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Geomagnetic Jerks in the Swarm Era

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The timely provision of geomagnetic observations as part of the ESA Swarm mission means analysis and modelling can be conducted rapidly and kept up-to-date in a manner not possible before. Observations from each of the three satellites in the Swarm constellation at 1Hz are available within 4 days and hourly mean ground observatory network measurements (AUX_OBS_2) are updated every 3 months by the British Geological Survey (BGS). This makes it possible to study very recent changes of the magnetic field. In particular here we investigate variations known as geomagnetic jerks.

Given that jerks represent (currently) unpredictable changes in the internal geomagnetic field, we ask what impact they might have on the accuracy of the International Geomagnetic Reference Field Model (IGRF). The 12th generation of the IGRF was last updated using observations up to mid-2014 and provides a snapshot of the geomagnetic field at 2015 as well as a prediction of variations until 2020.

1. Geomagnetic Jerks

The Earth's magnetic field is generated by the motion of electrically conductive, iron-rich fluid in the outer core. As this field passes through the mantle and crust it is filtered to give the generally large-scale and slowly varying field we observe at the surface and in space.

The most rapid known features we observe in the internal core field are variations on the timescale of months known as jerks - the result of rapid fluid motion in the core.

The first time derivative of the Earth's magnetic field is known as the **secular variation (SV)**, the second, the **secular acceleration (SA)**. The SV can be approximated as a series of linear trends separated by the abrupt vertices of jerks, equivalent to step changes in the SA (Figure 1).

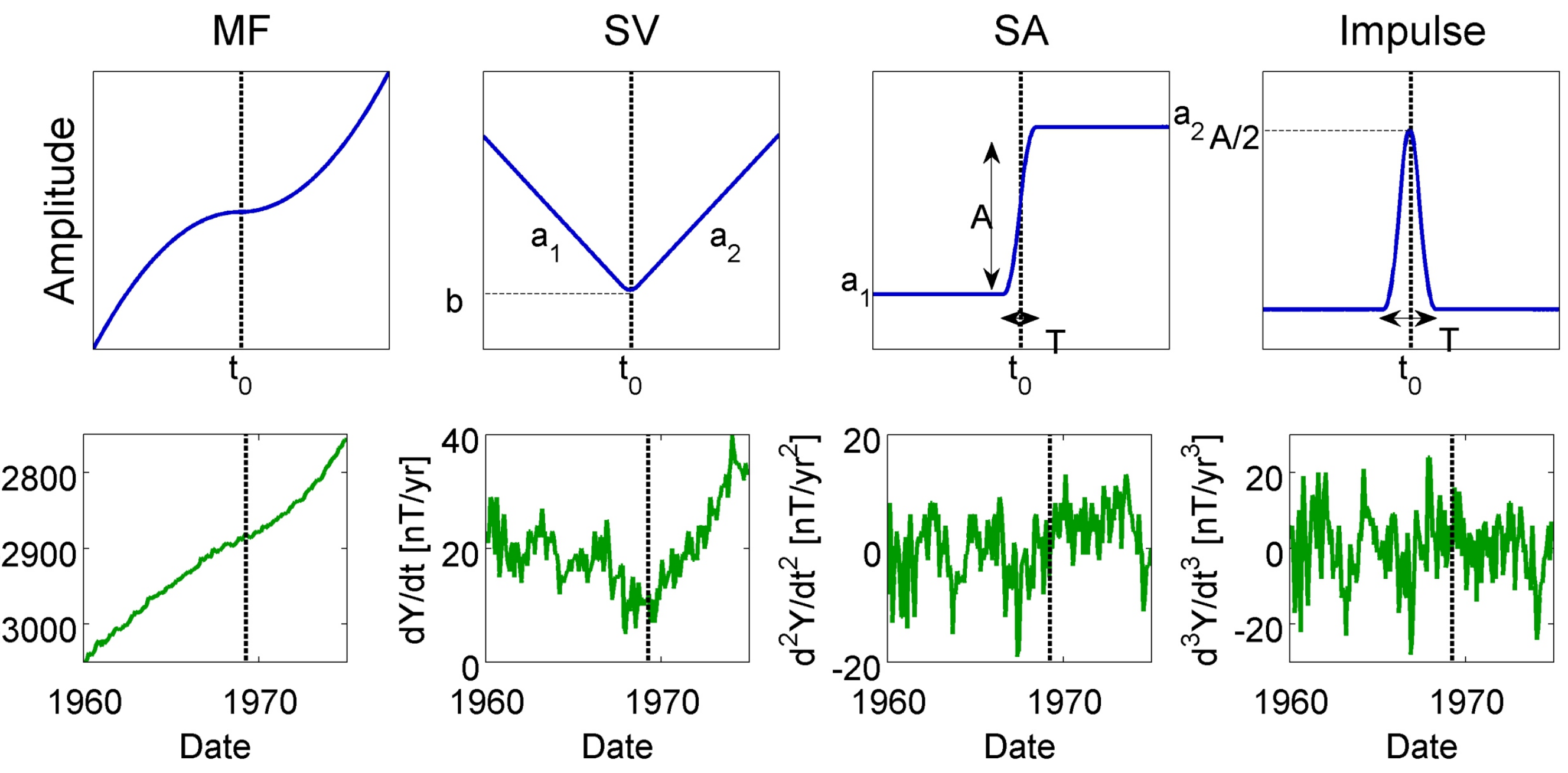

Figure 1: Idealised form of a jerk (at dashed line) in timeseries of the magnetic field (top) and in real observations from Eskdalemuir, Scotland (bottom). The main field (MF), secular variation (SV), secular acceleration (SA) and third time derivative (impulse) are shown.

2. Data and Modelling

We use vector and scalar geomagnetic observations collected by the 3 Swarm satellites - Alpha and Charlie in lower orbits and Bravo in a higher orbit - as well as the surface observatory network. This consists of some 155 stations across the globe (Figure 2).

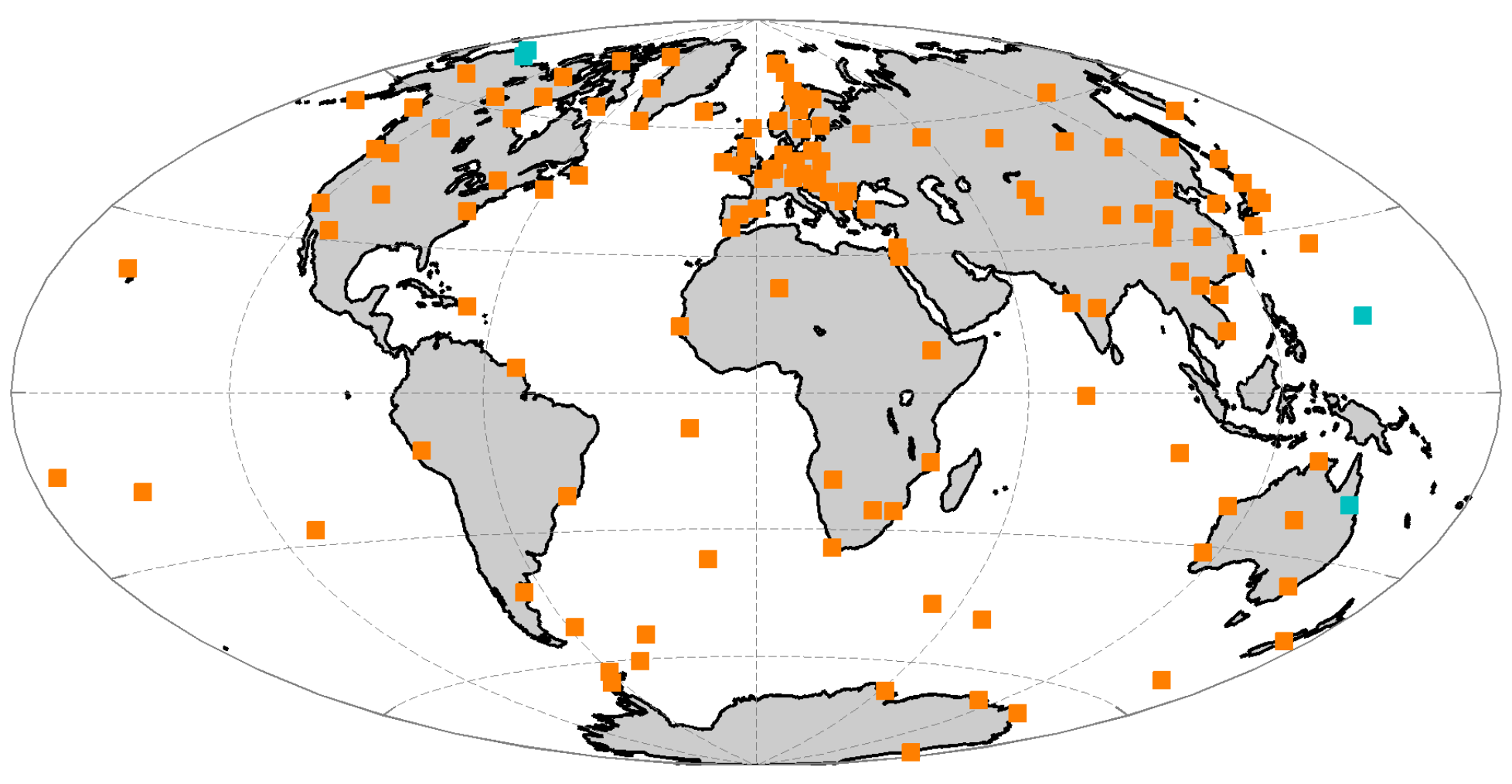

Figure 2: Locations of magnetic observatories used, highlighted locations refer to Figure 4.

Geomagnetic observations capture many sources of magnetic fields (Figure 3) - for example core, crust, ionosphere and magnetosphere. In order to best study the variations of the core field only, we require field models of the internal and external magnetic sources.

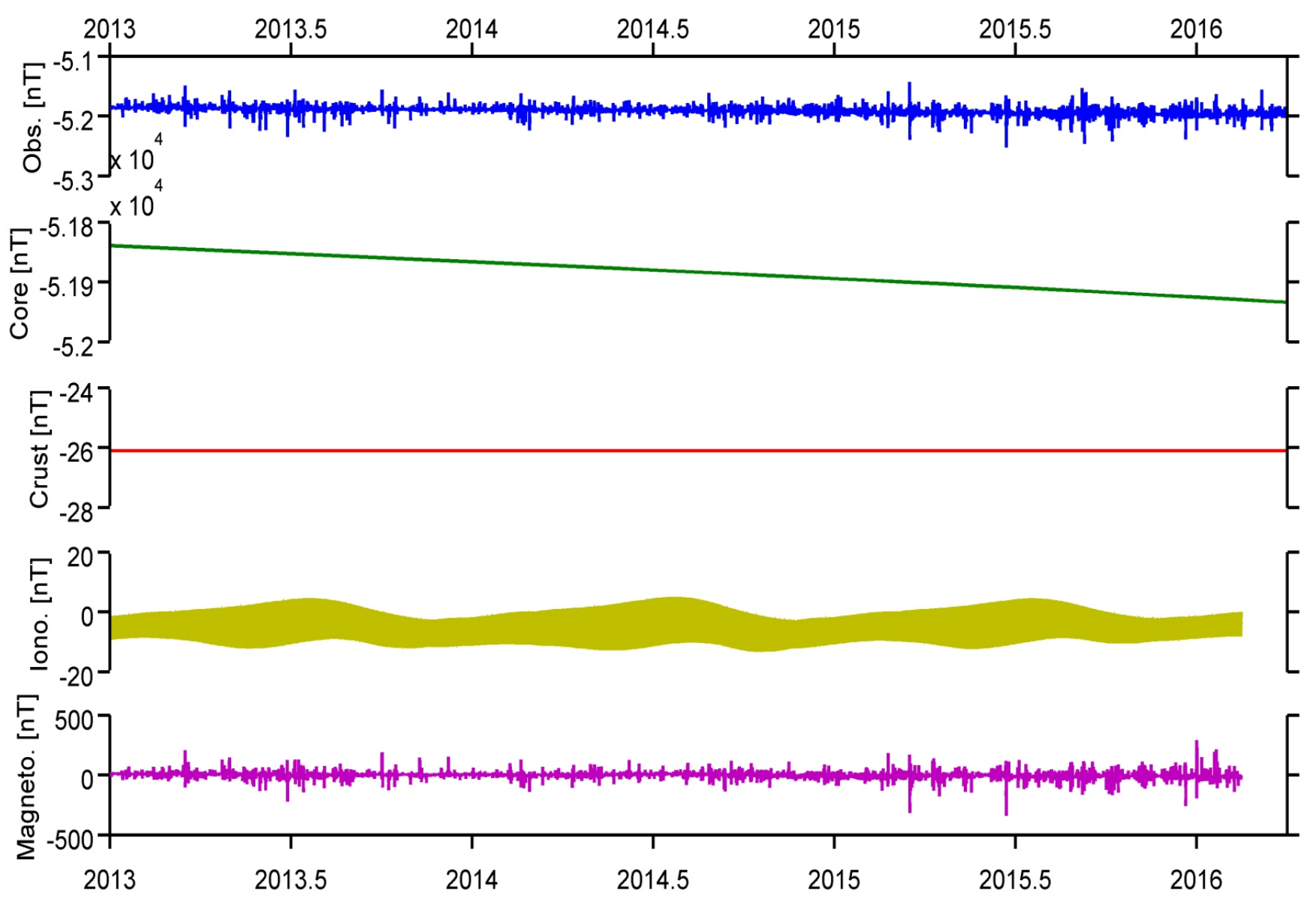

Figure 3: Separated field sources from an example observatory timeseries (radial component, Abisko, Sweden) using a BGS field model created from Swarm and AUX_OBS_2 data, CM4 and CHAOS-6.

A geomagnetic field model can be built from such observations, attempting to separate external and internal field sources. First we use careful selection of data during periods of "quiet" solar activity and at local night times when satellites or observatories are across the horizon from the Sun. Second we use modelling techniques designed to distinguish field sources by spatial and/or temporal characteristics.

Here we use a model of the core field derived by BGS using Swarm and AUX_OBS_2 [1] observatory data up to March 2016 and we "clean" observatory measurements directly by removing the ionospheric model of CM4 [2] and the magnetospheric model of CHAOS-6 [3].

3. Jerks During Swarm

Torta *et al*. (2015) [4] were first to point out the presence of a jerk around 2014 in observatory data which detailed SV to March 2015. Strong SA was seen particularly in the South Atlantic/Africa region, extending up into Europe and the North-Western Atlantic, and also in Australasia.

With AUX_OBS_2 data detailing SV to September 2015, we reassess the extent of the 2014 jerk and more recent developments (Figure 4).

In general we can confirm the presence of widespread jerks across much of the globe from late 2013 through to early 2015. This includes jerks in some regions (e.g. Alaska) not highlighted by Torta *et al*. (2015) which appear in only the most recent observations.

The significance of this is seen by comparing the capture and prediction of SV by the BGS model (Swarm and obs. data to March 2016), CHAOS-6pre (Swarm and obs. data to Nov 2015) and IGRF-12 [5] (Swarm and obs. data to mid-2014) (Figure 4), although the limitations of spline end effects must be acknowledged.

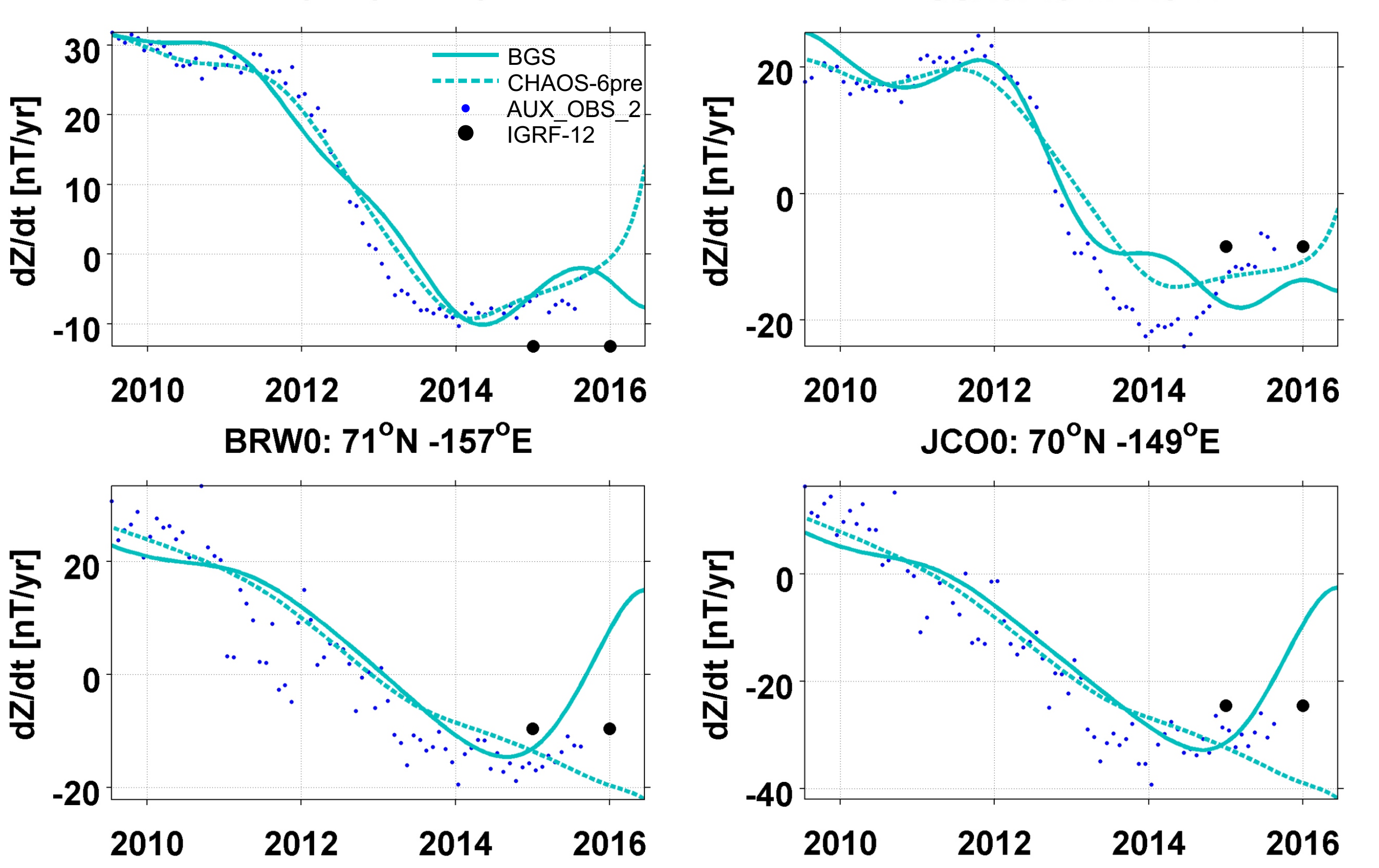

Figure 4: Z-component of SV data and models at Charters Towers (CTA), Australia, Guam (GUA) showing late-2013/early-2014 jerks and at Barrow, Alaska (BRW) and Jim Carrigan Observatory, Alaska (JCO) showing late-2014/early-2015 jerks.

4. IGRF SV Predictions

The presence of unpredictable, non-linear SV such as jerks so close to the release of IGRF-12 means that its linear SV estimate could be impaired early in its 5 year life span to 2020 (Figure 5).

IGRF-12 SV is derived from 9 candidate models. Of these models, 4 use physical processes such as forward projection of core flow or data assimilation to a dynamo model to forecast the SV while the remaining 5 use linear extrapolation. We compare here the performance of each as of 2016.0 relative to the new BGS model (Figure 6).

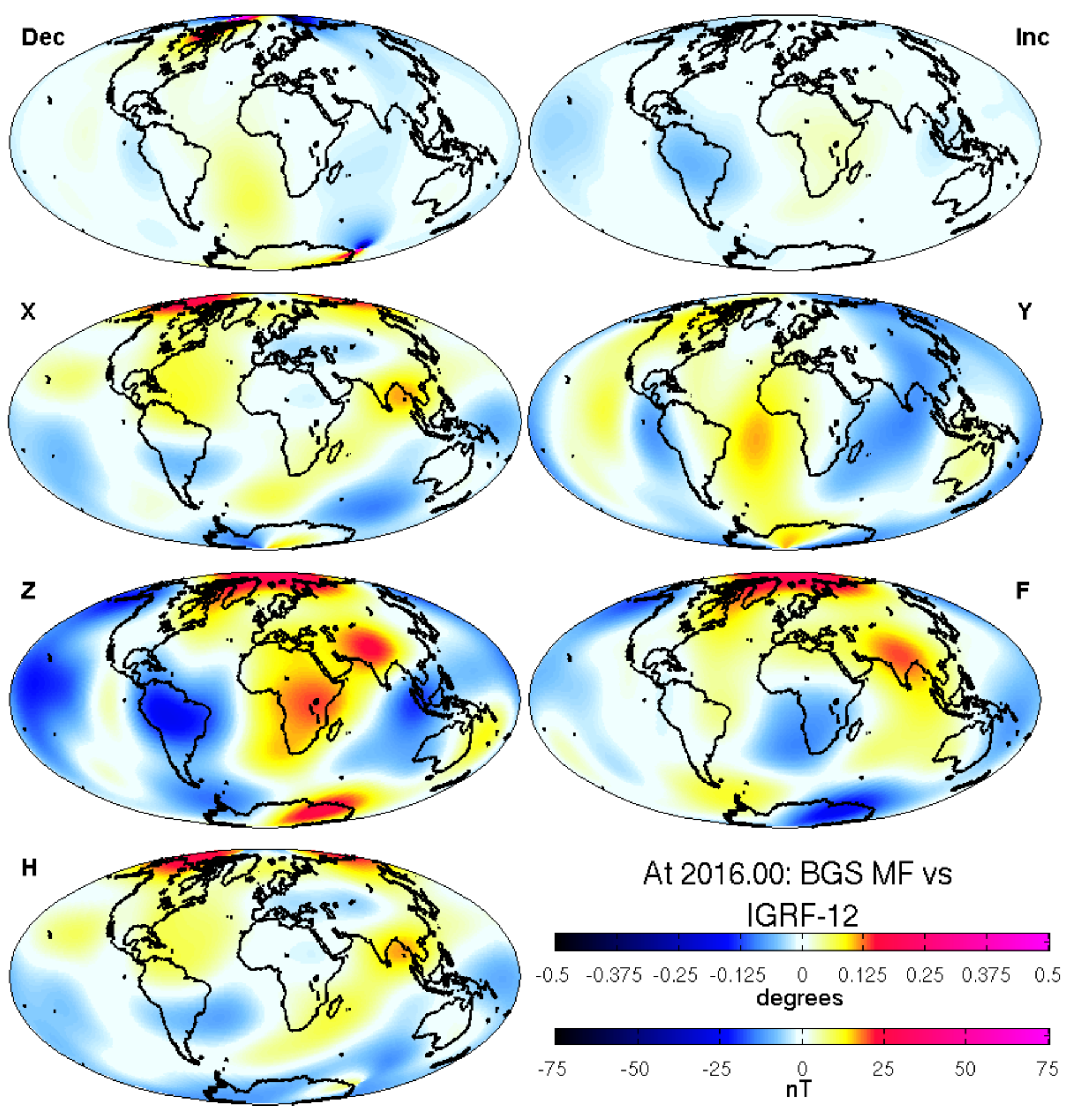

Figure 5: Difference maps between the BGS model built with data to March 2016 and IGRF-12 prediction, at 2016.0.

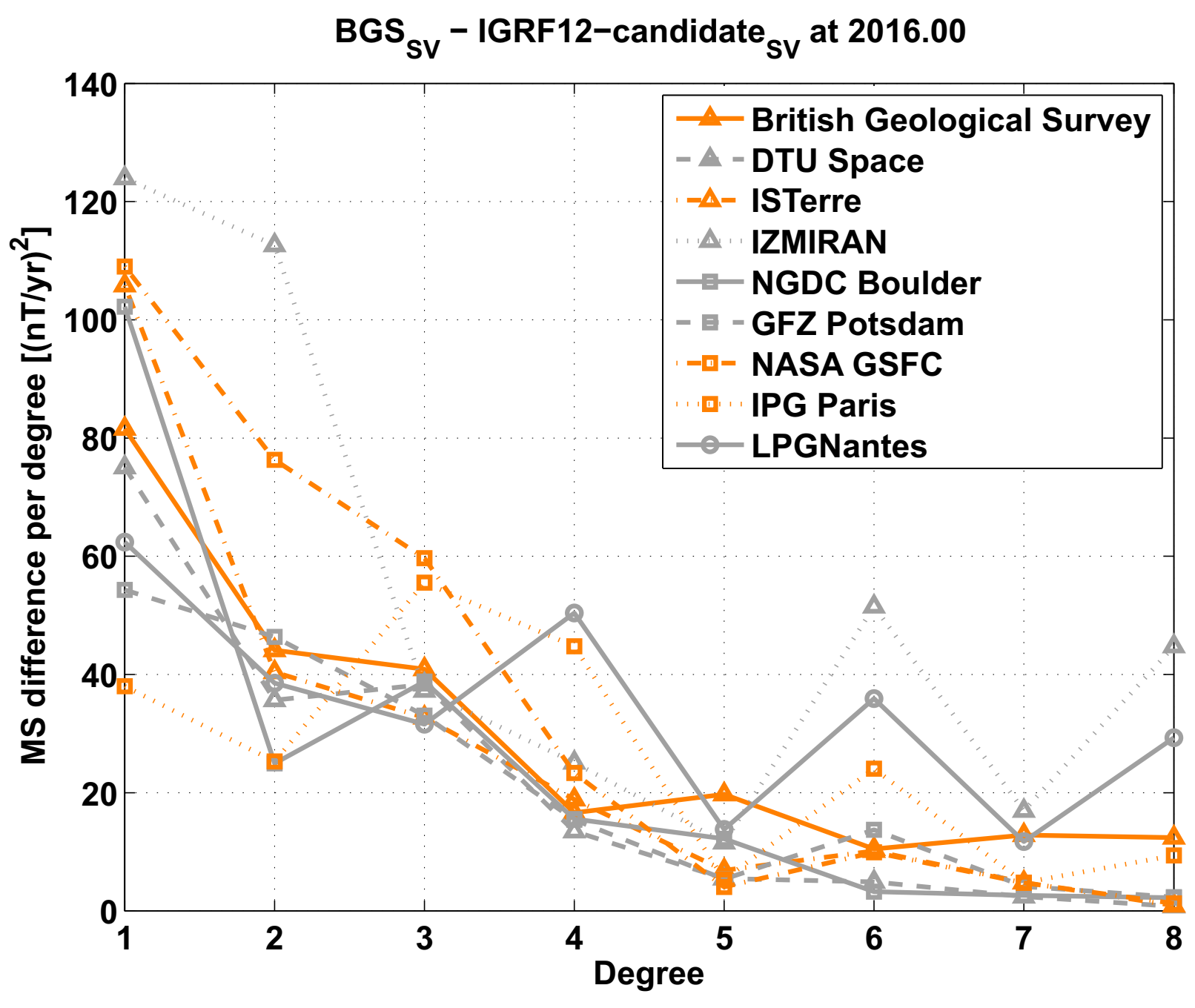

Figure 6: Mean square of differences per spherical harmonic degree between the 9 IGRF-12 SV candidate models and the new BGS model, at 2016.0. Candidates with physically derived SV predictions are shown in orange, mathematically extrapolated SV models, in grey.

Our analysis indicates there is no clear discrepancy between the accuracy of physical and non-physical SV predictions, at least between 2015 and 2016. This is likely due to the occurrence of jerks immediately after the production of IGRF-12 and illustrates the difficulty of forecasting the geomagnetic field until such phenomena are better understood.

Acknowledgements and References

The Swarm mission and data centre are operated by ESA. Many institutes and agencies are involved in the operation of geomagnetic observatories around the world. INTERMAGNET and the World Data Centre (WDC) for Geomagnetism (Edinburgh) assist in quality control and dissemination of these observatory data from which AUX_OBS_2 are produced by BGS for ESA as part of the Swarm mission.The models used here could not have been produced without the efforts of all of these bodies.

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