Antarctic Dynamic Topography, Tides and the Inverse Barometer for Ice Shelf Mass Balance Studies

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Motivation

We need to know ice thickness (H_i) and dH_i/dt for Antarctic ice shelves.

H_i is obtained from elevation h_i relative to sea surface height (*SSH*), and assumed ice density. **Note: $\Delta H_i \approx 10.\Delta h_i$.**

Satellite altimeters give h relative to an ellipse, but we want it relative to *SSH* (h_{ssh}).

How do we get from h to h_{ssh}?

$h_{ssh} = h + G + MDT + DT' + OT + OTL + IBE$

G = geoid

MDT = mean dynamic topography

DT' = dynamic topography relative to *MDT*

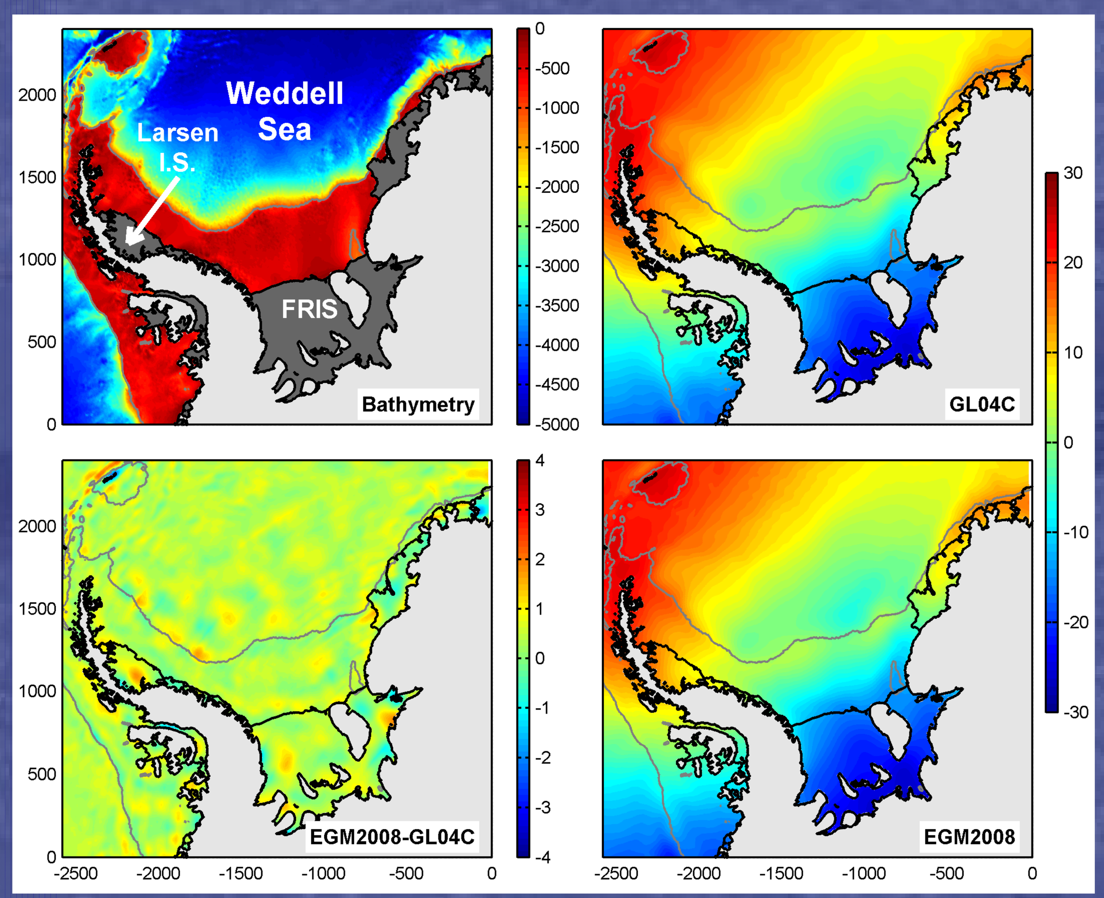
OT = ocean tide

OTL = ocean tide loading (from TPXO7.1; not discussed here)

IBE = inverse barometer effect

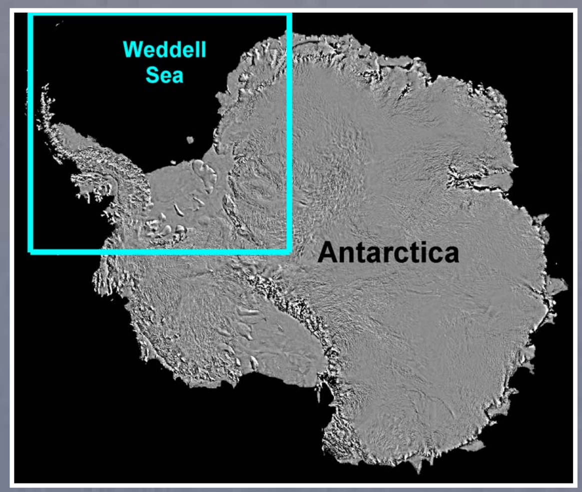
We look at these terms for the Weddell Sea.

Geoid: comparing GL04C and EGM2008

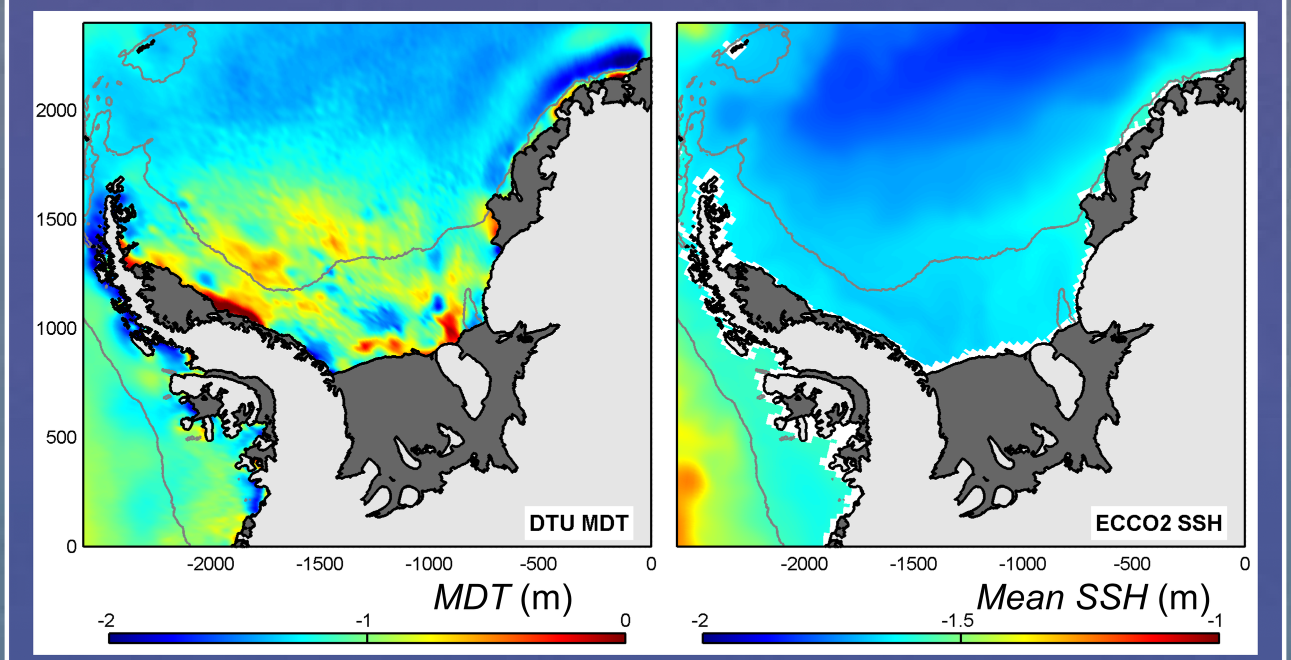


(*top left*) The Weddell Sea region, showing location of Larsen Ice Shelf and the Filchner-Ronne Ice Shelf (FRIS) and bathymetry offshore. Gray contour shows 1000 m isobath (shelf break). (*right*) GL04C and EGM2008 geoids. (*lower left*) Difference between geoids. All color scales in m.

Geoid differences come from different errors of commission (due to different data sets and combination approaches) and omission (including the inherent lower resolution of GL04C compared to EGM2008). Differences are of order 1 m (occasionally ~2 m), corresponding to change in calculated H_i of ~10-20 m.



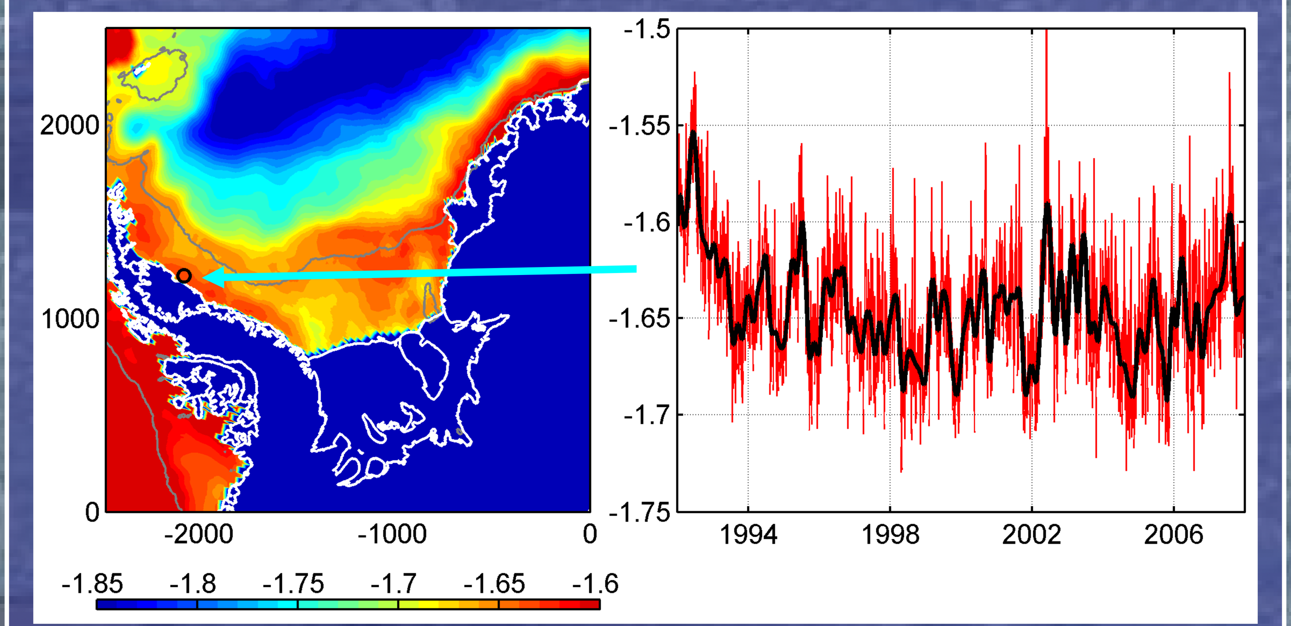
Dynamic Topography



(*left*) Mean dynamic topography (DNSC07MDT) from Delft Technical University (DTU). (*right*) Mean sea surface height (*SSH*) from ECCO2 (1992-2007). Note: different scales (in m).

Variability in DTU *MDT* comes from sea ice, which is almost always present in the western Weddell Sea. ECCO2 fields look more realistic as it shows DT of Weddell Gyre.

MDT-SSH differences are up to ~1 m, corresponding to error in calculated H_i of ~10 m.



(*left*) One-day snapshot of ECCO2 *SSH*. Note much smaller color range than for mean *SSH* plot, above. (*right*) Time series of daily (red) and 90-day low-passed (black) ECCO2 *SSH* from near front of Larsen Ice Shelf.

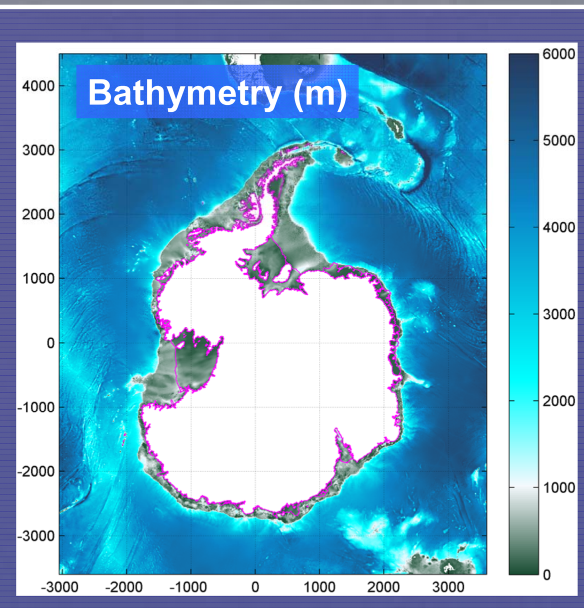
Total modeled range in *SSH* is ~0.2 m: annual cycle is ~0.05 m.

Current version of ECCO2 does not include ice shelves: need to "level" along ice front, and assume no gradient of *SSH* under the shelves. For thermodynamically active shelves (high basal melt) this may cause errors in h_{SSH} of ~0.1 m.

Tides

ESR/OSU circum-Antarctic tide model on polar stereographic (δx=4 km) grid.

Assimilate: coastal tide gauges; BPRs; GPS on ice shelves; TOPEX/Poseidon & /Jason ocean altimetry; ICESat laser altimetry over ice shelves.



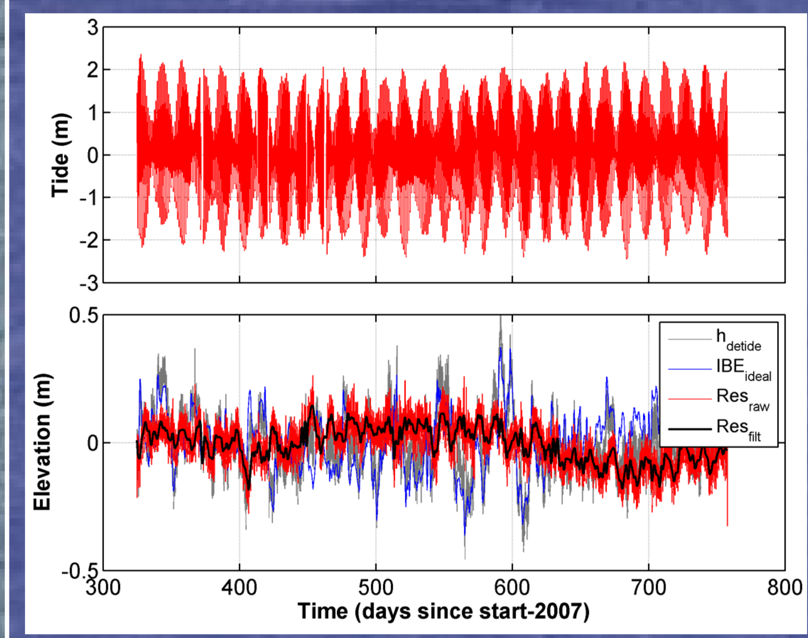
CATS2008a tide model domain

RMS (cm) of observation minus each model, high-quality, long records in Weddell Sea.

	M_2	S_2	O_1	K_1	All
TPX06.2	5.9	4.4	6.0	4.3	10.4
TPXO7.1	7.1	4.5	7.5	6.2	12.9
FES2004	6.0	4.3	3.1	3.5	8.7
CATS2008a	4.4	3.7	0.9	1.7	6.1
GOT4.7	5.2	4.1	5.8	4.1	9.7

We still have large errors on Larsen C Ice Shelf, because (*i*) no local assimilation (yet) and (*ii*) thickness of water column under ice shelf is not known.

Inverse Barometer Effect



(*top*) Detrended elevation time series from GPS on Larsen C Ice Shelf. (*bottom*) Detided time series (gray); IBE from measured air pressure (-1 cm/hPa) (blue); residual (red); one-day low-passed residual (black).

Annual cycle in h is ~0.1 m (cf. ECCO2 (left). Signal in h not explained by *IBE* and annual cycle has amplitude ~0.05-0.1 m.

We wish to equate annual and shorter variability in h_i to variations due to (*i*) basal melt rate, and (*ii*) dynamic topography from thermohaline circulation under ice shelf. Not there yet!

Summary

- **Geoid** uncertainty => potential errors in ice-shelf thickness (H_i) of order 10-20 m.
- ***MDT*** errors due to sea-ice contamination in satellite altimetry => potential errors in H_i of order 10 m.
- ***DT'*** has a ~0.2 m total range including 0.05 m annual cycle and 0.5-0.1 m weather-band variability.
- **Tide errors** <0.1 m; best chance of further improvement from CryoSat-2, and GPS mounted on ice shelves.
- Best-fit ***IBE*** is $-0.0085.P'_{air}$ (not shown).
- Remaining signal is small but important: allows testing of basal melt rate models and interior circulation in sub-ice-shelf cavities.

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