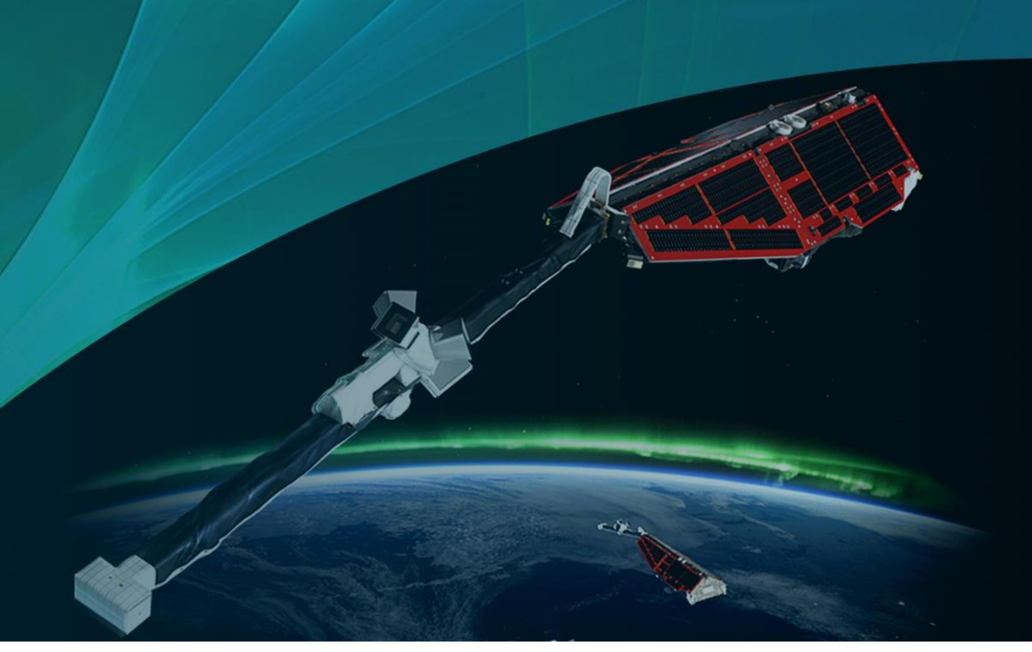

Reconstructing the ionospheric and magnetospheric magnetic fields using observatory and satellite observations

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Conventional Gauss representation based on ground observatory data cannot distinguish between ionospheric field and magnetospheric field. The addition of satellite dataset, however, makes it possible. The ionospheric field, which appears as the external contribution to ground observatories, changes its status to internal contribution when viewed from satellites. This geometric arrangement makes it possible for the ionospheric signal to be separated from the magnetospheric and mantle-induced signals. We present here the simultaneous reconstruction of the ionospheric, the magnetospheric, and the internal (mantle) magnetic field, utilising both ground observatory and satellite data.

Theory

In regions void of electrical currents, the magnetic field can be described by a harmonic scalar potential, which takes the following form under spherical harmonic (SH) expansion

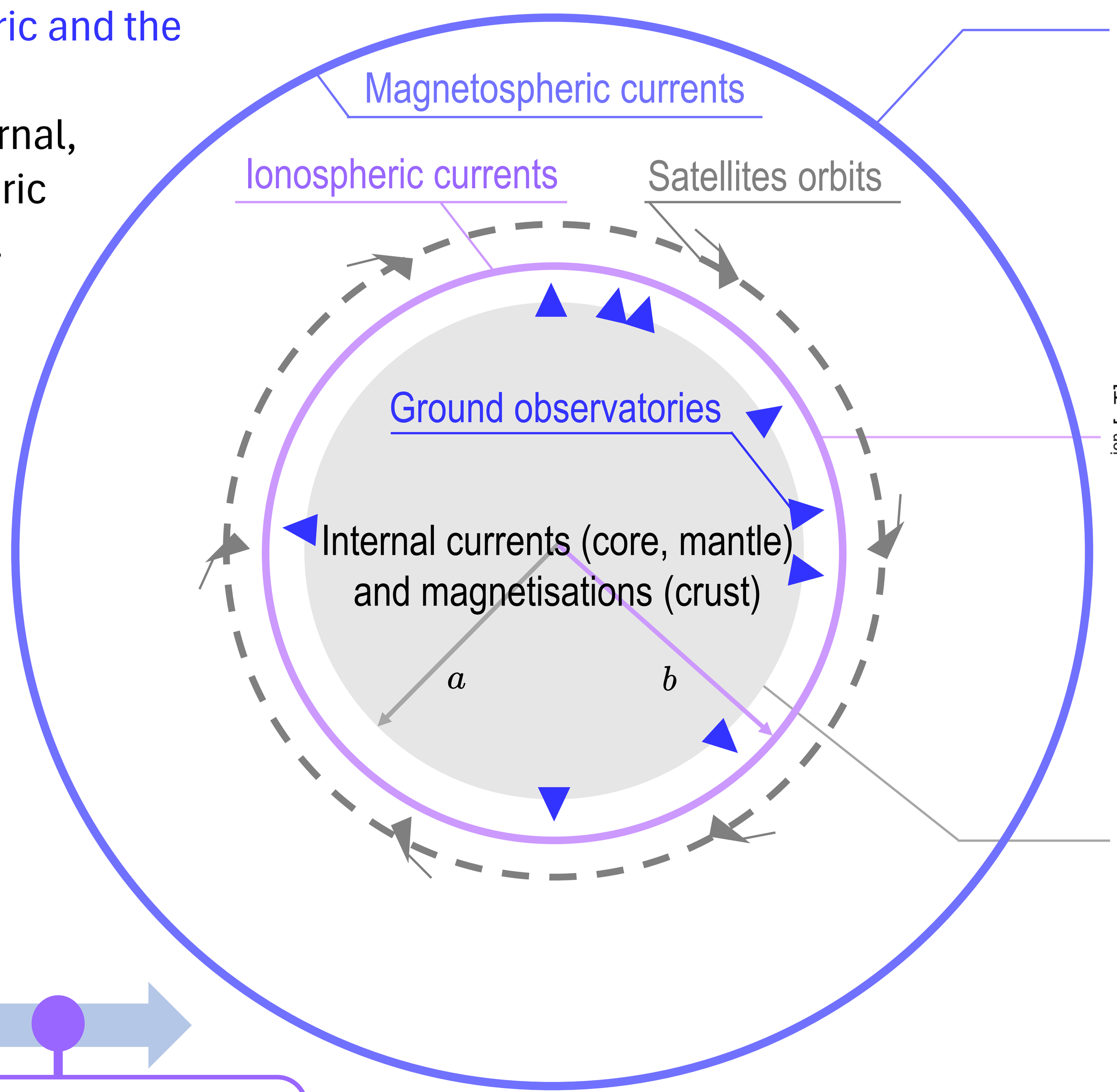
$$V = a\sum_{n=1}^{+\infty}\sum_{m=0}^{n}\left[\left(g_{nm}\cos m\phi + h_{nm}\sin m\phi\right)\left(\frac{r}{a}\right)^{-(n+1)} + \left(q_{nm}\cos m\phi + s_{nm}\sin m\phi\right)\left(\frac{r}{a}\right)^{n}\right]P_n^m(\cos\theta)$$

This formulation (Gauss representation) applies to both ground observatories and satellites. The gound observatories are located in between the internal and the ionospheric currents, and the satellites are assumed to locate in between the ionospheric and the magnetospheric currents.

For the ground observatories, the ionospheric contribution is external, denoted as q_{nm}^{ion} and s_{nm}^{ion}, whereas for the satellites, the ionospheric field serves as an internal contribution, denoted as g_{nm}^{ion} and h_{nm}^{ion}. These coefficients can be associated assuming a sheet current approximation and using continuity condition:

$$g_{nm}^{\text{ion}} = -\frac{n}{n+1}\left(\frac{b}{a}\right)^{2n+1} q_{nm}^{\text{ion}}$$

$$h_{nm}^{\text{ion}} = -\frac{n}{n+1}\left(\frac{b}{a}\right)^{2n+1} s_{nm}^{\text{ion}}$$



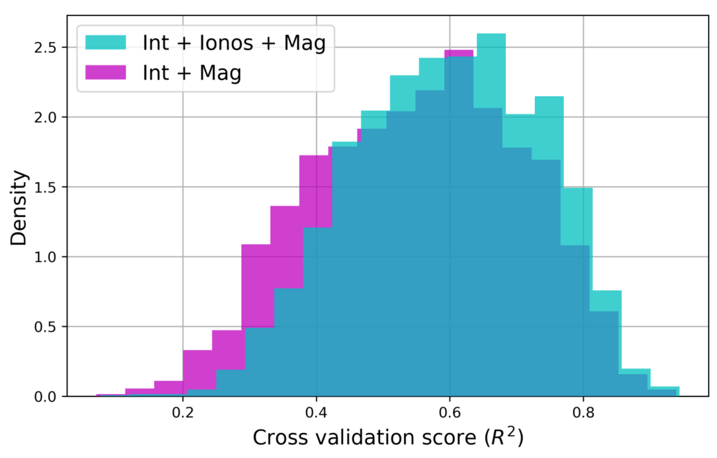
Data, Method, Implementation

- Vector magnetic field data from ground obs and satellites (Swarm A, B, C, Cryosat)
- Remove core, lithospheric models and the obs hourly mean biases from Comprehensive Inversion (CI) model[1]
- Binning data into 3-hr time bins
- Coestimate internal, ionospheric and magnetospheric Gauss coefficients to spherical harmonic N=3, M=2

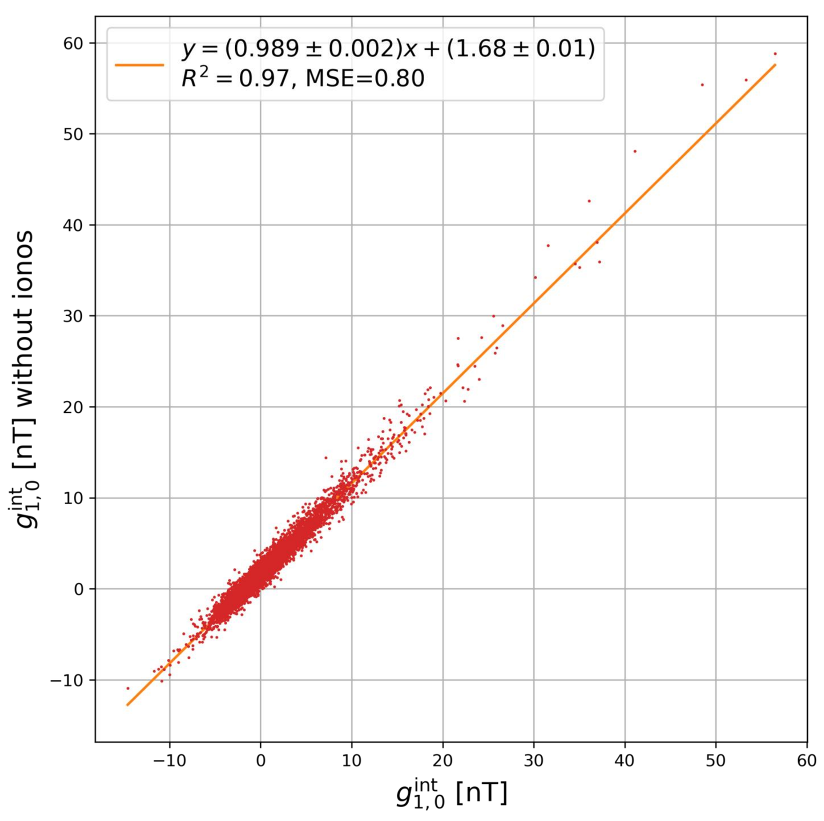
With or without the ionosphere: what's the difference?

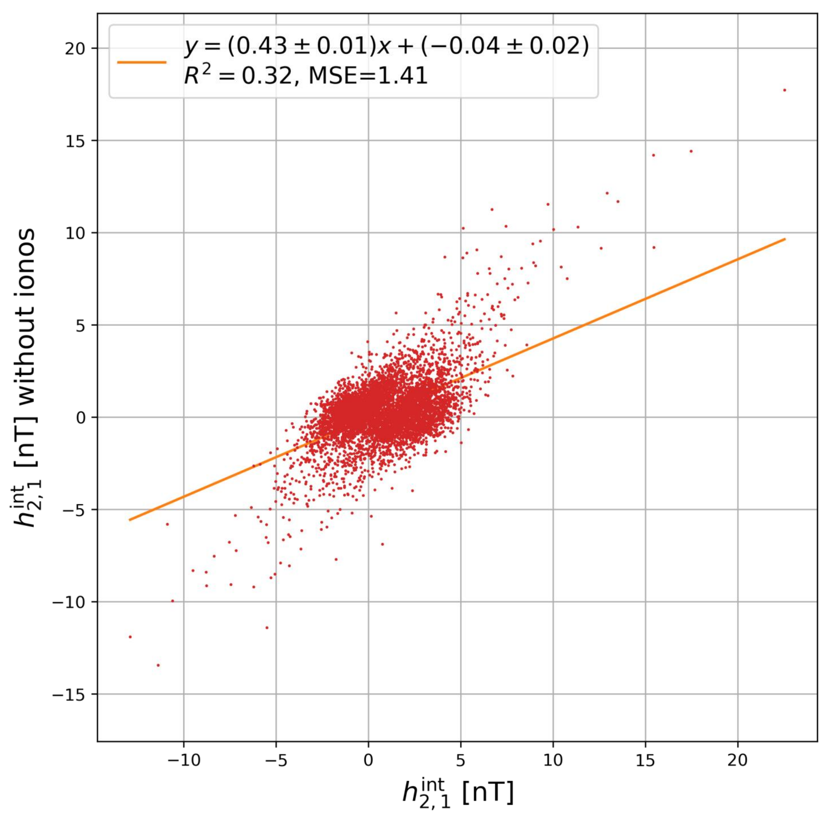
To explore the role of the ionosphere in field estimates, we designed another model where only the internal and the magnetospheric fields are estimated.

A K-fold cross-validation (k=5) is used to evaluate the two models. The cross-validation score shows that our model that coestimates the ionosphere consistently outperforms the model without the ionosphere.



The comparison shows that there is a systematic bias between the field estimates from these two models, most pronounced for the internal field. The (1,0) mode, for instance, is systematically offset by 1.7nT; the (2,1) mode estimates show a phase shift between the two models, which cannot be explained by an affine transform.



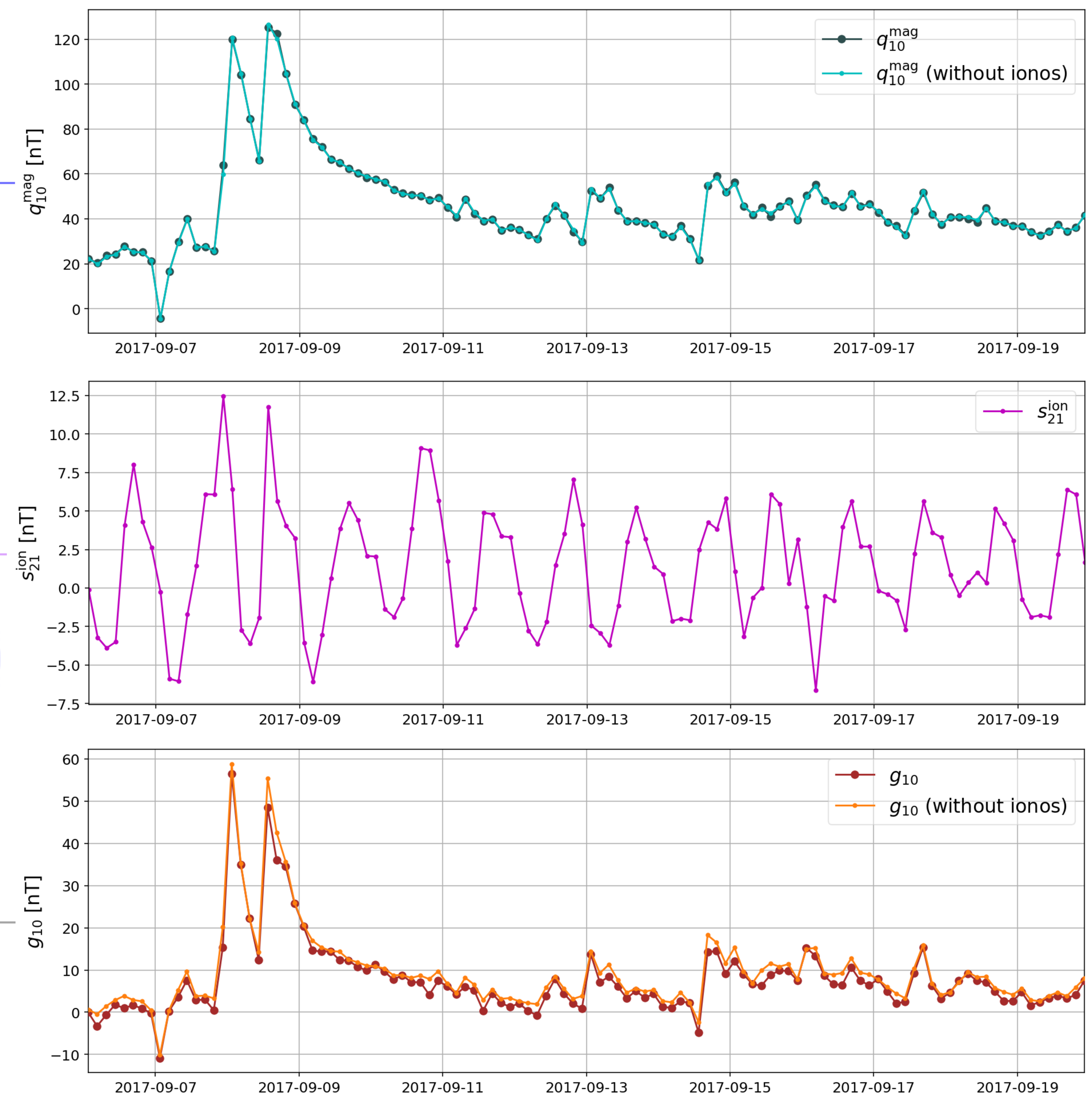


References

[1] Sabaka, T.J., Tøffner-Clausen, L., Olsen, N. *et al.* (2018), A comprehensive model of Earth's magnetic field determined from 4 years of Swarm satellite observations. *Earth Planets Space* **70**, 130.

Ionospheric and magnetospheric fields

The time series of the internal, ionospheric and magnetospheric coefficients are coestimated. During a magnetic storm, for instance, the magnetospheric signal is strongly distorted, but the diurnal periodic oscillation of the ionospheric field persists.

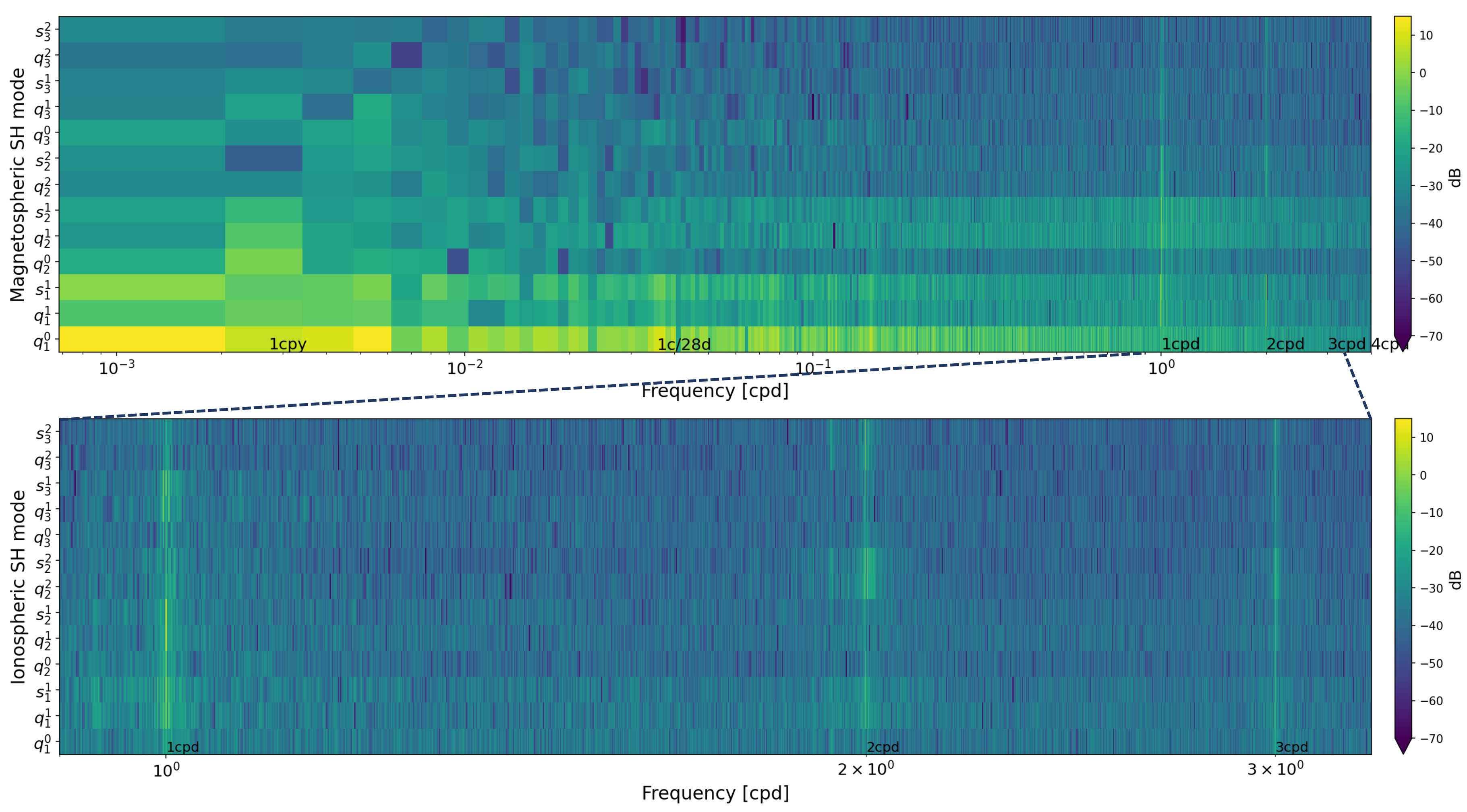


Magnetospheric (top), ionospheric (middle) and internal (bottom) field time series for selected SH mode during the magnetic storm in Sept 2017.

The coestimation of the magnetospheric and ionospheric fields also recovers their respective characteristic features in the frequency-spherical-harmonic domain.

The magnetospheric field has strong power in the dipolar components (n=1) at interdiurnal – annual periods. In comparison, the majority of the ionospheric field energy is limited to the diurnal band. For instance, the SH mode (n=2, m=1) exhibits strong peak at 1 cycle per day (cpd) for the ionospheric field. The ionospheric field also exhibits strong signal at 2 cpd, esp. for mode (n=3, m=2).

Note the peaks are also present for the magnetospheric signal, but with a smaller amplitude.



Conclusions and outlook

The ionospheric and magnetospheric magnetic signals can be separated by combining satellite and observatory datasets. We show that neglecting the ionospheric field has the risk of introducing systematic bias to the field estimate, esp. that of the internal field. The new method yields time series of ionospheric field without imposing strong temporal periodic constraints, and can be useful for induction studies that utilise ionospheric source, as well as core field modelling.

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