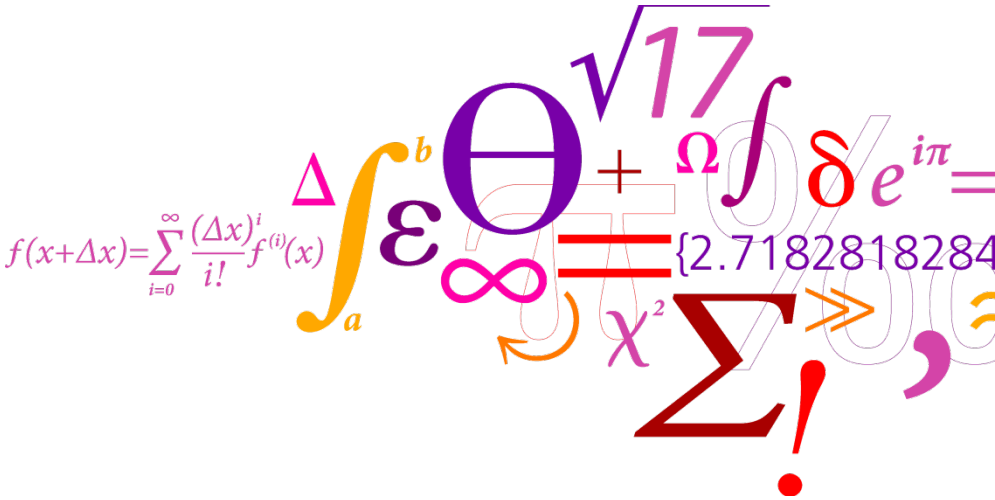
MoU 2012

Mean Sea Surface + Gravity

Ole B. Andersen and P. Knudsen (DTU-SPACE)



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Outline

The NGA – DTU/KMS MoU outline.

- Brief about satellite altimetry
- On Retracking

- The destriping issue.
- Cryosat.

The Baffin Bay

Coastal issues (the Gulf Stream)

Icesat.

The NGA- Appendix XXII

KMS has expressed a willingness to develop a new altimetric Mean Sea Surface/marine gravity field that will benefit NGA's future development of global geopotential models:…….. The newly launched Cryosat-2 satellite is a totally new type of altimeter which is foreseen to greatly improve global marine gravity recovery when data are released in January 2011. Cryosat-2 promises twice the accuracy of conventional altimetry, and will particularly improve polar and coastal regions. The development of the next generation altimetric gravity field will be focused around the following developments:

A Develop methods for gravity field determination from Cryosat-2.

Cryosat-2 will provide sea surface height data with an accuracy of a factor of two compared with conventional satellite altimetry used in previous versions of the DNSC/DTU gravity fields and this improvement should directly improves altimetric gravity fields. Cryosat-2 carries a novel delay-doppler interferometric altimeter and the methods must be developed to process, handle and integrate data from this satellite.

- Design and implement appropriate retrackers for the Cryosat-2 data (LRM data)
- Update Cryosat-2 with state of the art range corrections (i.e.,DTU10ocean tide model)
- Improve methods for marine gravity field prediction at higher spatial resolution
- Fine-tune handling, editing and filtering of Cryosat-2 data for stable gravity field prediction

MoU Continued

(B) Improved coastal regions.

Coastal regions must be handled separately. Cryosat-2 offers Syntetic Apertur Radar (SAR) data with 300 meters resolution in coastal regions to complement the LRM mode data for the oceans. ICESat laser altimetry is available at 700 meters (averaged) resolution (but at sparse ground tracks). The combination of these two sensors will improve gravity field in coastal regions.

- Design appropriate retrackers for the Cryosat-2 SAR data
- Improve Cryosat-2 and ICESat with state of the art range corrections
- Test of filtering and editing of Cryosat-2 and ICESat in coastal regions.
- Integrate Cryosat-2, ICESat and conventional Geodetic Mission altimetry in coastal regions.
- Investigate methods for improved gravity field determination in coastal regions
- Validation with marine gravity data.

(C) Improved next generation high resolution global marine gravity field.

Develop a new altimetric marine gravity field combining new and conventional GM altimetry through completing

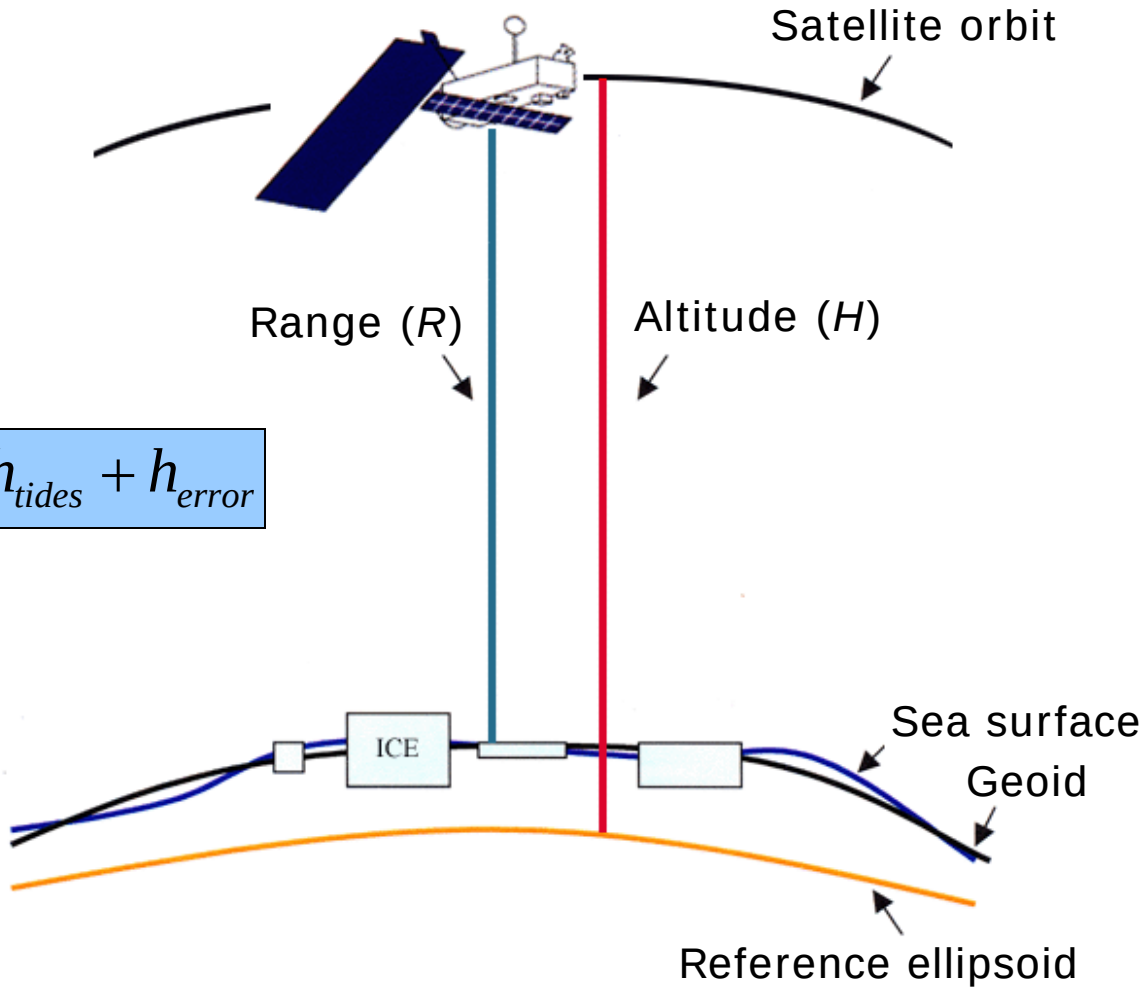
- Integrate ocean and coastal Cryosat SAR and coastal ICESat data from section A and B
- Derive global marine gravity at 1 arc minute resolution by integrating with GM altimetry.
- Provide NGA with the new high resolution global marine gravity field on 1 arc minute resolution.
- Validating the new marine gravity field using gravity observations from naval vessels.

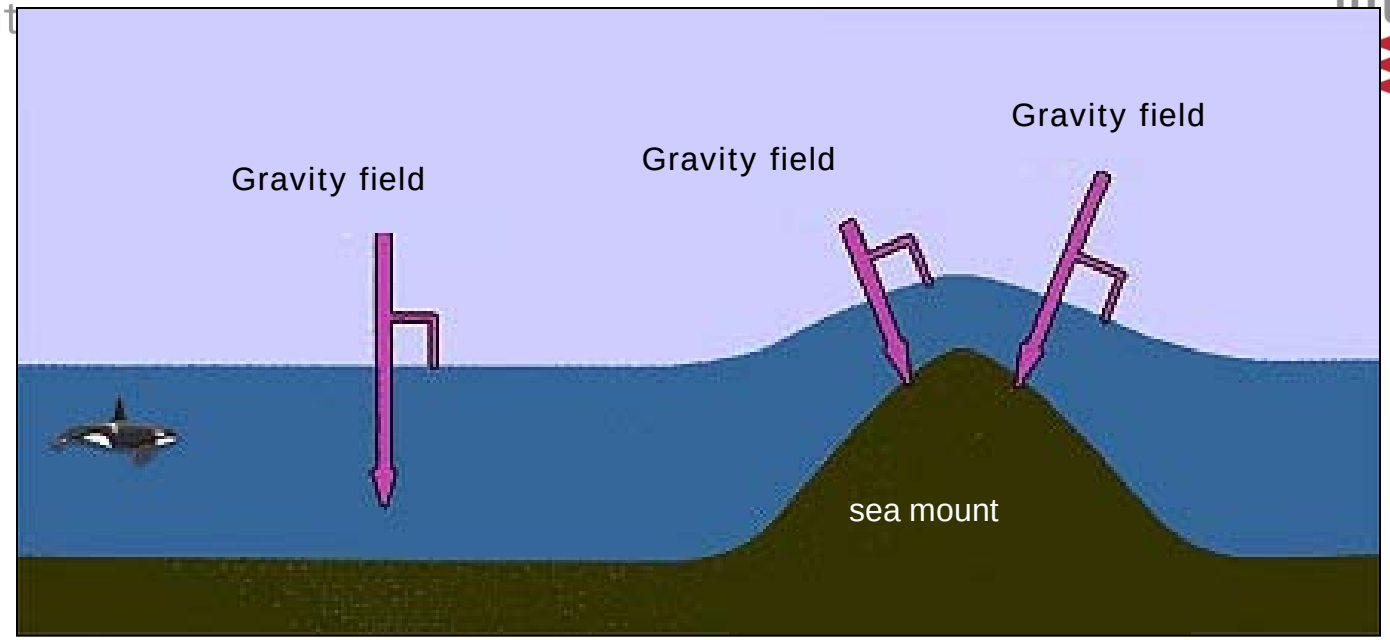

Cryosat
Jason-1
Envisat
ERS
Spot
GFO
TOPEX/POSEIDON

Altimetry – basic principles

$$h_{surface} = H - R$$

$$h_{ssh} = h_{geoid} + h_{DT} + h_{IB} + h_{tides} + h_{error}$$





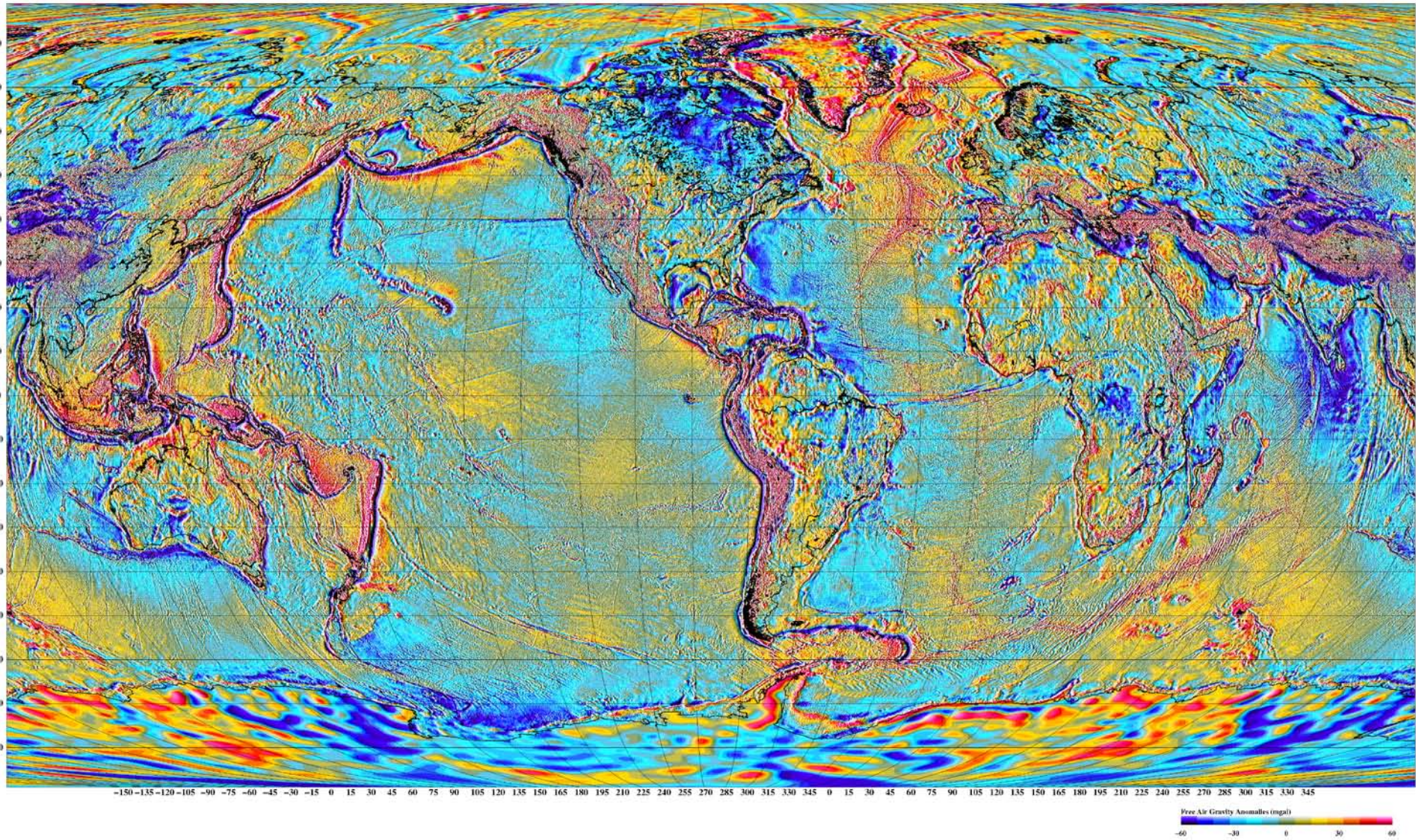
The Sea surface height mimicks the geoid
MSS = Geoid + Mean Dynamic Topography (MDT)

Map of the distribution of mass within the earth: density changes and bathymetry -> Bathymetry prediction.

Gravity from MDT corrected MSS (=Geoid)

$$\Delta g = L_{\Delta g}(T) = -\frac{\partial T}{\partial r} - 2\frac{T}{r} \approx -\frac{1}{\gamma}\left(\frac{\partial N}{\partial r} + 2\frac{N}{r}\right)$$

DNSC 08 / DTU10 Gravity



NGA, Feb 2012

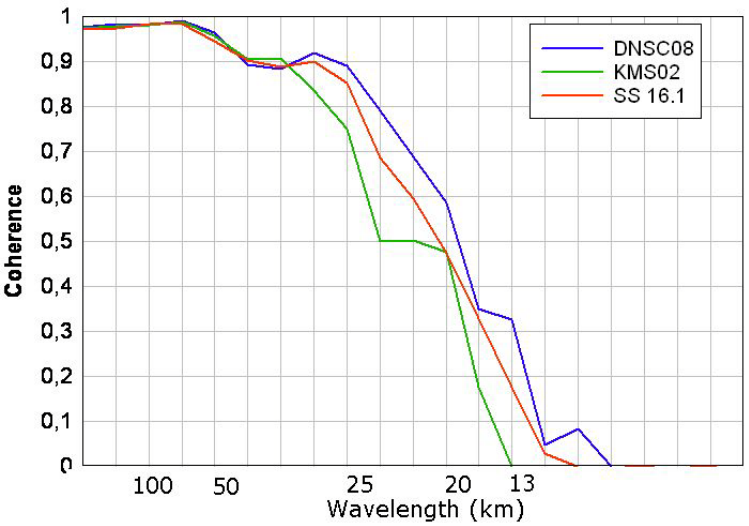
DNSC08 -> DTU 10 improvements

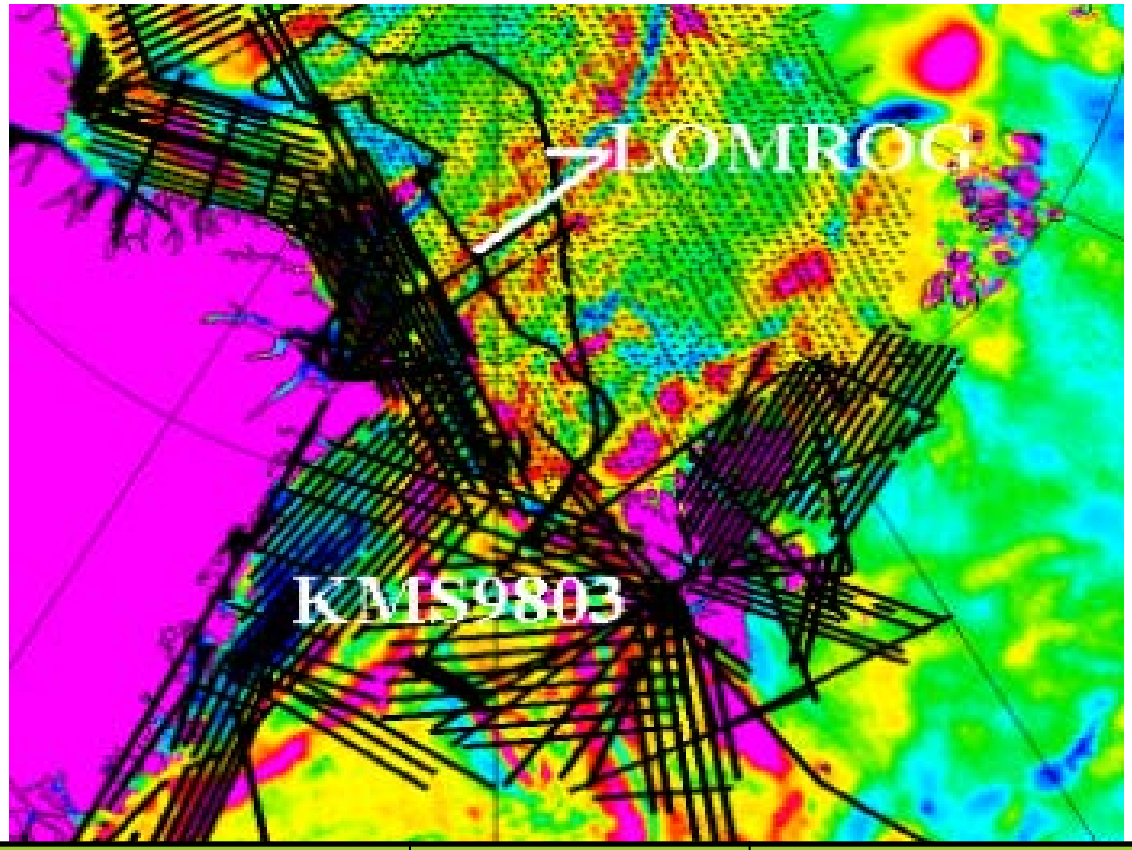
Generally four ways of improving data:

1. More data
2. Better accuracy of sea surface height data
3. Improved prediction methods / filtering.
4. Better reference (EGM2008)

DNSC08-DTU10 improved

- Destriping of EGM (better reference – remove restore)
- Additional 8 epochs of ICESat in Arctic Ocean. (more data)
- Improved filtering (more correctly correcting error in DNSC08)
- We did not improve (quality of data – did not update corrections)

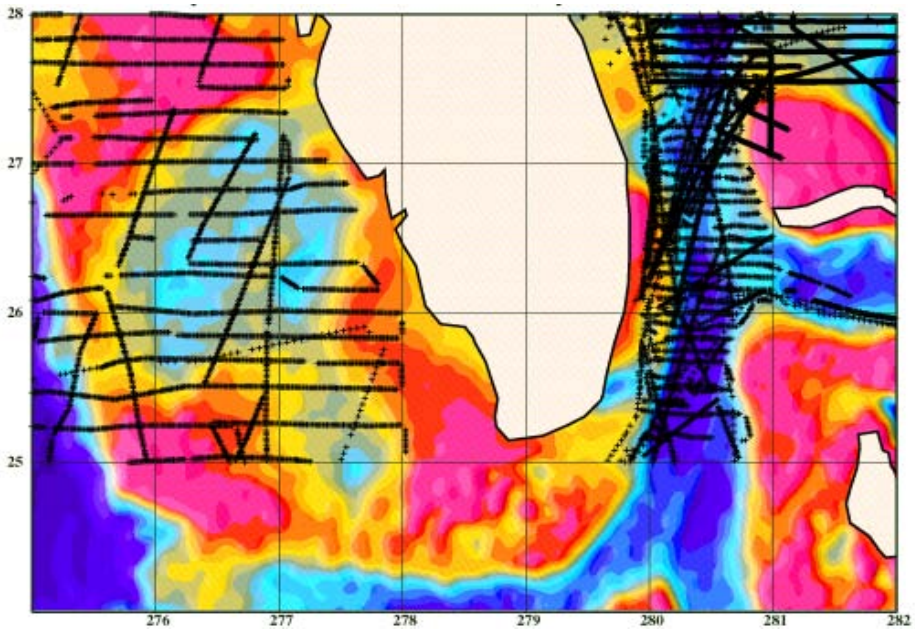




900 points	Std (mGal)	Max (mGal)
KMS02	9.4	51.2
Laxon and McAdoo (97)	7.2	46.2
ArcGP (01-06)	5.8	34.4
SS 16.1 / 18.1	8.2 / 5.9	44.9 / 37.4
DSNC08 /DTU10	4.1 / 4.0	24.0 / 24.1

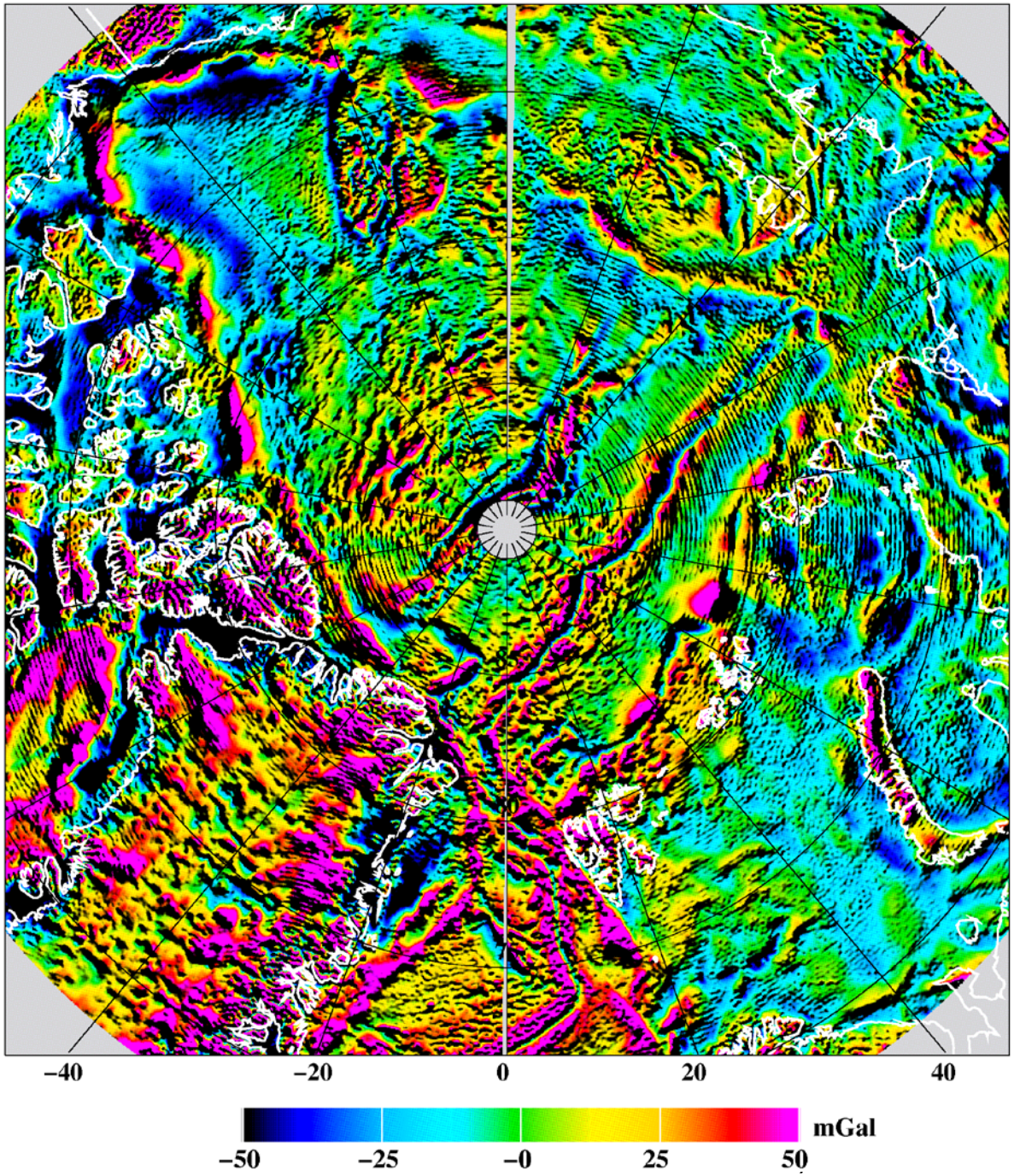
Florida

The importance of EGM2008

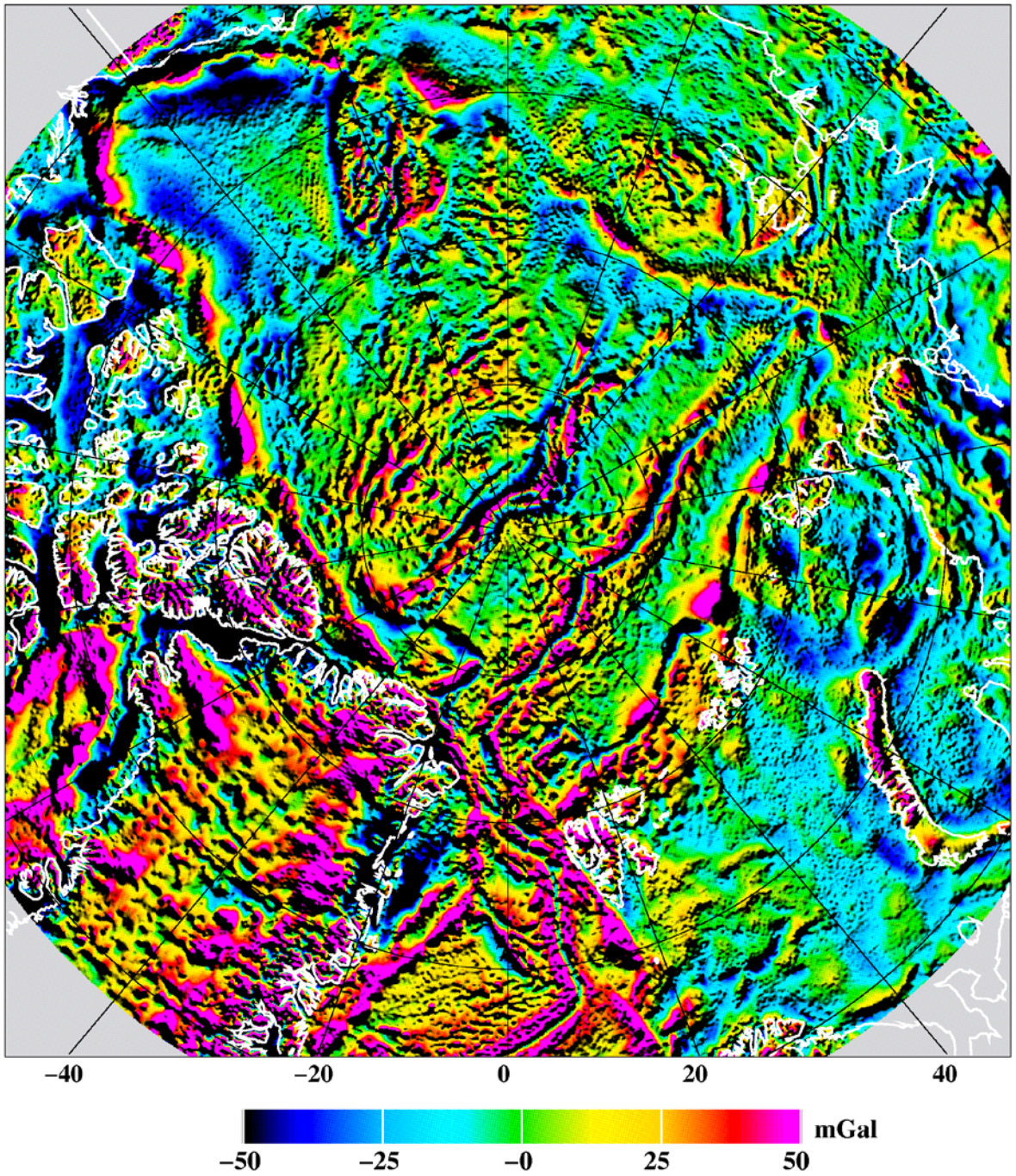


10100 marine Obs	Std Dev (mGal)
KMS02	4.99
SS 16.1	5.89
DNSC08/DTU10	**2.78 /2.71**

Arctic Straiation in EGM2008

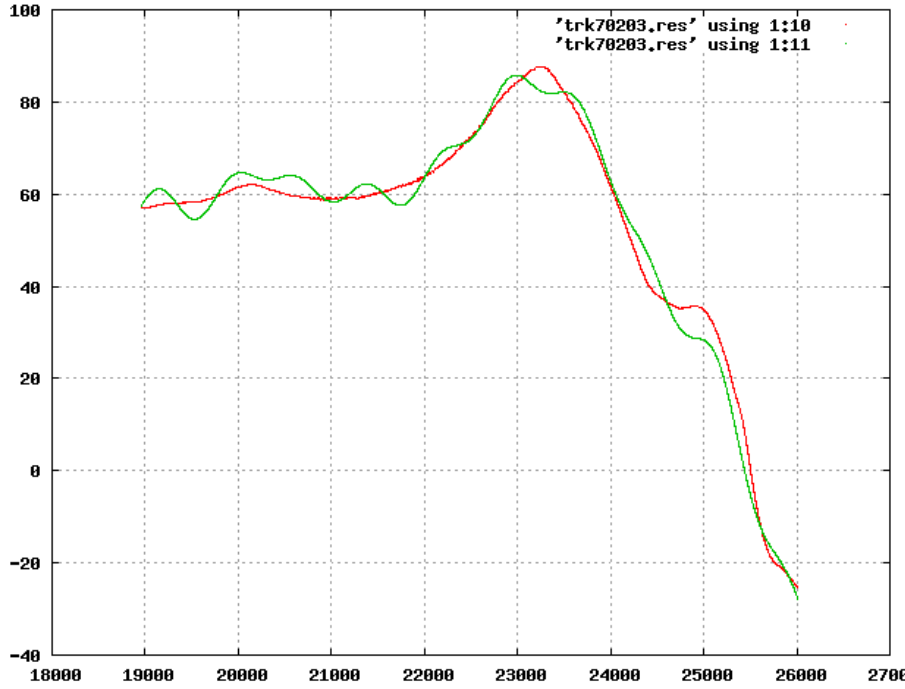


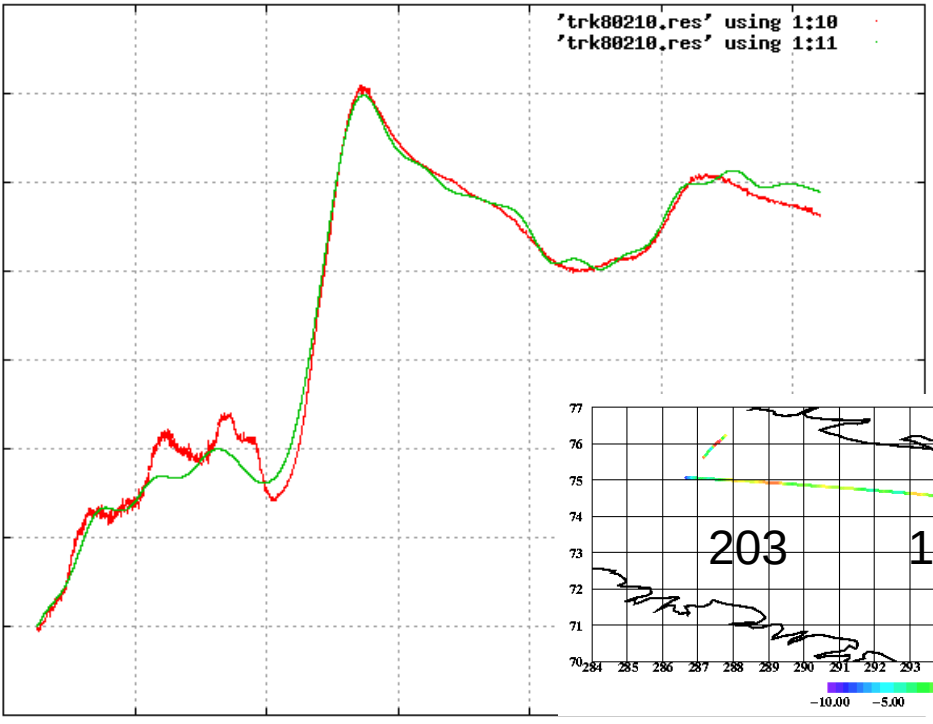
Can be ”removed” by re-interpolation from 5 minute grid

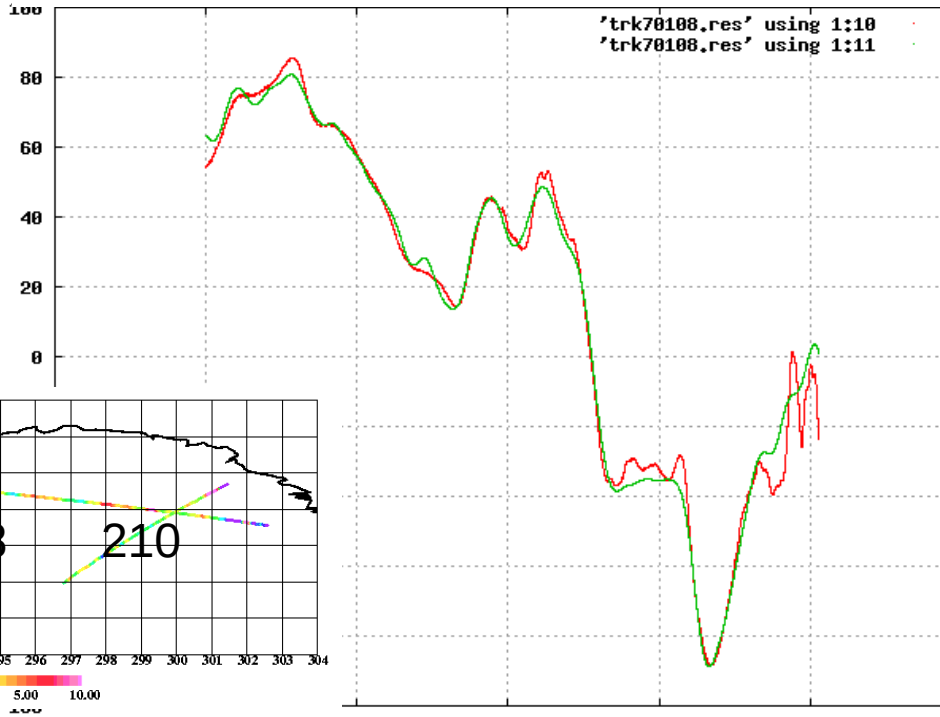


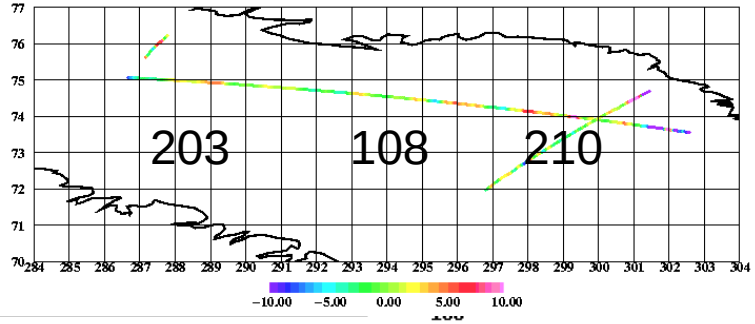
Some early indications.

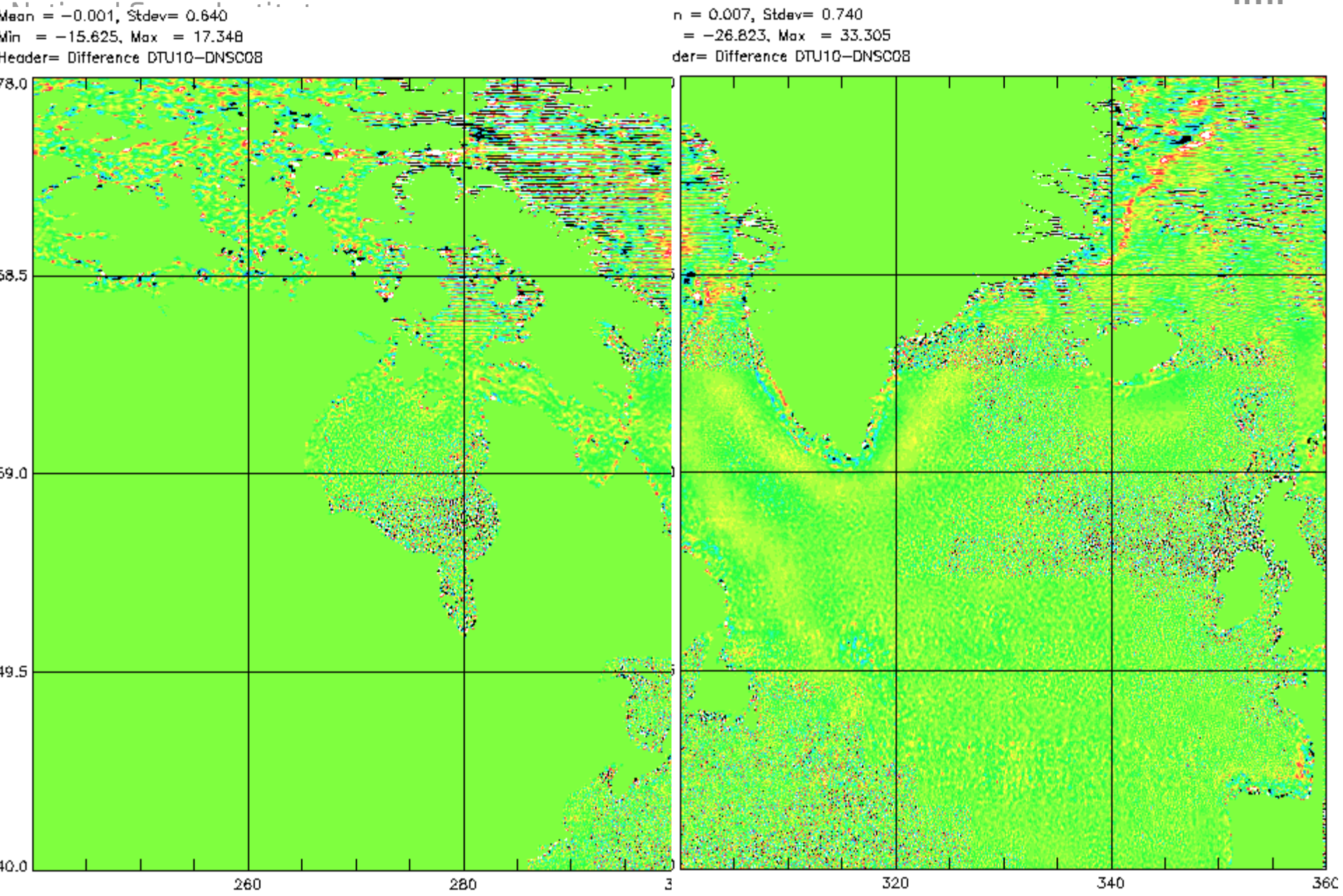
Gravity in the Baffin Bay (green DNSC08).



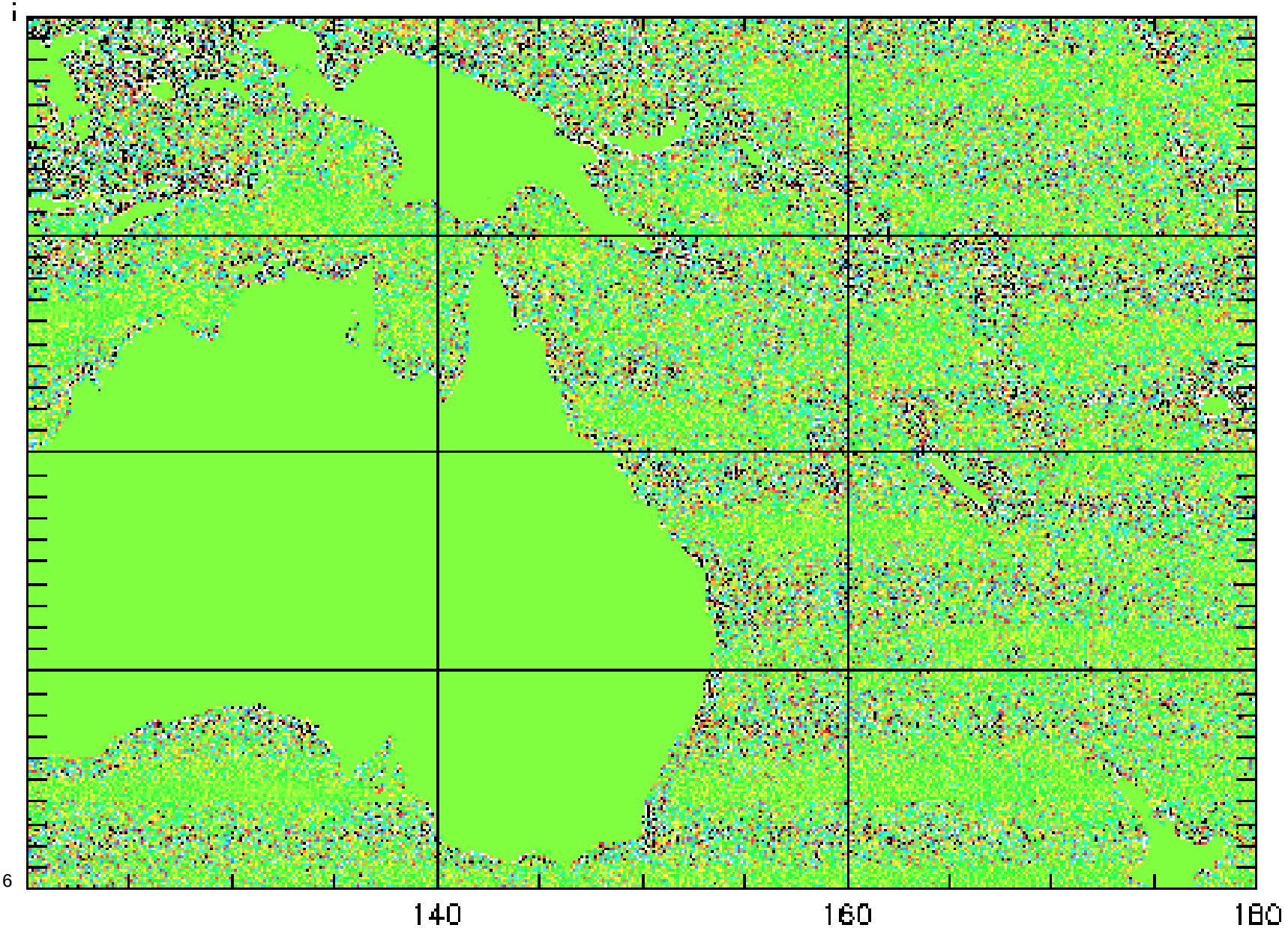


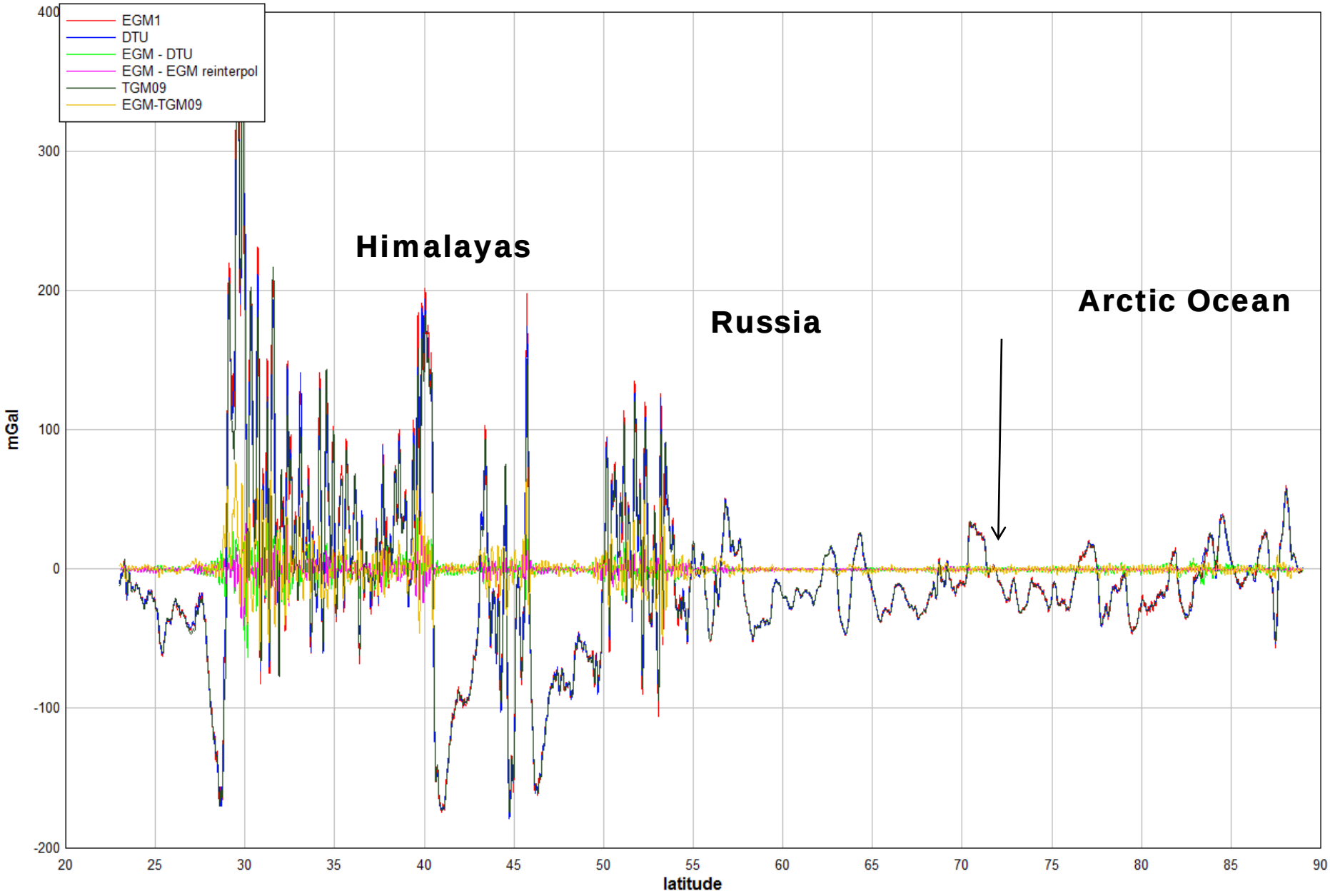





Mean = −0.001, Stdev= 0.640
Min = −15.625, Max = 17.348
Header= Difference DTU10−DNSC08
n = 0.007, Stdev= 0.740
= −26.823, Max = 33.305
der= Difference DTU10−DNSC08
78.0
68.5
59.0
49.5
40.0
260
280
320
340
360

The two-fold problem in DNSC08




EGM1
DTU
EGM - DTU
EGM - EGM reinterpol
TGM09
EGM-TGM09
Himalayas
Russia
Arctic Ocean
mGal
latitude
400
300
200
100
0
-100
-200
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90

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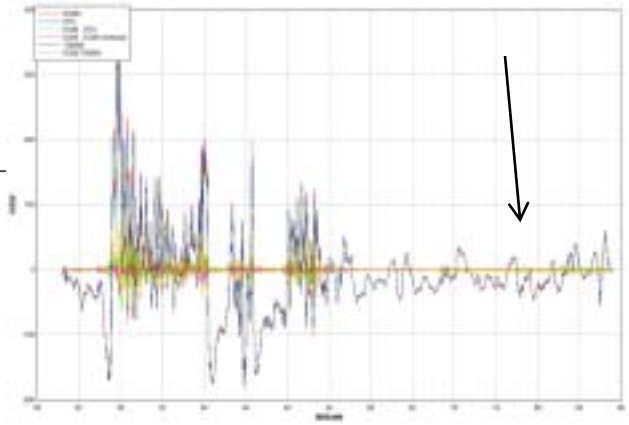
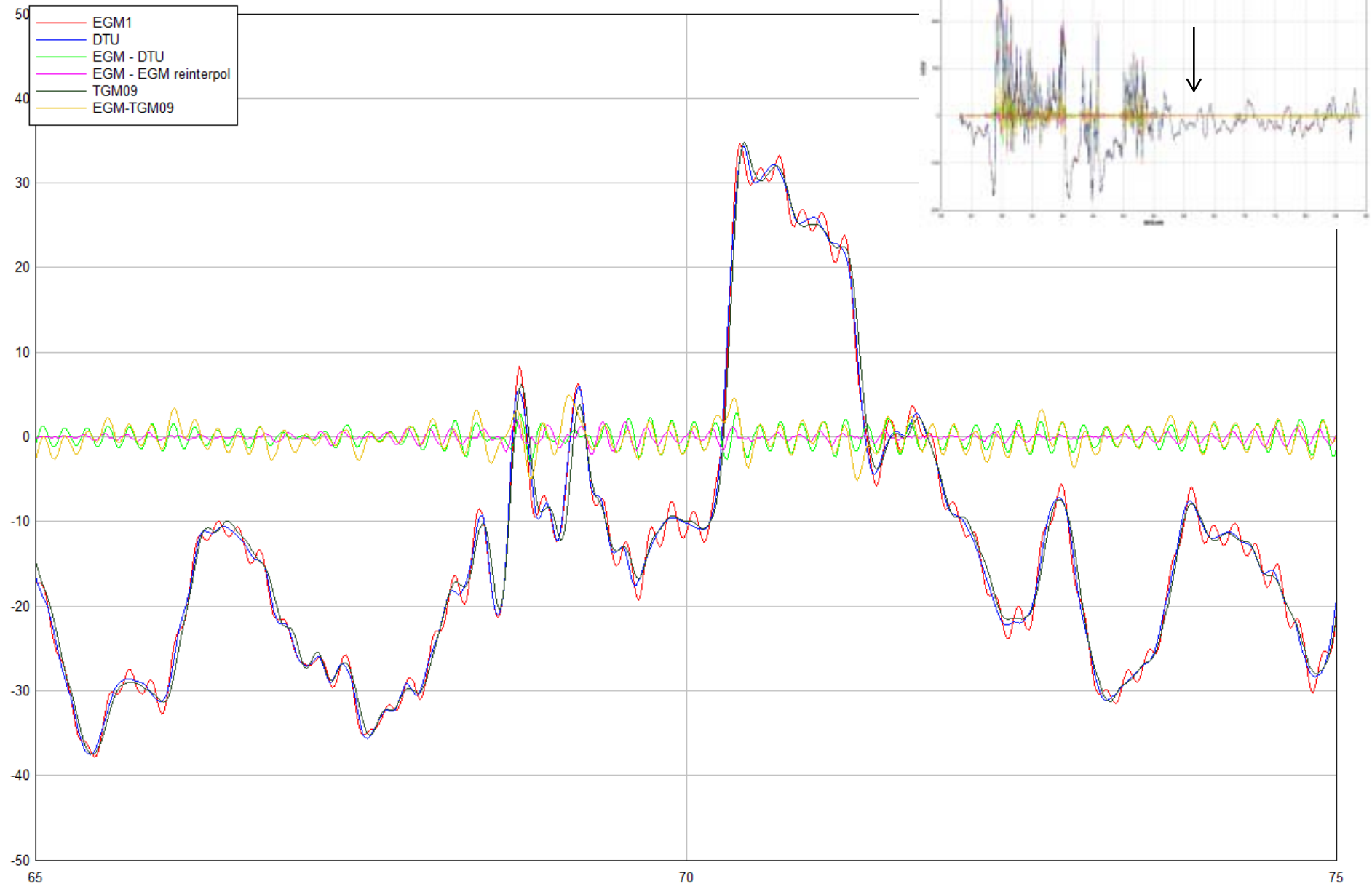
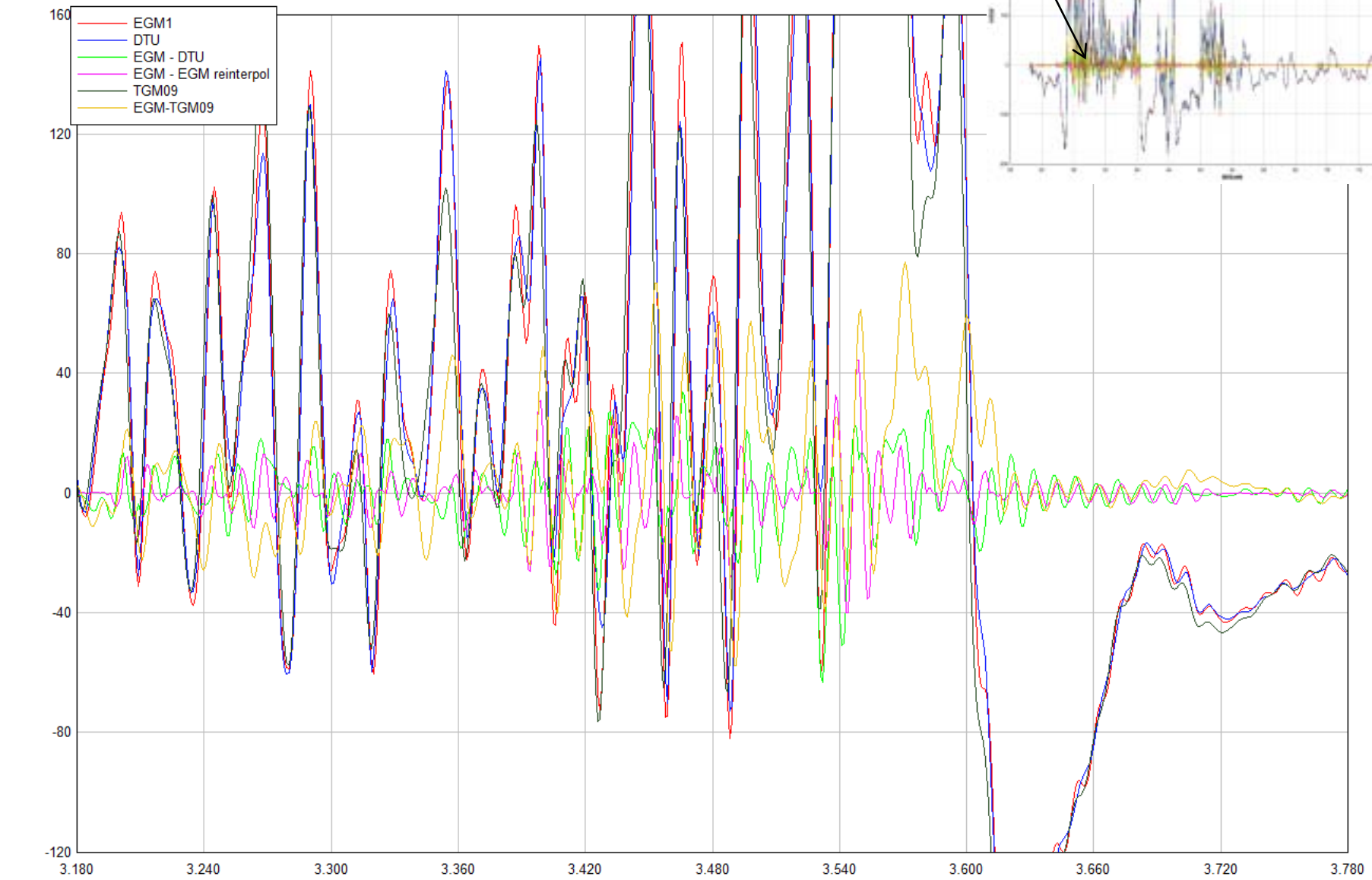
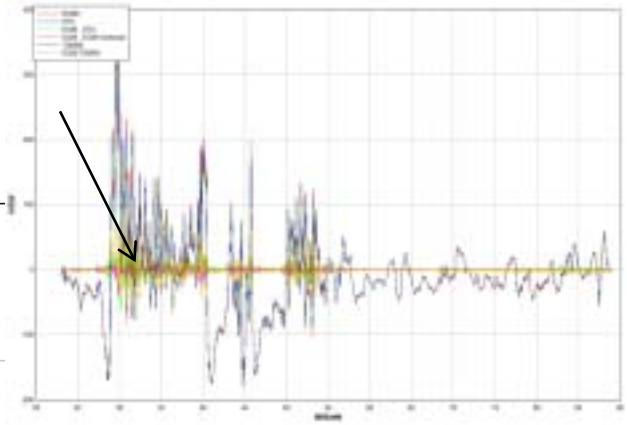
Arctic Ocean

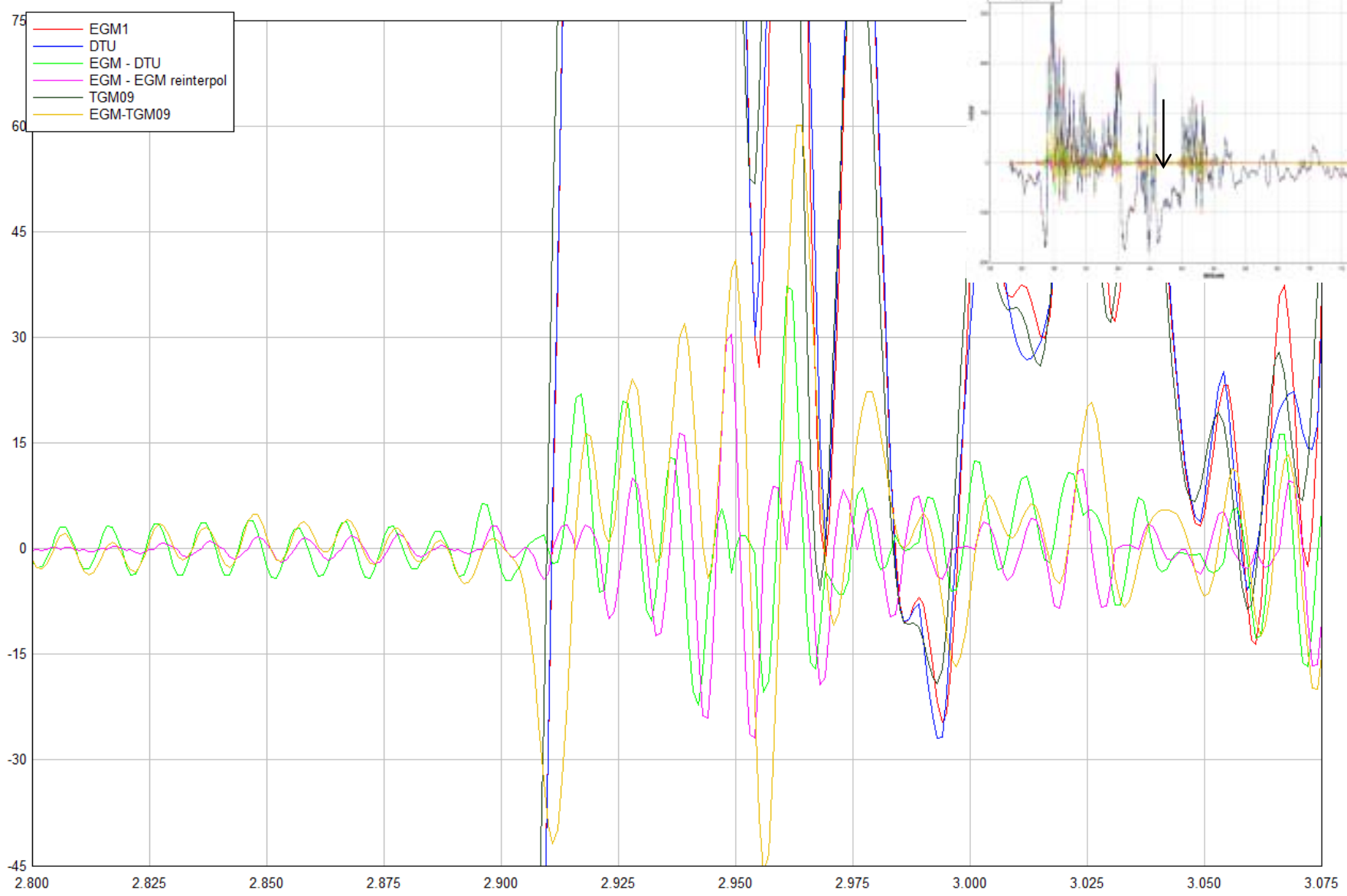



EGM1
DTU
EGM - DTU
EGM - EGM reinterpol
TGM09
EGM-TGM09
50
40
30
20
10
0
-10
-20
-30
-40
-50
65
70
75

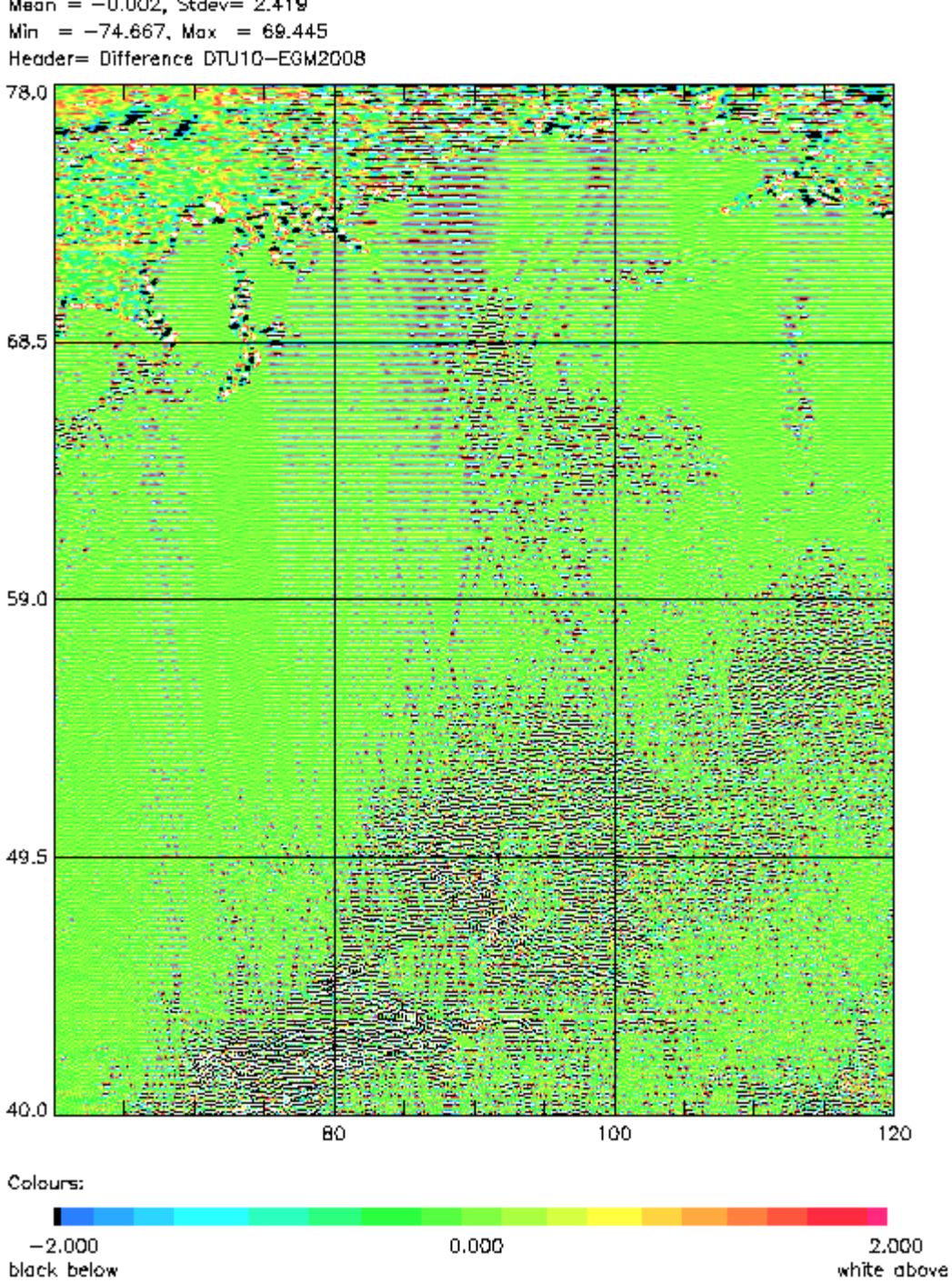




Axis reversed (sorry)


EGM1
DTU
EGM - DTU
EGM - EGM reinterpol
TGM09
EGM-TGM09
75
60
45
30
15
0
-15
-30
-45
2.800
2.825
2.850
2.875
2.900
2.925
2.950
2.975
3.000
3.025
3.050
3.075

Difference EGM08-DTU10



Max difference

82 mGal.

Gradual destriping

Created a DTU10GRA v1.1

Which gradually removes

Empirical lowering of

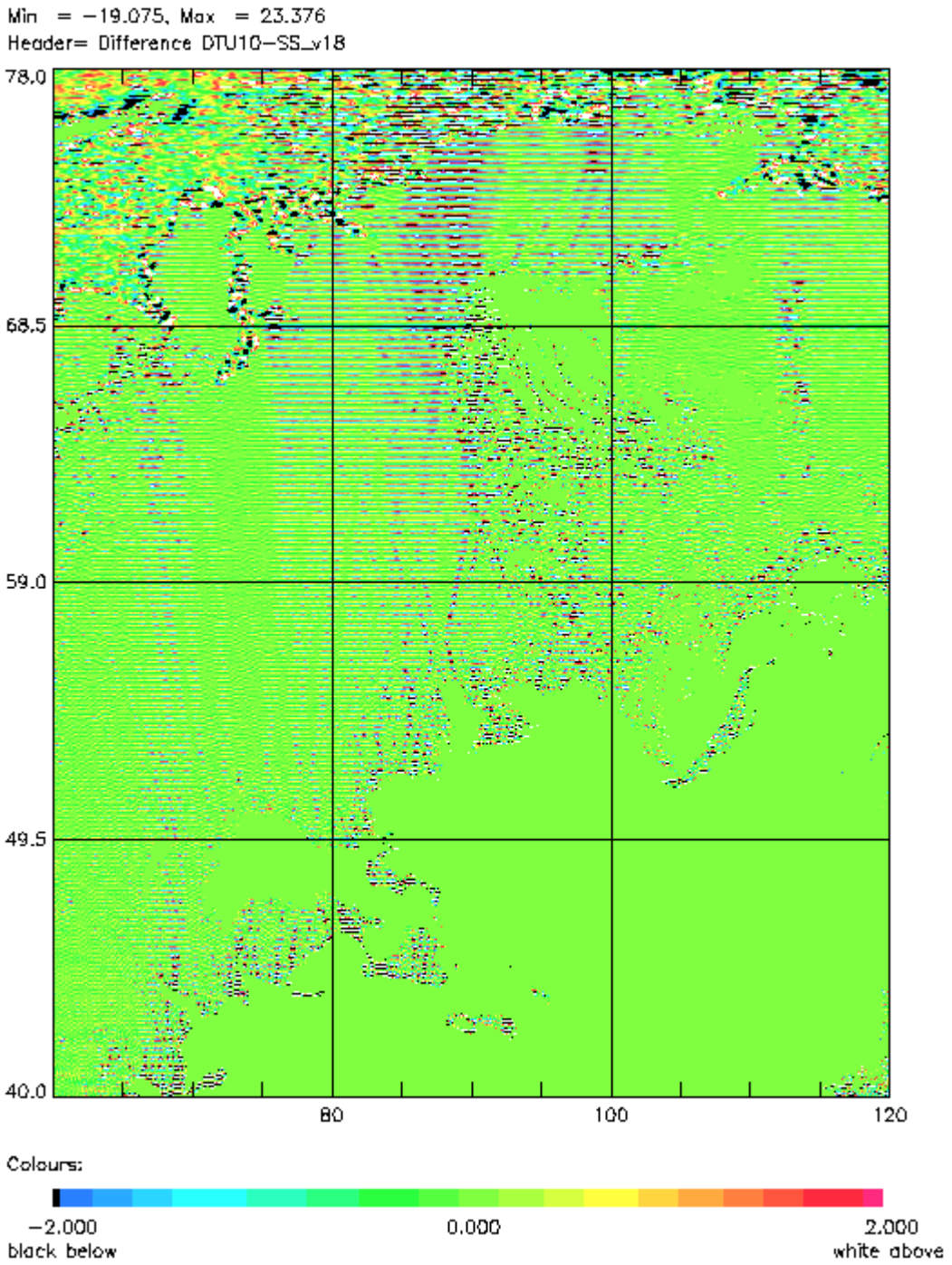
Destriping with altitude.

100% up to 300 meters

0% from 600 meters.

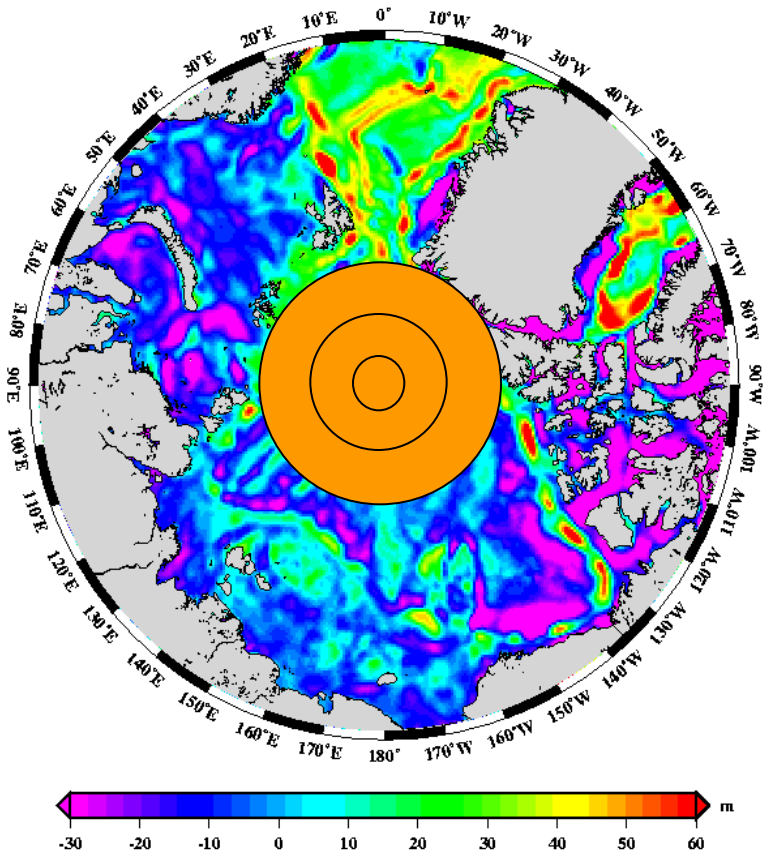
For Sylvian and Föerste

Global plots availale on ftp.

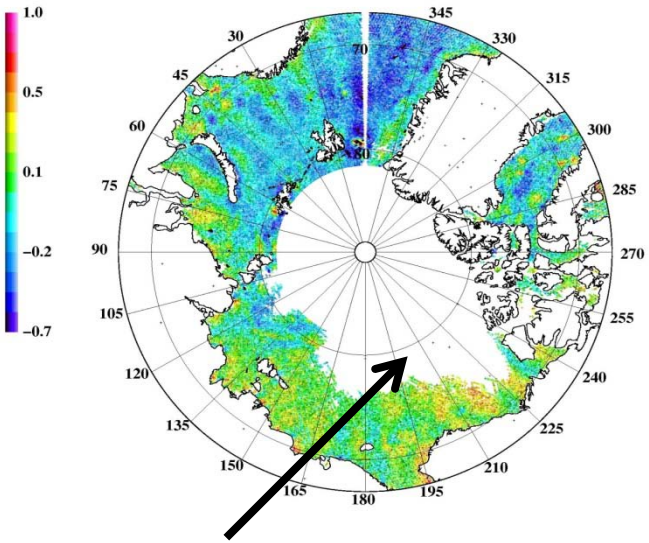


Where to go from here ?????

ICESat / CRYOSAT / Polar Gap



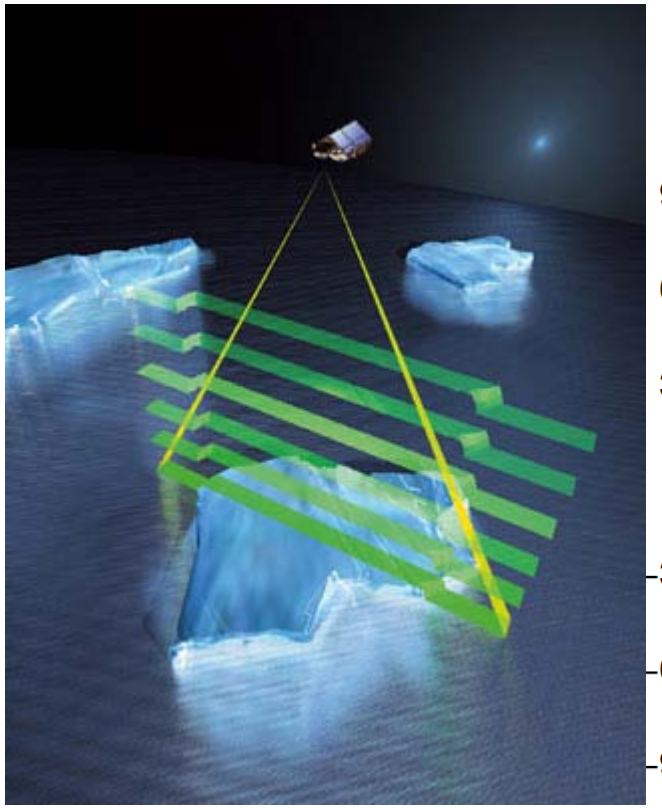
	Inclination (deg + Dist)	Repeat (days)
ERS + Envisat	82 – 1110 km	35
ICESat	86 – 440 km	91
Cryosat	92 - 220 km	369

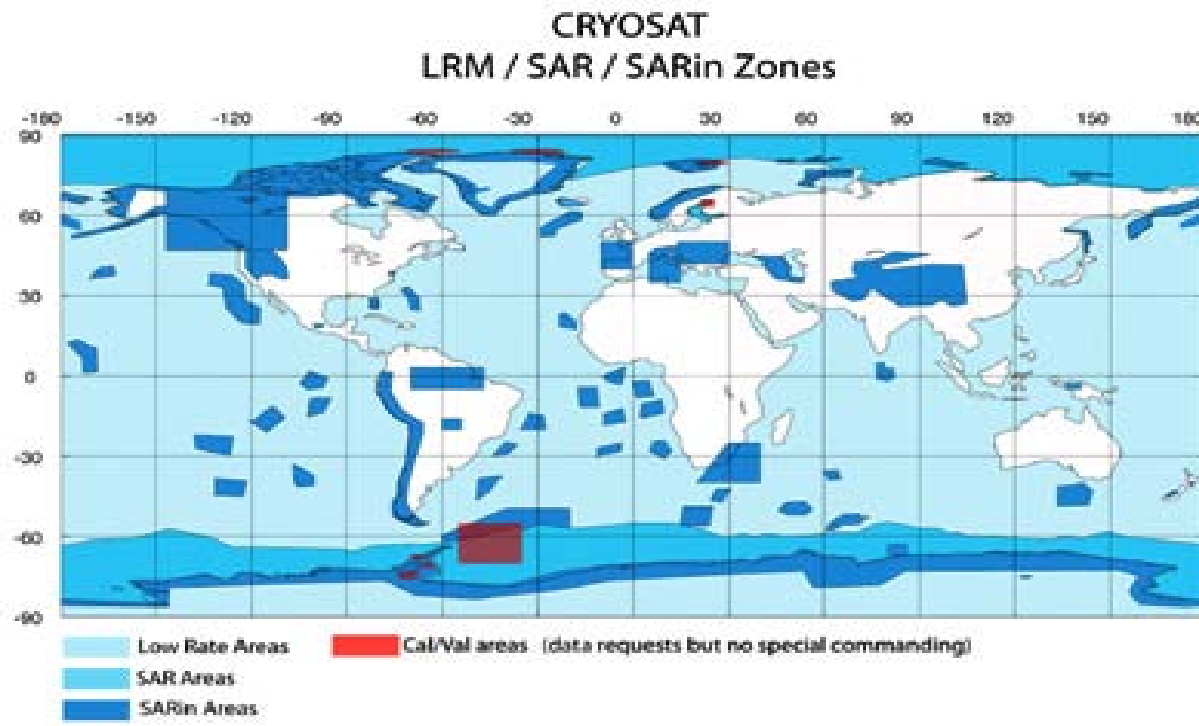


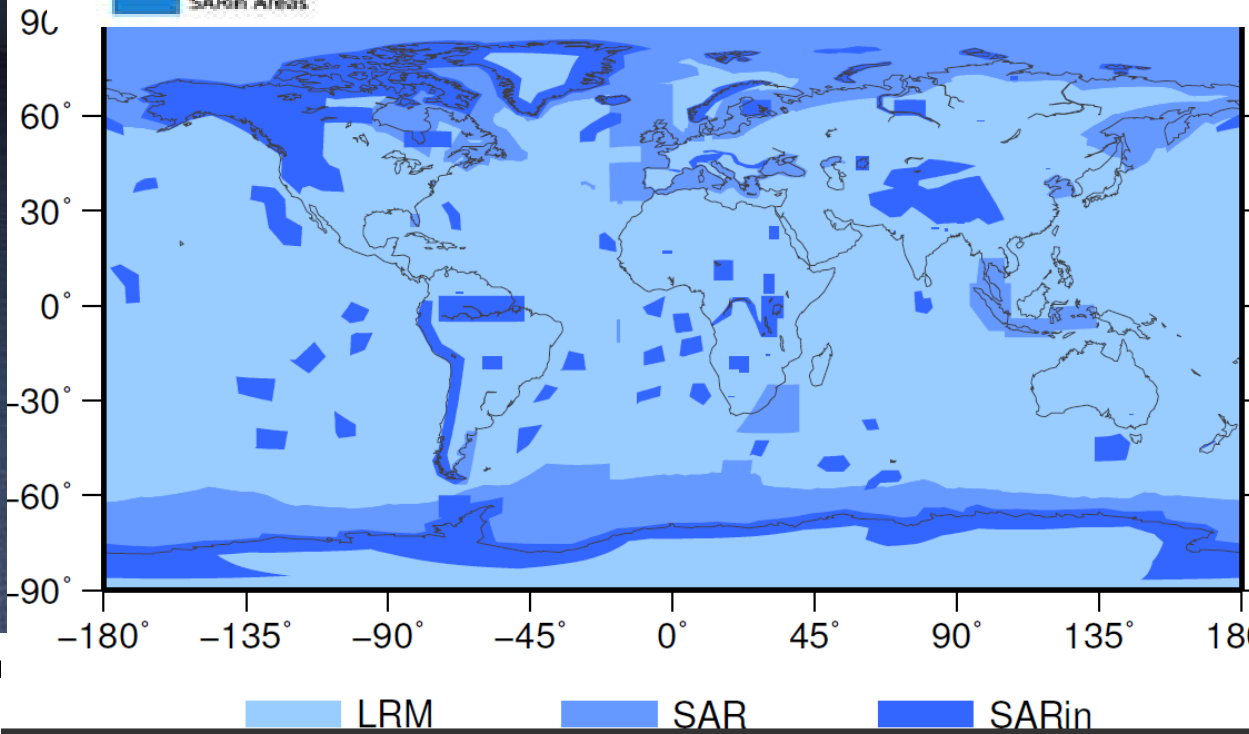
Two-fold problem

Un-retracked E1 / E2 / Envisat

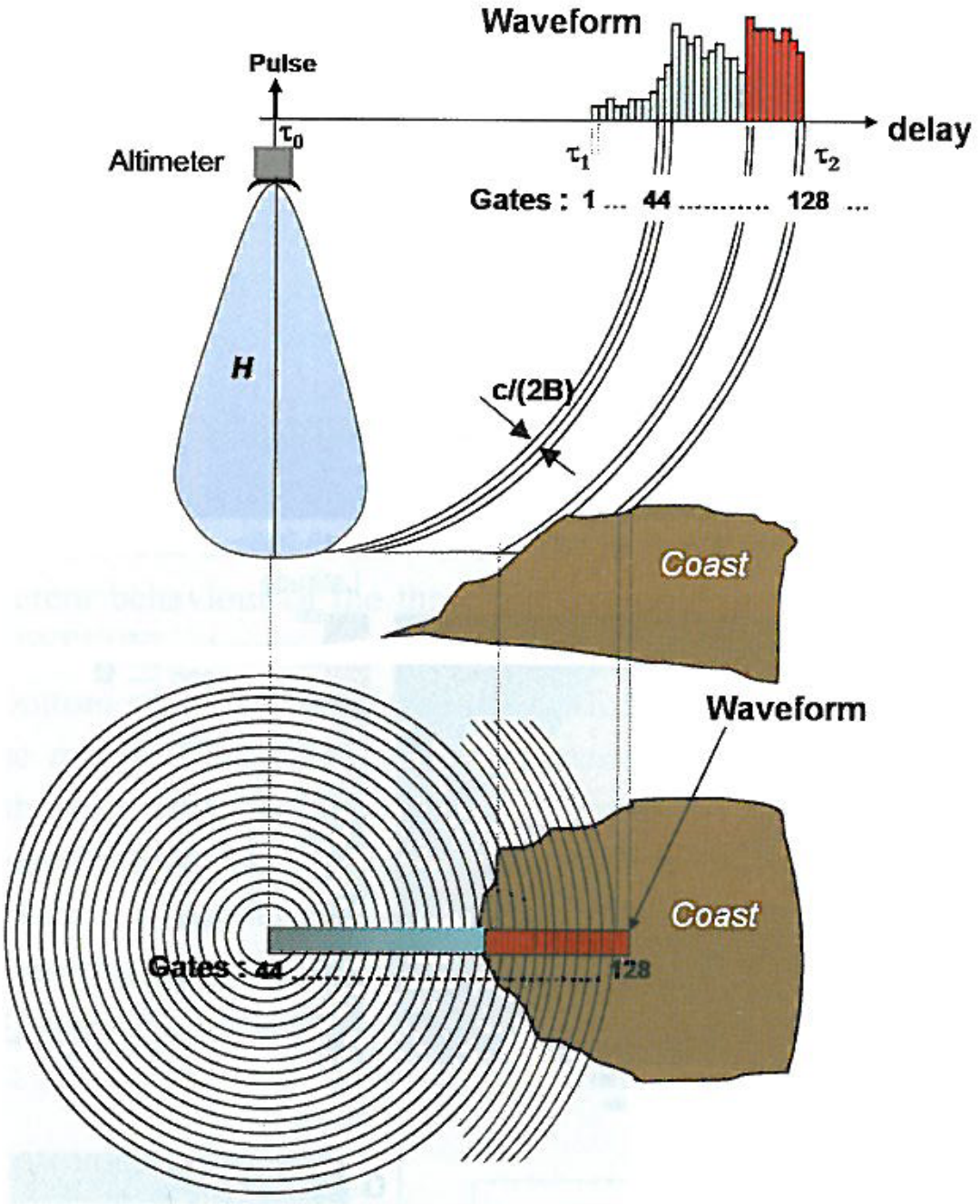
Cryosat

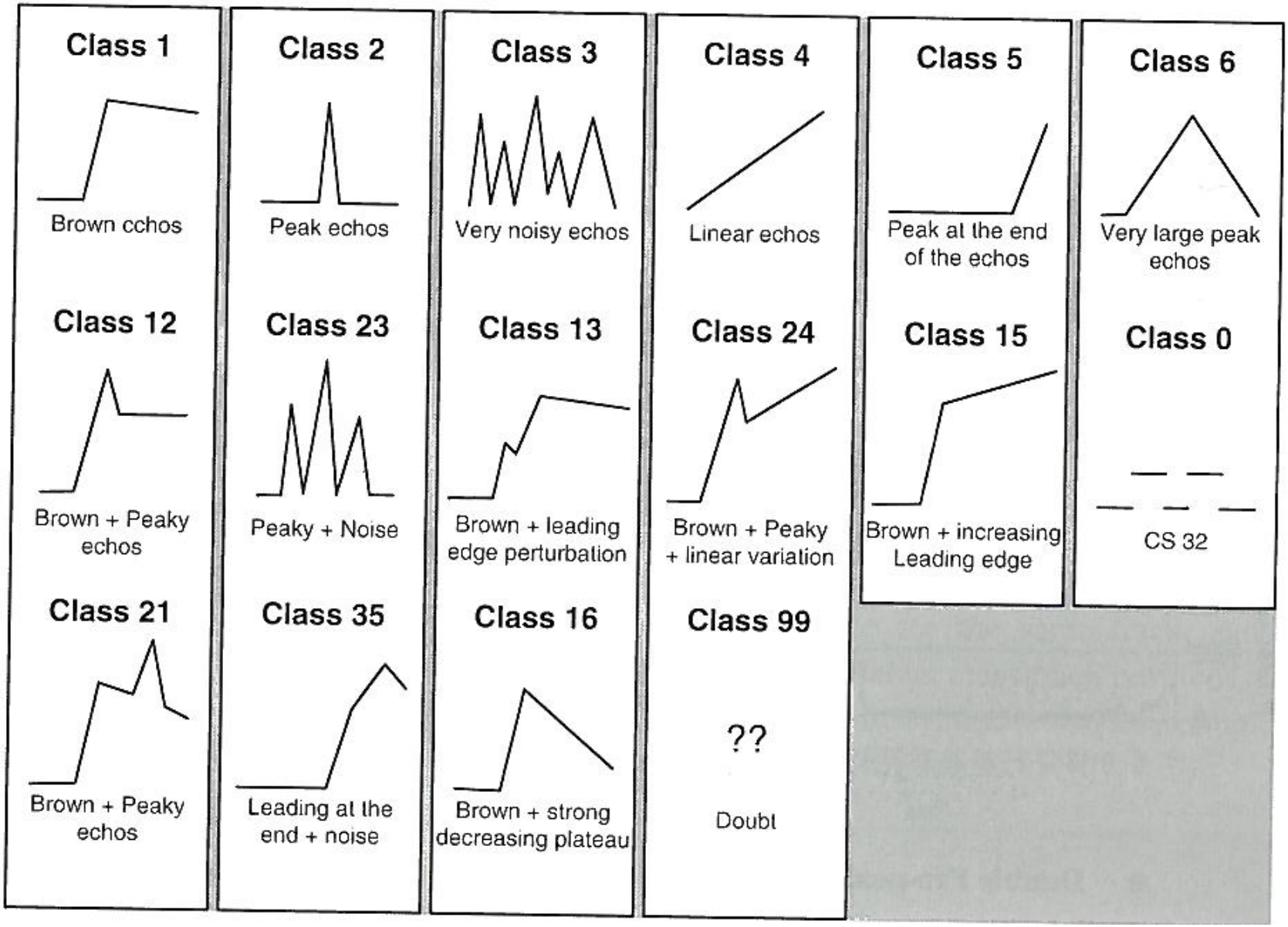


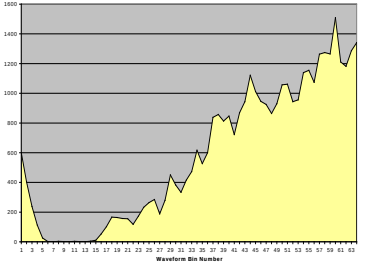

CRYOSAT
LRM / SAR / SARin Zones
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
90 60 30 0 -30 -60 -90
Low Rate Areas
SAR Areas
SARin Areas
Cal/Val areas (data requests but no special commanding)


90
60°
30°
0°
-30°
-60°
-90°
-180° -135° -90° -45° 0° 45° 90° 135° 180
LRM
SAR
SARin

Retracking

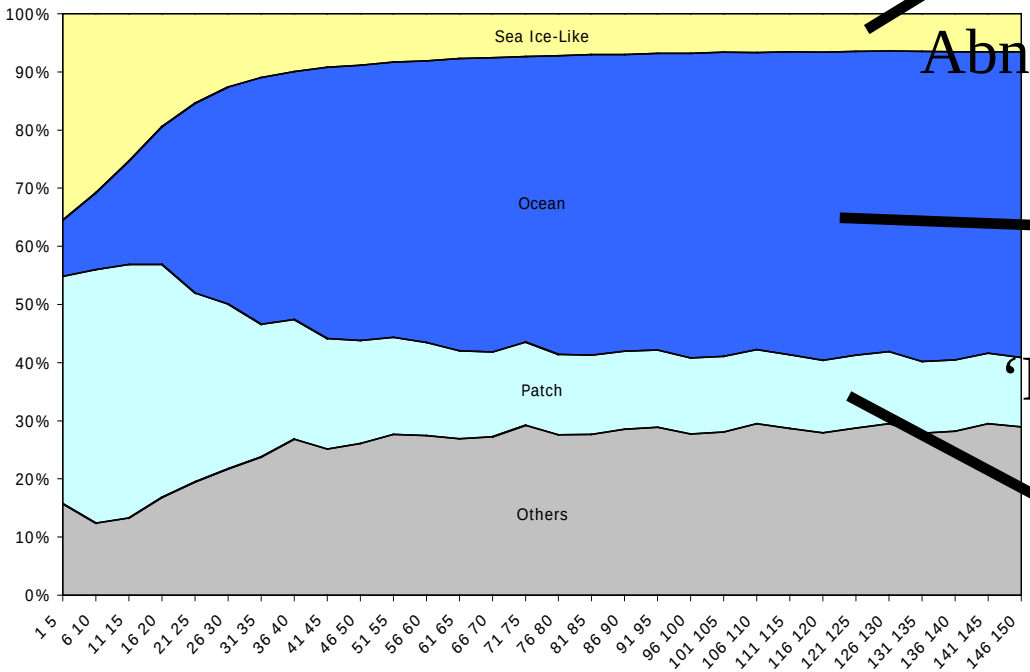

Waveform
Pulse
delay
Altimeter
τ_0
τ_1
τ_2
Gates : 1 ... 44 ..... 128 ...
H
c/(2B)
Coast
Waveform
Coast
Gates : 44
128

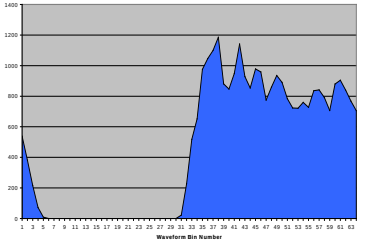

Class 1
Brown cchos
Class 2
Peak echos
Class 3
Very noisy echos
Class 4
Linear echos
Class 5
Peak at the end of the echos
Class 6
Very large peak echos
Class 12
Brown + Peaky echos
Class 23
Peaky + Noise
Class 13
Brown + leading edge perturbation
Class 24
Brown + Peaky + linear variation
Class 15
Brown + increasing Leading edge
Class 0
CS 32
Class 21
Brown + Peaky echos
Class 35
Leading at the end + noise
Class 16
Brown + strong decreasing plateau
Class 99
??
Doubl



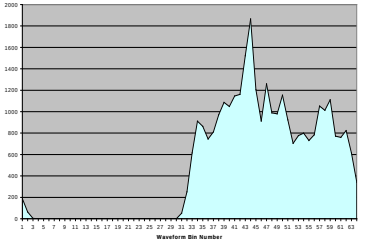
8

Abnormally wide leading edge



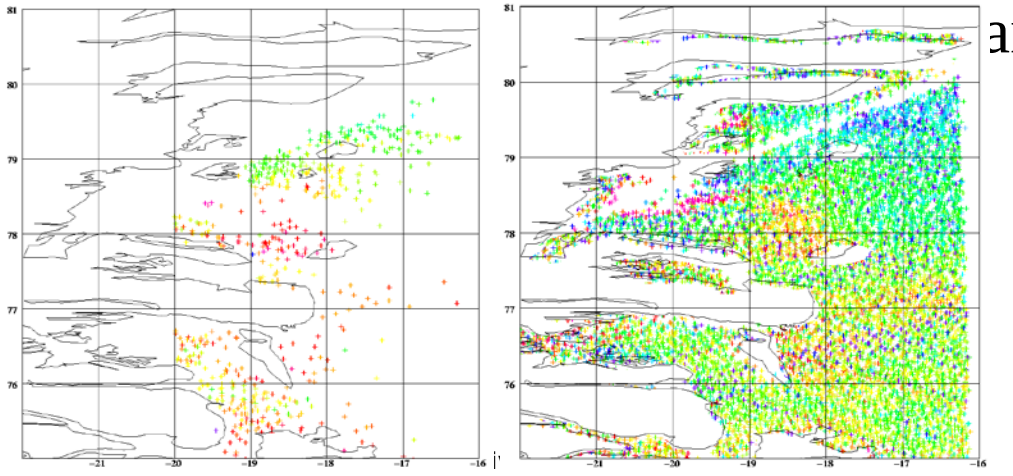


‘Real’ ocean waveforms



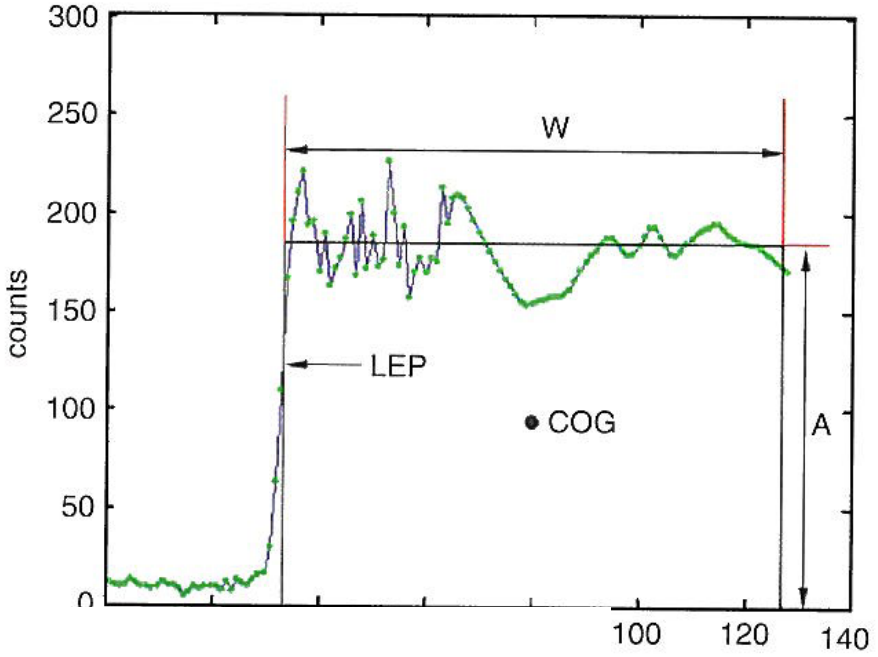
10

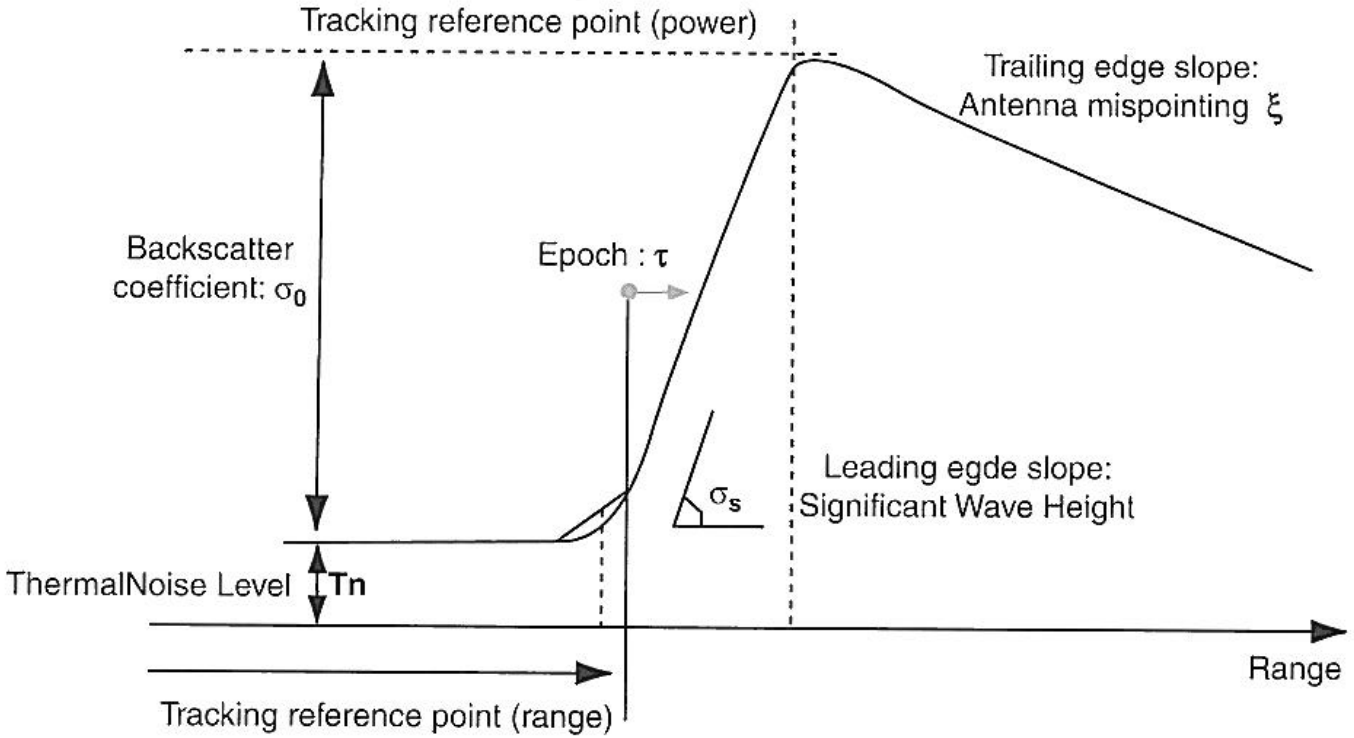
an-like with quasi-specular compo



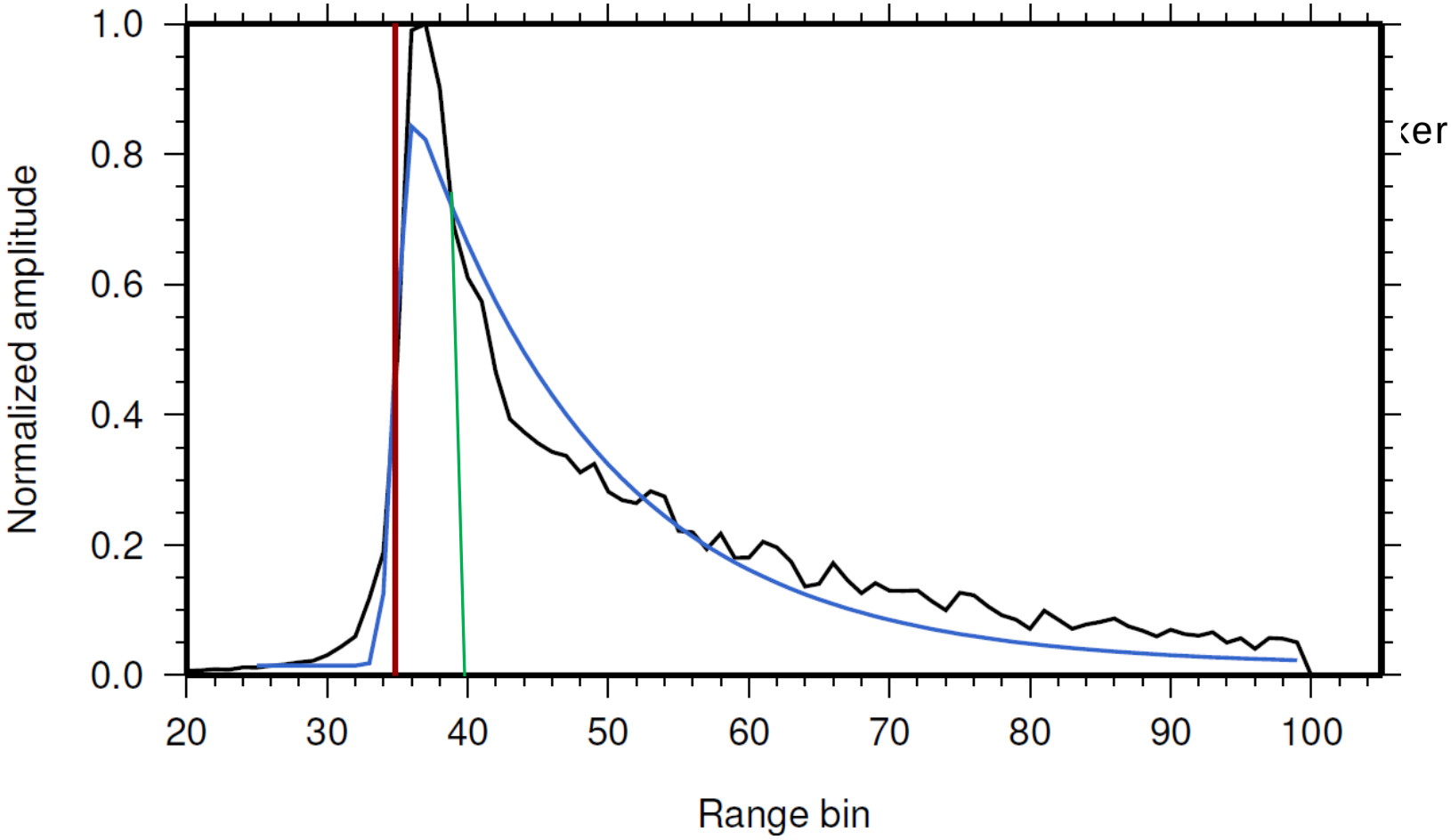
”Famous” GM example

Brown / OCOG etc



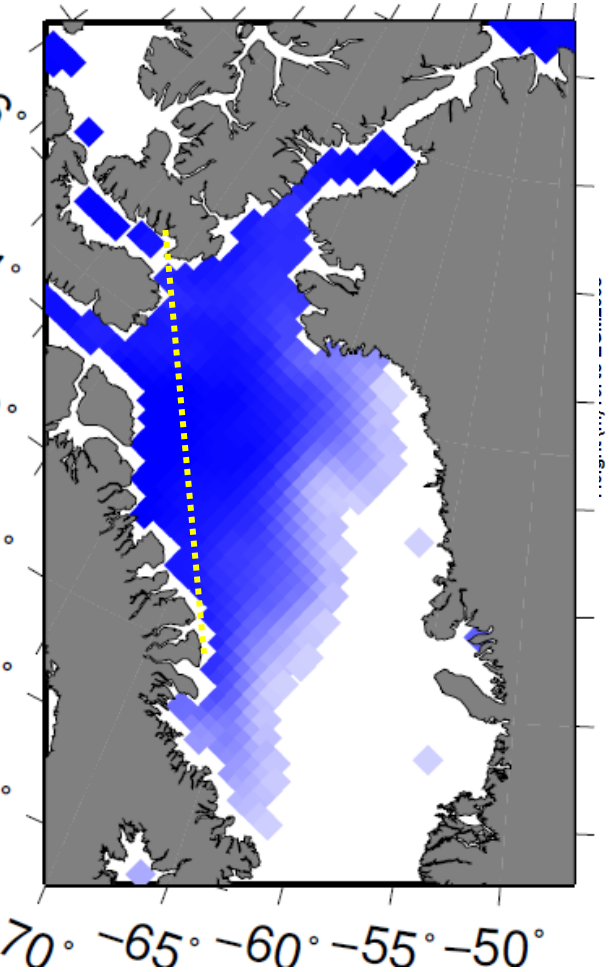


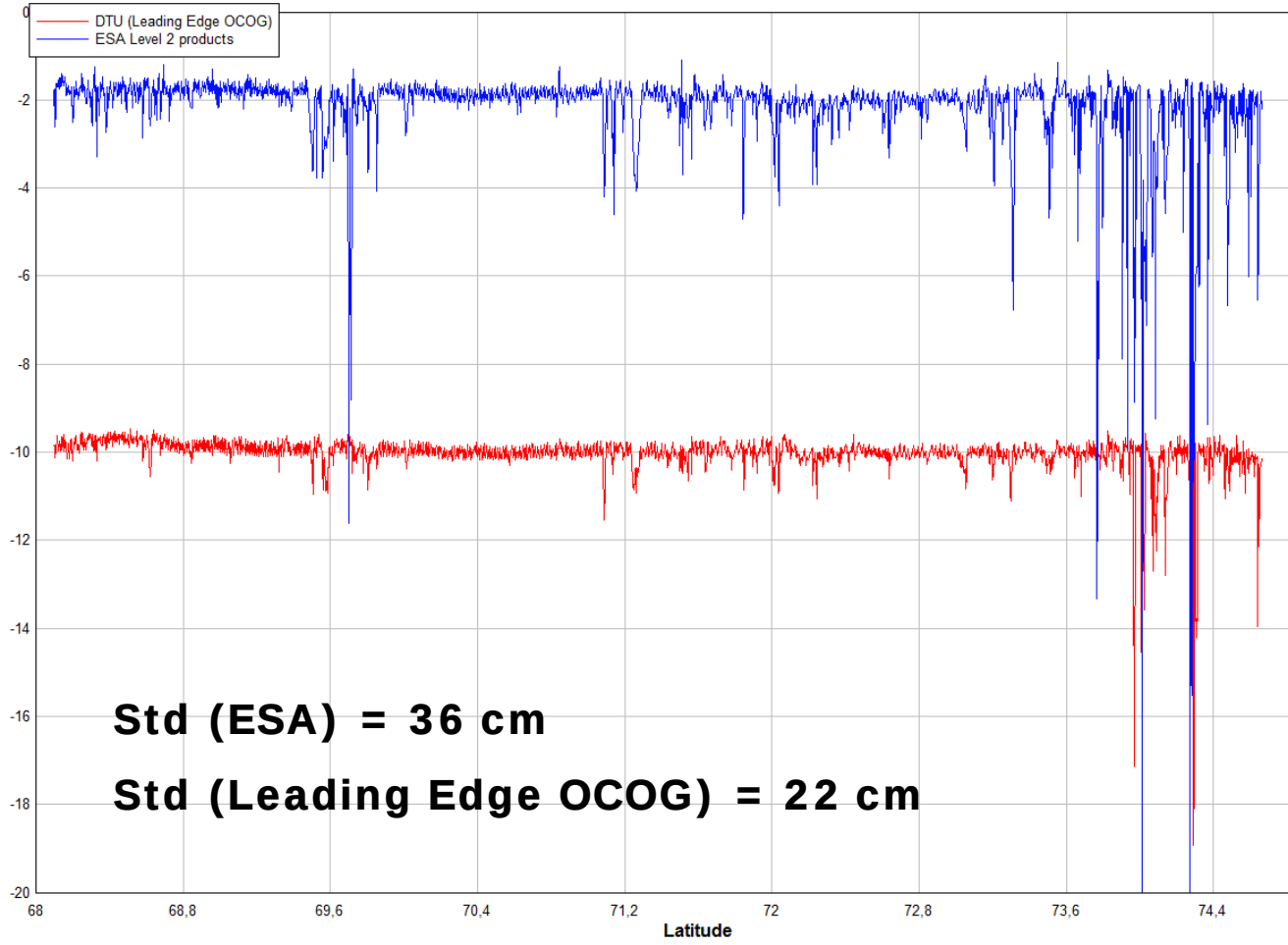
Retracking of Cryosat-2



Level 1b SAR waveform (black) with fitted five parameter beta retracker with exponential tail (blue) and surface estimate (red). Green is cut off for leading edge OCOG

Retracking 20 Hz SAR data only SSH data in Leads used.





Std (ESA) = 36 cm

Std (Leading Edge OCOG) = 22 cm

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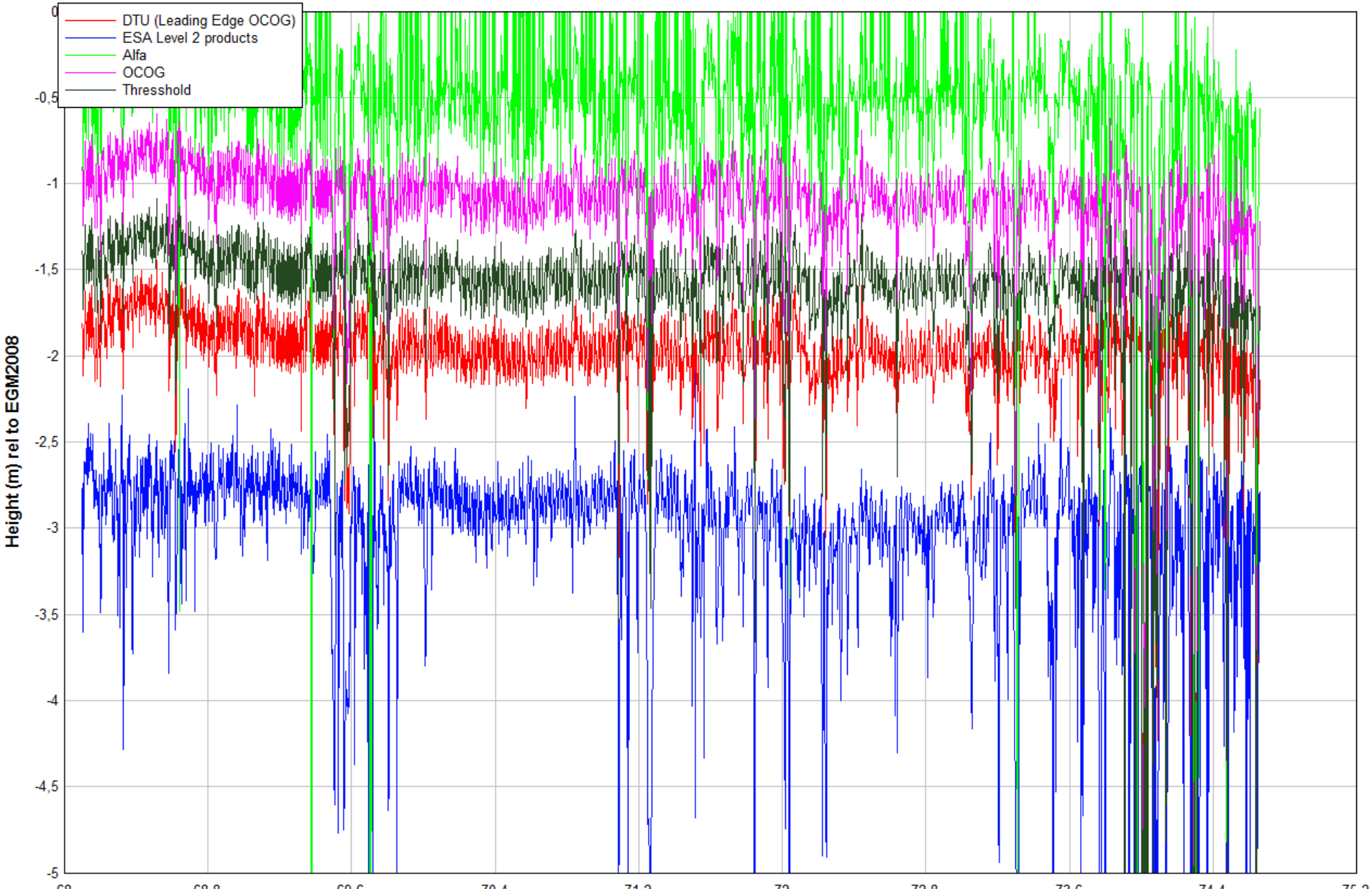
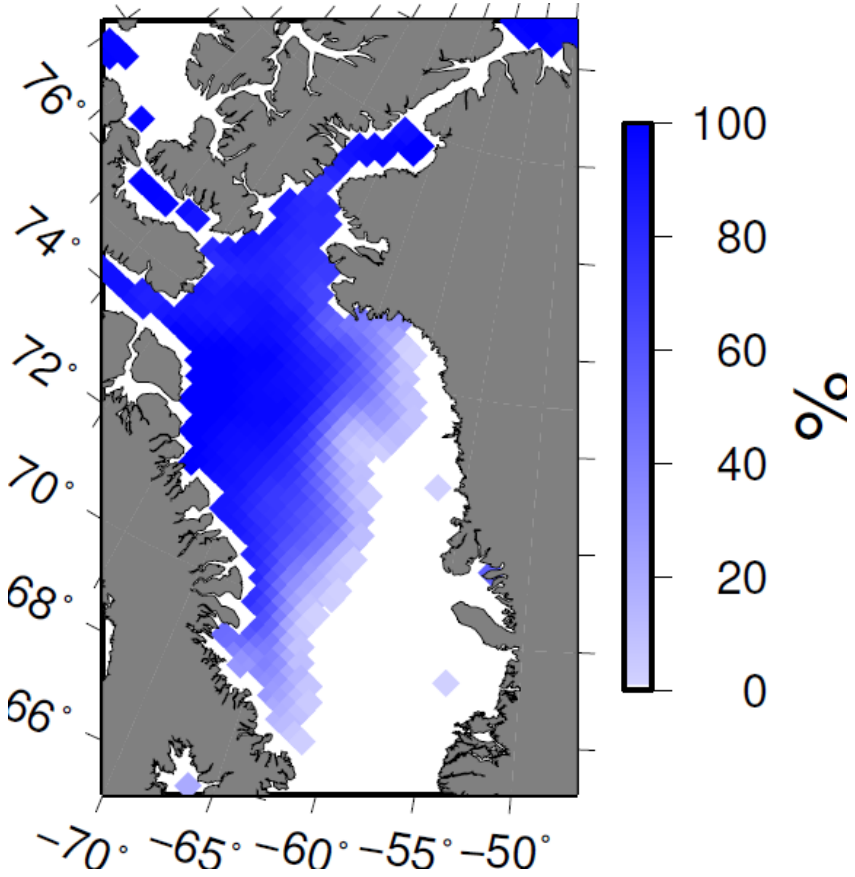
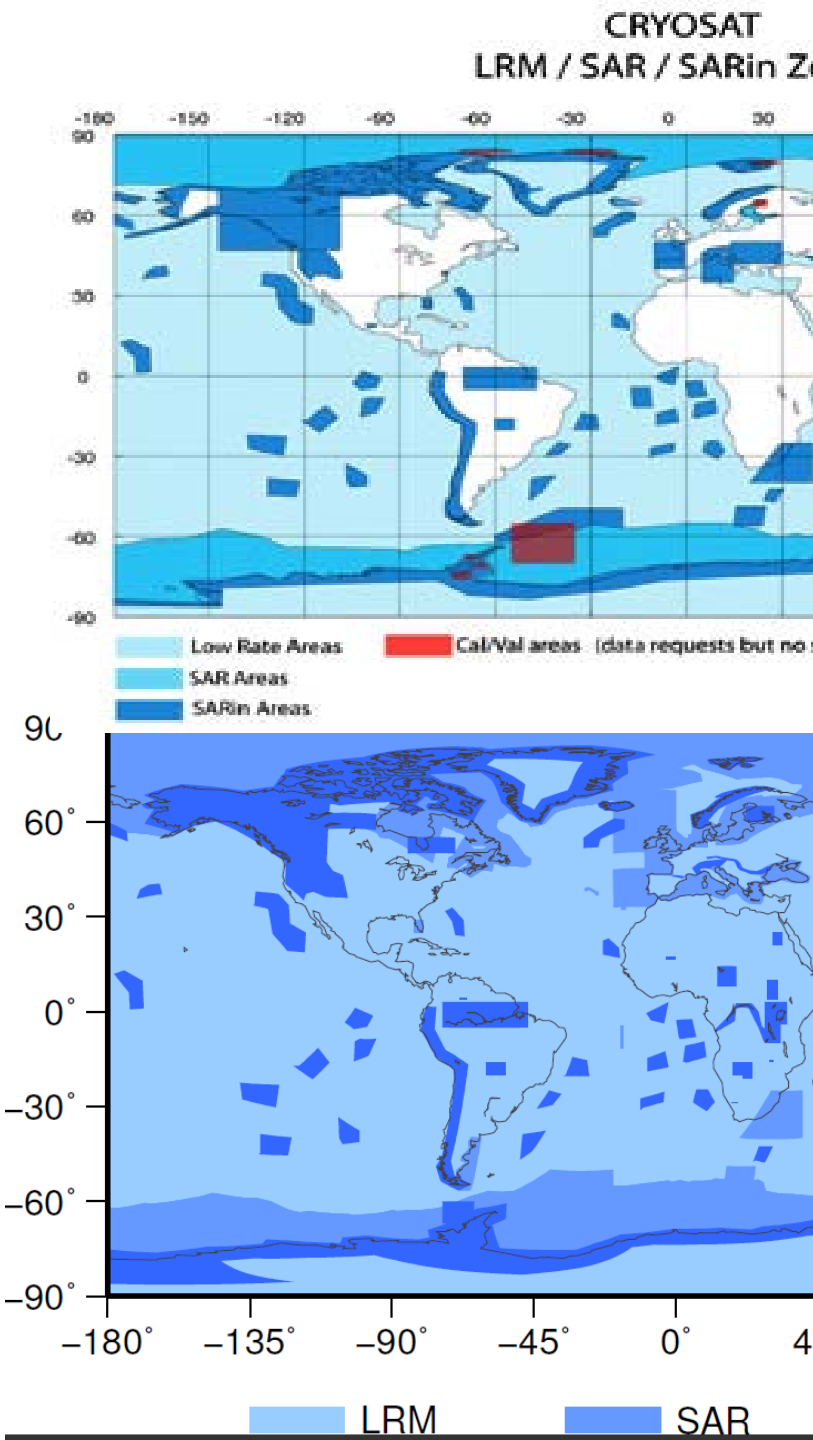
All DTU retrackers



Baffin Bay

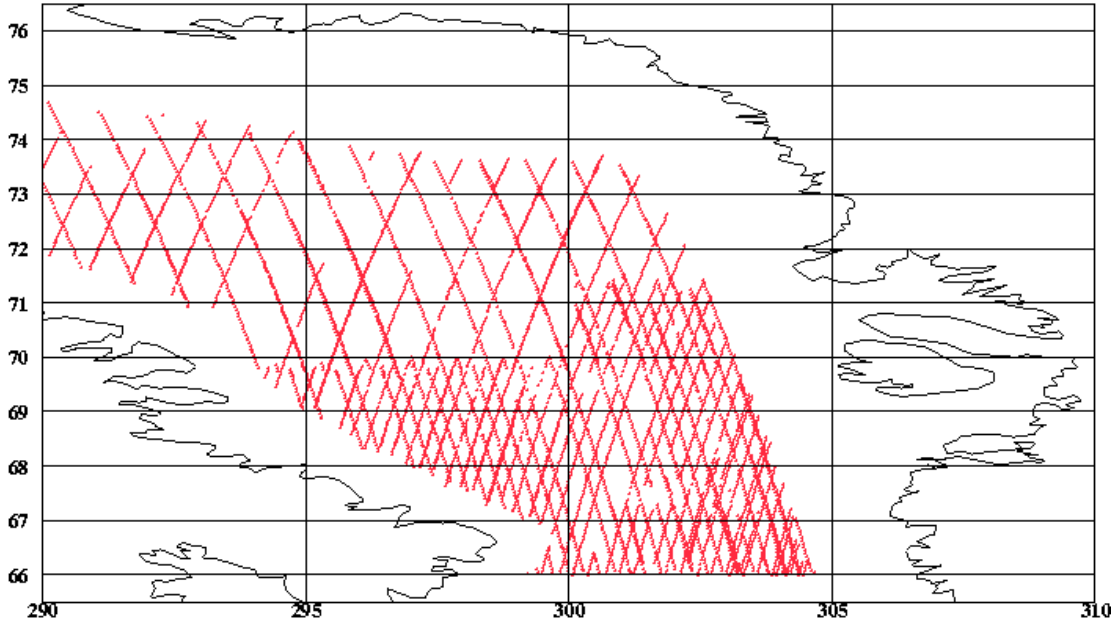
- Interesting because partly icecovered.
- This enables comparison C2 SAR and LRM



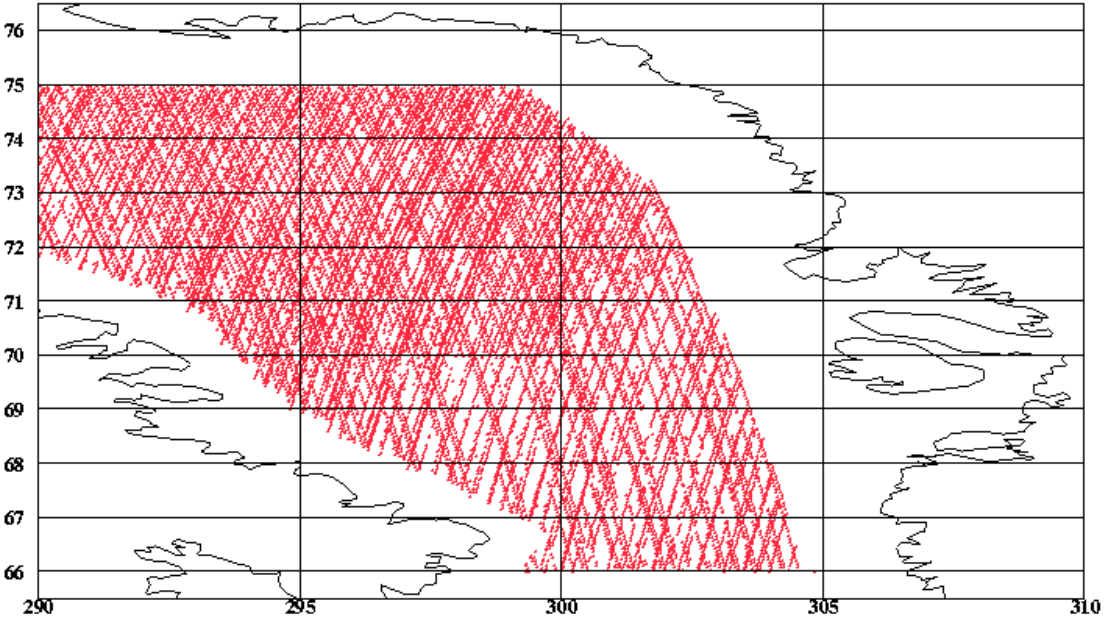


Cryosat (all 2011)

LRM mode (summer)

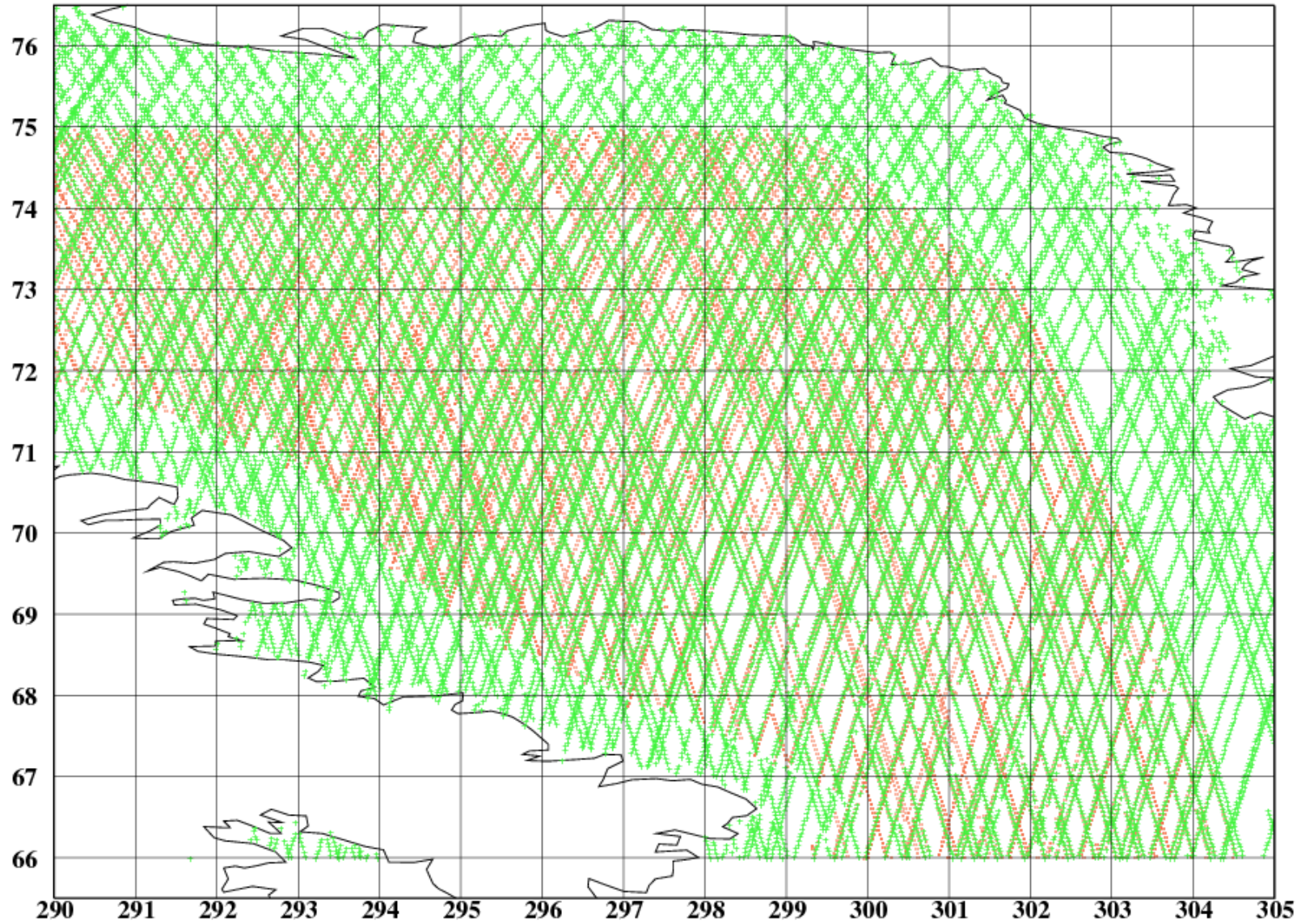


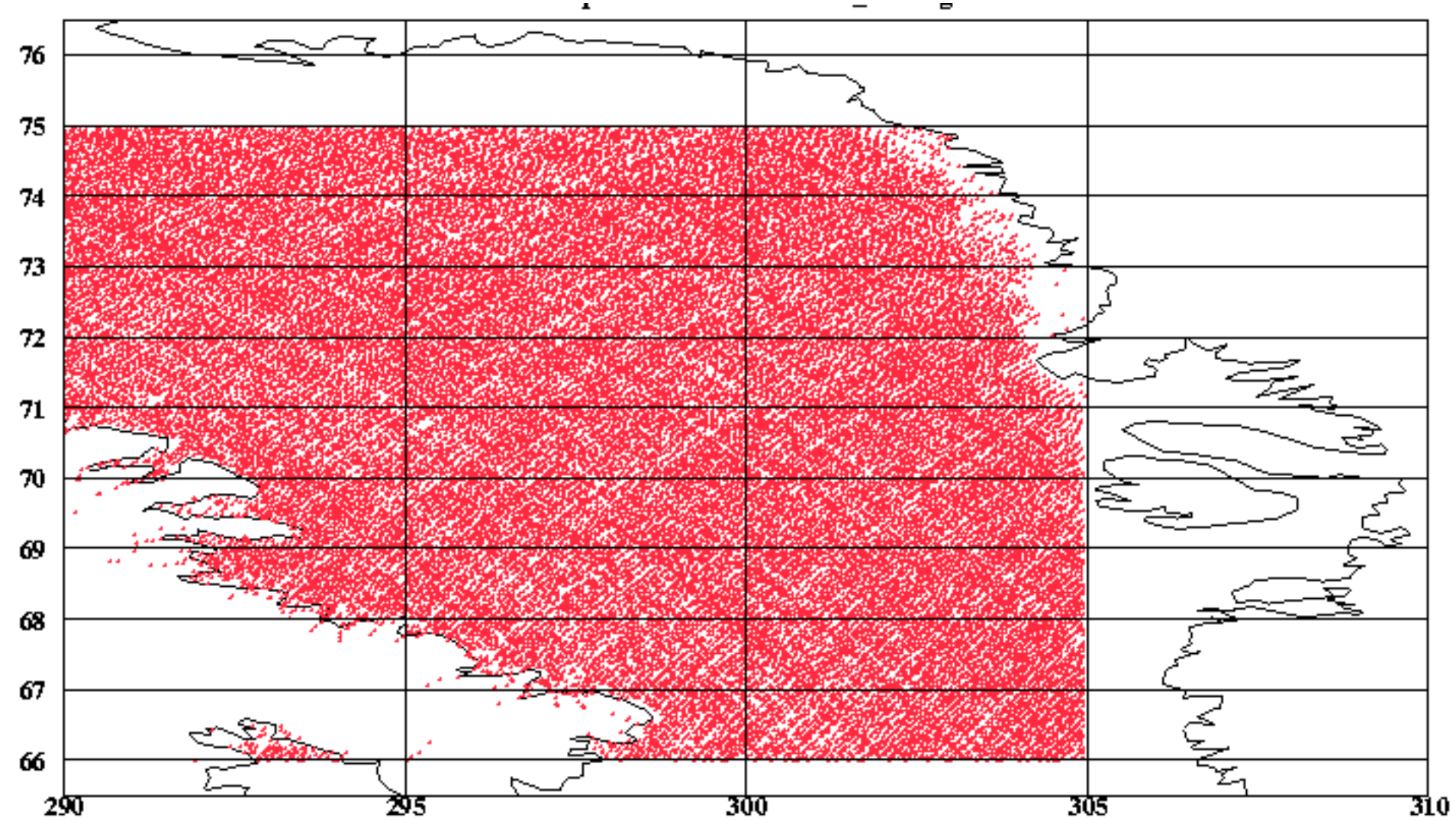
SAR mode (winter)



NGA, Feb 2012

Cryosat SAR-IN




76
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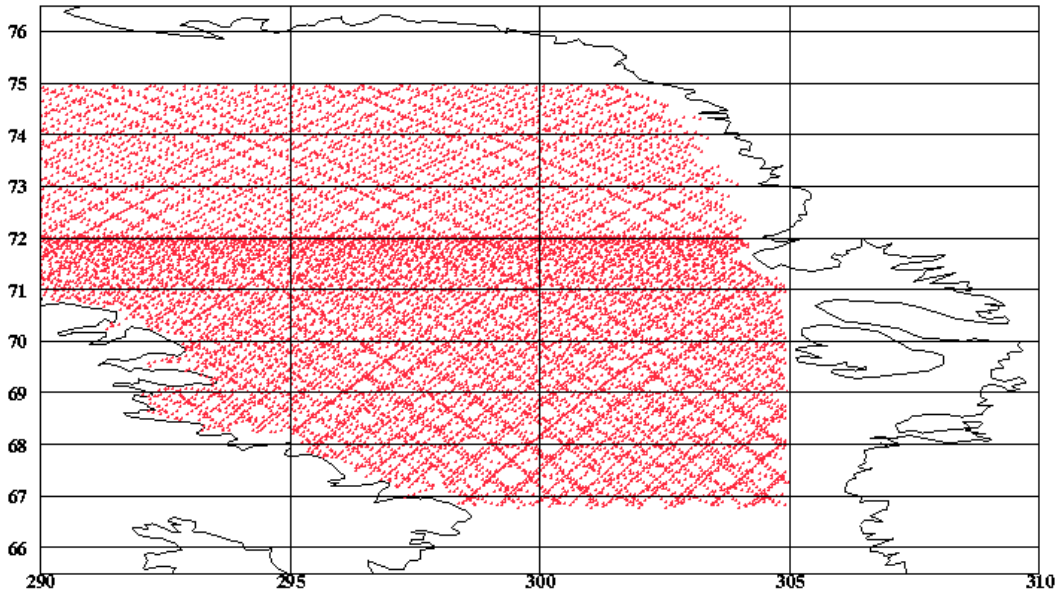
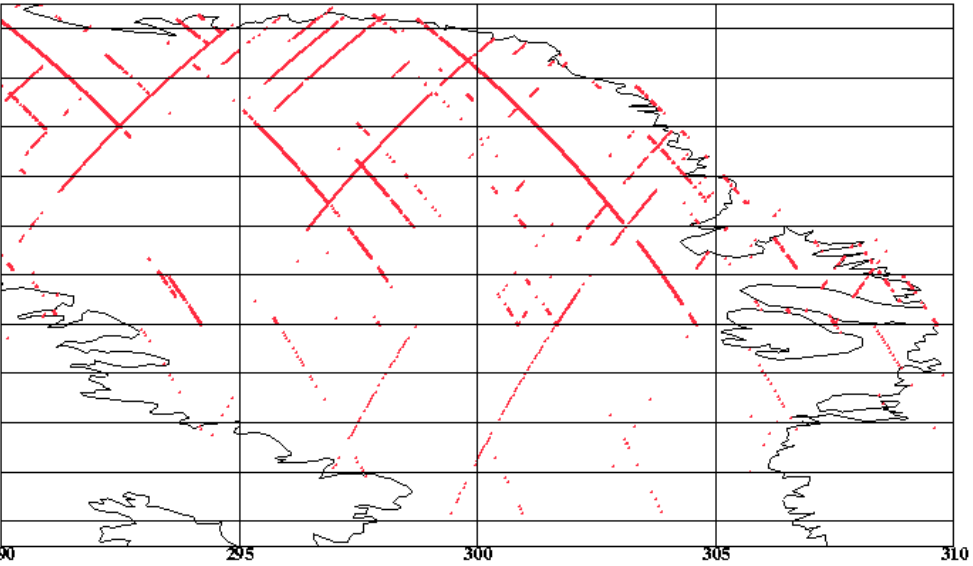
DTU

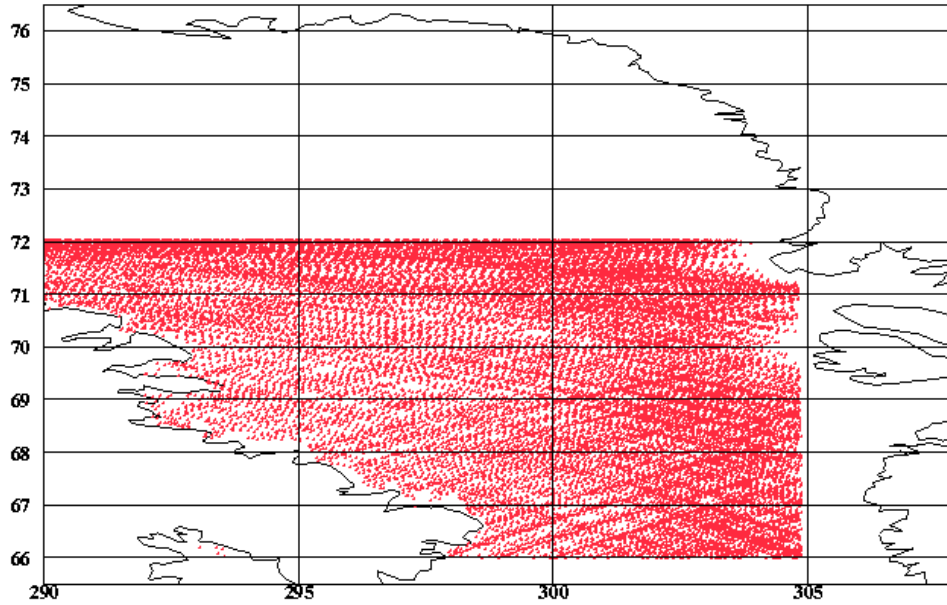
ERM
ENVISAT / TP / GFO



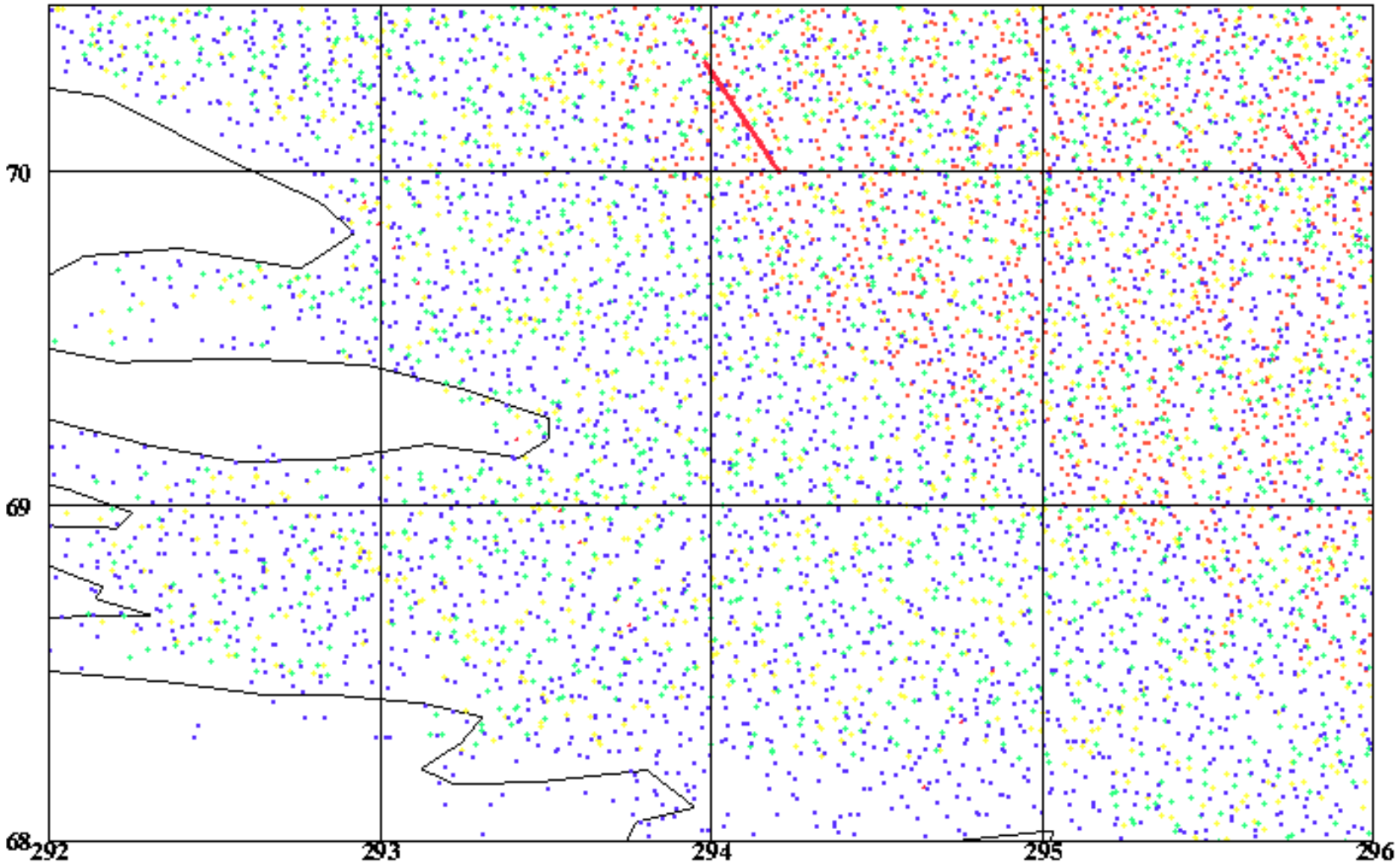
GEOSAT



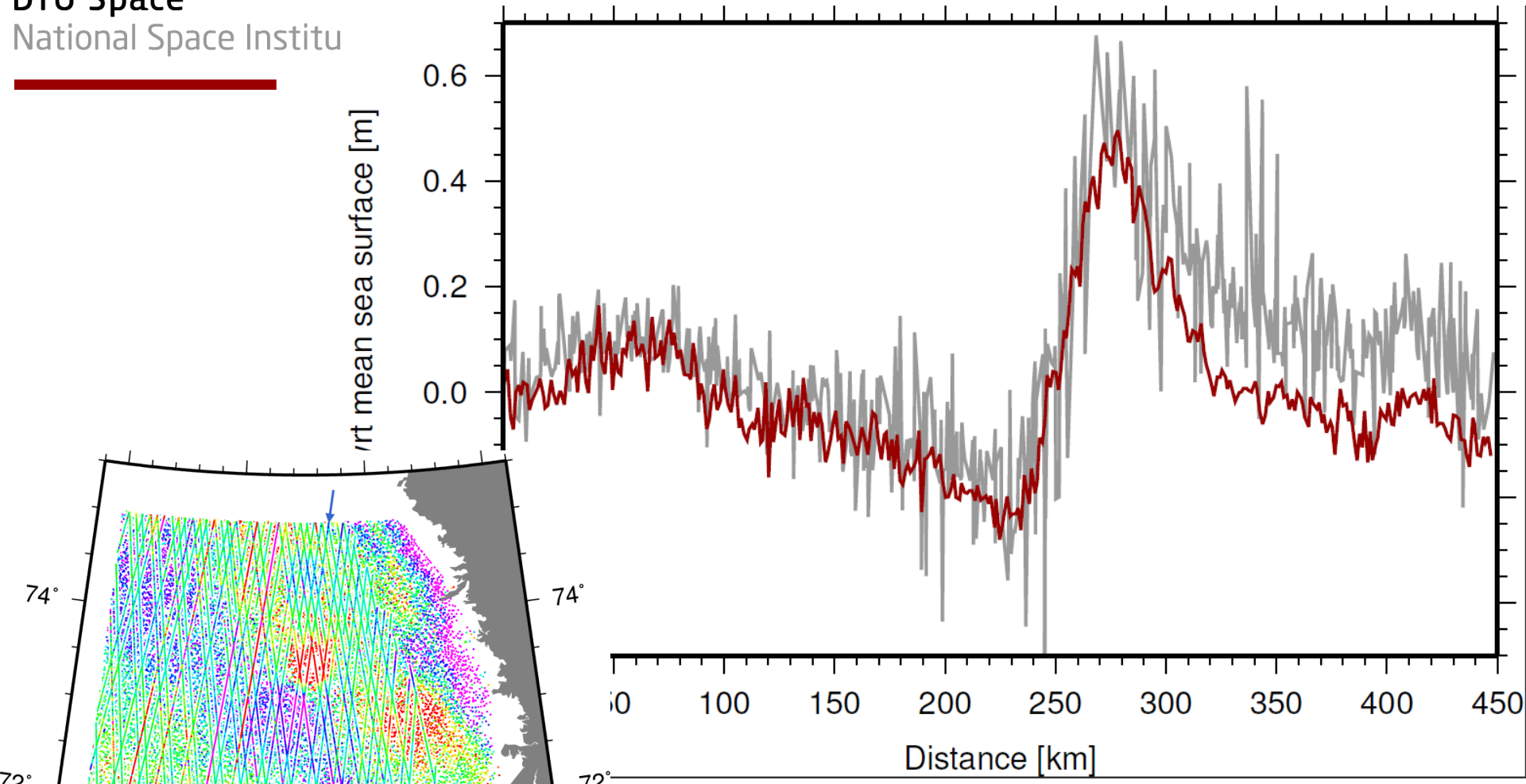
ICESAT



Coastal region is still ERS-1 driven.



DTU Space
National Space Institu



ark

NGA, Feb 2012

Marine Gravity.

6696 datapoints used

Within

67N to 75N

55W to 65 W

Unfortunately the comparison

Suffers from the fact that

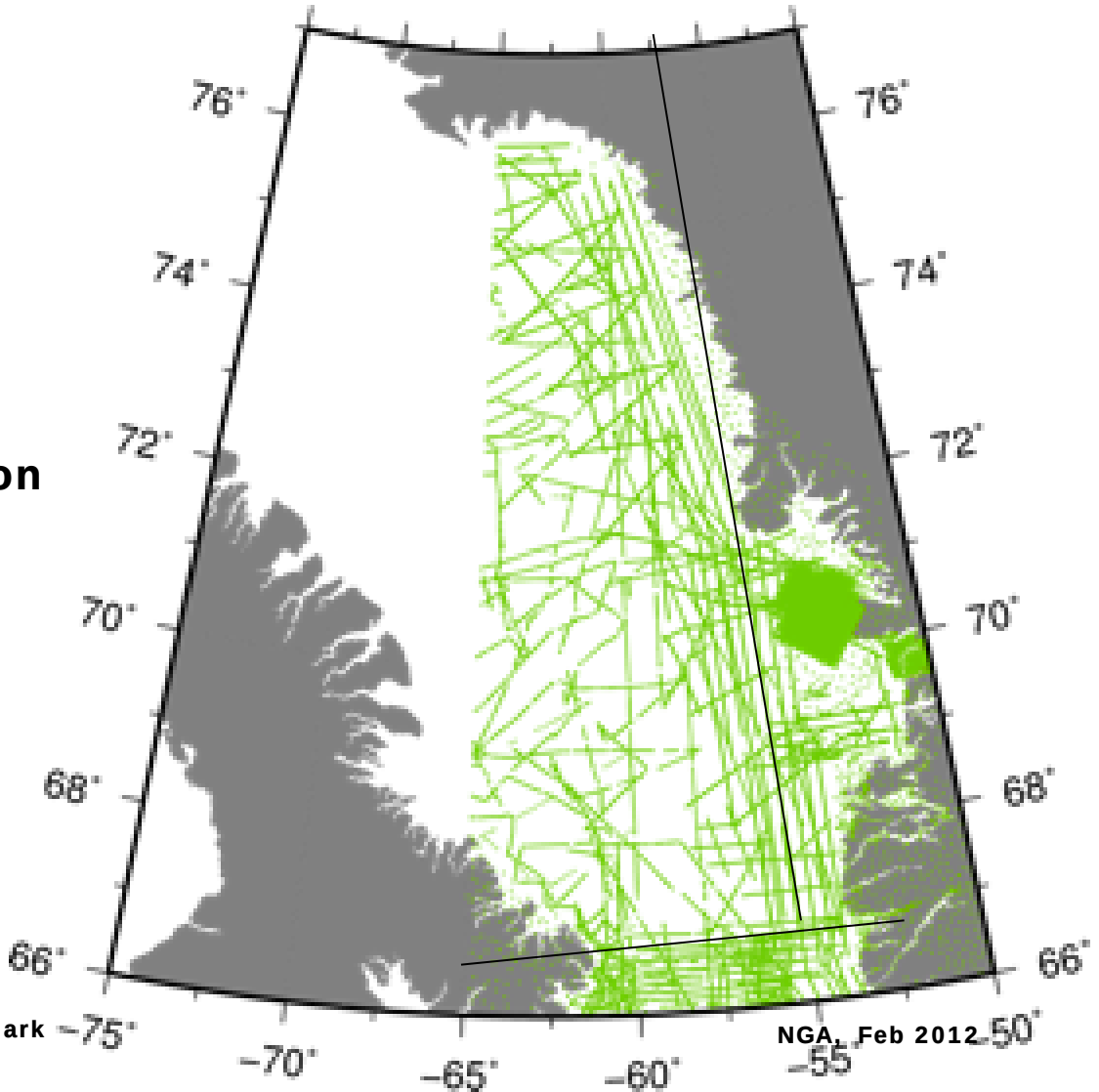
SAR + LRM data are not

Available in parts of the

Region.

Comparison / region should

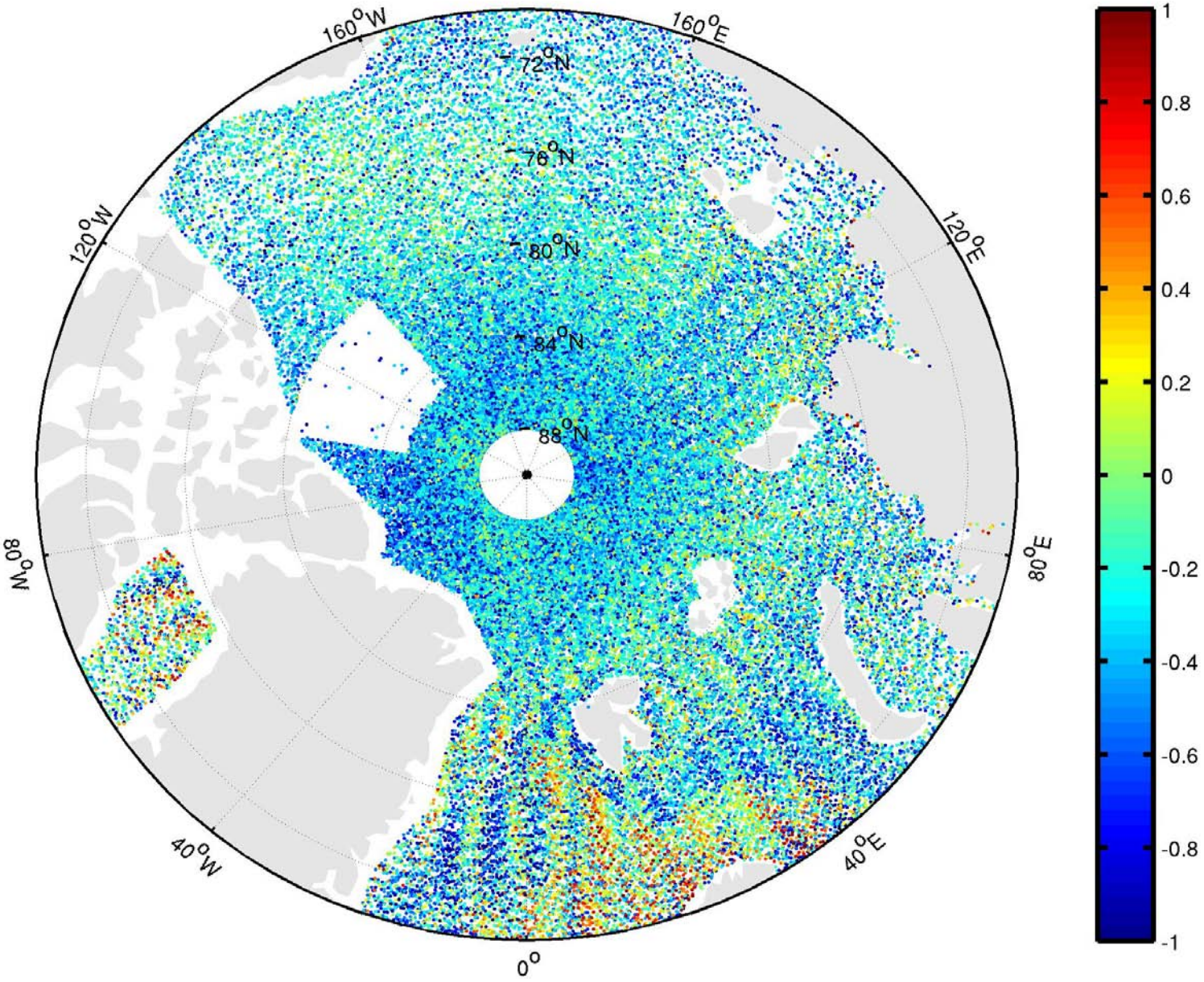
Be re-defined.



Gravity comparison

6696 obs	Max	std
EGM2008	35	4.51
DTU10	32	3.89
DTU (EIGEN 6C)	45	5.87
CRYOSAT		
OCOG (ONLY SAR)	33	4.09 *
ALFA(ONLY SAR)	33	4.10 *
Lead Edge OCOG	34	3.95 *
Tresshold(ONLY SAR)	34	4.01 *
GM + SAR + LRM	31	3.67 *

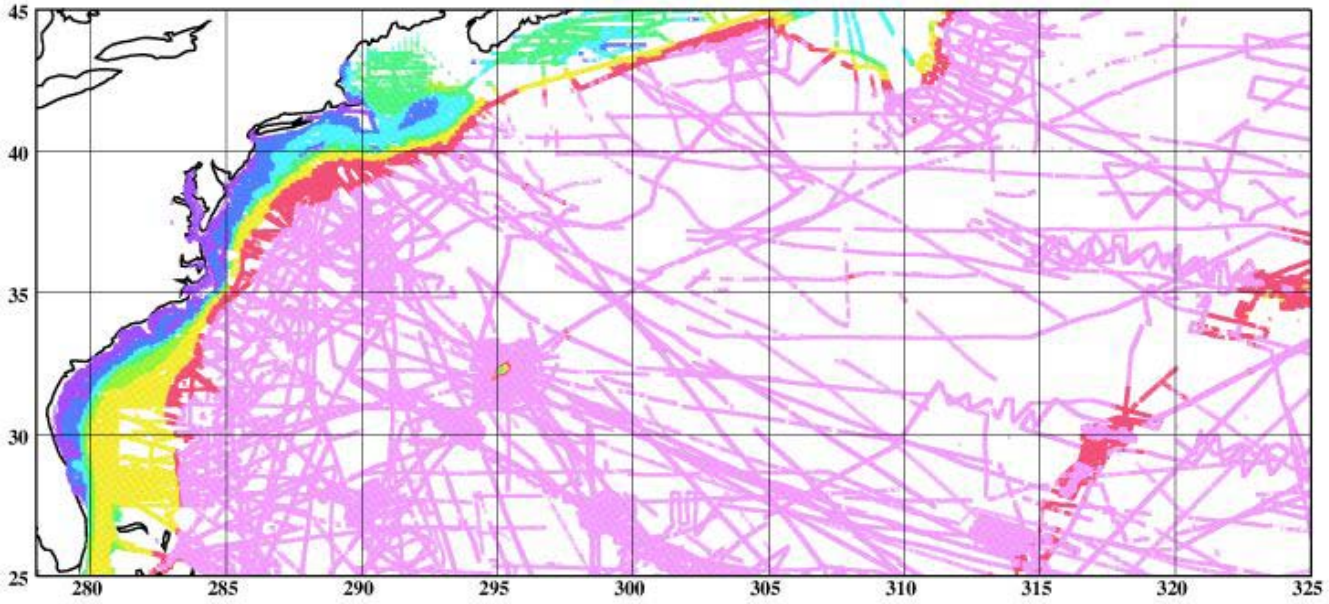
Cryosat in the Arctic



Coastal Issues.

- Very much work in progress.
- SAR-IN
- ICESAT

Re-investigating Gulf Stream



A´ll > 10.000 obs	Std(KMS02)	Std(DNSC08)	Percentage Imp
Purple (0-20 m DEPTH)	6.54	3.46	48
Dark Blue (20-50 m)	4.16	3.34	20
Light Blue (50-200 m)	4.06	3.83	6
Green (200-500 m)	5.74	4.89	15
Yellow (500-1000 m)	5.36	4.38	22
Red + Pink (1000-5000 m)	5.60	4.89	13

DTU 2012 Beta

Including CRYOSAT LRM data (1.8 year from NOAA).

Including CRYOSAT SAR data

Currently testing Cryosat SAR-IN

Updating all data.

Particularly Ocean tide correction to GOT 4.7

Also SSB correction updated (na for Cryosat.-2).

Standards	DNSC08/DTU10	DTU12 Beta
Dry troposphere	ECMWF	ECMWF
Wet troposphere	ECMWF	Radiometer
Ionosphere	Altimeter	Altimeter
Dynamic Atmosphere	IB (1013 mbar)	MOG-2D_IB
Ocean tides	GOT 00.2	GOT4.7
Sea State Bias	BM4	Non-PARAM

DTU 2012 Beta

A´ll > 10.000 obs	2012	DTU10	SAND 18	EGM2008
Purple (0-20 m DEPTH)	3.01	3.30	**3.69**	**3.20**
Dark Blue (20-50 m)	2.79	2.79	**3.42**	**2.80**
Light Blue (50-200 m)	3.22	3.27	**3.52**	**3.23**
Green (200-500 m)	3.53	3.49	**3.79**	**3.51**
Yellow (500-1000 m)	4.33	4.30	**4.35**	**4.35**
Red/Pink (>1000 m)	4.83	4.82	**4.69**	**4.85**
All 3210000		3.81	**4.09**	**3.83**
MitAtl Spreading	4.85	5.20	**4.74**	**5.32**

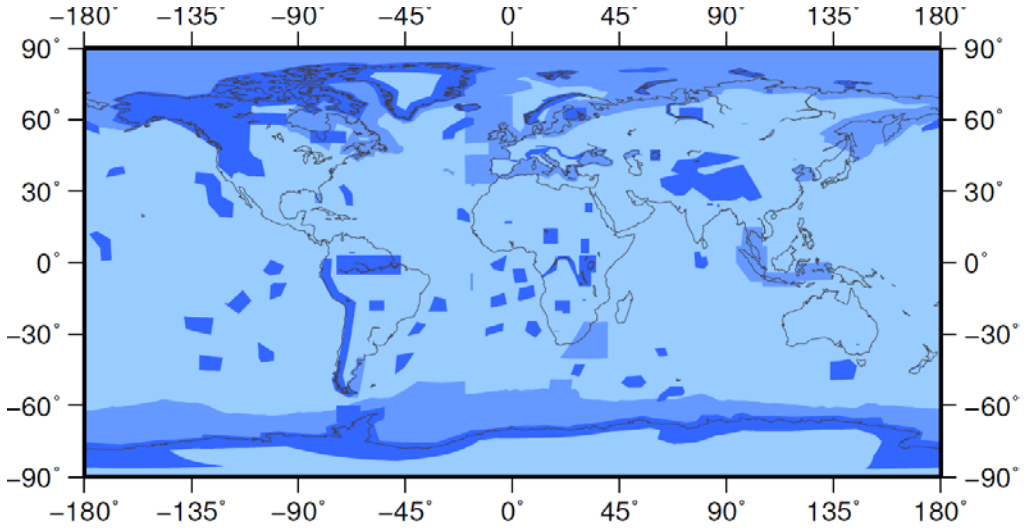
Results / considerations:

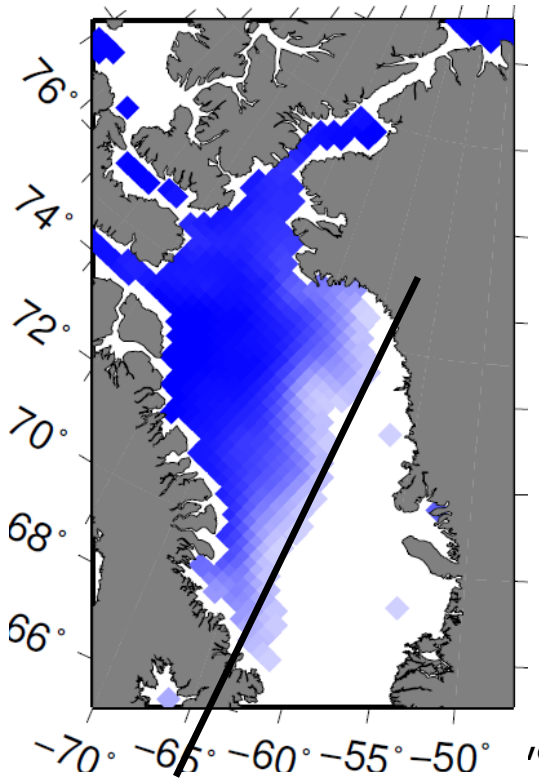
Cryosat improves the results marginally (5-10% most from CRYOSAT)

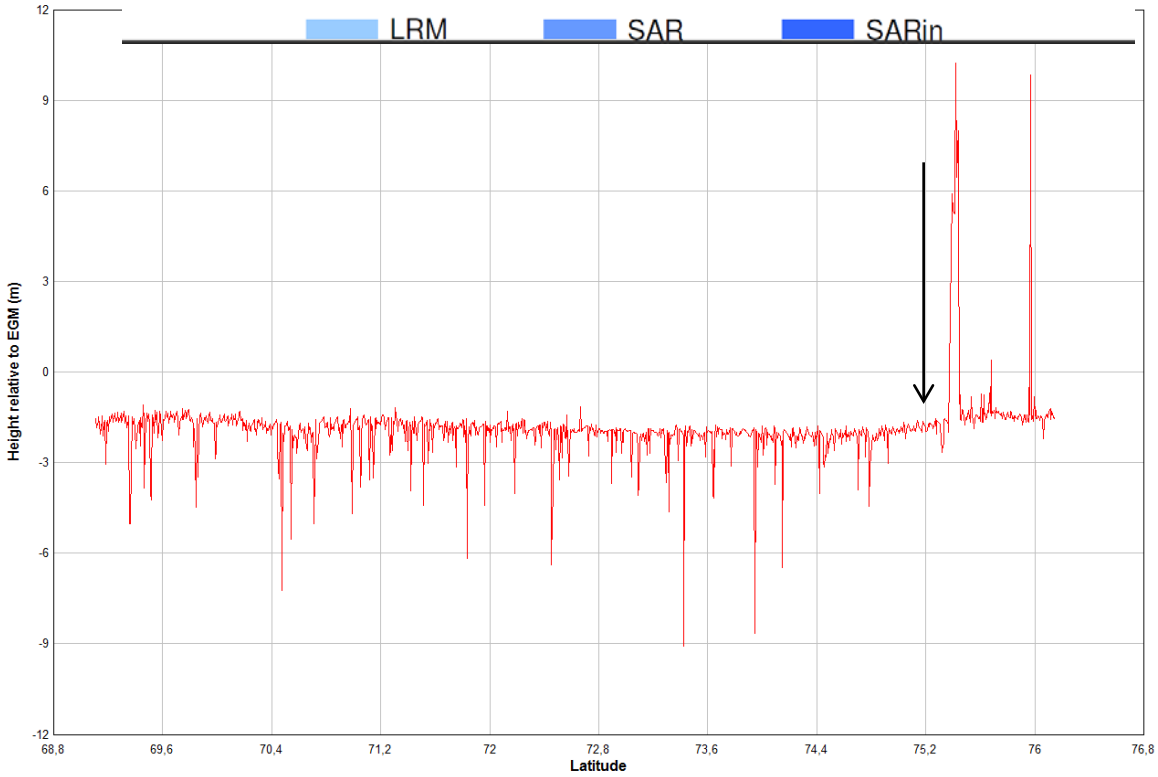
Coastal areas are much improved (also by increasing smoothing).

We NEED TO DO BETTER IN THE DEEP OCEAN (focus area).

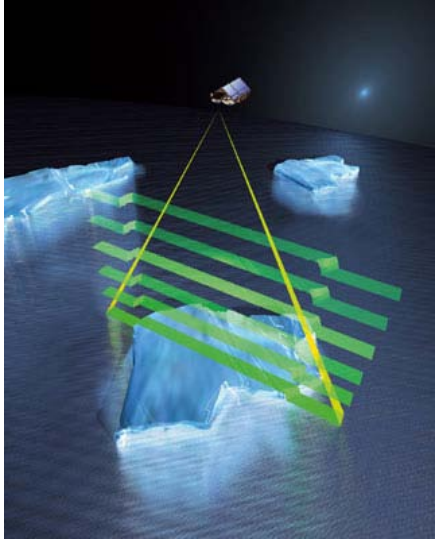
Coastal Issues (CRYOSAT SAR vs SAR-IN).







Cryosat considerations



- ESA starts release revised CRYOSAT data in february 2012.
- Problem is the sharp pulse. Should have been solved by ESA. This should lower noise considerably.
- LRM are of comparably accuracy to ERS GM
- SAR data is getting towards comparably accuracy

- No information on CRYOSAT range corrections and many areaerror. We currently use these.
- NOAA releases now far better Cryosat than ESA (RADS)
- We would like to apply reange corrections that we know (like GOT 4.7)

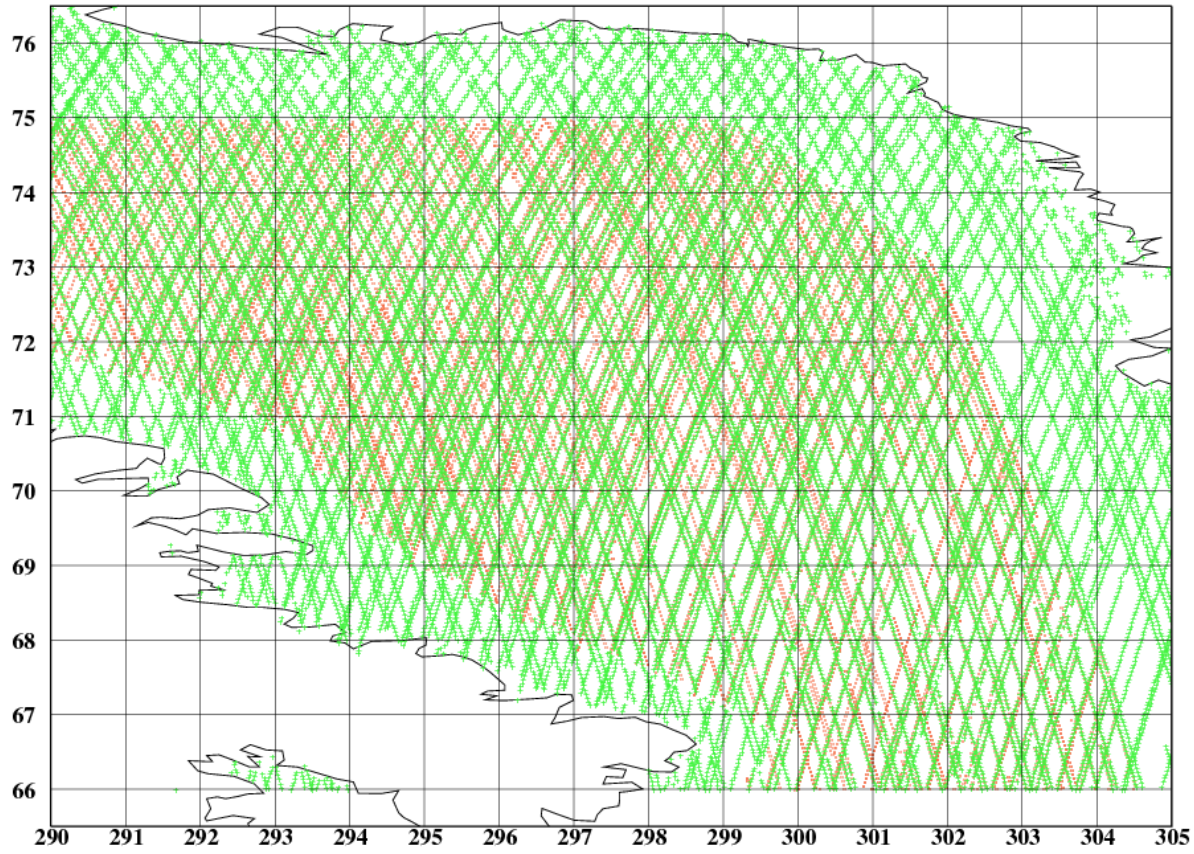
- Cryosat-2 is halfway into second repeat.
- We have tested using two repeats. Noise should be lowered by 1.4 = sqrt(2), but still very noisy signal
- Results are not much improved.

- We need to broaden to hole Arctic and compare.

Retracking first Cryosat SAR-IN

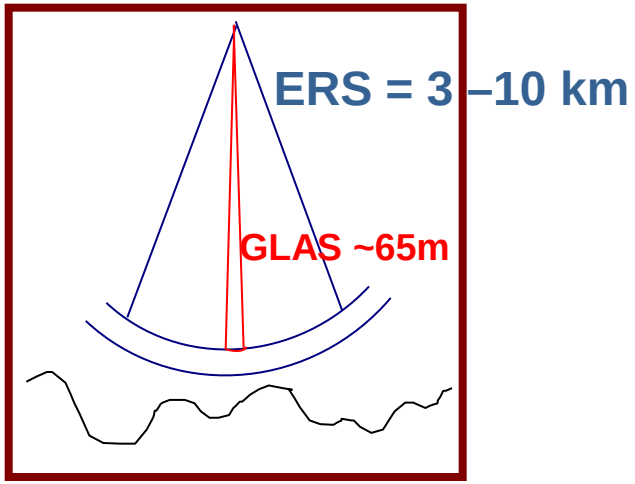
Gravity test in Baffin Bay.

RMS of gravity comparison increased marginally due to mainly more data.



Difference - Radar and Laser Altimetry

GLAS has much smaller footprint than radar altimeter instruments such as ERS and ENVISAT's RA-2 (3-10 km)

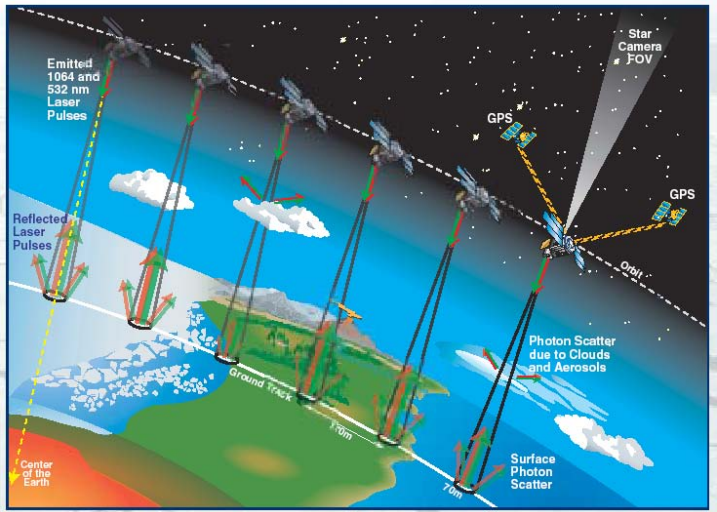


Small footprint enables GLAS to measure small-scale features on the ice sheet, previously unresolved in radar altimetry (65-70 meters)

Radar altimeter pulse (frequency 13.8 GHz) penetrates the surface of the ice, leading to volume scattering within the snow-pack. Effect increases in the dry snow zone and high accumulation areas

Observations at 40 Ghz corresponding to 150 meters distance between individual observations

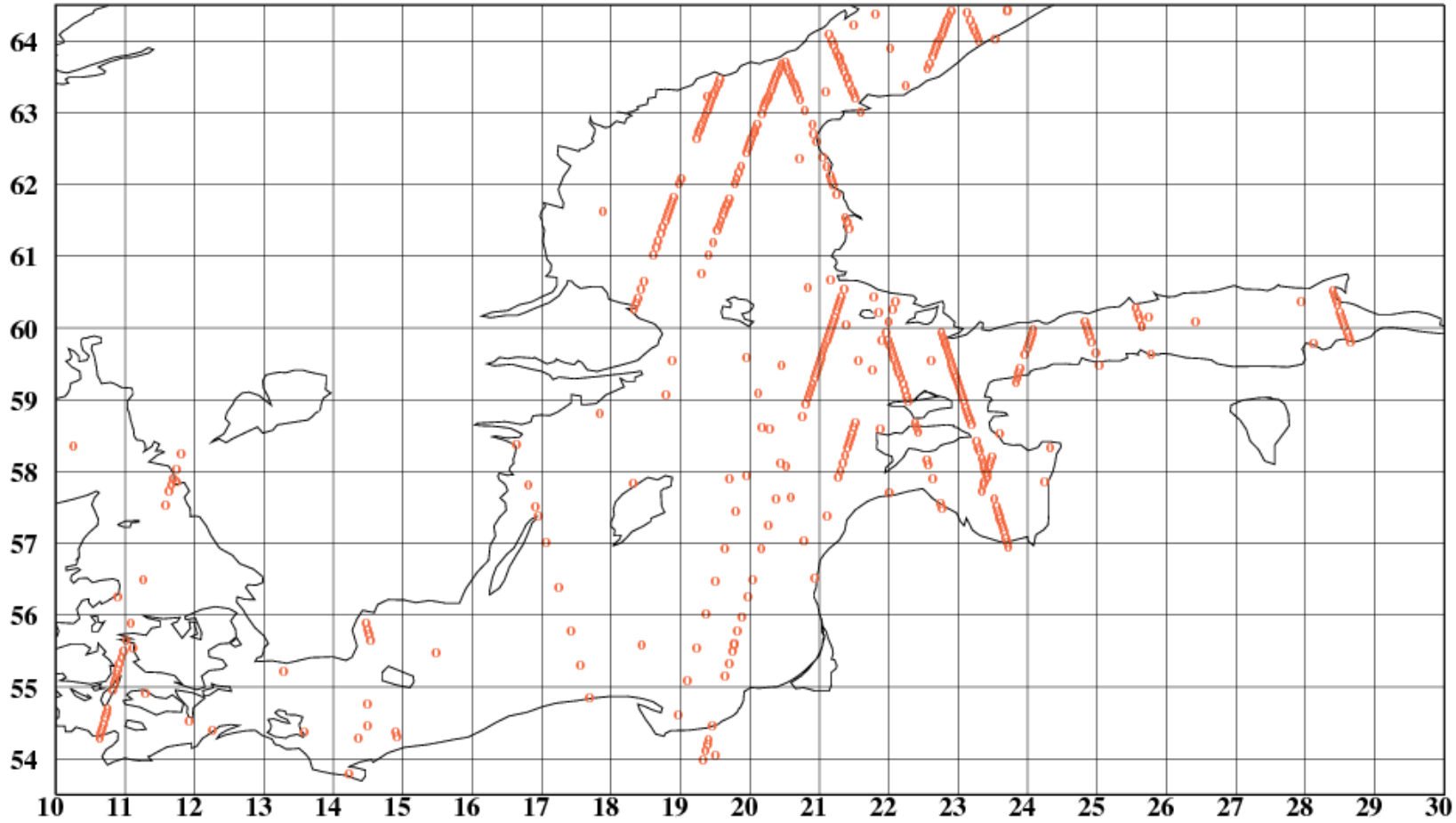
Coastal problems due to saturation.
Should be solved in newest issue



Using ICESat in coastal regions

120 m along-track resolution vs. 5-10 km for radar altimetry.

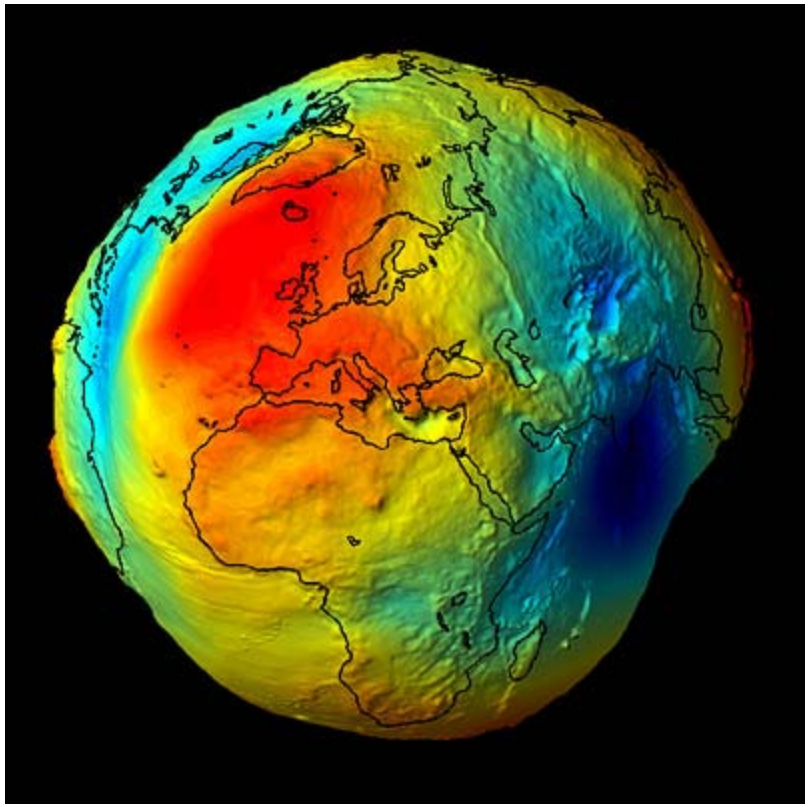
Currently being reprocessed and we await Release 33 of the data.



Example of data from last ICeSAT Epoch C3L with only 10 days data.

We have a total of 18 epochs of 30+ days.

GOCE.

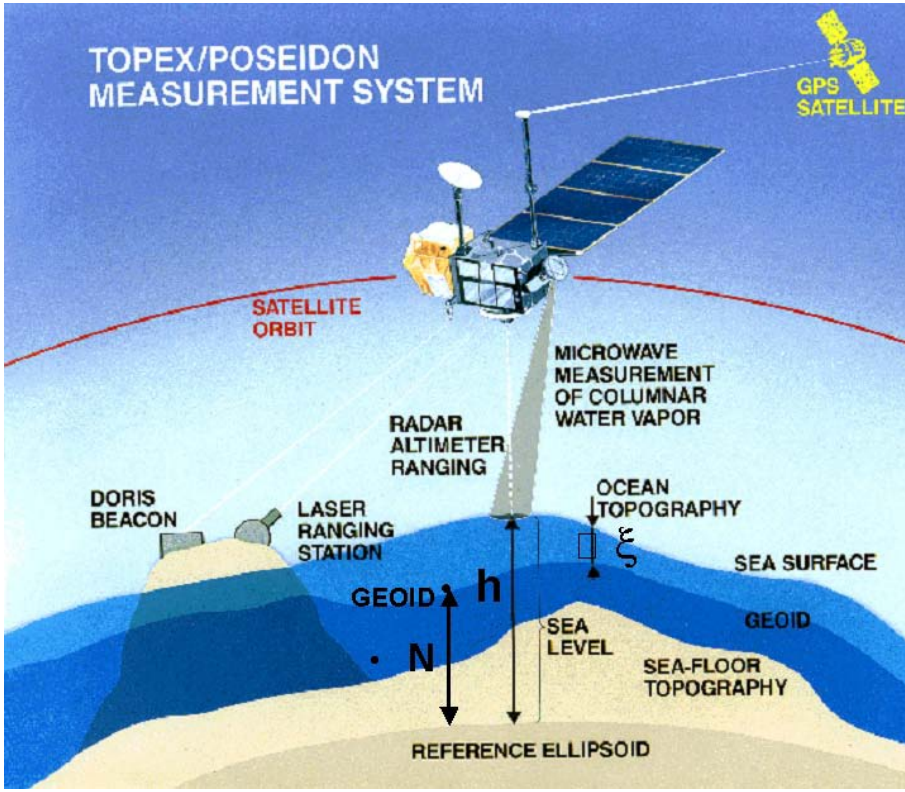


Altimetry observes the sea surface height (SSH)

The orbital height of the space craft (rel to the ref ellipsoid) minus the altimeter radar ranging to the sea surface corrected for path delays and environmental corrections yields the sea surface height:

$$h = N + \xi + e$$

$$h = N_{REF} + \Delta N + \xi_{MDT} + \xi(t) + e$$

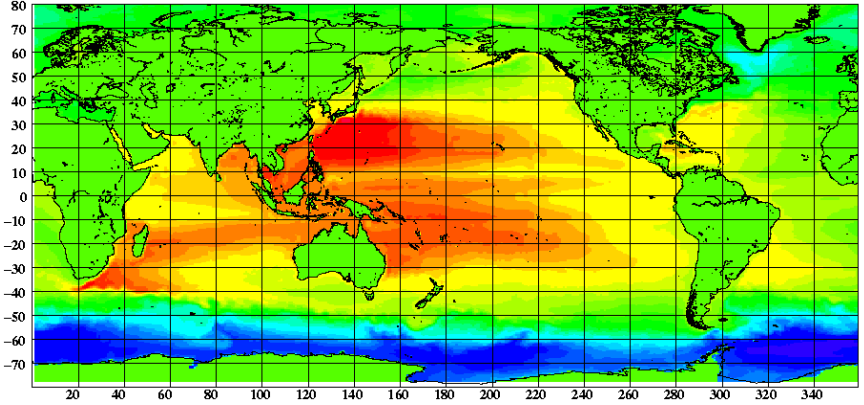


Enters altimetric gravity prediction in two ways:

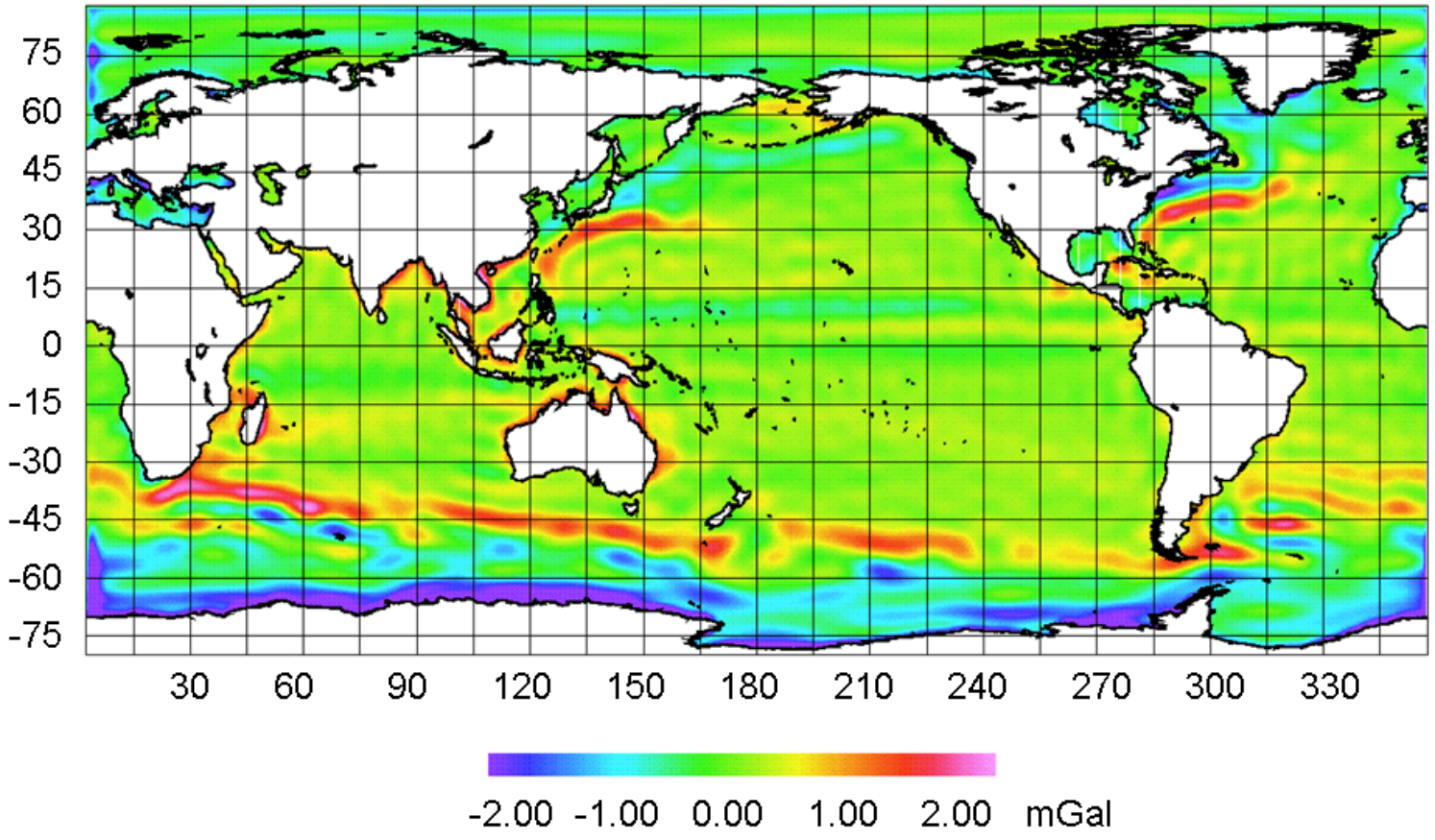
Through better estimation of ξ_{MDT}

Through better estimation of N_{REF}

The Mean Dynamic Topography (MDT)

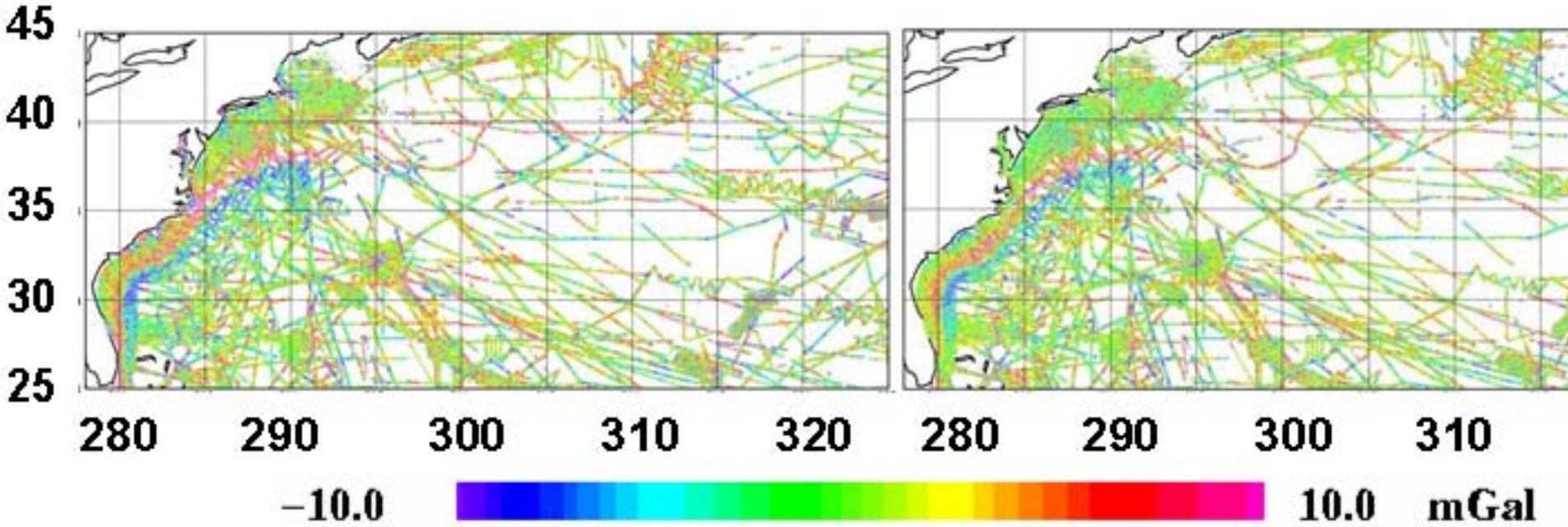


Gravity effect of MDT (DOT07A – dg 50)



MDT and Gravity Errors

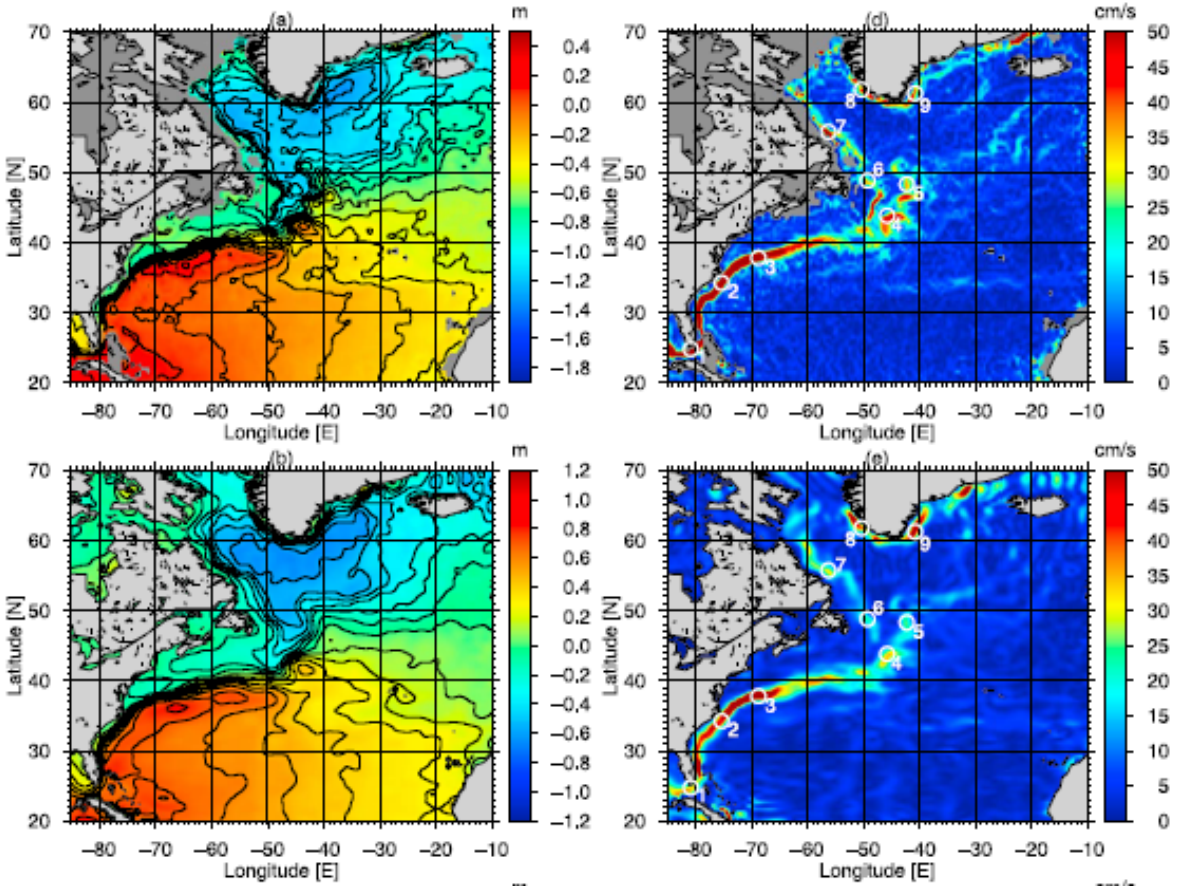
- Gravity Differences with 321400 Marine gravity observations
- KMS02 DTU10GRA



321.400 obs	Mean	Std Dev (mGal)	MDT
KMS02	0.44	5.15	None
DTU10	**0.39**	**3.82**	**DOT07A**

GOCE MDT test

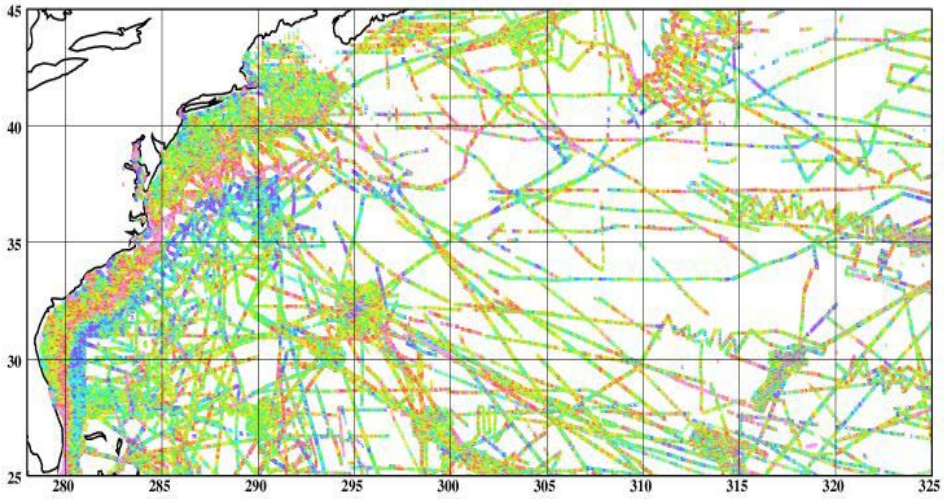
- Changing the DOT07A (degree and order 50) MDT used for DTU10 with
- MDT computed using GOCE R1 geoid and the DNSC08MSS
- 1.5 degree gaussian filter.
- Using the GUT toolbox
- MDT similar to the one
- Used by R. Bingham et al
- (GRL, 2011)



GOCE MDT Gravity Test

Recomputing DTU10 1 min Gravity in the Gulf Stream region (changing nothing else)

Comparison with 321.400 high quality marine Gravity obs



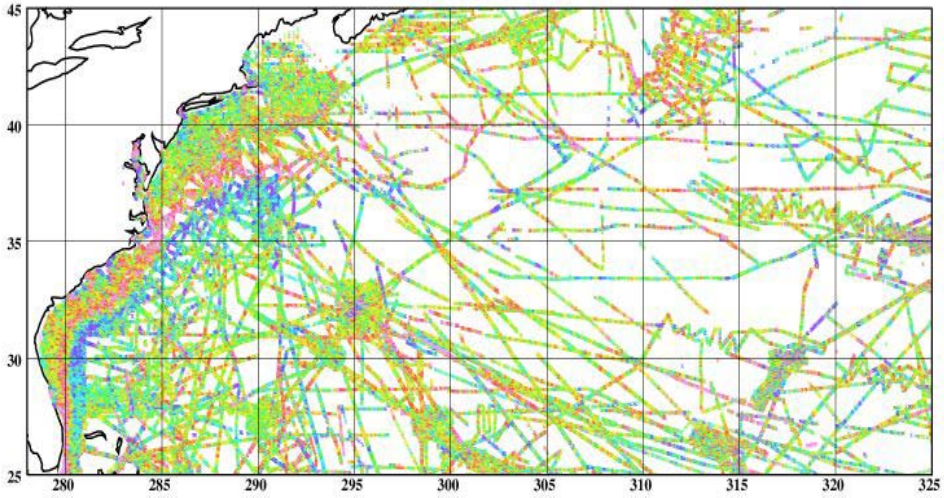
321.400 obs	Mean	Std Dev (mGal)	Max Dev	Note
KMS02	0.44	**5.15**	49.38	No MDT used
DNSC08	0.39	3.91	36.91	DOT07A MDT (do50)
DTU10	0.39	3.82	36.89	EGM2008 Geoid
GOCE DTU10	**0.39**	**3.71**	**33.71**	**GOCE MDT**

Altimetric Gravity improves

But more studies should be investigated (filtering etc)

Testing using 6 GOCE geoids
Lowest spharm for comparison

Gravity can be used for testing
DIR-1 contains some altimetry.



321.400 obs	Mean (mGal)	Std Dev. (mGal)	Max Dev(mGal)
GO_DIR_R1 (210)	-1.32	18.33	255
GO_DIR_R2 (210)	-1.39	19.45	261
GO_TIM_R1 (210)	-2.93	20.39	266
GO_TIM_R2 (210)	-3.11	20.11	264
GO_SPW_R1 (210)	-2.63	21.43	279
GO_SPW_R2 (210)	-2.48	19.69	259

Using GOCE via EIGEN 6C

Combination scheme of EIGEN-6C

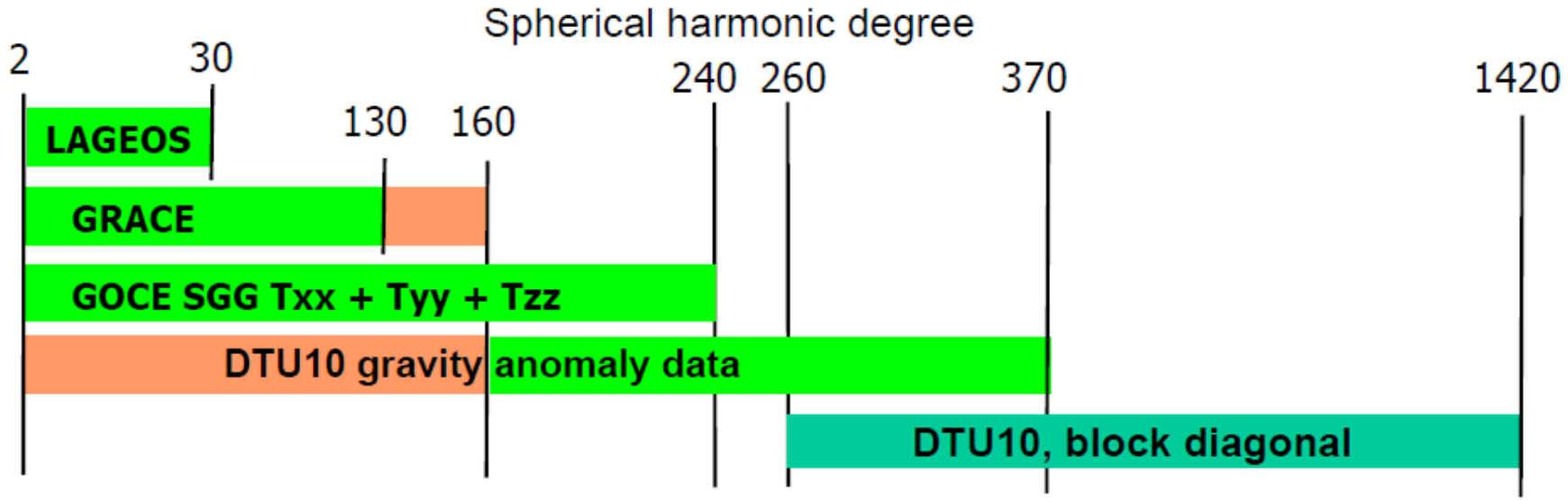
Accumulation of a full normal matrix up to d/o 370:

~200.000 parameters, ~ 250 GByte

contribution to the solution:

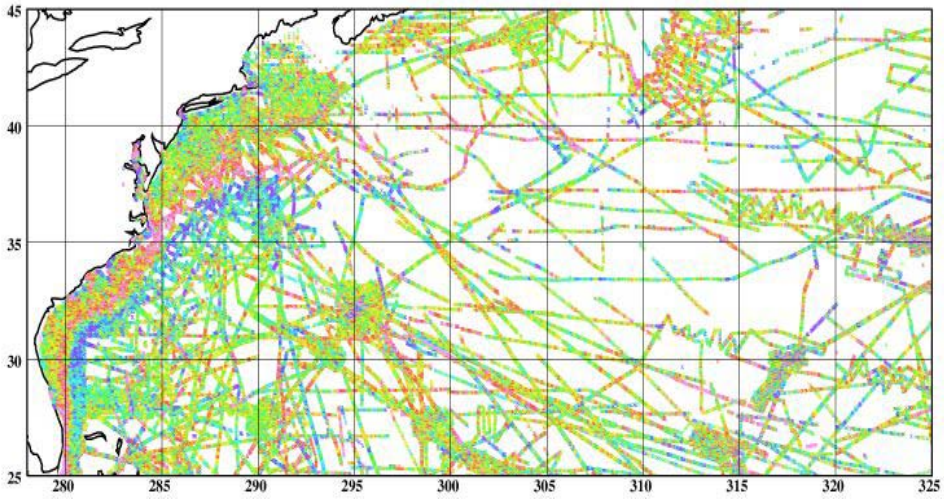
kept separately:

Separate block diagonal solution:



EIGEN 6C

Using Eigen 6C from GFZ (Foerste et al.,) changing nothing else.
EGM MDT used.



321.400 obs	Mean	Std Dev (mGal)	Max Dev	Note
KMS02	0.44	**5.15**	49.38	No MDT used
DNSC08	0.39	3.91	36.91	DOT07A MDT (do50)
DTU10	0.39	3.82	36.89	EGM2008 Geoid
EIGEN 6C	**0.05**	**4.28**	**38.88**	**GOCE**

Identical conclusions (EIGEN 6C) found for Baffin Bay

Summary

Employes a Ph.d on retracking.

Succesful retracking of SAR data. Trying SAR-IN now.

This is certainly work in progress and we are really on the way

Current Cryosat 2 data are comparable to existing GM altimetry

Need to await new Cryosat 2 and the back processing. Will take time

Rumours that Jason-1 will be changed to Geodetic Mission, but this will only improve up to 66N (no Arctic here).