DANISH NATIONAL SPACE CENTER

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Arctic Ocean Mean Sea Surface, Geoid and Gravity from Surface Data, Icesat and GRACE – a reference for Cryosat sea-ice mapping

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- Arctic Ocean geoid, MSS and sea-ice free-board heights
- Gravity from ICESat – improving the Arctic SSH
- Some comparisons to airborne data

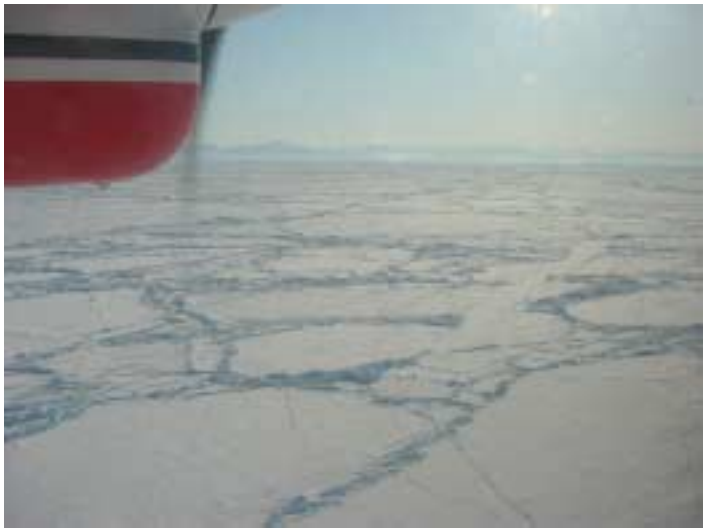
Freeboard, geoid and MSS

Basic principle:

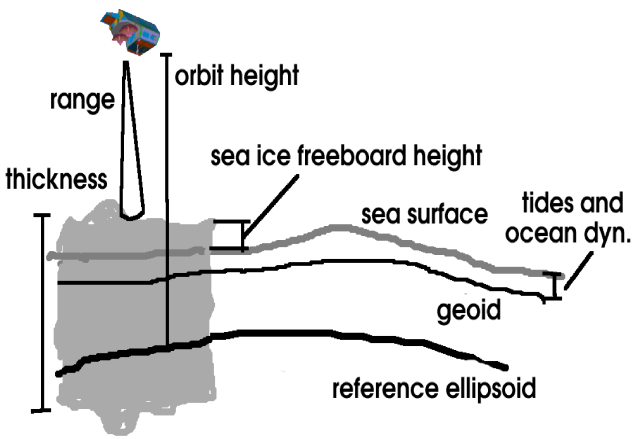
$$\mathbf{F = h_{satellite} - N - MDT + T}$$

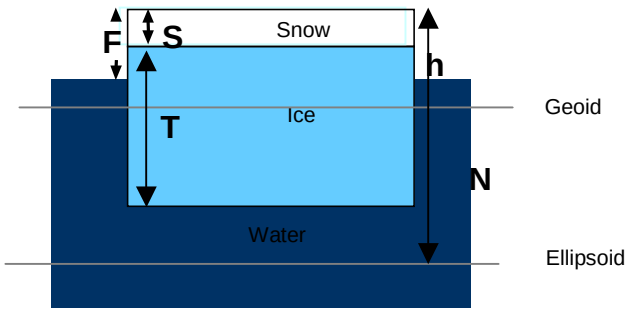
$$\mathbf{MSS = N + MDT}$$

F: Free-board (ICESat: snow, CryoSat: ice interface)
h: Ellipsoidal height of surface
N: Geoid model
MDT: Mean Ocean Dyn. Topography
T: Ocean tides

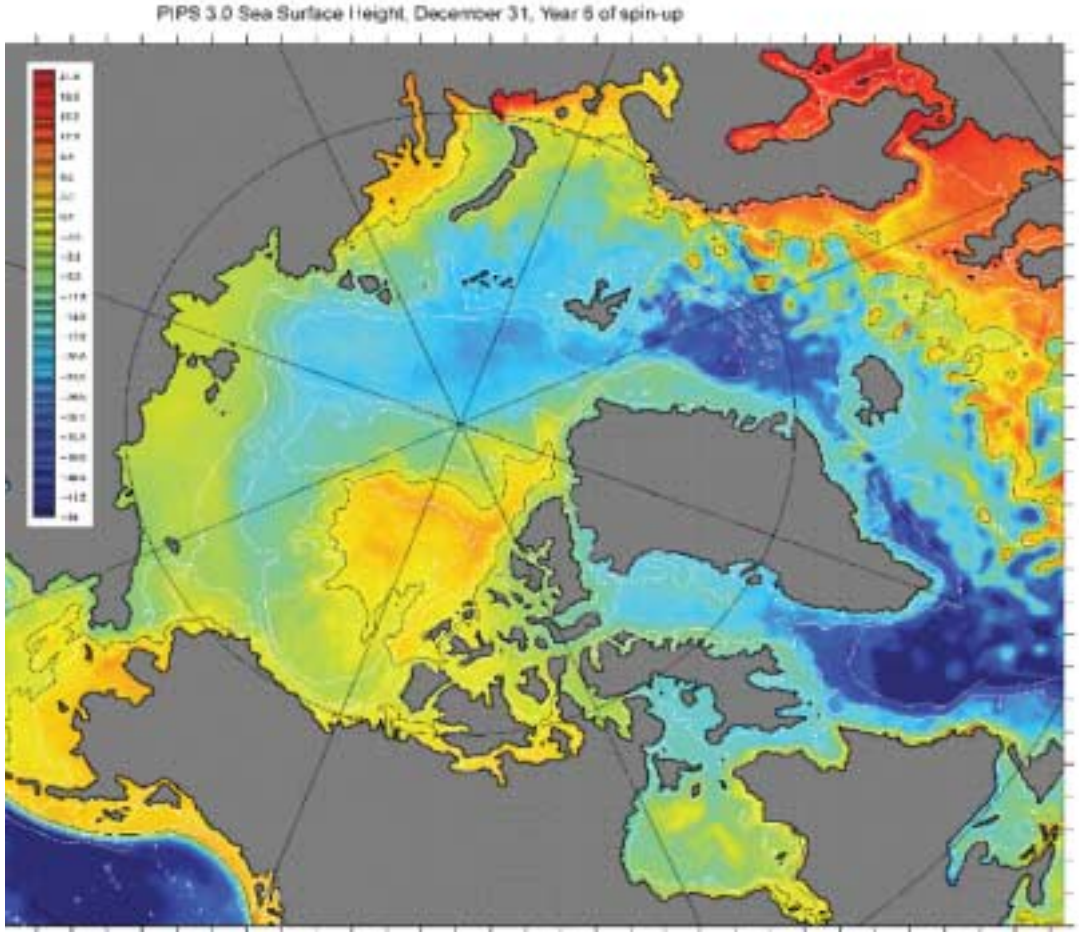


Sea-ice north of Greenland from 1000 ft, May 2002





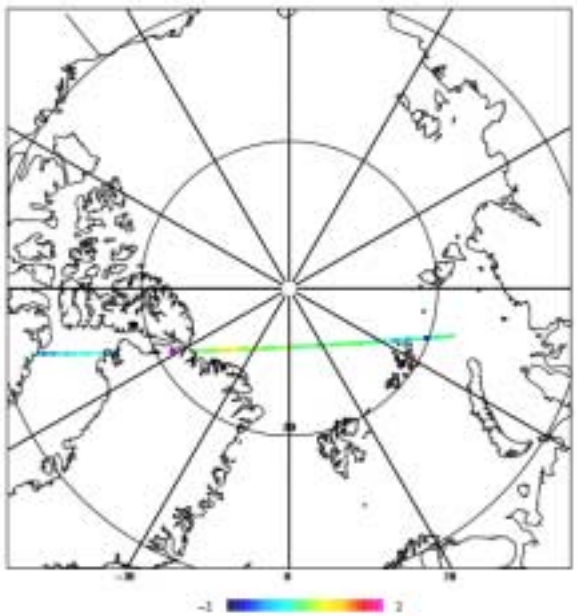
Example of MDT model of Arctic Ocean – PIPS / NPS (Maslowski)



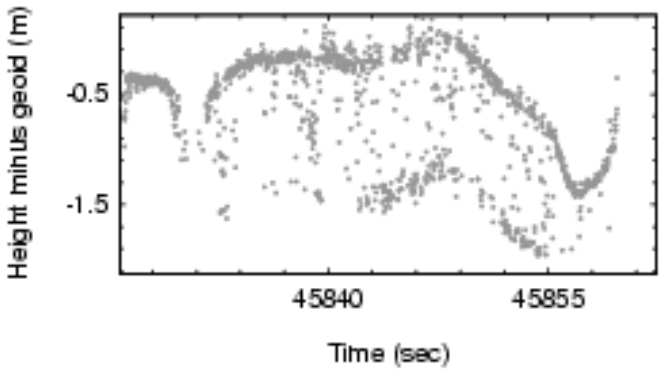
(provided by S: Laxon)

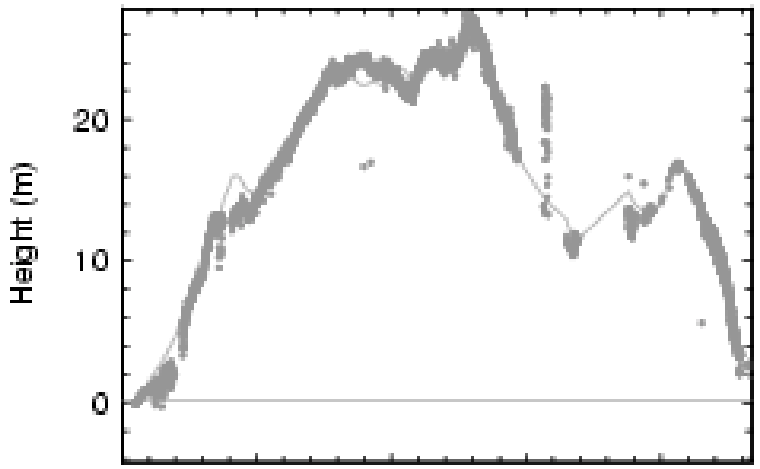
ICESAT track example: Geoid and ”lowest level” MDT

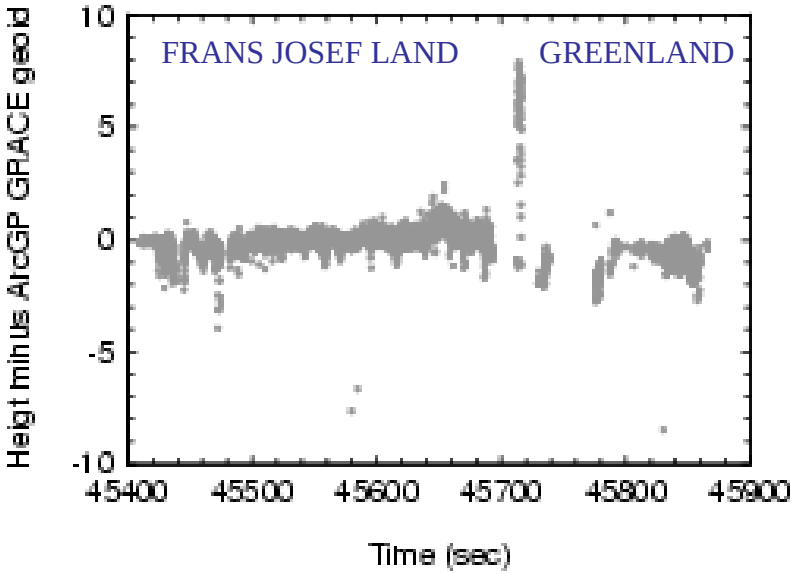
(Nov 2003)



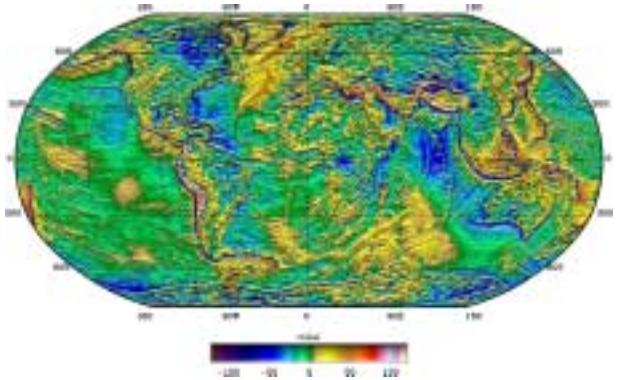
Details in Baffin Bay (Greenland)







Sources of geoid data (N):



1) Physical geodesy and GRACE:
Spherical harmonics and Stokes' formula:

$$N = N_{ref} + \frac{R}{4\pi G}\iint_{\sigma}(\Delta g - \Delta g_{ref})S(\psi)d\sigma$$

$$N_{ref}(r,\phi,\lambda) = \frac{GM}{r\gamma}\sum_{n=2}^{\infty}\sum_{m=0}^{n}\left(\frac{r}{R}\right)^{-n}\left[\overline{C}_{nm}\cos m\lambda + \overline{D}_{nm}\sin m\lambda\right]\overline{\mathrm{P}}_{nm}(\sin\varphi)$$

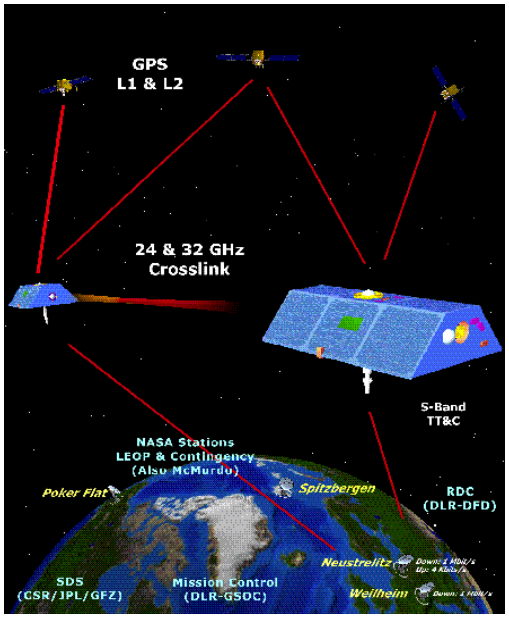
2) Altimetry – oceanographic modes:

$$N = SSH - MDT$$

New ESA study to make improved SSH and geoid by combining surface, airborne and satellite gravity measurements: **ARCGICE**

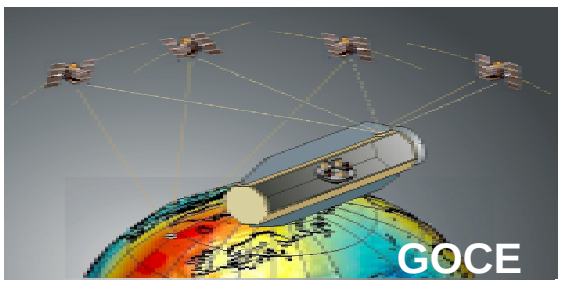
New satellite missions contributing to improved geoid and MSS

ICESAT

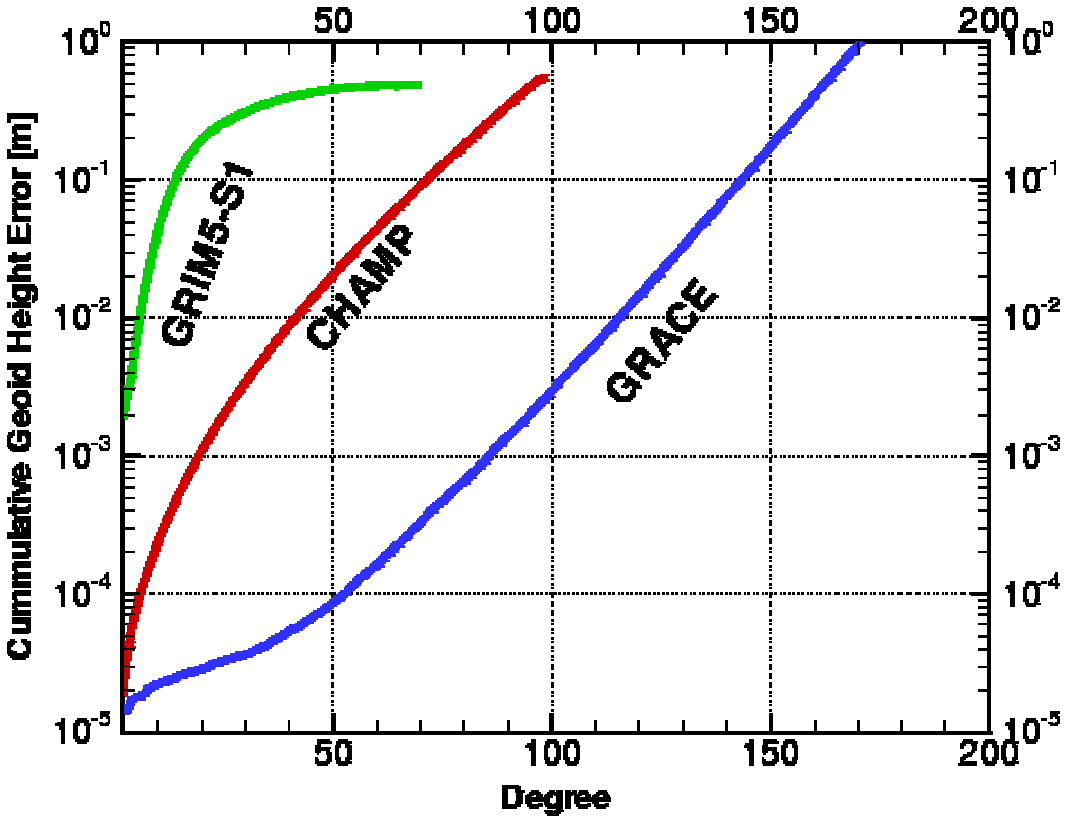


GRACE

CRYOSAT

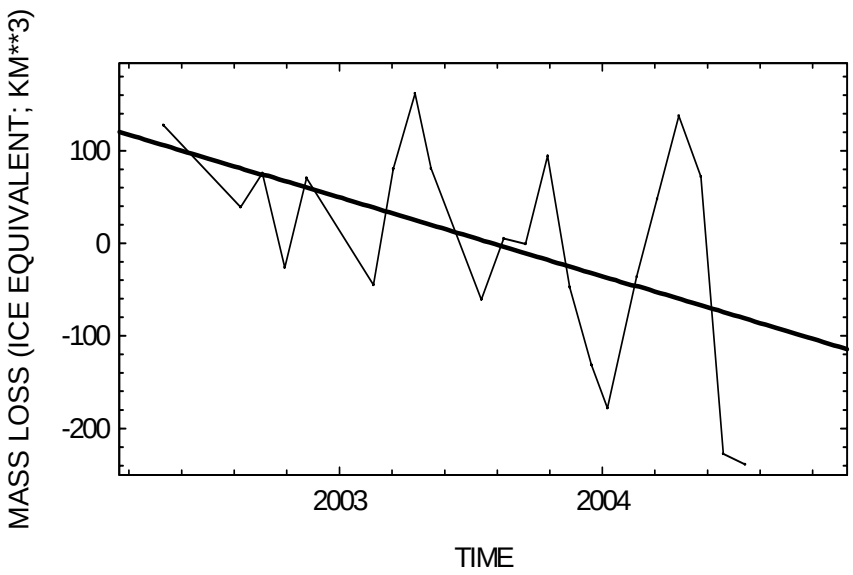


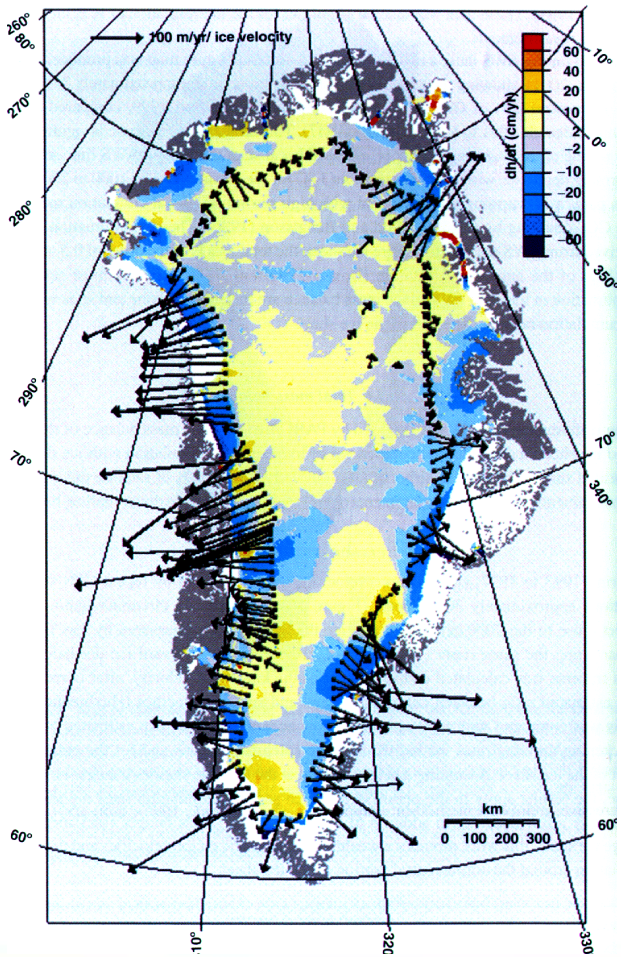
GRACE geoid: mm-accuracy at degree 90? (220 km resolution)



Real mission: ~1-2 cm r.m.s.?

GRACE and CryoSat symbiosis: Changing gravity field yields constraints on total ice cap mass loss

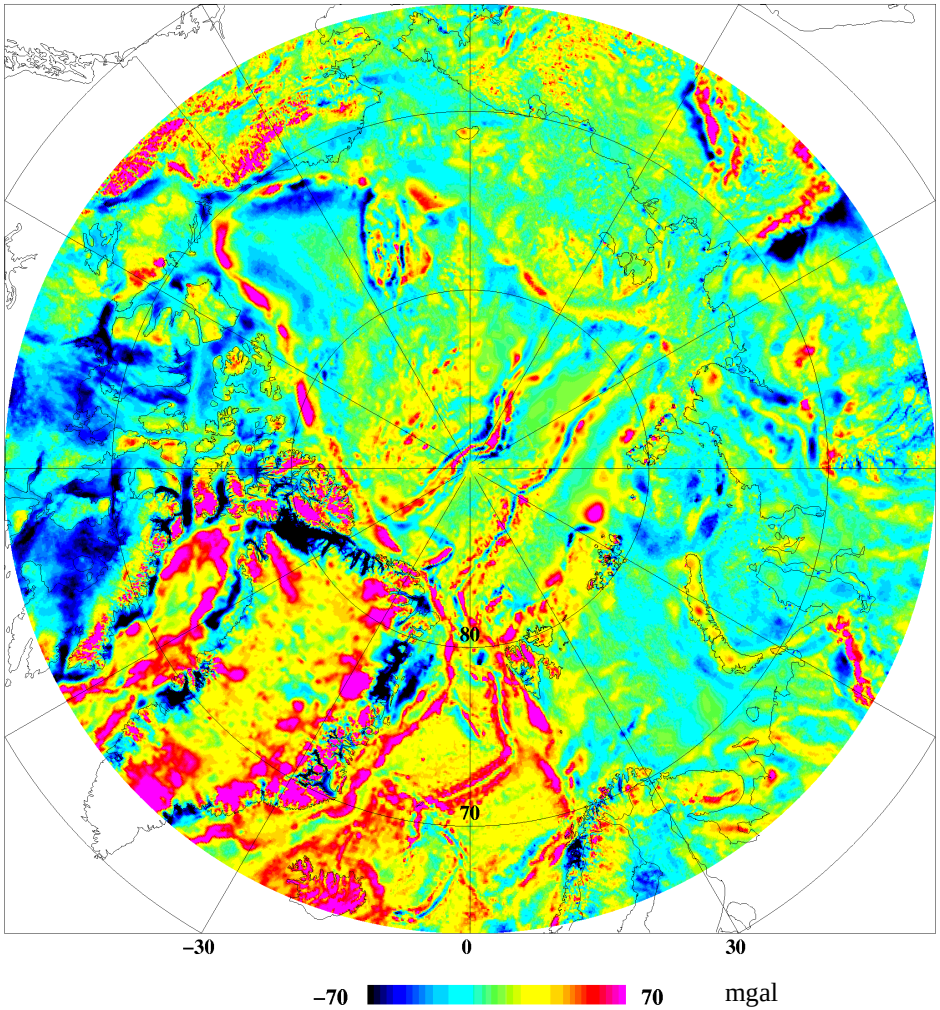




Greenland ice sheet total mass loss from GRACE monthly gravity fields 2002-04: **84 km^3/yr** (NASA Parca estimate 1993-99: 50 km^3/yr)

50 km3/yr ~ 0.13 mm/yr global sea level rise

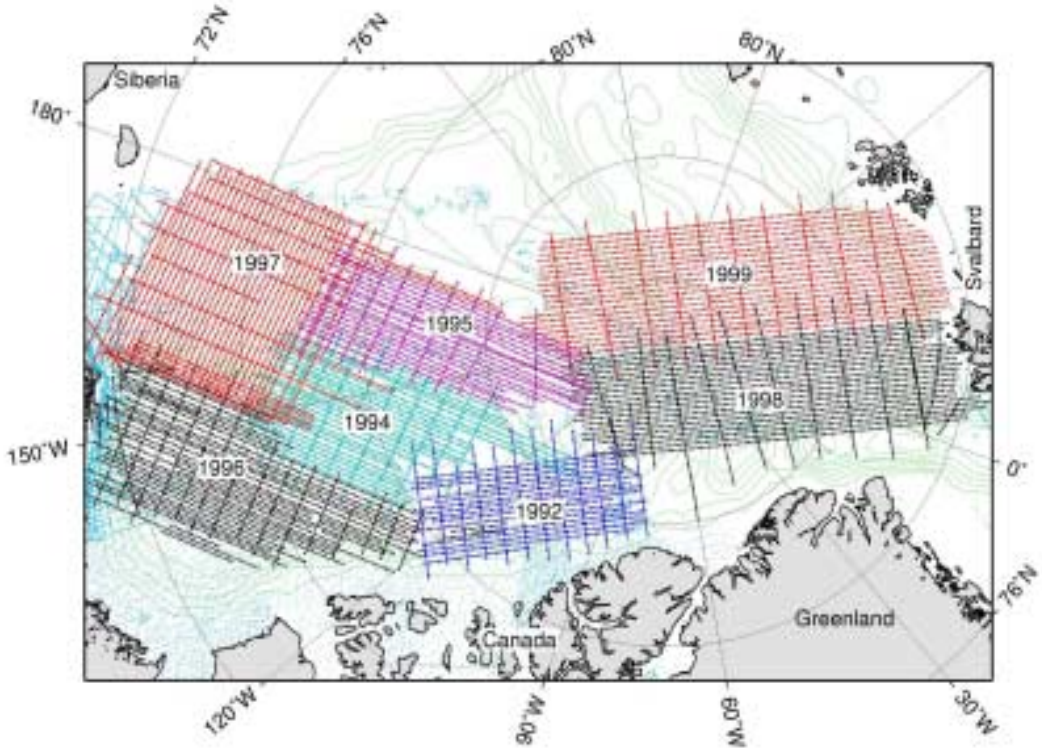
Source of geoid data: Arctic gravity project: Revised model 2005

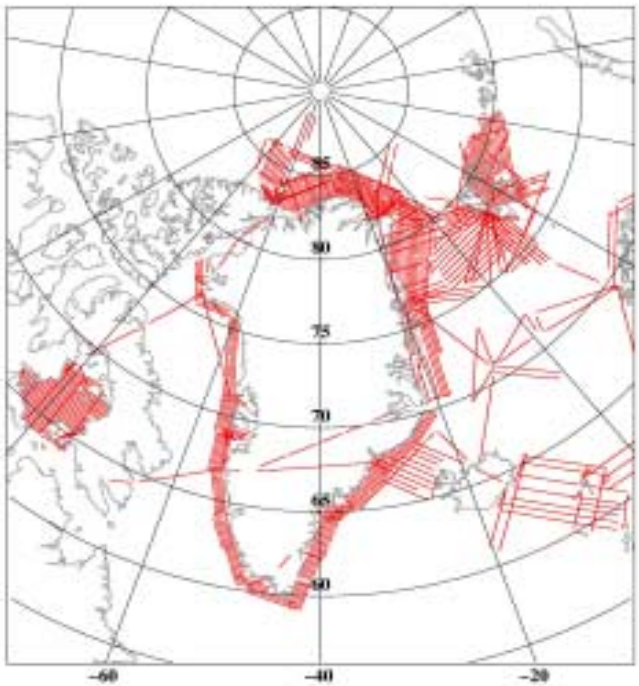


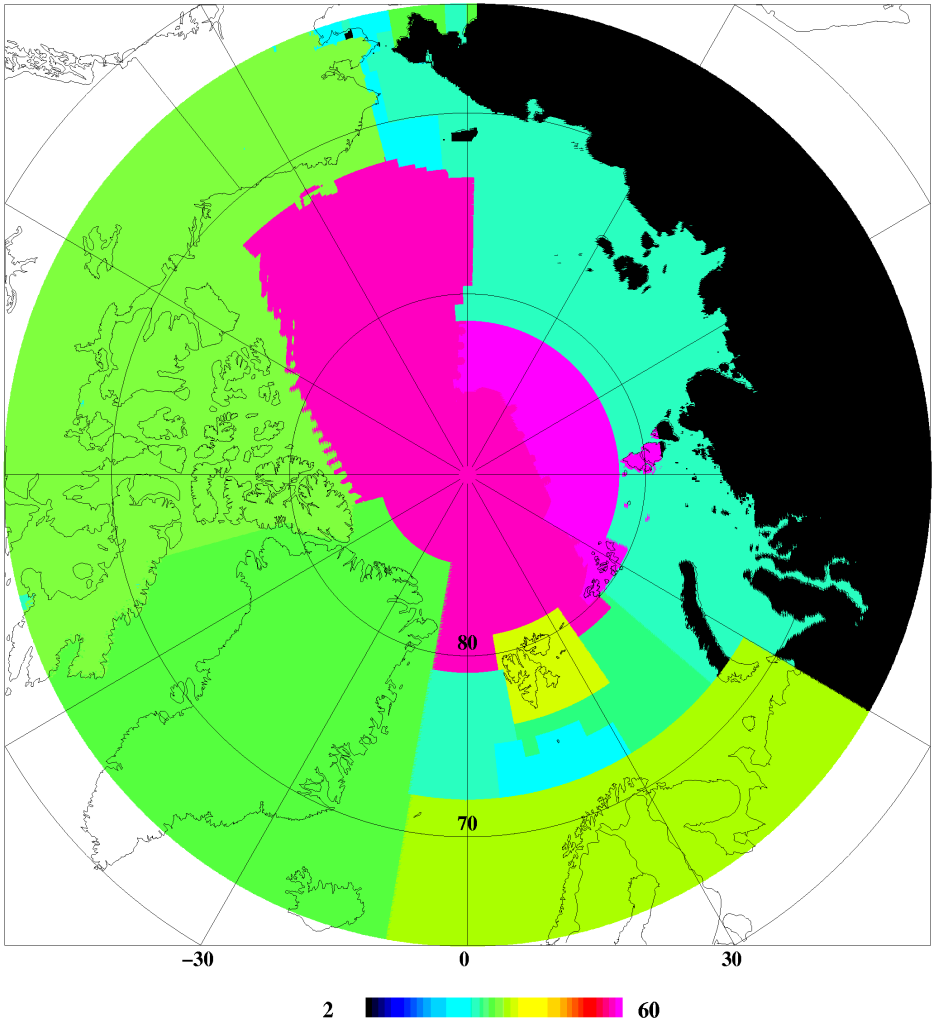
IAG Arctic Gravity project has compiled all available terrestrial, airborne and submarine data into 5’ grid

ARCGP data sources:

- Airborne, surface, submarine
- Satellite altimetry (Laxon/McAdoo)

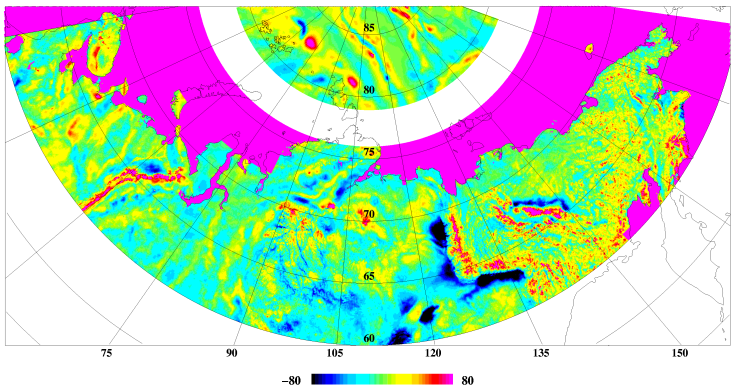






ArcGP data sources

New Russian Data



New geoid of the Arctic from ArcGP and GRACE

Method:

- Remove reference field (GRACE GGM02S + EGM96, merged at 100-110)

- Stokes integral on residuals, use Wong-Gore modified Stokes' kernel to avoid distortion at long wavelengths (kernel cut-off at degree 100)

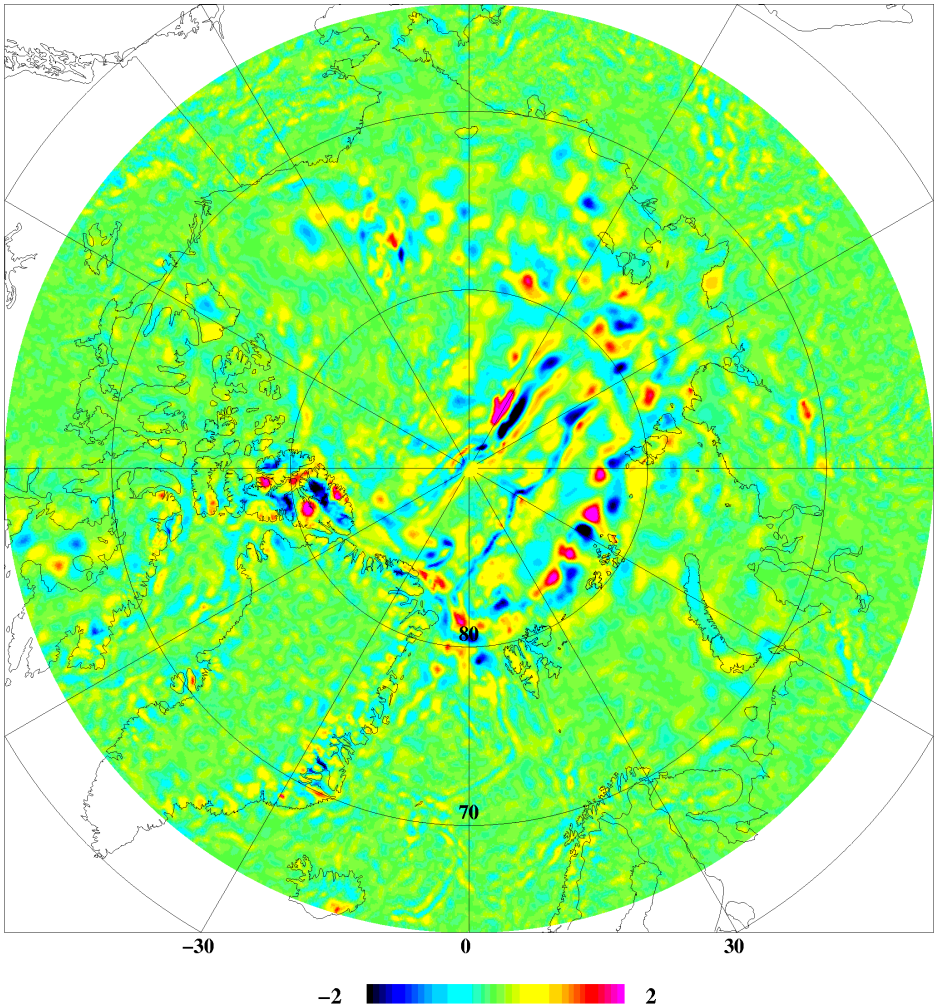
$$N = \frac{R}{4\pi G}\iint_{\sigma} \Delta g S'(\psi) d\sigma \qquad S'(\psi) = \sum_{l=N}^{\infty} \frac{2l+1}{l-1} w_1 P_l(\cos\psi)$$

- Stokes' integral implemented as 1-D spherical FFT (works at pole!)

- Restore reference field => final geoid

Statistics of reduction of gravity data

Unit: mgal	mean	std.dev.
ArcGP data	3.5	27.7
ArcGP – EGM96	0.1	17.4
ArcGP – GGM02S/EGM96	0.1	16.8

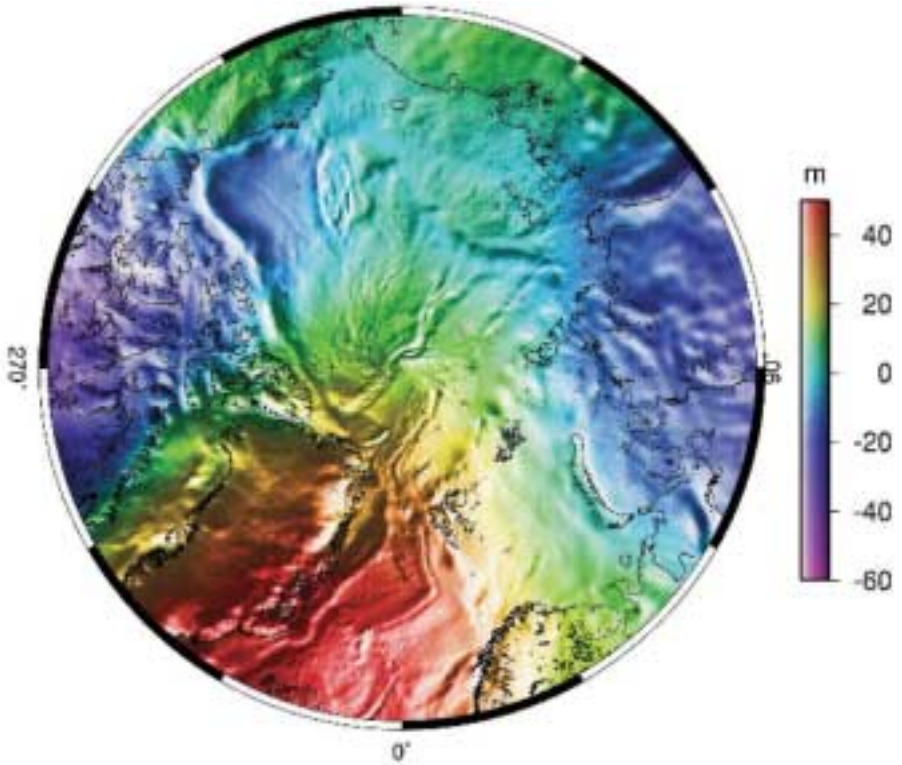


ArcGP-GRACE geoid model

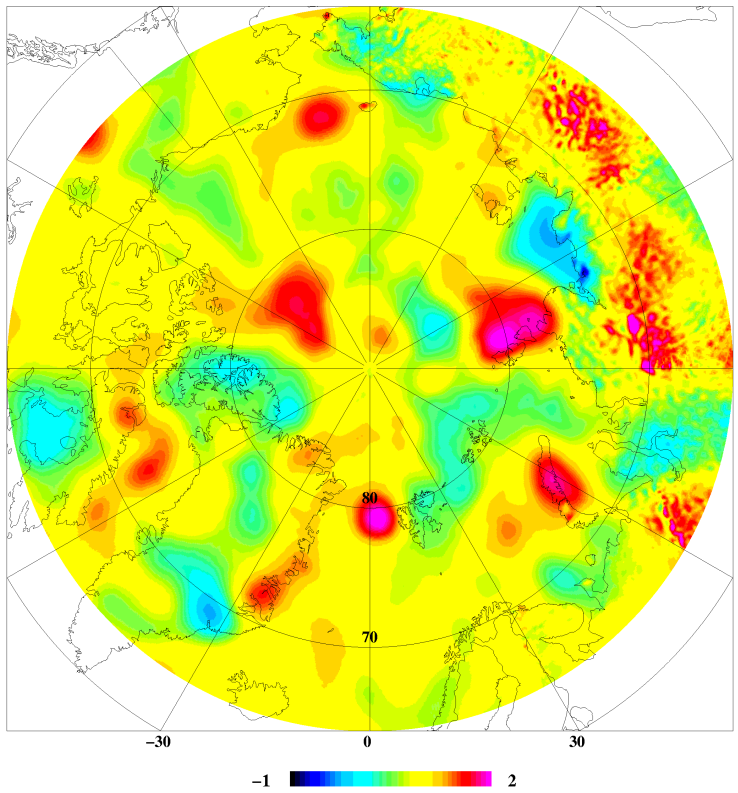
Geoid contribution from
local data (non-GRACE/EGM)

ArcGP-GRACE geoid model

”Old” 2002 ArcGP geoid model



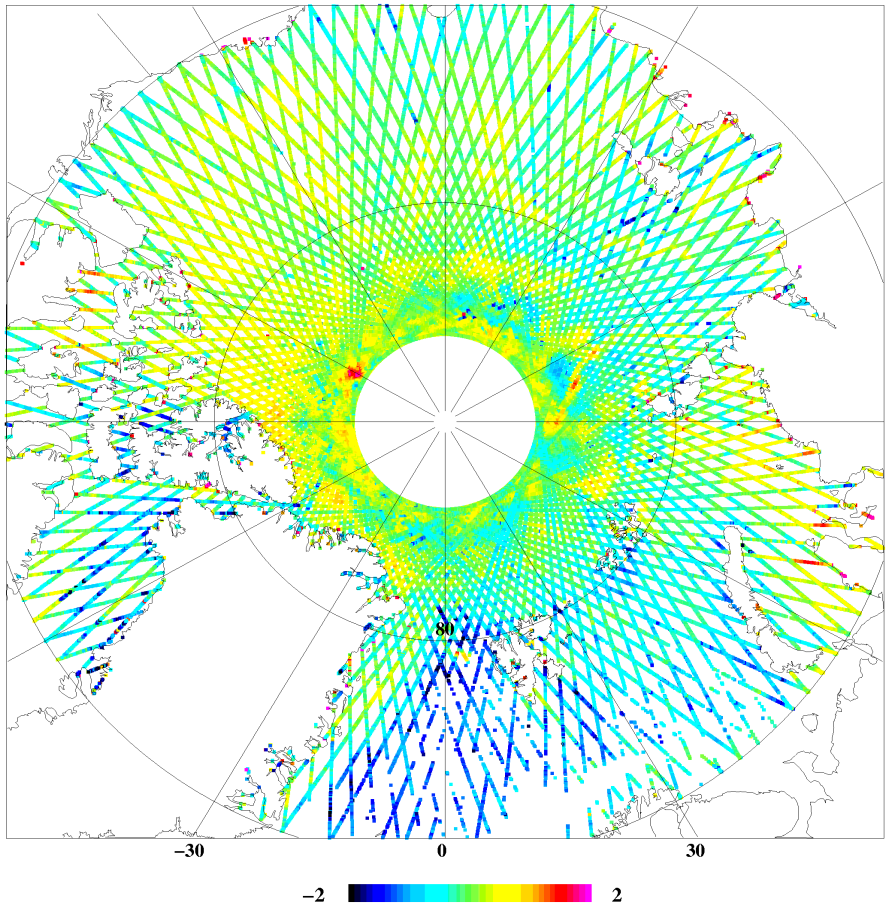
Difference between new and old geoid



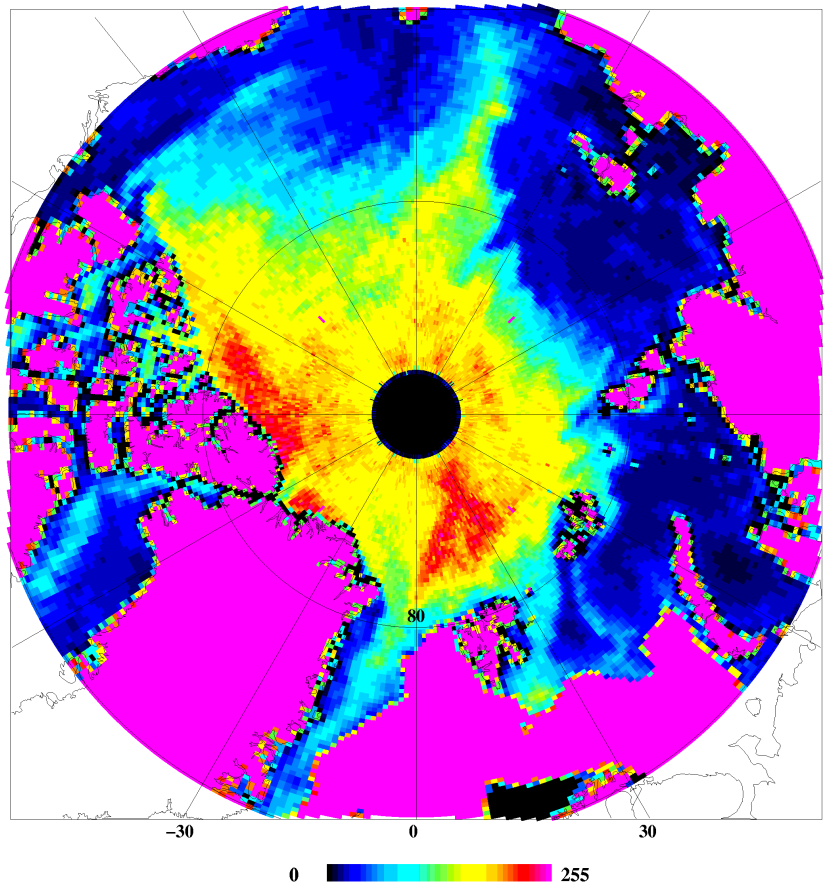
Unit: meter (scale –1 to 2)

ICESAT minus new geoid – March 2003

ICESAT residual mean heights: h - N (m)

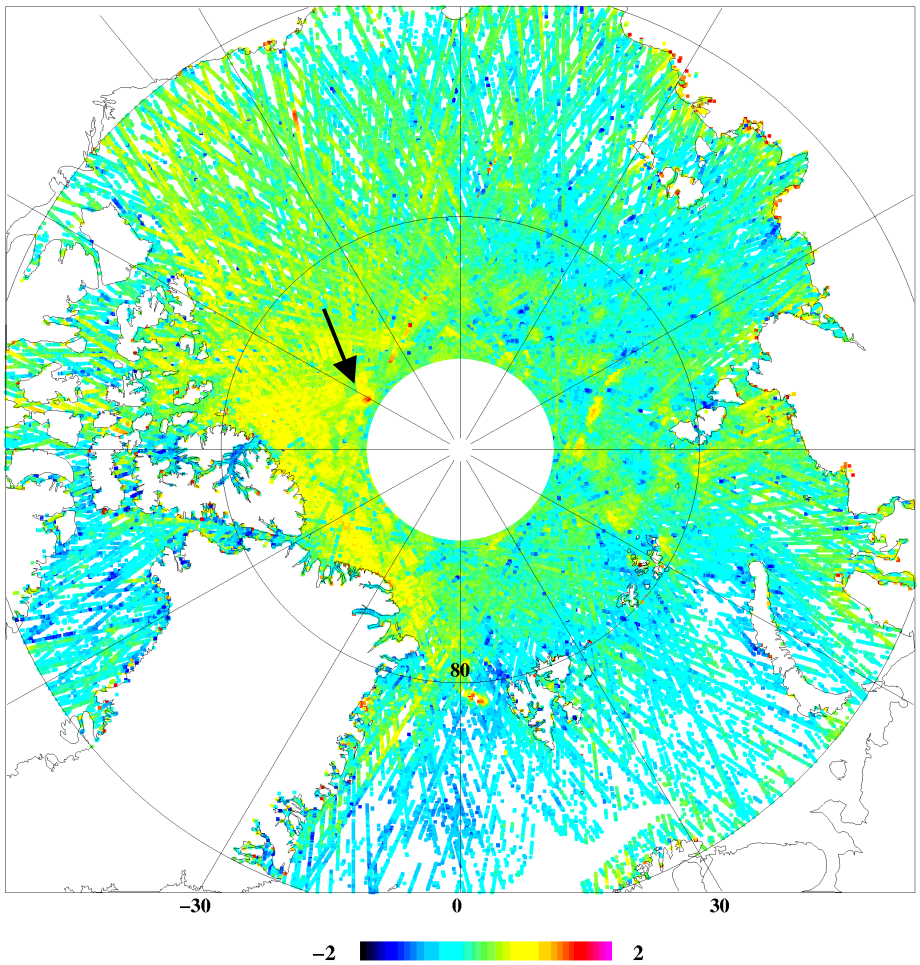


QUICKSCAT and 40% ice mask, Feb 21



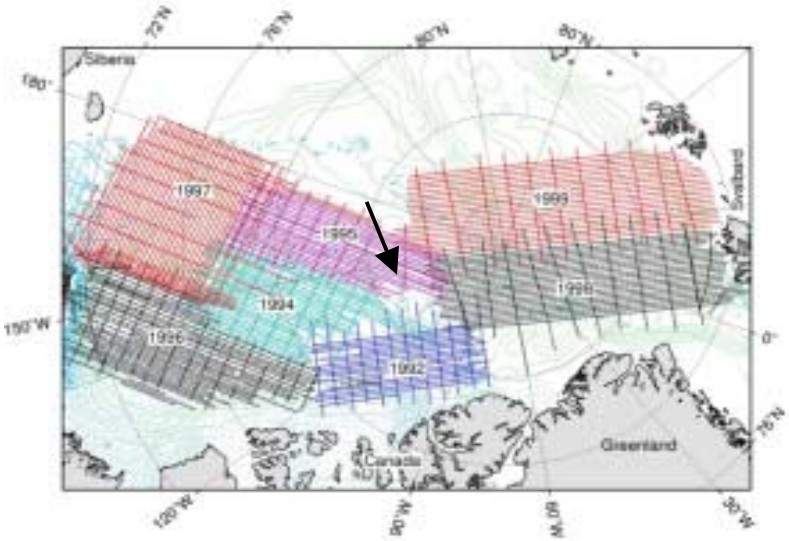
ICESAT-geoid difference – Oct/Nov 2003

ICESAT residual mean heights: h - N (m)

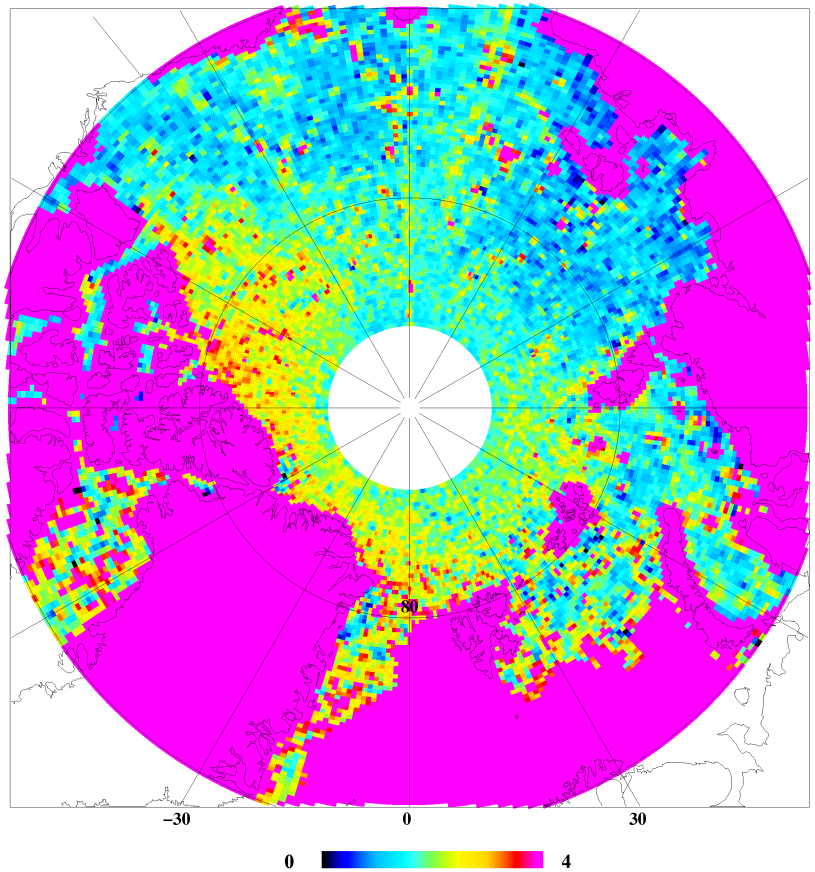


ArcGP data gap:

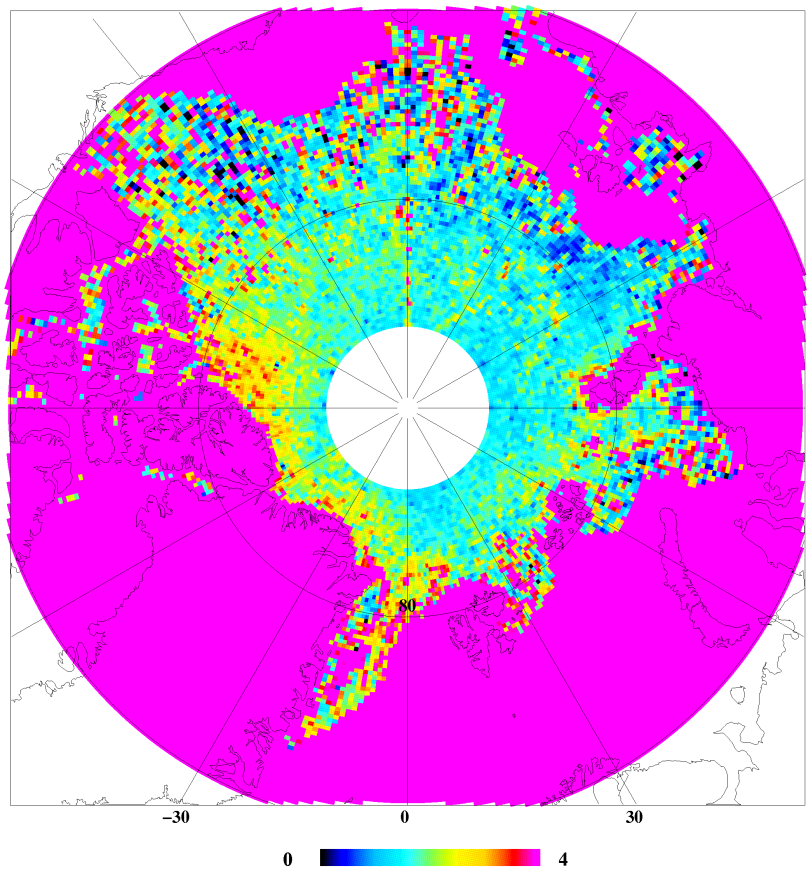
Coverage of US Naval Research Laboratory long-range airborne gravity in ArcGP



Thickness estimation (freeboard x 6.0) by lowest level filtering

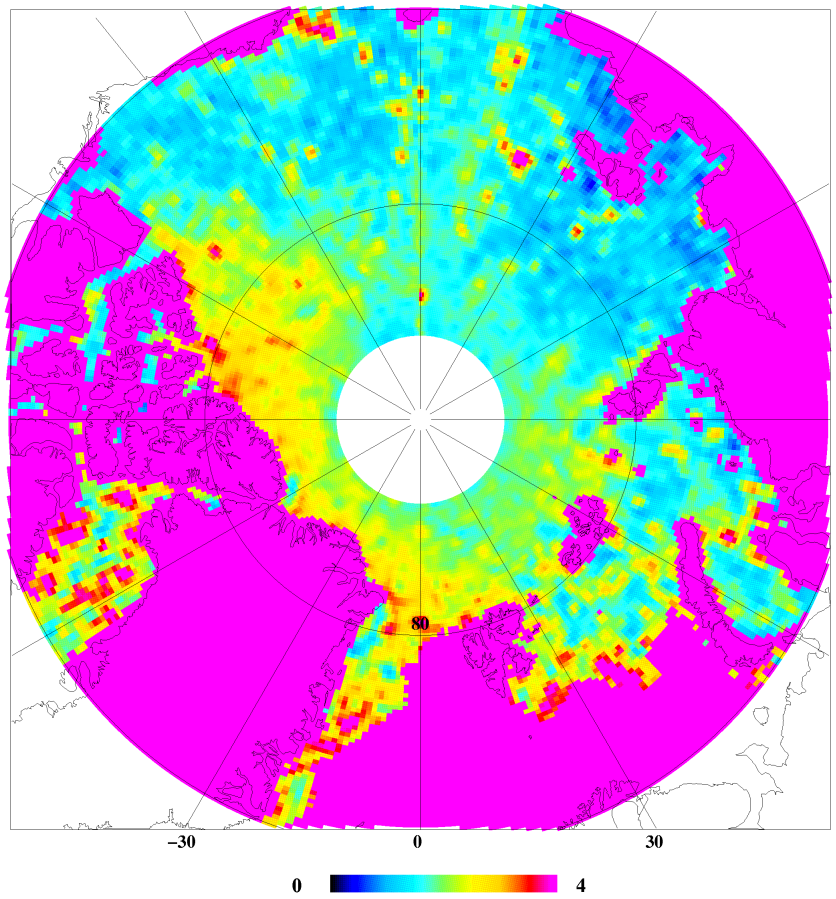


MARCH 2003

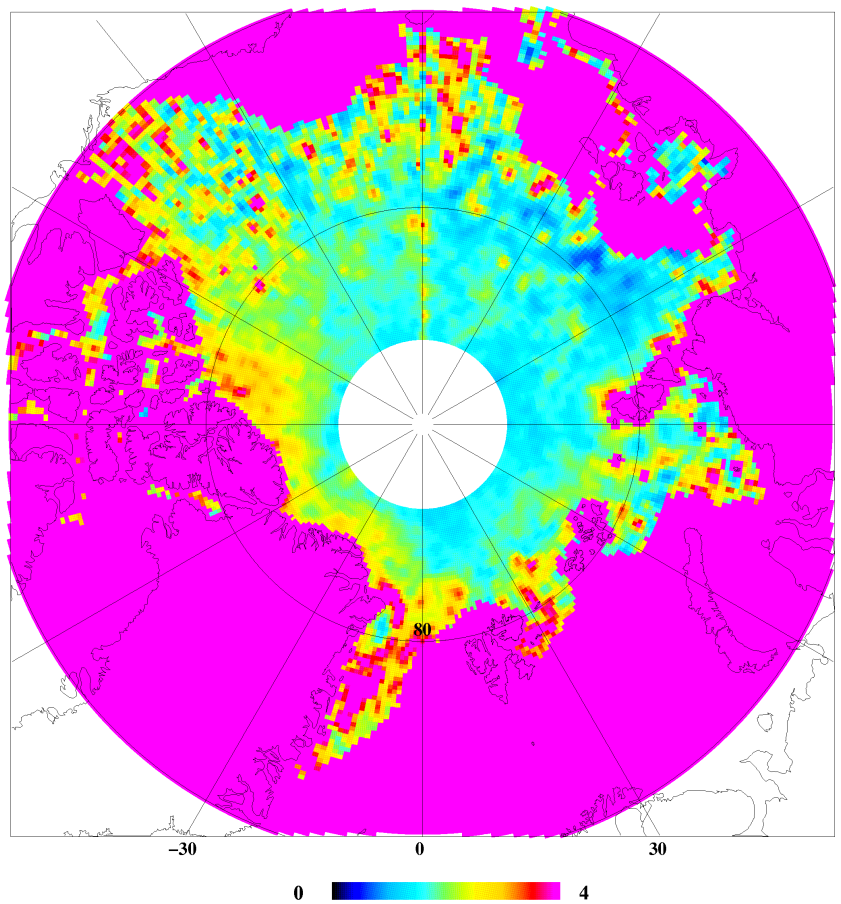


OCTOBER 2003

ICESAT thickness estimation (freeboard x 6.0) - filtered



MARCH 2003



OCTOBER 2003

ICESAT-derived gravity anomalies

ICESAT coverage to 86ºN => New gravity data recovery possibility – *update ArcGP*

Method principle:

Subtract sea-ice freeboard heights (in principle)

Geoid to gravity inversion by Wiener filtering FFT (Forsberg & Solheim, 1989)

$$N_{ICESAT} \cong h - F - MDT$$

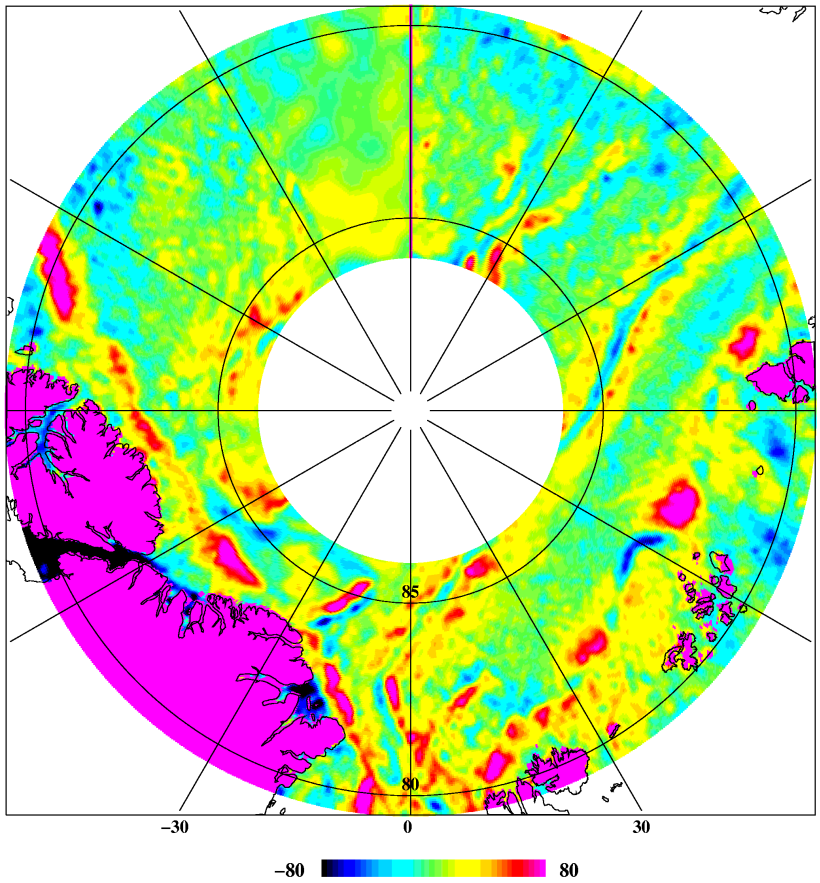
Here: F-MDT diminished by detrending

$$F(\Delta g) = \gamma \frac{k}{1 + ck^4} F(N)$$

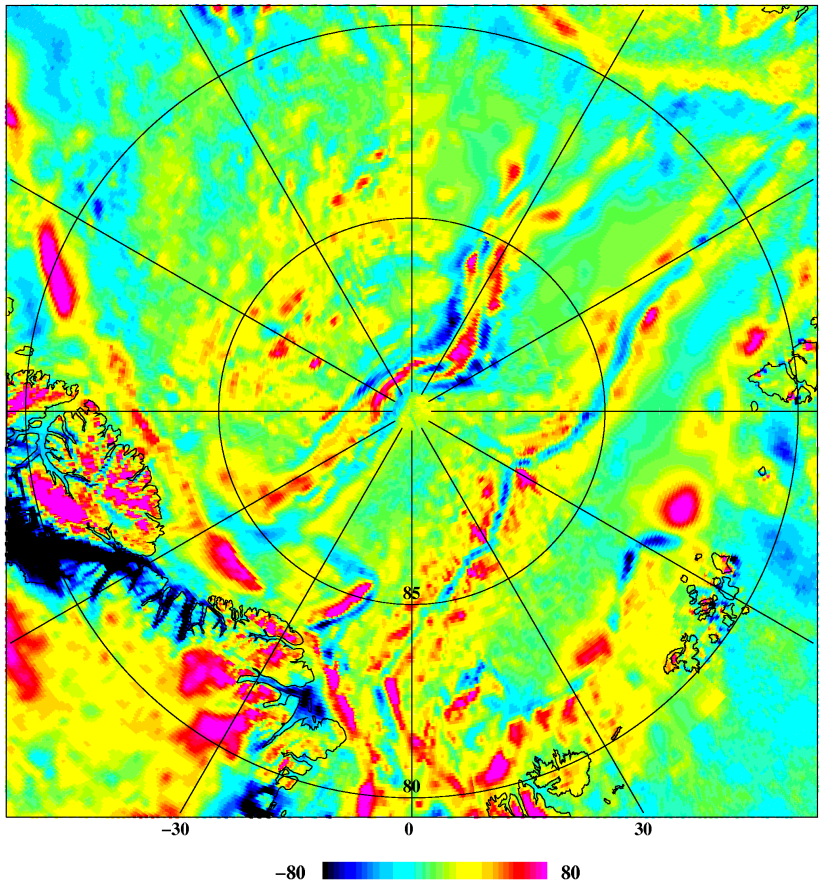
F two-dimensional Fourier transform, k wavenumber
c is Wiener filter resolution parameter

Remove-restore of GRACE/EGM reference field – computation in 2° latitude bands with overlap

Improved ICESAT gravity anomalies – high Arctic

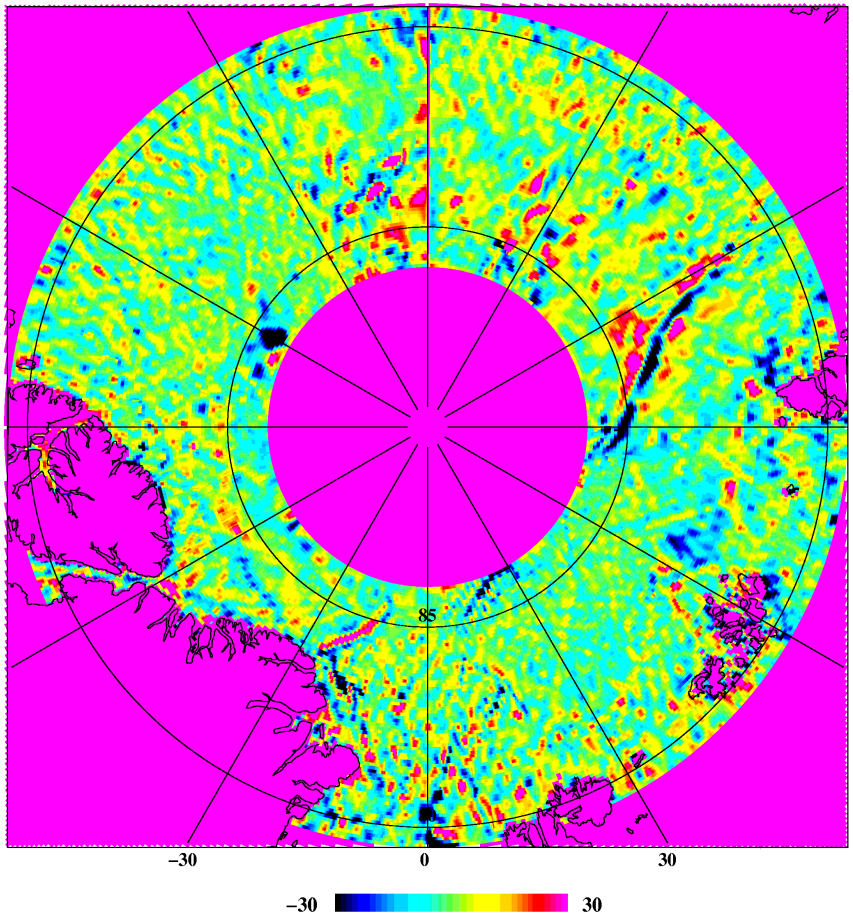


ICESAT gravity grid, all available data (Oct/Nov data draped to March)

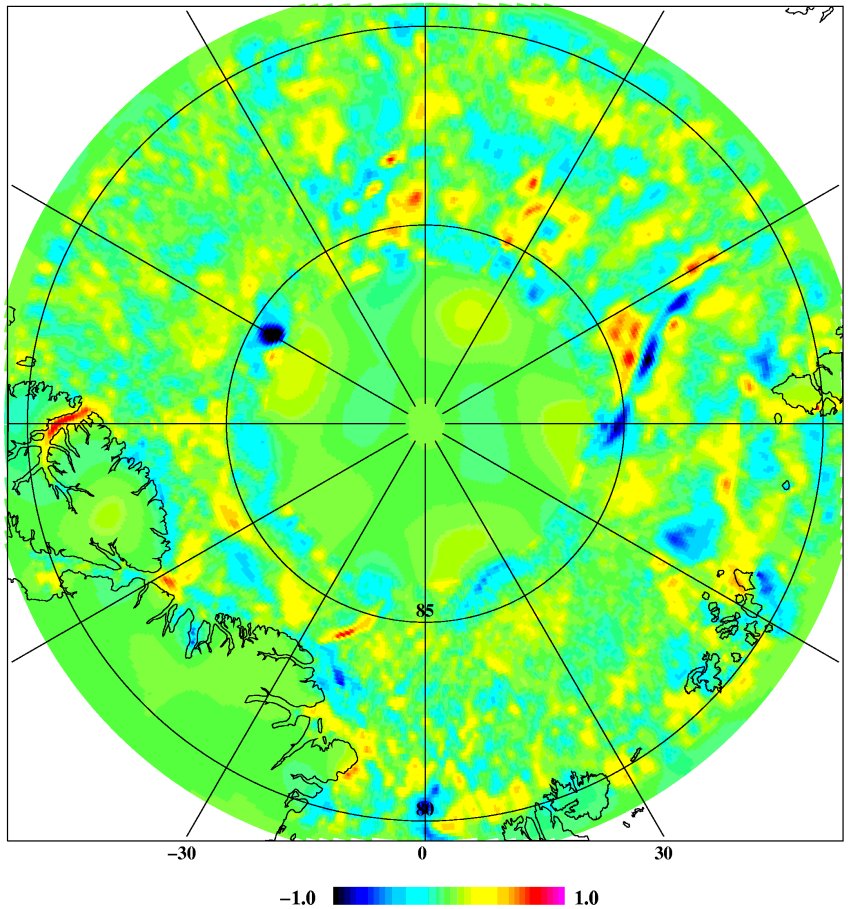


ArcGP free-air data

Improved ICESAT gravity anomalies – differences

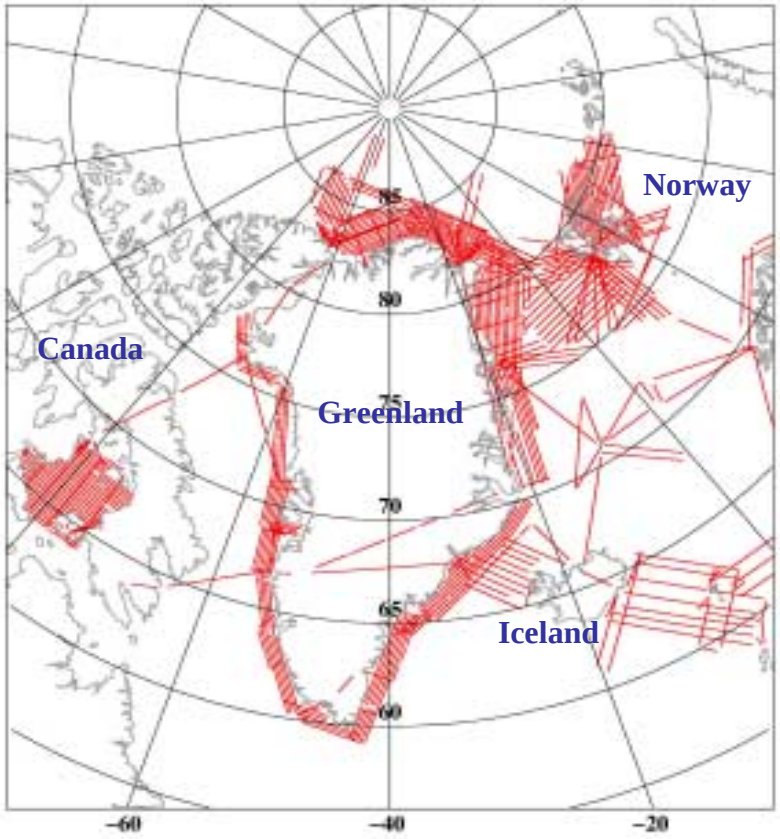


Gravity (mgal)



Geoid effect (meter – GRACE unchanged)

Gravity accuracy: KMS Greenland surveys 1998-2003

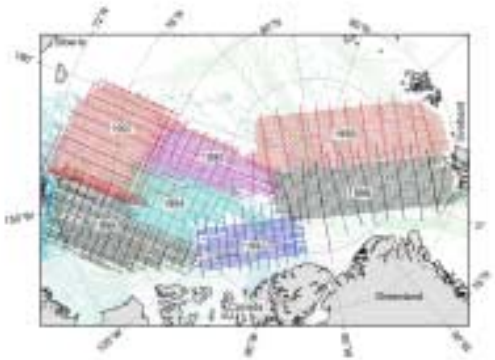


Acft speed 130-145 knots, resolution 5-6 km
Accuracy < 2 mgal (x-over errror/√2)

Data set	RMS x-over error (mGal)
1998	1.8
1999	2.5
2000	2.8
2001	2.6
2002 (ESAG)	2.6
2003	2.1
All years	2.5

Comparison of ICESat/ERS altimetry and airborne gravimetry

Gravity data (mgal)	Mean diff	Standard deviation
ICESat – KMS ESAG (north of 84°)	-0.1	6.3
ICESat – US Naval Research Lab 1998-99	-1.3	6.4
ERS (Laxon/McAdoo 97W) – KMS airborne	1.5	7.2



Conclusions

- Geoid and SSH models useful for support of ice-thickness mapping
- ICESat data useful for mapping sea-ice free-board heights .. Cryosat will be too
  (might be biased .. see poster by Skourup et al.)
- 3 months of ICESat data have yielded superior Arctic Ocean gravity field
  (*need more data for improved geoid)*

Pending: New composite ArcGP geoid pending, incorporating ICESat ..
New MSS model for Cryosat .. ArcGICE project ..