Elastic deformation due to Surface Mass Balance Variability in the Southern Antarctic Peninsula

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GPS-Observed Elastic Deformation Due to Surface Mass Balance Variability in the Southern Antarctic Peninsula

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Key Points:

- Global Positioning System time series of vertical deformation in the Southern Antarctic Peninsula show transient signals
- Modeled elastic deformation due to surface mass balance (SMB) variation can largely explain these signals
- Considering SMB elastic deformation improves estimates of linear vertical velocities

Full publication link

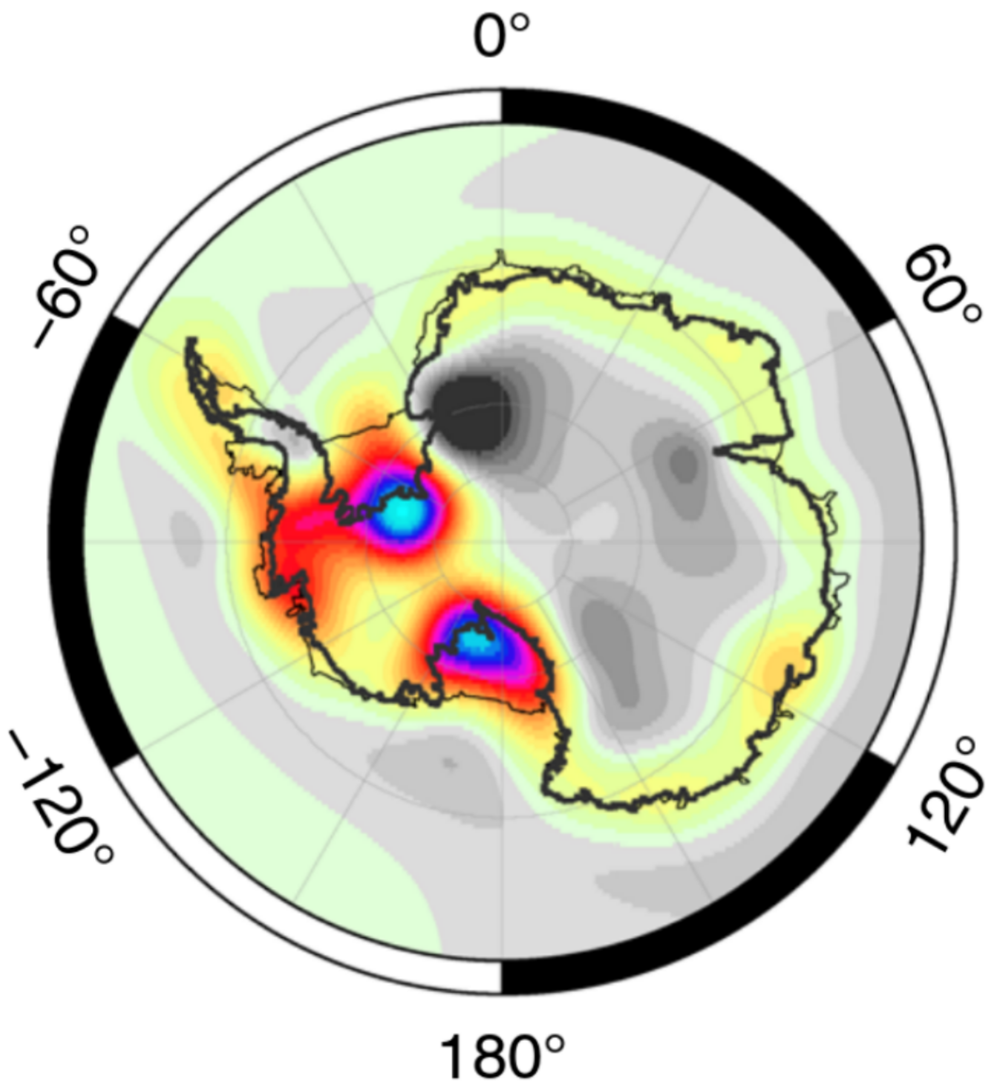
Vertical Land motion (VLM): Antarctica

Why do we need to know it?

- Impacts of sea level rise are driven by relative motion of the sea with respect to land.
- GNSS data constrain vertical VLM near cost and inland.
- Solid Earth VLM shows highly variable spatial and temporal scales.
- Diversity of processes contributing to VLM.

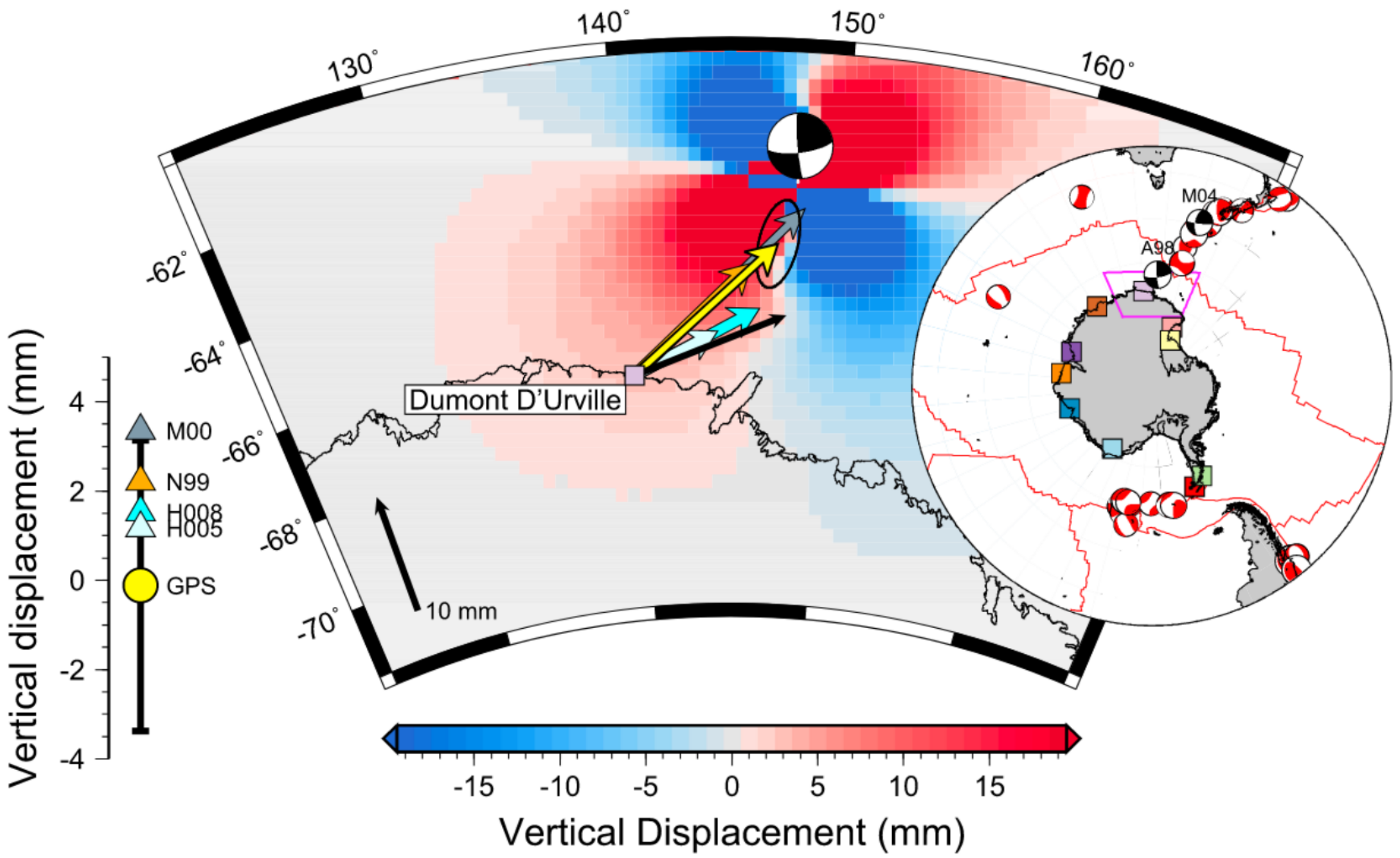
Vertical Land motion (VLM): Antarctica

GIA (Long term)



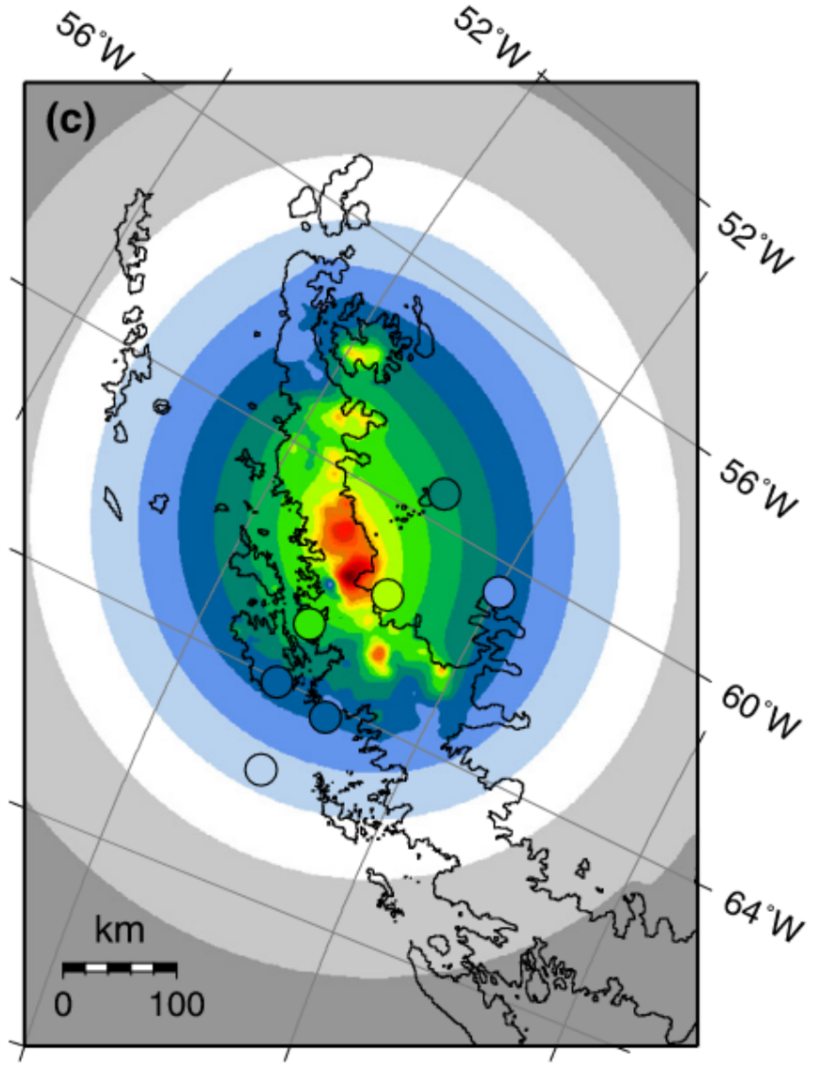
Whitehouse et al. (2019)

Tectonic deformation



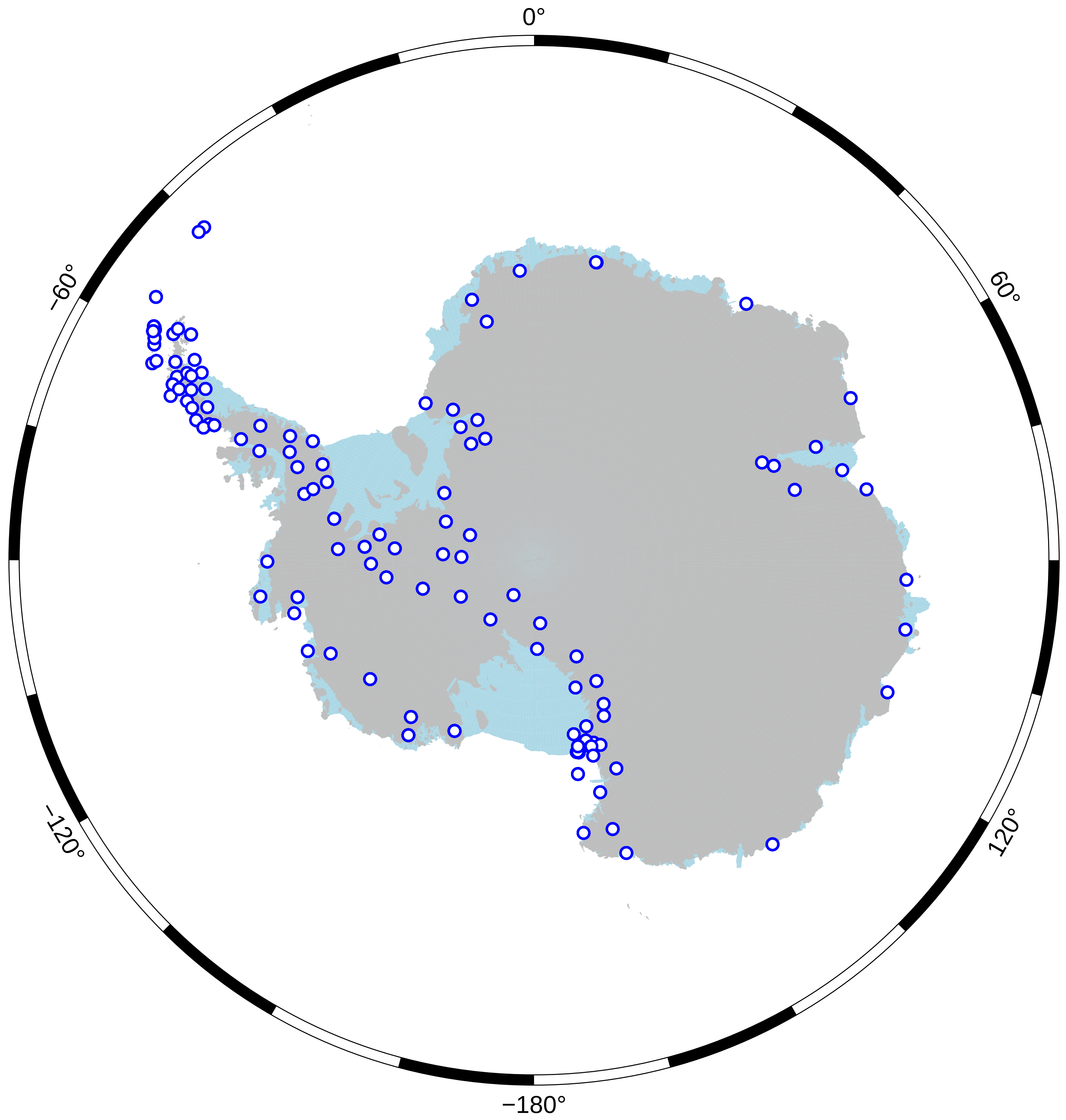
King and Santamaría-Gómez (2016)

Bedrock response to ice unloading



Nield et al. (2014)

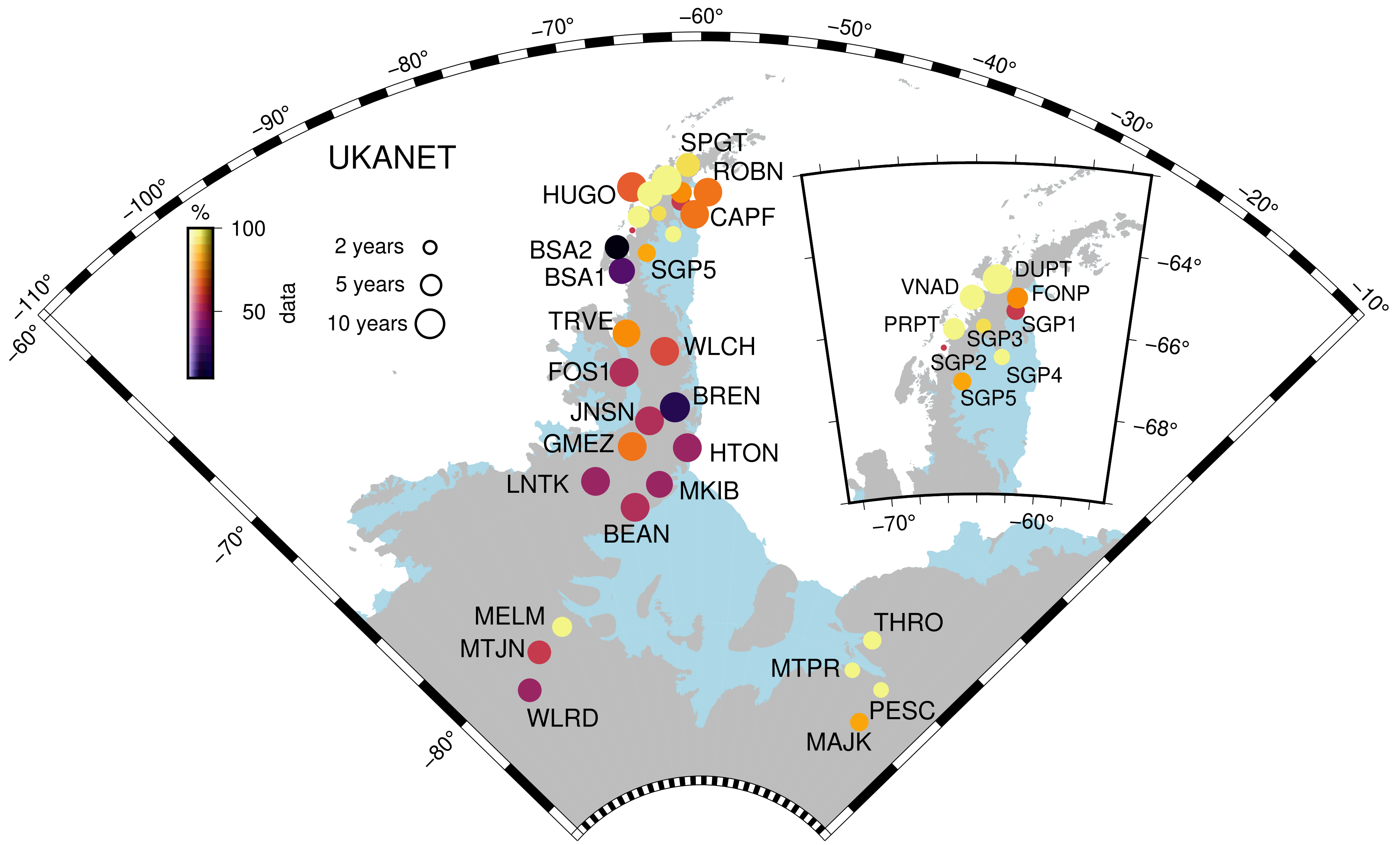
GNSS observations of VLM: Antarctica



Continuous GPS sites from UNAVCO's archive.

- Better power solutions at the majority of sites;
- Instruments transmitting data in real time, direct to UNAVCO;
- Servicing requirements monitored remotely.

GNSS observations of VLM: Antarctica / UKANET



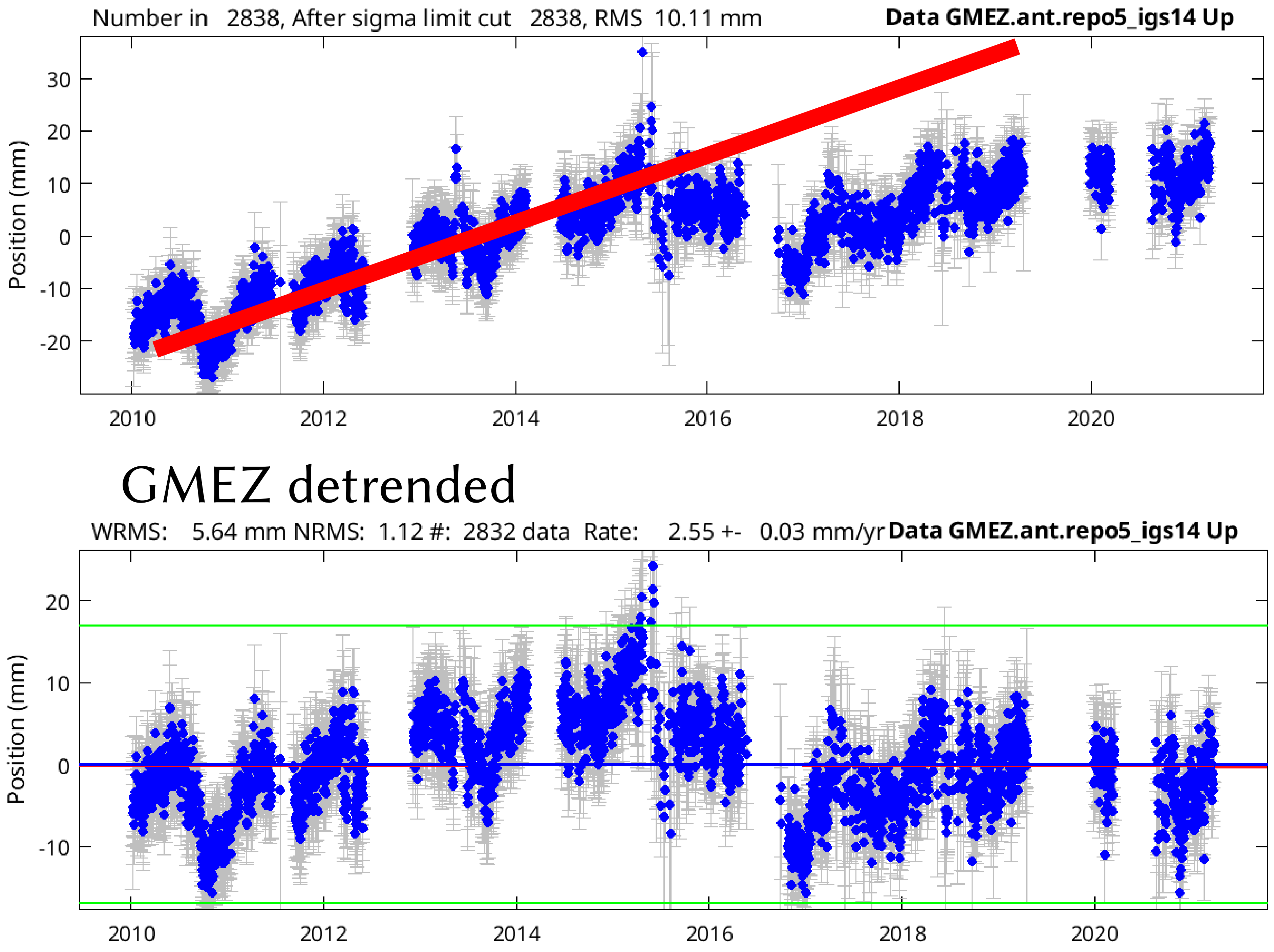
UKANET-GNSS network status

- All sites have been collecting data for at least 3 years, some for >10 years
- Percentage data return varies between <20% and close to 100%

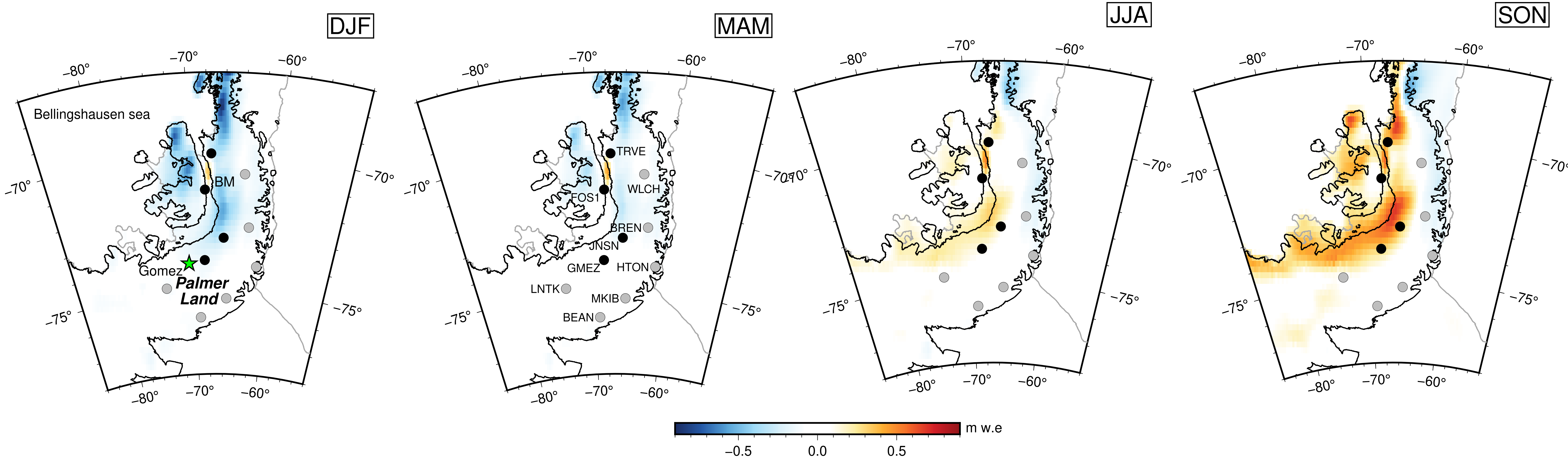
GNSS observations of VLM: Vertical time series

- Time series reveal dominant trends, with variability.
- The estimation of GPS velocities that reflect **long-term displacement** require applying corrections for **elastic deformation of the solid Earth**
- Can we explain the VLM signal using **contemporaneous surface loading** changes ?

GMEZ raw time series



Surface Mass Balance: Spatio-temporal variability



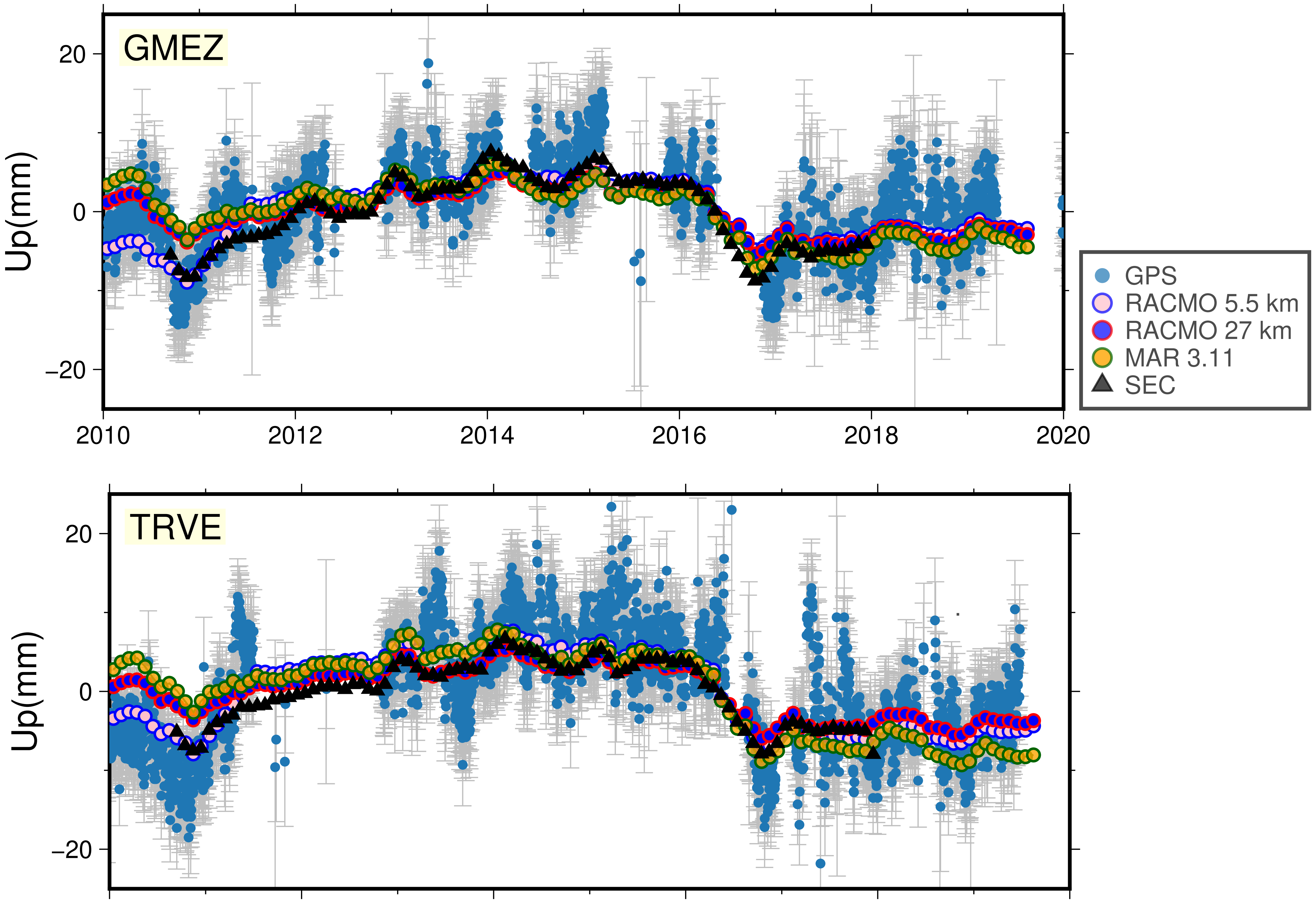
- The 2016 three-monthly mean of the SMB anomalies from RACMO2.3, over the Southern Antarctic Peninsula, shows a very pronounced variation.;
- The anomalies exhibit an east-west pattern.

Contemporaneous surface loading: elastic deformation of the solid Earth

We consider deformation due to annual and interannual fluctuations of SMB to be purely elastic in this region.

- Regional ElAstic Rebound calculator REAR (Melini et al., 2015).
- We adopted the Preliminary Reference Earth Model (PREM; Dziewonski & Anderson, 1981).

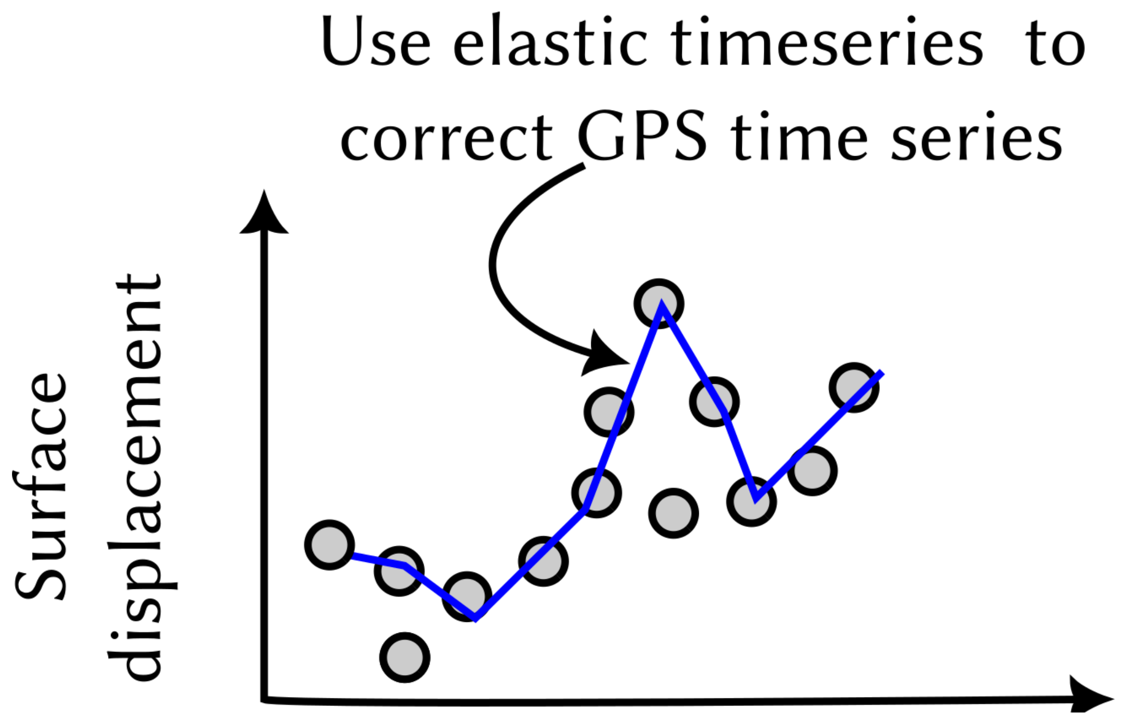
Contemporaneous surface loading: elastic deformation of the solid Earth



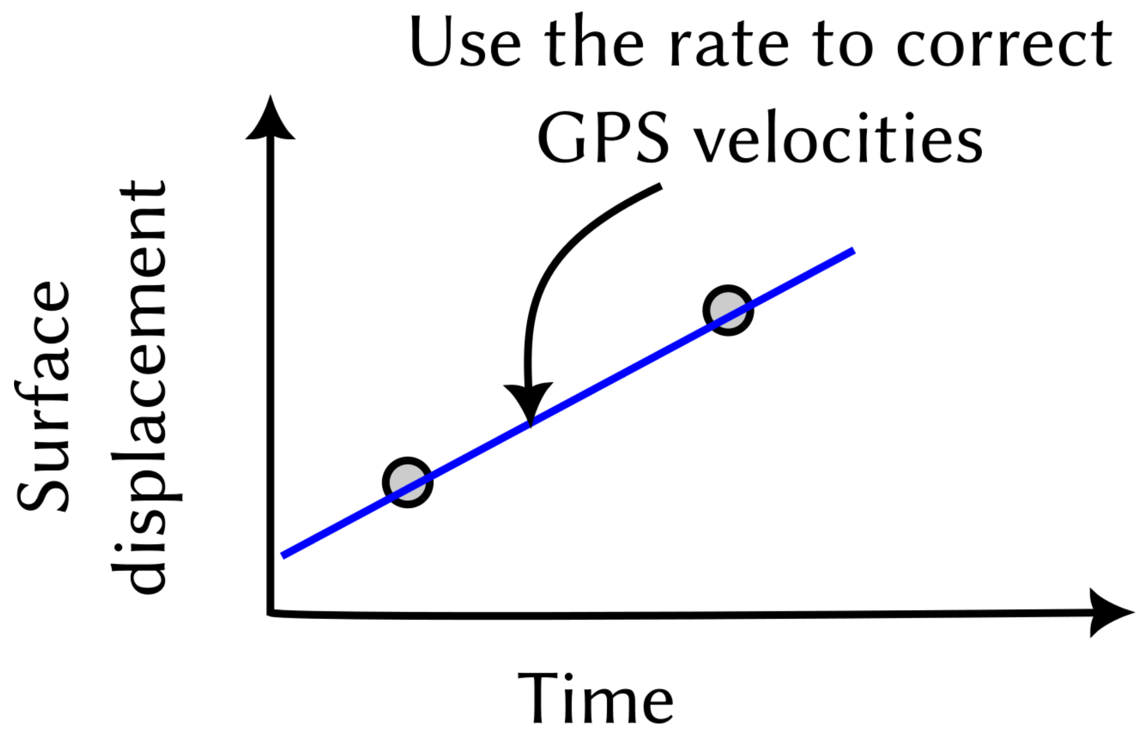
GPS data and Elastic corrections

We investigate two approaches for the calculation of the elastic deformation signal:

1 - Time Series Approach:



2 - "Linear Rates Approach":



→ This approach assumes SMB loading trend is constant in time.

GPS data and Elastic corrections

1 - Time Series Approach:

monthly SMB loads * Green's functions

surface deformation time series interpolated into daily series using a cubic spline.

Daily correction time series

2 - "Linear Rates Approach":

SMB trends

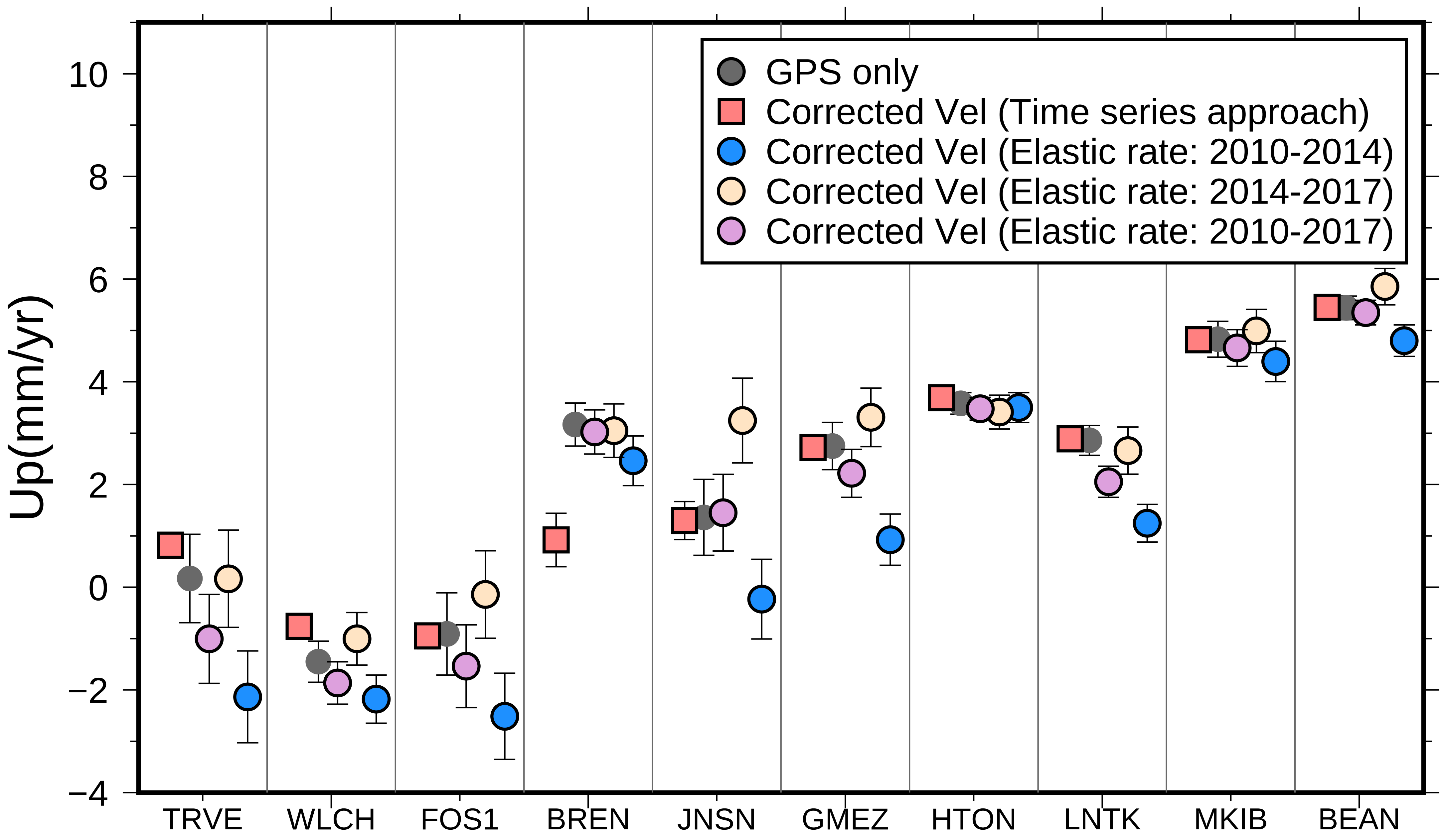
Corrected for firn densification (Ligtenberg et al., 2011).

Calculate elastic rates

For our study, we consider 3 periods:

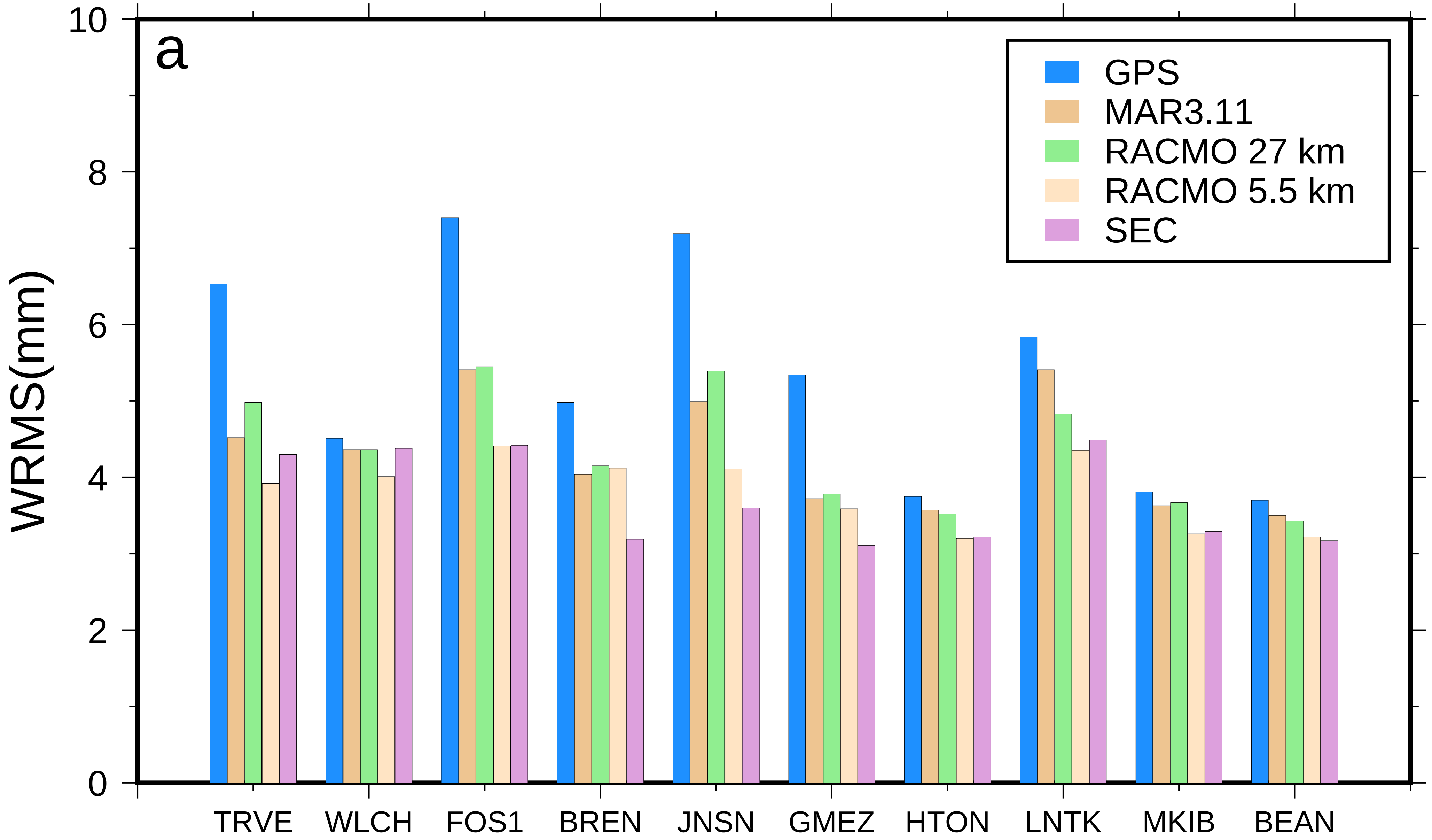
2010-2014 / 2014-2017 & 2010-2017

SMB Elastic correction: "Linear rate" vs "Time series"



- Corrected velocities over 2010–2014 differ from those of 2014–2017 or 20102017.
- This is a result of the large magnitude, time-dependent nature of surface mass change.

SMB Elastic correction time series (model resolution)

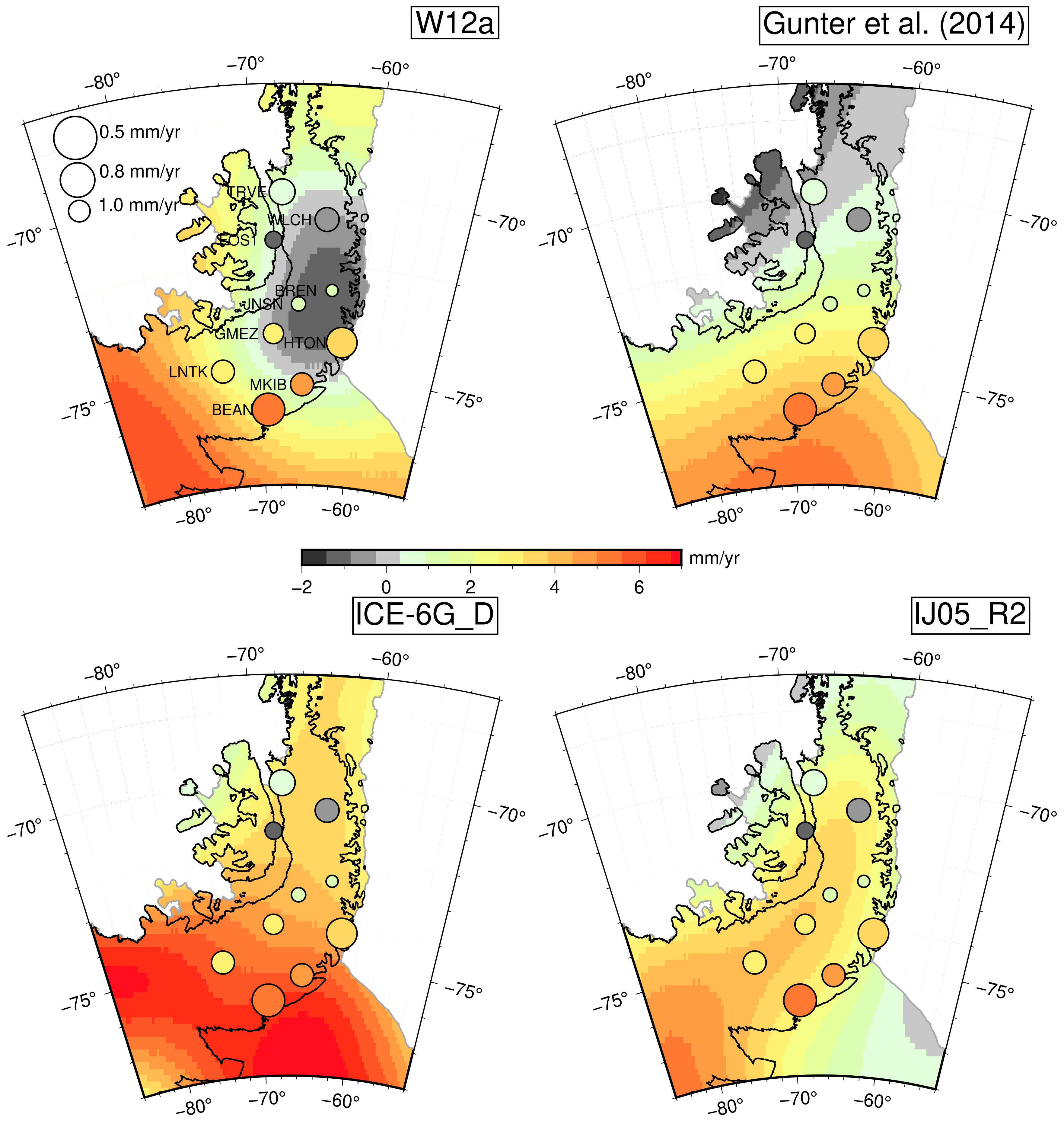


- WRMS reduction after correcting for SMB effects compared with the raw time series.
- The highest reduction in the WRMS occurs for the RACMO2.3 high resolution (5.5 km) model [See also Martín-Español et al. (2016)].

Implication for Vertical Land Motion Rates

- GPS estimates of bedrock velocities have become widely used for testing/informing the different GIA model predictions.
- We compare four model predictions of present-day GIA-related uplift rates and the estimated GPS rates after correction using the time series approach.

Implication for Vertical Land Motion Rates



Although all models reproduce well the overall pattern of deformation at most sites, disagreements are seen in different sites;

The solution of Gunter2014 is the closest to the GPS observations, with a WRMS of 0.95 mm/yr;

Conclusions

- We have modeled short-term variations in surface deformation using a purely elastic model.
- Given that GPS time series include a range of transient non-linear signals, their interpretation by simply fitting standard linear trajectory models is prone to biases.
- We have shown in this study, the background linear rate derived from GPS time series depends on how well we can model the present-day elastic deformation, hence caution should be applied when tuning GIA models using observations that contain multiple signals.