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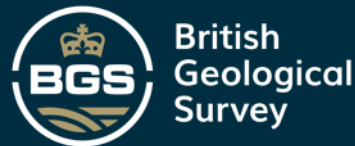
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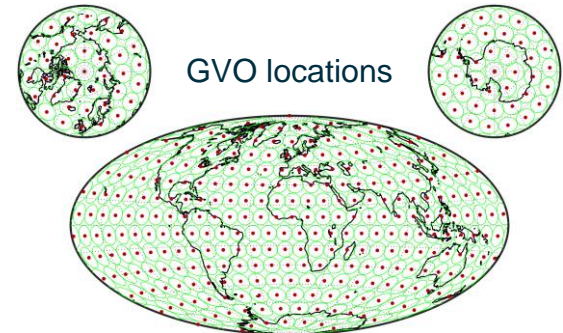
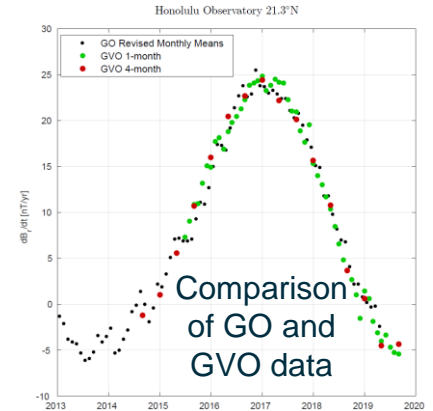
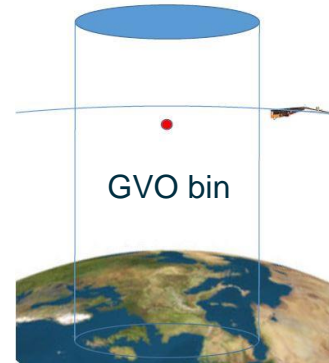
Isolating core field signals in Geomagnetic Virtual Observatory time series using Principal Component Analysis

DTU Space
National Space Institute



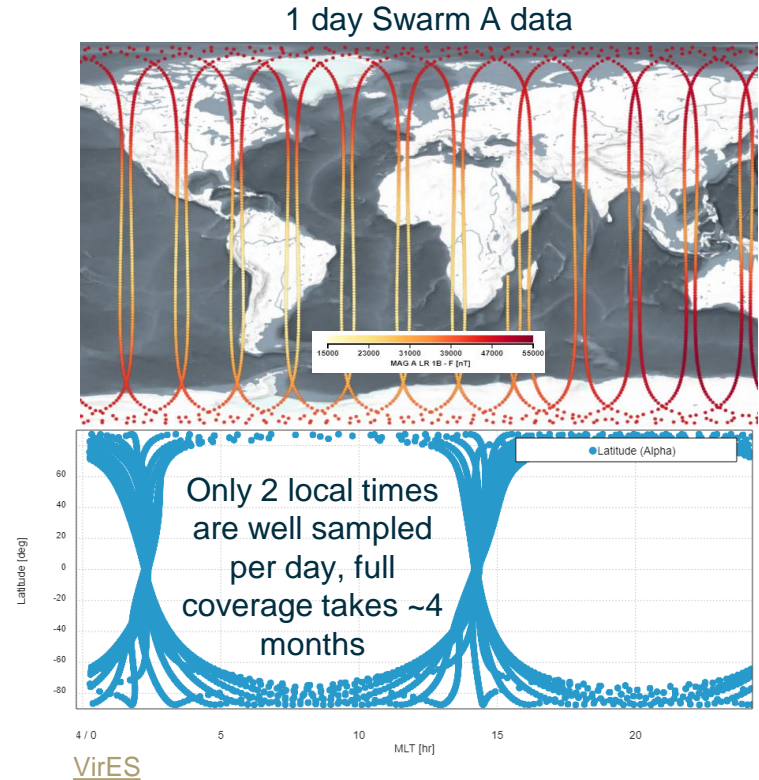
Geomagnetic Virtual Observatories (GVO)

- ESA Swarm DISC Level2 GVO product
- Bin data within a 700km radius cylinder, over sampling period (e.g. 1, 4 month)
- Remove estimate of core field from data in bin
- Fit a local cubic potential field to data residuals in bin
- Calculate potential at centre of bin in time and space
- Add back core field estimate
- Produce grid of 300 equidistant GVO for each sample period
- Sample-by-sample internal/external field spherical harmonic analysis to separate field sources



Isolating core field from GVO

- To isolate core field from GVO: use dark, quiet time selection
 - few data if bins are too small or short
- To counter slow **local time (LT)** drift of satellite: longer time bin
 - time resolution depends on orbit
- **Principal Component Analysis (PCA)** approach alternative retains data density without data selection, separates field sources, and allows correction of LT sampling biases
- PCA can be applied for satellite missions with long LT procession rates (e.g. Ørsted, CryoSat-2), without losing resolution in time or space

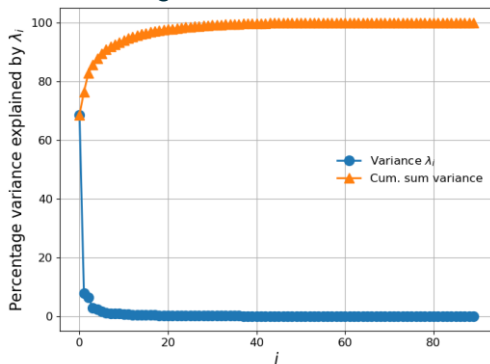


Principal Component Analysis (**PCA**) of GVO SV

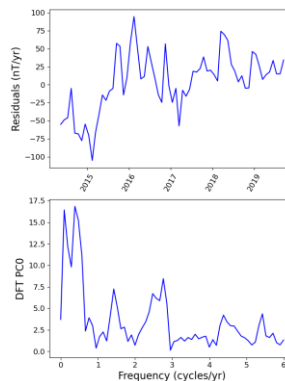
- We provide an update to the [MagPySV](#) Python software ([Cox et al 2018, EPS](#)), to process GVO data as well as GO data
- Remove estimate of core field from GVO to get detrended residual time series
- Calculate time derivative (annual differences SV) of residual time series
- Separate GVO locations into magnetic latitude activity zones – poles, auroral ovals, mid- to low-latitudes, perform PCA on each zone
- Characterise PC by spatial orientation, time-correlation to magnetic activity indices, frequency content
- Identify and remove unwanted PC, here the *most significant* few PC
- Return core field model and integrate in time

Example for Swarm in Northern auroral zone

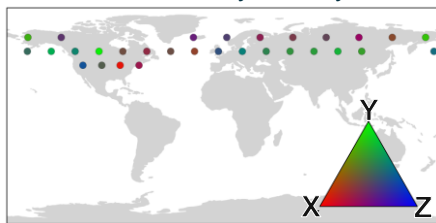
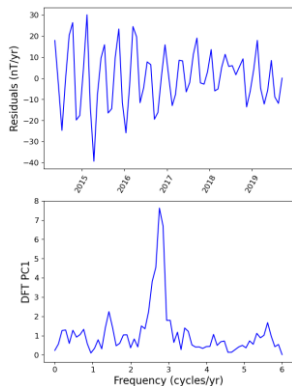
1. Eigenvalue spectrum indicates most significant PCs



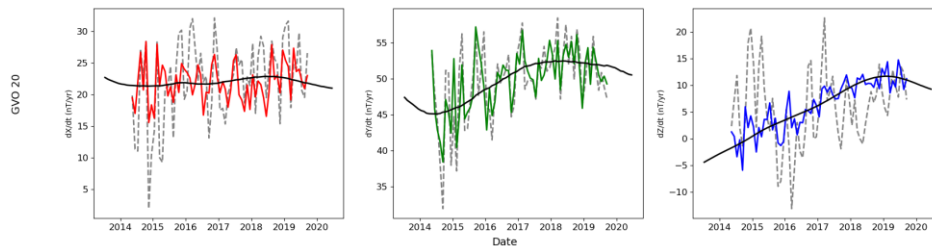
2. 1st PC has strong long-period signal, in X and Z, correlation of 0.73 with AE-index



3. 2nd PC has strong ~4.2 month signal, with complex spatial pattern, uncorrelated to any activity index

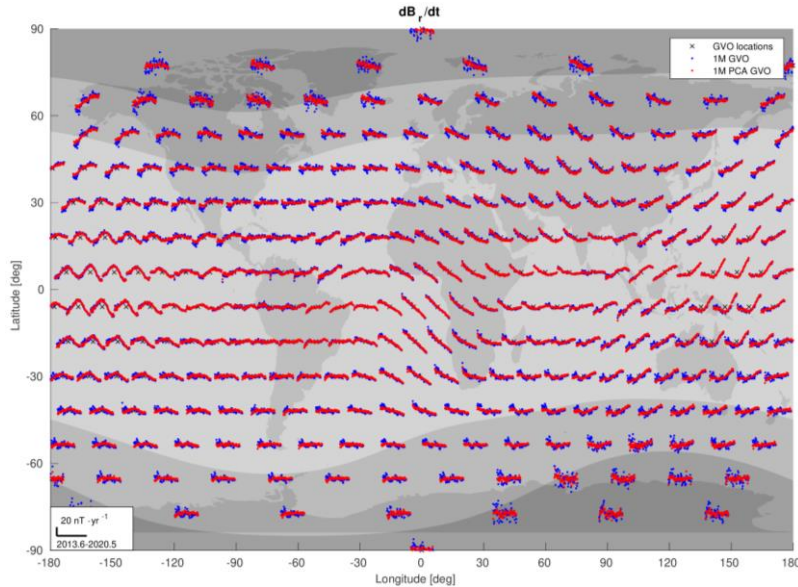


4. Removal of these 2 PC accounts for ~75% of variance, and removes significant external and LT bias content



Global results for Swarm AD

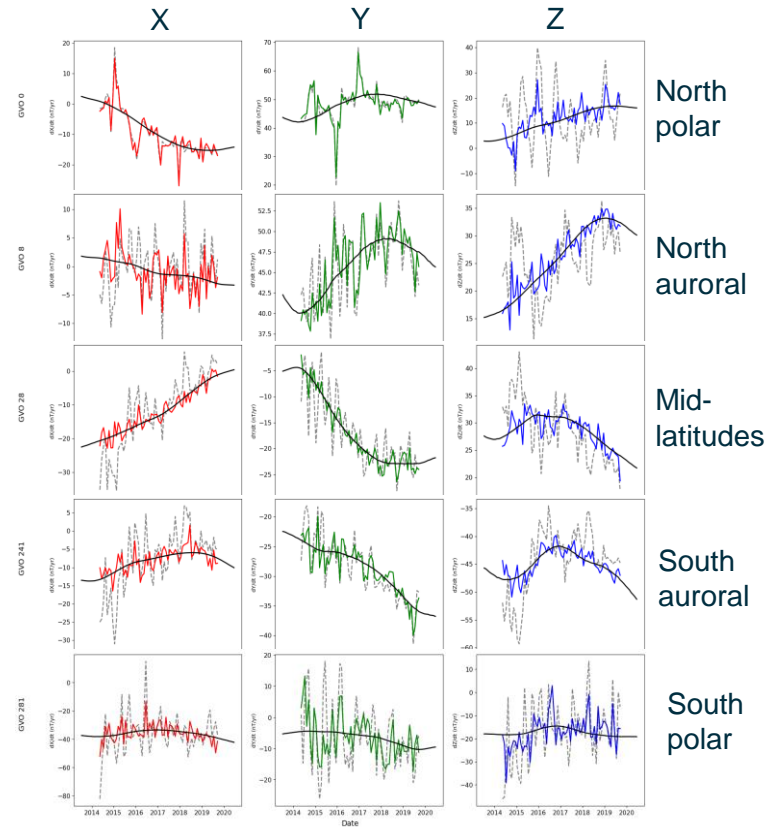
- Different external signals dominate in different magnetic latitude regions
- Local time effect seen at all latitudes but spatial manifestation depends on orbit track orientation



External fields mostly in Z

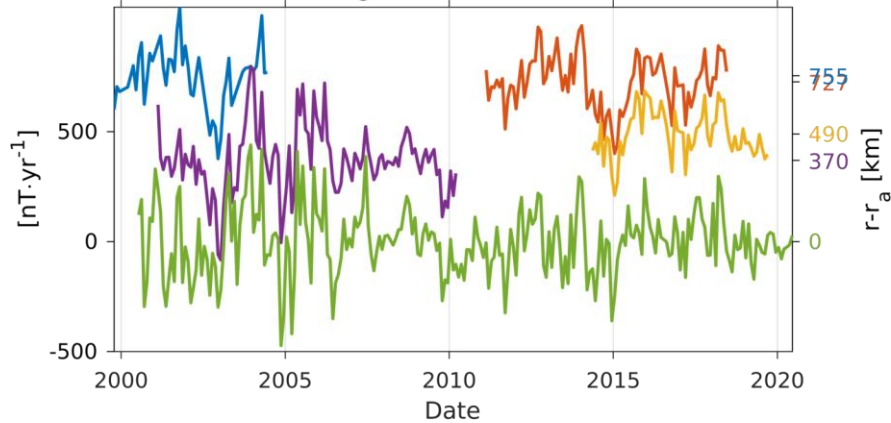
External fields mostly in X

External fields mostly in Z

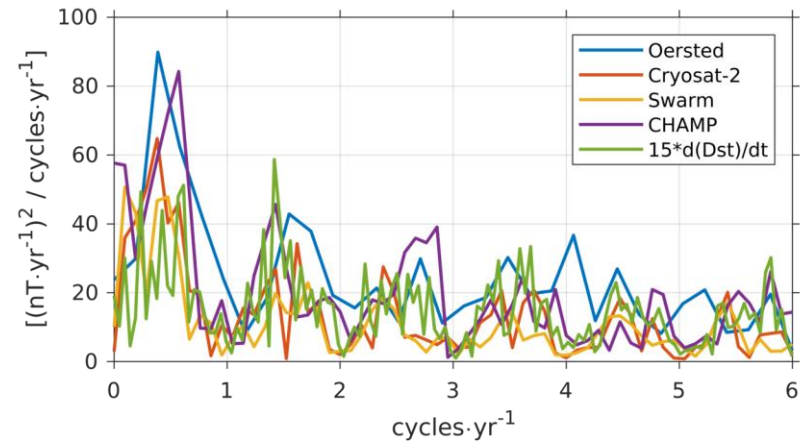


Application to GVO for other missions – ring-current

AD PC0 @ mid- to low-latitudes

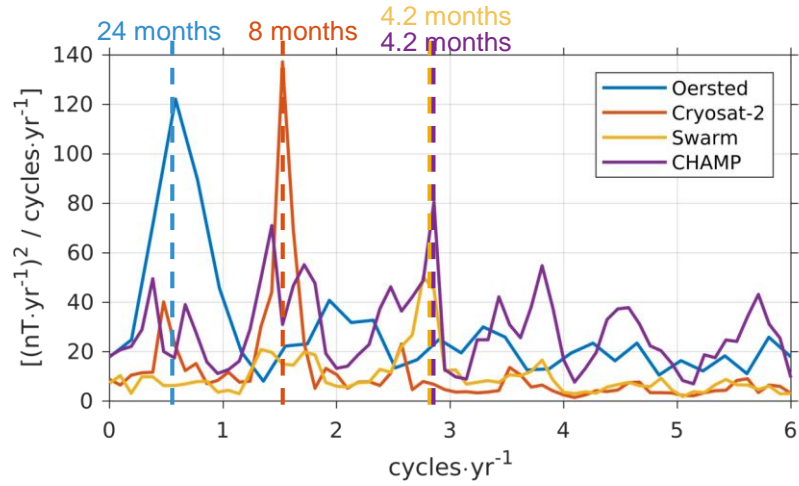
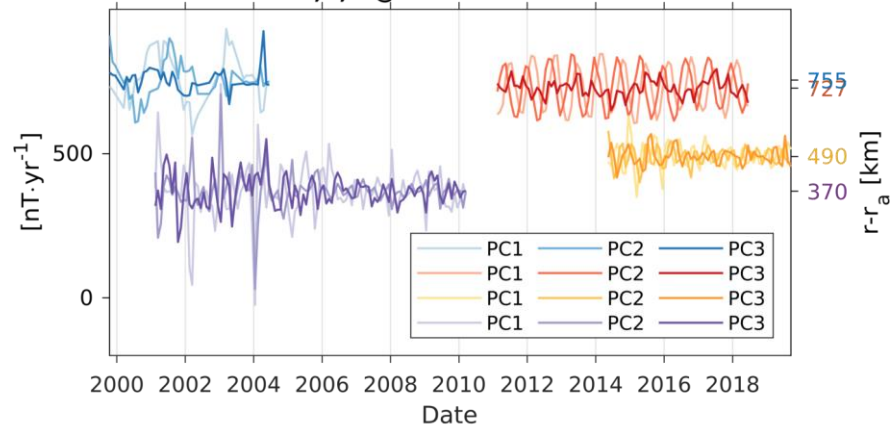


- At mid- to low-latitudes, the dominant PC for all missions is oriented roughly North-South
- This PC is strongly correlated ($c=0.63$ to 0.79) to the rate of change of the Dst-index
- We attribute this signal to magnetospheric origin, predominantly axial dipole
- This PC accounts for 39% (Ørsted) to 70% (Swarm) of variance in the residuals



Application to GVO for other missions – local time bias

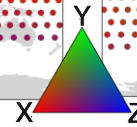
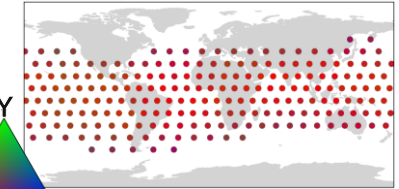
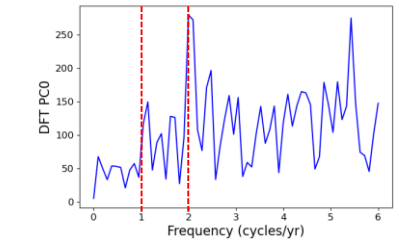
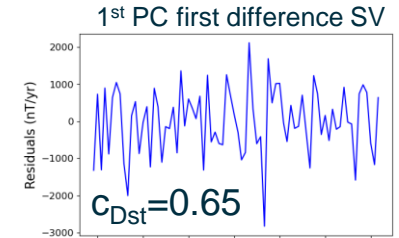
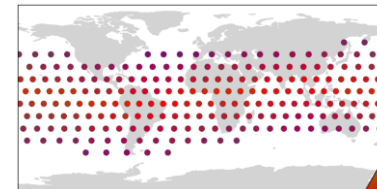
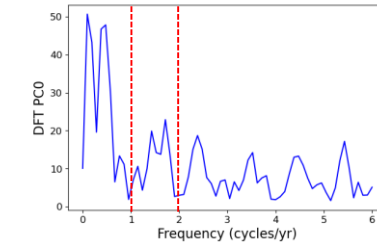
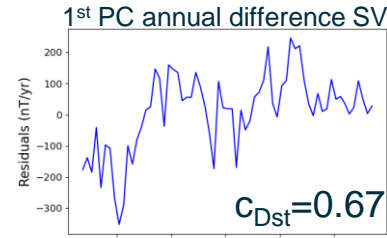
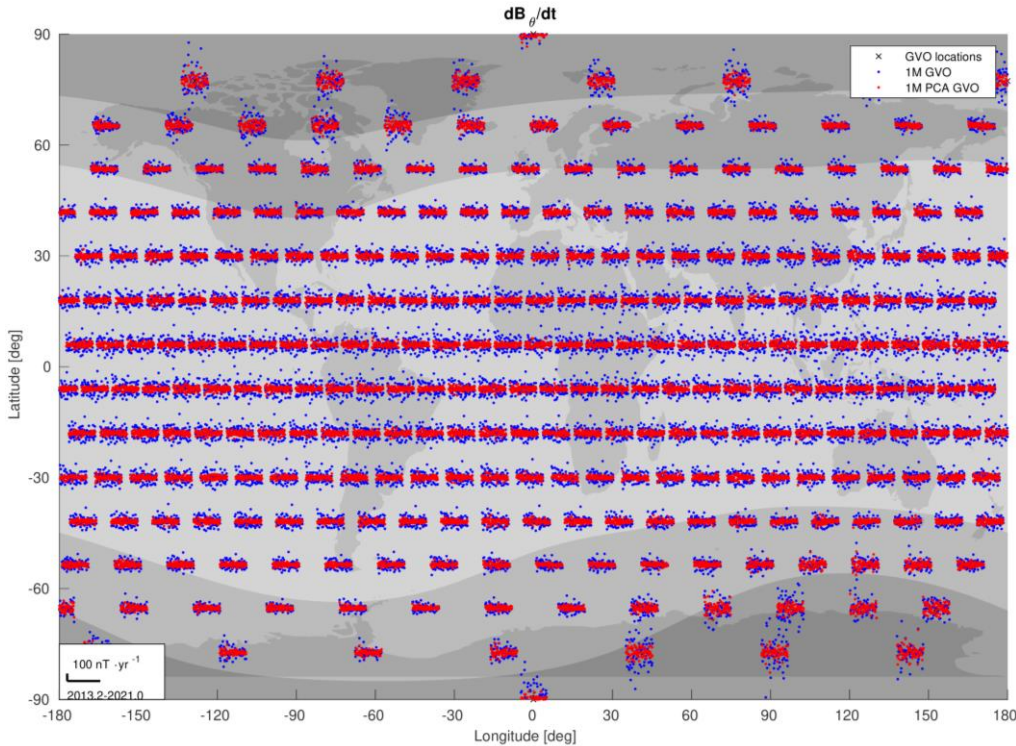
AD PC1,2,3 @ mid- to low-latitudes



- At mid- to low-latitudes, second most significant set of 3 PC for all missions are spatially complex, varying by region
- These PC do not correlate strongly with any magnetic activity indices
- Frequency content peaks at LT precession rate of each mission
- We attribute these signals to local time sampling biases
- These PC account for 15% (Swarm) to 42% (CryoSat-2) of variance in the residuals, agreeing with magnitudes of frequency spectra

Application of PCA to first-differences SV

PCA correction of Swarm monthly first difference SV



- Annual difference SV can't resolution sub-annual external field signals, first difference SV can
- For both SV types, primary contamination is southward dipole of magnetosphere
- Both SV types strongly correlated to $d(Dst)/dt$

Summary

- GVO provide a compact distillation of global satellite data in which time variations can be directly analysed, accessibly for non-expert users
- Principal Component Analysis can be applied to GVO secular variation to separate major components of internal and external field sources, and to remove local time sampling biases without reducing time or space resolution
- Our results show the method can be successfully applied to Ørsted, CHAMP, CryoSat-2 and Swarm GVO data sets, robustly identifying common external signals in each, and mission specific local time signals
- Applying PCA to monthly first differences allows us to isolate sub-annual external signals which cannot be sampled in annual difference SV
- Future work will be to finalise method for monthly-first-difference GVO secular variation for all missions, and to assess applying PCA directly to main field time series

References and resources

- Cox, G. A., Brown, W. J., Billingham, L., & Holme, R. (2018). MagPySV: A Python package for processing and denoising geomagnetic observatory data. *Geochemistry, Geophysics, Geosystems*, 19, 3347– 3363. <https://doi.org/10.1029/2018GC007714>
- Hammer, M.D., Cox, G.A., Brown, W.J. *et al.* Geomagnetic Virtual Observatories: monitoring geomagnetic secular variation with the Swarm satellites. *Earth Planets Space* **73**, 54 (2021). <https://doi.org/10.1186/s40623-021-01357-9>
- MagPySV Python software: <https://github.com/gracecox/MagPySV>
- ESA Swarm and other mission GVO data sets, documentation and software at Swarm DISC GVO project webpage at DTU Space: <https://www.space.dtu.dk/english/research/projects/project-descriptions/geomagnetic-virtual-observatories>
- Data access, visualisation, virtual research environment for ESA Swarm mission: <https://vires.services/>
- *viresclient* Jupyter notebook examples: https://swarm.magneticearth.org/notebooks/03i1_demo-vobs