Geoid and MDT of the Arctic Ocean

Rene Forsberg, Henriette Skourup
Geodynamics Dept
National Space Institute
Techical University of Denmark
rf@space.dtu.dk

Outline:

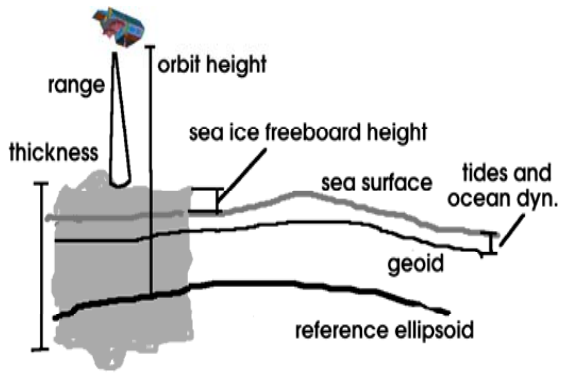
- Determination of MDT from remote sensing (geoid+altimetry) in ice-covered areas – *what can remote sensing do?*
- MDT estimate in Arctic Ocean from ICESat /ERS and GRACE/ArcGP
- Comparison to oceanographic models..

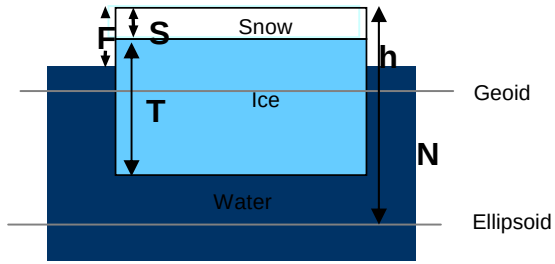
The problem in the Arctic Ocean: Sea-ice, geoid, MSS and MDT …

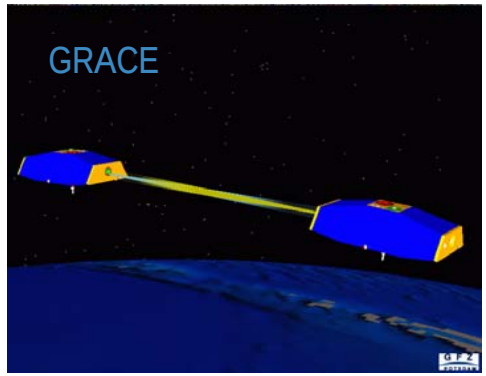
Basic equation and challenge:

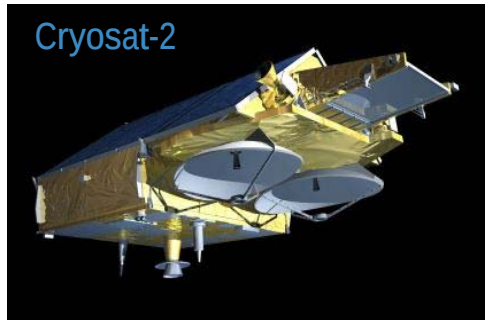
$$MDT = h - N - T - F$$

h: Ellipsoidal height of surface (= MSS + F + T)
N: Geoid model … from satellite and terrestrial gravity
MDT: Mean Ocean Dynamic Topography
T: Tides
F: Sea-ice freeboard (≈ 6*T)



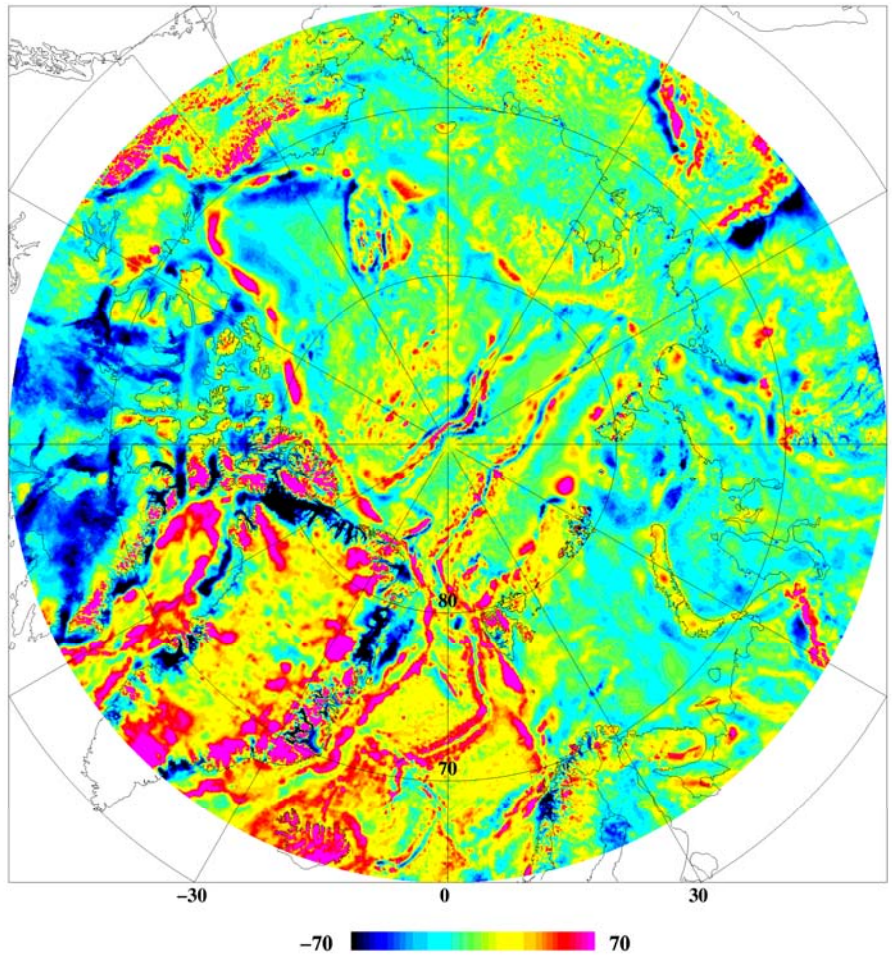






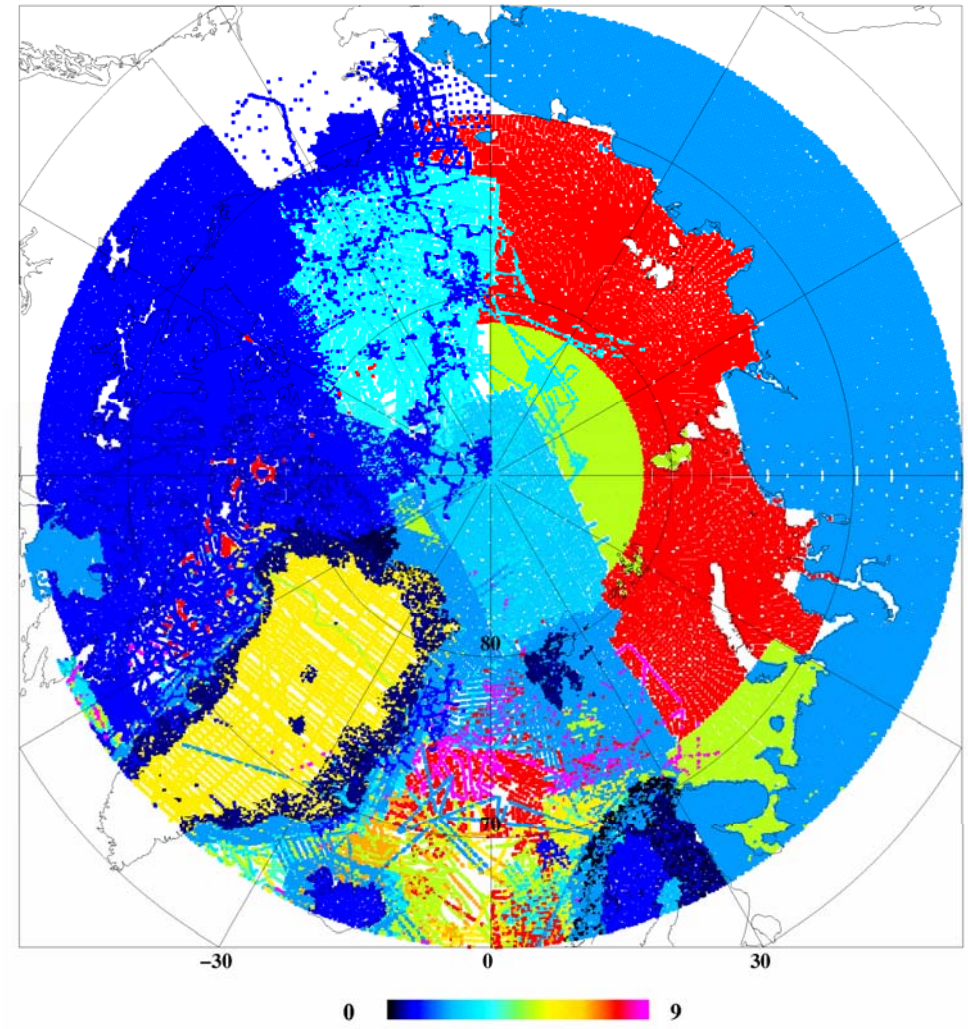
The Arctic Ocean gravity field

- Arctic Gravity Project 2002 first grid
- 2006 update (ESA ArcGICE project):
  - *GRACE data*
  - *New surface data (Russia, Alaska ..)*
  - *ICESat-derived gravity patches*
- 2008 update
  - *Better GRACE*
  - *New altimetry*
  - *More data*
  - *Incorporated in EGM08*

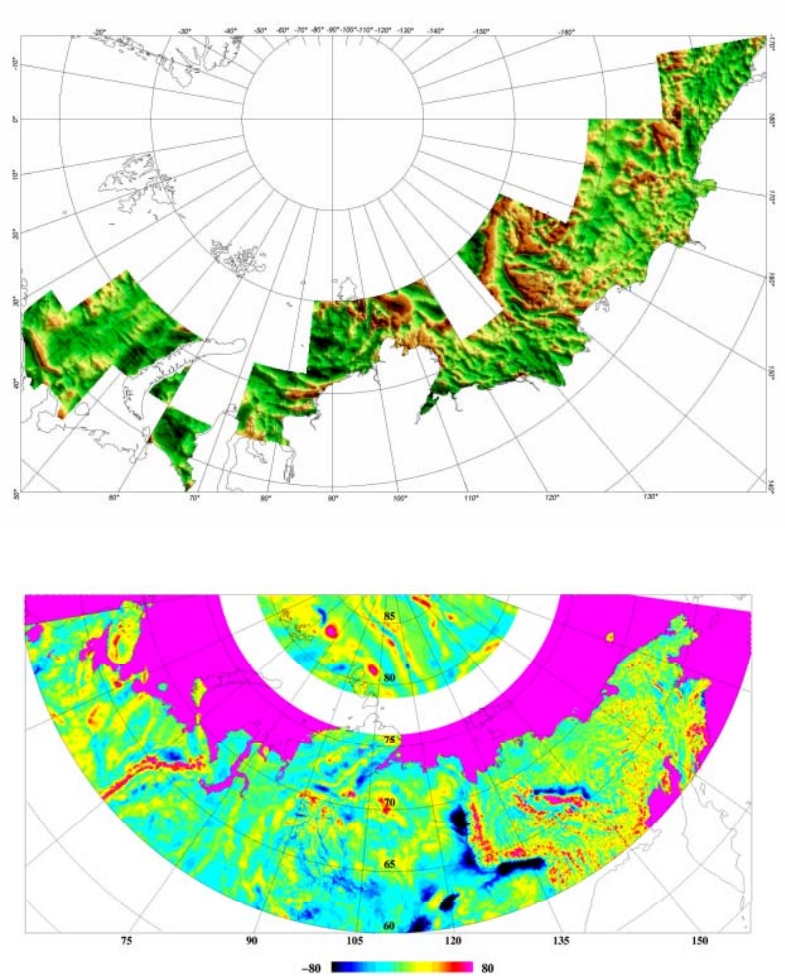


ArcGP free-air anomalies

ArcGP data sources



ArcGP 2006 standard deviations (mgal)



New Russian Data

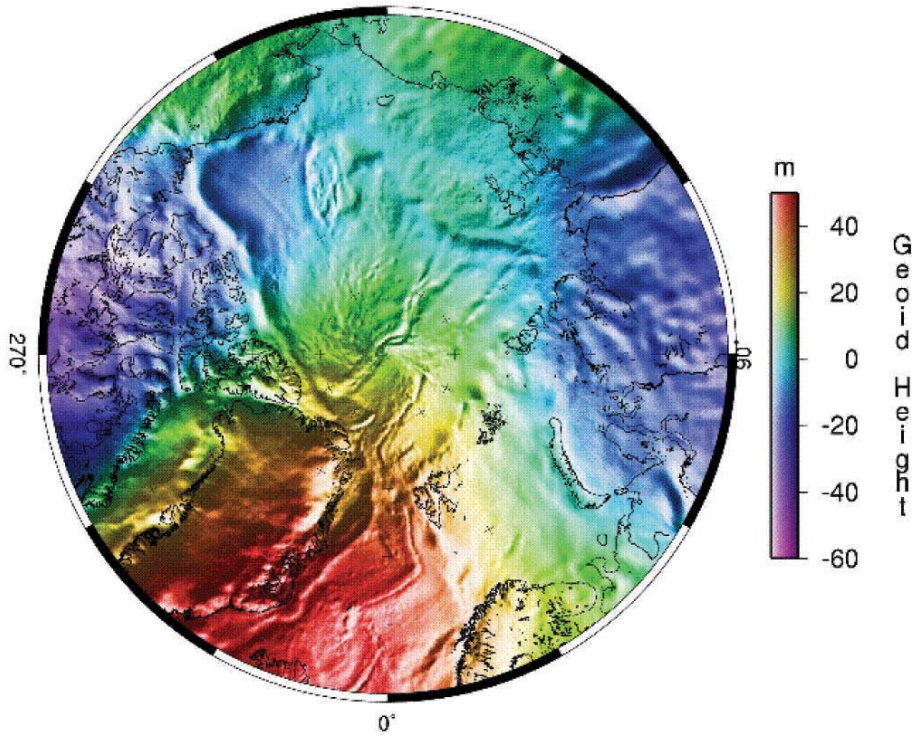
Geoid of the Arctic from ArcGP and GRACE

Method:

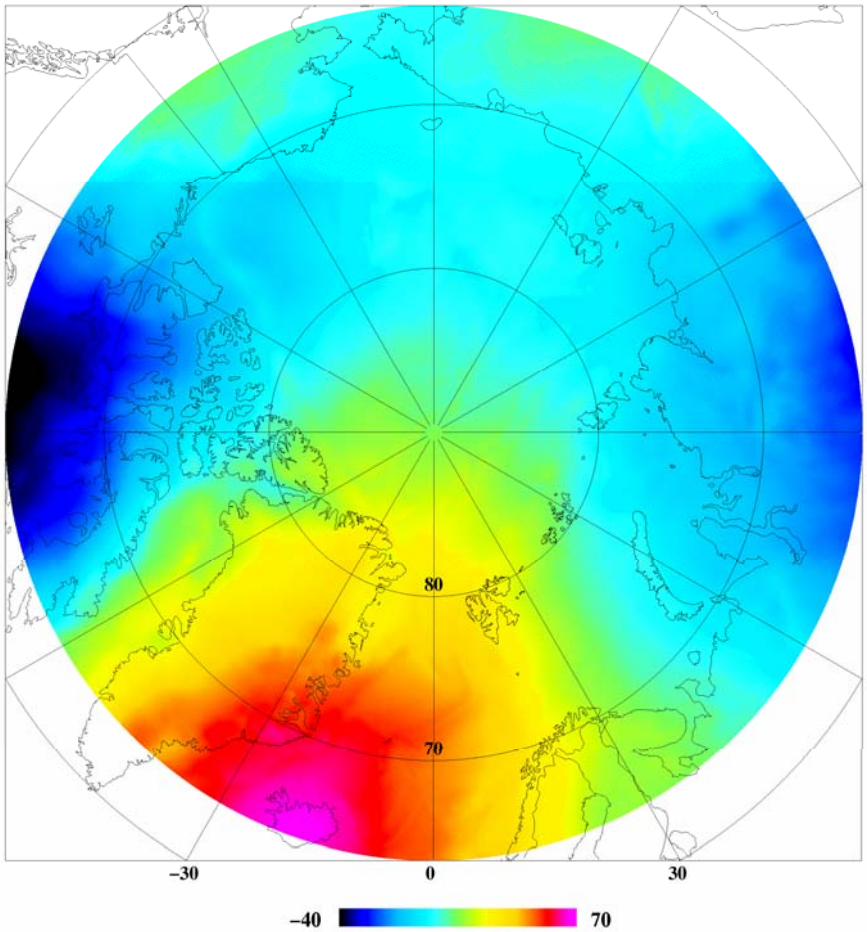
- Remove reference field spherical harmonics expansion
- Stokes integral on residuals, spectrally band-limited (Wong-Gore modified Stokes' kernel)

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

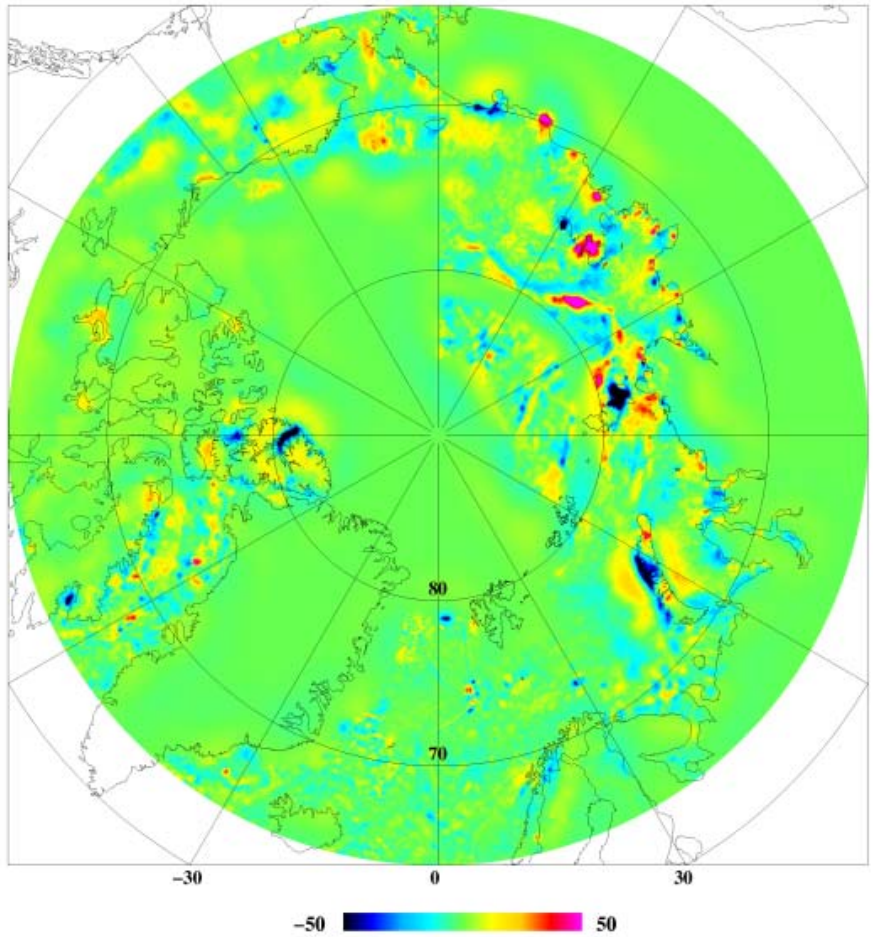
- Stokes' integral by spherical FFT
- Restore reference field => final geoid
- Formal error estimates by collocation



2006 ArcGP geoid (m)

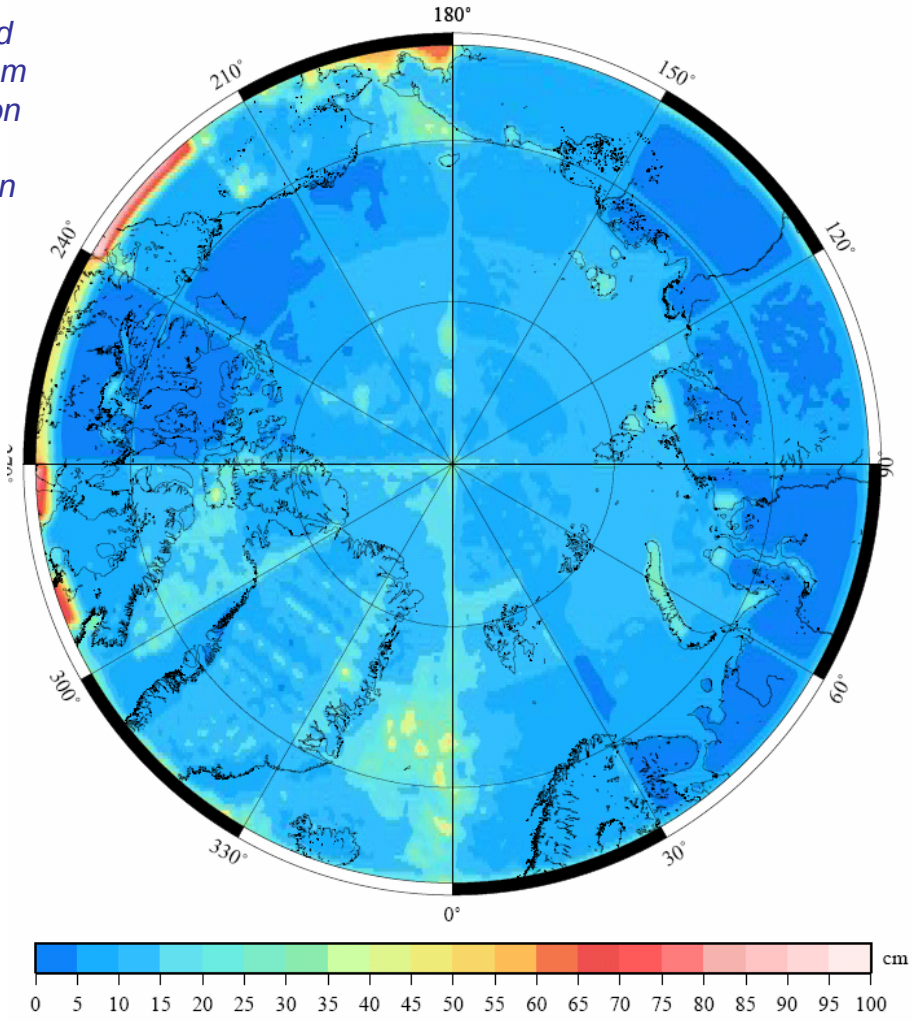


Difference 2008-2006 geoid (cm)

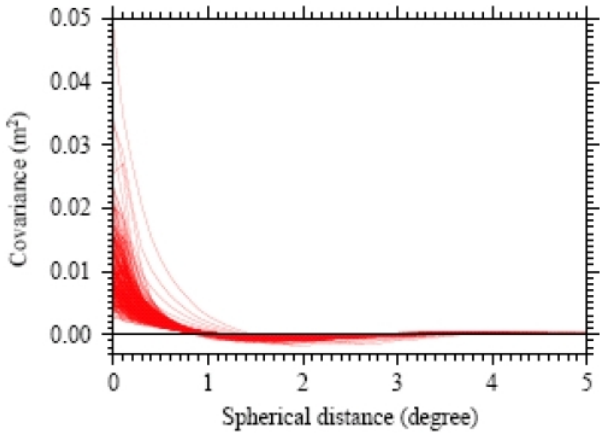


Error estimate of ArcGP geoid (2006 version – ESA ArcGICE study)

Estimated errors from collocation optimal estimation



Error covariance ensemble along meridians



MSS and MDT from ICESat

This study – January 2009:

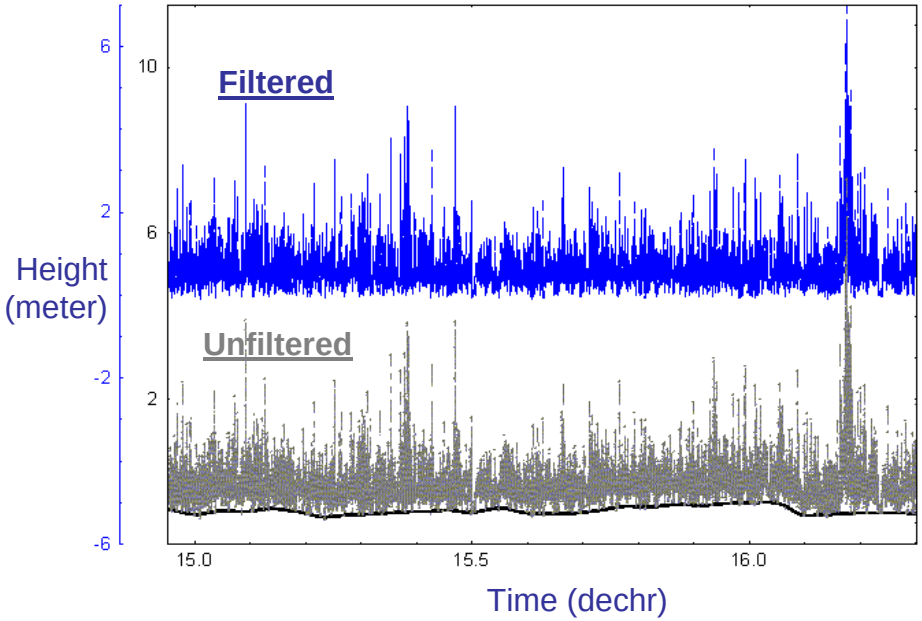
- 14 ICESat periods, release 28 (March 2003 – March 2008)
- TPX tidal models, No IB
- Along-track lowest level filtering for sea ice
- Ice freeboard gridded and smoothed
- MDT = SSH – geoid – freeboard height

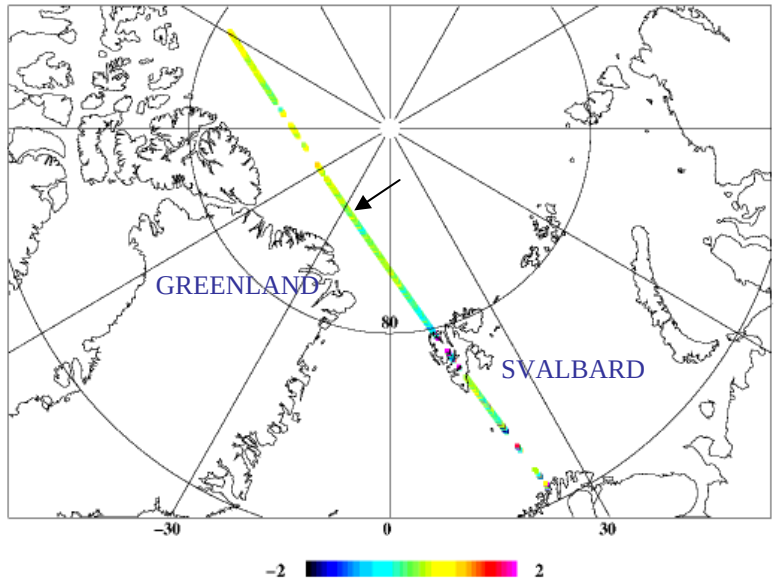
ICESAT periods

	FEB-MAR	JUN	OCT-NOV
2003:	L1A	-	L2A
2004:	L2B	L2C	L3A
2005:	L3B	L3C	L3D
2006:	L3E	L3F	L3G
2007:	L3H	-	L3I
2008:	L3J		

(r.i.p.)

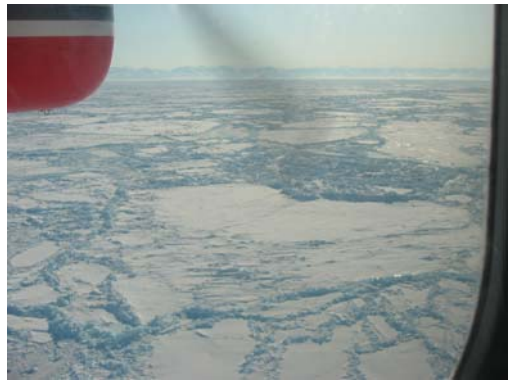
Lowest-level filtering: airborne lidar N of Greenland

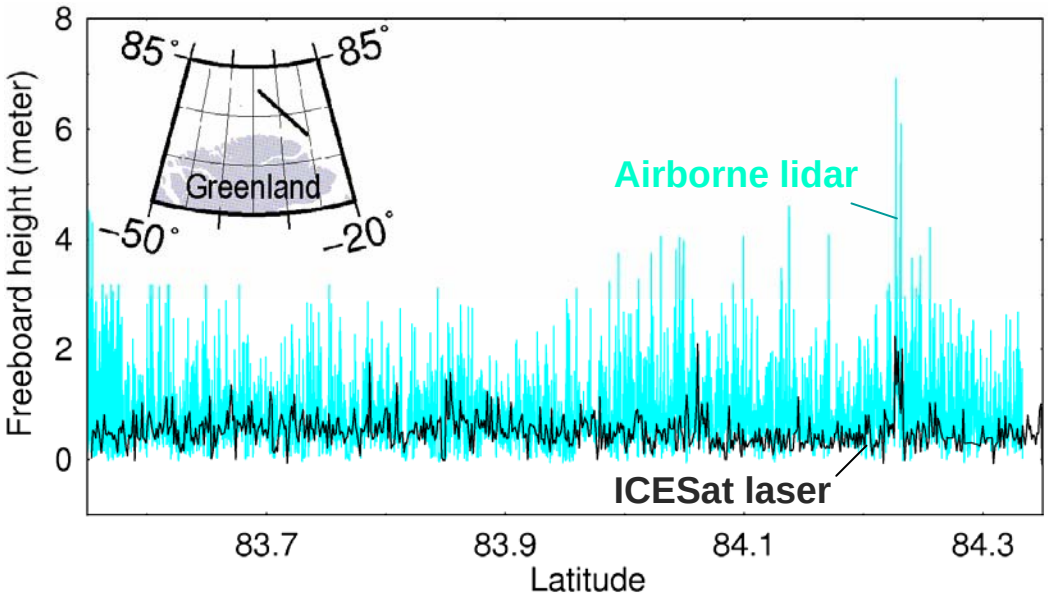




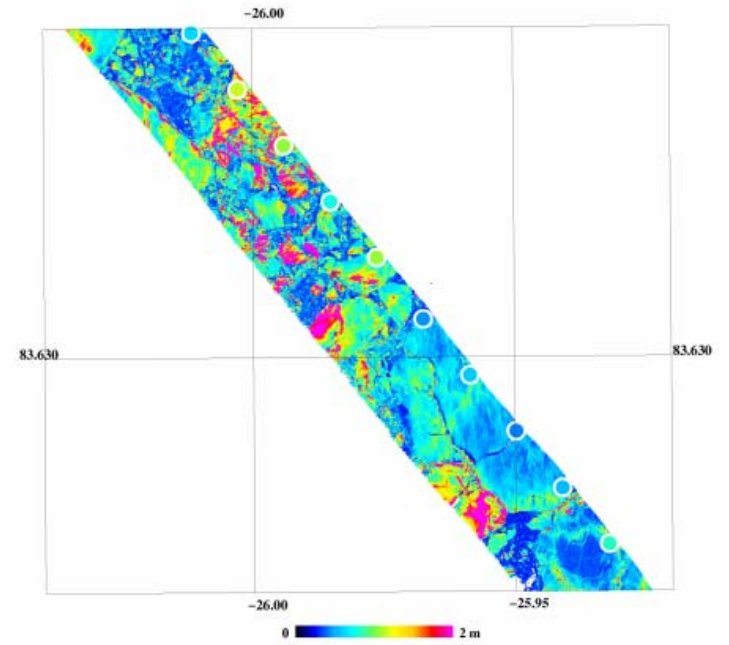
Airborne lidar underflight of ICESat (May 2004)

- ICESat tend to underestimate sea-ice freeboard due to footprint size ..
  - bias 25 cm N of Greenland [DTU], 9 cm N of Alaska [NASA P3] ..
- Complicates determination of ”absolute” MDT



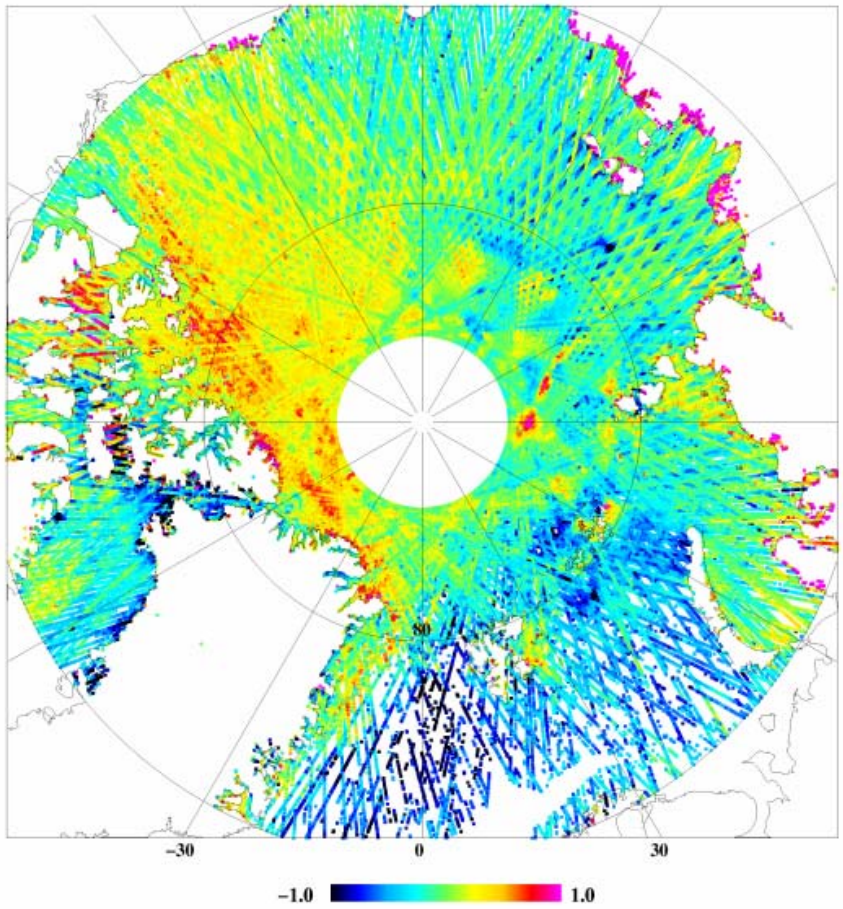


Laser swath scan and ICESat footprints

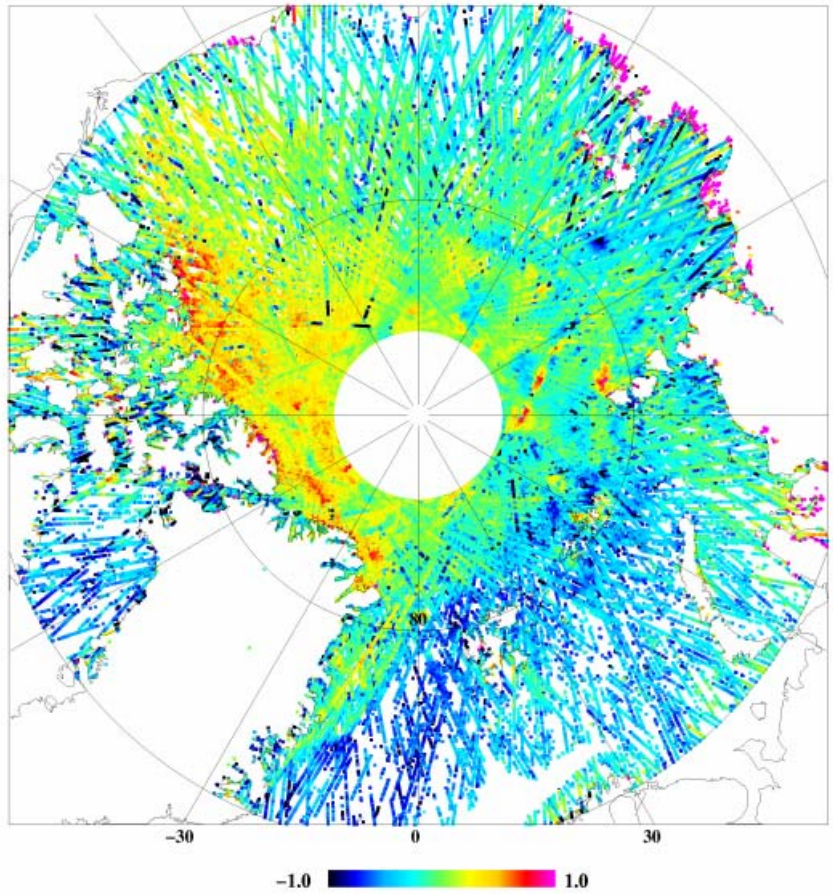


New study: ICESat SSH – ArcGP v2 geoid examples

L2B – Feb/Mar 04

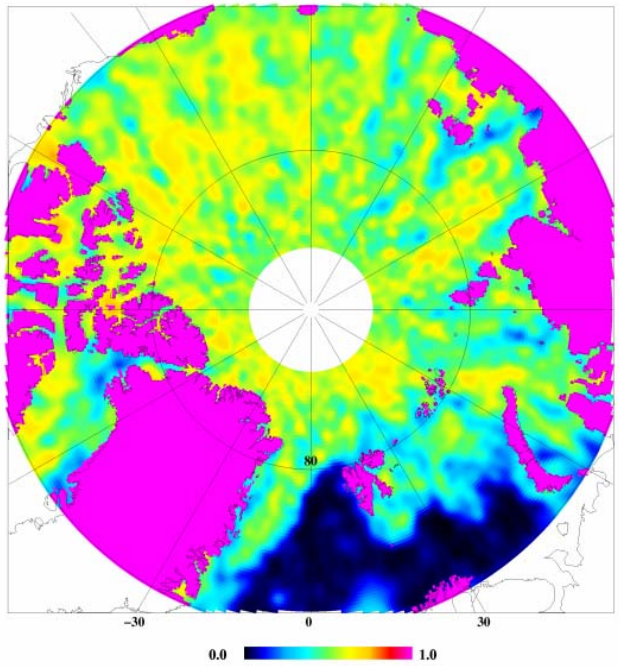


L3A – Oct/Nov 04

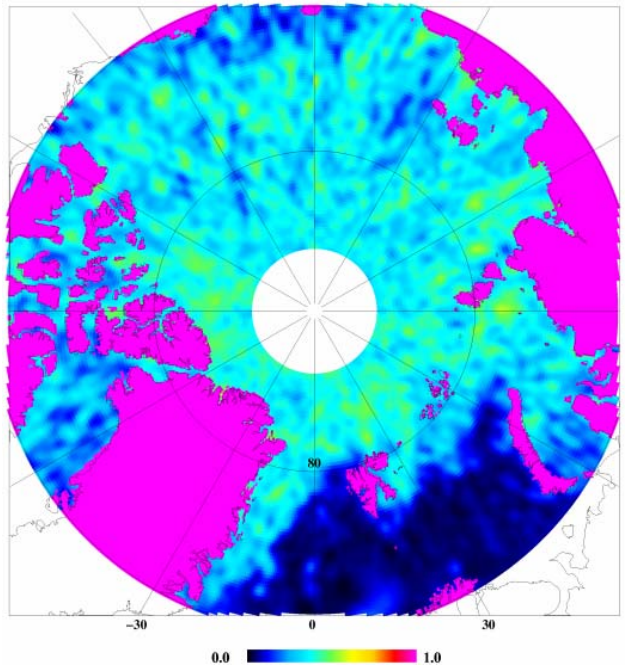


Reflectivity outlines ice edge

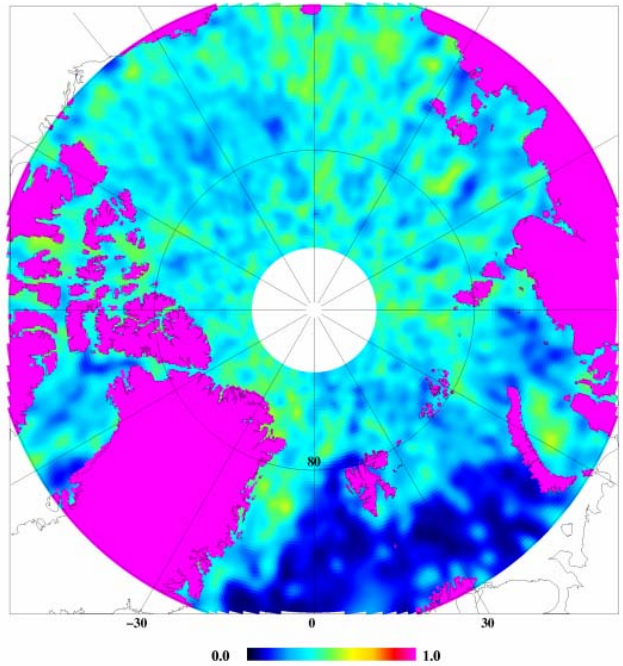
L1A - Mar 03



L2A - Oct 03



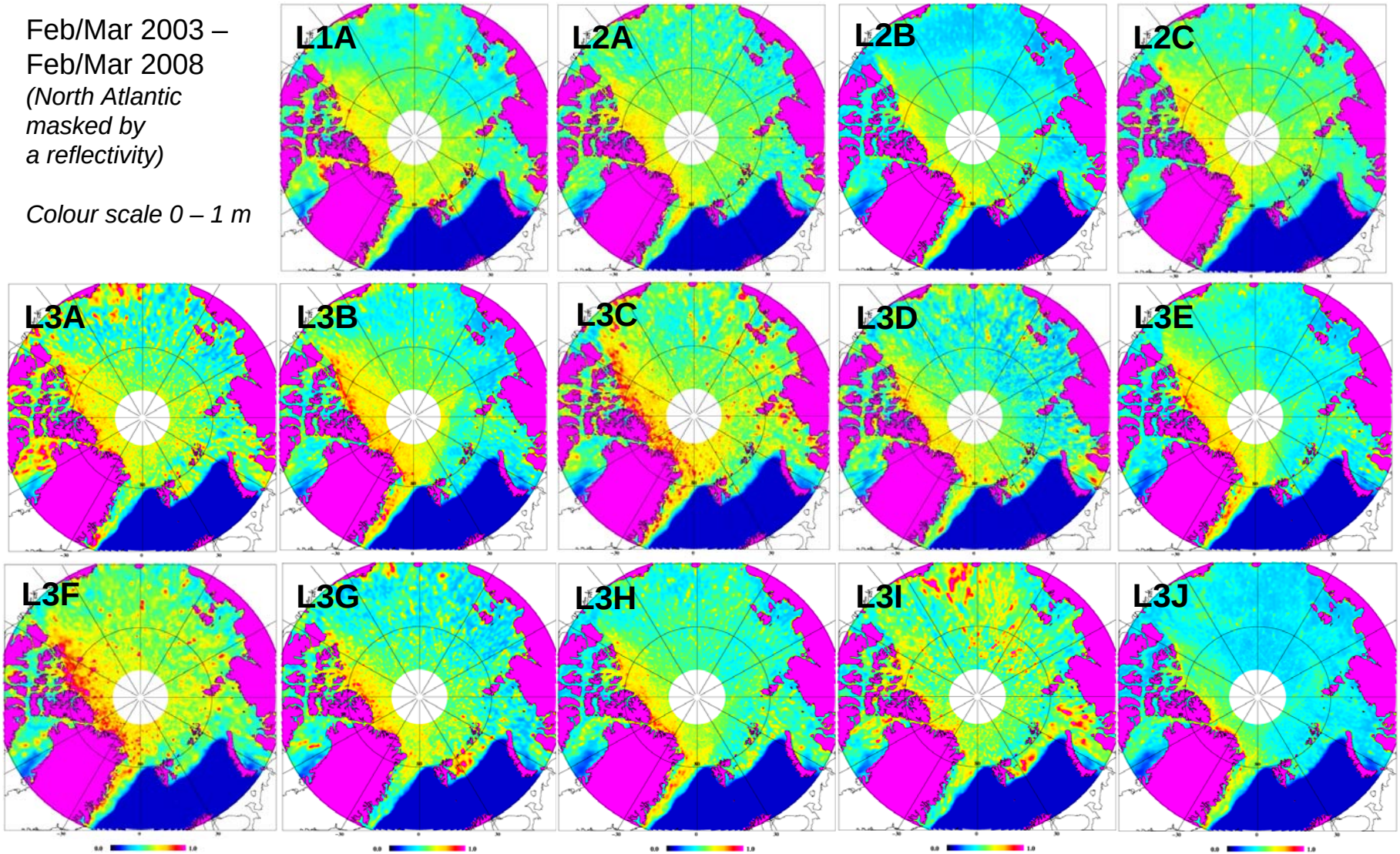
L2C - Jun 04



Sea-ice freeboard heights from ICESat

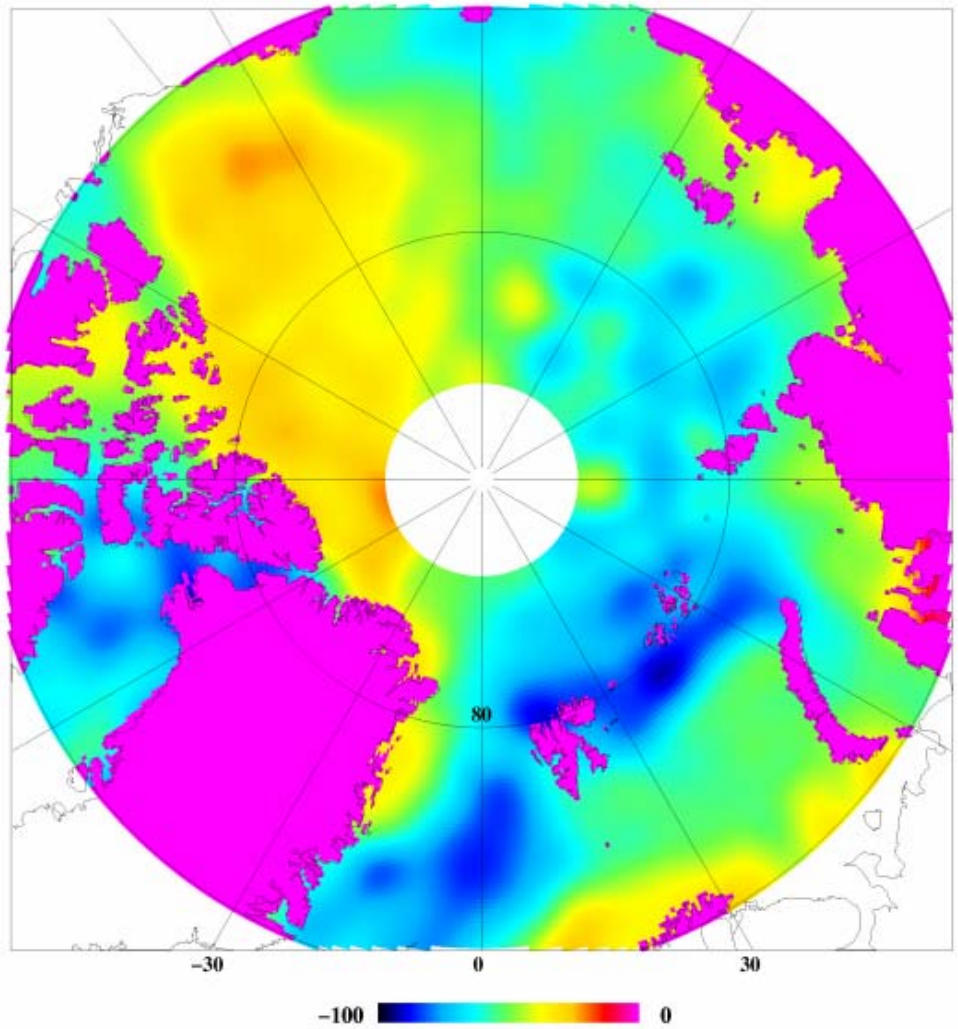
Feb/Mar 2003 –
Feb/Mar 2008
(North Atlantic masked by a reflectivity)

Colour scale 0 – 1 m

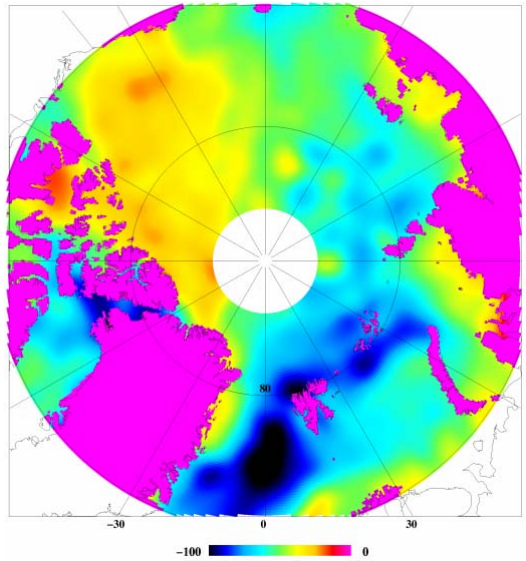


MDT from ICESAT alone March 2003-8 (L1A-L3J)

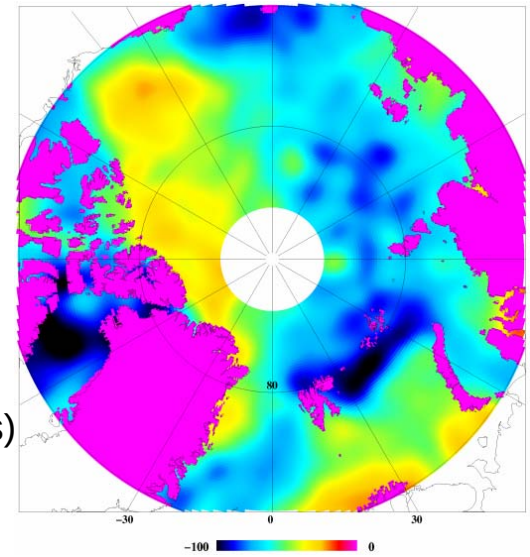
Average 2003-8 (14 periods)



March average (6 per.)



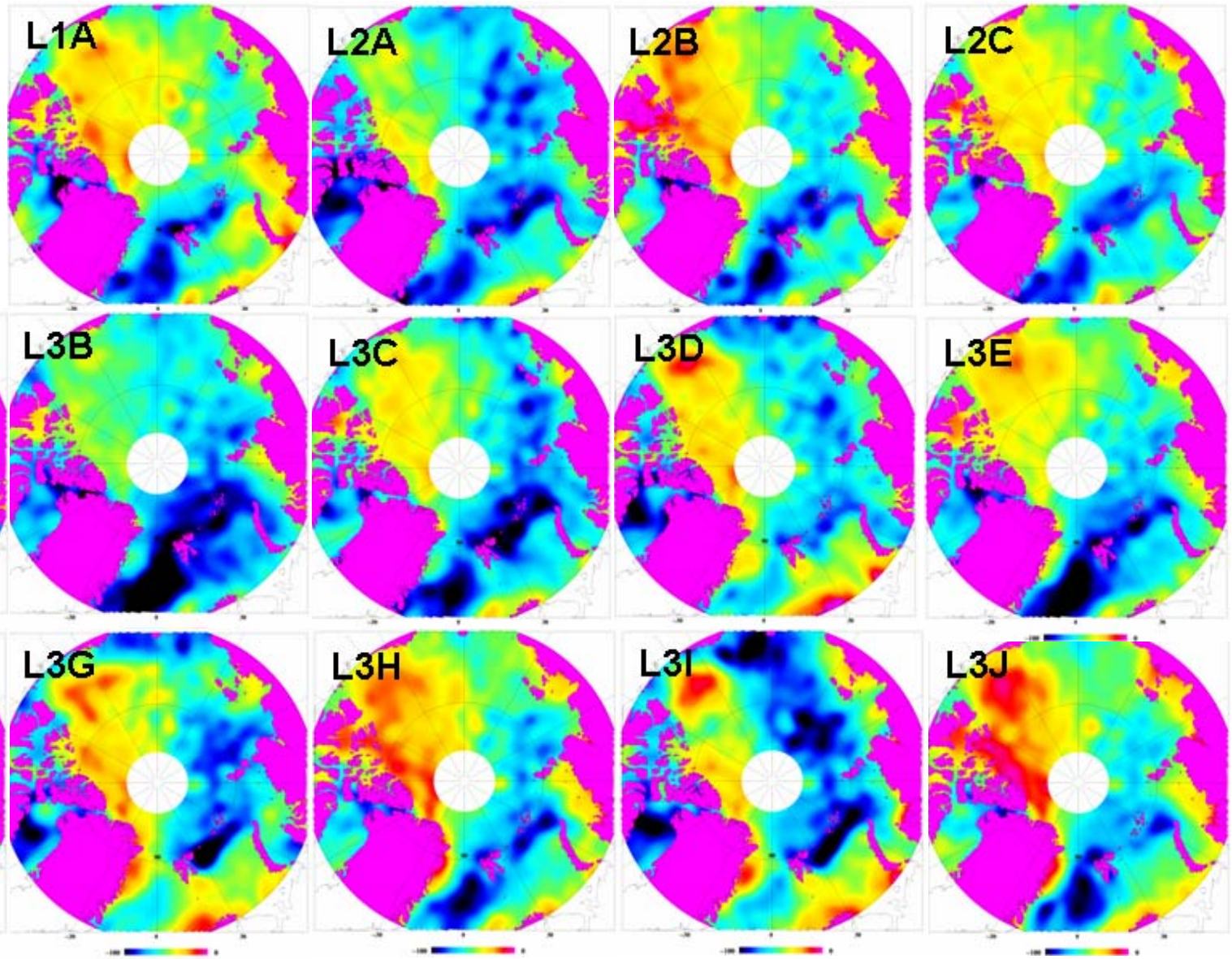
October average (5 periods)



MDT from ICESat (cm)

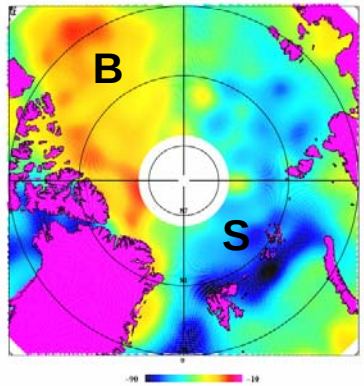
March 2003 - March 2008

Colour scale -1 – 0 m



Trend in MDT – as a function of time

- Slightly increasing difference in MDT from Svalbard sector (S) to Beaufort sector (B)
- Annual signatures, but not very clear



Average in 6 x 90 deg blocks

MSS application: MDT estimation - ”remote sensing” (ICESat/ArcGP) vs. oceanography

MDT = MSS - N

MDT Model	*Resolution in Arctic*	*Atmospheric Forcing*
MICOM	40 km	NCEP/NCAR
OCCAM	¼ x ¼ deg	ECMWF
PIPS (W. Maslowski)	9 km	ECMWF
Univ. Wash. (M. Steele)	40 km	NCEP/NCAR

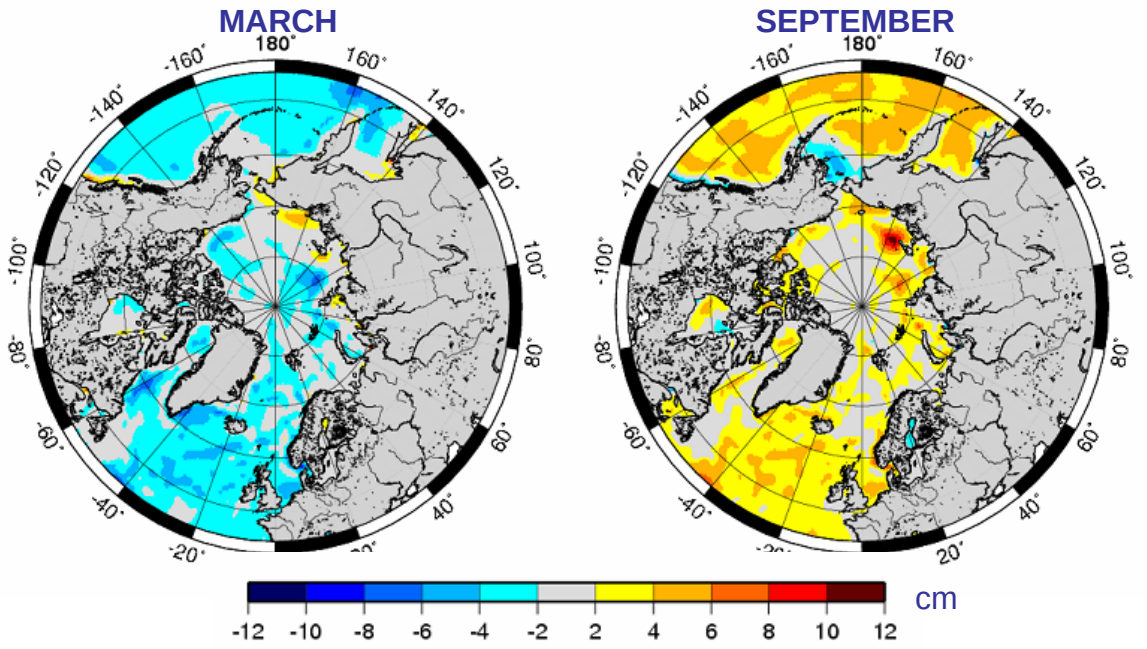
Example: New MICOM run (Nansen Center, Norway)

New Global Model, 2.4º x cos φ resolution

1948-2005 (3xNCEP)

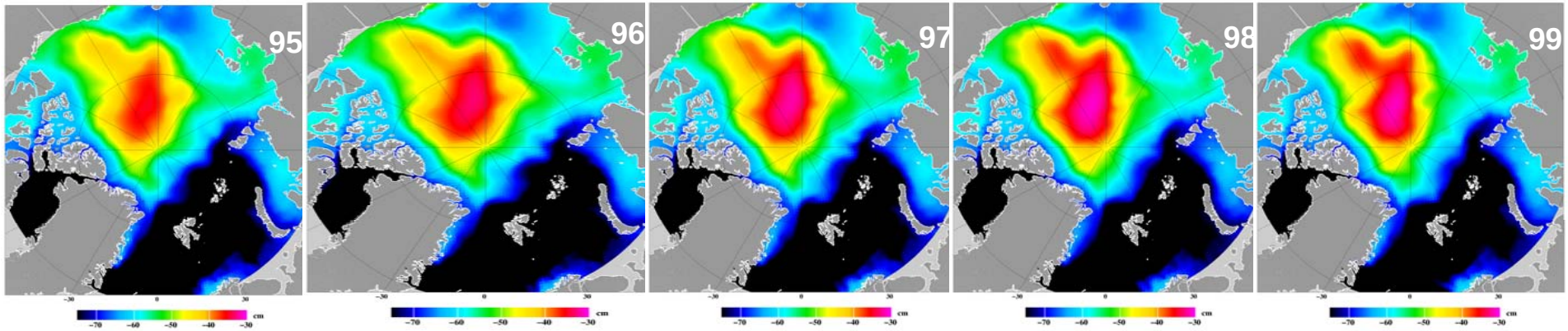
1958-2001 (5-10xERA)

MDT mean for 1948-2005 (NCEP), 1958-2001 (ERA) + anomalies March/September



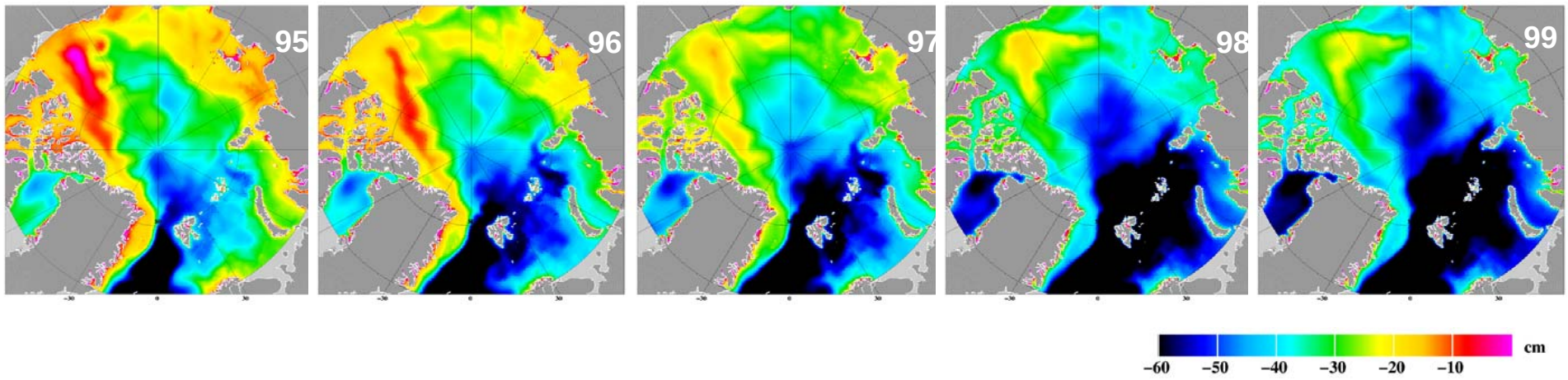
MDT: OCCAM interannual variability 1995-1999

Old model (ArcGICE)



Colour scale -75 to -30 cm)

Newer model

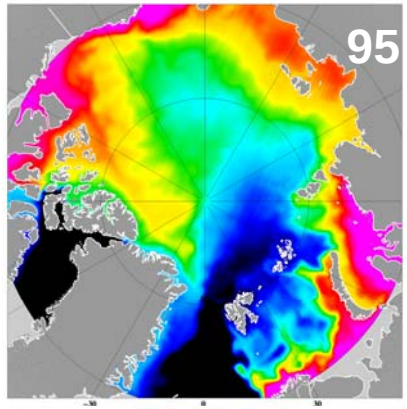


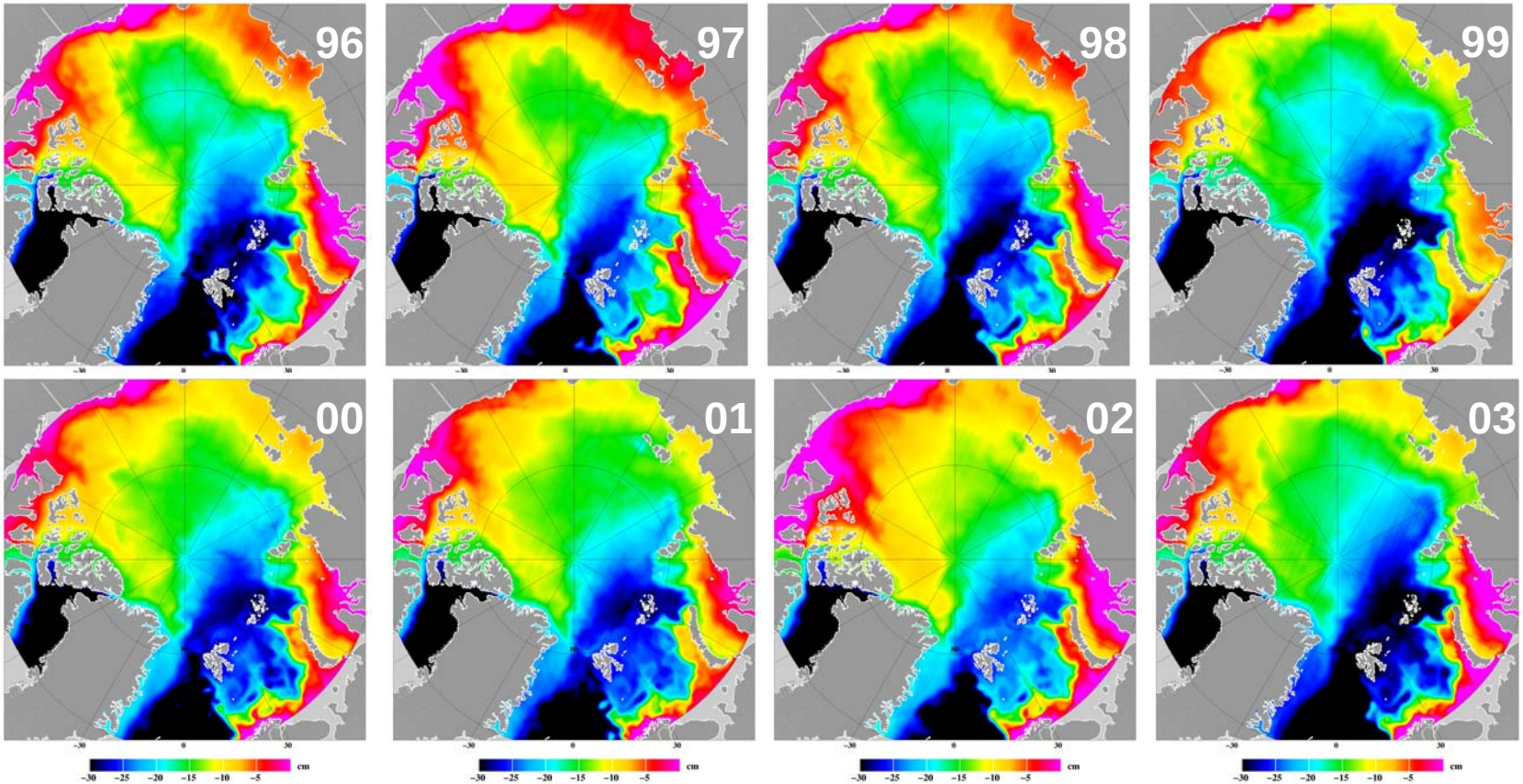
Courtesy: UK Oceanographic Center in Southampton

MDT: PIPS interannual variability
March 1995-2003

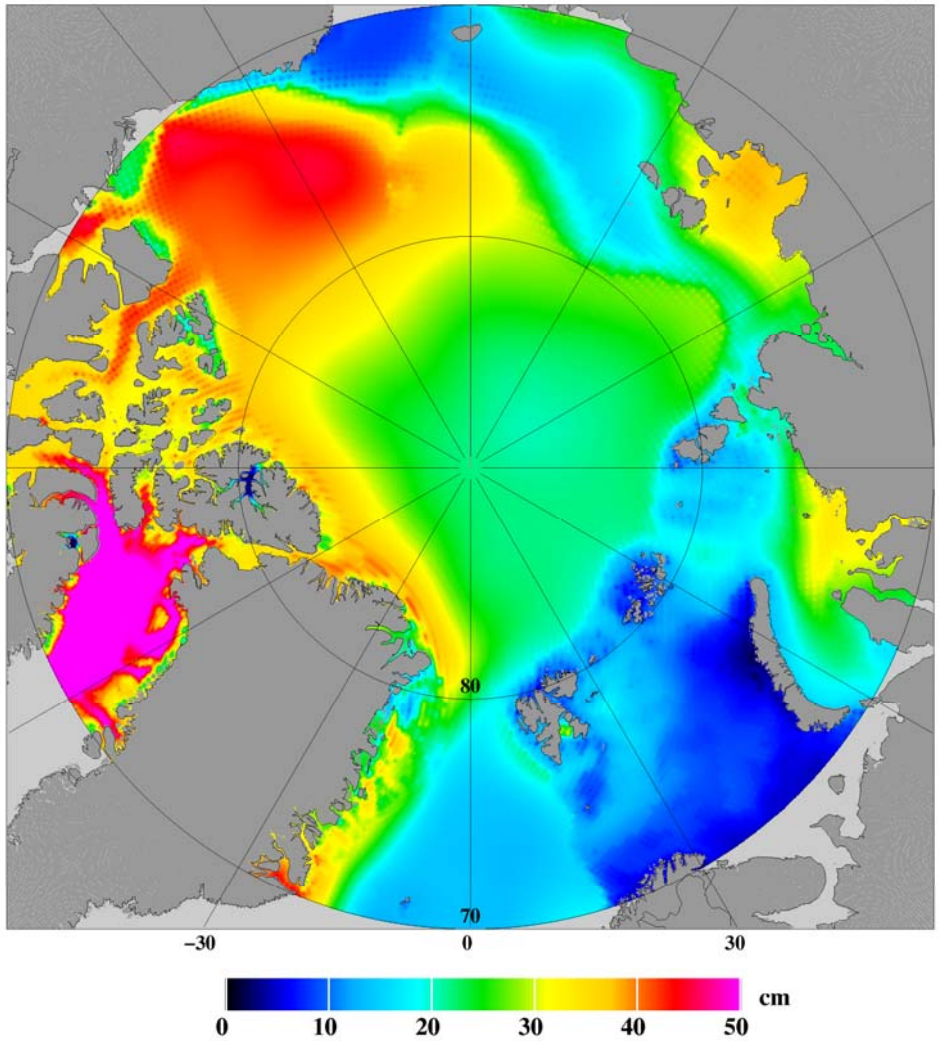
Courtesy: W. Maslowski, Naval Postgraduate School

Colour scale -30 to 0 cm

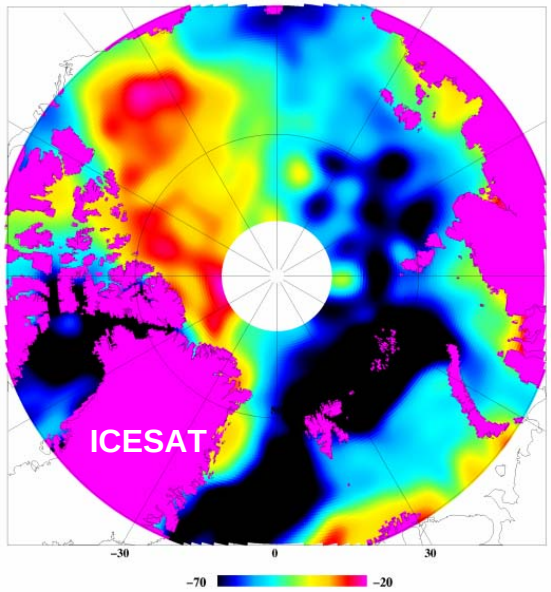


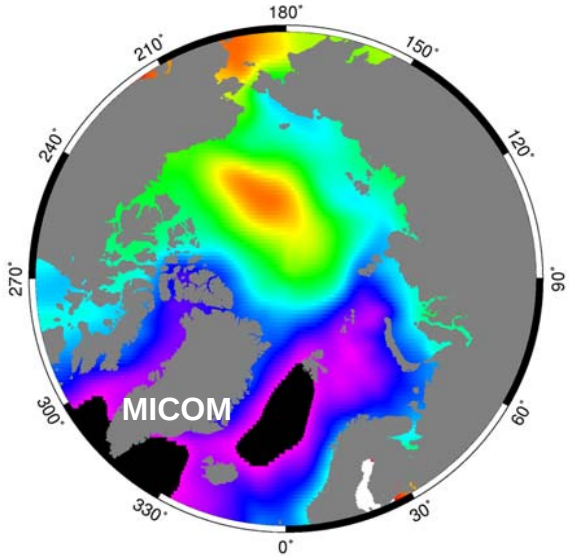


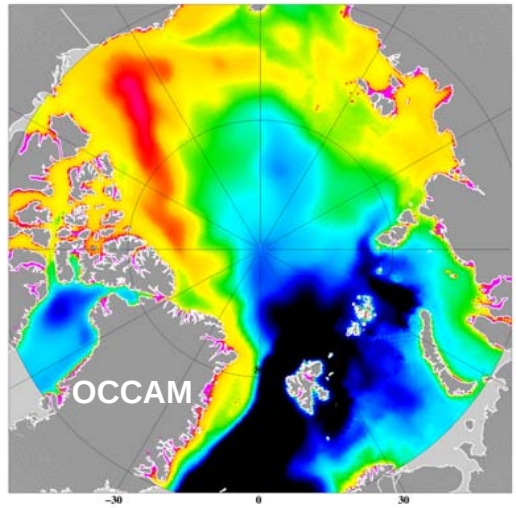
MDT: UW average 1955-2006

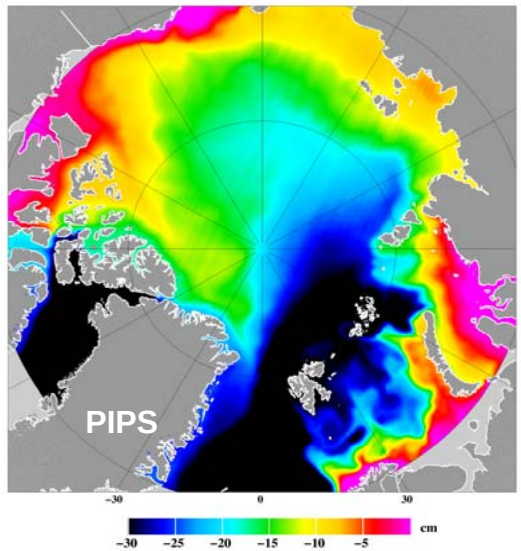


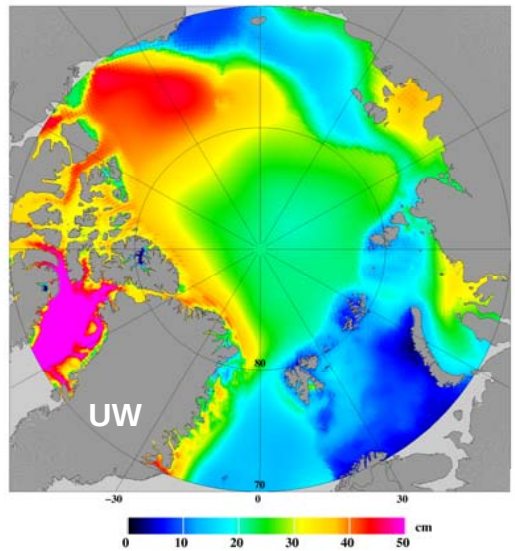
Courtesy: M. Steele, University of Washington











Intercomparison of mean MDT from ”remote sensing” (ICESat/GRACE) and ocenographic models

(colour scale ranges ~50 cm)

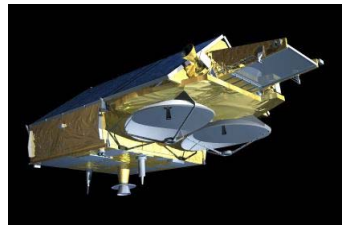
Conclusions

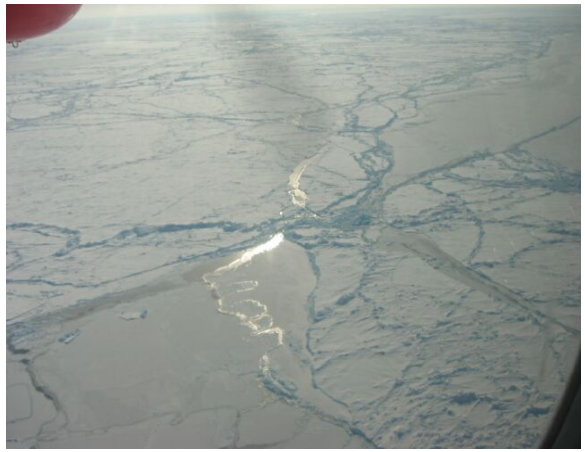
• New ArcGP geoid incorporating new data and GRACE

• ICESat provides Arctic Ocean realistic MSS and sea-ice free-board heights
- *ICESAT MSS may expand 8-year ERS MSS to 86°N – seasonal changes seen*

• MDT determined from ICESat+ERS MSS and GRACE/ArcGP geoid agrees qualitatively well with oceanographic models ..
- *Large difference between oceanographic models ..*

CryoSat and GOCE will significantly improve determination of MDT





Thanks for the attention

Greenland workshops, Nuuk AUG 25-27, 2009:
- Changes of the Greenland Cryosphere
- Arctic Freshwater Budget (FreshNor)

see www.space.dtu.dk/nuuk2009