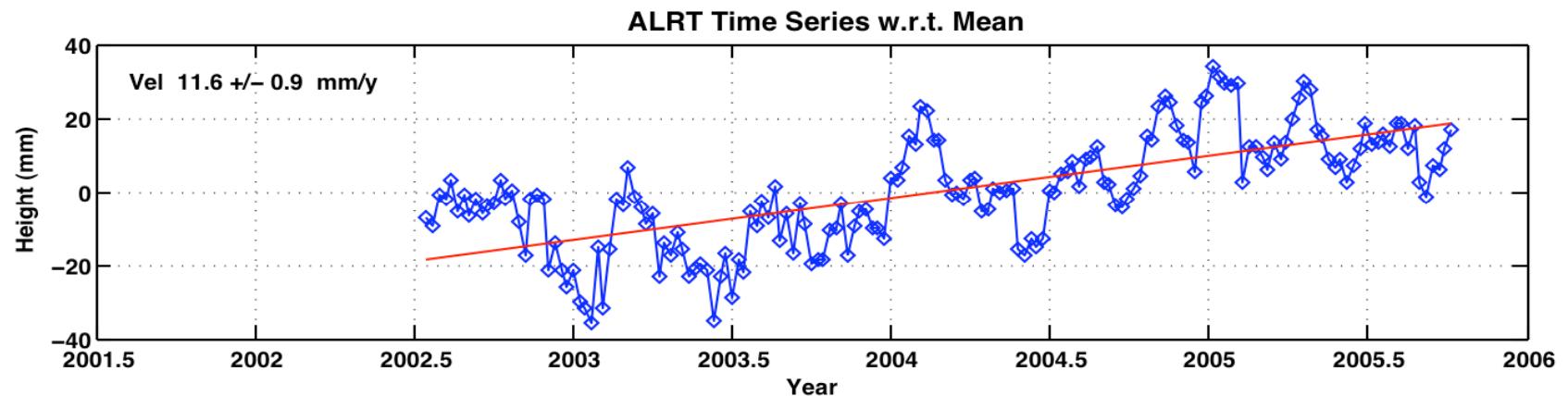
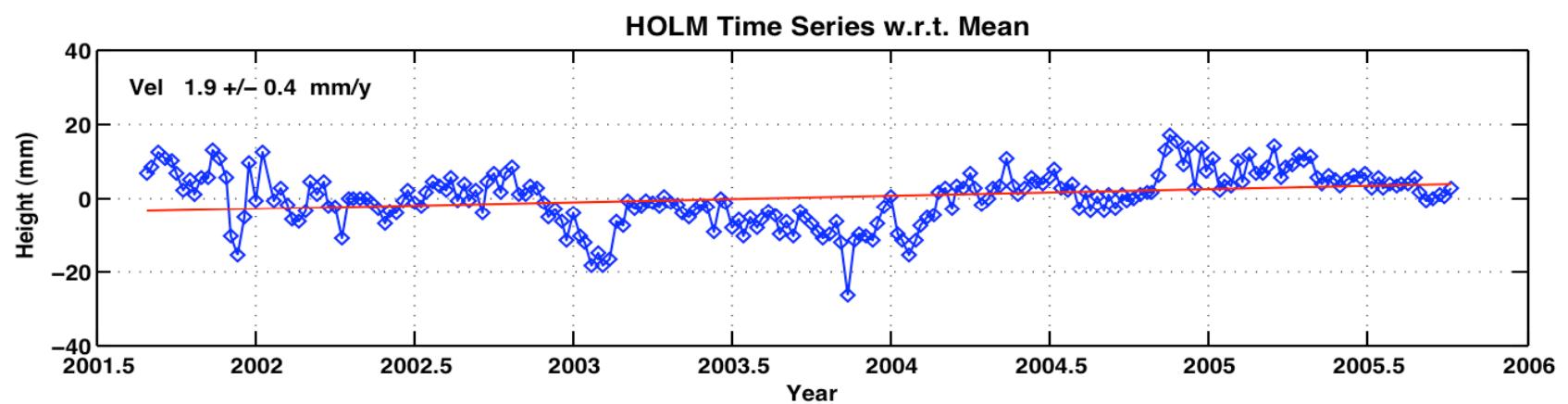
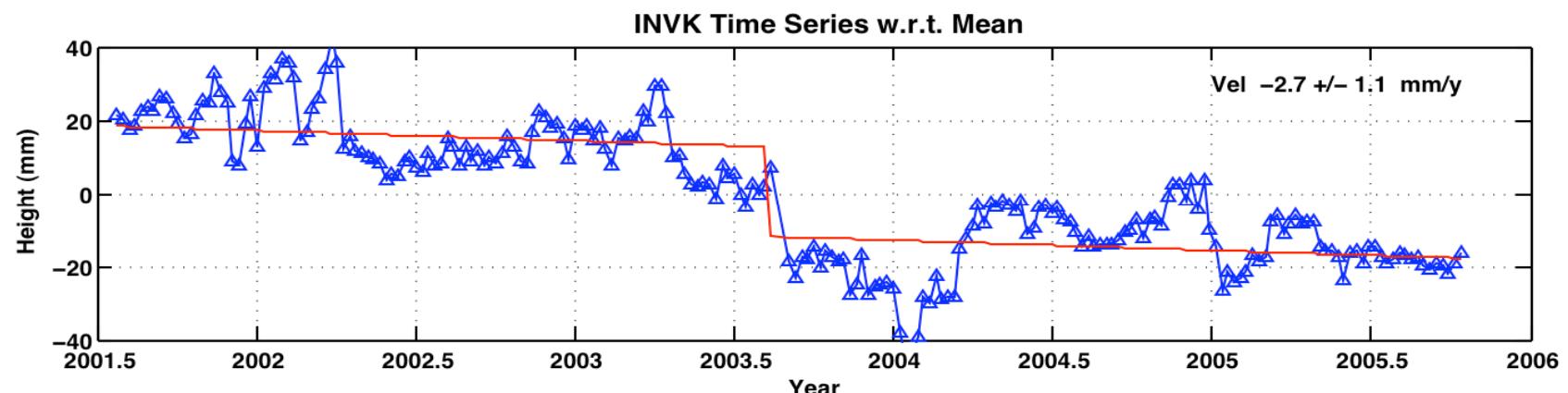
# INVK Problem



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# Episodic GPS Solutions

*GPS processing identical to CGPS solutions*

*Reference frame definition*

- Fixed IGS orbits
- Each epoch solution aligned & weighted w.r.t. IGS cumulative

*CBN Velocity solution*

- Combined 28 epoch surveys from 1994 to 2002
- Arctic episodic solutions not yet included (will be soon)
- ALGO weighted to IGS05P01 solution
- Will be rigorously combined together with CGPS solution

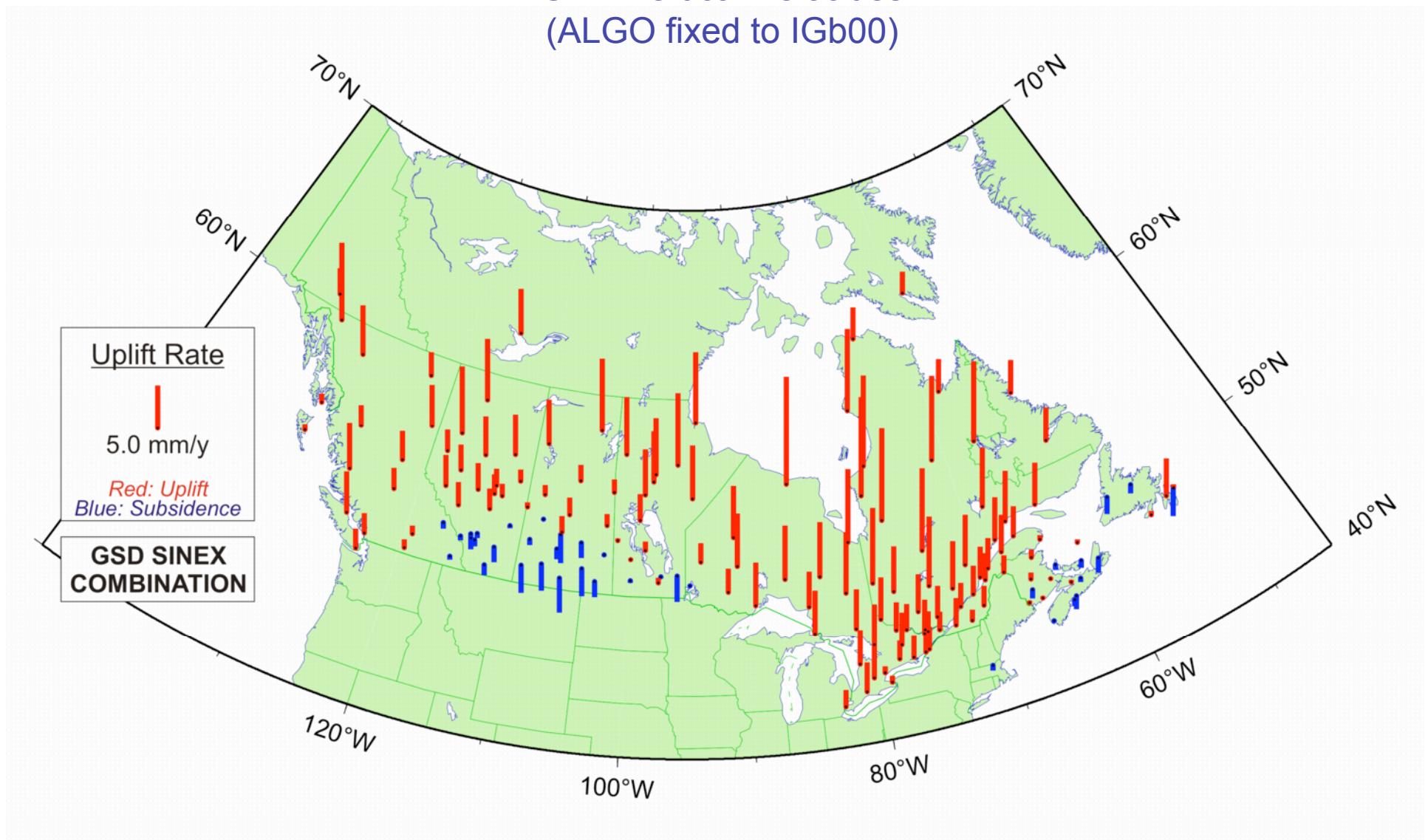


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## CBN Vertical Velocities (ALGO fixed to IGb00)



# Tide Gauge Data

*Collocated with CGPS*

- Installed by Canadian Hydrographic Service

NAIN	2001.5	TUKT	2003.5
ALRT	2002.5	QIKI	2004.5
HOLM	2002.5		

- Referenced directly to CGPS

*Not enough data yet for sea level analysis*

- Require data for at least ten years, preferably more
- Need to model tidal constituents

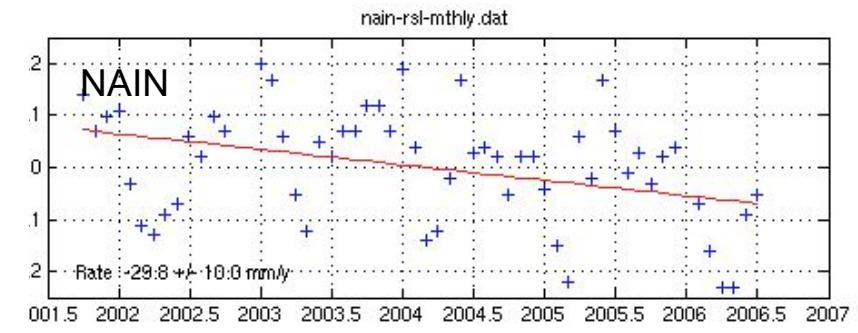
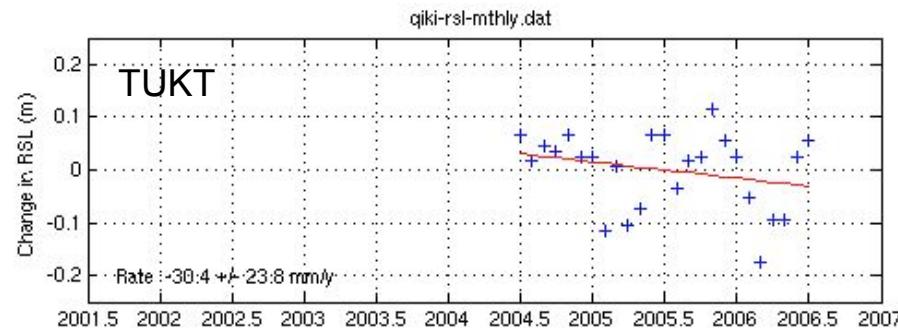
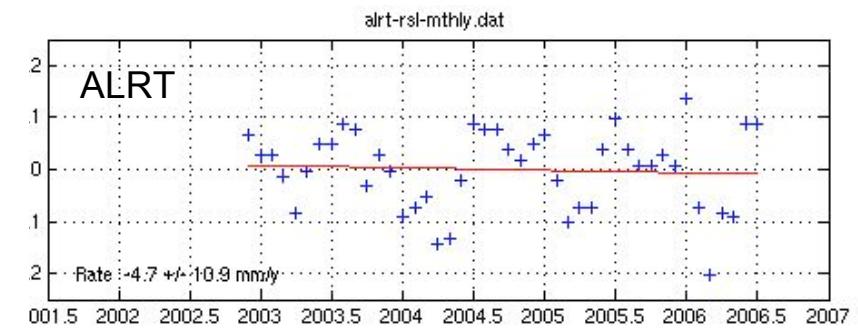
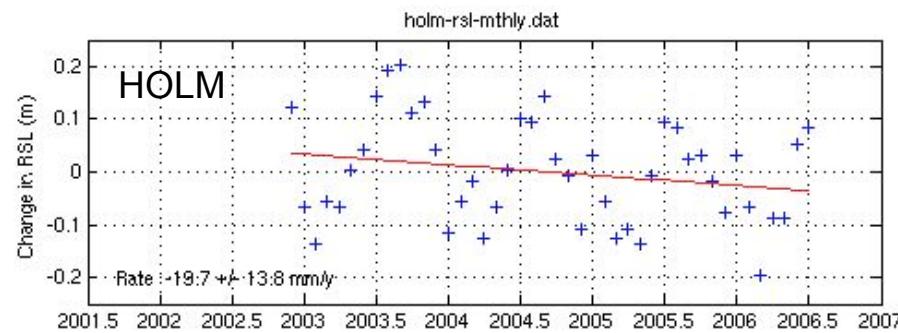


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# Monthly RSL Time Series



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# Proposals for Future

## IPY/NCGN (Northern Canada Deformation Network)

- 4 new CGPS site in Arctic with tide gauges
- Episodic observations of 8 CBN stations and/or NARES strait
- Absolute gravity at 4 CGPS sites

## IPY/CANCO (Canadian Arctic Network of Coastal Observatories)

- Part of Arctic Circumpolar Coastal Observatory Network
- Includes “contribution to network of sea level measurement sites and earth crustal deformations”

## US-IPY/Stein et al.

- 10 new CGPS sites in US/Canadian Arctic for GIA modelling



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# Other Proposals

Seth Stein et al. NSF proposal

- Several episodic GPS sites for GIA modelling
- In remote area west of Hudson Bay

CAGENET (led by Univ. of Calgary)

- 50 new CGPS sites, about 20 in Arctic
- 5 collocated tide gauges
- *Rejected earlier this week*

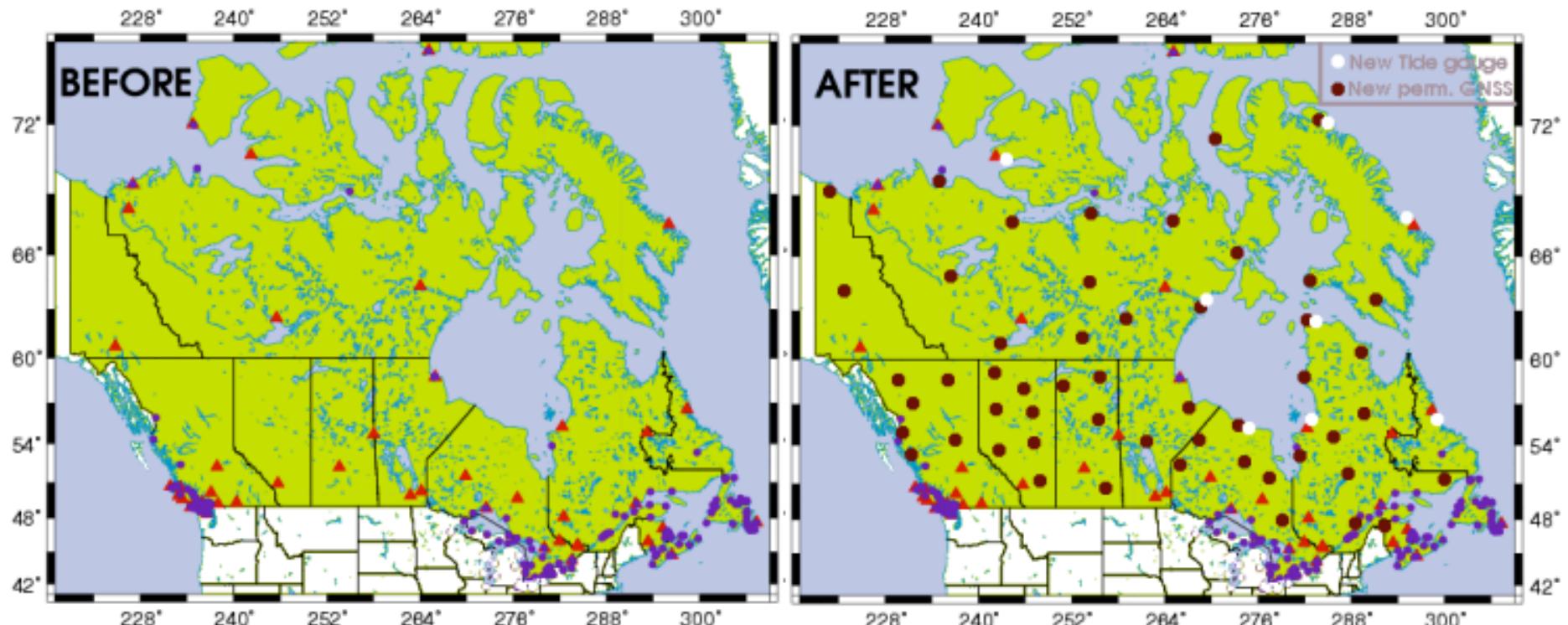


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# Proposed CAGENET Network



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*Thank you*



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# TUKT Monuments in Permafrost

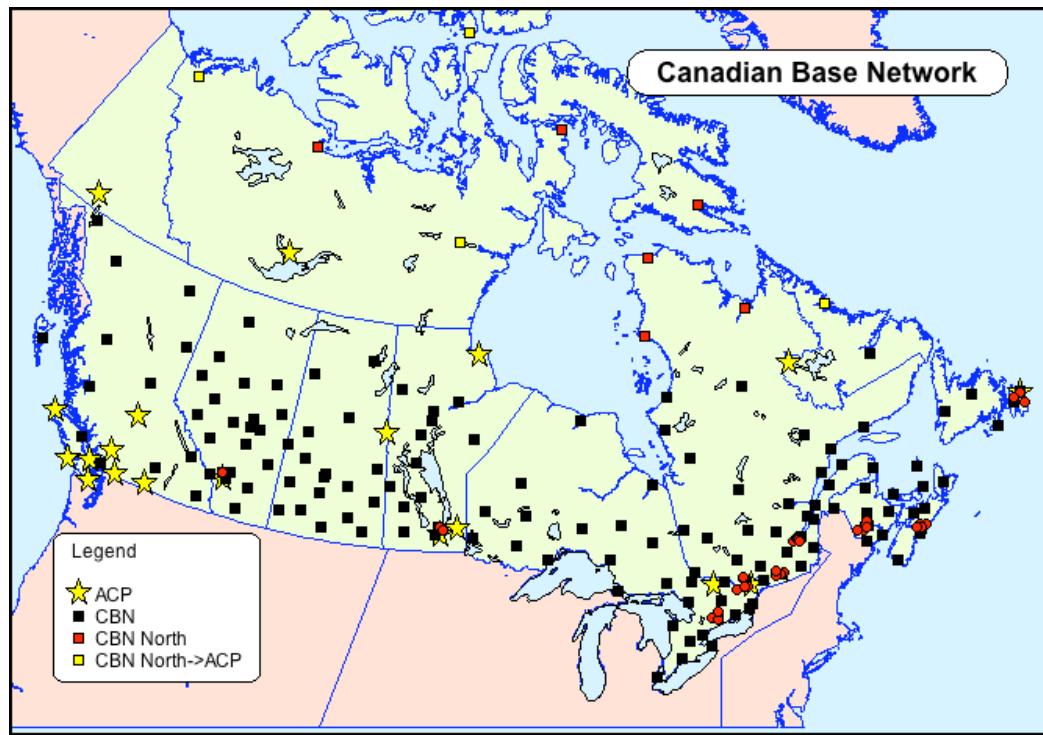


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# Canadian Base Network Episodic GPS



- Part of national reference frame
- 165 forced centering pillars
  - 10 Arctic sites (above Lat 60)
- Monumentation
  - Forced-centering pillars in bedrock when possible
- Occupations
  - 3 main campaigns  
1994-2000, 2001/2, 2005/6
  - Only 2 campaigns for Arctic sites  
2000, 2005/6

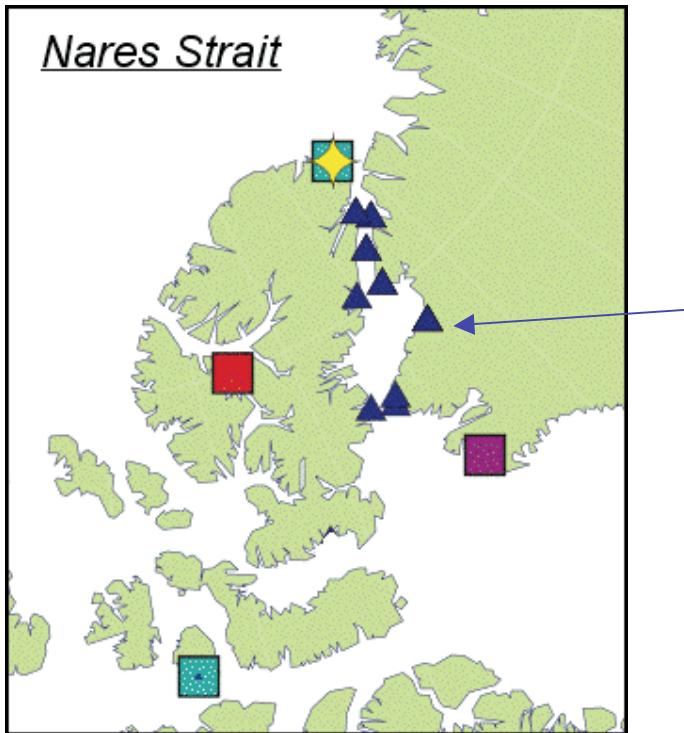


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# Nares Strait Episodic GPS



- To monitor crustal motion
- Collaborative effort with Denmark
- 8 sites (7 old + 8 new)
- Monumentation
  - Replaced 1995 monumentation in 2001 with more stable bolts in rock
- Occupations
  - 7 sites in 1995
  - 7 + 8 new sites in 2001
- Plan to reoccupy during IPY (part of NCGN proposal)

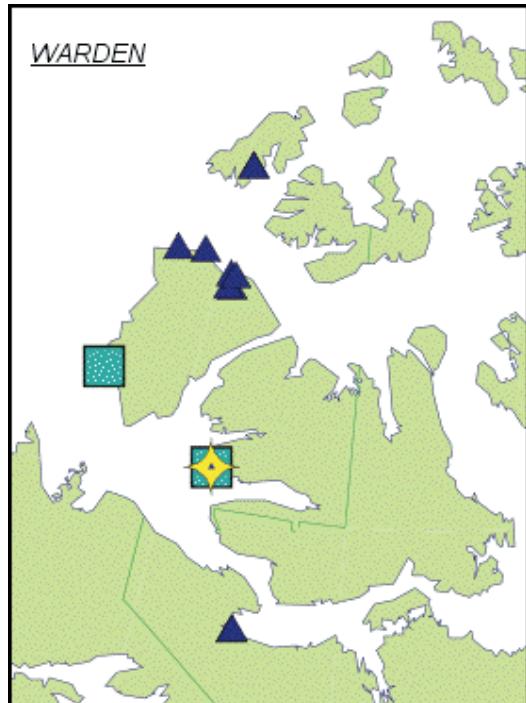


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# Western Arctic Episodic GPS



- Part of Western Arctic Deformation Network
  - Densification of CGPS
- >6 sites
- Monumentation
  - Forced-centering bolts in bedrock
  - Antenna mounted flush with ground
- First occupations 2001-2003
- Second occupations 2006 only on Banks Island



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# Example Episodic Bedrock Monument

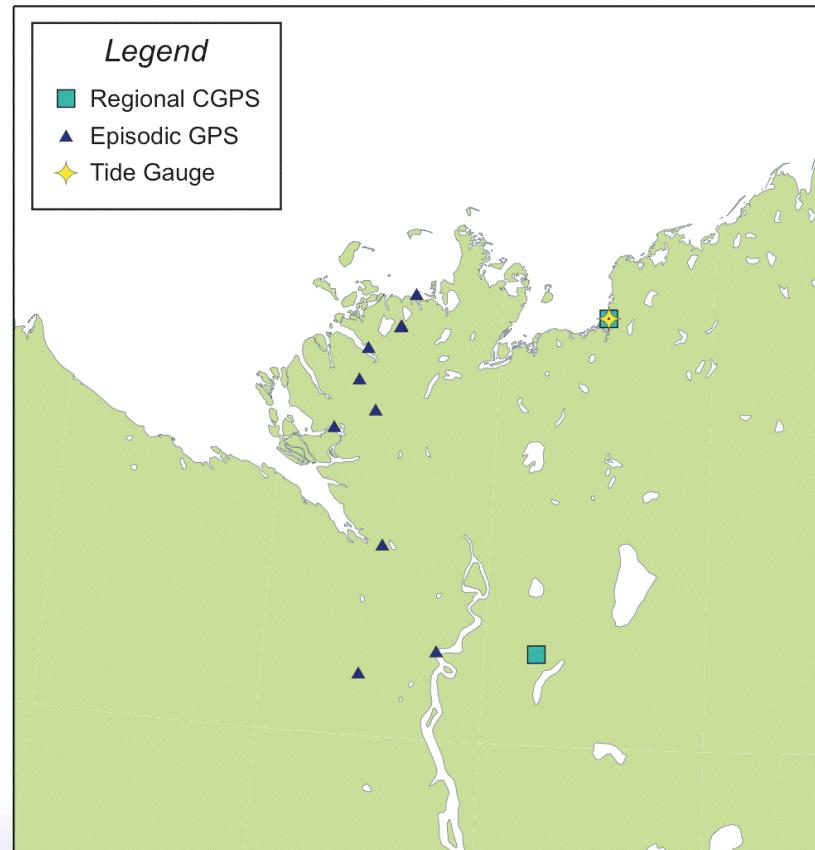


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# Mackenzie Delta Episodic GPS



- To monitor possible subsidence due to oil industry activities
- 10 sites
- Monumentation in permafrost
  - 5 sites on existing 3" pipes to 10 m depth
  - 5 sites on new 1" pipes to 10 m depth (water jet drilled)
- Occupied twice yearly since 2004
  - 2004.25      2006.25
  - 2005.25      2006.75 (in progress)
  - 2005.75



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# Example Delta Monuments



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