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Geomagnetic Virtual Observatories for investigating sub-annual core field variation

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GEOMAGNETIC VIRTUAL OBSERVATORIES (GVOs)

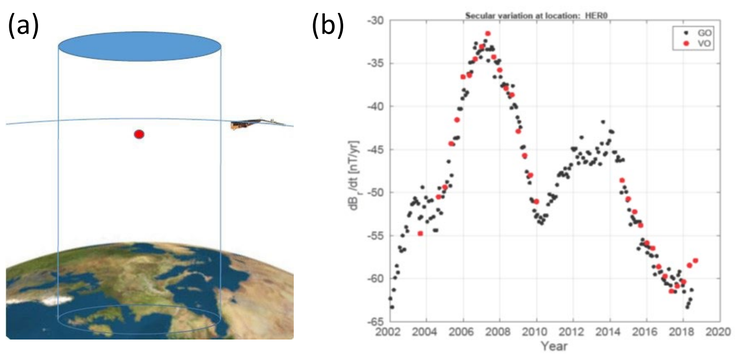
- Magnetic measurements from Low Earth Orbit (LEO) satellites can be accumulated into a single point in time and space called a GVO.
- We collect all the satellite data passing through a 700 km radius cylinder above a fixed point for a month (or longer) and reduce it to a single GVO value
- The aim is to mimic the manner in which ground observatories measure the Earth's magnetic field
- GVOs placed over the same location as a ground observatory generally reproduce the same time-series (**Fig. 1**)
- *Swarm* GVOs are available on the Swarm PDGS and *viresclient*: https://swarm-diss.eo.esa.int/#swarm%2FLevel2longterm%2FVOB

- **GVOs provide an exciting new tool for studying rapid variations of the Earth's core across the globe (Fig. 2)**

Figure 1.

(a) *Swarm* passing through a GVO cylinder.

(b) Comparison of the rate of change of the radial magnetic field (dBr/dt) over Hermanus (South Africa): satellite VO data [red] and ground observatory [black].



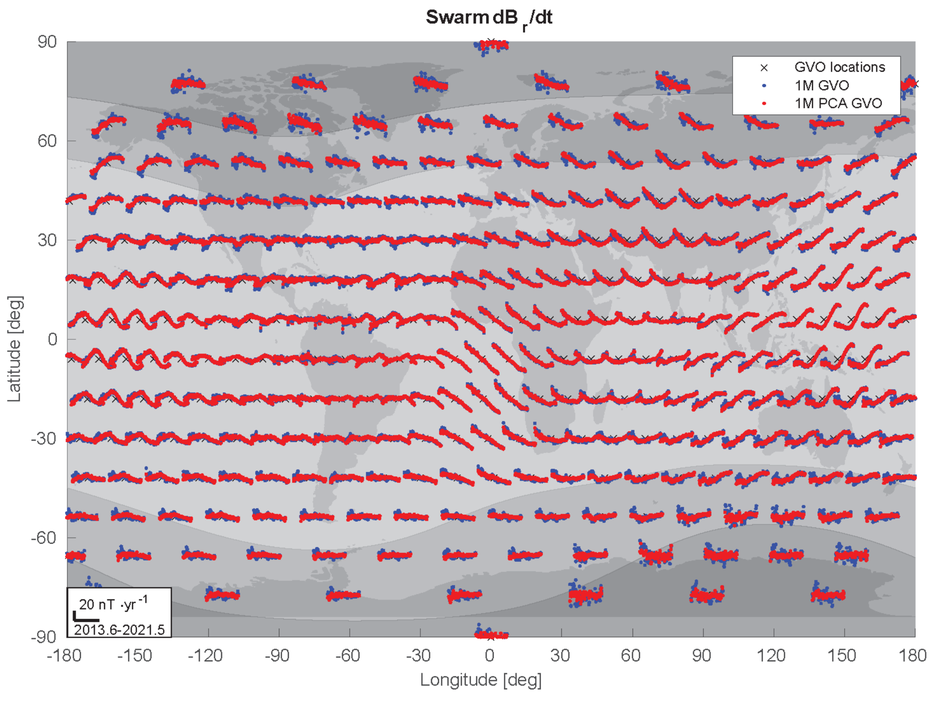


Figure 2

Rate of change of the radial magnetic field (dBr/dt) at 300 *Swarm* GVOs from 2014 to 2020. Two sets of GVO are shown: 1-monthly bins (blue) and 1-monthly bins with additional processing (PCA) to remove external magnetic field noise (red). Polar regions experience more noise due to aurora. 4-monthly values are cleaner than the 1-monthly values. Grey bands show auroral zones (55°) and polar caps (75°)

Current Drawbacks:

- Polar orbiting LEO satellites tend to **drift slowly in local time** (LT)
- To avoid aliasing and local-time biases in magnetic fields, GVOs need **24-hour local time coverage**
- At present it takes **4.2 months** for *Swarm* to precess through all local times
- We can use **Principal Component Analysis** (PCA) to remove external field noise in the GVOs and to improve internal field (core) resolution for periods less than the LT precession
- **Monthly mean GVOs are more prone to external field noise interfering with the sub-annual core field signal**

Proposed Improvements:

- Can we augment and/or **improve local time coverage** and hence better image the core field over shorter periods?
- Can we better **remove external fields** using geophysical insights?

NANOMAGSAT: IMPROVING LOCAL TIME COVERAGE

- Using the proposed *NanoMagSat* mission low-inclination (60°) satellites to augment the Swarm polar orbits will **improve local time coverage (Fig 3.)**
- Depending on Swarm's orbital configuration, our results show high-quality full LT GVO can be created on a **3-weekly basis**, substantially increasing the current time resolution of 17 weeks

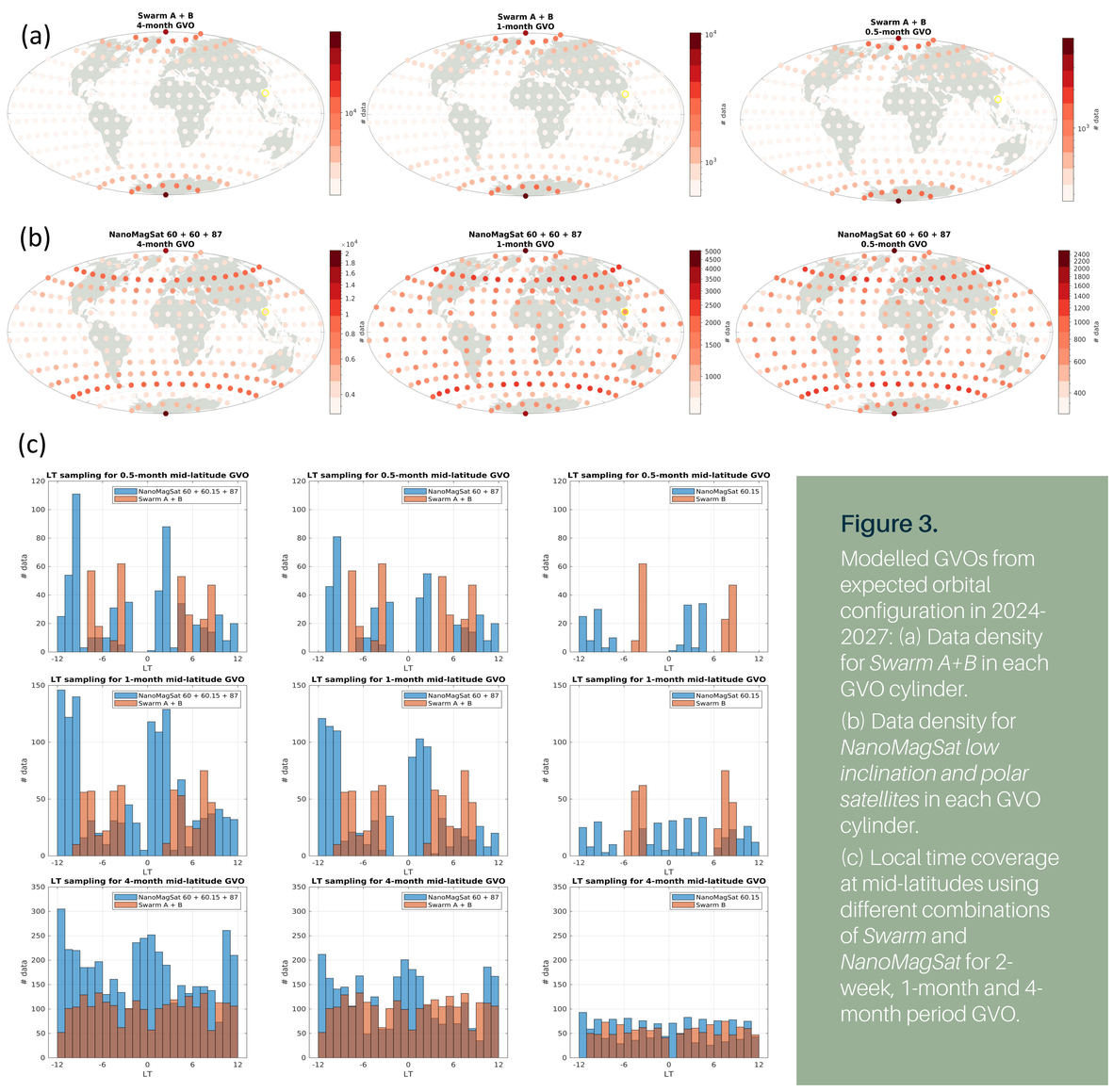


Figure 3.

Modelled GVOs from expected orbital configuration in 2024-2027: (a) Data density for *Swarm A+B* in each GVO cylinder.

(b) Data density for *NanoMagSat low inclination and polar satellites* in each GVO cylinder.

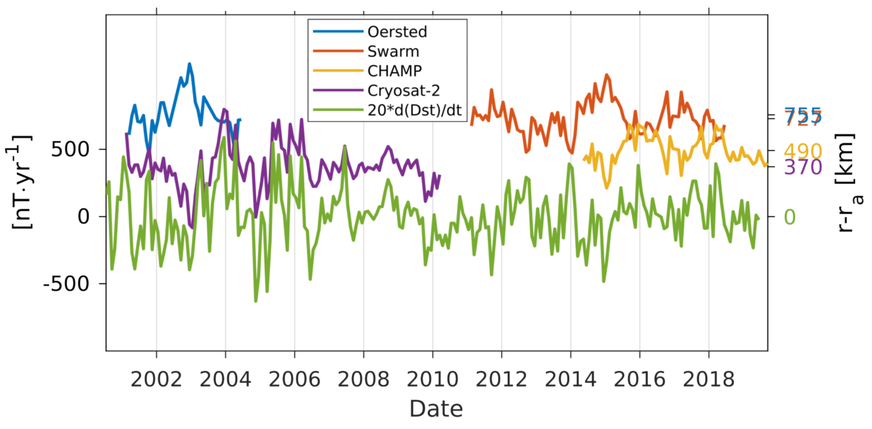
(c) Local time coverage at mid-latitudes using different combinations of *Swarm* and *NanoMagSat* for 2-week, 1-month and 4-month period GVO.

REMOVING EXTERNAL FIELD NOISE USING PCA

- Principal Component Analysis (PCA) allows a vector signal to be described in terms of maximum and minimum variance along a particular orientation
- We use it to determine which geophysical signals are predominant in multiple GVO data series
- Figure 4 shows the correlation of the ring current (Dst) with the first principal component (PC) from four magnetic missions

Figure 4

Comparison of first PC of the monthly secular variation with the Dst index variation (x20) for the four magnetic missions covering 2000 to 2020. The primary noise source is the ring current.



Conclusions

- Using Swarm and NanoMagSat data together will radically improve the local time coverage to allow imaging of more rapid core field signals.
- External field noise is dominated by the ring current. PCA can be used to identify and remove external field noise to substantially improve the core field signal

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