Two Decades of Ice Mass Loss from SLR versus GRACE

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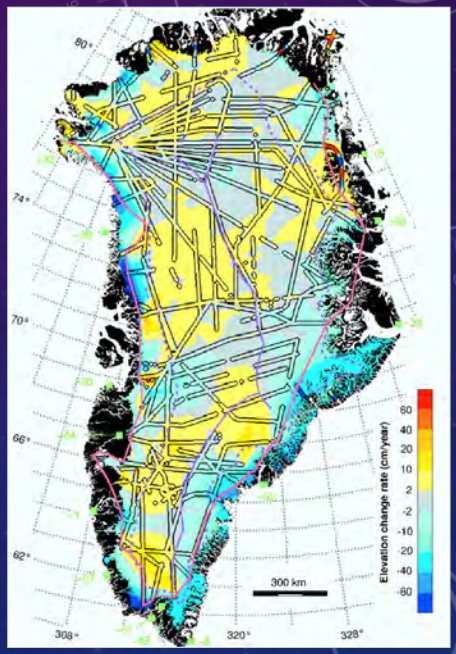
GSTM: October 2017

Extending the mass time-series back before GRACE

Before 2002, measurements of polar land ice mass change were sparse:

- Volume change: satellite radar and airborne laser altimetry.
- Ice motion: changes in repeat GPS or interferometry.
- Combination of these and modeling to get total mass budget.

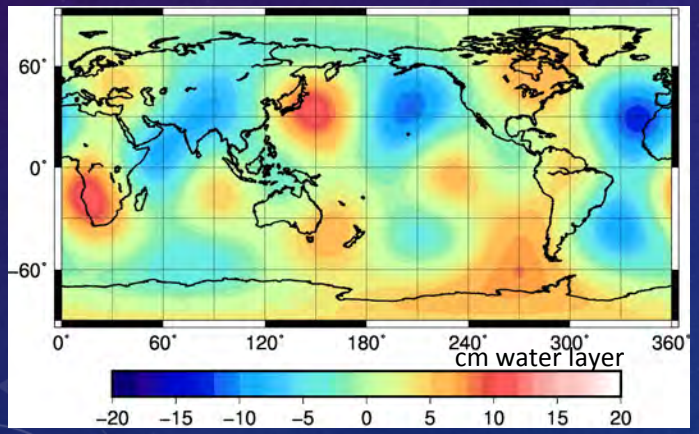


Ice elevation change, circa ~2000

Krabill et al. "Greenland ice sheet: high elevation balance and peripheral thinning." Science. 2000.

Can we use Satellite Laser Ranging (SLR) to fill in for GRACE?

- Exists since 1994, but low spatial resolution (max deg/ord 5-10).



Example SLR Month

(5x5 spherical harmonics)

How can we get sufficient resolution from this?

Simple least-squares inversion method

Determine regional amplitudes each month:

Smoothing pattern for transforming each region into 5x5 spherical harmonics

$$\hat{a} = (H^T H + N)^{-1}(H^T y)$$

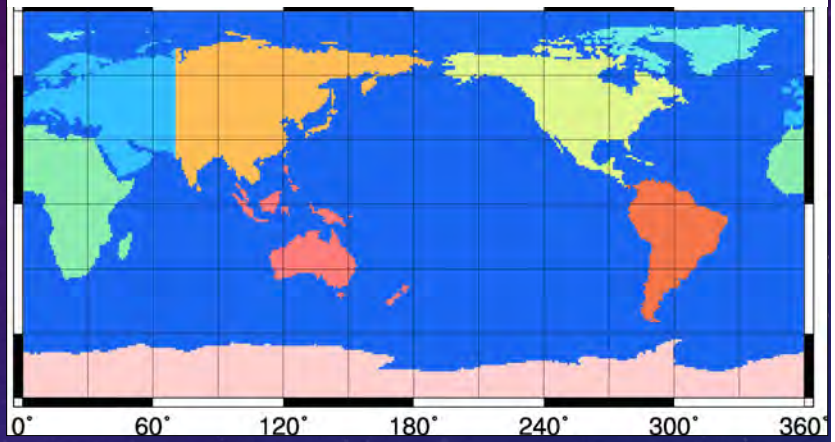
for each month

Average mass in each region

Diagonal process noise matrix

GRACE / SLR observations

A few, large regional kernels:



The low-resolution SLR data requires few, very large regions.

- Implies that the mass in each region changes as one block.
- Not accurate in Antarctica.

Some other tactic must be used.

Correlated least-squares inversion method

Tie each mass estimate to other regions and to itself in neighboring months.

The matrix of modeled lag-1 autocorrelations and the multiplier to use with it

The previous/next month's estimate

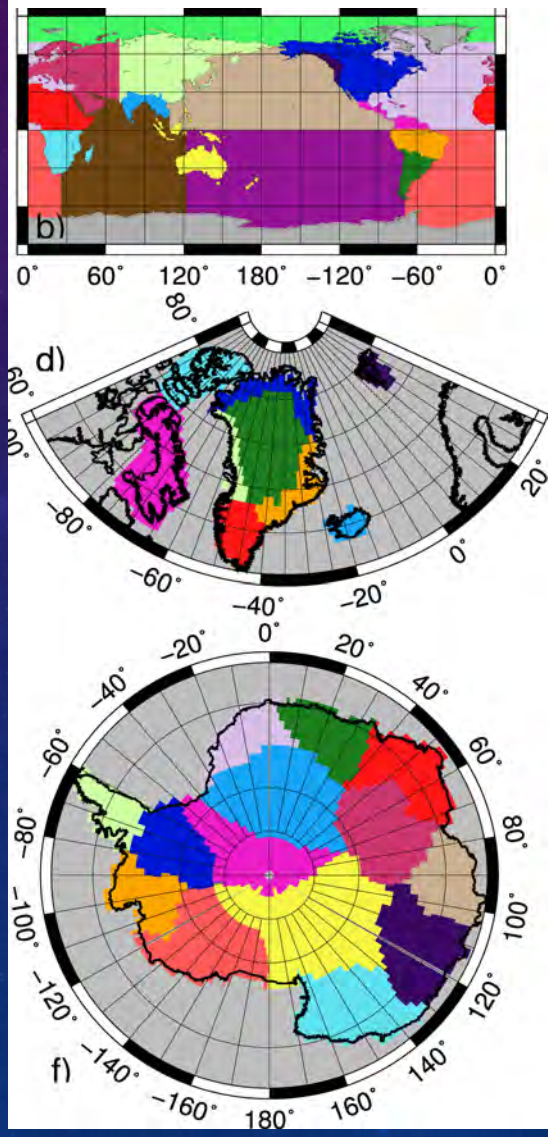
$$\hat{a}_t = \left[H^T H + \alpha^2_{time}(L^T L) + \alpha^2_{space}(C^T C)\right]^{-1}\left[H^T y + \alpha^2_{time}(L^T L)\bar{a}_{t-1}\right]$$

The matrix of modeled correlations between regions and the multiplier to use with it

Constraint matrices **L** and **C** defined from a model.
Multipliers α_L and α_C determined empirically, via simulation.

Can this adequately constrain 5x5 data, while still providing the flexibility needed to place differing signals in different areas?

Many local kernels:



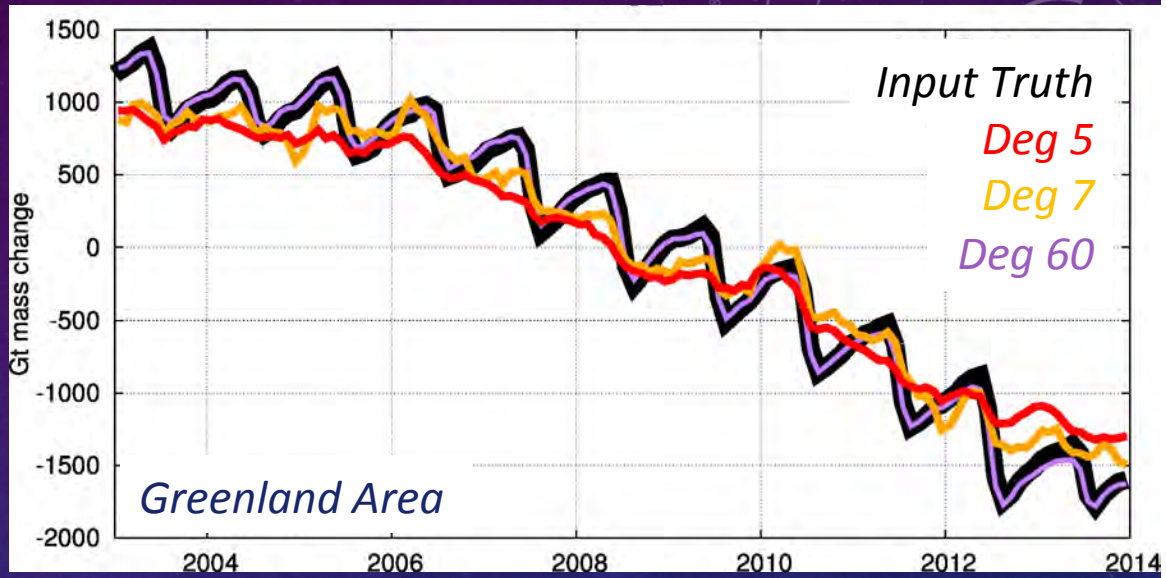
Resolution of the inversion method (modeled)

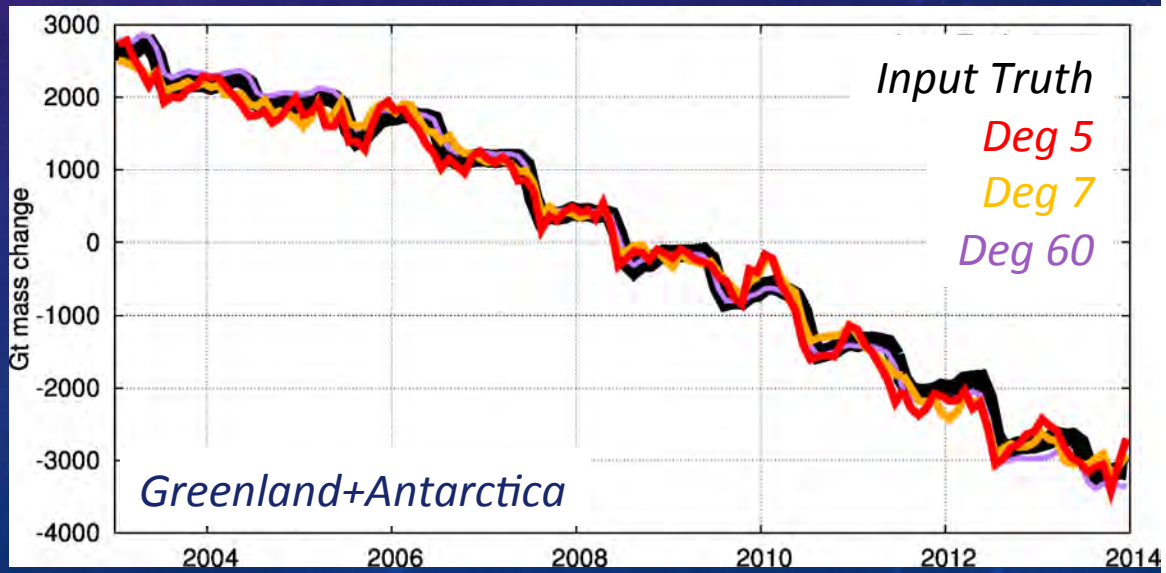
Based on a simulation:

When using only low-degree harmonics, Greenland and Antarctica are inseparable.

Errors in one area are countered by inverse errors in the other.

However, the combination of mass change over Greenland AND Antarctica is stable.





Mass change from real GRACE and SLR series

Series 1 (Krzysztof Sośnica et al):

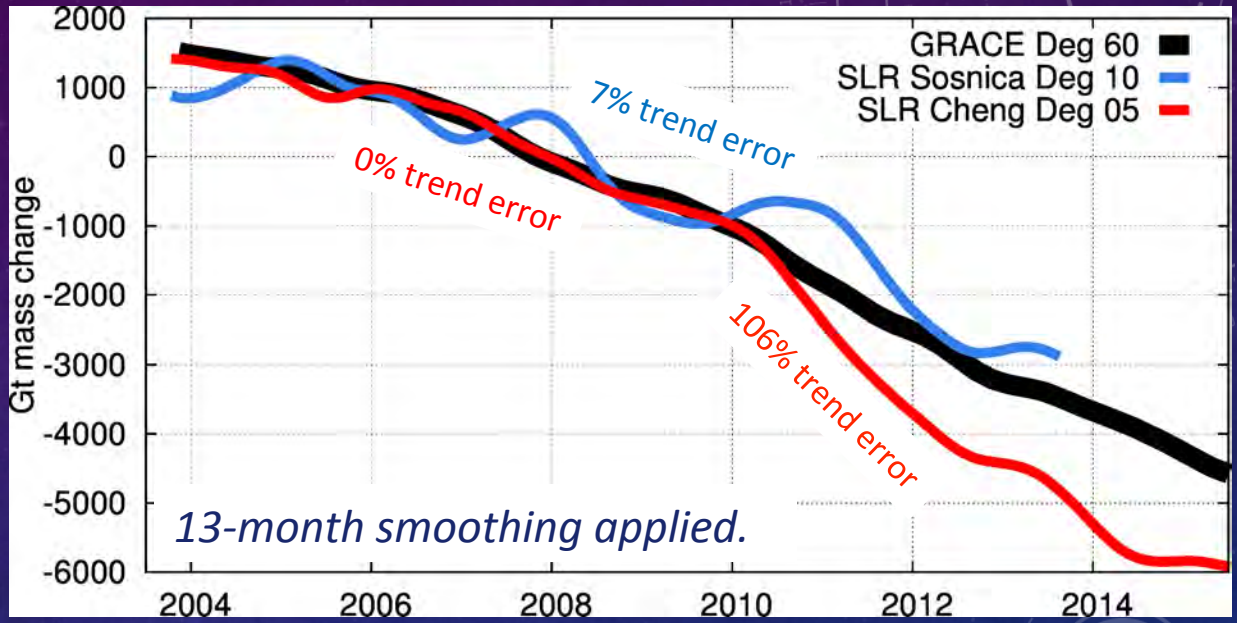
- Monthly average
- 10x10 spherical harmonics
- 2000-2014
- *Sośnica, et al. "Time variable Earth's gravity field from SLR satellites." J. Geod. 2015.*

Series 2 (Minkang Cheng):

- Monthly average
- 5x5 spherical harmonics
- 1994-2017

Series 2b (Minkang Cheng):

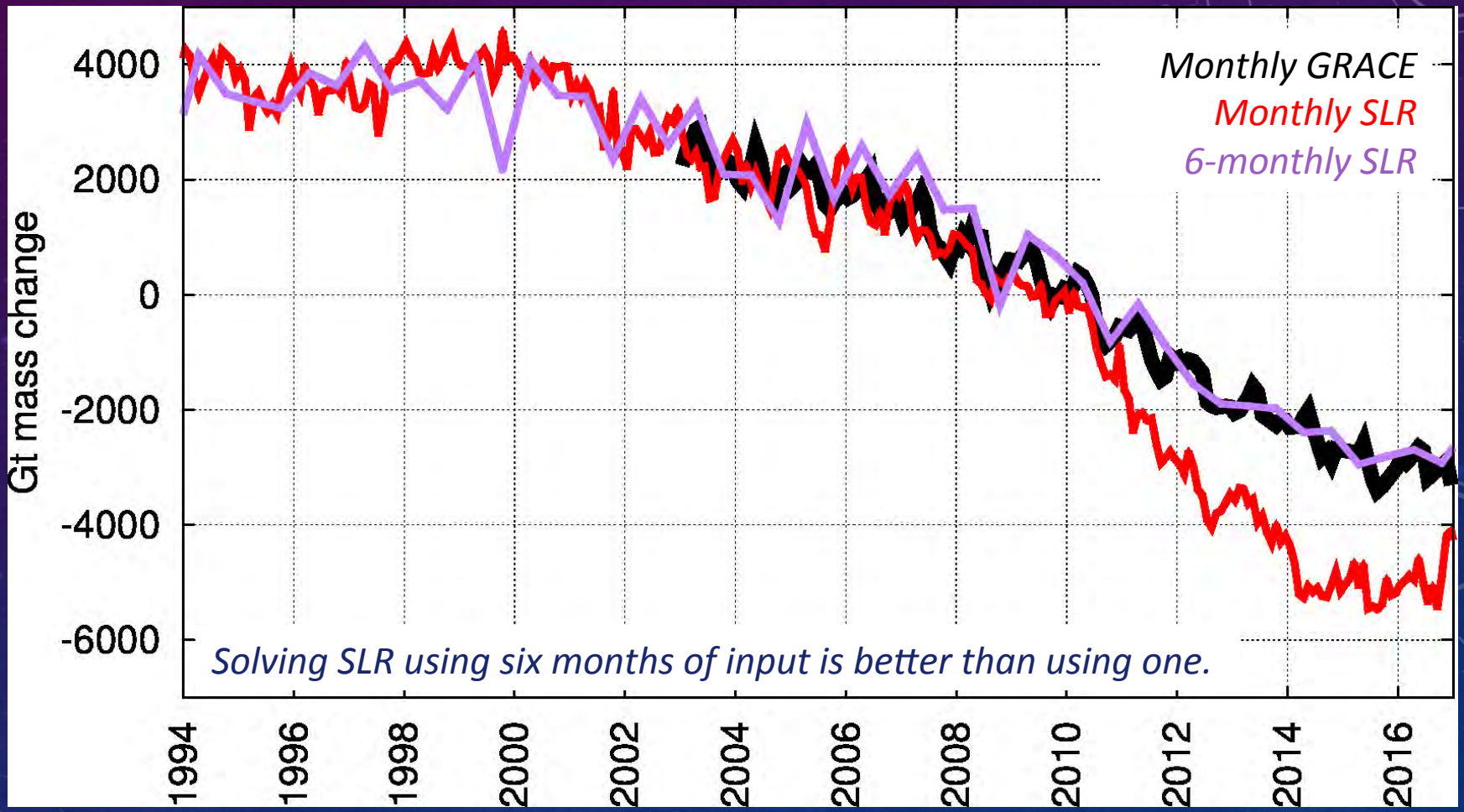
- 6-monthly average
- 7x7 spherical harmonics
- 1994-2017



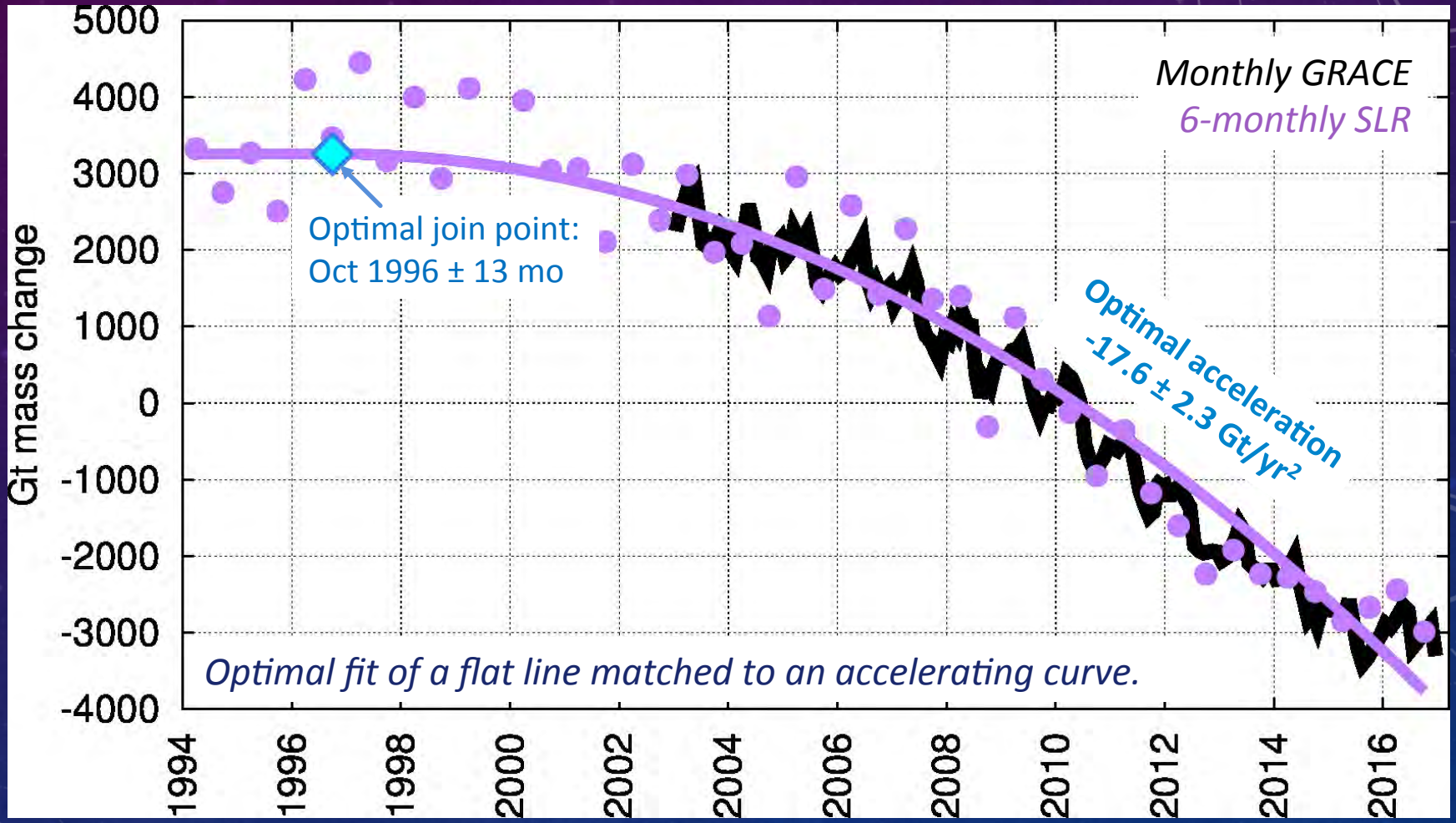
Sośnica series matches GRACE long-term pattern better.
(No indication that more mass was lost in 2010-2014.)
But the Sośnica series only runs for 14 years.

Can we improve the Cheng SLR inter-annual signal, by sacrificing the sub-annual?

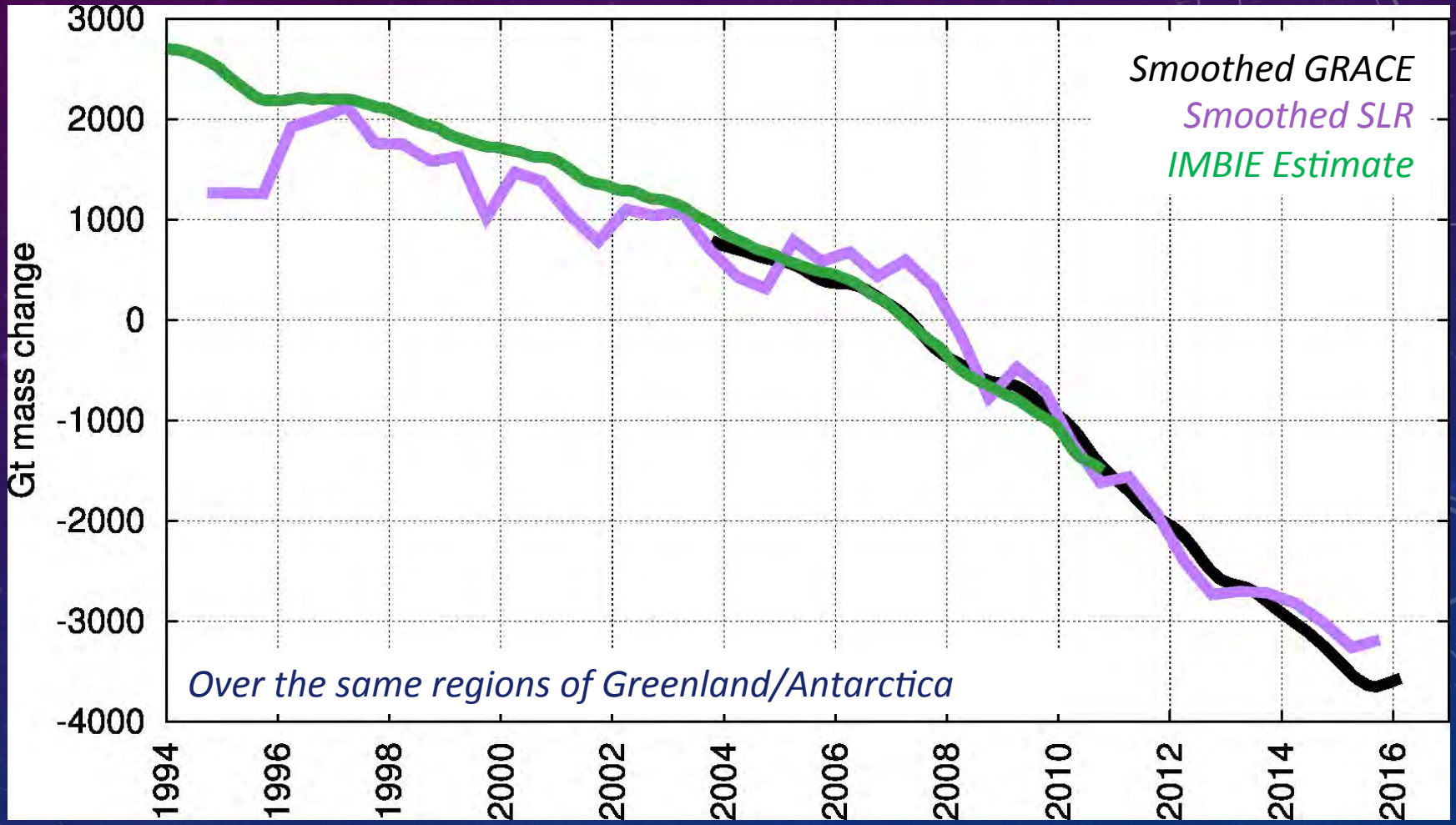
Mass change from monthly vs. 6-monthly SLR series



When did Greenland/Antarctica start to lose mass?



Is this reasonable from what we already know?



Conclusion

A least squares inversion of SLR data can be used to estimate ice mass loss:

- Greenland and Antarctica are not separable at this low spatial resolution.
- Acceleration of 17 Gt/yr^2, started between Sept 1995 and Nov 1997.
- Resulted in about 7000 Gt of total mass loss from 1994-2017.

Ice mass estimate using SLR alone!

- SLR is a totally independent time series, back to 1994.
- SLR can fill the gap and verify that we're on track when we switch from GRACE to GRACE Follow-On.

Paper in discussion in The Cryosphere:
"Using Satellite Laser Ranging to measure ice mass change in Greenland and Antarctica"
by J. A. Bonin, D. P. Chambers, and M. Cheng