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Validation of a Modeling System for Tides in the Canadian Arctic Archipelago

by

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Table of Contents

List of Figures iv

List of Tables v

Abstract/Résumé vi

1 Introduction 1

2 Methods 1
- 2.1 The tidal modelling system 1
- 2.2 Mesh 5
- 2.3 Error metrics 6

3 Data Sources 8

4 Results 10

5 Tidal Currents in Barrow Strait 19

6 Tidal mixing: h/u^3 23

7 Conclusion 23

References 27

A Stations 29

B Complete station by station comparisons 34
- B.1 Baffin Bay 34
- B.2 Arctic West 39
- B.3 Arctic North 43
- B.4 Arctic Northwest 48
- B.5 Arctic Central 51
- B.6 Arctic South Central 57
- B.7 Arctic Southeast 59

C Prediction errors 63
- C.1 Baffin Bay 63
- C.2 Arctic West 64
- C.3 Arctic North 65
- C.4 Arctic Northwest 65
- C.5 Arctic Central 66
- C.6 Arctic South Central 67
- C.7 Arctic Southeast 67

D Errors at Padman and Erofeeva (2004) locations 67

E Tidal ellipse errors for Barrow Strait ADCP Data 70

List of Figures

1 The Arctic Archipelago 2
2 Schematic of the data assimilation process 2
3 Ice coverage 4
4 The Finite Element Mesh 5
5 Map of the Arctic Archipelago 7
6 M2 elevation solution 10
7 N2 elevation solution 11
8 S2 elevation solution 11
9 K1 elevation solution 12
10 O1 elevation solution 12
11 M2 amplitude error (Assimilation) 15
12 M2 amplitude error (Validation) 16
13 Barrow Strait ADCP mooring locations 20
14 Barrow Strait velocity data 21
15 Tidal Mixing Factor h/u^3 24
16 Map of known polynyas 25
17 Baffin Bay 37
18 Arctic West 39
19 Arctic North 45
20 Arctic Northwest 49
21 Arctic Central 52
22 Arctic South Central 58
23 Arctic Southeast 60

List of Tables

1 Additional tide/pressure gauge data 9
2 2002-2003 ADCP Data 9
3 RMS Error Results 13
4 Normalised *rms* Error 14
5 RMS Error, Regional Comparison 14
6 Prediction error by region 17
7 Prediction errors for the additional stations 18
8 Comparison with another tidal model. 19
9 Tidal currents comparison for M2 and K1 22
10 List of Stations Selected 29
11 List of Stations used for Validation 30
12 List of Unused Stations 32
13 Amplitude and phase comparison: Baffin Bay 34
14 Amplitude and phase comparison: Arctic West 39
15 Amplitude and phase comparison: Arctic North 43
16 Amplitude and phase comparison: Arctic Northwest 48
17 Amplitude and phase comparison: Arctic Central 51
18 Amplitude and phase comparison: Arctic South Central 57
19 Amplitude and phase comparison: Arctic Southeast 59
20 Prediction error: Baffin Bay 63
21 Prediction error: Arctic West 64
22 Prediction error: Arctic North 65
23 Prediction error: Arctic Northwest 65
24 Prediction error: Arctic Central 66
25 Prediction error: Arctic South Central 67
26 Prediction error: Arctic Southeast 67
27 Errors at PE2004 stations in Baffin Bay 68
28 Erorrs at PE2004 stations in Nares Strait 69
29 Tidal current comparison for N2, S2, and O1 70

Abstract

Dunphy, M., F. Dupont, C. G. Hannah, D. Greenberg. 2005. Validation of Modeling System for Tides in the Canadian Arctic Archipelago. Can. Tech. Rep. Hydrogr. Ocean Sci. **XXX**: vi + 70 pp.

An assimilation system for coastal tidal observations into a finite element model has been applied to the Canadian Arctic Archipelago. The system included a user-specified static ice field to partly account for the frictional effects of the ice coverage. The rms error of the tidal constituents, when averaged across all the observations, is about 14 cm for M2 and (5, 7, 8, 3) cm for (N2, S2, K1, O1) respectively. The normalized rms error for M2 is about 13% and between 20-30% for the other four constituents. The regional tidal prediction errors range from 8-25 cm. These errors vary substantially from region to region, reflecting the regional tidal amplitudes, and from station to station. The fields are of sufficient quality for many applications. As an example we map the parameter h/u^3 which can be used to identify potential areas of tidal mixing fronts and polynyas. The fields are available over the internet as part of the WebTide tidal prediction package (www.mar.dfo-mpo.gc.ca/science/ocean/home.html).

Résumé

Dunphy, M., F. Dupont, C. G. Hannah, D. Greenberg. 2005. Validation of Modeling System for Tides in the Canadian Arctic Archipelago. Can. Tech. Rep. Hydrogr. Ocean Sci. **XXX**: vi + 70 pp.

Un système d’assimilation d’observations côtières des marées dans un modèle d’éléments finis a été appliqué à l’archipel canadien arctique. Ce système inclut un champ statique de glace spécifié par l’utilisateur afin de tenir compte de la friction due à la couverture de glace. L’erreur rms des constituentes de marée, lorsque moyennée sur toutes les observations, est de 14 cm pour M2 et (5, 7, 8, 3) cm pour (N2, S2, K1, O1) respectivement. L’erreur rms normalisée pour M2 est de 13% and entre 20 et 30% pour les quatre autres constituentes. L’erreur de prédiction régionale de marée varie entre 8-25 cm. Ces erreurs varient substantiellement d’une région à une autre, illustrant les variations regionales de l’amplitude de marée, et d’une station à l’autre. Les champs sont cependant de qualité suffisante pour de nombreuses applications. En guise d’exemple, nous avons tracé le paramètre h/u^3 qui peut être utilisé pour identifier les zones potentielles de front dû au mélange de marée et les polynies. Les champs sont disponibles sur l’internet en tant que partie intégrante du logiciel WebTide de prédiction de marée (www.mar.dfo-mpo.gc.ca/science/ocean/home.html).

1 Introduction

A tidal prediction system for the five major constituents (M2, N2, S2, K1, O1) has been developed for the Arctic Archipelago and neighbouring shelf areas (Fig. 1). High resolution tidal solutions were created by assimilating coastal tide gauge data into the modelling system. The solutions were then subject to an extensive comparison with archived data. The validation considers three different aspects. As a basic error analysis, for each tidal constituent we report the model-data misfit for over 101 coastal tide gauge stations and offshore pressure gauges. To evaluate the magnitude of the errors related to tidal prediction we report the differences between tidal predictions made using the modelled tides and the archived constituents. Finally we evaluate the model currents against observation in Barrow Strait.

The modelling system is based on the technology developed by Dupont et al. (2002) for the northwest Atlantic tidal modelling system. An important feature of the underlying numerical models is the spatially variable resolution of the finite element method which is important for representing the complex geometry of the Archipelago with its numerous islands, narrow channels and long inlets. A new feature for this application is an attempt to account for some of the frictional effects of ice coverage.

A useful application of tidal models is the identification of tidal mixing fronts using the scaling parameter h/u^3 (Simpson and Hunter, 1974). We map h/u^3 and consider whether it can be used to identify tidally driven polynyas.

This report consists of the following parts. The modelling system and the error metrics are described in Section 2 and the data sets are surveyed in Section 3. The tidal elevations are presented and evaluated in Section 4 and the currents are evaluated in Section 5. The map of h/u^3 is presented in Section 6 and the conclusions in Section 7.

2 Methods

The goal is a high quality set of tidal model solutions for the Arctic Archipelago and neighbouring shelf areas. We follow the procedure of Dupont et al. (2002) and assimilate tidal data into a high resolution model. There are two key differences between this study and Dupont et al. (2002): we use coastal tide gauge data rather than Topex/Posieden data in the assimilation procedure, and we attempt to account for some of the frictional effects of ice coverage.

2.1 The tidal modelling system

The modelling system consists of a forward model and an inverse model which work together to reduce the misfit between the observations and the model solution (Figure 2). The forward model, MOG-2D (Carrère and Lyard, 2003), is a 2-d nonlinear time-stepping

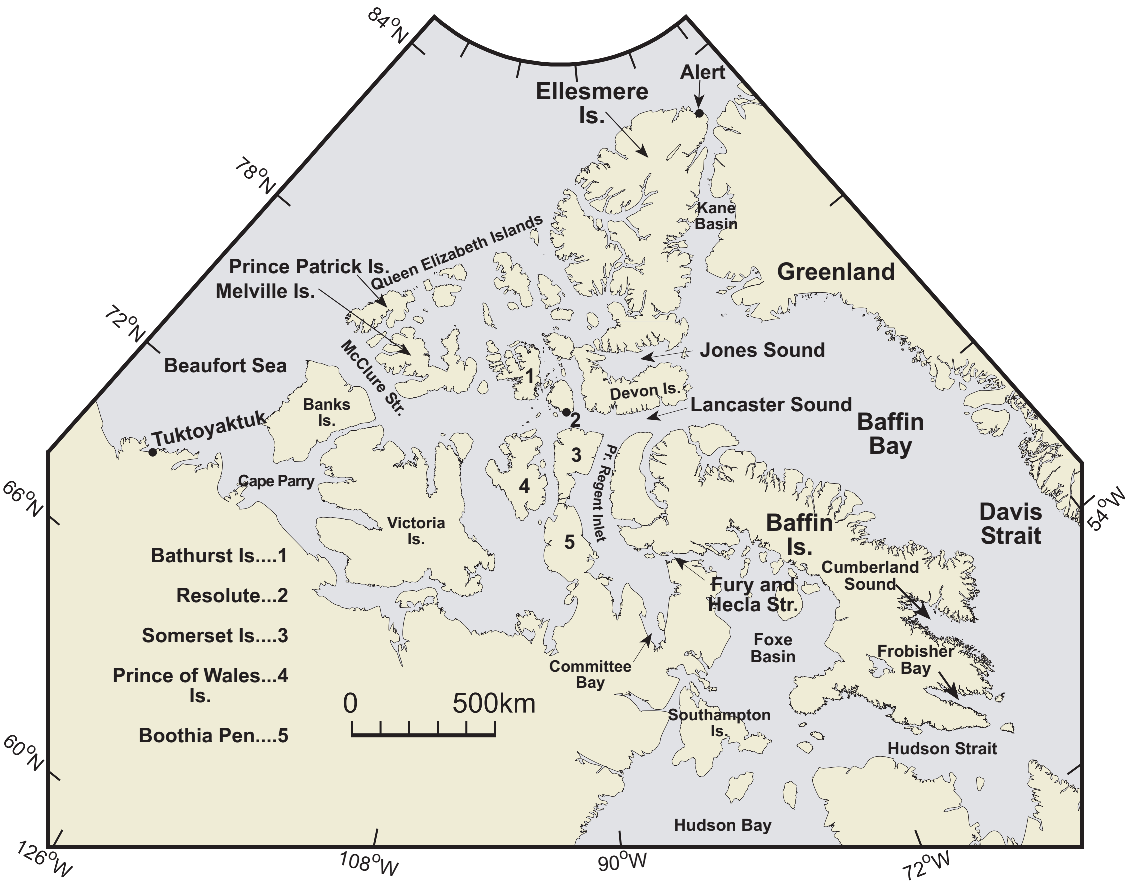

Figure 1: The Arctic Archipelago.

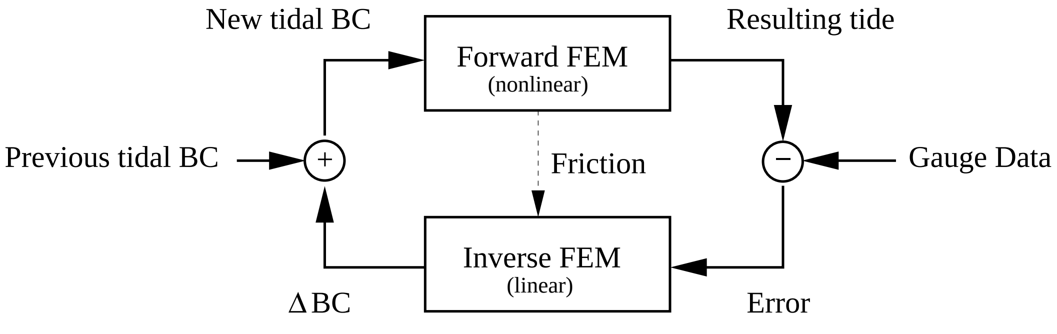

Figure 2: Schematic of the data assimilation process.

model which is forced by elevations along the open boundaries. Given elevation boundary conditions, it computes elevations and depth-averaged currents for the entire model domain. The errors in elevation are then used by the inverse model to calculate a set of perturbation boundary conditions that reduces the misfit between the model and data. The inverse model is the linear harmonic model TRUXTON (Lynch et al., 1998) modified to use spherical polar coordinates and to accept a two-dimensional field of *rms* velocity from the forward model for computing a spatially variable drag coefficient.

The step-by-step procedure is as follows:

1. Select a subset of the available observations for use in the assimilation system. The available observations should be distributed approximately evenly across the model domain. These observation are the initial values for the model-data misfit (called Error in Fig. 2).
2. Use the model-data misfits as input to the inverse model and construct a new set of boundary conditions that reduces the model-data misfit.
3. Use the new boundary conditions to run the forward model to compute the tidal solutions and the model-data misfits.
4. Repeat steps 2 and 3 until the solution converges or reaches the target error.
5. Evaluate the solutions against independent data.

The bottom friction formulation in the models follows Dupont et al. (2002). In the forward model, the bottom friction is computed as:

$$\mathbf{F}_b = C_d(u_0 + \sqrt{u^2 + v^2})\mathbf{u} \qquad (1)$$

where $C_d = 0.0025$ (nondimensional), $u_0 = 1$ cm s^{-1}, and $\mathbf{u} = (u, v)$ is the velocity field. In the inverse model, the bottom friction is written as:

$$\mathbf{F}_b = C_d(u_0 + u_{rms})\mathbf{u} \qquad (2)$$

where u_{rms} is the *rms* speed at each node from the forward model (represented by the arrow labelled ‘Friction’ in Figure 2). This allows TRUXTON to account for the spatially varying bottom drag that arises in the forward model.

Additional friction due to ice coverage was added as follows. In MOG2D a pre-computed variable friction coefficient (C_D) based on the fractional sea ice coverage was added to the constant bottom friction coefficient:

$$C_D = C_{Dbot} + C_{Dsurf} \qquad (3)$$

$$C_{Dsurf} = C_{Dice}\max(0., 2(A - 1/2)) \qquad (4)$$

where $C_{Dbot} = 2.5 \times 10^{-3}$ is the bottom friction coefficient, $C_{Dice} = 1.8 \times 10^{-2}$ (Tang and Fissel, 1991) and A is the fractional sea ice coverage at the node of interest. C_{Dsurf} is

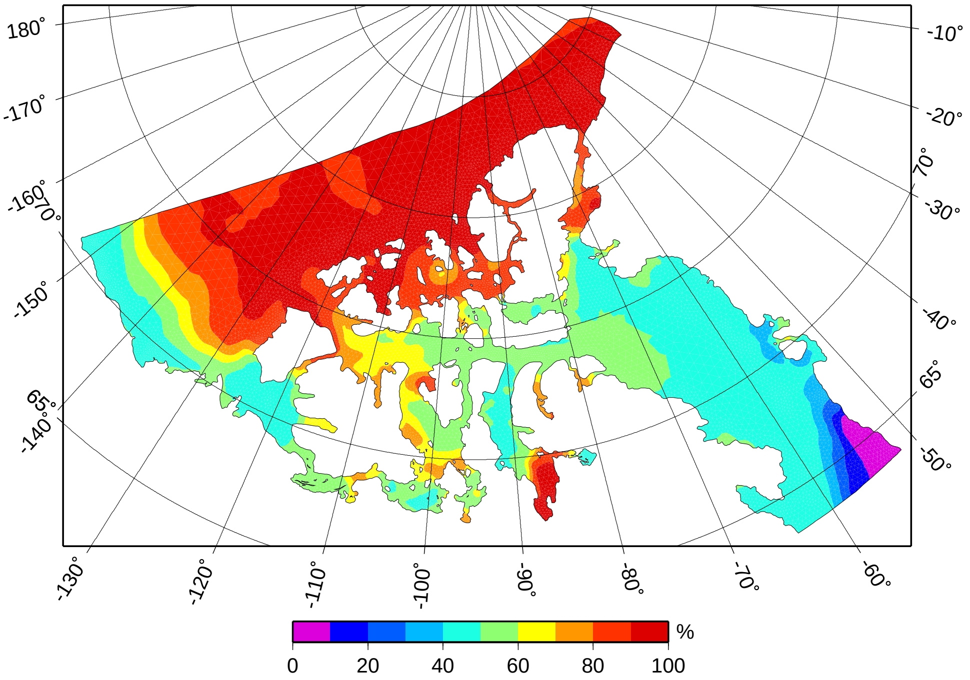

Figure 3: The fractional ice coverage field used to compute the additional friction due to ice. The field is the average of the observed coverages for September 1989 and January 1990.

zero for $A < 1/2$ and ramps linearly to its maximum value at $A = 1$. This takes advantage of the fact that MOG2D is a 2D model and surface and bottom friction enter the equations as a single term. The sea ice coverage used in these simulations is shown in Figure 3.

TRUXTON is a three-dimensional model and the bottom and ice friction coefficients must be given separately. Since the ice fraction is fixed in time and variable in space, we read the ice friction coefficient (C_{Dsurf}) from a file. This approach follows the work of Dave Greenberg (BIO) and Mike Foreman (IOS) in adding sea ice effects to FUNDY5.

In Barrow Strait, the tidal amplitudes of O1, K1 and N2 typically changed by less than 2 cm between ice-free and ice-covered seasons. The M2 and S2 changed by 3 to 6 cm (Prinsenberg and Hamilton, 2005). This is about the level of error that we expected in the tidal solutions. The seasonal and inter-annual variability of the ice coverage will become an issue when one tries to improve the tidal simulations beyond that reported here.

TRUXTON requires 3 parameters as part of the inversion process: E_{rms} the expected error level; ω_0 the inverse square of the expected size of the boundary conditions; and ω_1 a slope control (dimensionless) that penalizes wiggly solutions along the boundary. For all inversions $E_{rms} = 0.06$ m. For the first iteration, which captures the broad features of each constituents, ω_0 is set to 10 m^{-2} for M2, 100 m^{-2} for N2, S2 and K1 and 1000 m^{-2} for O1, the weakest of all. Following the same philosophy, ω_1 is set to 10^{-3} for M2, N2, S2 and K1 and 10^{-4} for O1. For all other inversions, $\omega_1 = 10^{-4}$. For M2 $\omega_0 = 100$ m^{-2}

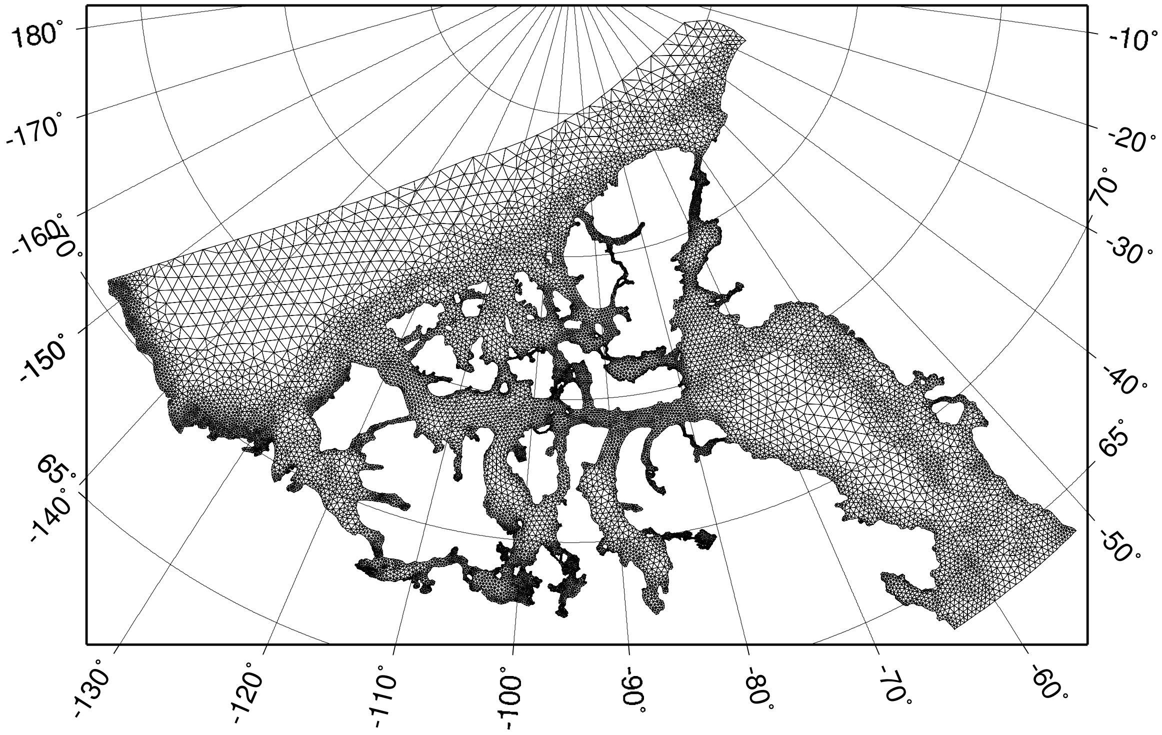

Figure 4: The mesh used for the Canadian Arctic Archipelago tidal assimilation system. It consists of 17356 nodes and 29352 elements.

and for the other constituents $\omega_0 = 1000$ m^{-2}. The inversion process is the simultaneous inversion described by Dupont et al. (2002).

The choice of inversion parameters was driven by our desire to have smooth solutions along the Arctic shelf. In preliminary experiments the model shows a tendency to generate a series of amphidromes along the Arctic shelf which we choose to suppress. A consequence is less accurate simulation of the low amplitude tides in the western Arctic.

2.2 Mesh

The mesh used in the model (Fig. 4) is a finite element mesh of triangles with 17356 nodes and 29352 elements. It has higher resolution near the coast (1 km), and lower resolution in the open ocean (45 km). The domain covers the Arctic shelf, the Canadian Arctic Archipelago, and Baffin Bay. It is bounded on the North and Northwest sides by the Arctic Ocean, on the east by Greenland, and on the South by mainland Canada. On the Southeast there is a boundary at Fury and Hecla strait in the northwest corner of Foxe Basin and a boundary to the south of Davis Strait at about 63.5^oN, The mesh includes Cumberland Sound.

The bathymetry for the mesh is based primarily on the International Bathymetric Chart of the Arctic Ocean (IBCAO) with additional data provided by Ron Macnab and Gordon

Oakey of NRCAN-GSC Atlantic (Dartmouth NS, Canada). The document describing the database is called 'International Bathymetric Chart of the Arctic Ocean (IBCAO) Beta Version Technical Reference and User's Guide'. It is written by Martin Jakobsson (Stockholm University), Ron Macnab (Geological Survey of Canada) and members of the Editorial Board (IBCAO). It is available on the web at `www.ngdc.noaa.gov/mgg/bathymetry/arctic`.

2.3 Error metrics

The first error metric was designed to measure how well each constituent was modelled. At each station (for each constituent) the error is defined as the magnitude of the observed constituent minus the modelled constituent evaluated in the complex plane:

$$\text{Error1} = |A_o e^{\phi_o} - A_m e^{\phi_m}| \tag{5}$$

where A_o, ϕ_o are the observed amplitude and phase and A_m, ϕ_m are the modelled values. This combines both elevation and phase error into a single error measure. To evaluate the solutions for one constituent over broader areas the root-mean-square (*rms*) values over multiple stations were calculated. This was done to evaluate whether the assimilation improved the solutions at the stations that were not assimilated and to estimate regional error statistics. A normalized version of this error was calculated by dividing by the observed amplitude (Error1$/A_o$). Regional averages (*rms*) of this normalized error were also calculated.

The second error metric was designed to measure the quality of tidal predictions made using the tidal solutions. At each station, tidal predictions for 1 year were made using the observed and modelled constituents. The prediction error was defined as

$$\text{Error2} = rms(T_{obs} - T_{mod}) \tag{6}$$

where T_{obs} and T_{mod} were the elevation time series constructed from the observed and modelled constituents. A relative error was also computed where the prediction error was scaled by the size of the observed time series:

$$\text{Relative Error2} = \frac{rms(T_{obs} - T_{mod})}{rms(T_{obs})} \tag{7}$$

The tidal synthesis was done using `T_PREDIC` which is part of the `T_TIDE` package (Pawlowicz et al., 2002).

The prediction error comparison was done for three cases. In the first, called 5 *vs.* 5, the tidal synthesis for both the observed and modelled tides was done using the 5 tidal constituents (M2,N2,S2,K1,O1). In the second, called 5 *vs. all*, the observed time series was constructed using all the available constituents. The first is a measure of how well the 5 constituents were modelled, the second is a measure of the expected error relative to the complete tidal spectrum. The third case, 5 *vs. signal*, was applied to data that was

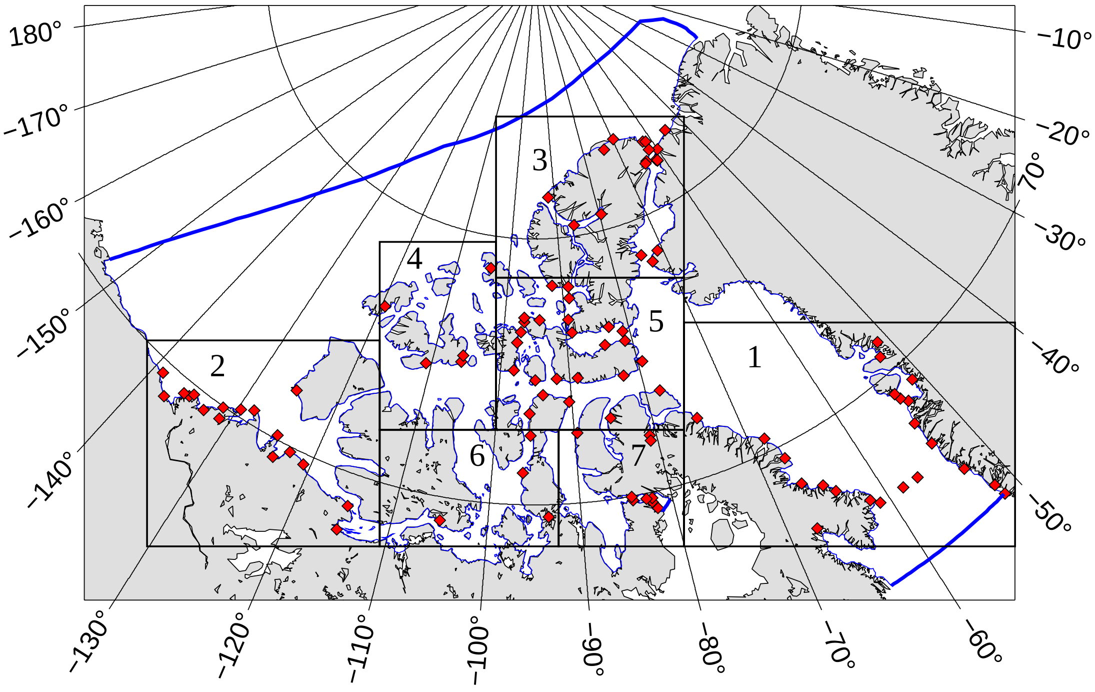

Figure 5: Map of the Arctic Archipelago showing the locations of the model open boundaries (thick blue lines) and the tide/pressure gauge distribution (red diamonds). The boxes labelled 1-7 are subregions for which statistics are calculated.

available as a water level time series. In this case, a time series was constructed from the model solution using `T_PREDIC` of the same duration and start date as the observed time series. The prediction error metric (6) was then applied using the constructed time series and the observed signal (with the mean removed). This 5 *vs. signal* measures how large the error is between the model and the water level.

There are large variations in the amplitudes and phases of the tidal in the Archipelago. For example the M2 ranges from a few centimeters in the west along the Arctic shelf to over 1 m in the eastern areas. Error statistics in areas of large tides are not likely relevant in areas of small tides. Therefore for the purposes of reporting model error statistics, we chose to divide the Archipelago into seven regions. Figure 5 shows the partitioning of the model domain and the regions are shown in more detail in Appendix B (Figures 17-23.) The names of the regions are:

1. Baffin Bay
2. Arctic West : Amundsen Gulf and Victoria Island
3. Arctic North : Ellesmere Island and Nares Strait
4. Arctic Northwest : Prince Patrick Island, Melville Island and Amund Ringnes Island
5. Arctic Central : Barrow Strait, Lancaster Sound and Jones Sound

6. Arctic South Central : M’Clintock Channel and Somerset Island
7. Arctic Southeast : Baffin Island North

3 Data Sources

CHS tide gauge data

Tidal constituents were extracted from the Canadian Hydrographic Service ‘Blue Book’ database maintained by the Marine Environmental Data Service (MEDS, Ottawa, Canada: `www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm`). A subset from this database consisting of 139 stations located in the Arctic Archipelago and surrounding area were selected as potential candidates. This list was examined for stations that were located within the model domain and with records longer than 29 days, such that the 5 main constituents would be resolved. Most stations in unresolved inlets and fjords were removed. These criteria resulted in 89 acceptable stations. The locations of the tide gauges can be found using the tables in Appendix A to identify the station ID as an index to the maps in Appendix B.

Greenland tide gauge data

The Greenland tide gauge data were extracted from the Danish tidal office report (Farvandsvæsenet, 2000). There were 24 stations in this set, with unknown record lengths and no data for the N2 constituent (which suggests that the record lengths were short). After eliminating stations outside the mesh and one that was duplicated in the CHS database, this set was reduced to 12 acceptable stations.

Additional tide and pressure gauge data

Tide and pressure gauge data were obtained from recent field programs (Table 1). From the MEDS archives we obtained data from Alert, Holman and Tuktoyaktuk, three of the ’Arctic Tide Gauges’ (H. Melling (IOS), S. Prinsenberg (BIO), R. Solvison (CHS, Central and Arctic)). From S. Prinsenberg and J. Hamilton (BIO, pers. comm. 2005) we obtained pressure gauge data at two locations in Barrow Strait and one near Resolute (Table 1) from ongoing PERD and NOAA funded programs (Prinsenberg and Hamilton, 2005). The tidal constituents were calculated from the time series using `T_TIDE` (Pawlowicz et al., 2002) to resolve the five main constituents. It is worth noting that the record length for these stations is considerably longer than most of the CHS records. The locations of the measurements can be found using the Station IDs from Table 1 and the maps in Appendix B.

Station Name	**Station ID**	**Date**	**Duration**
Barrow Strait (1)	B1489	Oct 2003-Aug 2004	300 days
Barrow Strait (2)	B1491	Aug 2003-Aug 2004	359 days
Resolute	B1492	Aug 2003-Jul 2004	353 days
Alert	M3765	Dec 2002-Jul 2004	589 days
HOLMAN	M6380	Dec 2002-Jul 2004	589 days
Tuktoyaktuk	M6485	Aug 2003-Jul 2004	341 days

Table 1: The additional tide/pressure gauge data used for model validation. The stations IDs for the stations extracted from the MEDS archives are prefixed by M and those acquired from BIO colleagues are prefixed by B. Tidal constituents for stations M3765 and M6485 are also present in the CHS dataset.

Mooring Description	**Mooring ID**	**Longitude**	**Latitude**	**Duration**	**Bins**
South side shallow	1438	-91.0502	74.0834	349 days	18
South side deep	1439	-91.0329	74.0818	349 days	35
South-Central Strait	1441	-90.8511	74.1955	349 days	18
Central Barrow Strait	1443	-90.7210	74.3205	348 days	18
North Barrow Strait	1445	-90.4249	74.5366	349 days	17

Table 2: The ADCP data collected from Aug19-20 2002 to Aug 3-4 2003. These current meters form section across Barrow Strait.

Barrow Strait current meter data

For validation of the tidal currents, we obtained ADCP data for the Barrow Strait section from S. Prinsenberg and J. Hamilton (BIO, pers. comm. 2005). The station IDs in Table 2 can be used to find the station locations in Fig. 13 (Appendix E). The time series were vertically averaged and then analyzed with `T_TIDE` (Pawlowicz et al., 2002) for comparison with the model.

Assimilation and validation

The stations chosen for assimilation were primarily the stations with the longest records in the CHS dataset. Stations with records longer than 40 days were preferred, with the exception of two stations along the Arctic shelf which had 29 day records. Nine stations were selected along the Greenland coast. In total, 54 stations were selected to use in the assimilation process. Table 10 (Appendix A) lists the stations assimilated into the model.

The remaining stations located within the domain of the mesh were used for validation (Table 11). This consisted of the remaining 44 Arctic stations, 3 Greenland stations, and the 6 additional tide/pressure gauges. The comparison with the 6 additional gauges was

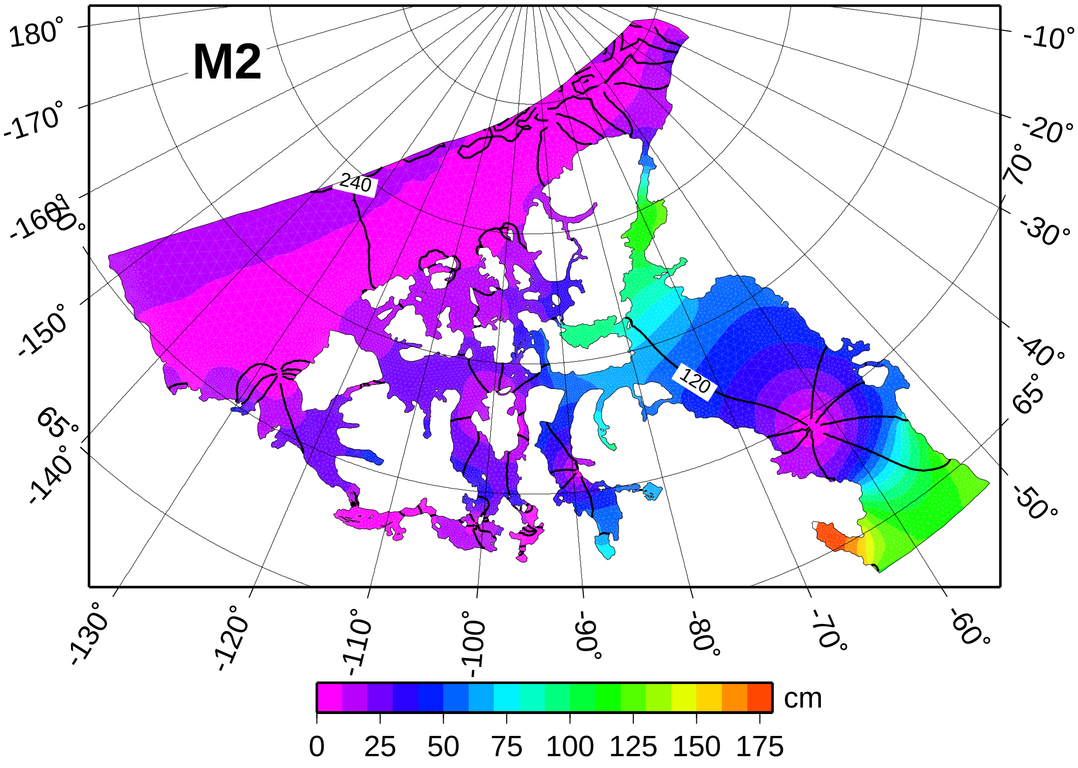

Figure 6: The M2 elevation solution. Phase lines are shown at 20 degree contours.

done separately from the rest.

There were a total of 62 stations that were not considered for either assimilation or validation. These stations were rejected either because they lie outside of the model domain (such as in a channel that was not sufficiently resolved), or had a record too short (less than 29 days). Greenland station G22 (Nuuk-Godthab) was not included because a more complete record was available in the CHS dataset (MEDS #3575). The stations not included are shown in Table 12.

4 Results

The assimilation loop in Figure 2 was run 8 times by which point the solutions were no longer improving. The maps of amplitude and phase for each of the 5 modelled constituents are shown in Figures 6-10. Note that the colour scale is adjusted from figure to figure. The semi-diurnal tides all show an amphidromic system in Baffin Bay and large amplitude in Cumberland Sound. The two diurnal tides are generally small with a substantial amplification in Boothia Bay. This amplification is not well observed because southern Boothia Bay is ice covered all year.

A feature of the M2 tide along the Arctic shelf (Tuktoyaktuk to Alert) is that it starts at

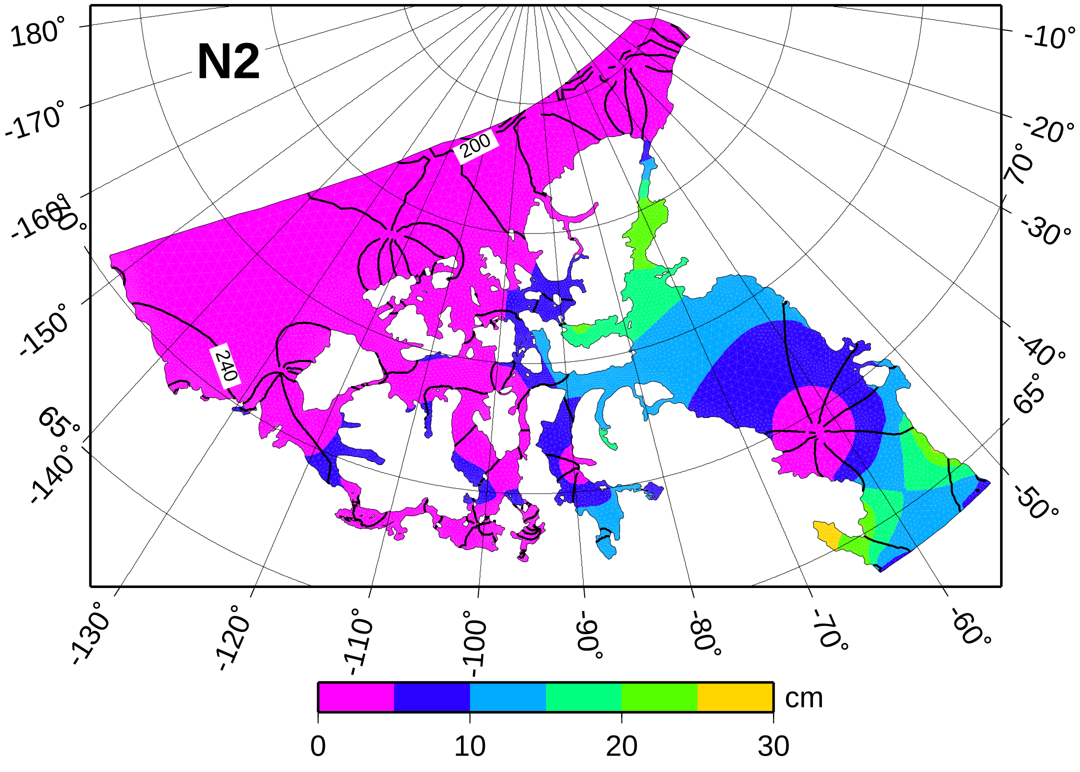

Figure 7: The N2 elevation solution.

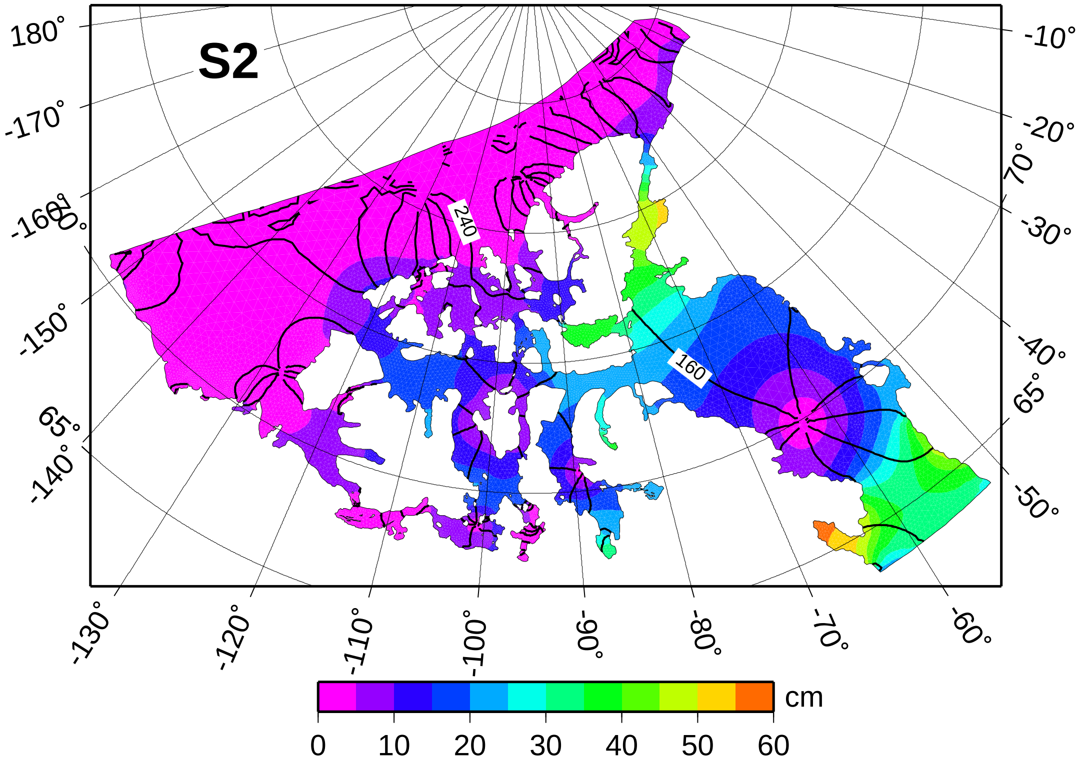

Figure 8: The S2 elevation solution.

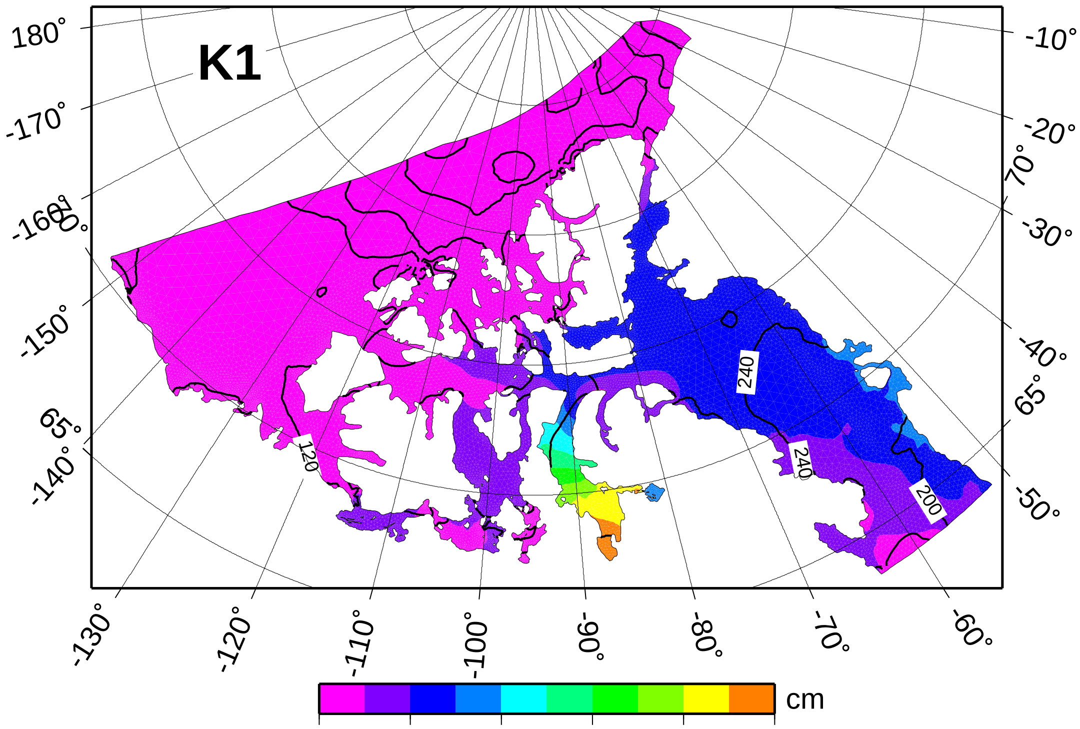

Figure 9: The K1 elevation solution.

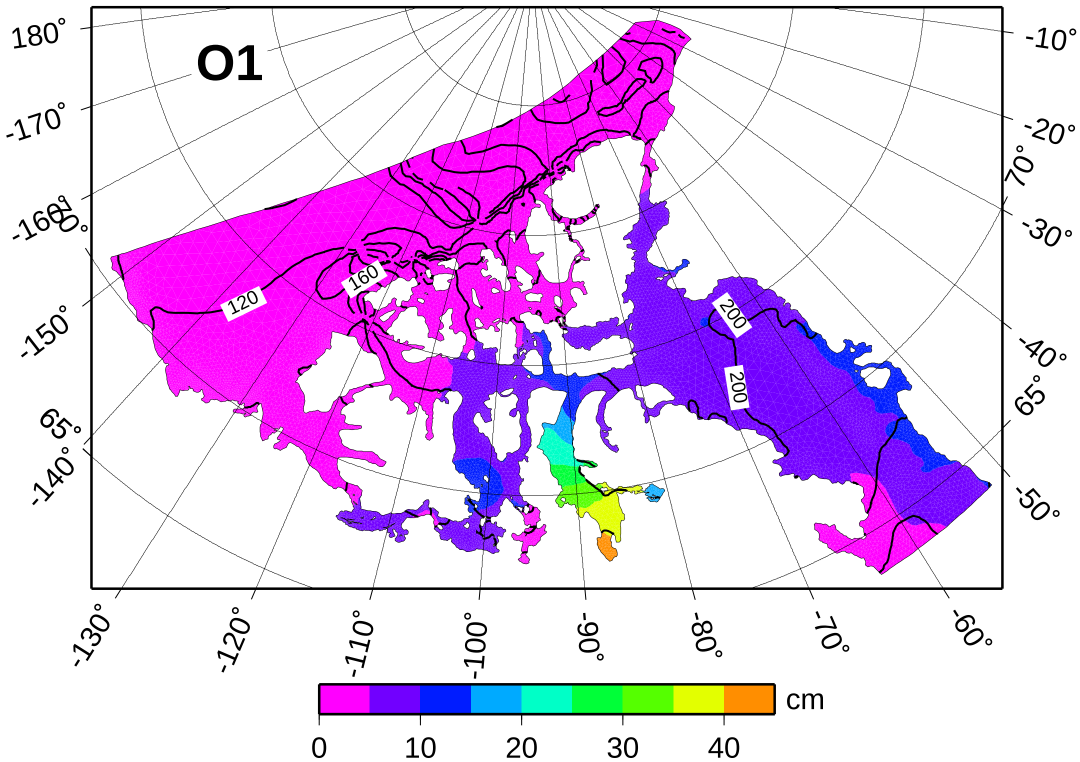

Figure 10: The O1 elevation solution.

Tide	Assimilation (cm)			Validation (cm)			All (cm)
	prior	1^{st}	8^{th}	prior	1^{st}	8^{th}	8^{th}
M2	52.73	14.85	10.35	67.76	21.16	16.68	13.67
N2	9.22	2.83	2.49	12.47	6.55	6.14	4.67
S2	20.83	8.00	4.95	25.91	12.12	9.42	7.36
K1	19.56	6.67	5.59	24.42	8.24	9.35	7.58
O1	7.67	3.12	2.20	10.90	4.36	4.08	3.22

Table 3: *rms* value of Error1 for the prior, iteration 1 and iteration 8. The prior is the *rms* amplitude of the observations as there is no prior model solution (i.e., the model solution is set zero in Error1). The 'Assimilation' columns were computed using the 54 assimilation stations, the 'Validation' columns were computed using the 47 validation stations, and 'All' represents the combination of both data sets.

about 12 cm in magnitude at Tuktoyaktuk, decreases to about (1 cm) at Kleybolt Peninsula (station 6704) on the north coast of Ellesmere Island and then increases to 20 cm at Alert. The M2 solution captures the general character of this feature, but does not achieve the very low values.

To evaluate the assimilation procedure we consider the basic error measure (5) averaged over the assimilation stations and the validation stations. The results in Table 3 show that the first iteration of the assimilation system captures most of the tidal signal. The subsequent iterations result in modest improvement; the improvement is limited by the smoothness constraints on the boundary conditions.

For the assimilation stations, the desired accuracy of 6 cm (E_{rms}) is achieved for all constituents except M2 where the demand for smoothness has limited the accuracy. A value of E_{rms} less than 6 cm might be more appropriate for the other 4 constituents.

Overall the M2 error was reduced by over 40 cm relative to the observed M2 amplitude (recall that there was no prior estimate of the solution), the N2 by 6 cm, the S2 by 15 cm, the K1 by 15 cm and the O1 by 5 cm. An important point is that the assimilation procedure improved the solutions at both the assimilation stations and the validation stations by about the same amount, indicating that the assimilation procedure is not compromising the solution elsewhere (within the limited established by the inversion parameters).

The changes in the error statistics for the K1 component between iteration 1 and 8 provide an interesting anomaly. The error at the assimilation stations decreases by 1.1 cm, while it increases by about 1.1 cm at the validation stations. This suggests that the assimilation system is having a difficult time improving the K1 solution.

Table 4 shows the normalized values of the error after the 8^{th} iteration. For the assimilated stations, the normalized error is in the range 0.12-0.20 for each constituent. For the validation stations it is a bit higher, in the 0.13-0.33 range.

The amplitude and phase errors and the combined error metric (Eq. 5) are tabulated for

Tide	**Normal Error**		
	Assimiation	Validation	All
M2	0.127	0.134	0.131
N2	0.176	0.331	0.286
S2	0.120	0.241	0.198
K1	0.192	0.315	0.270
O1	0.229	0.272	0.257

Table 4: Normalised *rms* Error1 for iteration 8. This is the *rms* value of each station's normalised complex error.

Region	**M2 (cm)**	**N2 (cm)**	**S2 (cm)**	**K1 (cm)**	**O1 (cm)**
Baffin Bay	16.4	10.1	12.3	7.6	2.7
Arctic West	12.8	2.2	3.3	3.7	2.1
Arctic North	14.9	3.7	6.0	3.8	2.4
Arctic Northwest	7.4	1.6	3.6	5.1	2.1
Arctic Central	12.1	2.4	5.3	5.1	2.4
Arctic South Central	6.9	0.8	3.2	3.7	2.4
Arctic Southeast	14.0	5.1	7.0	18.8	7.5

Table 5: Regional comparison using Error1 for each constituent.

each constituent for each station in Appendix B. The tables are organized by region. Regional averages for amplitude, error and relative error are reported in the tables, however, given the large variability in tidal phase in each of the regions, it does not make sense to compute regional averages for phase.

The regional summaries of the error metric are presented in Table 5. The largest regional errors are for the M2 tide, which has the largest amplitude. Careful study of the tables in Appendix B shows that the error can be much larger at some stations. In some cases the very large errors at a handful of stations dominate the regional error. However we have not examined the errors on a station by station basis to evaluate whether the results at particular stations should be excluded from the regional averages.

Overall the M2 errors are in the 7-17 cm range. For the other constituents the errors are in the 1-6 cm range, with the exception of N2, S2, K1 in Baffin Bay, and K1 and O1 in the Southeast (recall the large diurnal tides in Boothia Bay).

In order to illustrate the spatial patterns of the errors for M2, we have plotted the errors at each station using shaded symbols in Figures 11 and 12. The model overpredicts the amplitude in the western part of the domain (Amundsen Gulf and Beaufort sea) and along the Arctic shelf in general but underpredicts the amplitude in southern and eastern Baffin Bay with the exception of the most southern Greenland station. Along the Arctic shelf, the very small of number stations and their short record lengths is likely partly responsible for

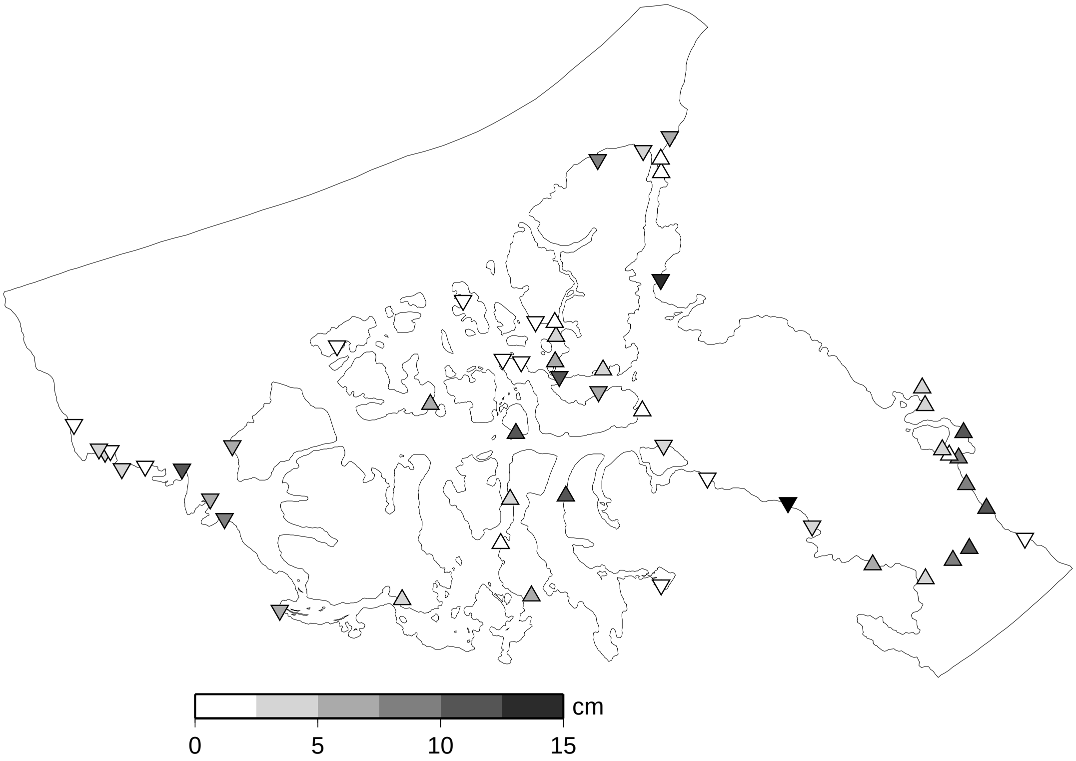

Figure 11: M2 amplitude error for the assimilation stations. A triangle pointing upward indicates that the observed amplitude exceeds the modelled value (underprediction) and a downward pointing triangle indicates that the modelled amplitude exceeds the observed one (overpredicted). The triangles do not show the phase error. Stations with errors in excess of 15 cm are shown as 15 cm.

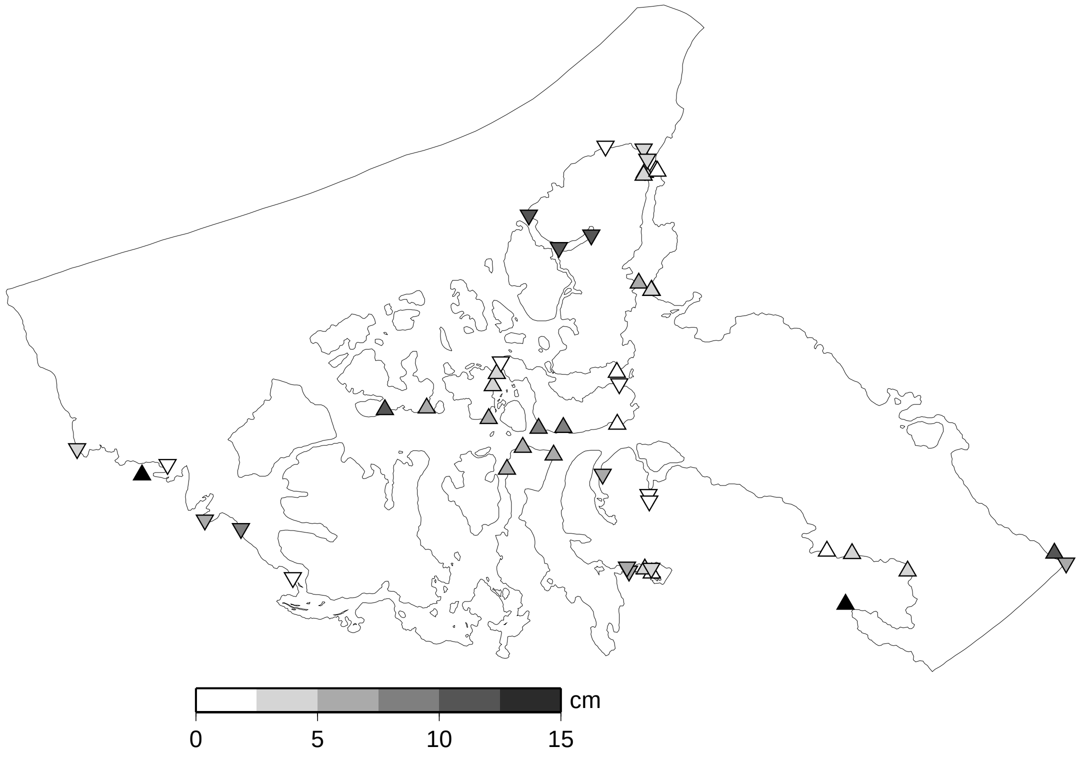

Figure 12: M2 amplitude error for the validation stations. Stations with errors in excess of 15 cm are shown as 15 cm.

Region	**5** *vs.* **5**		**5** *vs. all*	
	cm	norm	cm	norm
Baffin Bay	17.8	0.413	18.9	0.419
Arctic West	10.0	0.829	12.2	0.900
Arctic North	13.2	0.890	14.7	0.854
Arctic Northwest	7.1	0.465	8.1	0.489
Arctic Central	10.3	0.250	12.9	0.298
Arctic South Central	6.3	0.634	7.8	0.684
Arctic Southeast	18.5	0.313	23.0	0.374

Table 6: Regional prediction error (using the Error2 metric). The normalized error (norm) is the *rms* regional value of the station by station normalized error (see Eq. 7).

the poor agreement. Close to Alert where the model solution underpredicts the M2 amplitude, two Greenland stations are in agreement with the model. In the central Canadian Archipelago the model solution shows less significant trends. There are no easy explanations for some of the large errors in southern and eastern Baffin Bay. In some cases there are large amplitude errors and small phase errors and some case the opposite (Table 13). A combination of local model errors, a small phase error in the amphidromic system, and few low quality stations may provide an explanation. The very large error (46 cm) in Cumberland Sound is due in part to the large tidal amplitude (2.26 m) and in part to a poorly resolved fjord. The large error at Resolute is surprising given the long record and the generally high quality of the solutions in the central archipelago. Further numerical experiments could be conducted to assess whether the large errors at some stations are due to model errors (boundary conditions, water depth, resolution) or observational errors.

The overall quality of the solutions for predicting the tides was estimated using the prediction errors defined by Eq. 6-7 in Section 2. The station by station prediction errors are tabulated in Appendix C and regional averages are given in Table 6. For the Greenland stations, the results for 5 *vs.* 5 and 5 *vs. all* are identical because only four constituents were available (M2, S2, K1, O1).

Overall, the 5 *vs.* 5 errors are the in the range 6-20 cm and the 5 *vs. all* errors are slightly larger at 8-25 cm. This indicates that the 5 tidal constituents include most of the tidal variability. The exception may be the Arctic Southeast where the 5 cm increase in the error suggests that some important tidal constituents were not modelled.

The region with the highest quality simulations is the Arctic Central region (Barrow Strait) where the regional *rms* tidal prediction error is about 13 cm or 30%. The regions with small tides such as Arctic West, North, North West, and South Central have large normalized errors (0.5 - 0.9). However, in all cases the normalized error is < 1 indicating that using the model is better than using nothing. However there are individual stations where the prediction error is > 1.

The prediction errors for the additional stations are tabulated in Table 7. The 5 *vs. all* error

Station	5 *vs. all* (cm)	*rms*(all) (cm)	5 *vs. signal* (cm)	*rms*(signal) (cm)
M3765	7.0	19.0	11.8	21.3
M6380	13.2	17.0	16.6	19.8
M6485	5.7	8.6	21.8	22.7
B1489	68.3	51.6	69.3	52.9
B1491	8.9	56.4	14.1	57.4
B1492	10.1	39.9	13.6	40.9

Table 7: Prediction errors for the additional stations: 5 *vs. all* is as before; *rms*(all) is the *rms* amplitude of the observed tidal time series (reconstructed from the constituents); 5 *vs. signal* the *rms* error found when using the modelled tides to predict the observed pressure signal (tides plus everything else) with the mean removed; *rms*(signal) is the *rms* amplitude of the observed signal. Thus 5 *vs. signal* is the expected error found using the model to predict observed sea level at the stations and *rms*(signal) is the *rms* sea level (or subsurface pressure) variability at each location.

at B1489 (68 cm) is much larger than the others and larger than errors at other stations, so there is likely a problem with the observations (possibly the time). At the other stations, the 5 *vs. all* errors are in the 6-13 cm range and consistent with the regional analysis. The prediction error relative to the entire sea level (or pressure) signal is generally about 4-6 cm larger than relative to the tides. The exception is M6485 (Tuktoyaktuk) where there is clearly a large non-tidal signal.

The recent results of Padman and Erofeeva (2004) provide the opportunity for a model intercomparison. They report on a tidal model of the entire Arctic Ocean with 5 km resolution that includes good solutions in the Archipelago. For a rough comparison of their solutions with ours we have computed regional errors using approximately the same stations as Padman and Erofeeva (2004) for two of their regions: Baffin Bay (their region 6) and Nares Strait (their region 7). The identification of common locations was not precise, we did a visual inspection of our map and theirs. The stations (and errors) used from our results are listed in Appendix D.

The comparison is shown in Table 8. The solutions reported here (Arctic8) are generally as good or better than the AODTM solutions of Padman and Erofeeva (2004) and generally a little worse than the AOTIM solutions. A word of explanation is required. The AODTM solutions were computed using a tidal model and their best boundary conditions at the edges of the Arctic Ocean. The AOTIM solutions are an assimilation that combines the AODTM solution with corrections related to the model-data misfit. The assimilation scheme is different from ours where we use the model-data misfit to modify the boundary conditions and then compute the new solution using the tidal model. Thus we do not expect to match the AOTIM solutions.

The station errors listed in Appendix D show that our errors are dominated by large errors a few locations. A more careful evaluation of which stations were used by Padman and

Constituent	AODTM	AOTIM	Arctic8
Baffin Bay			
M2	14.5	11.8	14.5
N2	NA	NA	3.6
S2	6.5	2.5	6.9
K1	7.6	2.9	4.0
O1	2.6	1.7	2.1
Nares Strait			
M2	4.2	3.5	3.6
N2	NA	NA	0.8
S2	2.2	1.9	1.3
K1	1.6	1.1	1.2
O1	0.7	0.3	1.0

Table 8: Comparison of the errors in our Arctic8 solutions with the model of Padman and Erofeeva (2004) (who did not compute an N2 component). AODTM is the dynamics only model of Padman and Erofeeva (2004) and AOTIM is the assimilation model. Arctic8 is the model described in this report. The errors for Arctic8 were assessed using stations that corresponded visually to those shown on the map in Padman and Erofeeva (2004). The error metric used is that of Padman and Erofeeva (2004) which is $1/\sqrt{2}$ smaller than the peak error of $Error1$ (5).

Erofeeva (2004) may indicate locations where our model is performing particularly badly or where the observations are incorrect.

5 Tidal Currents in Barrow Strait

For the comparison of the observed and modelled tidal ellipses the ADCP data was depth-integrated from 10m and downward. The upper 10m was ignored due to data quality issues (largely due to ice cover). The locations of the ADCP moorings in Barrow Strait are shown in Figure 13. The records at A1438 and A1439 were merged (A1439_39) to provide coverage over the water column at that location. The comparison of the observed and modelled tidal ellipses is shown in Figure 14. Visually the length of the major axis is generally well modelled, as is the orientation of the ellipse (or the inclination) when the currents are reasonably large.

The comparison of the tidal ellipse parameters for M2 and K2 are tabulated in Table 9, and the rest are tabulated in Appendix E (Table 29). For M2 and K1 the major axis is well modelled (within 1 or 2 cm/s) and the inclination of the ellipse is also reasonable well modelled (errors less than about 10°). The magnitude of the minor axis (or eccentricity) is less well modelled. The observed M2 phases show substantial structure across the strait (note A1443) while the modelled phases are quite uniform. Even ignoring A1443, the M2

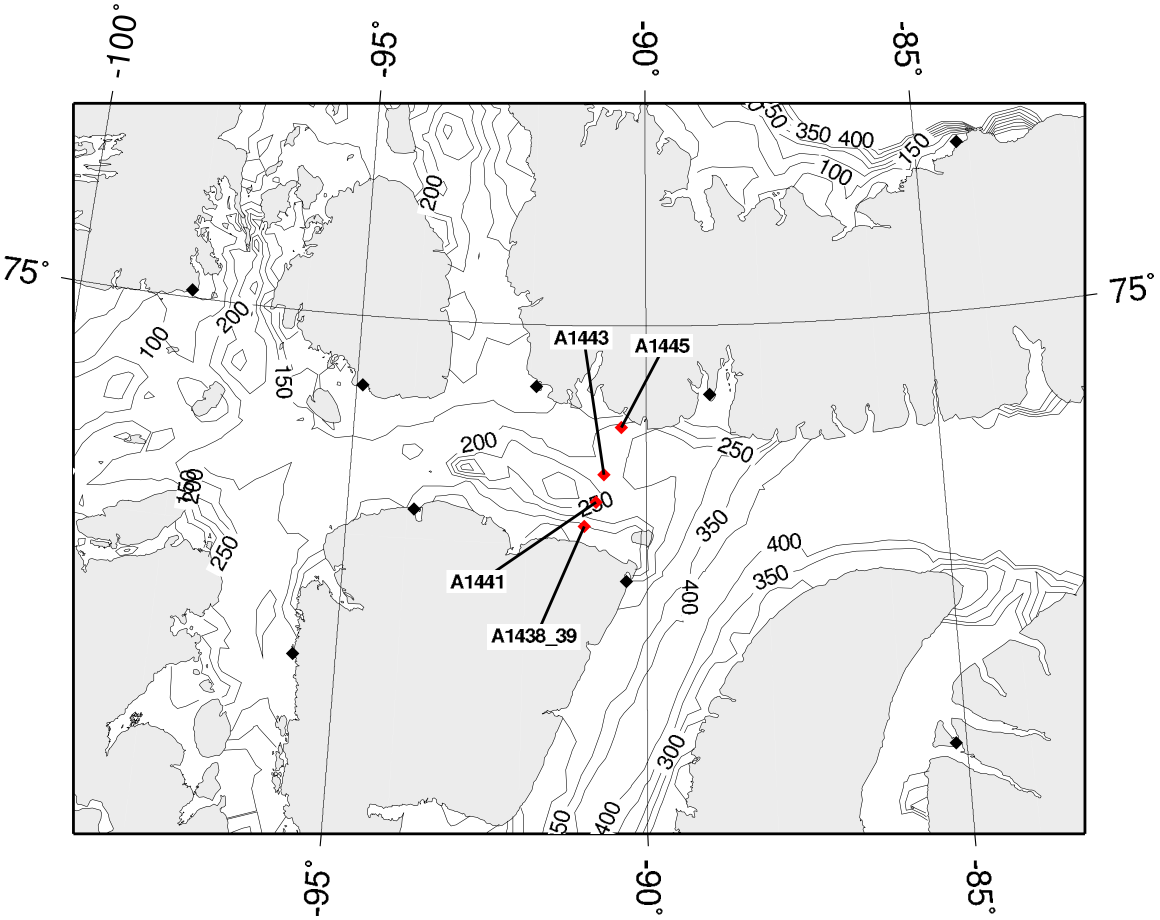

Figure 13: Map of Barrow Strait showing the locations of the ADCP moorings. The black diamonds are the tide gauge locations.

phase differences are much larger than the can be attributed to the 10 minute drift over 1 year that occurred with some of the instruments. The phase differences require further investigation.

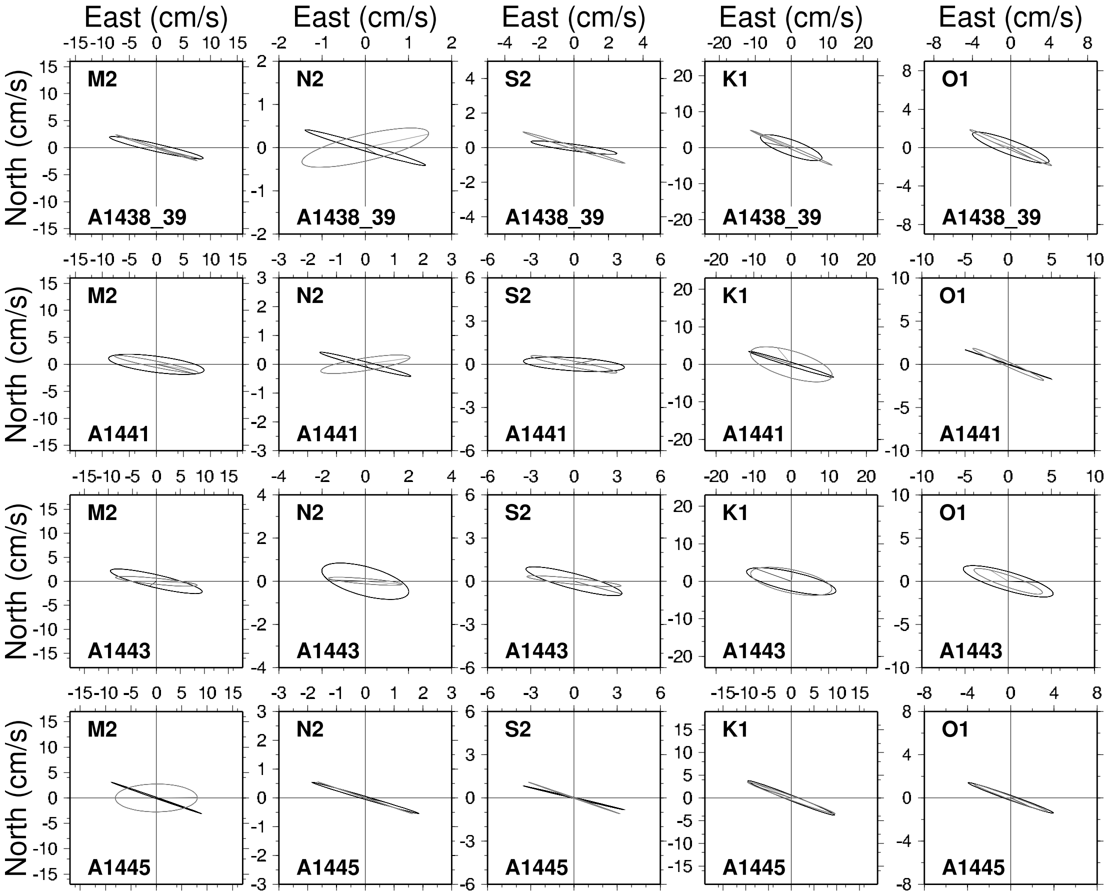

Figure 14: Tidal ellipses showing the difference between the model's current solution and the depth-integrated Barrow Strait ADCP data. The black ellipse shows the ADCP currents and the grey ellipse shows the modeled current.

Stat #	**Major (cm)**		**Eccentricity**		**Inclination (deg)**		**Phase (deg)**	
	obs	mod	obs	mod	obs	mod	obs	mod
M2								
A1438_39	8.9	7.9	-0.079	-0.022	167.3	162.4	160.5	206.0
A1441	8.9	7.8	-0.168	-0.019	172.8	162.3	146.2	206.0
A1443	9.8	7.9	-0.137	-0.072	167.0	168.5	83.2	205.9
A1445	9.3	8.5	0.013	-0.074	160.8	174.5	153.2	203.6
K1								
A1438_39	9.0	12.2	0.237	0.030	160.5	156.8	328.4	355.2
A1441	11.8	12.3	-0.044	0.030	163.0	156.9	354.3	355.4
A1443	12.2	11.3	-0.206	0.311	167.4	163.4	328.9	64.4
A1445	10.2	11.0	0.059	0.280	158.5	168.3	314.0	90.0

Table 9: Tidal currents comparison for M2 and K1 in Barrow Strait. The major axis (also called the semi-major axis) is the maximum tidal current. The eccentricity (unitless) is the ratio between the semi-minor axis and the semi-major axis, and is negative if the ellipse is traversed clockwise. The inclination is the angle of the major axis with the x (east) axis measured counterclockwise (the mathematical convention). The phase is the timing of the maximum current, expressed as phase lag relative to Greenwich.

6 Tidal mixing: h/u^3

Tidal currents can make a major contribution to vertical mixing. Features such as tidal mixed fronts are important for both the physics and biology of shelf regions. Recently, Saucier et al. (2004) found that proper representation of tidal mixing is important for the proper simulation of ice dynamics in the Hudson Bay. The parameter h/u^3 is commonly used as an indicator of the strength of tidal mixing relative to the stratifying potential of the surface heat flux (Simpson and Hunter, 1974; Garrett et al., 1978). In the Arctic the surface salinity is at least as important as the surface heat flux in stratifying the water column. Nevertheless we will use h/u^3 as an indicator of the potential of the tidal currents to homogenize the water column.

Figure 15 is a map of

$$\log_{10} \frac{h}{\mathrm{rms}(|u|^3)} \tag{8}$$

where h is the water depth and u is a 1 year time series of tidal currents reconstructed from the tidal constituents. Garrett et al. (1978) argue that, in a thermally stratified regime, values below 2 indicate well mixed water, values higher than 4 indicate stratification, and values between 2 and 4 represent transitional zones. Most of the region has values greater than 4 suggesting a stratified water column. The only location with values close to 2 is Hell Gate (upper inset), a narrow channel with very large tidal currents. Several areas with narrow channels or shallow sills have values in the 2 to 4 range.

Topham et al. (1983) argue that strong tidal mixing combined with a nearby source of warm water can lead to polynya formation. The well known Hell Gate polynya (Fig. 10 of Smith and Rigby, 1981) is the best known example. Several of the polynyas identified by Smith and Rigby (1981) and shown in Fig. 16, such as Penny Strait and Queens Channel, Hell Gate and Cardigan Channel, and Committee Bay (south Boothia Bay) can be identified with regions in Fig. 15 where $\log_{10} h/u^3 < 3$ (green and blue). Obvious exceptions are the coastal leads and the well known North Water polynya (Barber et al., 2001) whose formation mechanisms are not related to tidal mixing. The Bellot Strait polynya between the Boothia Peninsula and Somerset Island is not represented likely because the model mesh does not resolve the narrow Bellot Strait which is the probable source of the large tidal currents. Overall we expect that regions with values close to 2 would freeze later in the season than surrounding waters and melt earlier. The relationship between polynyas and Fig. 15 will be explored further in a separate paper.

7 Conclusion

The tidal modelling system of Dupont et al. (2002) was successfully applied to the Canadian Arctic Archipelago. A useful modification was the addition of a user-specified static ice field to partly account for the frictional effects of the ice coverage. The fields are

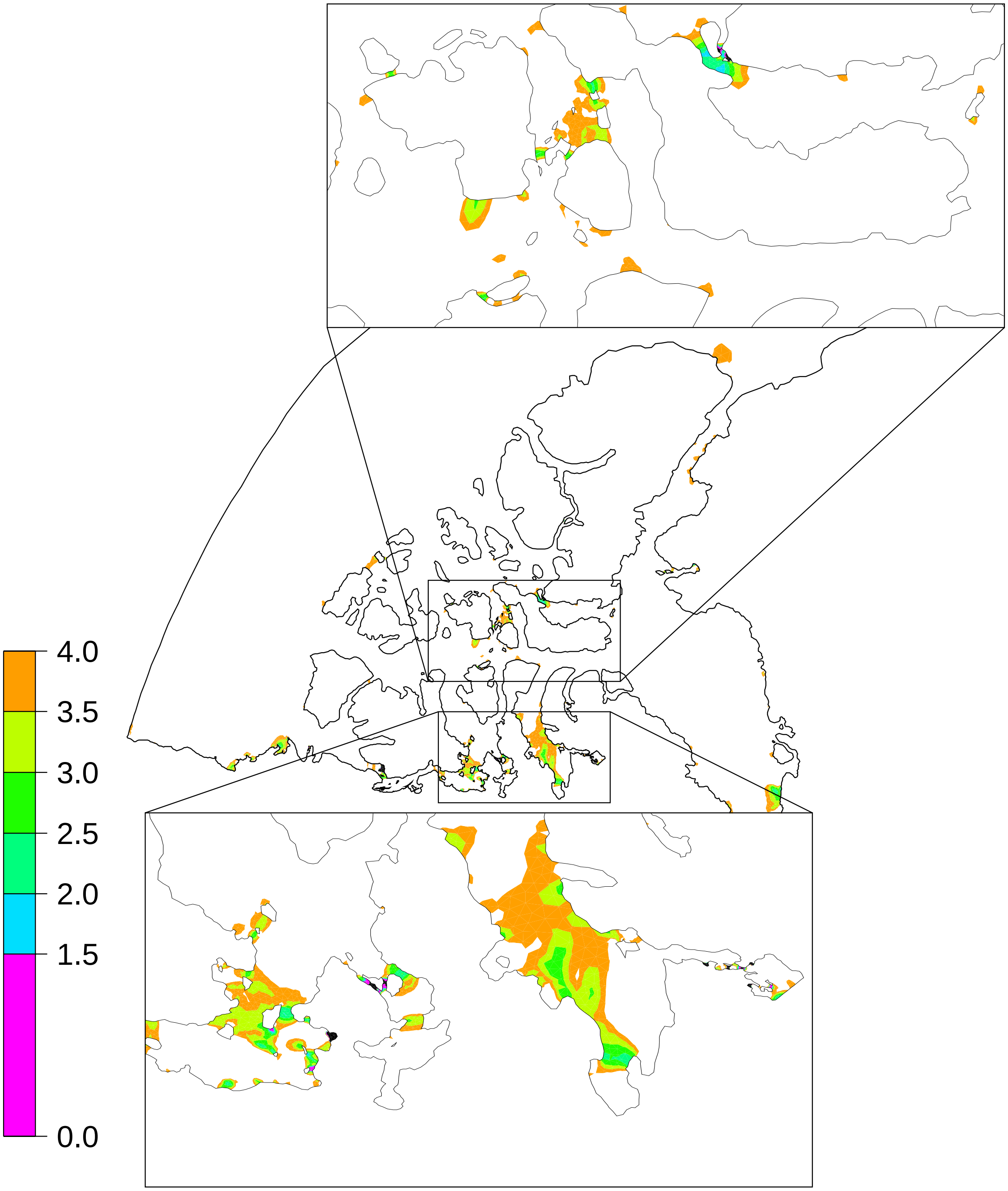

Figure 15: The tidal mixing factor h/u^3 over the entire model domain (contours of $\log_{10} h/u^3$ are shown). Two regions with the smallest values (strongest mixing) are expanded for detail.The upper inset shows the region around Devon Island and includes Hell Gate, Cardigan Channel, Penny Strait and Queens Channel. The lower inset shows the region around the Boothia Peninsula.

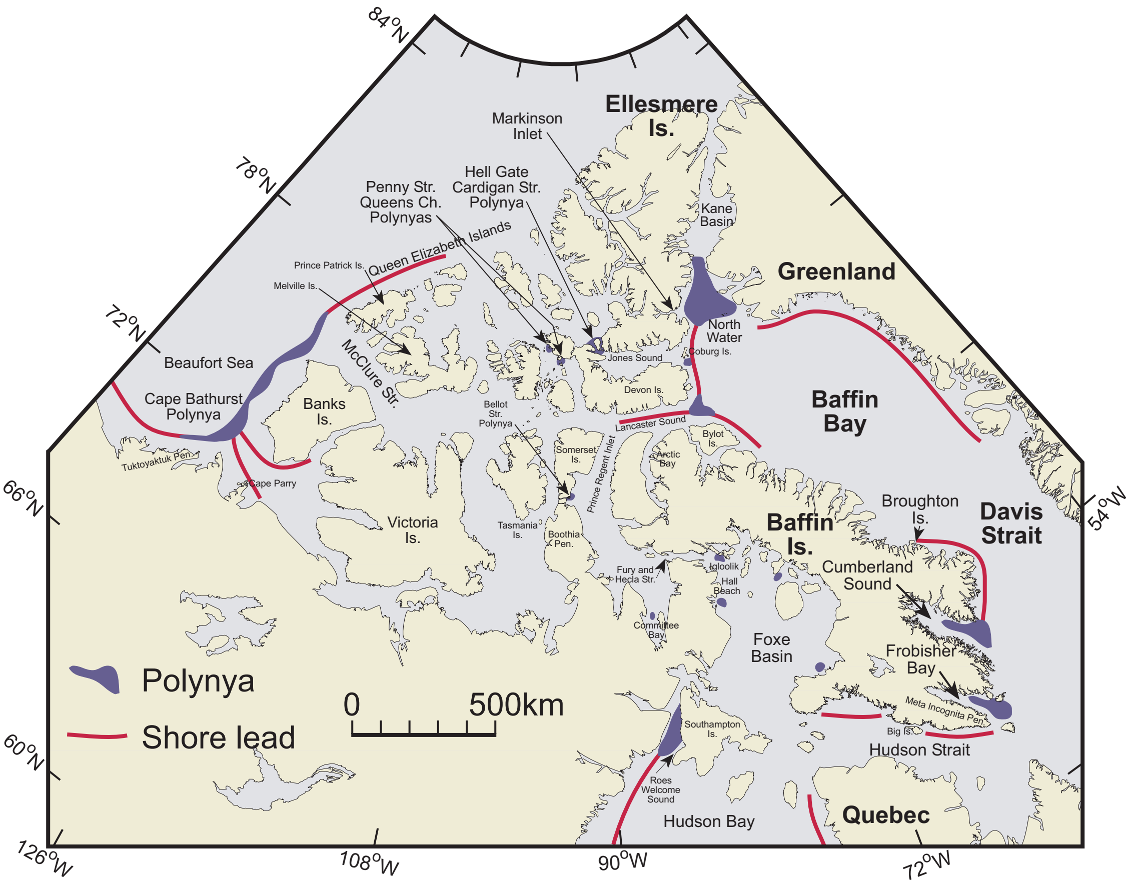

Figure 16: A map of known polynyas in the Canadian Arctic (based on Fig. 1 in Stirling, 1981).

available over the internet as part of the WebTide tidal prediction package (www.mar.dfo-mpo.gc.ca/science/ocean/home.html, or search for ‘WebTide BIO’).

The rms error of the tidal constituents, when averaged across all the observations, is about 14 cm for M2 and about (5, 7, 8, 3) cm for (N2, S2, K1, O1) respectively. The normalized rms error for M2 is about 13% and between 20-30% for the other four constituents. These error levels are comparable to those reported by Padman and Erofeeva (2004) for their Arctic model. The regional tidal prediction errors range from 8-25 cm. These errors vary substantially from region to region, reflecting the tidal amplitudes, and from station to station.

We have generally adopted an goal of 10 cm or 10% (which ever is greater) for the tidal prediction error. This ambitious goal was not achieved here. The fact that there are some spatial patterns in the errors suggests that the boundary conditions could be improved. However the very large errors at a small number of station suggests that there are serious local problems unrelated to the boundary conditions. The likely sources of differences between the model and observations are: 1) model bathymetry errors in poorly surveyed areas; 2) observational errors; and 3) poor resolution of inlets and fjords some locations. Further analysis would be required to assees the likely sources of error the stations with large errors.

The Arctic Shelf region, which is a region of very low tides, had a combined relative error of about 85% from the 5 *vs. all* case compared to 41% in Baffin Bay and 31% in Arctic Central. The small number of stations and the low tidal amplitudes along the Arctic Shelf were sources of problems in the assimiliation scheme which were addressed by using the assimilation parameters to strongly constrain the smoothness of the solution along the open boundary. The high value of E_{rms} is largely responsible for the high relative errors on the Arctic Shelf. The solution along the Arctic shelf might be improved by allowing E_{rms} to be specified for each station. This would require straight-forward modifications to the input modules of the inverse model.

We note that the N2 constituent may not be well modelled on the Greenland side of Baffin Bay because N2 is absent in the Greenland tide gauge data. In addition the bathymetry along the Greenland coastline displays abrupt changes which may not be properly resolved.

The quality of the assimilation has a poorly understood relationship with the number of stations and the distribution of the stations. There is a general preference for having a large number of stations evenly distributed across the region. This is not possible in the Archipelago. History and operational constraints have resulted in an uneven distribution of data: low density along the Arctic Shelf and high density along the western Arctic and Eastern Baffin Bay. Understanding how this affects the quality of the solutions is an open problem.

These solutions for the Canadian Arctic Archipelago have some weaknesses (areas of large errors), nevertheless, they are of sufficient quality for many applications. For example, these solutions are being used to help with multi-beam sonar surveys in the

Archipelago (John Hughes Clarke, UNB, pers. comm. 2005), they could be used to help with the quality control of new observations, and the map of h/U^3 could be used to identify potential regions of tidally mixed fronts and polynyas.

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Appendix

A Stations

Table 10: The stations selected for the assimilation process including the MEDS code and record length. For the Greenland data, the station number has a G prefix and the record length is unknown.

Station Name	**Station Number**	**Record Length**
DAVIS STRAIT	64000	1 X 398
DAVIS STRAIT	64005	1 X 399
DAVIS STRAIT	64010	1 X 395
RENSSELAER BAY	3710	1 X 44
THANK GOD HARBOUR	3735	1 X 44
NEWMAN BAY GREENLAND	3740	1 X 42
CAPE BRYANT	3755	1 X 44
ALERT	3765	1 X 362
CAPE LIVERPOOL	3902	1 X 52
NOVA ZEMBLA ISLAND	3916	1 X 53
CAPE CHRISTIAN	3941	1 X 54
AULITIVING ISLAND	3948	1 X 49
BROUGHTON ISLAND	3980	1 X 44
IGLOOLIK	5295	1 X 105
CAPE COCKBURN	5428	1 X 61
RESOLUTE	5560	1 X 364
MCBEAN ISLAND	5920	1 X 52
OTRICK ISLAND	6090	1 X 58
TASMANIA ISLAND	6110	1 X 56
SPENCE BAY	6150	1 X 112
CAMBRIDGE BAY	6240	1 X 331
COPPERMINE	6290	1 X 290
PEARCE POINT	6340	1 X 69
CAPE PARRY	6360	1 X 363
SACHS HARBOUR	6424	1 X 174
BAILLIE IS (S. SPIT)	6443	1 X 58
ATKINSON POINT	6476	1 X 59
TUKTOYAKTUK	6485	1 X 333
RAE ISLAND	6492	1 X 57
HOOPER ISLAND	6495	1 X 49
GARRY ISLAND	6498	3 X 56

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Station Name	Station Number	Record Length
HERSCHEL ISLAND	6525	1 X 50
CAPE SKOGN NWT	6560	1 X 61
GRISE FIORD NWT	6570	1 X 62
BAY OF WOE	6580	1 X 43
HELL GATE	6584	1 X 43
BERE BAY	6588	1 X 45
NORWEGIAN BAY	6595	1 X 142
CAPE SOUTHWEST	6598	1 X 42
HYPERITE POINT	6605	1 X 42
DISRAELI FIORD	6730	1 X 78
NORAH ISLAND	6781	1 X 43
Rae Point Melville I	6835	1 X 366
ISACHSEN	6910	1 X 29
MOULD BAY	6955	1 X 29
Aasiatt-Egedesminde	G01	N/A
ILulissat-Jacobshavn	G09	N/A
Kronprinsens-Ejland	G14	N/A
Maniitsoq-Sukkertoppen	G16	N/A
Qaamarujuk	G24	N/A
Qeqertarsuaq-Godhavn	G26	N/A
Rifkol	G28	N/A
Sisimiut-Holsteinsborg	G29	N/A
Uummannaq	G31	N/A

Table 11: The stations used for validating the modelled results including the MEDS code and record length. For the Greenland data, the station number has a G prefix and the record length is unknown.

Station Name	Station Number	Record Length
GODTHAAB	3575	4 X 29
FOULKE FIORD	3690	2 X 29
CAPE LUPTON GREENLAND	3736	1 X 33
CAPE SHERIDAN	3780	5 X 29
LINCOLN BAY	3782	1 X 35
ST.PATRICK BAY	3788	1 X 35
DISCOVERY HARBOUR	3790	1 X 29
PIM ISLAND	3840	1 X 29

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Station Name	**Station Number**	**Record Length**
CAPE HOOPER	3960	1 X 29
KIVITOO	3970	1 X 29
CAPE DYER	3995	1 X 29
CLEARWATER FIORD	4040	1 X 29
BOUVERIE ISLAND	5305	1 X 29
SEVIGNY POINT	5310	1 X 31
BONNE ISLAND	5315	1 X 32
PURFUR COVE	5330	1 X 32
BAFFIN	5332	1 X 32
DUNDAS HARBOUR	5430	1 X 29
BEECHY ISLAND	5510	1 X 29
MAXWELL BAY	5530	1 X 32
CAPE CAPEL	5600	1 X 31
WINTER HARBOUR	5645	1 X 29
KOLUKTOO BAY	5790	1 X 29
MILNE INLET (HEAD)	5791	1 X 29
ARCTIC BAY	5865	1 X 29
PORT LEOPOLD	5905	1 X 29
CUNNINGHAM INLET	5910	1 X 37
WADSWORTH ISLAND	6080	1 X 59
BERNARD HARBOUR	6310	1 X 29
TYSOE POINT	6338	1 X 36
PAULATUK	6350	1 X 29
KRUBLUYAK POINT	6457	1 X 46
CAPE DALHOUSIE	6472	1 X 29
SHINGLE BAY	6505	1 X 36
KING EDWARD POINT	6556	1 X 30
BELCHER POINT	6557	1 X 31
ICEBERG POINT	6660	1 X 29
GREELY FIORD	6670	1 X 29
KLEYBOLT PENINSULA	6704	1 X 29
CAPE ALDRICH	6735	1 X 29
AIRSTRIP POINT	6765	1 X 29
HYDE PARKER ISLAND	6770	1 X 39
NORTHUMBERLAND SOUND	6780	1 X 29
BYAM CHANNEL(Z3)	6834	1 X 38
Foulke-Havn	G08	N/A
Kangerluarsoruseq-Faering	G11	N/A
Thank-God-Havn	G30	N/A

Table 12: The stations not used for assimilation or validation.

Station Name	**Station Number**	**Record Length**
EKALUGARSUIT	3515	1 X 29
NORTH STAR BAY	3670	1 X 24
WRANGEL BAY	3785	1 X 17
CAPE DEFOSSE	3800	1 X 24
CLYDE RIVER	3940	1 X 98
AULATSIVIK PT.	4031	1 X 27
IMIGEN ISLAND	4045	1 X 15
BREVOORT HARBOUR	4070	1 X 29
RESOR ISLAND	4100	1 X 29
FROBISHER S FARTHEST	4120	1 X 29
LEWIS BAY	4135	1 X 29
FROBISHER	4140	1 X 337
ACADIA COVE	4170	1 X 63
LAKE HARBOUR	4205	1 X 362
PORT BURWELL	4265	1 X 29
KOKSOAK R. WEST ENT.	4295	1 X 29
FORT CHIMO	4298	1 X 26
LEAF BASIN	4315	1 X 29
HOPES ADVANCE BAY	4325	2 X 29
AGVIK ISLAND	4335	1 X 29
PIKIYULIK ISLAND	4340	1 X 29
KOARTAC	4379	1 X 113
CAPE WILSON 3	5230	1 X 55
CAPE WILSON 1	5231	1 X 18
CAPE WILSON 2	5232	1 X 46
ROCHE BAY	5252	1 X 48
HALL BEACH	5275	1 X 338
ENTRANCE ISLAND	5350	1 X 28
NEEDLE COVE	5358	1 X 35
LONGSTAFF BLUFF #1	5385	1 X 32
RIGBY BAY	5490	2 X 15
RADSTOCK BAY	5500	1 X 15
HAMILTON ISLAND	5615	1 X 15
PISIKTARFIK ISLAND	5795	1 X 15
STRATHCONA SOUND	5860	1 X 15
FORT ROSS	5930	1 X 15

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Station Name	**Station Number**	**Record Length**
CROWN PRINCE FREDERICK	5970	1 X 27
FALSE STRAIT	6100	1 X 15
FRANKLIN BAY	6367	1 X 21
BAILLIE ISLAND	6442	1 X 21
LIVERPOOL BAY	6455	1 X 23
ESKIMO LAKES STN 1C	6461	1 X 17
ESKIMO LAKES STN 2B	6462	1 X 19
PELLY ISLAND	6497	1 X 20
KAY POINT YUKON.	6515	1 X 25
SURPRISE FIORD	6600	1 X 18
EUREKA	6640	1 X 15
TANQUARY CAMP	6680	1 X 29
LITTLE CORNWALLIS IS.	6757	1 X 27
BYAM CHANNEL(LP)	6833	1 X 15
Ammassalik	G02	N/A
Danmarkshavn	G04	N/A
Danmarks-0	G05	N/A
Finsch-Oer	G07	N/A
Kangilinnguit-Gronnedal	G12	N/A
Mestersvig	G17	N/A
Nanortalik	G18	N/A
Narsaq	G19	N/A
Nuuk-Godthab	G22	N/A
Paamiut-Frederikshab	G23	N/A
Qaqortoq-Julianehab	G25	N/A
Uunarteq-Kap-Tobin	G33	N/A

B Complete station by station comparisons

B.1 Baffin Bay

Table 13: Baffin Bay - M2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G01	66.7	-9.0	57.1	-4.8	9.6	-4.2	10.6	0.159
G09	66.7	-2.0	56.5	0.5	10.2	-2.5	10.5	0.158
G11	116.5	-70.0	122.6	-69.0	-6.1	-1.1	6.5	0.056
G14	57.0	-13.0	54.6	-4.0	2.4	-9.1	9.1	0.160
G16	124.7	-58.9	125.7	-60.3	-1.0	1.3	3.1	0.025
G24	45.6	40.0	42.1	41.4	3.5	-1.5	3.6	0.080
G26	59.5	-6.0	54.5	-2.5	5.0	-3.6	6.1	0.102
G28	78.0	-38.0	70.0	-12.4	8.0	-25.7	33.8	0.434
G29	117.1	-44.0	106.7	-41.9	10.4	-2.2	11.2	0.096
G31	46.5	35.0	42.1	41.4	4.4	-6.4	6.6	0.143
3575	138.0	-68.1	127.6	-68.7	10.4	0.7	10.5	0.076
3916	44.8	138.3	46.5	130.1	-1.7	8.3	6.8	0.151
3941	11.0	151.3	30.4	140.2	-19.4	11.1	19.8	1.797
3948	18.7	-156.5	21.8	176.8	-3.1	26.7	9.9	0.527
3960	20.4	-122.1	19.5	-149.6	0.9	27.6	9.5	0.468
3970	24.6	-106.1	20.8	-133.6	3.8	27.5	11.4	0.464
3980	30.4	-106.1	25.2	-122.3	5.2	16.3	9.4	0.309
3995	83.5	-87.1	80.1	-102.3	3.4	15.3	22.0	0.263
4040	226.7	-66.1	180.5	-71.4	46.2	5.3	49.9	0.220
64000	89.9	-88.2	85.3	-92.2	4.6	4.0	7.6	0.085
64005	90.2	-67.1	81.4	-70.0	8.8	2.9	9.8	0.109
64010	98.9	-58.0	87.7	-60.2	11.2	2.2	11.8	0.119
Mean	75.2	–	70.0	–	5.3	4.2	12.7	0.3
Absolute	–	–	–	–	8.1	9.3	–	–
RMS	89.6	82.9	81.2	89.0	12.4	13.2	16.4	0.454

Table 13 continued: Baffin Bay - N2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G01	NA	NA	11.7	-27.5	NA	NA	NA	NA
G09	NA	NA	11.6	-21.9	NA	NA	NA	NA
G11	NA	NA	6.1	-141.6	NA	NA	NA	NA
G14	NA	NA	11.1	-26.4	NA	NA	NA	NA

G16	NA	NA	23.4	-127.5	NA	NA	NA	NA
G24	NA	NA	9.0	19.8	NA	NA	NA	NA
G26	NA	NA	11.1	-25.0	NA	NA	NA	NA
G28	NA	NA	14.6	-37.6	NA	NA	NA	NA
G29	NA	NA	22.7	-74.7	NA	NA	NA	NA
G31	NA	NA	9.0	19.7	NA	NA	NA	NA
3575	28.3	-90.7	7.5	-168.6	20.8	77.9	27.7	0.979
3916	10.9	114.3	9.8	102.2	1.1	12.0	2.4	0.222
3941	2.4	132.6	6.6	110.5	-4.2	22.0	4.5	1.881
3948	6.5	174.9	4.6	142.1	1.9	32.8	3.6	0.556
3960	3.0	-157.2	3.7	173.9	-0.7	28.8	1.8	0.610
3970	4.5	-158.2	3.8	-168.3	0.7	10.1	1.0	0.221
3980	5.1	-130.2	4.6	-154.3	0.5	24.1	2.1	0.408
3995	12.8	-129.2	16.2	-122.2	-3.4	-7.0	3.8	0.296
4040	36.5	-81.2	26.0	-52.6	10.5	-28.6	18.5	0.507
64000	18.4	-113.8	16.1	-110.0	2.3	-3.8	2.6	0.141
64005	18.3	-91.5	14.0	-94.4	4.3	2.9	4.4	0.242
64010	20.1	-81.6	15.3	-89.6	4.8	8.0	5.4	0.268
Mean	13.9	–	11.7	–	3.2	14.9	6.5	0.5
Absolute	–	–	–	–	4.6	21.5	–	–
RMS	17.3	125.0	13.3	106.0	7.2	29.2	10.1	0.704

Table 13 continued: Baffin Bay - S2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G01	25.8	25.0	23.2	29.4	2.6	-4.4	3.2	0.126
G09	27.4	30.0	22.9	34.5	4.5	-4.5	4.9	0.178
G11	40.0	-34.0	26.6	-50.7	13.4	16.7	16.4	0.410
G14	27.0	25.0	22.2	30.2	4.8	-5.2	5.3	0.195
G16	44.7	-25.3	44.6	-40.8	0.1	15.5	12.0	0.269
G24	17.0	62.0	15.9	73.8	1.1	-11.8	3.6	0.210
G26	24.6	31.0	22.2	31.8	2.4	-0.8	2.4	0.098
G28	32.0	-8.0	28.1	22.0	3.9	-30.0	16.0	0.500
G29	45.1	-8.0	42.4	-8.3	2.7	0.3	2.7	0.060
G31	18.1	61.0	15.9	73.8	2.2	-12.8	4.4	0.242
3575	56.6	-30.0	29.7	-56.5	26.9	26.5	32.8	0.580
3916	15.1	-176.6	16.0	174.2	-0.9	9.2	2.6	0.174
3941	3.4	-165.1	9.5	-173.8	-6.1	8.7	6.2	1.824
3948	6.7	-90.5	7.0	-126.3	-0.3	35.8	4.2	0.632
3960	5.7	-60.0	7.5	-88.2	-1.8	28.2	3.6	0.639
3970	10.9	-54.0	8.5	-75.1	2.4	21.1	4.3	0.391
3980	12.8	-60.0	10.5	-67.4	2.3	7.4	2.7	0.211

3995	24.6	-41.0	31.8	-52.5	-7.2	11.5	9.1	0.370
4040	81.3	-23.0	56.3	-2.0	25.0	-21.0	35.1	0.432
64000	33.9	-45.5	32.6	-42.9	1.3	-2.6	2.0	0.058
64005	34.9	-27.3	30.2	-27.9	4.7	0.6	4.7	0.134
64010	38.2	-19.8	32.7	-22.4	5.5	2.6	5.7	0.150
Mean	28.4	–	24.4	–	4.1	4.1	8.4	0.4
Absolute	–	–	–	–	5.5	12.6	–	–
RMS	33.6	65.9	27.5	74.8	9.0	16.3	12.3	0.512

Table 13 continued: Baffin Bay - K1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G01	35.5	-151.9	30.9	-145.8	4.6	-6.0	5.8	0.163
G09	34.1	-139.9	31.3	-143.6	2.8	3.7	3.5	0.104
G11	18.2	170.1	23.4	164.6	-5.2	5.6	5.6	0.307
G14	35.0	-146.9	30.3	-144.8	4.7	-2.1	4.9	0.139
G16	21.0	165.7	21.3	167.1	-0.3	-1.3	0.6	0.027
G24	36.5	-160.9	30.7	-129.9	5.8	-31.0	18.8	0.516
G26	31.7	-145.9	29.7	-144.0	2.0	-1.8	2.2	0.070
G28	36.0	-154.9	33.3	-154.9	2.7	-0.0	2.7	0.074
G29	33.5	179.1	32.3	-176.7	1.2	-4.1	2.7	0.080
G31	35.5	-124.9	30.7	-129.9	4.8	5.0	5.6	0.159
3575	20.1	174.1	23.4	169.6	-3.3	4.5	3.7	0.184
3916	26.3	-108.0	19.8	-123.1	6.5	15.1	8.8	0.336
3941	10.5	-104.0	20.6	-117.6	-10.1	13.5	10.7	1.019
3948	22.7	-99.2	19.3	-117.6	3.4	18.3	7.5	0.330
3960	18.8	-108.8	19.0	-118.4	-0.2	9.5	3.2	0.168
3970	21.3	-110.8	18.2	-119.0	3.1	8.2	4.2	0.197
3980	24.6	-110.8	18.3	-121.1	6.3	10.3	7.3	0.298
3995	10.9	-103.8	12.5	-118.4	-1.6	14.5	3.4	0.308
4040	8.2	99.2	11.5	-139.1	-3.3	-121.8	17.3	2.105
64000	6.2	-80.4	11.7	-134.2	-5.5	53.8	9.4	1.520
64005	16.3	-155.6	17.8	-152.8	-1.5	-2.8	1.7	0.104
64010	23.8	-149.7	20.9	-153.6	2.9	3.9	3.3	0.139
Mean	23.9	–	23.0	–	0.9	-0.2	6.0	0.4
Absolute	–	–	–	–	3.7	15.3	–	–
RMS	25.8	136.9	24.0	141.5	4.4	30.2	7.6	0.632

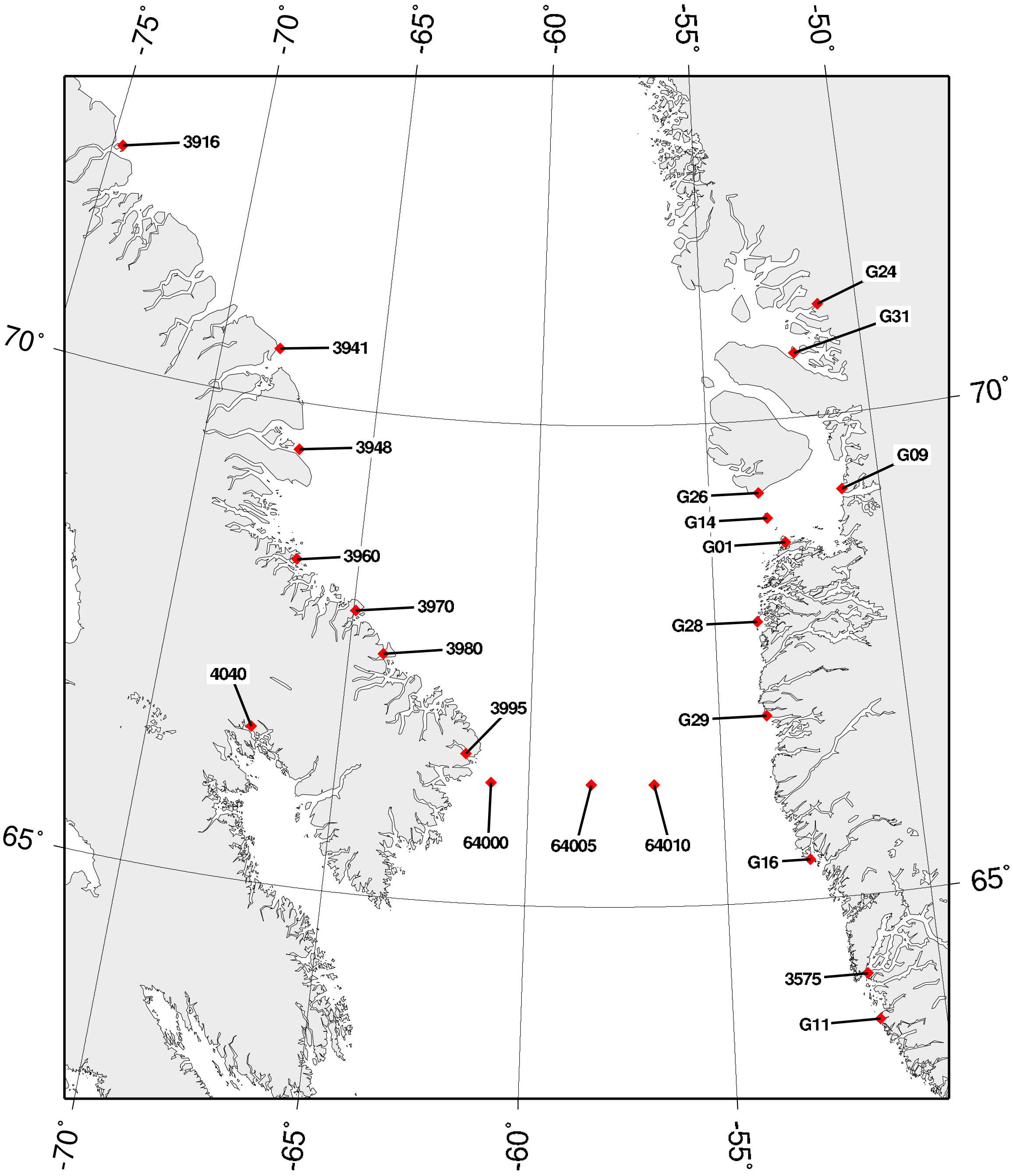

Figure 17: Baffin Bay

Table 13 continued: Baffin Bay - O1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G01	10.6	-178.2	11.3	168.7	-0.7	13.2	2.6	0.245
G09	11.6	178.8	11.4	170.8	0.2	8.0	1.6	0.139
G11	9.7	141.8	10.5	118.3	-0.8	23.5	4.2	0.431
G14	12.0	166.8	11.1	169.5	0.9	-2.7	1.1	0.089
G16	10.1	126.9	10.1	128.1	-0.0	-1.2	0.2	0.021
G24	8.9	-170.2	11.1	-175.6	-2.2	5.4	2.4	0.268
G26	12.8	177.8	10.9	170.2	1.9	7.6	2.5	0.195
G28	9.0	148.8	12.5	162.7	-3.5	-13.9	4.3	0.480
G29	12.7	139.8	12.4	142.9	0.3	-3.0	0.7	0.058
G31	11.9	-165.2	11.1	-175.6	0.8	10.4	2.2	0.188
3575	10.3	132.8	10.5	122.4	-0.2	10.5	1.9	0.185
3916	9.3	-149.5	5.9	-160.9	3.4	11.4	3.7	0.394
3941	3.4	-153.9	6.6	-157.5	-3.2	3.6	3.3	0.958
3948	7.3	-146.9	6.0	-157.2	1.3	10.3	1.8	0.243
3960	12.4	-162.2	5.8	-160.3	6.6	-1.9	6.6	0.530
3970	6.0	-159.2	5.5	-161.6	0.5	2.4	0.6	0.098
3980	8.2	178.8	5.6	-165.5	2.6	-15.7	3.2	0.390
3995	2.7	-172.2	3.1	-164.6	-0.4	-7.7	0.5	0.199
4040	2.7	114.8	3.4	133.7	-0.7	-18.9	1.2	0.455
64000	1.3	-172.6	2.9	167.6	-1.6	19.8	1.8	1.363
64005	7.3	147.7	6.4	152.5	0.9	-4.8	1.1	0.150
64010	10.1	159.2	7.9	156.0	2.2	3.2	2.3	0.224
Mean	8.6	–	8.3	–	0.4	2.7	2.3	0.3
Absolute	–	–	–	–	1.6	9.0	–	–
RMS	9.3	157.5	8.8	157.3	2.2	11.0	2.7	0.449

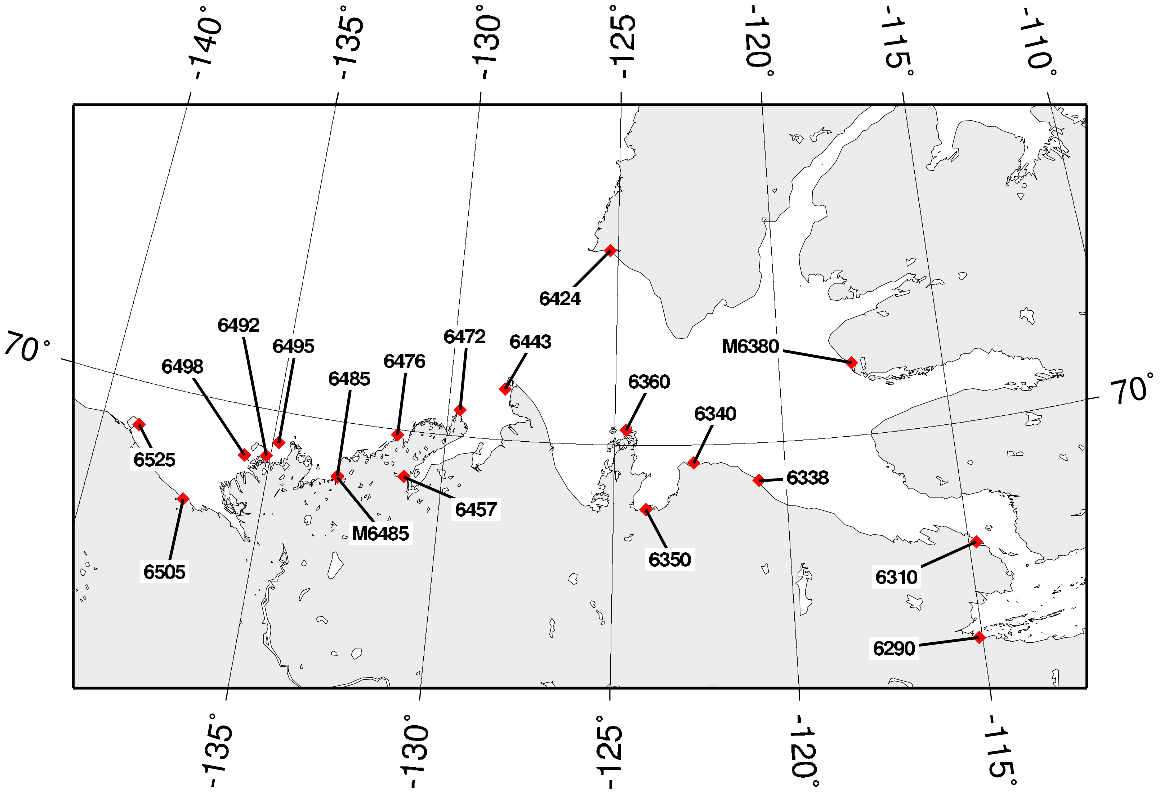

Figure 18: Arctic West

B.2 Arctic West

Table 14: Arctic West - M2 Results

Stat #	Observed		Modelled		Error		Complex Error	
	cm	deg	cm	deg	cm	deg	cm	relative
6290	1.6	-18.0	7.2	-110.5	-5.6	92.4	7.4	4.646
6310	17.3	80.9	18.1	77.0	-0.8	3.9	1.4	0.084
6338	17.3	45.4	25.6	60.2	-8.3	-14.8	9.9	0.574
6340	13.2	48.0	22.4	56.2	-9.2	-8.3	9.6	0.724
6350	16.4	48.9	23.3	55.2	-6.9	-6.3	7.2	0.440
6360	11.9	40.0	19.3	44.0	-7.4	-4.0	7.4	0.626
6424	4.6	134.3	9.9	100.7	-5.3	33.6	6.6	1.431
6443	8.1	14.2	18.9	12.7	-10.8	1.5	10.8	1.332
6457	31.7	91.3	15.0	-78.6	16.7	169.9	46.6	1.469
6472	21.8	-36.8	23.7	-40.7	-1.9	3.9	2.4	0.112
6476	12.8	-88.9	14.5	-79.1	-1.7	-9.8	2.9	0.227
6485	12.1	-55.6	16.1	-67.5	-4.0	11.9	4.9	0.409
6492	3.9	-58.6	8.0	-70.3	-4.1	11.6	4.3	1.100
6495	6.7	-101.2	7.6	-76.9	-0.9	-24.3	3.1	0.466

6498	5.2	-80.4	8.3	-61.2	-3.1	-19.3	3.8	0.732
6505	10.2	-89.3	14.2	-72.1	-4.0	-17.3	5.4	0.527
6525	7.9	-100.4	10.0	-82.7	-2.1	-17.7	3.4	0.432
Mean	11.9	–	15.4	–	-3.5	12.2	8.1	0.9
Absolute	–	–	–	–	5.5	26.5	–	–
RMS	14.0	73.7	16.5	70.9	6.8	49.0	12.8	1.365

Table 14 continued: Arctic West - N2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
6290	0.3	-71.9	1.1	-162.6	-0.8	90.7	1.1	3.654
6310	2.7	46.1	3.8	35.7	-1.1	10.4	1.2	0.460
6338	2.8	4.7	5.0	15.6	-2.2	-10.9	2.3	0.809
6340	2.4	-21.5	4.3	11.7	-1.9	-33.2	2.7	1.118
6350	3.0	13.5	4.5	10.7	-1.5	2.7	1.5	0.505
6360	2.7	8.5	3.7	-0.3	-1.0	8.8	1.1	0.423
6424	0.8	107.6	2.0	54.4	-1.2	53.3	1.6	2.050
6443	1.4	8.1	3.0	-32.1	-1.6	40.2	2.1	1.508
6457	4.5	27.5	2.6	-126.2	1.9	153.7	6.9	1.538
6472	3.5	-74.1	3.9	-82.7	-0.4	8.5	0.7	0.187
6476	2.1	-86.1	2.5	-127.3	-0.4	41.2	1.7	0.792
6485	1.9	-82.2	2.7	-113.4	-0.8	31.2	1.5	0.765
6492	0.3	18.4	1.1	-131.4	-0.8	149.8	1.3	4.437
6495	0.3	-109.8	1.1	-138.1	-0.8	28.3	0.8	2.717
6498	1.0	-54.1	1.0	-118.1	0.0	64.0	1.0	1.041
6505	1.7	-51.8	1.6	-116.5	0.1	64.7	1.8	1.038
6525	1.1	-127.4	1.2	-132.7	-0.1	5.3	0.1	0.127
Mean	1.9	–	2.6	–	-0.7	41.7	1.7	1.4
Absolute	–	–	–	–	1.0	46.9	–	–
RMS	2.2	66.1	3.0	98.7	1.2	65.1	2.2	1.803

Table 14 continued: Arctic West - S2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
6290	0.6	47.7	1.6	1.4	-1.0	46.3	1.3	2.166
6310	6.0	143.0	5.1	109.5	0.9	33.5	3.3	0.553
6338	6.4	105.5	6.0	99.7	0.4	5.8	0.7	0.114
6340	3.5	93.7	5.3	96.0	-1.8	-2.3	1.8	0.506
6350	4.8	106.0	5.5	95.0	-0.7	11.0	1.2	0.251
6360	3.4	85.0	4.5	84.4	-1.1	0.6	1.1	0.317
6424	1.1	-166.4	2.4	138.0	-1.3	55.6	2.0	1.841

6443	2.4	63.7	3.5	60.5	-1.1	3.2	1.1	0.454
6457	8.6	153.3	3.6	-29.1	5.0	-177.6	12.2	1.421
6472	6.4	18.4	5.0	10.3	1.4	8.1	1.7	0.258
6476	5.1	-30.7	3.6	-29.7	1.5	-1.0	1.5	0.302
6485	4.8	-7.0	4.4	-13.0	0.4	6.0	0.6	0.127
6492	2.5	-9.5	2.6	-31.2	-0.1	21.7	1.0	0.384
6495	3.3	-39.0	2.4	-34.9	0.9	-4.1	0.9	0.280
6498	2.4	-37.2	2.5	-26.6	-0.1	-10.6	0.5	0.192
6505	4.5	-30.4	3.9	-34.0	0.6	3.6	0.7	0.155
6525	3.2	-54.0	2.7	-47.9	0.5	-6.1	0.6	0.185
Mean	4.1	–	3.8	–	0.3	-0.4	1.9	0.6
Absolute	–	–	–	–	1.1	23.4	–	–
RMS	4.5	85.6	4.0	67.9	1.5	47.8	3.3	0.824

Table 14 continued: Arctic West - K1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
6290	7.8	-135.2	14.7	167.2	-6.9	57.6	12.4	1.588
6310	8.5	133.3	9.1	150.0	-0.6	-16.7	2.6	0.308
6338	5.5	137.8	5.1	119.2	0.4	18.6	1.8	0.320
6340	5.2	137.8	4.8	117.3	0.4	20.5	1.8	0.351
6350	6.4	124.3	4.9	117.0	1.5	7.3	1.7	0.263
6360	5.5	115.0	4.7	110.9	0.8	4.0	0.9	0.160
6424	4.0	150.8	3.8	131.3	0.2	19.5	1.3	0.334
6443	2.1	132.0	1.5	101.8	0.6	30.2	1.1	0.523
6457	1.5	-126.8	2.0	127.6	-0.5	105.6	2.8	1.882
6472	0.7	-155.0	1.5	111.1	-0.8	93.9	1.7	2.453
6476	2.8	122.9	2.1	127.9	0.7	-5.0	0.7	0.263
6485	3.1	165.6	2.7	136.6	0.4	29.0	1.5	0.485
6492	7.0	-179.4	3.3	126.5	3.7	54.1	5.7	0.817
6495	2.9	148.2	3.1	127.9	-0.2	20.3	1.1	0.373
6498	3.2	134.3	3.6	121.5	-0.4	12.8	0.8	0.260
6505	3.5	147.7	3.8	106.6	-0.3	41.1	2.6	0.736
6525	2.8	137.8	3.5	104.0	-0.7	33.8	1.9	0.687
Mean	4.3	–	4.4	–	-0.1	31.0	2.5	0.7
Absolute	–	–	–	–	1.1	33.5	–	–
RMS	4.8	141.1	5.4	124.8	2.0	44.0	3.7	0.942

Table 14 continued: Arctic West - O1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
6290	2.3	129.1	7.0	73.5	-4.7	55.6	6.0	2.600
6310	3.9	141.6	3.3	100.1	0.6	41.5	2.6	0.670
6338	3.1	155.8	2.5	145.9	0.6	9.9	0.8	0.259
6340	3.2	140.9	2.4	145.8	0.8	-4.9	0.8	0.259
6350	3.0	149.5	2.4	145.6	0.6	3.9	0.6	0.194
6360	3.3	147.0	2.4	141.6	0.9	5.4	1.0	0.295
6424	2.6	-177.5	2.2	154.4	0.4	28.1	1.2	0.473
6443	1.7	177.2	1.1	162.4	0.6	14.8	0.7	0.394
6457	1.9	-116.5	1.7	150.3	0.2	93.3	2.6	1.371
6472	2.0	-154.5	1.4	153.5	0.6	52.0	1.6	0.794
6476	2.7	168.6	1.7	149.8	1.0	18.8	1.2	0.453
6485	2.4	-172.7	1.9	153.7	0.5	33.6	1.3	0.556
6492	3.3	179.8	2.0	144.2	1.3	35.6	2.0	0.616
6495	2.5	160.3	1.9	145.2	0.6	15.1	0.8	0.325
6498	2.1	161.5	2.1	140.7	0.0	20.9	0.8	0.361
6505	4.8	147.7	2.2	128.3	2.6	19.4	2.8	0.584
6525	3.2	157.2	2.1	126.4	1.1	30.8	1.8	0.555
Mean	2.8	–	2.4	–	0.5	27.9	1.7	0.6
Absolute	–	–	–	–	1.0	28.4	–	–
RMS	2.9	156.1	2.7	140.5	1.5	36.1	2.1	0.845

B.3 Arctic North

Table 15: Arctic North - M2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G08	110.9	117.0	106.2	106.2	4.7	10.8	20.9	0.189
G30	54.9	115.0	54.3	110.5	0.6	4.4	4.2	0.077
3690	110.9	82.9	106.2	106.2	4.7	-23.2	44.0	0.397
3710	102.7	93.9	116.6	107.3	-13.9	-13.3	29.0	0.282
3735	54.8	111.9	54.3	110.5	0.5	1.4	1.4	0.026
3736	55.5	114.9	53.3	110.5	2.2	4.4	4.7	0.085
3740	38.3	118.2	35.8	110.5	2.5	7.7	5.6	0.146
3755	12.8	123.9	19.1	107.7	-6.3	16.3	7.7	0.601
3765	20.9	64.9	24.0	66.9	-3.1	-2.0	3.2	0.155
3780	24.3	65.9	28.3	79.6	-4.0	-13.6	7.4	0.306
3782	37.9	101.5	41.7	97.5	-3.8	4.0	4.7	0.125
3788	58.2	106.7	54.0	101.3	4.2	5.4	6.8	0.116
3790	59.7	103.9	55.1	101.6	4.6	2.3	5.1	0.086
3840	116.7	113.9	110.9	110.7	5.8	3.3	8.7	0.075
6660	4.5	-101.8	15.4	-145.4	-10.9	43.6	12.5	2.784
6670	5.1	-86.8	15.9	-145.1	-10.8	58.4	13.9	2.725
6704	1.2	116.5	13.0	-135.8	-11.8	-107.7	13.4	11.168
6730	3.7	14.5	11.6	-50.3	-7.9	64.8	10.6	2.866
6735	11.5	9.9	12.6	-5.8	-1.1	15.7	3.5	0.302
Mean	46.6	–	48.9	–	-2.3	4.4	10.9	1.2
Absolute	–	–	–	–	5.4	21.2	–	–
RMS	60.3	98.3	60.2	105.3	6.6	34.6	14.9	2.801

Table 15 continued: Arctic North - N2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G08	NA	NA	21.3	82.0	NA	NA	NA	NA
G30	NA	NA	9.9	88.6	NA	NA	NA	NA
3690	20.4	54.8	21.3	82.0	-0.9	-27.3	9.9	0.483
3710	21.3	63.8	23.1	83.6	-1.8	-19.9	7.9	0.369
3735	10.6	85.8	9.9	88.6	0.7	-2.9	0.9	0.081
3736	8.5	81.1	9.7	88.7	-1.2	-7.6	1.7	0.201
3740	5.6	91.8	6.2	89.9	-0.6	1.8	0.7	0.120
3755	2.4	109.8	2.7	87.4	-0.3	22.4	1.0	0.430
3765	3.4	43.9	4.0	38.4	-0.6	5.5	0.7	0.193
3780	4.2	38.8	4.6	53.3	-0.4	-14.6	1.2	0.283

3782	5.8	65.3	7.2	74.5	-1.4	-9.3	1.8	0.307
3788	9.7	74.1	9.7	78.5	-0.0	-4.4	0.7	0.077
3790	11.5	78.8	9.9	78.8	1.6	-0.0	1.6	0.138
3840	26.2	99.2	21.9	86.3	4.3	12.9	6.9	0.262
6660	1.4	-125.6	2.3	-136.0	-0.9	10.4	1.0	0.698
6670	2.4	-107.9	2.9	-134.3	-0.5	26.4	1.3	0.541
6704	0.4	123.5	2.2	-121.8	-1.8	-114.7	2.4	6.008
6730	0.6	-53.4	3.1	-69.9	-2.5	16.5	2.6	4.292
6735	1.8	-25.8	3.0	-36.9	-1.2	11.1	1.2	0.690
Mean	8.0	–	9.2	–	-0.4	-5.5	2.5	0.9
Absolute	–	–	–	–	1.2	18.1	–	–
RMS	11.1	82.9	11.6	88.0	1.6	31.2	3.7	1.826

Table 15 continued: Arctic North - S2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G08	46.3	150.0	42.6	148.3	3.7	1.7	3.9	0.084
G30	25.3	156.0	22.9	155.3	2.4	0.7	2.4	0.094
3690	46.3	125.0	42.6	148.3	3.7	-23.3	18.3	0.396
3710	45.4	132.0	47.7	149.7	-2.3	-17.7	14.5	0.320
3735	25.2	153.0	22.9	155.3	2.3	-2.3	2.5	0.097
3736	24.3	155.7	22.5	155.4	1.8	0.3	1.8	0.074
3740	16.1	162.4	15.2	156.1	0.9	6.3	1.9	0.120
3755	7.0	167.0	8.0	155.5	-1.0	11.5	1.8	0.255
3765	10.1	114.4	9.7	116.1	0.4	-1.7	0.5	0.049
3780	11.5	114.0	11.6	127.6	-0.1	-13.6	2.7	0.237
3782	18.2	147.0	17.4	143.5	0.8	3.5	1.3	0.072
3788	24.0	148.4	22.7	146.4	1.3	2.0	1.6	0.065
3790	NA	NA	23.1	146.7	NA	NA	NA	NA
3840	48.1	148.0	44.8	153.6	3.3	-5.6	5.6	0.117
6660	0.2	-128.3	0.7	144.1	-0.5	87.6	0.7	3.371
6670	1.5	117.4	0.8	133.5	0.7	-16.1	0.8	0.502
6704	2.6	4.6	1.1	75.2	1.5	-70.6	2.5	0.948
6730	2.2	58.9	5.3	-1.8	-3.1	60.7	4.6	2.108
6735	4.8	64.0	5.1	43.6	-0.3	20.4	1.8	0.370
Mean	19.9	–	19.3	–	0.9	2.4	3.8	0.5
Absolute	–	–	–	–	1.7	19.2	–	–
RMS	25.8	131.5	24.5	135.8	2.0	31.9	6.0	0.987

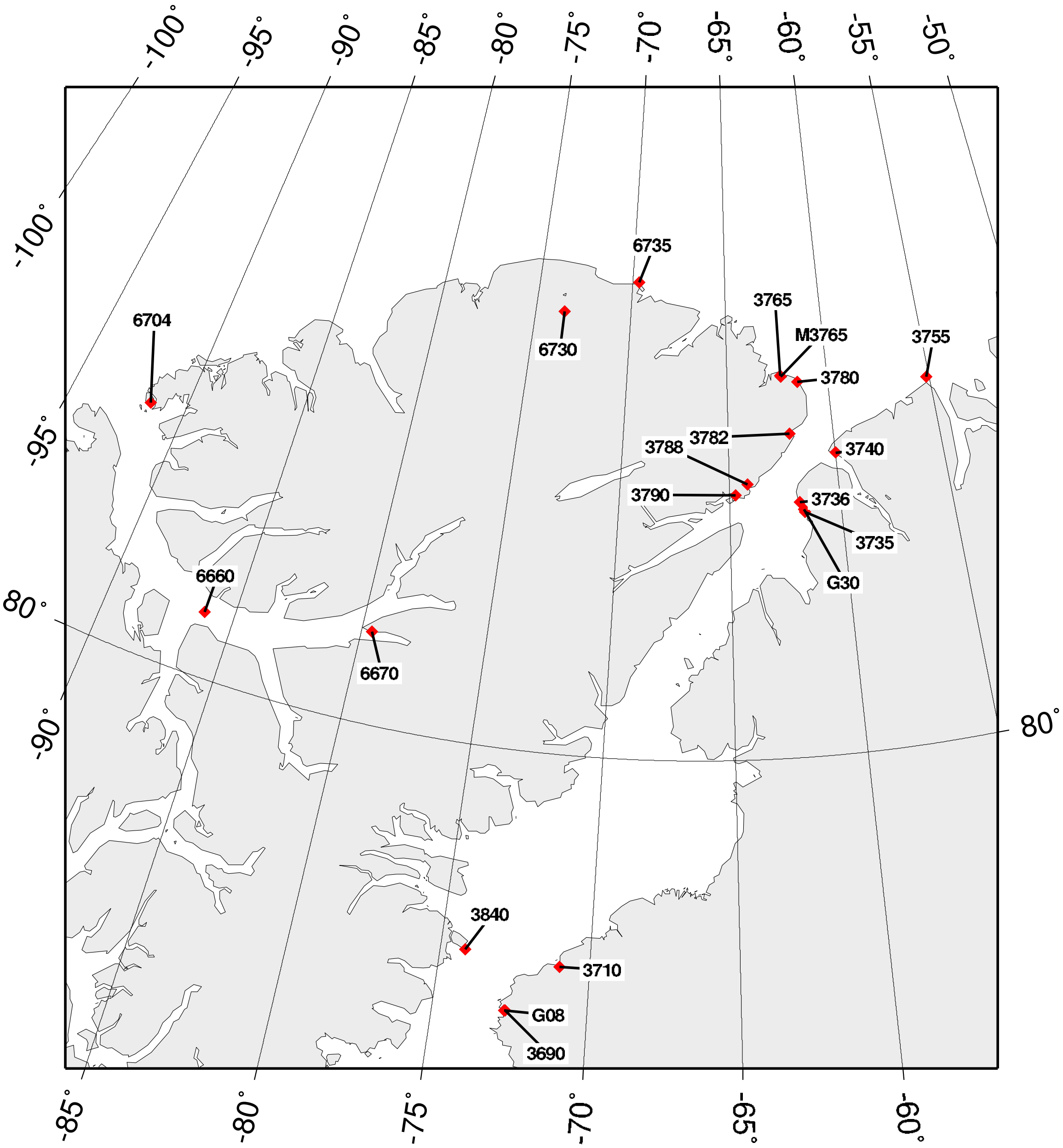

Figure 19: Arctic North

Table 15 continued: Arctic North - K1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G08	32.0	-99.9	27.3	-106.4	4.7	6.5	5.8	0.181
G30	12.2	-51.9	10.0	-61.2	2.2	9.3	2.8	0.230
3690	32.0	-112.8	27.3	-106.4	4.7	-6.5	5.8	0.181
3710	25.9	-106.8	26.1	-102.8	-0.2	-4.0	1.8	0.071
3735	12.1	-53.8	10.0	-61.2	2.1	7.3	2.5	0.206
3736	12.2	-56.7	10.0	-60.0	2.2	3.3	2.3	0.189
3740	9.6	-38.6	8.9	-40.8	0.7	2.1	0.7	0.077
3755	9.7	-13.8	8.3	-14.2	1.4	0.4	1.4	0.147
3765	4.7	2.8	4.6	1.1	0.1	1.7	0.2	0.033
3780	4.8	-0.8	4.4	-11.8	0.4	11.0	1.0	0.204
3782	6.5	-52.7	5.7	-50.8	0.8	-2.0	0.9	0.134
3788	8.3	-65.0	6.9	-70.4	1.4	5.4	1.5	0.185
3790	8.5	-73.8	7.1	-72.1	1.4	-1.8	1.4	0.169
3840	34.4	-106.8	24.8	-109.9	9.6	3.1	9.8	0.284
6660	5.5	35.5	3.9	100.2	1.6	-64.7	5.2	0.947
6670	6.2	101.5	4.6	92.6	1.6	9.0	1.8	0.298
6704	8.0	64.9	4.3	98.5	3.7	-33.6	5.0	0.627
6730	2.9	27.9	4.1	-41.8	-1.2	69.7	4.1	1.420
6735	5.1	21.2	4.7	-4.8	0.4	26.0	2.2	0.440
Mean	12.7	–	10.7	–	2.0	2.2	3.0	0.3
Absolute	–	–	–	–	2.1	14.1	–	–
RMS	16.1	67.1	13.6	73.0	3.1	24.4	3.8	0.460

Table 15 continued: Arctic North - O1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
G08	12.4	-142.2	9.5	-152.2	2.9	10.0	3.5	0.279
G30	4.6	-89.2	3.0	-103.1	1.6	13.9	1.8	0.393
3690	12.4	-154.2	9.5	-152.2	2.9	-2.0	2.9	0.235
3710	12.8	-149.2	9.0	-149.0	3.8	-0.3	3.8	0.296
3735	4.5	-91.2	3.0	-103.1	1.5	11.9	1.7	0.367
3736	4.3	-89.1	3.0	-101.6	1.3	12.5	1.5	0.356
3740	3.7	-78.0	2.6	-75.5	1.1	-2.6	1.1	0.290
3755	4.2	-38.2	2.7	-48.7	1.5	10.4	1.6	0.383
3765	2.6	-17.1	1.7	-19.2	0.9	2.1	0.9	0.340
3780	2.7	-19.2	1.4	-27.5	1.3	8.3	1.3	0.496
3782	2.1	-74.9	1.4	-85.4	0.7	10.5	0.8	0.369
3788	3.0	-94.0	1.9	-115.8	1.1	21.8	1.4	0.481
3790	2.7	-96.2	2.0	-117.6	0.7	21.4	1.1	0.416
3840	13.1	-161.3	8.7	-157.1	4.4	-4.3	4.4	0.339
6660	2.7	-2.7	1.4	59.0	1.3	-61.7	2.4	0.882
6670	5.0	38.7	1.5	81.8	3.5	-43.1	4.0	0.810
6704	2.1	-53.6	1.6	68.8	0.5	-122.4	3.2	1.539
6730	1.3	8.6	2.0	-73.3	-0.7	81.9	2.2	1.713
6735	3.3	-9.3	1.9	-35.4	1.4	26.1	1.8	0.551
Mean	5.2	–	3.6	–	1.7	-0.3	2.2	0.6
Absolute	–	–	–	–	1.7	24.6	–	–
RMS	6.6	89.7	4.6	100.0	2.1	39.7	2.4	0.685

B.4 Arctic Northwest

Table 16: Arctic Northwest - M2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5645	36.8	-104.1	25.7	-107.4	11.1	3.3	11.2	0.304
6834	30.4	-112.1	25.1	-120.1	5.3	8.0	6.5	0.215
6835	32.1	-123.5	24.6	-129.0	7.5	5.5	8.0	0.248
6910	8.8	-102.1	10.8	-129.9	-2.0	27.8	5.1	0.578
6955	14.6	-83.1	15.3	-98.5	-0.7	15.3	4.0	0.277
Mean	24.5	–	20.3	–	4.2	12.0	7.0	0.3
Absolute	–	–	–	–	5.3	12.0	–	–
RMS	26.8	105.8	21.2	117.6	6.5	14.9	7.4	0.350

Table 16 continued: Arctic Northwest - N2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5645	5.1	-142.9	5.1	-121.7	0.0	-21.2	1.9	0.367
6834	4.2	-126.4	4.8	-140.8	-0.6	14.4	1.3	0.305
6835	5.9	-155.2	4.9	-154.4	1.0	-0.8	1.0	0.173
6910	2.1	-133.9	2.8	175.6	-0.7	50.5	2.2	1.055
6955	2.4	-104.9	3.3	-114.9	-0.9	10.0	1.1	0.441
Mean	3.9	–	4.2	–	-0.3	10.6	1.5	0.5
Absolute	–	–	–	–	0.7	19.4	–	–
RMS	4.2	133.7	4.3	143.2	0.8	25.7	1.6	0.559

Table 16 continued: Arctic Northwest - S2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5645	21.6	-55.0	17.7	-50.8	3.9	-4.2	4.2	0.192
6834	11.3	-64.6	15.6	-63.9	-4.3	-0.7	4.3	0.377
6835	14.5	-69.1	14.5	-75.2	0.0	6.1	1.5	0.106
6910	2.4	-56.0	4.8	-111.9	-2.4	55.9	4.0	1.658
6955	7.0	-36.0	9.8	-47.3	-2.8	11.3	3.3	0.469
Mean	11.4	–	12.5	–	-1.1	13.7	3.4	0.6
Absolute	–	–	–	–	2.7	15.7	–	–
RMS	13.1	57.3	13.3	73.6	3.1	25.7	3.6	0.795

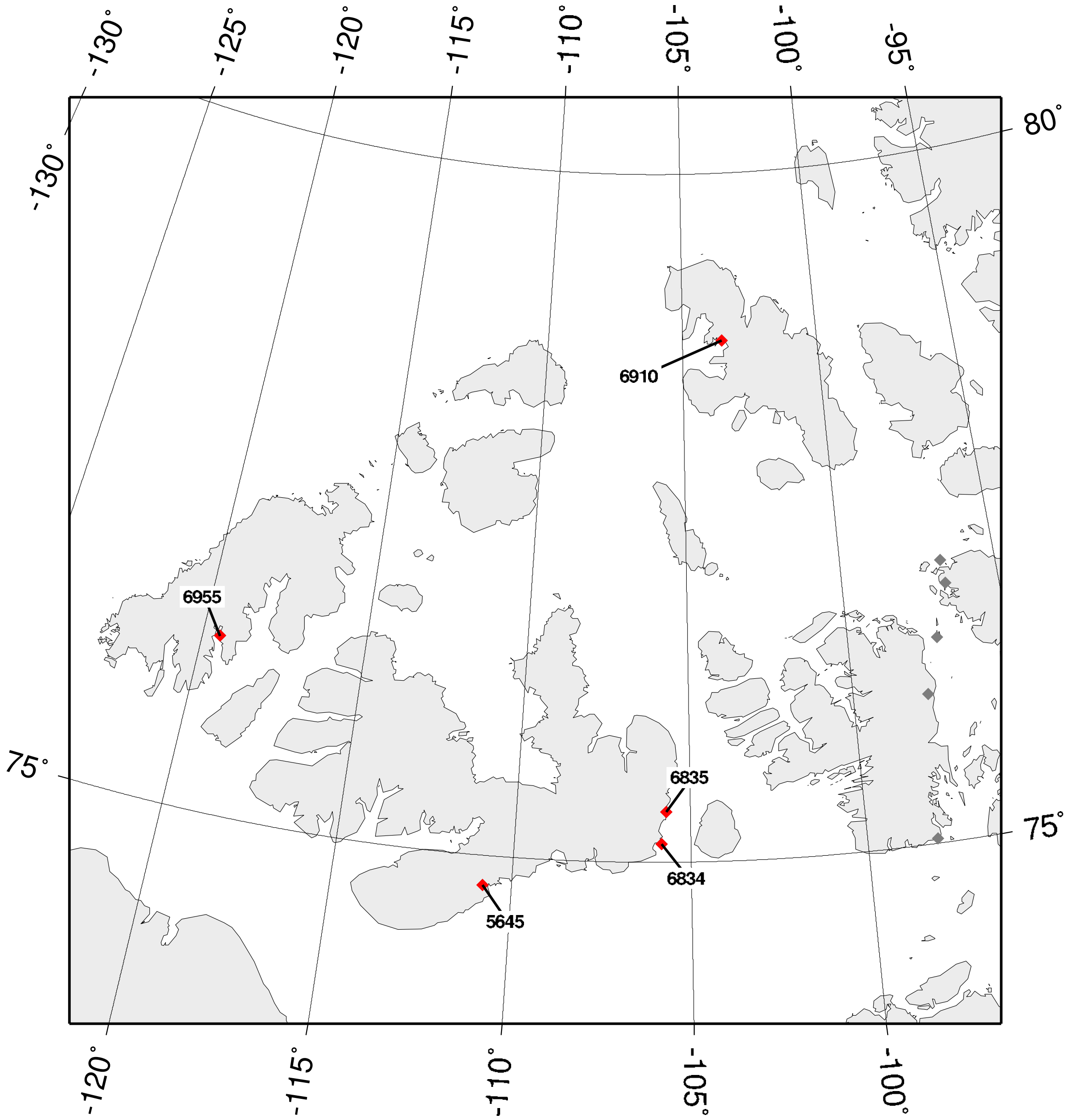

Figure 20: Arctic Northwest

Table 16 continued: Arctic Northwest - K1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5645	6.7	18.3	9.1	16.9	-2.4	1.4	2.4	0.354
6834	7.2	-18.0	10.7	2.3	-3.5	-20.3	4.7	0.652
6835	6.9	5.0	9.3	-3.9	-2.4	8.9	2.7	0.390
6910	4.8	43.3	4.4	43.9	0.4	-0.6	0.4	0.077
6955	3.9	-132.7	6.0	57.6	-2.1	169.7	9.8	2.525
Mean	5.9	–	7.9	–	-2.0	31.8	4.0	0.8
Absolute	–	–	–	–	2.1	40.2	–	–
RMS	6.0	63.5	8.2	33.3	2.4	76.5	5.1	1.190

Table 16 continued: Arctic Northwest - O1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5645	3.0	-119.4	4.2	-83.9	-1.2	-35.5	2.5	0.820
6834	5.6	-53.1	5.4	-89.2	0.2	36.2	3.4	0.609
6835	3.5	-103.4	4.6	-96.2	-1.1	-7.2	1.2	0.335
6910	2.1	-14.4	1.6	-25.4	0.5	11.1	0.6	0.287
6955	0.9	139.6	0.9	-39.4	-0.0	179.0	1.8	2.020
Mean	3.0	–	3.3	–	-0.3	36.7	1.9	0.8
Absolute	–	–	–	–	0.6	53.8	–	–
RMS	3.4	97.4	3.8	72.7	0.8	83.4	2.1	1.031

B.5 Arctic Central

Table 17: Arctic Central - M2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
3902	53.9	135.9	58.4	128.0	-4.5	7.9	9.0	0.167
5428	69.0	134.6	67.2	127.3	1.8	7.3	8.8	0.128
5430	66.4	137.9	65.1	130.7	1.3	7.2	8.4	0.127
5510	60.9	170.9	52.9	154.8	8.0	16.1	17.8	0.292
5530	67.5	172.4	60.0	143.6	7.5	28.8	32.5	0.482
5560	46.3	178.6	35.7	169.5	10.6	9.1	12.4	0.269
5600	36.8	-160.7	30.2	-170.5	6.6	9.9	8.8	0.239
5865	61.2	147.9	68.3	132.6	-7.1	15.3	18.6	0.304
5905	60.9	151.9	54.0	143.6	6.9	8.3	10.8	0.177
5910	43.6	162.6	36.4	146.4	7.2	16.2	13.4	0.306
6080	22.9	152.0	16.7	132.5	6.2	19.5	9.1	0.397
6556	89.4	129.9	89.2	123.9	0.2	6.0	9.4	0.105
6557	84.7	132.7	85.6	127.1	-0.9	5.6	8.4	0.100
6560	88.4	135.9	94.5	128.8	-6.1	7.1	12.9	0.146
6570	96.3	132.5	93.5	125.6	2.8	6.9	11.7	0.122
6580	82.3	142.4	94.0	134.0	-11.7	8.4	17.4	0.211
6584	42.3	165.2	35.2	169.3	7.1	-4.1	7.6	0.181
6588	23.8	165.4	24.6	170.5	-0.8	-5.1	2.3	0.095
6595	35.1	169.1	32.3	175.2	2.8	-6.1	4.5	0.128
6598	28.1	176.4	28.8	179.7	-0.7	-3.3	1.8	0.065
6605	33.7	173.1	31.9	177.9	1.8	-4.8	3.3	0.097
6765	37.7	-174.1	33.8	168.5	3.9	17.4	11.5	0.305
6770	32.2	-168.9	29.3	176.0	2.9	15.1	8.6	0.267
6780	20.1	-166.1	20.9	-172.8	-0.8	6.7	2.5	0.125
6781	18.6	-160.3	21.1	-172.8	-2.5	12.5	5.0	0.268
Mean	52.1	–	50.4	–	1.7	8.3	10.3	0.2
Absolute	–	–	–	–	4.5	10.2	–	–
RMS	57.1	156.7	56.3	152.6	5.5	11.8	12.1	0.229

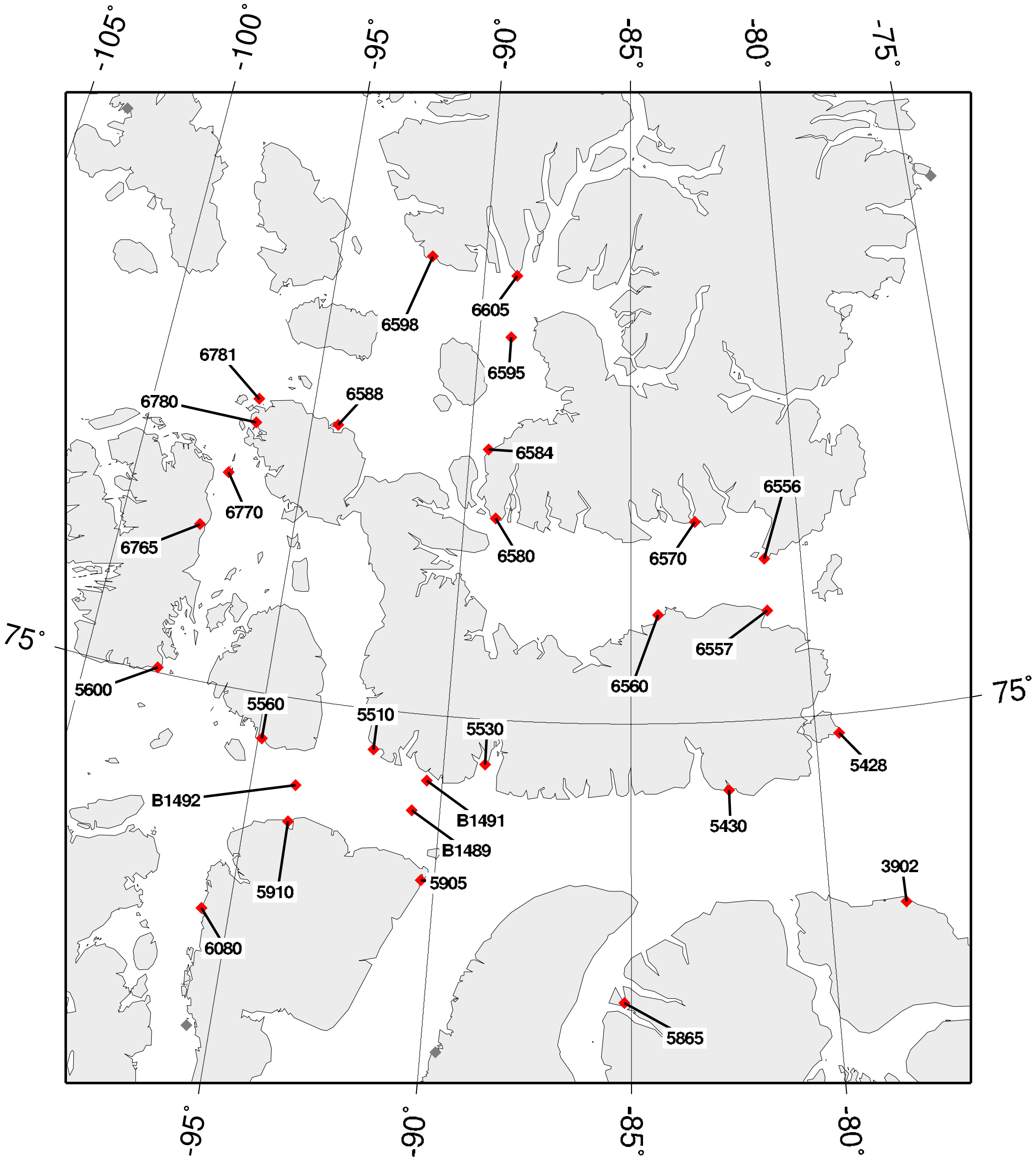

Figure 21: Arctic Central

Table 17 continued: Arctic Central - N2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
3902	12.2	110.6	12.0	100.8	0.2	9.8	2.1	0.169
5428	13.1	106.0	13.8	101.0	-0.7	5.0	1.4	0.103
5430	13.5	102.6	13.2	104.2	0.3	-1.6	0.5	0.035
5510	13.1	138.6	10.6	129.8	2.5	8.8	3.1	0.237
5530	8.1	126.9	11.9	118.1	-3.8	8.8	4.1	0.502
5560	8.4	149.6	7.0	144.9	1.4	4.7	1.5	0.183
5600	7.6	174.6	5.8	165.3	1.8	9.2	2.1	0.280
5865	14.6	116.2	13.7	105.6	0.9	10.6	2.8	0.190
5905	12.8	116.6	10.5	118.5	2.3	-1.9	2.3	0.181
5910	5.5	137.3	7.2	121.5	-1.7	15.8	2.4	0.437
6080	3.6	119.3	3.4	109.4	0.2	9.9	0.6	0.177
6556	20.0	97.9	18.2	98.4	1.8	-0.5	1.8	0.089
6557	16.7	107.5	17.4	101.6	-0.7	5.9	1.9	0.115
6560	18.7	101.7	19.2	103.6	-0.5	-1.9	0.8	0.045
6570	16.4	98.0	19.1	100.3	-2.7	-2.3	2.8	0.170
6580	18.8	128.0	19.5	109.7	-0.7	18.4	6.2	0.327
6584	9.6	149.9	7.5	155.8	2.1	-5.9	2.3	0.239
6588	5.6	149.2	6.0	159.4	-0.4	-10.1	1.1	0.194
6595	7.9	149.3	7.1	162.4	0.8	-13.0	1.9	0.240
6598	6.5	161.0	6.5	166.9	0.0	-5.8	0.7	0.102
6605	7.7	157.8	7.0	164.7	0.7	-6.9	1.1	0.148
6765	7.0	169.6	7.6	147.6	-0.6	22.0	2.9	0.410
6770	6.9	150.4	6.9	153.0	-0.0	-2.6	0.3	0.046
6780	3.9	175.6	5.6	163.3	-1.7	12.4	2.0	0.503
6781	3.9	162.9	5.6	163.2	-1.7	-0.2	1.7	0.430
Mean	10.5	–	10.5	–	-0.0	3.5	2.0	0.2
Absolute	–	–	–	–	1.2	7.8	–	–
RMS	11.6	136.6	11.6	133.4	1.5	9.5	2.4	0.261

Table 17 continued: Arctic Central - S2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
3902	19.4	-176.9	21.1	172.8	-1.7	10.3	4.0	0.207
5428	26.0	-178.1	25.1	171.4	0.9	10.5	4.8	0.184
5430	26.2	180.0	24.6	176.1	1.6	3.9	2.4	0.091
5510	21.0	-142.0	22.0	-156.1	-1.0	14.1	5.4	0.255
5530	25.6	-140.1	24.0	-168.7	1.6	28.6	12.3	0.482
5560	19.1	-129.6	15.5	-137.7	3.6	8.1	4.3	0.226
5600	15.6	-112.2	14.3	-113.2	1.3	1.0	1.3	0.083
5865	21.9	-160.0	25.8	179.7	-3.9	20.3	9.3	0.422
5905	19.5	-151.0	21.9	-167.5	-2.4	16.5	6.4	0.329
5910	16.5	-150.7	15.0	-160.0	1.5	9.3	3.0	0.179
6080	8.9	-151.1	8.4	-176.2	0.5	25.1	3.8	0.427
6556	34.6	170.2	34.3	167.5	0.3	2.7	1.7	0.048
6557	32.4	175.0	32.8	170.8	-0.4	4.2	2.4	0.074
6560	36.7	173.4	36.6	172.6	0.1	0.8	0.5	0.014
6570	37.7	177.5	36.1	169.3	1.6	8.2	5.5	0.146
6580	33.2	-175.0	36.4	178.2	-3.2	6.8	5.2	0.157
6584	17.1	-159.4	12.8	-137.6	4.3	-21.8	7.1	0.413
6588	9.1	-163.4	9.8	-132.4	-0.7	-31.0	5.1	0.562
6595	14.5	-157.7	11.8	-130.8	2.7	-26.9	6.7	0.460
6598	11.2	-151.1	10.6	-125.3	0.6	-25.8	4.9	0.438
6605	13.7	-153.4	11.7	-128.6	2.0	-24.8	5.8	0.423
6765	14.9	-134.0	15.8	-139.9	-0.9	5.9	1.8	0.123
6770	11.0	-119.9	13.6	-133.8	-2.6	13.9	4.0	0.361
6780	7.0	-135.0	9.7	-121.6	-2.7	-13.4	3.3	0.473
6781	4.6	-116.4	9.7	-121.9	-5.1	5.5	5.2	1.122
Mean	19.9	–	20.0	–	-0.1	2.1	4.6	0.3
Absolute	–	–	–	–	1.9	13.6	–	–
RMS	22.0	154.6	22.0	153.9	2.3	16.4	5.3	0.384

Table 17 continued: Arctic Central - K1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
3902	21.6	-105.7	17.6	-115.5	4.0	9.7	5.2	0.241
5428	30.1	-97.2	26.0	-102.2	4.1	5.0	4.8	0.160
5430	34.1	-91.8	22.8	-87.7	11.3	-4.0	11.5	0.338
5510	27.4	-24.8	27.0	-30.3	0.4	5.6	2.7	0.097
5530	28.1	-40.0	27.9	-47.9	0.2	8.0	3.9	0.139
5560	19.5	-21.2	21.4	-18.1	-1.9	-3.0	2.2	0.112
5600	16.2	-6.2	18.5	-7.8	-2.3	1.6	2.4	0.145
5865	15.8	-79.8	10.9	-89.2	4.9	9.4	5.4	0.339
5905	27.4	-53.8	26.5	-46.7	0.9	-7.0	3.4	0.125
5910	10.6	-39.3	13.8	-39.4	-3.2	0.1	3.2	0.300
6080	8.7	-12.8	11.9	-13.0	-3.2	0.2	3.2	0.367
6556	35.8	-99.6	27.0	-105.6	8.8	6.0	9.4	0.261
6557	33.4	-103.3	26.2	-105.6	7.2	2.3	7.3	0.220
6560	32.0	-100.9	25.9	-104.0	6.1	3.1	6.3	0.197
6570	30.8	-94.8	26.9	-104.5	3.9	9.7	6.2	0.202
6580	23.3	-83.8	25.4	-95.0	-2.1	11.2	5.2	0.222
6584	8.6	-35.8	3.1	2.4	5.5	-38.2	6.4	0.748
6588	5.4	37.8	6.3	53.9	-0.9	-16.0	1.9	0.346
6595	6.3	-19.7	3.4	26.0	2.9	-45.7	4.6	0.732
6598	5.6	-2.9	3.7	30.0	1.9	-32.8	3.2	0.574
6605	5.7	-12.5	3.4	26.2	2.3	-38.7	3.7	0.652
6765	10.9	-13.8	7.6	-27.2	3.3	13.5	4.0	0.363
6770	10.2	6.6	7.9	-4.9	2.3	11.6	2.9	0.285
6780	9.4	11.2	8.2	34.8	1.2	-23.6	3.8	0.403
6781	8.3	29.5	7.8	34.1	0.5	-4.6	0.8	0.097
Mean	18.6	–	16.3	–	2.3	-4.7	4.5	0.3
Absolute	–	–	–	–	3.4	12.4	–	–
RMS	21.4	61.3	18.7	65.8	4.3	17.8	5.1	0.359

Table 17 continued: Arctic Central - O1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
3902	7.8	-147.1	5.9	-149.0	1.9	1.9	1.9	0.247
5428	12.7	-143.1	9.8	-149.0	2.9	5.9	3.1	0.243
5430	10.8	-134.4	9.6	-133.4	1.2	-1.0	1.2	0.112
5510	14.9	-106.3	13.2	-93.1	1.7	-13.2	3.7	0.246
5530	16.3	-96.2	13.3	-106.5	3.0	10.2	4.0	0.245
5560	10.9	-82.0	10.8	-87.1	0.1	5.1	1.0	0.088
5600	8.1	-78.4	9.4	-81.5	-1.3	3.1	1.4	0.172
5865	8.2	-120.3	5.6	-114.3	2.6	-5.9	2.7	0.329
5905	13.5	-112.3	12.9	-105.8	0.6	-6.6	1.6	0.120
5910	8.7	-106.7	8.3	-101.1	0.4	-5.6	0.9	0.106
6080	7.2	-95.2	8.0	-89.7	-0.8	-5.5	1.1	0.147
6556	12.8	-136.7	9.8	-152.7	3.0	16.0	4.4	0.340
6557	11.7	-140.9	9.5	-152.9	2.2	12.1	3.1	0.265
6560	11.1	-138.5	9.4	-152.0	1.7	13.5	2.9	0.265
6570	12.8	-141.0	9.7	-151.9	3.1	10.9	3.7	0.292
6580	8.6	-132.8	8.6	-144.3	-0.0	11.4	1.7	0.199
6584	4.1	-80.3	1.8	-56.4	2.3	-23.9	2.6	0.624
6588	2.8	-27.6	2.5	-16.9	0.3	-10.8	0.6	0.209
6595	3.1	-63.2	1.7	-40.6	1.4	-22.7	1.7	0.548
6598	2.9	-54.7	1.7	-35.8	1.2	-18.9	1.4	0.497
6605	2.8	-59.0	1.6	-40.9	1.2	-18.1	1.4	0.491
6765	5.7	-75.3	3.8	-100.9	1.9	25.6	2.8	0.495
6770	6.5	-62.5	3.7	-78.0	2.8	15.4	3.1	0.473
6780	4.5	-50.3	3.4	-36.1	1.1	-14.2	1.4	0.320
6781	4.7	-35.7	3.3	-37.1	1.4	1.3	1.4	0.301
Mean	8.5	–	7.1	–	1.4	-0.6	2.2	0.3
Absolute	–	–	–	–	1.6	11.2	–	–
RMS	9.4	103.4	8.1	105.8	1.9	13.1	2.4	0.329

B.6 Arctic South Central

Table 18: Arctic South Central - M2 Results

Stat #	Observed		Modelled		Error		Complex Error	
	cm	deg	cm	deg	cm	deg	cm	relative
6090	15.9	103.4	11.0	79.9	4.9	23.5	7.3	0.460
6110	23.4	53.8	22.7	33.1	0.7	20.7	8.3	0.355
6150	6.1	100.0	0.4	-56.1	5.7	156.1	6.5	1.061
6240	14.7	178.9	9.9	168.2	4.8	10.7	5.3	0.363
Mean	15.0	–	11.0	–	4.1	52.7	6.9	0.6
Absolute	–	–	–	–	4.1	52.7	–	–
RMS	16.2	117.9	13.5	98.6	4.5	79.8	6.9	0.631

Table 18 continued: Arctic South Central - N2 Results

Stat #	Observed		Modelled		Error		Complex Error	
	cm	deg	cm	deg	cm	deg	cm	relative
6090	2.1	71.3	2.1	67.1	0.0	4.3	0.2	0.076
6110	3.3	12.2	3.8	11.9	-0.5	0.3	0.5	0.141
6150	1.2	65.2	0.0	-87.9	1.2	153.0	1.2	1.030
6240	2.7	140.7	1.8	141.9	0.9	-1.2	0.9	0.326
Mean	2.3	–	1.9	–	0.4	39.1	0.7	0.4
Absolute	–	–	–	–	0.6	39.7	–	–
RMS	2.5	85.6	2.3	90.1	0.8	76.6	0.8	0.546

Table 18 continued: Arctic South Central - S2 Results

Stat #	Observed		Modelled		Error		Complex Error	
	cm	deg	cm	deg	cm	deg	cm	relative
6090	7.2	167.2	8.4	143.4	-1.2	23.8	3.4	0.475
6110	9.3	126.1	13.3	114.0	-4.0	12.1	4.6	0.497
6150	2.4	158.4	0.2	34.7	2.2	123.7	2.5	1.041
6240	5.5	-121.2	5.6	-127.9	-0.1	6.7	0.7	0.119
Mean	6.1	–	6.9	–	-0.8	41.6	2.8	0.5
Absolute	–	–	–	–	1.9	41.6	–	–
RMS	6.6	144.6	8.3	113.0	2.4	63.4	3.2	0.627

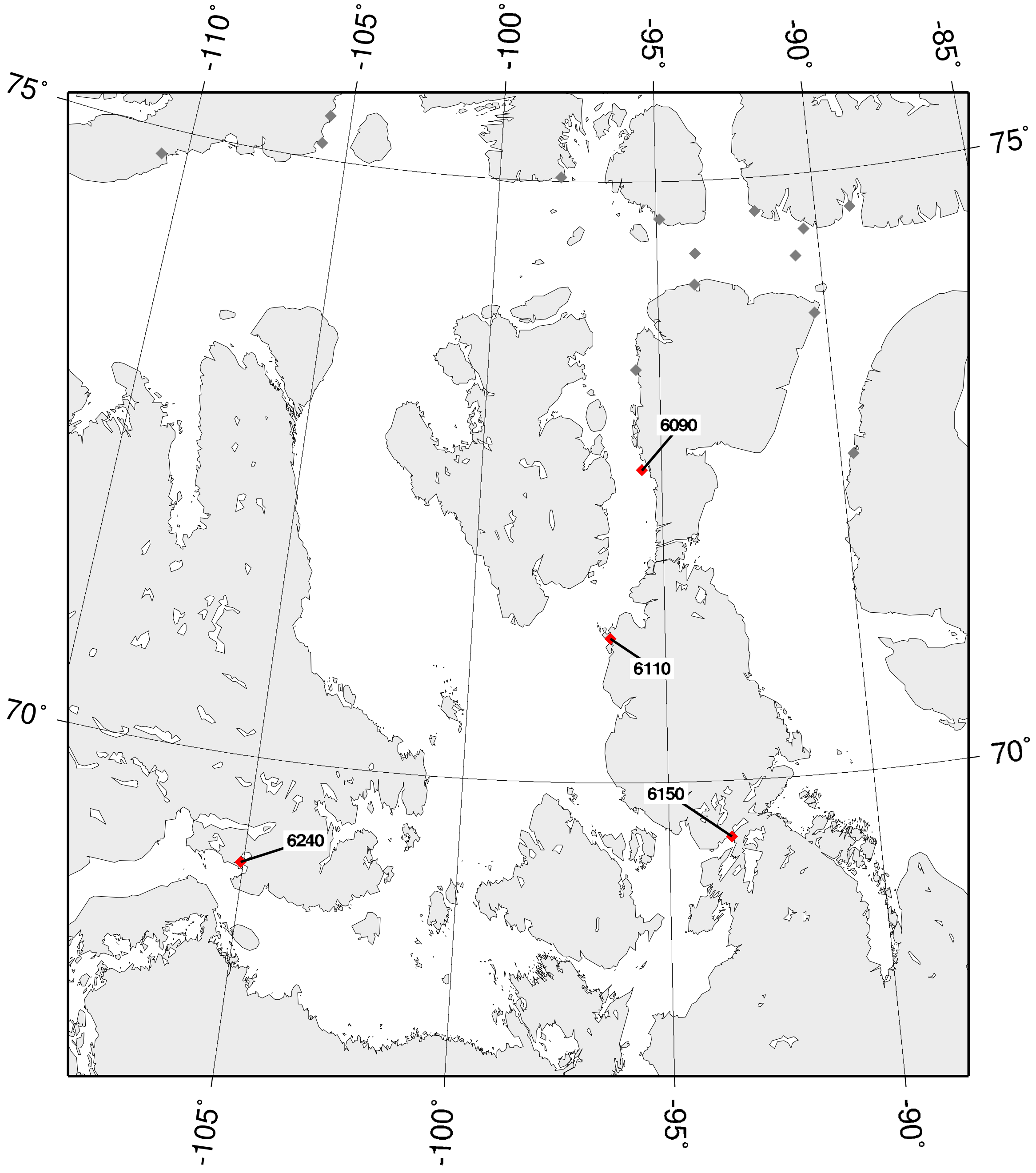

Figure 22: Arctic South Central

Table 18 continued: Arctic South Central - K1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
6090	9.9	-0.4	13.8	-4.7	-3.9	4.3	4.0	0.401
6110	10.2	11.3	14.3	6.7	-4.1	4.7	4.2	0.415
6150	2.1	137.2	1.4	-171.0	0.7	-51.8	1.7	0.787
6240	5.1	128.9	8.4	103.4	-3.3	25.5	4.4	0.865
Mean	6.8	–	9.5	–	-2.6	-4.3	3.6	0.6
Absolute	–	–	–	–	3.0	21.6	–	–
RMS	7.6	94.3	10.8	100.0	3.3	29.1	3.7	0.652

Table 18 continued: Arctic South Central - O1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
6090	7.6	-93.2	8.9	-85.5	-1.3	-7.7	1.7	0.222
6110	7.4	-91.2	9.1	-78.9	-1.7	-12.4	2.5	0.336
6150	1.6	30.4	1.0	112.7	0.6	-82.3	1.8	1.098
6240	3.6	-13.8	6.3	8.5	-2.7	-22.3	3.3	0.907
Mean	5.0	–	6.3	–	-1.3	-31.2	2.3	0.6
Absolute	–	–	–	–	1.6	31.2	–	–
RMS	5.7	67.3	7.1	81.1	1.8	43.2	2.4	0.740

B.7 Arctic Southeast

Table 19: Arctic Southeast - M2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5295	65.6	0.0	66.1	0.6	-0.5	-0.6	0.8	0.013
5305	68.3	4.8	67.8	-0.0	0.5	4.8	5.8	0.084
5310	64.2	8.0	67.7	-0.3	-3.5	8.3	10.1	0.158
5315	61.4	-14.3	58.5	-36.8	2.9	22.5	23.6	0.384
5330	49.3	-20.1	54.6	-39.3	-5.3	19.2	18.1	0.367
5332	47.9	-20.9	53.4	-37.3	-5.5	16.5	15.5	0.324
5790	57.3	139.9	57.5	128.2	-0.2	11.7	11.7	0.204
5791	55.6	132.5	57.5	128.2	-1.9	4.3	4.7	0.084
5920	52.5	163.5	40.8	145.6	11.7	17.9	18.6	0.354
Mean	58.0	–	58.2	–	-0.2	11.6	12.1	0.2
Absolute	–	–	–	–	3.5	11.8	–	–
RMS	58.4	85.0	58.8	80.5	5.0	13.8	14.0	0.257

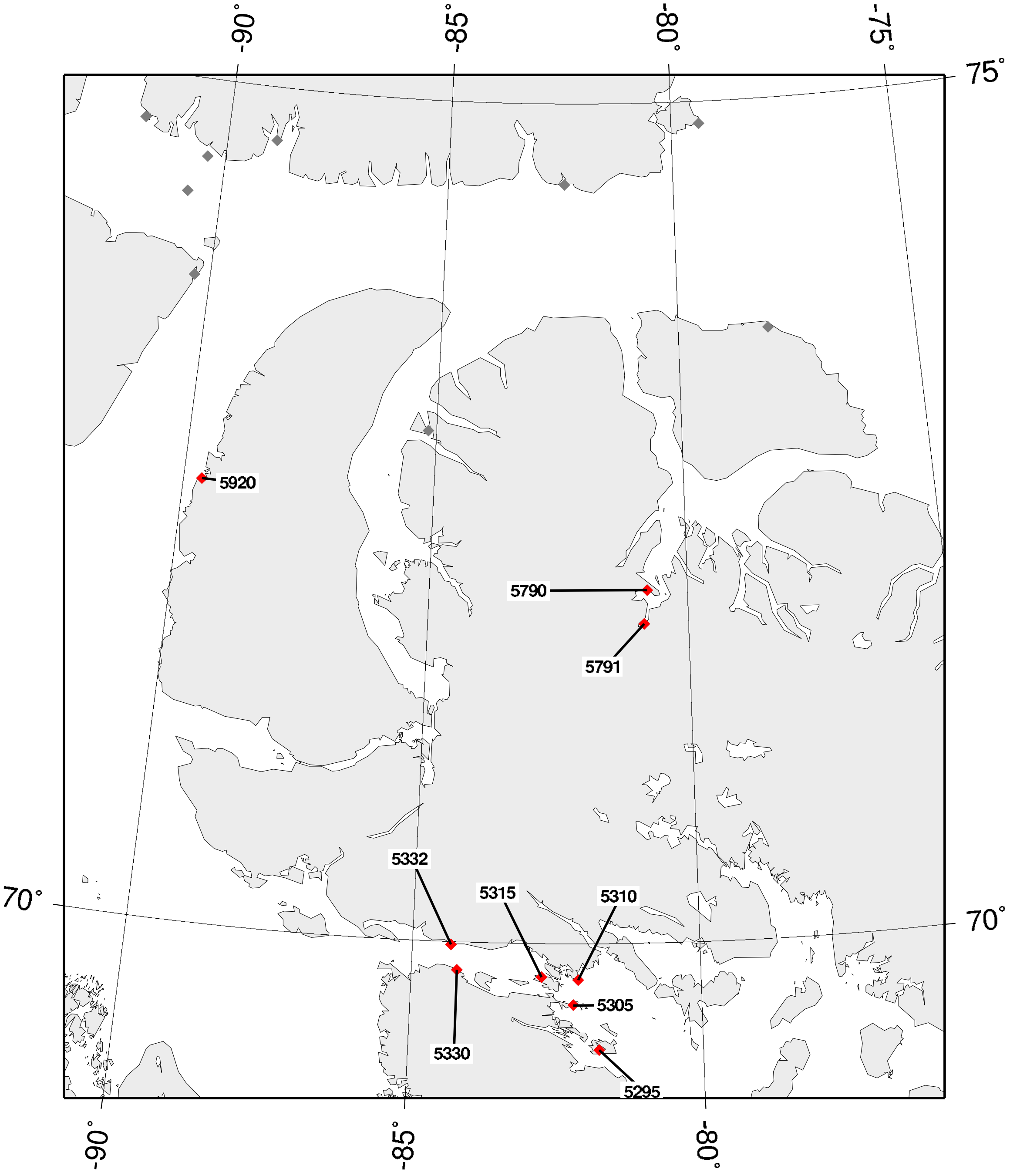

Figure 23: Arctic Southeast

Table 19 continued: Arctic Southeast - N2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5295	9.8	-40.1	9.9	-39.6	-0.1	-0.5	0.1	0.011
5305	15.6	-39.6	10.0	-41.6	5.6	2.0	5.6	0.360
5310	10.9	-15.9	10.0	-42.0	0.9	26.1	4.8	0.440
5315	8.9	-11.2	11.9	-64.2	-3.0	53.0	9.7	1.089
5330	16.7	-68.0	11.3	-66.4	5.4	-1.6	5.5	0.327
5332	16.8	-54.7	11.1	-64.7	5.7	10.0	6.2	0.370
5790	12.8	103.2	11.9	100.8	0.9	2.4	1.0	0.079
5791	9.7	85.0	11.9	100.8	-2.2	-15.8	3.7	0.382
5920	9.0	131.4	7.4	120.7	1.6	10.8	2.2	0.243
Mean	12.2	–	10.6	–	1.6	9.6	4.3	0.4
Absolute	–	–	–	–	2.8	13.6	–	–
RMS	12.6	71.7	10.7	76.5	3.5	21.0	5.1	0.467

Table 19 continued: Arctic Southeast - S2 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5295	23.0	57.5	23.3	58.3	-0.3	-0.8	0.4	0.019
5305	23.0	52.1	23.5	56.6	-0.5	-4.5	1.9	0.082
5310	21.8	68.5	23.3	56.5	-1.5	12.0	5.0	0.228
5315	21.5	56.8	22.9	13.6	-1.4	43.2	16.4	0.762
5330	15.1	28.0	21.2	10.4	-6.1	17.6	8.2	0.542
5332	21.0	16.3	20.6	12.4	0.4	3.9	1.5	0.070
5790	20.4	-176.0	20.5	172.8	-0.1	11.2	4.0	0.196
5791	23.4	-178.9	20.5	172.8	2.9	8.3	4.3	0.185
5920	18.5	-143.4	17.5	-162.6	1.0	19.2	6.1	0.329
Mean	20.9	–	21.5	–	-0.6	12.2	5.3	0.3
Absolute	–	–	–	–	1.6	13.4	–	–
RMS	21.0	104.6	21.5	103.5	2.4	18.0	7.0	0.353

Table 19 continued: Arctic Southeast - K1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5295	34.1	48.3	35.1	52.8	-1.0	-4.5	2.9	0.084
5305	34.8	18.3	36.2	51.4	-1.4	-33.1	20.3	0.582
5310	30.6	35.5	35.7	51.7	-5.1	-16.2	10.6	0.347
5315	65.4	13.6	89.9	11.7	-24.5	1.9	24.6	0.376
5330	61.4	2.7	89.2	10.3	-27.8	-7.6	29.5	0.481
5332	61.6	-0.4	88.3	11.1	-26.7	-11.5	30.5	0.495
5790	25.6	-111.8	18.8	-118.6	6.8	6.8	7.3	0.283
5791	25.3	-114.3	18.8	-118.6	6.5	4.3	6.7	0.264
5920	21.5	-9.6	33.1	0.5	-11.6	-10.1	12.5	0.582
Mean	40.0	–	49.5	–	-9.4	-7.8	16.1	0.4
Absolute	–	–	–	–	12.4	10.7	–	–
RMS	43.3	57.5	57.2	63.8	16.1	13.9	18.8	0.418

Table 19 continued: Arctic Southeast - O1 Results

Stat #	**Observed**		**Modelled**		**Error**		**Complex Error**	
	cm	deg	cm	deg	cm	deg	cm	relative
5295	16.4	-21.6	16.0	-19.0	0.4	-2.6	0.8	0.050
5305	15.9	-28.8	16.0	-21.5	-0.1	-7.3	2.0	0.127
5310	15.6	-29.3	15.8	-21.2	-0.2	-8.1	2.2	0.141
5315	27.0	-49.7	37.6	-58.5	-10.6	8.8	11.7	0.433
5330	29.3	-35.3	37.4	-59.8	-8.1	24.6	16.2	0.554
5332	28.9	-52.8	37.0	-59.1	-8.1	6.3	8.8	0.306
5790	8.2	-150.3	6.0	-153.6	2.2	3.3	2.2	0.268
5791	7.5	-158.6	6.0	-153.6	1.5	-5.0	1.6	0.209
5920	13.6	-70.7	15.9	-68.7	-2.3	-2.1	2.3	0.171
Mean	18.0	–	20.9	–	-2.8	2.0	5.3	0.3
Absolute	–	–	–	–	3.7	7.6	–	–
RMS	19.7	82.6	24.2	84.1	5.3	9.9	7.5	0.293

C Prediction errors

C.1 Baffin Bay

Stat #	# Cons.	MaxTide	5 vs 5		5 vs All		Diff
			cm	norm	cm	norm	
G01	4	138.6	12.3	0.215	12.3	0.215	0.0
G09	4	139.8	12.0	0.209	12.0	0.209	0.0
G11	4	184.4	14.1	0.159	14.1	0.159	0.0
G14	4	131.0	11.3	0.219	11.3	0.219	0.0
G16	4	200.5	18.8	0.197	18.8	0.197	0.0
G24	4	108.0	15.3	0.351	15.3	0.351	0.0
G26	4	128.6	9.4	0.183	9.4	0.183	0.0
G28	4	155.0	28.6	0.437	28.6	0.437	0.0
G29	4	208.4	18.2	0.197	18.2	0.197	0.0
G31	4	112.0	9.5	0.216	9.5	0.216	0.0
3575	9	279.4	31.4	0.289	33.5	0.307	2.1
3916	31	130.2	8.7	0.219	11.3	0.280	2.6
3941	31	48.3	17.0	1.486	17.6	1.426	0.7
3948	31	81.8	9.7	0.431	11.3	0.489	1.7
3960	9	68.4	9.0	0.409	10.0	0.445	1.0
3970	9	80.3	9.2	0.369	10.8	0.423	1.6
3980	9	94.1	9.1	0.303	11.1	0.362	2.0
3995	9	147.8	17.3	0.275	18.1	0.287	0.9
4040	7	381.5	46.8	0.271	49.5	0.285	2.7
64000	69	206.6	9.0	0.129	12.8	0.182	3.8
64005	69	214.4	8.4	0.119	12.7	0.178	4.3
64010	69	245.7	10.4	0.132	15.0	0.189	4.6
RMS	–	–	17.8	0.413	18.9	0.419	–

Table 20: Baffin Bay Prediction error

C.2 Arctic West

Stat #	**# Cons.**	**MaxTide**	**5 vs 5**		**5 vs All**		**Diff**
			cm	norm	cm	norm	
6290	39	21.4	11.1	1.890	11.4	1.767	0.3
6310	9	44.7	3.8	0.257	4.5	0.302	0.7
6338	25	42.5	7.4	0.528	8.2	0.568	0.8
6340	25	39.9	7.3	0.679	8.6	0.736	1.3
6350	9	37.8	5.4	0.410	5.7	0.427	0.3
6360	48	51.7	5.5	0.544	10.6	0.781	5.1
6424	41	21.1	5.2	1.078	5.9	1.057	0.8
6443	28	29.4	7.9	1.236	10.7	1.108	2.8
6457	28	69.6	34.5	1.468	34.9	1.450	0.4
6472	28	56.1	2.7	0.166	7.8	0.435	5.1
6476	28	41.1	2.8	0.273	7.6	0.608	4.8
6485	40	49.6	3.9	0.406	10.0	0.747	6.0
6492	28	34.7	5.4	0.844	8.9	0.933	3.5
6495	27	32.6	2.6	0.431	7.4	0.809	4.8
6498	28	18.7	2.9	0.592	3.2	0.624	0.3
6505	29	60.9	4.8	0.536	17.2	0.914	12.4
6525	27	32.2	3.1	0.453	7.3	0.768	4.2
RMS	–	–	10.0	0.829	12.2	0.900	–

Table 21: Arctic West Prediction error

C.3 Arctic North

Stat #	# Cons.	MaxTide	5 vs 5		5 vs All		Diff
			cm	norm	cm	norm	
G08	4	201.6	22.1	0.249	22.1	0.249	0.0
G30	4	97.0	8.2	0.188	8.2	0.188	0.0
3690	8	246.5	34.7	0.387	36.6	0.405	1.9
3710	7	229.0	23.8	0.285	26.0	0.309	2.2
3735	8	118.7	3.0	0.067	6.3	0.142	3.4
3736	27	136.0	4.3	0.097	9.3	0.207	5.1
3740	29	97.9	4.3	0.141	8.2	0.261	3.9
3755	8	41.8	5.9	0.455	6.4	0.489	0.6
3765	48	63.4	2.5	0.144	6.0	0.337	3.6
3780	11	53.5	5.8	0.295	6.3	0.317	0.5
3782	27	92.6	3.8	0.126	7.1	0.228	3.3
3788	27	134.6	5.2	0.114	9.5	0.206	4.3
3790	9	101.7	16.8	0.386	18.6	0.419	1.7
3840	10	269.4	11.6	0.122	17.2	0.179	5.5
6660	10	17.6	9.8	1.794	9.9	1.753	0.1
6670	10	26.9	10.4	1.492	10.9	1.419	0.5
6704	10	24.2	10.7	1.730	11.5	1.534	0.8
6730	28	15.0	9.0	2.373	9.1	2.239	0.1
6735	11	30.7	3.5	0.359	3.9	0.387	0.3
RMS	–	–	13.2	0.890	14.7	0.854	–

Table 22: Arctic North Prediction error

C.4 Arctic Northwest

Stat #	# Cons.	MaxTide	5 vs 5		5 vs All		Diff
			cm	norm	cm	norm	
5645	10	82.8	8.9	0.289	9.9	0.318	1.0
6834	28	89.8	7.0	0.290	9.0	0.364	2.0
6835	52	88.5	6.1	0.238	7.8	0.298	1.7
6910	9	22.9	4.8	0.638	5.0	0.648	0.1
6955	9	31.2	8.0	0.672	8.1	0.675	0.1
RMS	–	–	7.1	0.465	8.1	0.489	–

Table 23: Arctic Northwest Prediction error

C.5 Arctic Central

Stat #	**# Cons.**	**MaxTide**	**5 vs 5**		**5 vs All**		**Diff**
			cm	norm	cm	norm	
3902	31	157.5	8.1	0.182	12.3	0.270	4.1
5428	33	185.3	8.2	0.142	12.4	0.212	4.2
5430	9	170.0	10.3	0.179	13.9	0.238	3.6
5510	8	150.9	13.7	0.266	14.9	0.288	1.2
5530	28	196.8	25.2	0.447	27.8	0.482	2.6
5560	18	138.9	9.5	0.243	13.2	0.328	3.7
5600	25	104.0	6.8	0.214	9.0	0.279	2.2
5865	9	134.6	15.4	0.316	16.4	0.333	1.0
5905	18	158.1	9.4	0.184	11.6	0.225	2.2
5910	27	129.5	10.1	0.293	15.1	0.416	5.0
6080	27	65.5	7.4	0.383	8.1	0.413	0.7
6556	31	233.5	10.0	0.135	15.3	0.203	5.2
6557	33	222.5	8.5	0.122	14.0	0.197	5.5
6560	31	238.9	10.5	0.143	16.2	0.218	5.7
6570	31	233.7	10.7	0.138	15.3	0.195	4.6
6580	27	200.7	14.1	0.211	16.8	0.250	2.7
6584	27	99.4	9.0	0.267	10.1	0.297	1.1
6588	23	57.3	4.3	0.224	5.1	0.265	0.8
6595	27	80.9	6.8	0.243	7.8	0.277	1.0
6598	27	67.9	4.5	0.200	5.7	0.251	1.2
6605	27	79.1	5.5	0.207	6.8	0.251	1.3
6765	10	90.0	9.2	0.302	10.6	0.342	1.4
6770	27	83.4	7.3	0.282	8.5	0.321	1.1
6780	11	52.1	4.3	0.255	5.1	0.294	0.7
6781	20	48.7	5.3	0.346	5.9	0.375	0.5
RMS	–	–	10.3	0.250	12.9	0.298	–

Table 24: Arctic Central Prediction error

C.6 Arctic South Central

Stat #	**# Cons.**	**MaxTide**	**5 vs 5**		**5 vs All**		**Diff**
			cm	norm	cm	norm	
6090	27	57.1	6.5	0.425	7.3	0.468	0.8
6110	27	67.2	7.6	0.379	8.3	0.409	0.7
6150	27	22.3	5.3	1.039	5.9	1.030	0.7
6240	48	57.9	5.5	0.452	9.2	0.649	3.7
RMS	–	–	6.3	0.634	7.8	0.684	–

Table 25: Arctic South Central Prediction error

C.7 Arctic Southeast

Stat #	**# Cons.**	**MaxTide**	**5 vs 5**		**5 vs All**		**Diff**
			cm	norm	cm	norm	
5295	27	183.3	2.2	0.039	9.9	0.173	7.7
5305	25	199.3	15.6	0.265	18.7	0.314	3.2
5310	31	194.3	11.6	0.213	15.9	0.287	4.4
5315	26	252.9	28.8	0.422	33.5	0.476	4.7
5330	25	252.0	27.9	0.454	38.8	0.578	10.9
5332	26	231.4	25.4	0.411	28.8	0.456	3.4
5790	10	141.5	10.3	0.215	12.6	0.260	2.3
5791	10	139.2	7.1	0.152	10.3	0.216	3.1
5920	27	138.1	16.6	0.379	17.8	0.403	1.3
RMS	–	–	18.5	0.313	23.0	0.374	–

Table 26: Arctic Southeast Prediction error

D Errors at Padman and Erofeeva (2004) locations

Padman and Erofeeva (2004) report on a tidal model of the Arctic Ocean that includes good solutions in the Archipelago. Their solutions were computed on a model domain that covered the entire Arctic Ocean at 5 km resolution and using a very different assimilation scheme.

For a rough comparison of their solutions with ours we have attempted to evaluate our solutions at the same locations for two regions: Baffin Bay (their region 6) and Nares Strait (their region 7). The identification of common locations was not precise, we did a visual inspection of our map and theirs. They report 19 Stations in Baffin Bay (for M2) and we identified 12 common locations. Their locations include 2 or more in southern Greenland which are outside our domain. For Nares Strait they report 7 stations and we identified 9. While the station lists may not be identical, we think they suffice for a rough comparison of the errors based on similar region partitioning.

Tables 27 and 28 list our errors at the stations we identified (extracted from the tables in Appendix B). The comparison with the regional statistics of Padman and Erofeeva (2004) are reported in Section 4. It is worth noting that the regional errors are dominated by large errors at a few stations.

Note that our error metric is the difference in the tidal phasors and represents a peak error. The errors reported by Padman and Erofeeva (2004) are the rms error which is the peak error divided by $\sqrt{2}$.

Stat #	M2 cm	N2 cm	S2 cm	K1 cm	O1 cm
G09	10.5	NA	4.9	3.5	1.6
3995	22.0	3.8	9.1	3.4	0.5
G16	3.1	NA	12.0	0.6	0.2
G28	33.8	NA	16.0	2.7	4.3
3970	11.4	1.0	4.3	4.2	0.6
3902	9.0	2.1	4.0	5.2	1.9
5428	8.8	1.4	4.8	4.8	3.1
6557	8.4	1.9	2.4	7.3	3.1
6556	9.4	1.8	1.7	9.4	4.4
3840	8.7	6.9	5.6	9.8	4.4
3710	29.0	7.9	14.5	1.8	3.8
3690	44.0	9.9	18.3	5.8	2.9
RMS	20.5	5.1	9.8	5.6	3.0

Table 27: Errors at Padman and Erofeeva (2004) stations in Baffin Bay (their region 6).

Stat #	M2 cm	N2 cm	S2 cm	K1 cm	O1 cm
3755	7.7	1.0	1.8	1.4	1.6
3765	3.2	0.7	0.5	0.2	0.9
3782	4.7	1.8	1.3	0.9	0.8
3788	6.8	0.7	1.6	1.5	1.4
3790	5.1	1.6	NA	1.4	1.1
G30	4.2	NA	2.4	2.8	1.8
3735	1.4	0.9	2.5	2.5	1.7
3736	4.7	1.7	1.8	2.3	1.5
3740	5.6	0.7	1.9	0.7	1.1
RMS	5.1	1.2	1.8	1.7	1.4

Table 28: Errors at Padman and Erofeeva (2004) stations in Nares Strait (their region 7).

E Tidal ellipse errors for Barrow Strait ADCP Data

Here we report the comparison between the modelled and observed tidal currents for N2, S2, O1. The larger velocity components are reported in Section 5. The eccentricity (ratio of minor to major axis currents, is dimensionless and negative when the ellipse is traversed clockwise smaller constituents. The inclination is the angle of the major axis with the x (east) axis measured counterclockwise (the mathematical convention).

Stat #	**Major (cm)**		**Eccentricity**		**Inclination (deg)**		**Phase (deg)**	
	obs	mod	obs	mod	obs	mod	obs	mod
N2								
A1438_39	1.5	1.5	-0.053	-0.238	163.7	11.2	102.0	354.2
A1441	1.6	1.5	-0.054	-0.164	165.4	14.8	94.3	354.5
A1443	2.1	1.6	-0.322	-0.139	164.9	8.8	35.2	355.4
A1445	1.9	1.7	0.027	-0.072	163.7	175.3	110.2	175.3
S2								
A1438_39	2.5	3.1	0.076	-0.029	172.2	163.0	267.2	240.9
A1441	3.5	3.1	-0.130	-0.024	176.4	162.8	244.9	240.7
A1443	3.4	3.0	-0.153	-0.070	165.4	169.2	178.4	241.3
A1445	3.6	3.3	0.010	-0.063	166.7	174.4	224.3	238.6
O1								
A1438_39	4.2	4.6	0.175	0.048	159.8	156.3	215.3	292.0
A1441	5.3	4.7	-0.005	0.048	161.3	156.4	249.3	292.1
A1443	5.4	4.5	-0.198	-0.061	163.9	155.8	231.4	304.4
A1445	4.2	4.2	0.053	-0.162	160.5	161.2	239.5	303.9

Table 29: Tidal current comparison for N2, S2, and O1.