living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

MAGIC goals related to Cryosphere, Solid Earth and Neutral Atmosphere

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24/05/2022

Mass change signals are expected to enable the investigation of:

- Mass balance of ice sheets and glaciers.
- Global Isostatic Adjustment (GIA); Geohazards; Deep interior properties and dynamics; Reshaping of Earth surface; Natural resources.
- Provide measurements of thermosphere neutral density and wind
- Ground-water storage change; Soil moisture; Extreme events warning (e.g. drought, flood); Water balance closure; Global change impact on water cycle.
- Global and regional sea level change; Ocean bottom pressure; ACC and AMOC variability; Tidal models Heat and mass observations for ocean; Ocean circulation models.
- Mass transport related to climate change

The key science questions in Cryo, SE and atmos:

For ice:

C1. How much will ice sheets and glaciers contributing to sea level change, globally and regionally, over the next decade and beyond? How much are they contributing now?

C2. What will be the consequences of climate change on mass changes of ice sheets and glaciers?

C3. How can we improve the description of geodynamic processes, induced by continental ice mass changes, which act globally? How can we better interpret Glacial Isostatic Adjustment (GIA) and distinct spatial "fingerprints" of global oceanic mass redistributions?

Solid Earth questions:

S1. How can large-scale geological hazards be accurately forecast and monitored in a socially relevant time frame?

S2. How does energy flow from the core to Earth's surface? Can we better quantify the physical properties in the deep interior and their relationship to deep and shallow geodynamic processes?

S3. How can we jointly quantify and improve separation of the ongoing solid Earth deformation in response to surface loads, as the last deglaciation (i.e., the post-glacial rebound (GIA) signal), or resulting from the internal dynamics, together with the present-day ice sheet loss and water mass variations

S4. How much water is traveling deep underground and how does it affect geological processes over the long term and short term (earthquakes) and water supplies (e.g. water management)? How do we improve discovery and management of energy, mineral, and soil resources? How can we achieve sustainable exploitation of natural resources?

Each question => set of objectives

For example take C1:

C1. How much will ice sheets and glaciers contributing to sea level change, globally and regionally, over the next decade and beyond? How much are they contributing now?

=>

- C1-a. Determine the contribution of the ice sheets and mountain glaciers to global mean sea level change to within 0.1 mm/yr over the course of a decade (assuming 15 Gt/yr [See C2-b]).
- C1-b. Improve the knowledge on the dynamic response of ice flow to changing oceanic and atmospheric boundary conditions, including interactions with intra- and sub-glacial hydrology [See C2].
- C1-c. Determine the contribution of ice sheets and mountain glaciers to regional patterns of sea-level change to within 0.05 mm/yr over the course of a decade

GRACE vs E.motion2 resolution at different t scales

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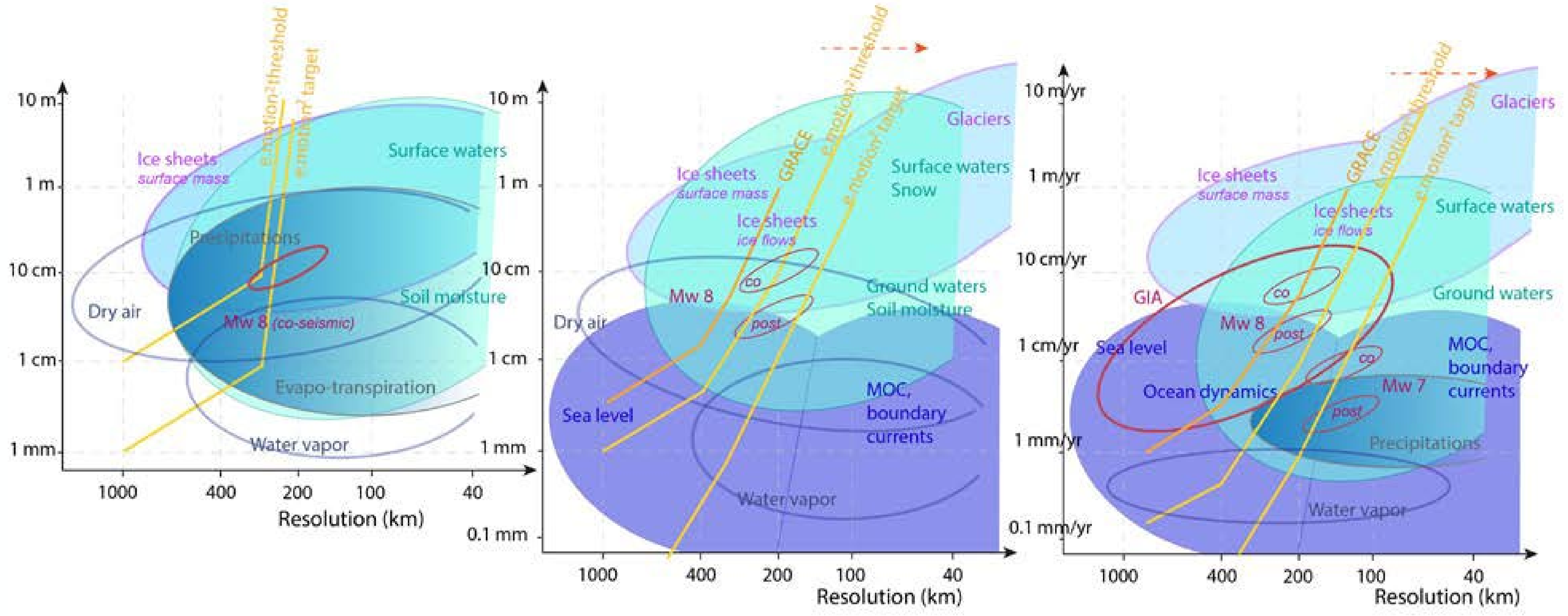


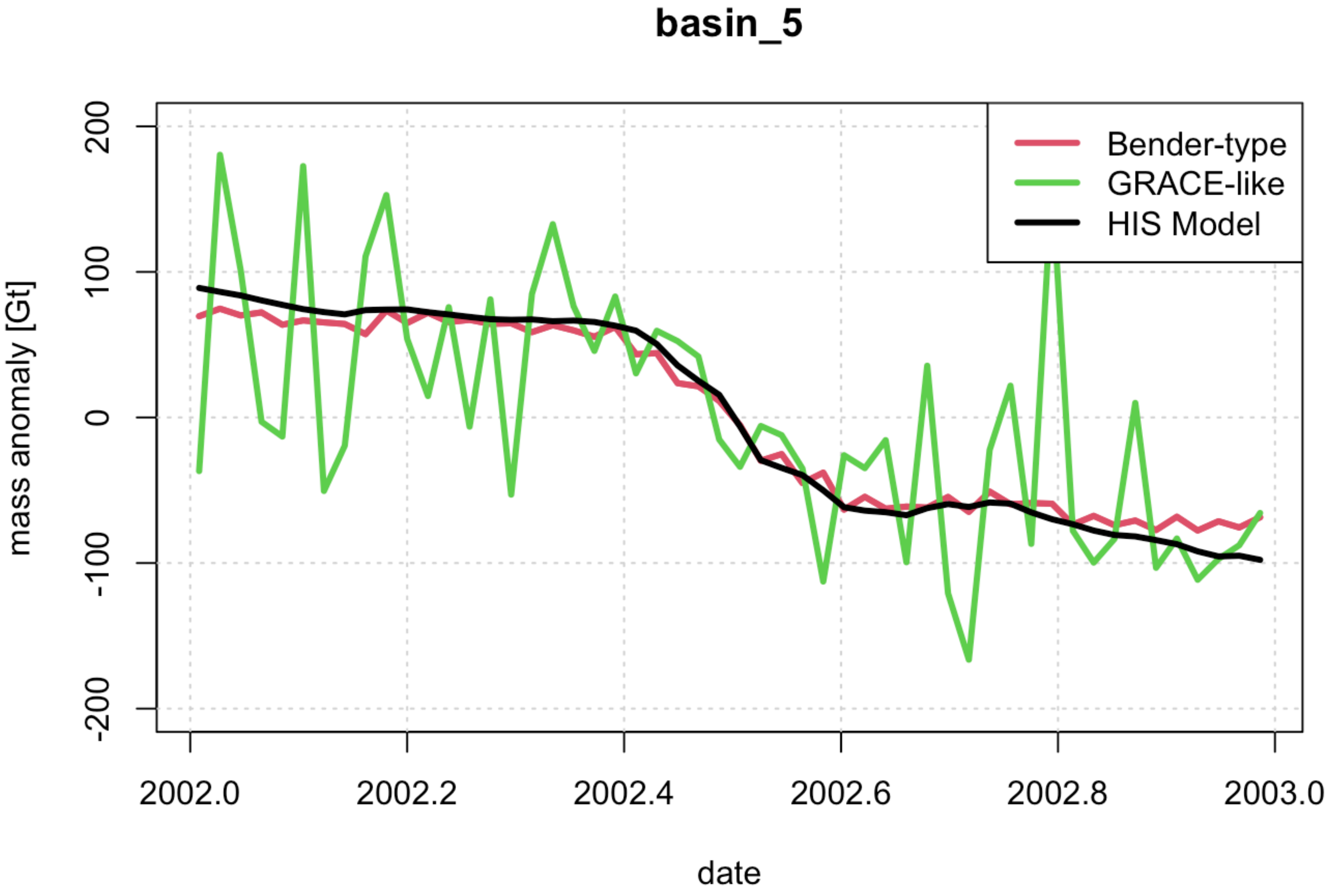
1 Week

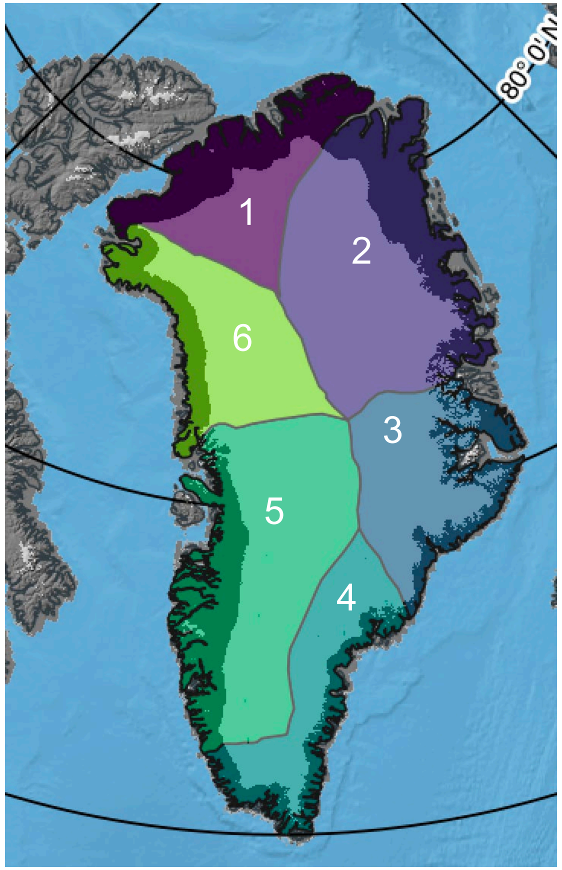
monthly-seasonal

long-term trends

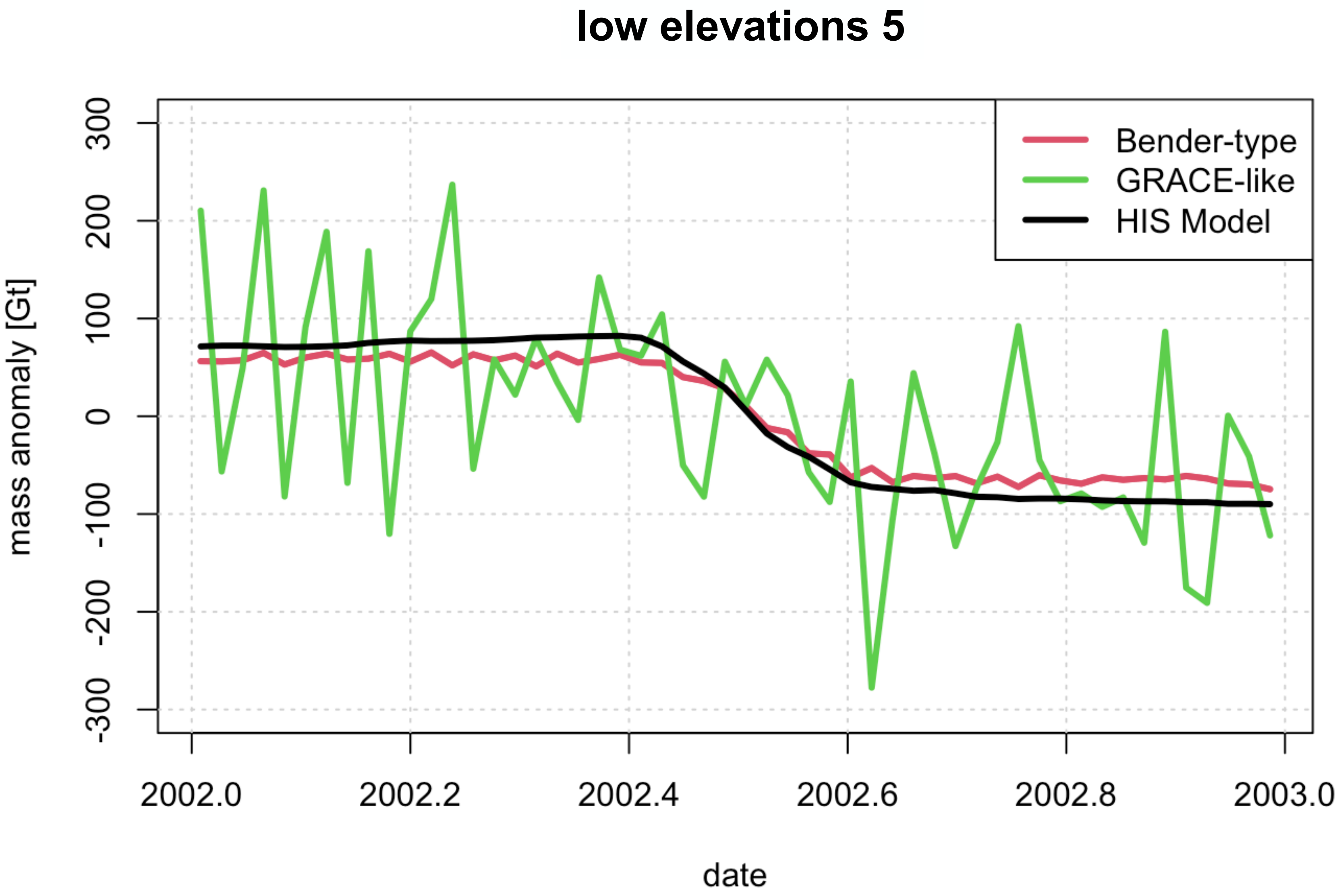
What does this actually mean for the science ?

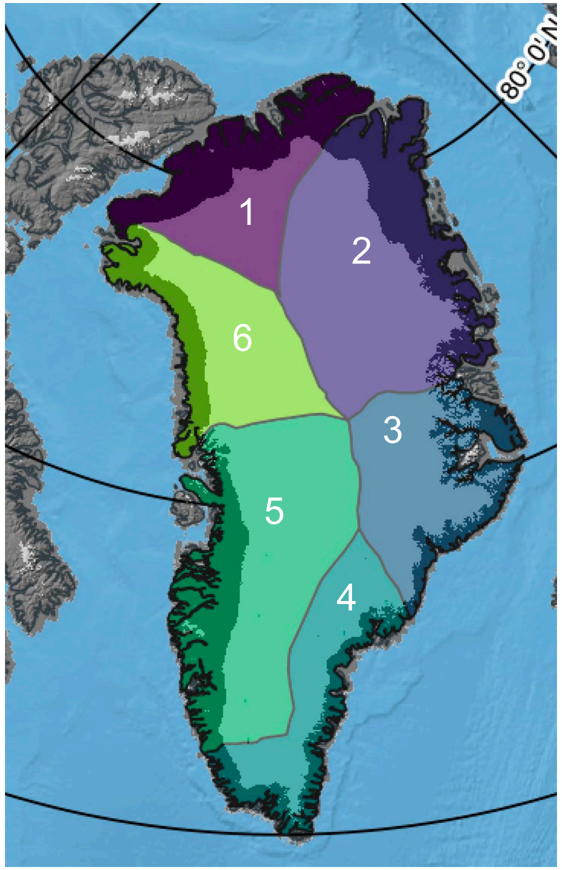
Evaluation of simulation results



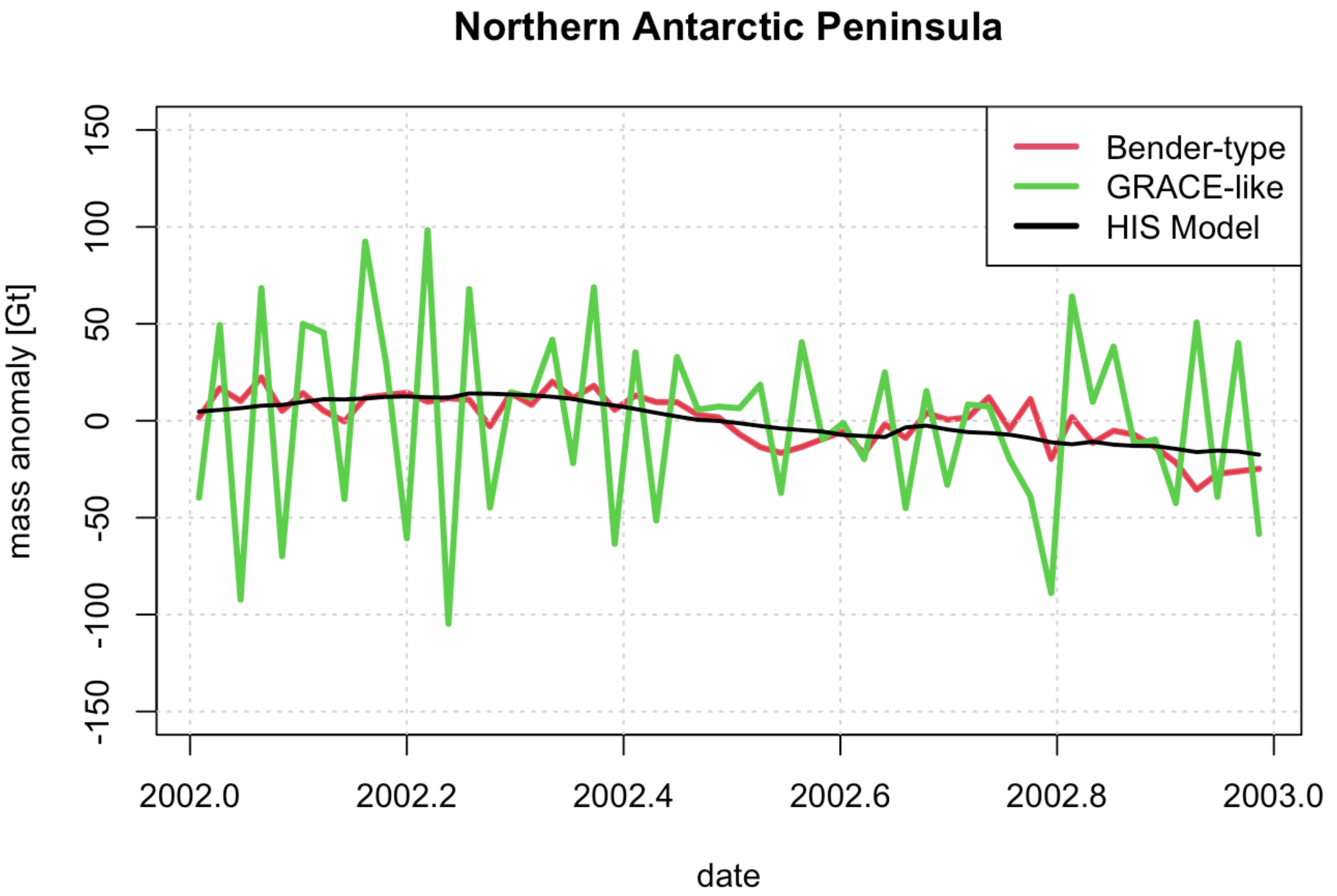


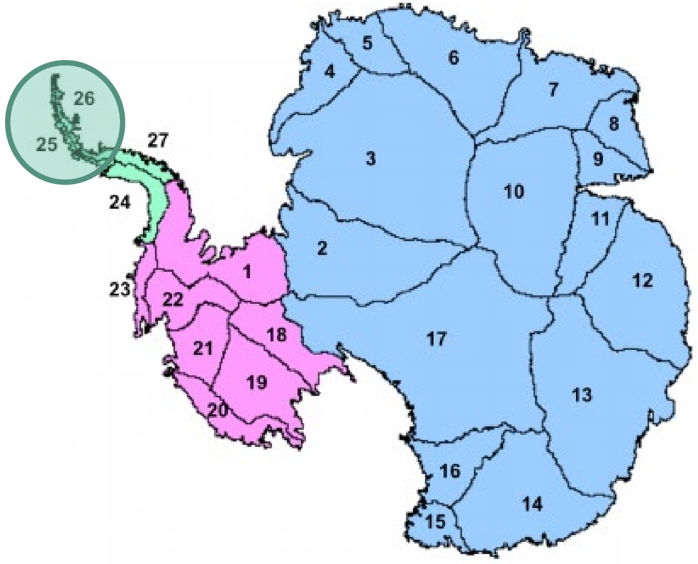
Evaluation of simulation results



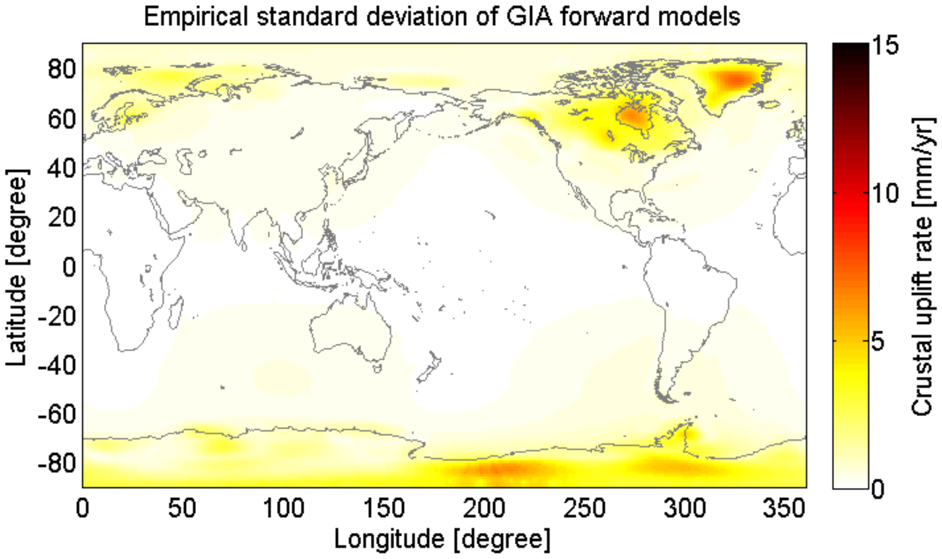


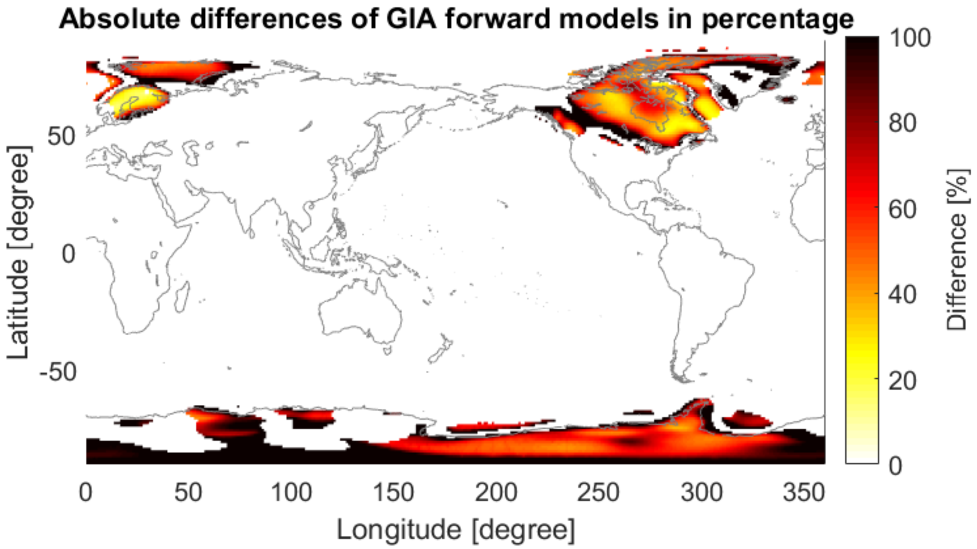
Evaluation of simulation results

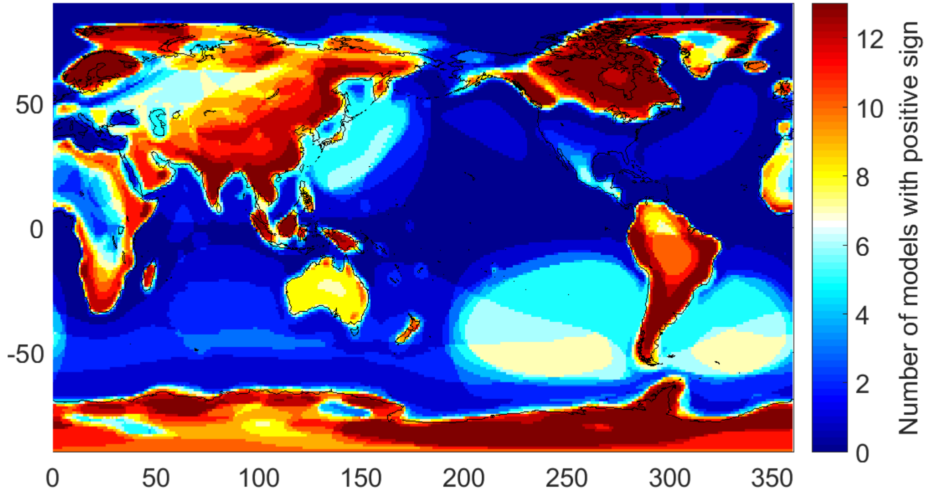




Uncertainties in GIA: Evaluating 13 GIA forward model solutions*





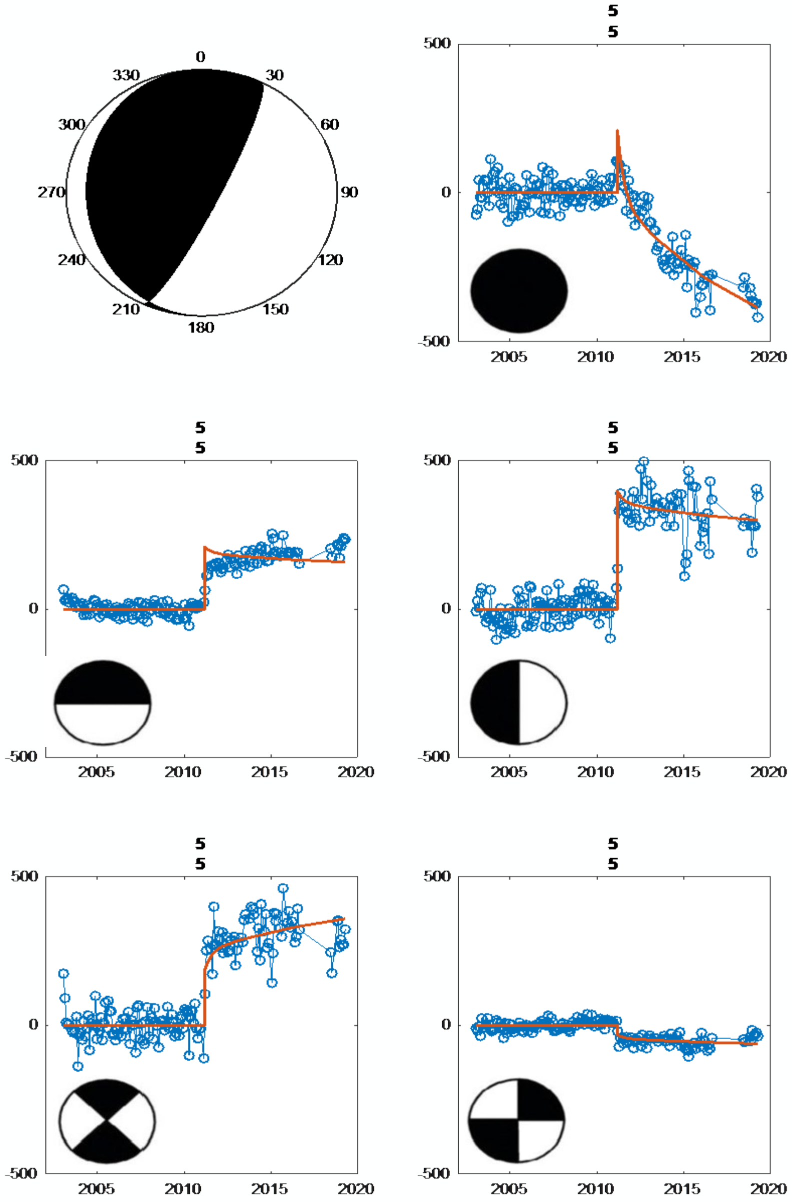


Motivation for data-driven GIA solution:

- Permanent GPS data (since ~1980)
- GRACE data since 2003

*provided by Chaoyang Zhang (Guo et al., 2012)

GRACE & GRACE-FO derived gravimetric change constrains processes associated with the earthquake cycle:



2011 Tohoku earthquake example:

- Pre-EQ deformation (**next slide**)
- Coseismic tensor components, i.e., mechanism & magnitude, (**left**), (ex. *Han et al.*, 2015, 2019)
- Post-earthquake components (**left**): the magnitude & extent have implications for stress redistribution & geohazard

MAGIC would extend the record

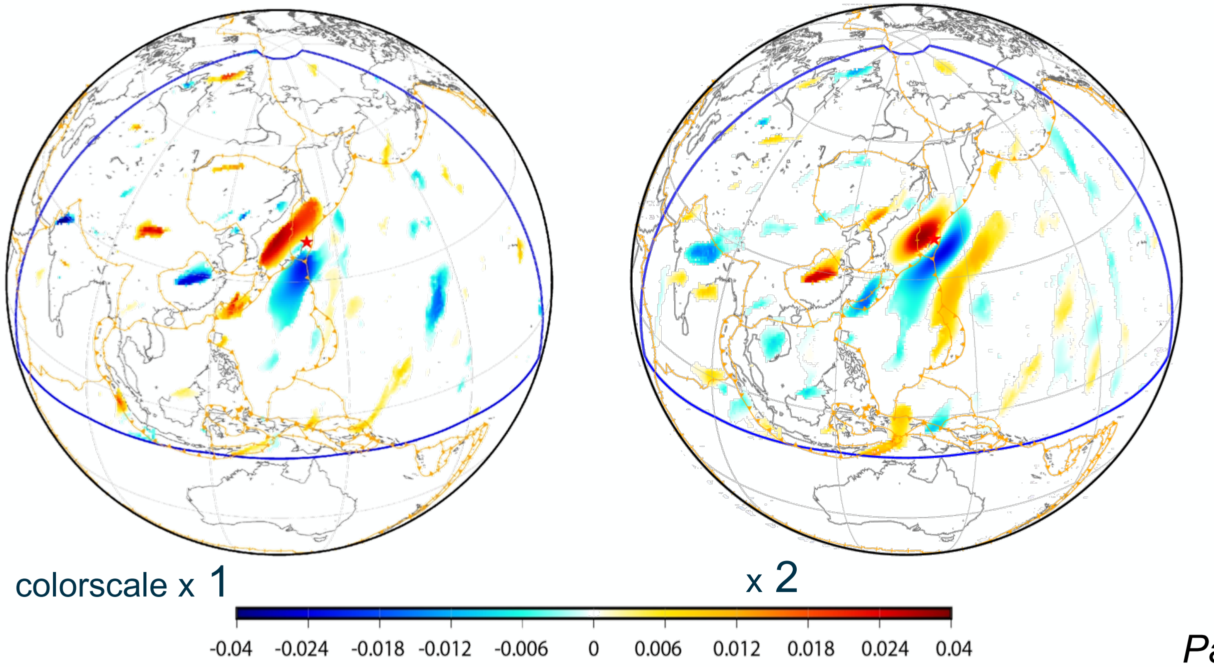
Detection of deep pre-seismic signals from GRACE

Pre-seismic (GRGS03)

July-February 2011

Co-seismic

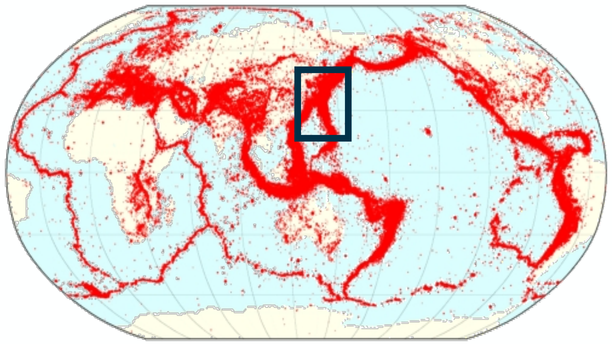
March 2011



Analysis of horizontal gravity gradients

cumulated variations, mEötvös

11 March 2011, M_w 9.0 Tohoku earthquake



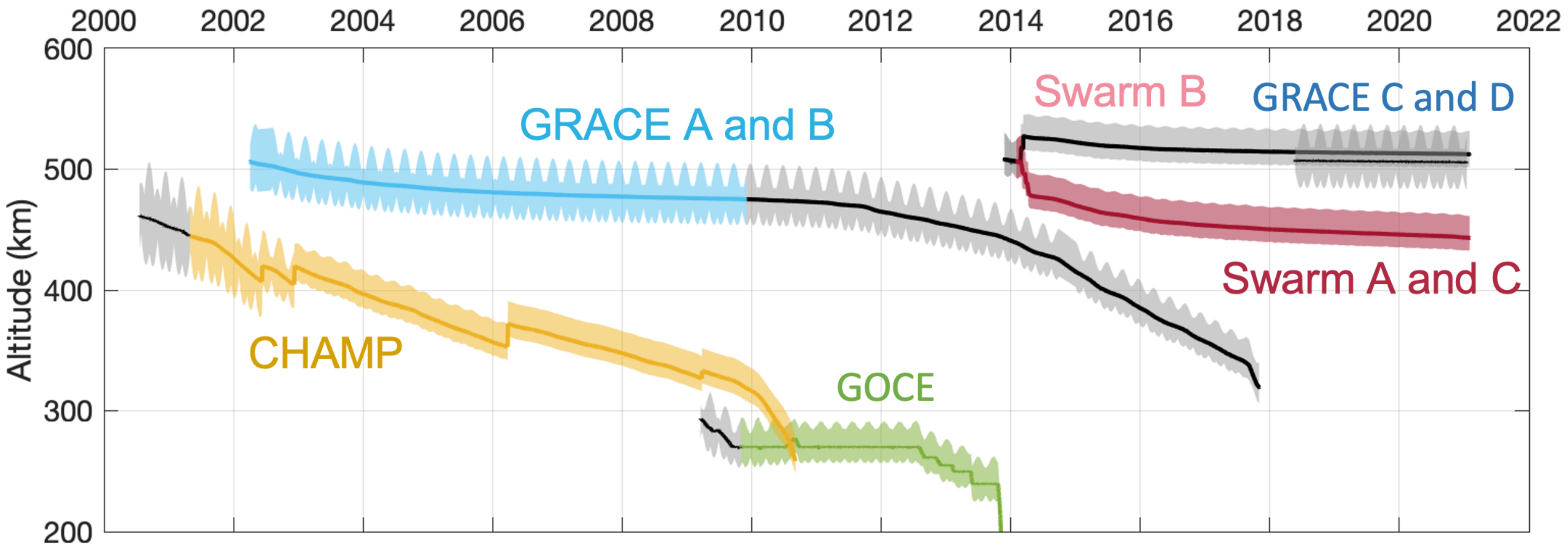
1964-2008 world seismicity (ISC)

Panet et al., Nat. Geo., 2018

*Detection of **anomalous gravity gradient signals in the months before a giant rupture**, attributed to pre-seismic extension of the subducted slabs at 150 to 300 km depth. A unique observation to document interactions between deep mass redistributions and shallow seismicity at subduction zones.*

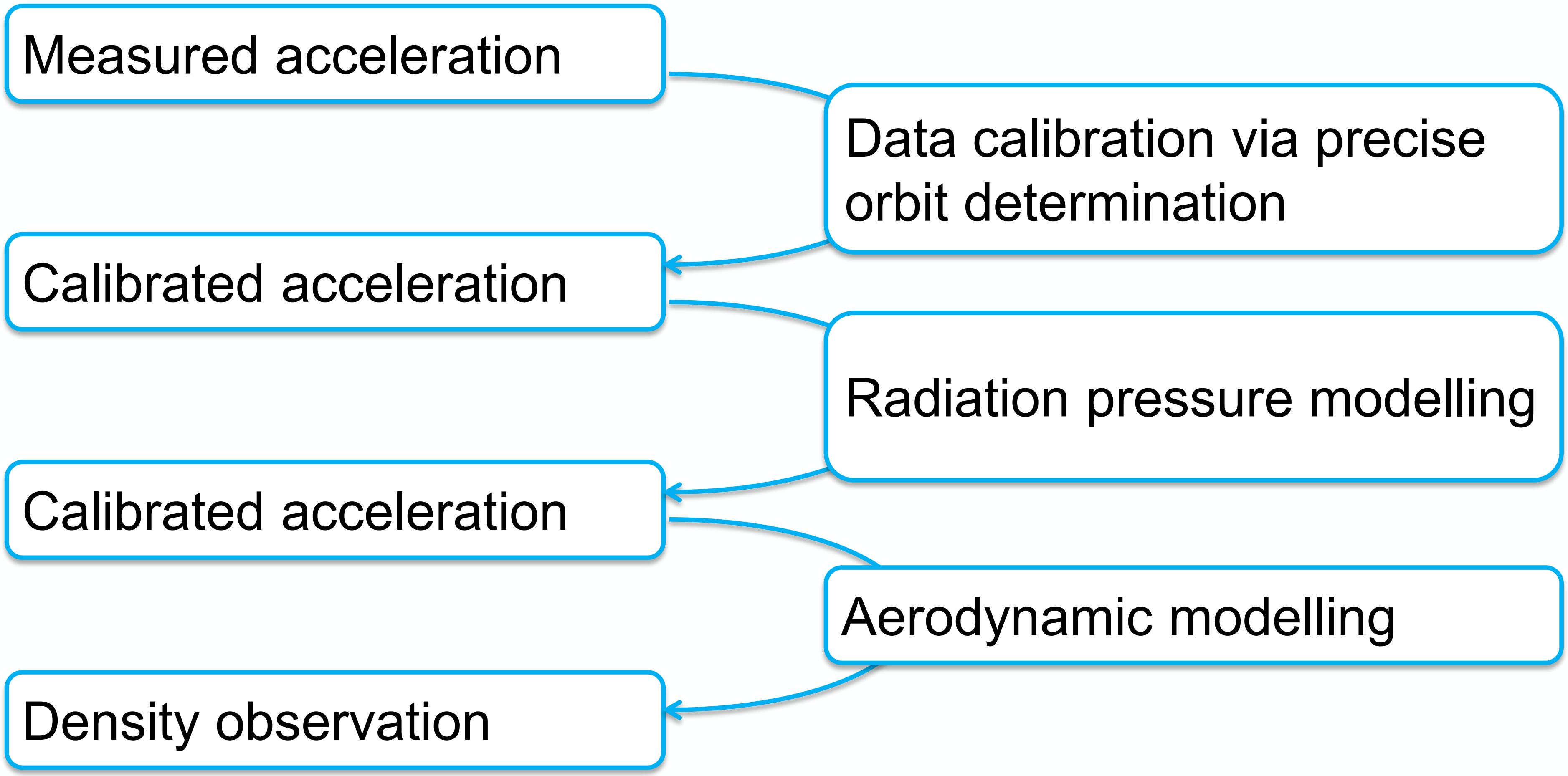
MAGIC would provide greater accuracy and less noisy gravimetric data

Altitude of thermosphere obs:



(courtesy C Siemes)

Thermosphere density from acceleration



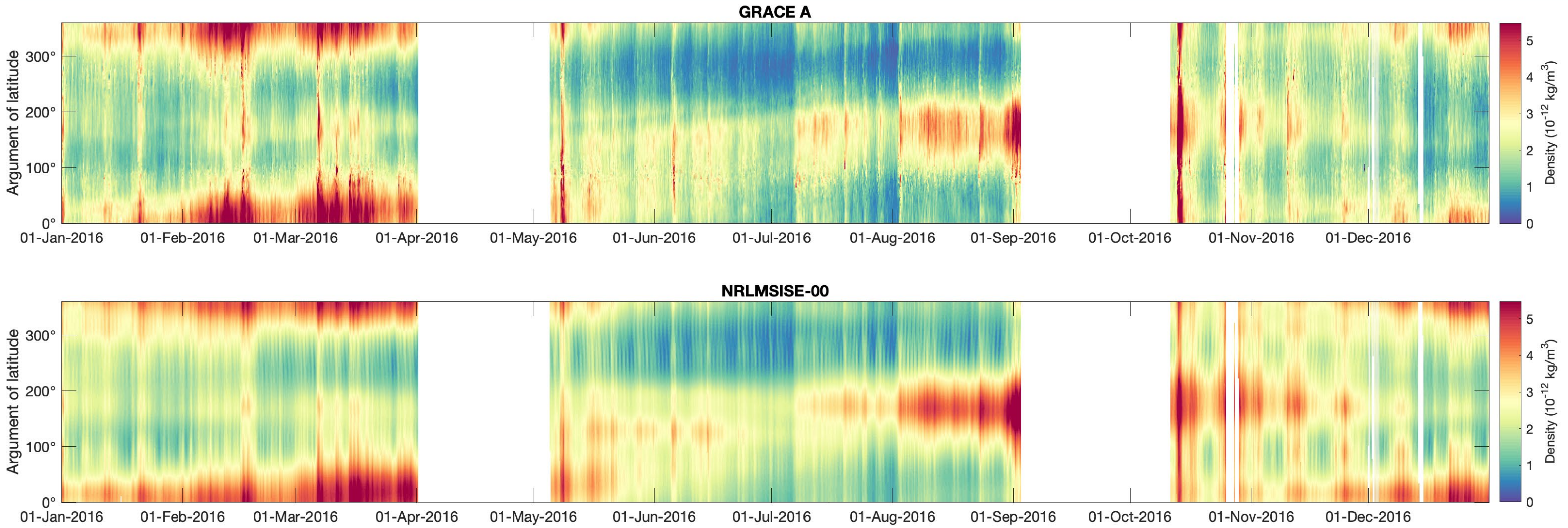
(courtesy C Siemes)

Density results (courtesy C Siemes)

GRACE A density observations in 2016 (typical result)

For validation, see poster by Kodikara et al. presented today:

“Preliminary Validation of Thermosphere Observations from the TOLEOS Project”



Summary

1. Extend the GRACE/GFO mass transport record. Key for monitoring but also improved understanding of driving processes such as ice dynamics, core/mantle dynamics and interaction with rest of ES
2. Improved spatial resoln for secular trends will allow basin scale analyses
3. New applications and uses of the high-low dual pair configuration will surely be developed!

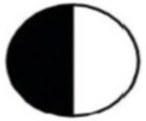
Gravity change by an earthquake point source

$$g(\theta,\varphi,t)=\left(\frac{-M_{rr}}{2}\right)g_{rr}(\theta,\varphi,t)+M_{r\theta}g_{r\theta}(\theta,\varphi,t)+M_{r\varphi}g_{r\varphi}(\theta,\varphi,t)$$
$$+\left(\frac{M_{\theta\theta}-M_{\lambda\lambda}}{2}\right)g_{\theta\theta,\lambda\lambda}(\theta,\varphi,t)+M_{\theta\varphi}g_{\theta\varphi}(\theta,\varphi,t)$$

Five response (Green's) functions of the *viscoelastic* Earth

$$g_{rr}(\theta,\varphi,t)=b_{rr}(\theta,\varphi)\{1+b_0(t)\},$$

$$g_{r\theta}(\theta,\varphi,t)=b_{r\theta}(\theta,\varphi)\{1+b_1(t)\},$$



$$g_{r\varphi}(\theta,\varphi,t)=b_{r\varphi}(\theta,\varphi)\{1+b_1(t)\},$$

$$g_{\theta\theta,\lambda\lambda}(\theta,\varphi,t)=b_{\theta\theta,\lambda\lambda}(\theta,\varphi)\{1+b_2(t)\},$$

$$g_{\theta\varphi}(\theta,\varphi,t)=b_{\theta\varphi}(\theta,\varphi)\{1+b_2(t)\},$$

where
$b_{??}(\theta,\varphi)$ is the *spatial* function determined by the layered ***elastic*** Earth model,
$b_i(t)$ is the *time-dependent* relaxation function governed by the ***viscosity profile***.