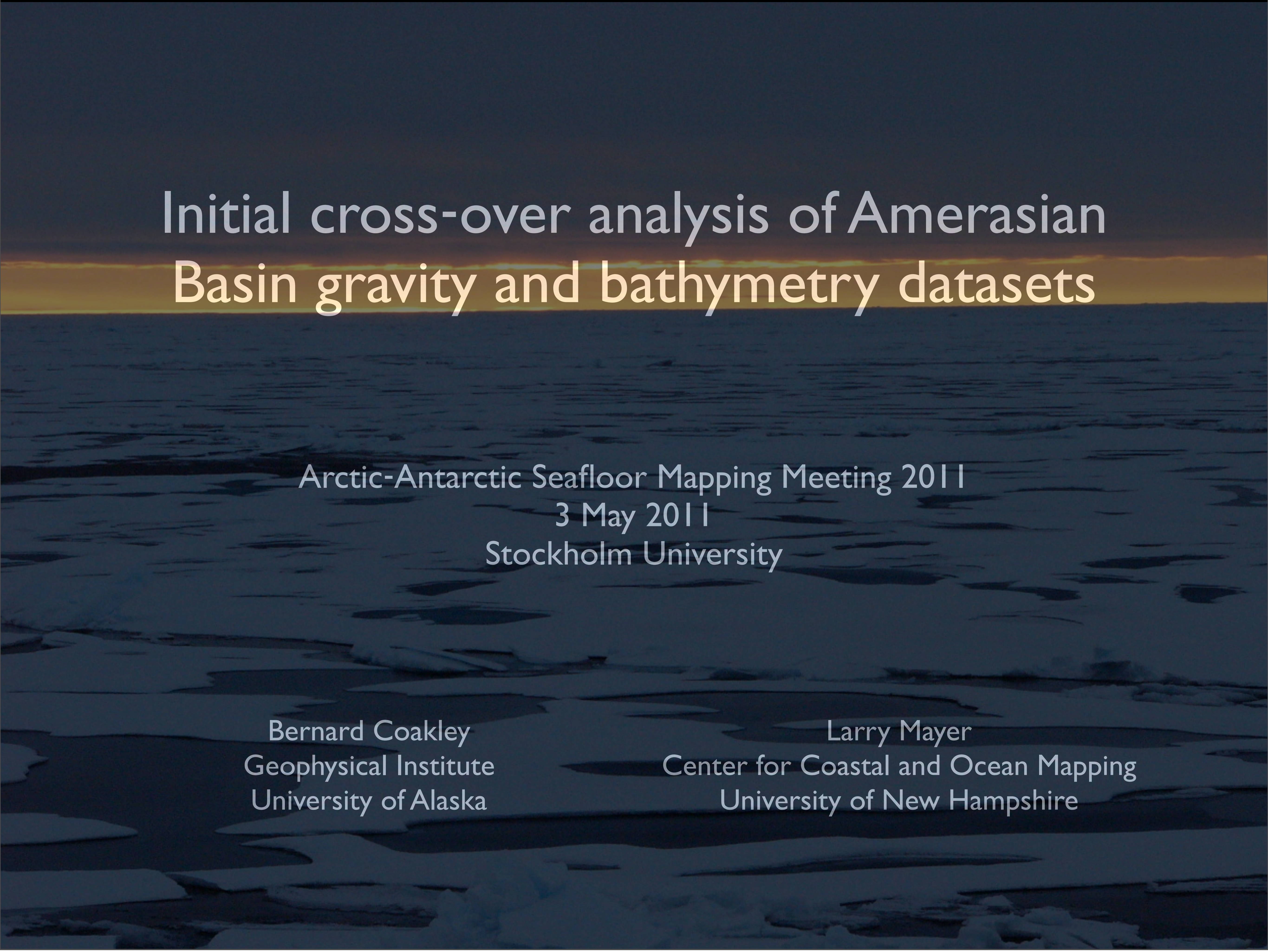

Initial cross-over analysis of Amerasian Basin gravity and bathymetry datasets

Arctic-Antarctic Seafloor Mapping Meeting 2011
3 May 2011
Stockholm University

Bernard Coakley
Geophysical Institute
University of Alaska

Larry Mayer
Center for Coastal and Ocean Mapping
University of New Hampshire

Error Analysis

- Compare repeat measurements at crossing tracks
- Treat GPS Navigation as TRUE
- We can isolate instrumental errors
- And errors from processing and calibration
- Different error models
- Empircal calibration of Gravimeters
- Physically based calibration of Multi-beams (eg. patch tests and SVPs)

Objectives

- Identify and correct data problems
- Prepare for gridding

Using the GMT package

x2sys

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. B1, PAGES 393-413, JANUARY 10, 1988

On the Accuracy of Marine Gravity Measurements

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We have assessed the accuracy of Lamont-Doherty Geological Observatory's global marine gravity data bank by examining the crossover errors (COEs) at intersecting ship tracks. More than 63,000 COEs were found, having a standard deviation of 22.43 mGal (mGal = 10^{-5} m s^{-2}). We use the COEs to find and remove linear drifts and DC shifts present in the data set. This adjustment reduces the standard deviation to 13.96 mGal. COEs generally decrease with latitude, which we attribute to uncertainties in the Eötvös correction. High COEs occur in areas of high gravity gradients. These two features point to poor navigation as the principal source of error in marine gravity surveys. COEs have generally been decreasing during the last two decades, reflecting improvements in instrumentation and quality of navigation. A comparison of the shipboard gravity data to Seasat derived gravity revealed a 9-mGal bias in the terrestrial data, which probably reflects uncertainties in choice of reference field. The adjusted data set was used to generate a gravimetric geoid for the NW Atlantic Ocean. By removing this geoid from the Seasat sea surface heights, a residual "geoid" was obtained. A special feature of this map is an elongate ENE trend that appears to correlate with the edge of the Gulf Stream.

INTRODUCTION

During the past few decades there have been numerous gravity measurements obtained over the Earth's surface by university, government, and industry groups. The global data bank at the Lamont-Doherty Geological Observatory (LDGO) currently contains more than 4.8 million point gravity measurements. This data set provides one of the principal means of determining crustal and upper mantle structure beneath oceans and continents. Its use in gravity model improvement, ground truth for satellite and airborne data, and gravimetric geoid computation has been somewhat limited, however, chiefly because of uncertainties in the accuracy of the data, particularly in the case of measurements obtained at sea [e.g. *Neuman and Talwani*, 1972].

In recent years a number of geologic, geodetic, and geophysical applications have stressed the need for a selfconsistent globally adjusted gravity data set based on terrestrial measurements. For example, in gravity model improvement studies, terrestrial data are now being incorporated into combination solutions for the gravity field which are complete to degree and order 180. Although mean "block" gravity anomalies are now available over most of the Earth's surface [e.g., *Rapp*, 1981], there has been no systematic analysis of the accuracy of the point data used to construct these block anomaly means. In the case of most land data, errors due to instruments, drift, and topographic corrections are generally small and less than about 1 mGal. Marine data, on the other hand, can be subject to errors up to a few tens of mGal.

A major factor in the accuracy of marine gravity data is the quality of the ship's navigation. A primary error source is incorrect computation of the Eötvös effect, which is a strong function of the ship's heading and over-the-ground velocity. In order to achieve a 1-mGal accuracy for a ship traveling at 5 m s^{-1} at the equator, for example, it is necessary to know the heading to better than 1° and the velocity to better than 0.1 m s^{-1}. Prior to about 1967, most ships utilized celestial navigation, so large errors (up to a few tens of mGal) may still remain in these data. The magnitude of the errors was thought to have been reduced following introduction of the U.S. Navy satellite navigation system (TRANSIT). However, it is generally agreed that significant errors related to navigational uncertainties still remain in gravity data, even those data acquired after 1967.

In addition to errors related to navigation, there are several other sources of error that contribute to uncertainties in marine gravity data. Among the most significant of these for measurements obtained with the beam-type sea gravimeters [*LaCoste*, 1959; *Graf and Schulze*, 1961] are off-leveling, cross-coupling, nonlinear drift and a mechanical "tare" or "jar" of the gravity measuring system.

Unfortunately, it is difficult to quantify the accuracy of marine gravity data because the types of navigation, measuring system response, and sea conditions vary among individual legs. The principal method used to estimate the accuracy of gravity data at sea has been the analysis of the discrepancies in free-air gravity anomaly values at intersecting ship tracks [e.g., *Talwani*, 1971]. We believe this method to be the most reliable technique with which to evaluate the accuracy of marine gravity data. Most previous studies have computed the crossover discrepancies manually and so have only assessed the accuracy of gravity data over small regions of the ocean basins. This paper presents the results of a systematic analysis of the LDGO marine gravity data bank based on 63,257 ship track intersections. We have used gravity data collected along more than 3.7 million km of ship track by 16 different collecting agencies. The overall objectives of the study are (1) to provide statistical information on the accuracy of individual ship gravity surveys, (2) to determine the principal sources of error in gravity measurements at sea and, where possible, correct for these errors, and (3) to construct an "adjusted" gravity data base from which gridded averages can easily be computed and used in geologic, geodetic, and geophysical applications.

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0148-0227/88/007B-1039$05.00

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On the Accuracy of Digital Bathymetric Data

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The global 5-arcmin gridded topography data ETOPO-5 are based on contour maps rather than original soundings and have large errors. The artificial statistical distribution generated by digitizing contours makes these data unsuitable for use in regression models for depth-age variations. Their amplitude spectrum is bounded by a $(\text{frequency})^{-4}$ power law, so that they should not be used when the gravity-topography transfer function is important, such as in studies of flexural isostasy and mantle convection. I assess the accuracy of 14,491,069 digital ship soundings in 2253 cruise surveys collected between 1955 and 1992 in the Lamont-Doherty Earth Observatory on-line data base by analyzing 329,038 crossover errors (COEs) at intersecting ship tracks. Five percent of cruises with internal COEs yield root-mean-square COE amplitudes exceeding 500 m; all of these have errors in digitizing two-way travel time from analog precision depth recorder traces. Twenty-eight cruises were found which had errors caused by misinterpretation of the nominal sound velocity used when travel times were reported as nominal depths. Two nominal sound velocities in common use differ by 2.5%, an amount which is often undetectable, producing uncertainties in depth of this magnitude. Ship data have been acquired at different rates over time, with the peak of activity in the early 1970s. Although present technologies can yield very accurate data, these are acquired at a rate which is small with respect to the total available data; the cumulative median global COE has remained constant at 26 m since the late 1970s. Most recent data acquisition has been in the northern hemisphere oceans, and the oldest and least accurate data are in the southern oceans where median COEs are 100 – 250 m. The majority of the data in the South Pacific were acquired before the advent of satellite navigation.

INTRODUCTION

Topography is the fundamental physical characteristic of any planet. Topographic data are essential to the study of planetary dynamics, not only as the principal boundary condition but also because surface relief is indicative of nonhydrostatic stress in the planet's interior [*Bowie*, 1927; *Jeffreys*, 1976]. The elevations of the surfaces of Mars [*Carr et al.*, 1977] and Venus [*Ford and Pettengill*, 1992] are better known than those of some areas of Earth. Two factors make Earth's topography difficult to measure. Nearly three-quarters of the surface lies under water and cannot be observed by airborne or orbiting vehicles using electromagnetic means; it must be sensed acoustically by surface or sub-surface craft. Much of the land area is in the northern hemisphere and the southern oceans are remote; there are areas of the southern hemisphere larger than 10,000 km^2 for which no digital ship sounding data are available.

Ocean basin- and global-scale investigations of Earth's fundamental dynamic processes require bathymetric data in a computerized form because of the large quantity of data involved and the nature of the calculations required. Digital bathymetric data are available in two forms, as sequences of soundings collected by oceanographic ships, and in a grid array of values for 5 arcmin "squares" of latitude and longitude (the Synbaps, or DBDB-5, data set [*Van Wyckhouse*, 1973], now part of ETOPO-5 [*National Geophysical Data Center*, 1988]). The 5 arcmin gridded data create the illusion of global coverage; to the extent that they are faithful to actual soundings they offer a convenient synthesis of the ship data. Because they are widely available and convenient to use, most recent studies of isostasy and thermal boundary layer cooling have been based on these data. The original ship sounding data have been difficult to use and accessible only through research institutions which have the facilities to maintain a large data bank; furthermore, only in the last few years have computer processing and storage media evolved to the point where it is practical to maintain a comprehensive global collection of these data in an "on-line" searchable manner. The U.S. National Geophysical Data Center (NGDC) has recently released its digital bathymetric data on CD-ROM [*National Geophysical Data Center*, 1992], and it is now possible for the scientific community to have access to these original soundings "on-line".

The accuracy and spatial distribution of digital bathymetric data is of fundamental importance to all scientists interested in Earth physics, yet the errors and limitations of these data are not widely appreciated. In this paper, I illustrate some peculiarities of the ETOPO-5 gridded data which argue against their use in geophysical studies. I present an analysis of global crossover errors in the original ship sounding data, and remark upon the limitations of their accuracy and distribution. This analysis is of the soundings in the on-line data bank at Columbia University's Lamont-Doherty Earth Observatory (Figure 1). I used these data because they are available over Internet through the view-server system [*Menke et al.*, 1991], and because a crossover error study of the gravity data in this data bank was made earlier by *Wessel and Watts* [1988]. These data are very similar to those available from NGDC. The LDEO data bank includes some data not held at NGDC and probably lacks some that NGDC has, particularly the most recent contributions. However, as will be shown, the accuracy of the data is determined by soundings made before the mid-1980s,

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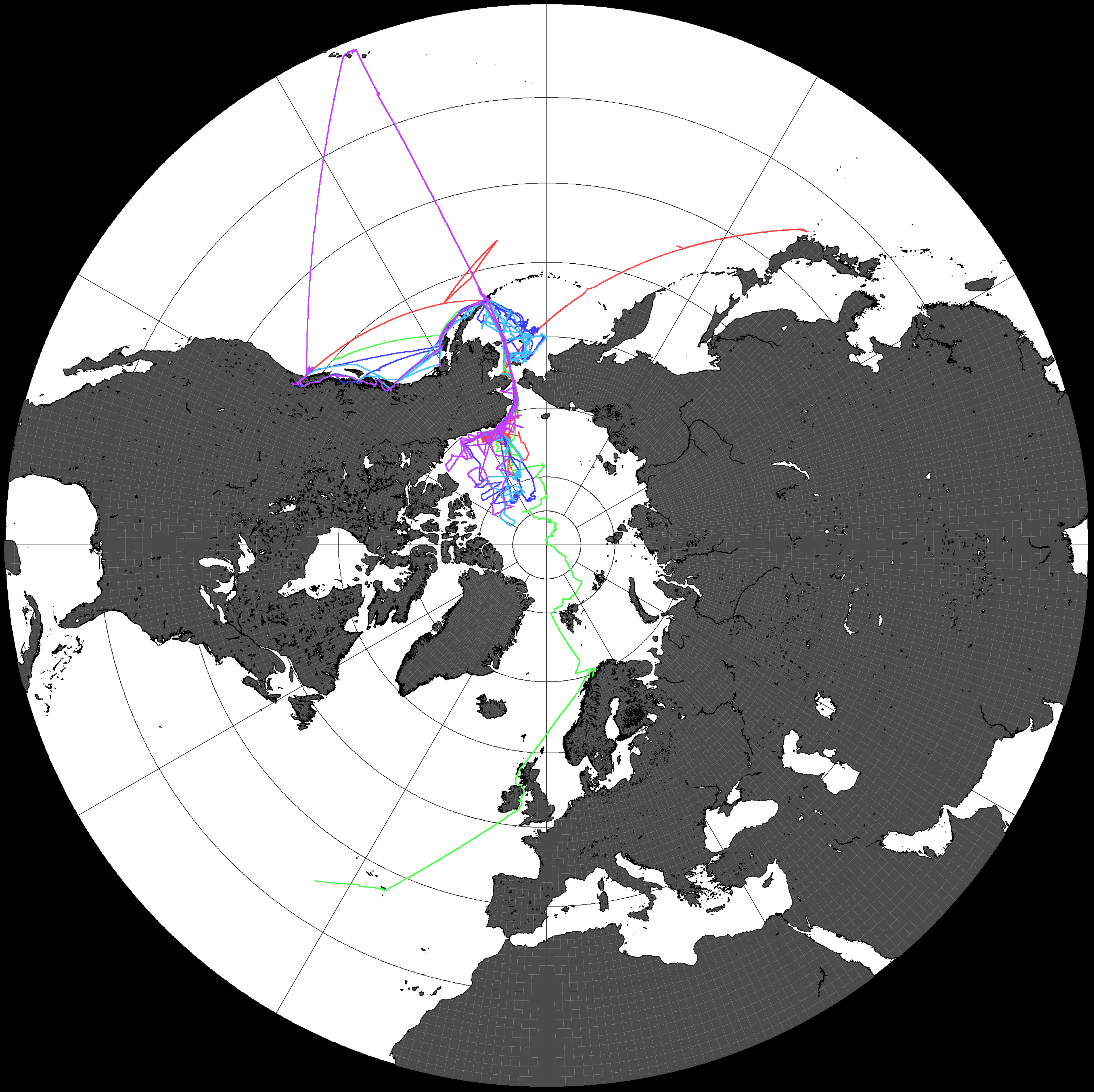
0148-0227/93/93JB-00716$05.00

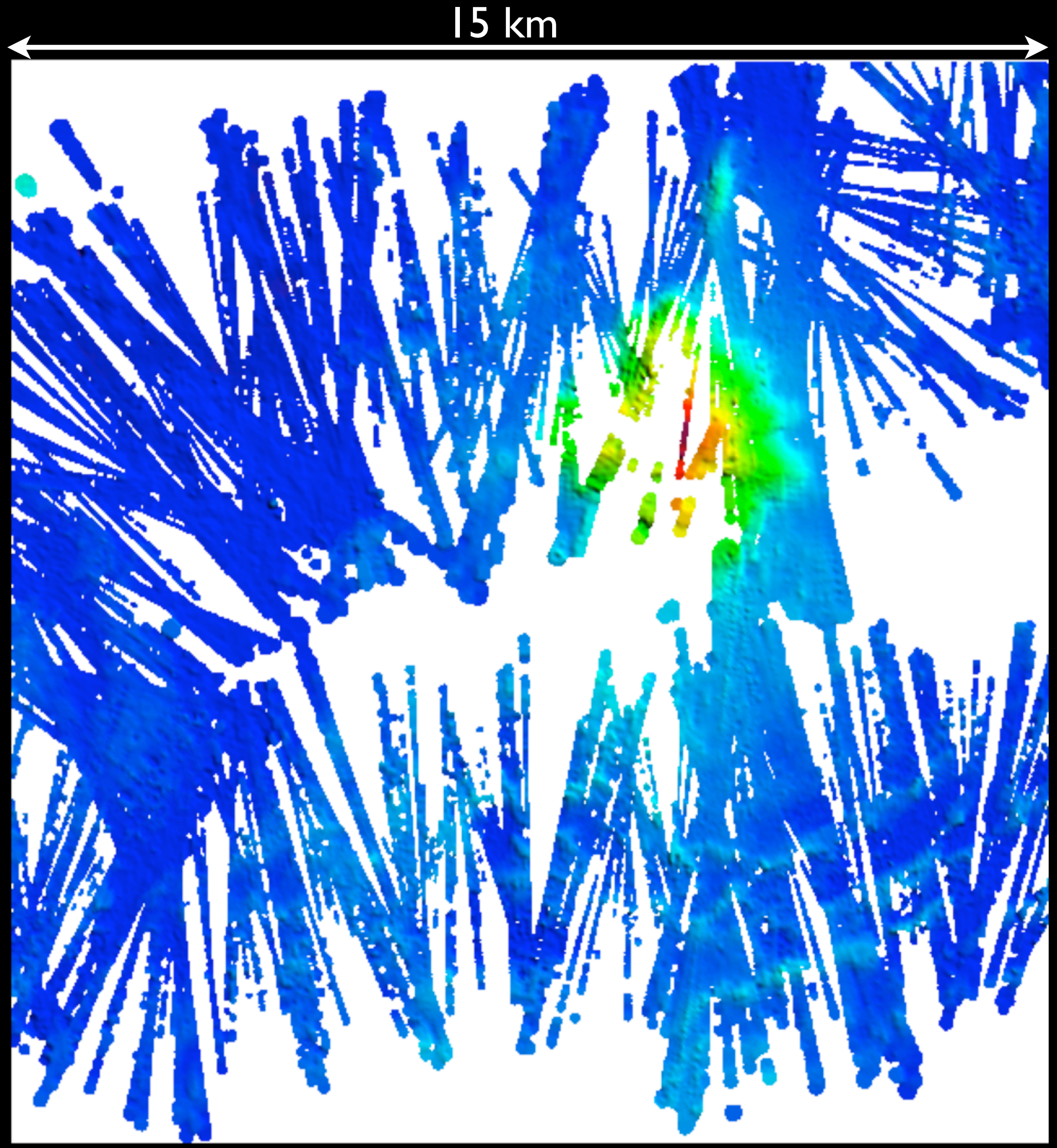
Healy Gravity Data Set

2004, 2005 and 2008-2010

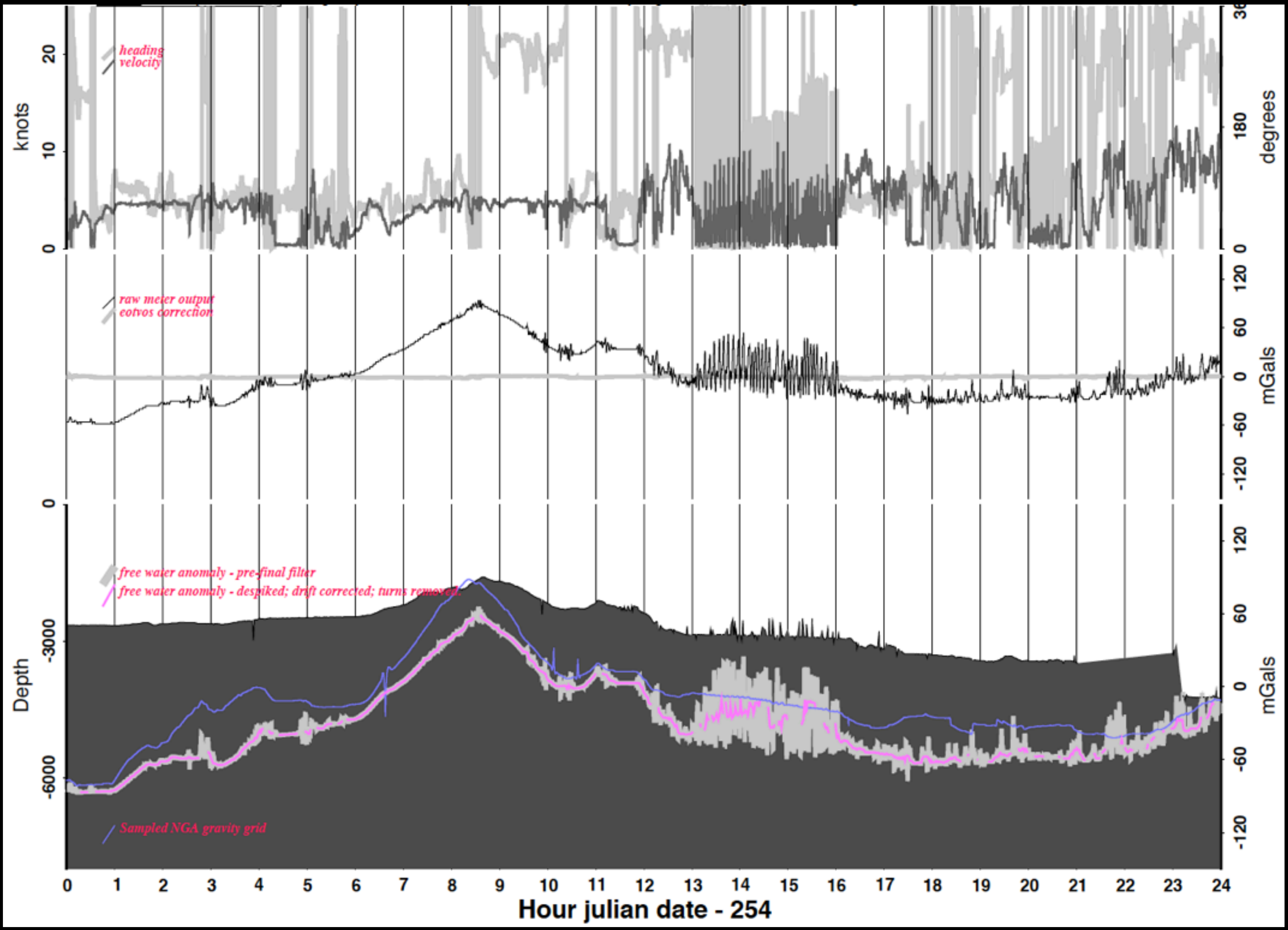


Dual BGM-3 Gravimeters on USCGC Healy

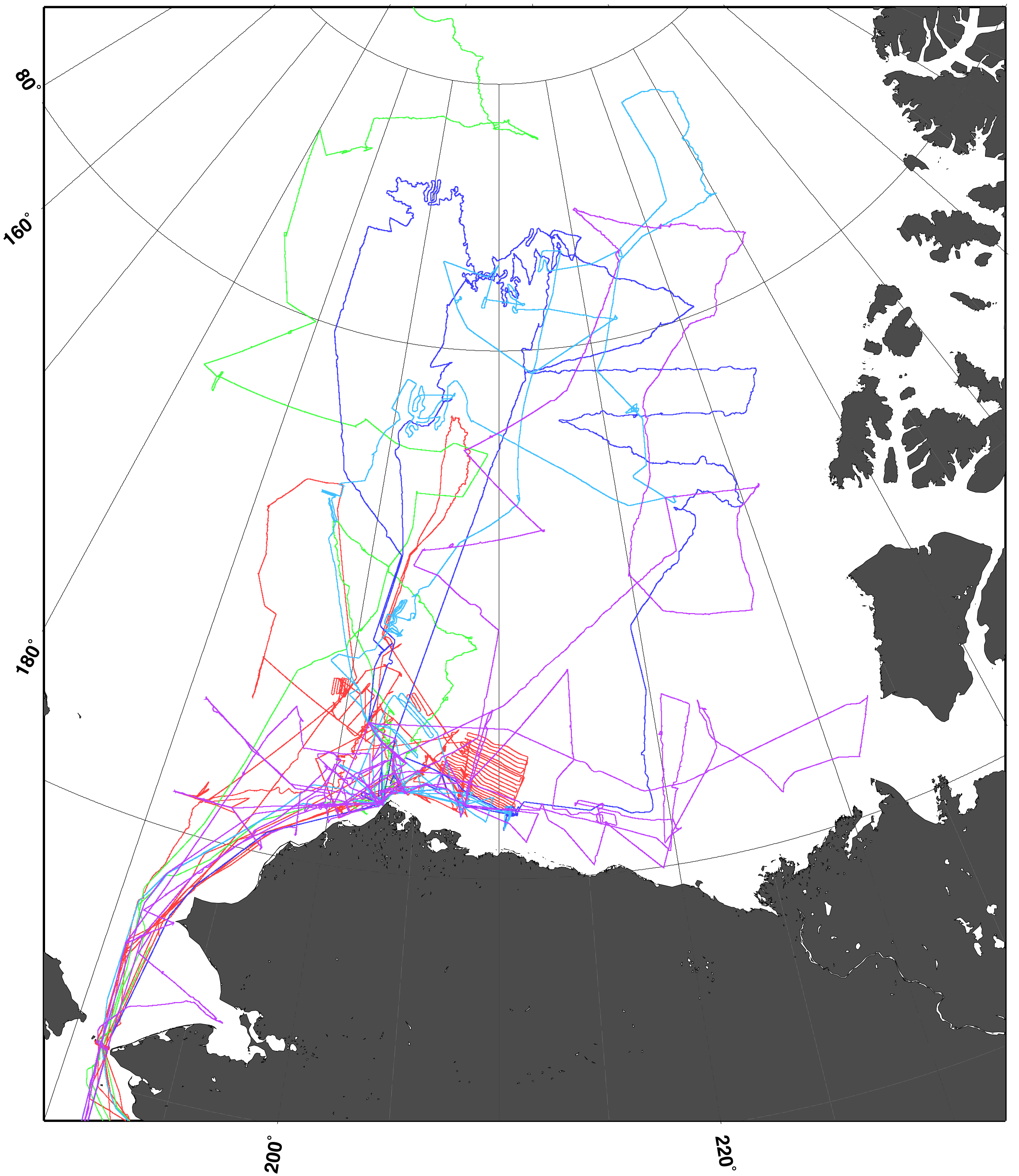
Backing and Ramming



Effect on Gravity Anomaly Data

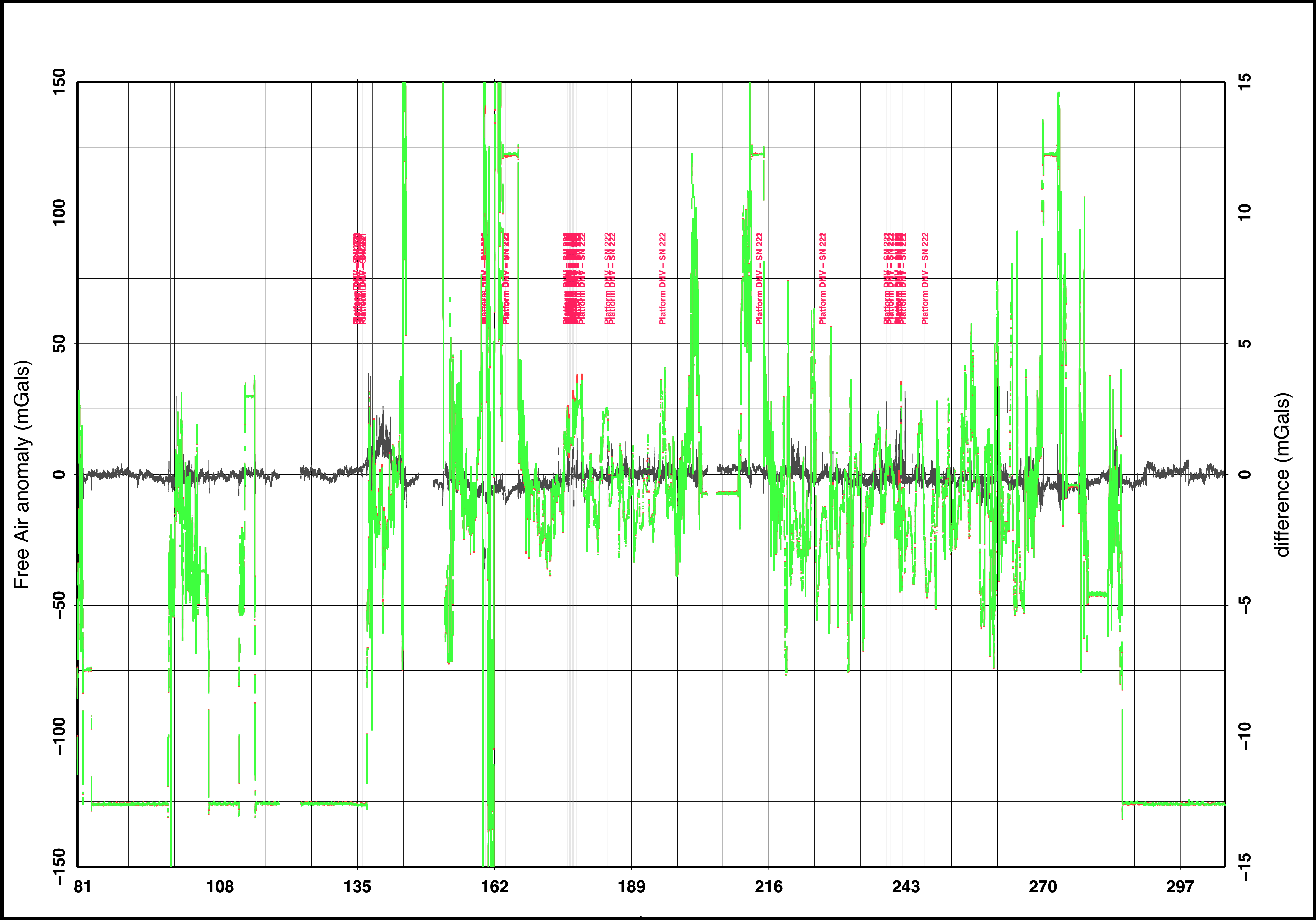


Arctic Gravity



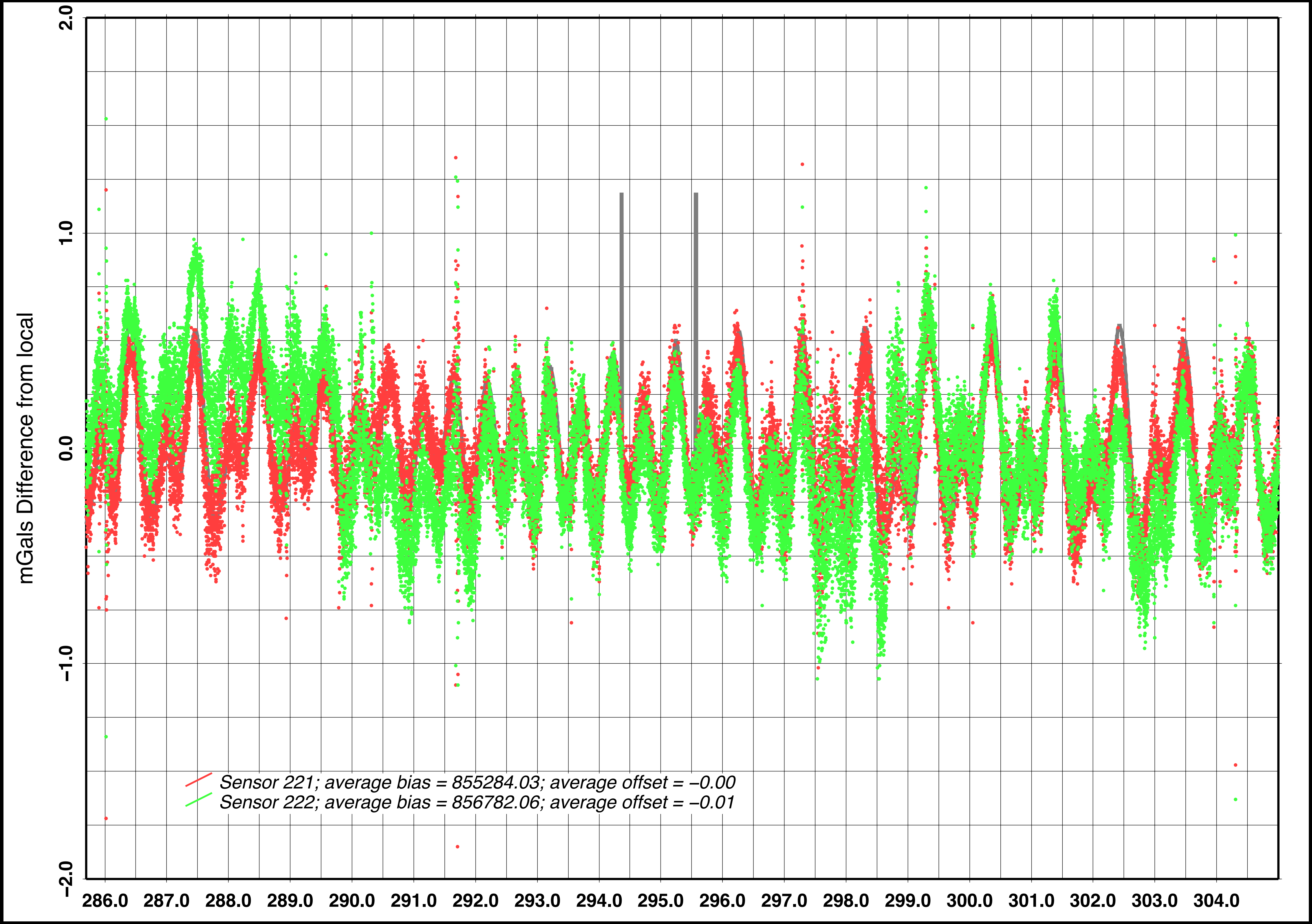
world’s largest crossover data set

USCGC Healy 2010 Season

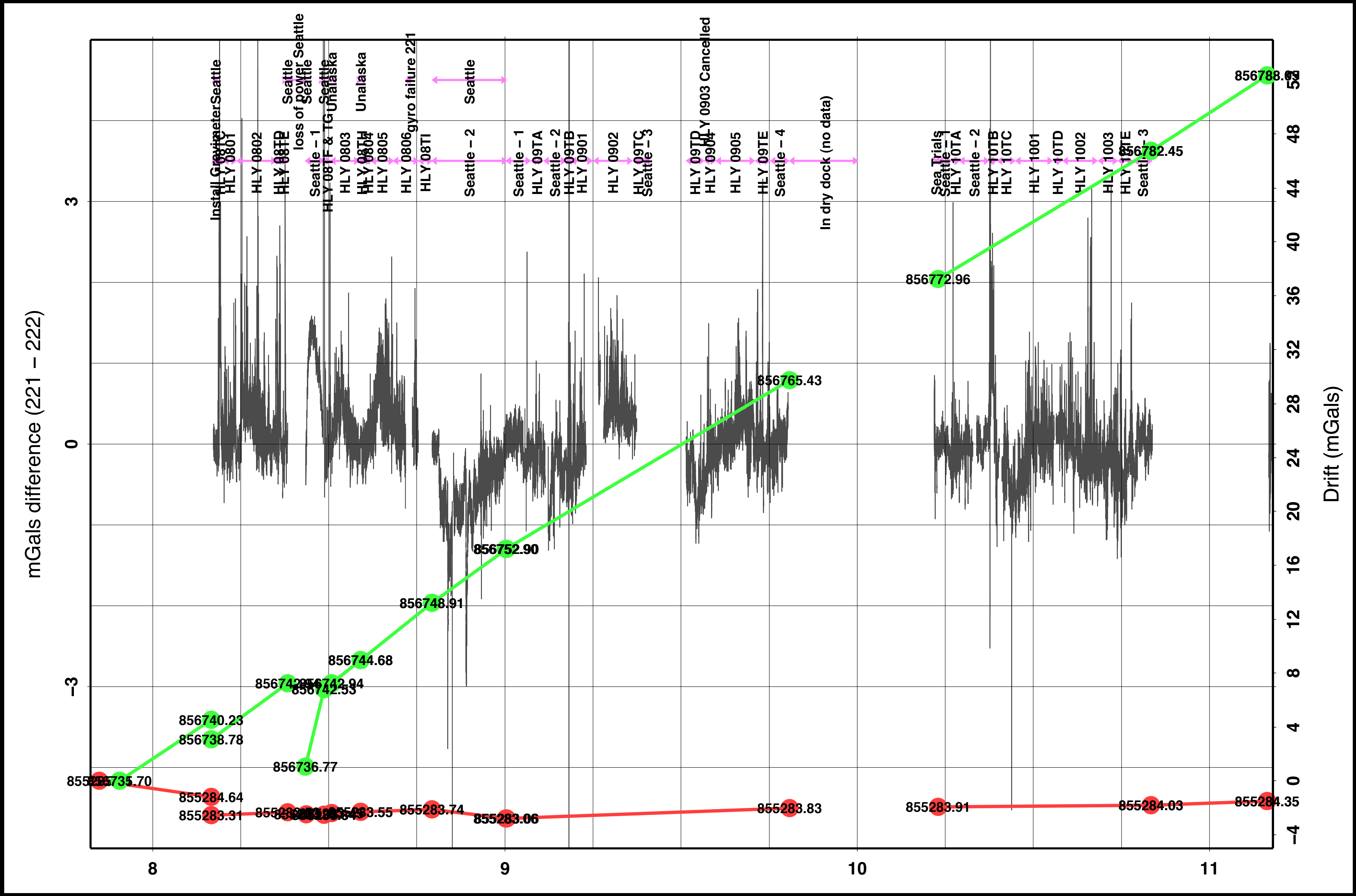


Dockside Gravity Tie

Coast Guard Dock Seattle November 2010

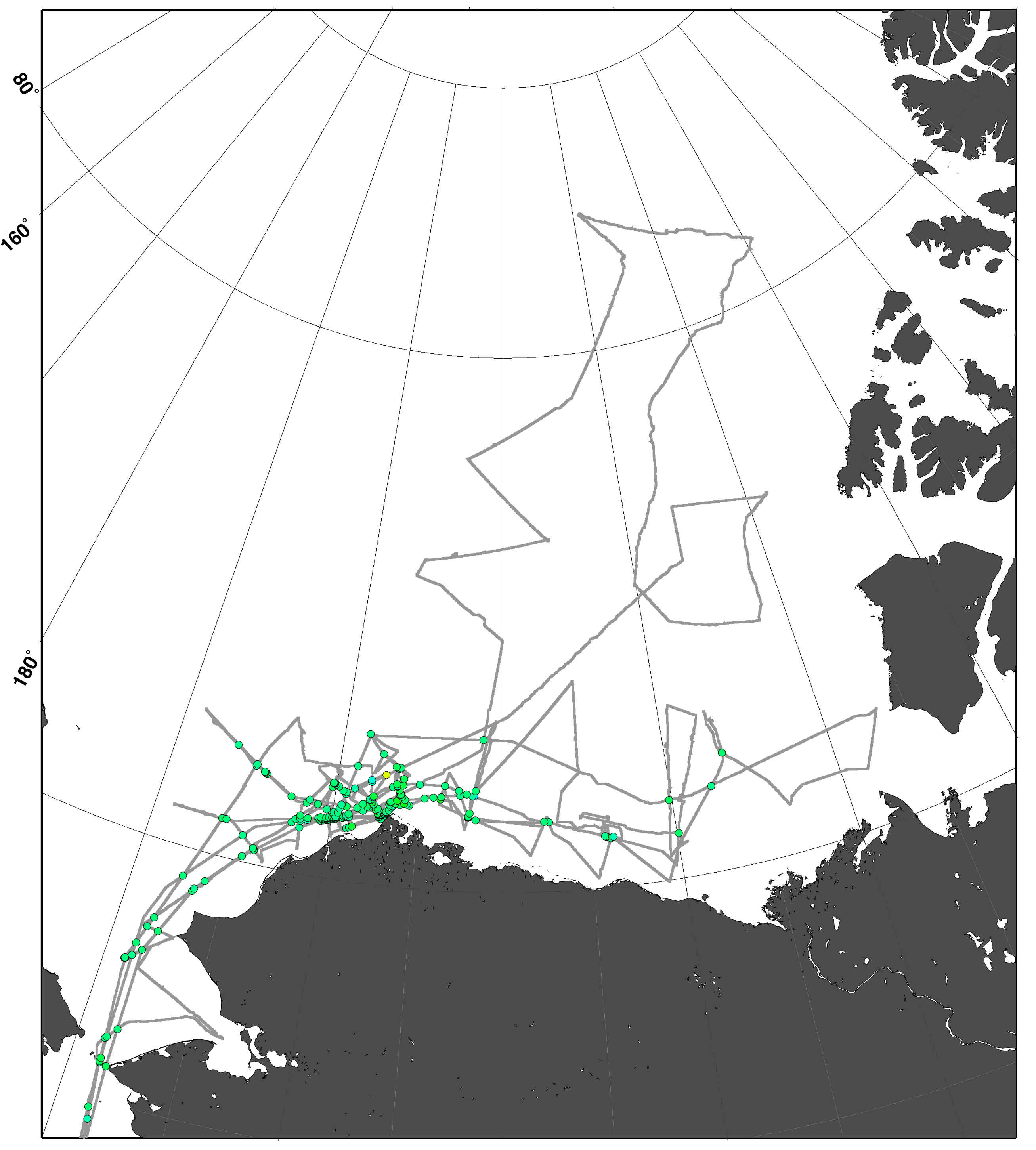


History of Gravimeter Bias



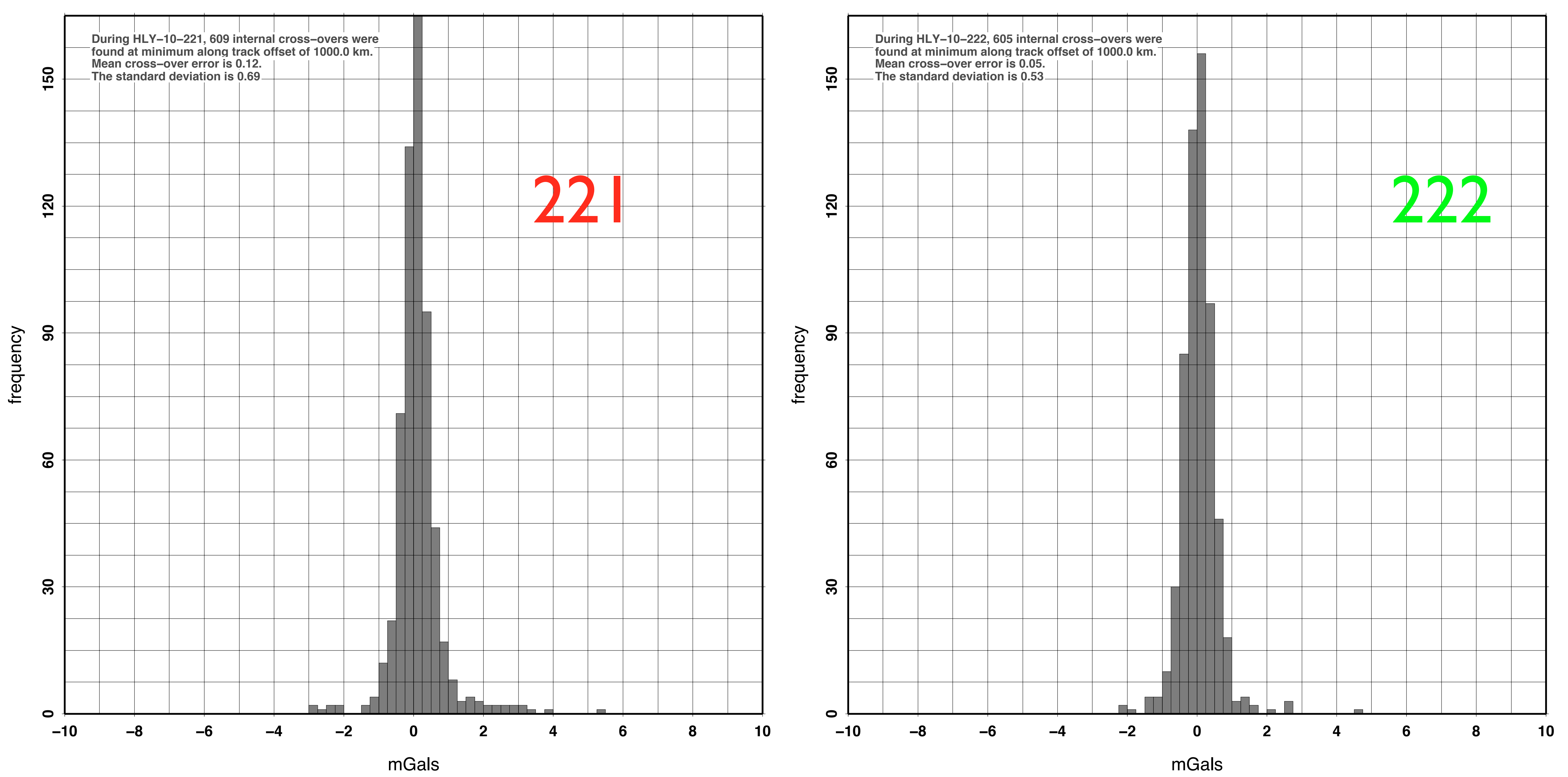
2010 Internal Cross-overs

greater than 1000 km along track separation



Internal gravity anomaly cross-overs

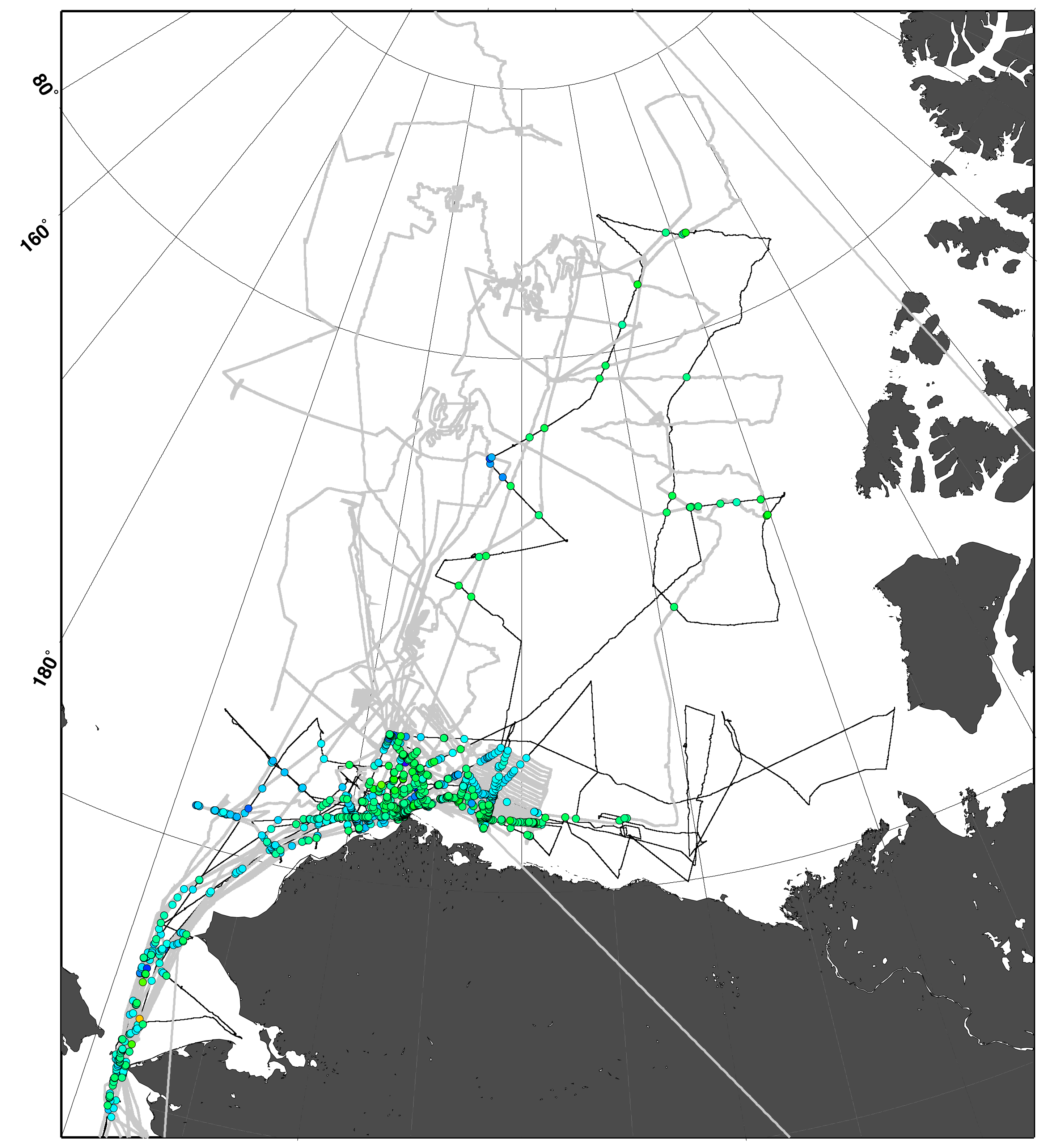
2010 Season



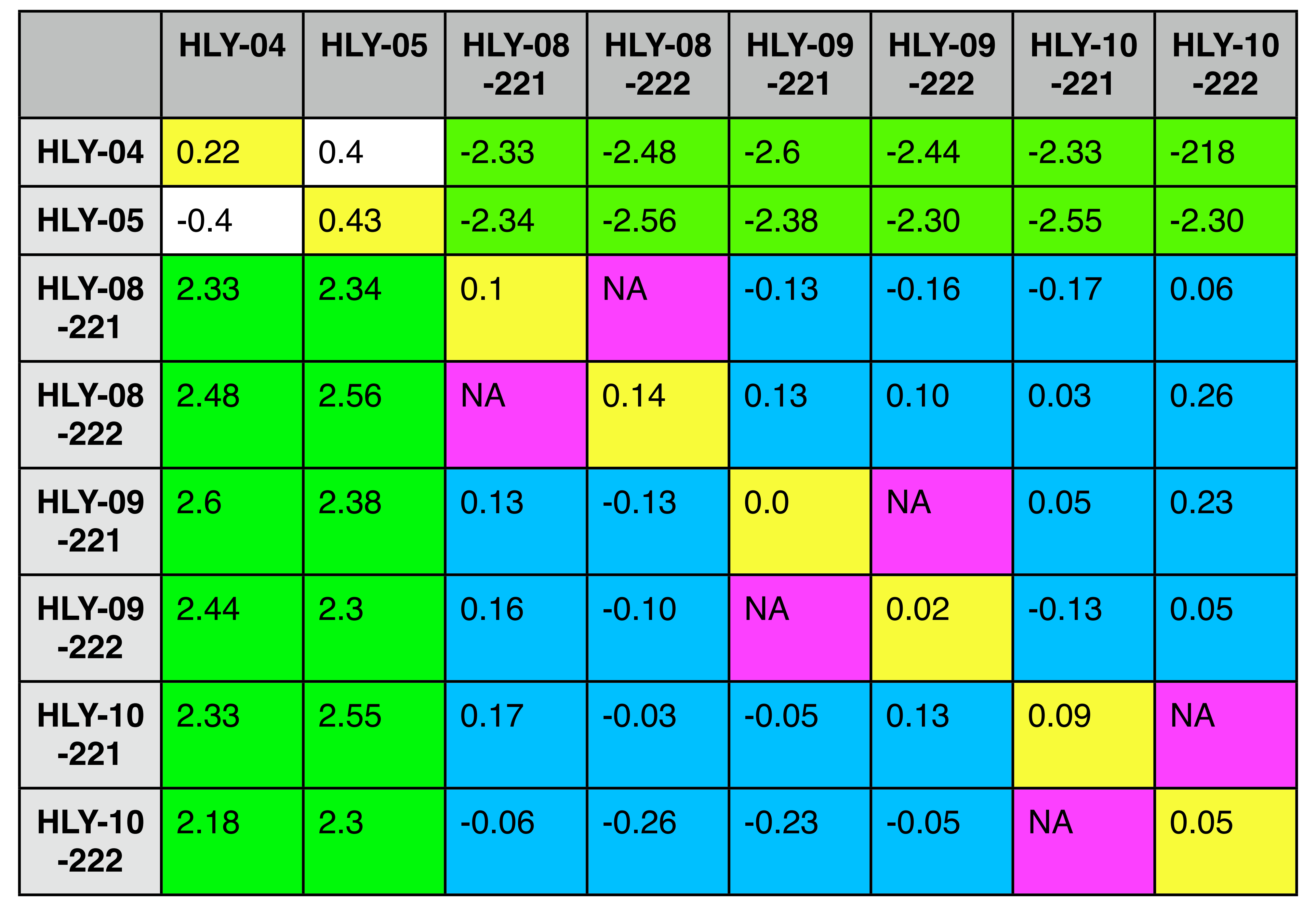
During HLY–10–221, 609 internal cross–overs were found at minimum along track offset of 1000.0 km.
Mean cross–over error is 0.12.
The standard deviation is 0.69

During HLY–10–222, 605 internal cross–overs were found at minimum along track offset of 1000.0 km.
Mean cross–over error is 0.05.
The standard deviation is 0.53

2010 External Cross-overs



Mean Gravity Crossovers

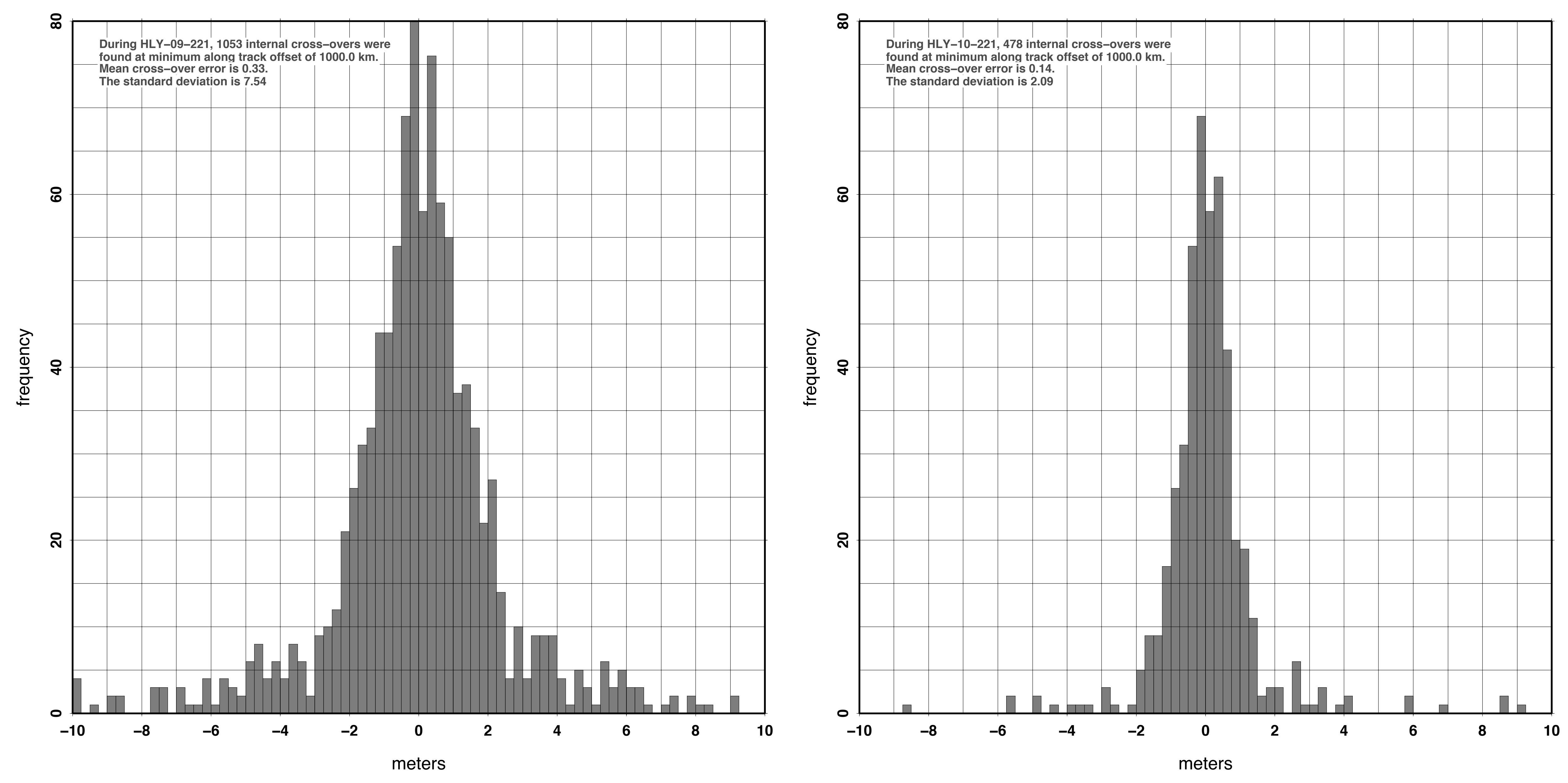


	HLY-04	HLY-05	HLY-08 -221	HLY-08 -222	HLY-09 -221	HLY-09 -222	HLY-10 -221	HLY-10 -222
HLY-04	0.22	0.4	-2.33	-2.48	-2.6	-2.44	-2.33	-218
HLY-05	-0.4	0.43	-2.34	-2.56	-2.38	-2.30	-2.55	-2.30
HLY-08 -221	2.33	2.34	0.1	NA	-0.13	-0.16	-0.17	0.06
HLY-08 -222	2.48	2.56	NA	0.14	0.13	0.10	0.03	0.26
HLY-09 -221	2.6	2.38	0.13	-0.13	0.0	NA	0.05	0.23
HLY-09 -222	2.44	2.3	0.16	-0.10	NA	0.02	-0.13	0.05
HLY-10 -221	2.33	2.55	0.17	-0.03	-0.05	0.13	0.09	NA
HLY-10 -222	2.18	2.3	-0.06	-0.26	-0.23	-0.05	NA	0.05

Internal Bathymetry cross-overs

2009 (SeaBeam 2112) and 2010 Season (EM 122)

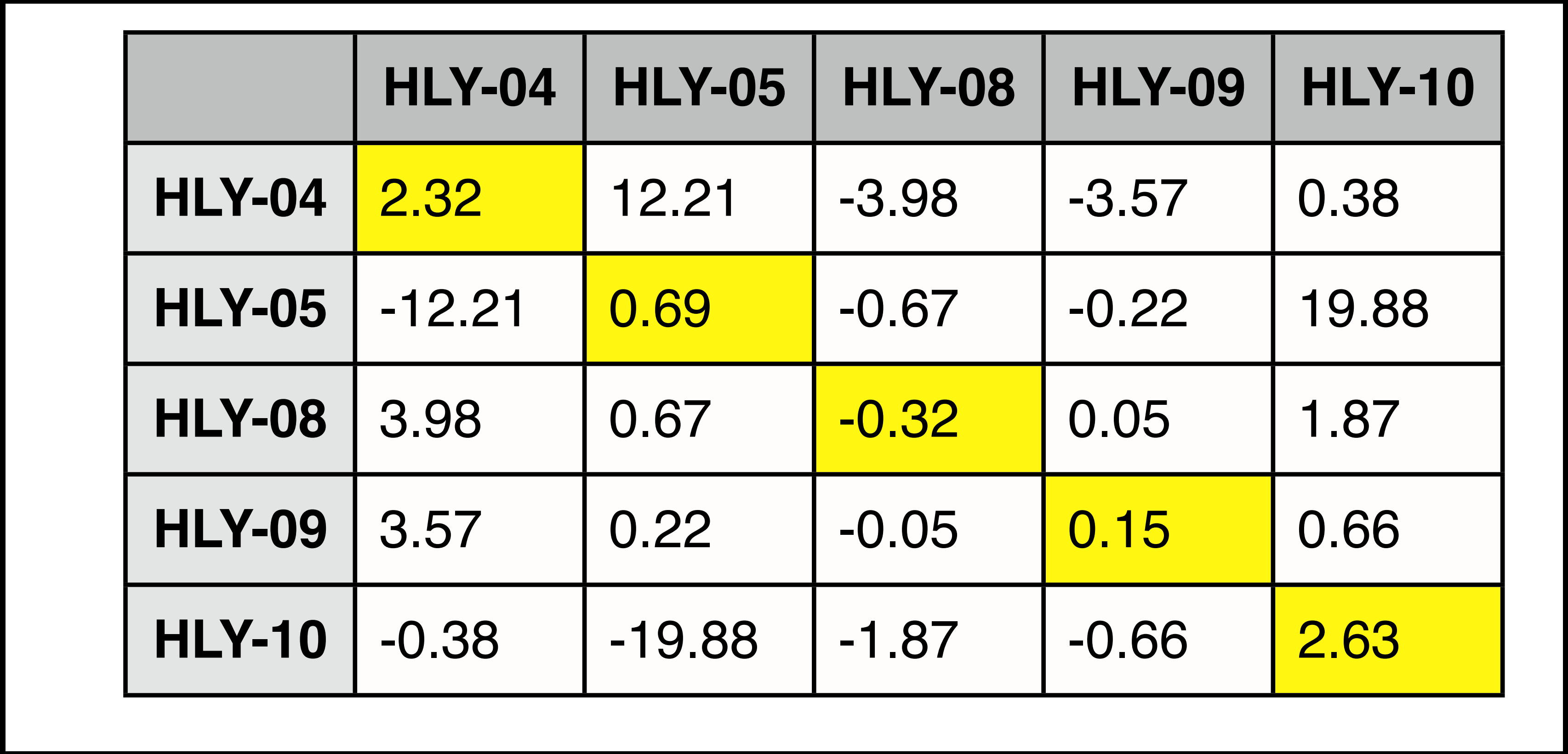
Center Beam Only



During HLY−09−221, 1053 internal cross−overs were found at minimum along track offset of 1000.0 km.
Mean cross−over error is 0.33.
The standard deviation is 7.54

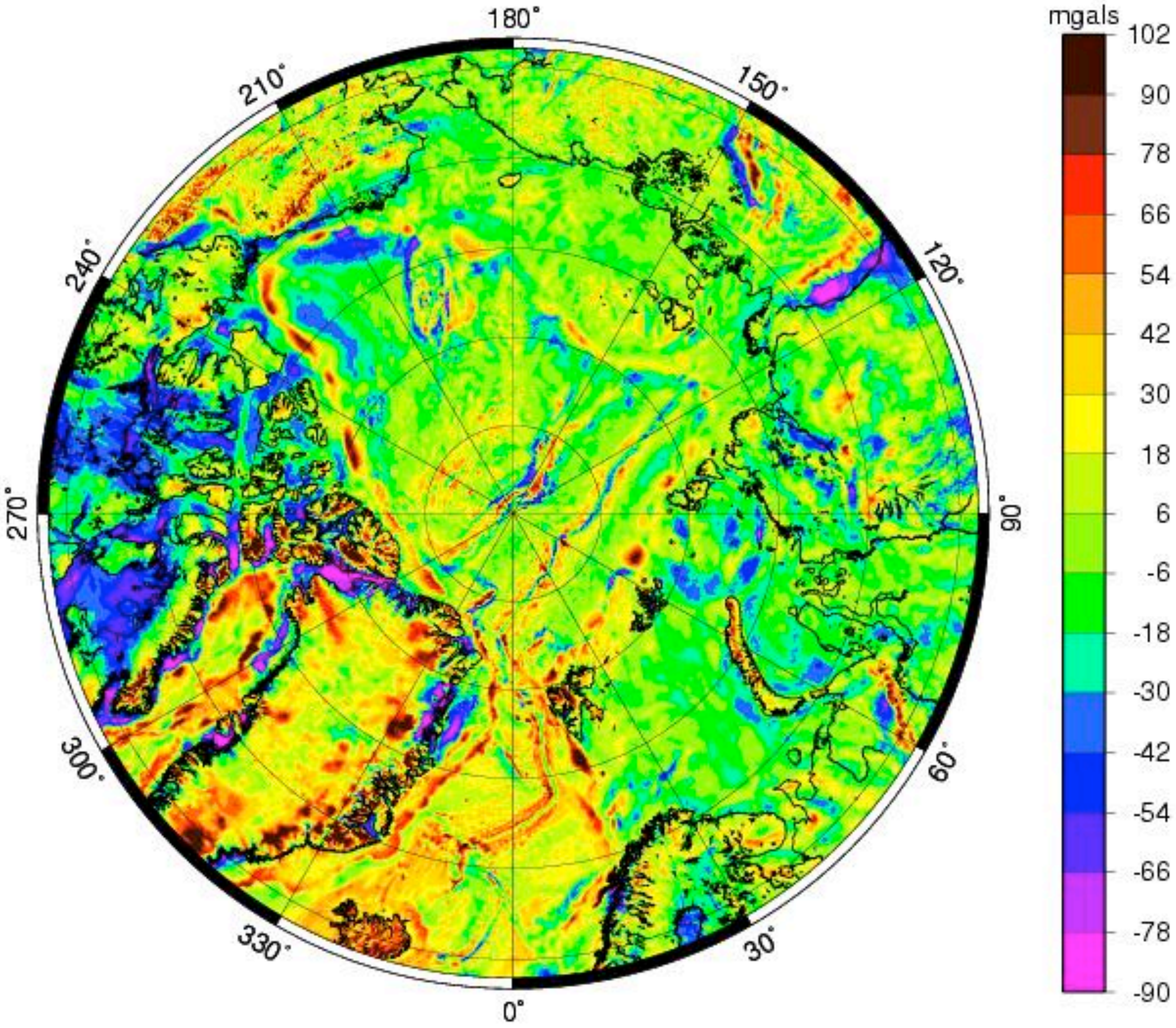
During HLY−10−221, 478 internal cross−overs were found at minimum along track offset of 1000.0 km.
Mean cross−over error is 0.14.
The standard deviation is 2.09

Mean Bathymetry Crossovers



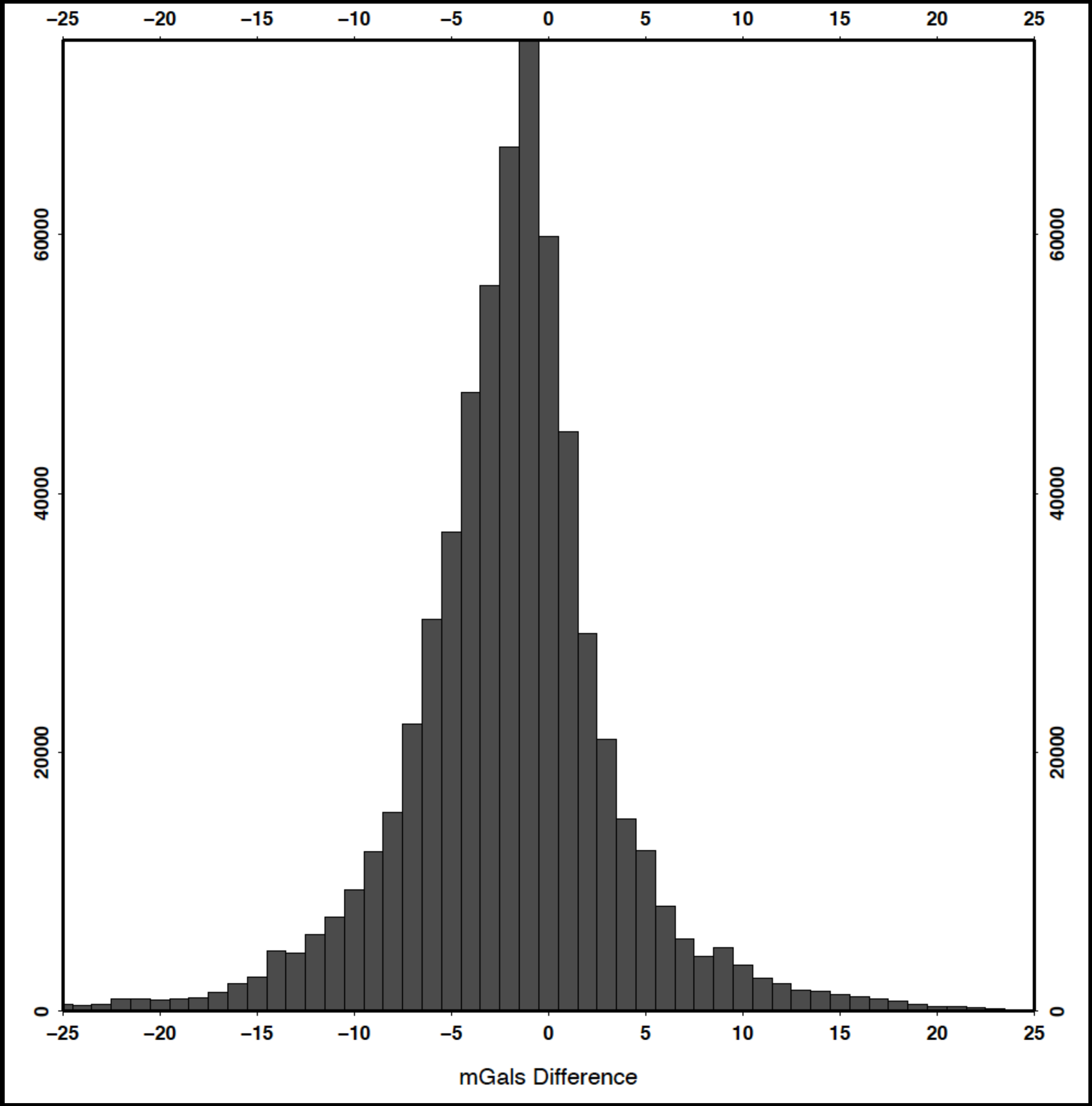
	HLY-04	HLY-05	HLY-08	HLY-09	HLY-10
HLY-04	2.32	12.21	-3.98	-3.57	0.38
HLY-05	-12.21	0.69	-0.67	-0.22	19.88
HLY-08	3.98	0.67	-0.32	0.05	1.87
HLY-09	3.57	0.22	-0.05	0.15	0.66
HLY-10	-0.38	-19.88	-1.87	-0.66	2.63

Arctic Gravity Project Grid



AGP vs Healy

underway gravity anomalies



Mapped differences