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# THE ROLE OF GEOMAGNETIC OBSERVATORY DATA DURING THE SWARM MISSION

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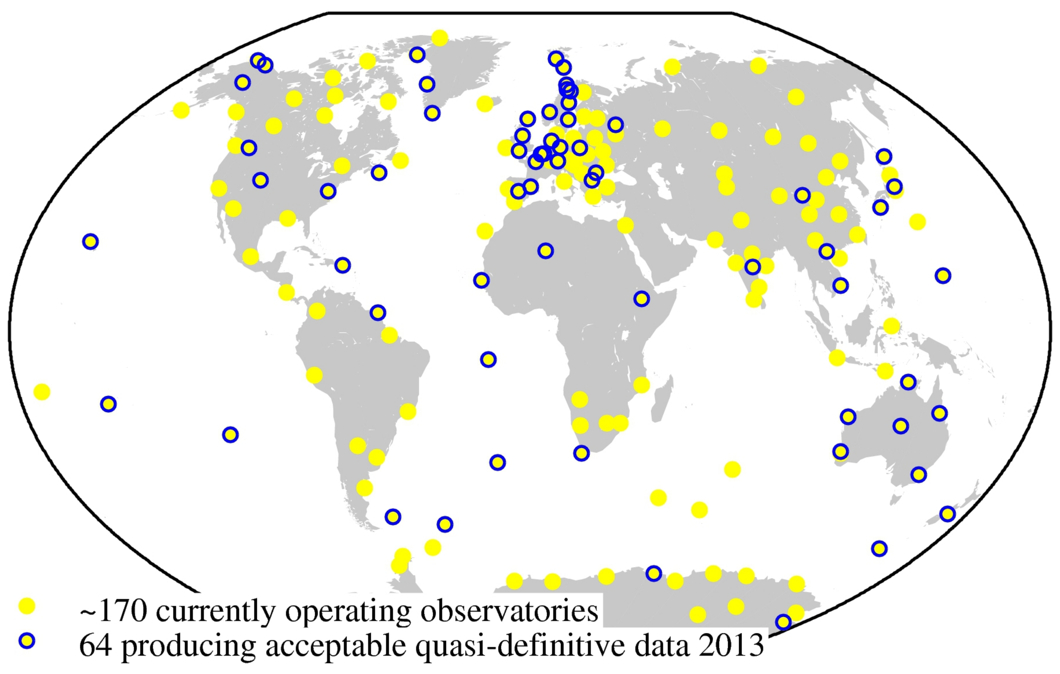
## SUMMARY

The ESA Swarm mission will measure magnetic signals from all sources of the geomagnetic field with unprecedented accuracy. The scientific use of Swarm data is greatly enhanced when used in combination with observatory data and indices and this has increased interest in ground based measurements. As part of the Swarm Level-2 data activities, plans are in place to distribute such data along with the satellite data [1]. Here, we also discuss how observatory data can be used for the Calibration/Validation of Swarm and how observatory data may better constrain the time parameterisation of global field models.

## 1. TIMELINESS OF OBSERVATORY DATA

- Every 3 months during the whole of the Swarm mission we aim to update files of observatory hourly mean values.
- During the first 6 months of the mission we aim to update files of observatory minute mean values to provide independent data for ground-truthing purposes.
- Advantage is taken of INTERMAGNET and other efforts in Norway, France & UK to improve the timeliness of quasi-definitive (QD) observatory data.
- QD data aims to be within 5 nT of definitive data (averaging on a monthly basis) and available within 3 months of measurement. The map shows the observatories producing such data as of December 2013.




## 2. QUALITY OF OBSERVATORY DATA

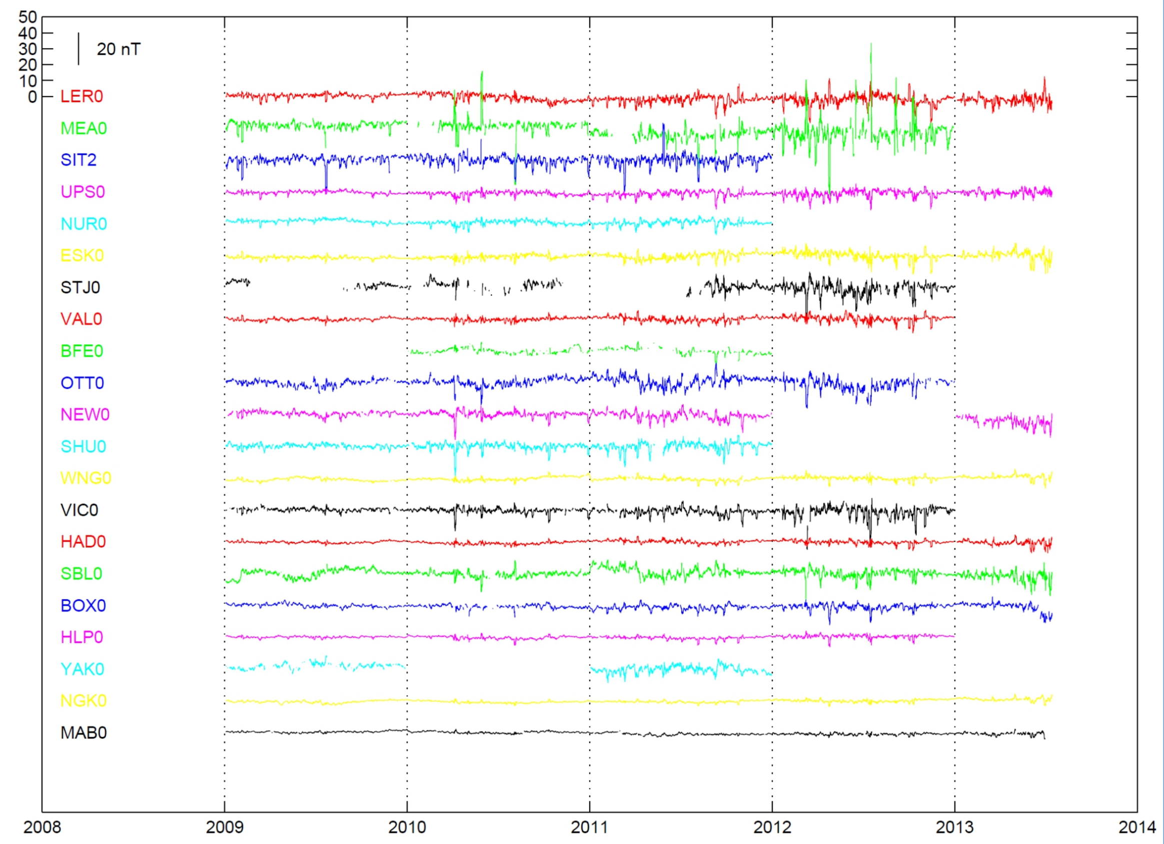
- To aid quality control of global observatory data prior to joint analyses with Swarm data, misfits of spherical harmonic models can be inspected in the temporal & spatial domains [1].
- This pre-processing and modelling removes all signals that can be modelled, except at high latitudes, and the misfits represent measurement artefacts on the 0-10 nT scale.
- Tests using definitive hourly mean data contemporary with the Ørsted and CHAMP missions showed that the method was useful for detecting these small artefacts. The plot shows a subset of the misfits: in the geomagnetic south component for observatories between geomagnetic latitudes 58° (top) and 46° (bottom). The data used were a combination of definitive and quasi-definitive hourly mean data 2009-2013 spanning the gap between CHAMP and the launch of Swarm.
- High quality data is reflected by values being:

a) Close to zero (more so the lower the latitude),

b) No discernible discontinuities present

c) Coherent with geomagnetic latitude if large (indicating a natural storm signal).

- To achieve this, poor quality data are excluded and time series are split to account for unmeasured jumps
- In addition to being available from the ESA data centre once the Swarm Level 2 processing starts, the cleaned-up hourly mean observatory data will also be regularly updated at ftp://ftp.nmh.ac.uk/geomag/smac/AUX_OBS_2/

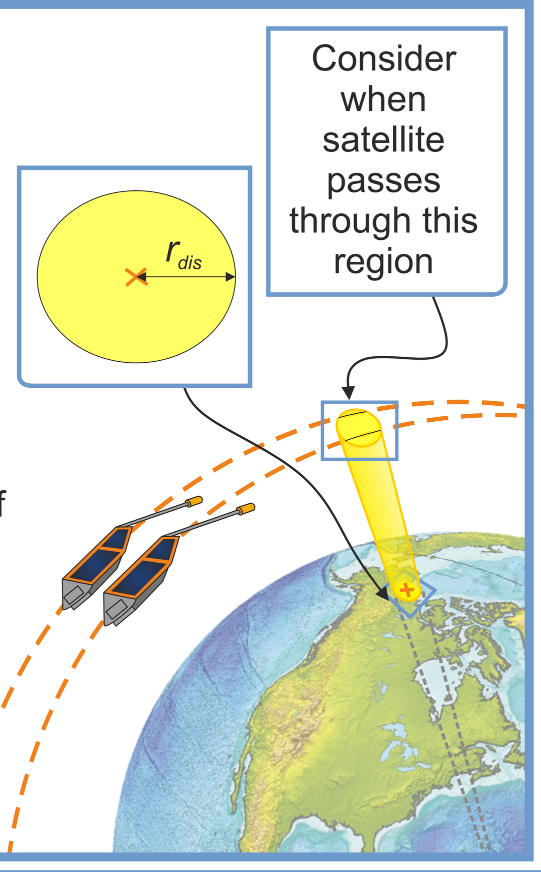



## 3. GROUND-TRUTHING SWARM DATA FOR CAL/VAL

- The Calibration/Validation (Cal/Val) period, forming the first 3 months of the Swarm mission, will be used to confirm the instruments are operating as expected.
- ***Can Swarm measurements be ground-truthed with QD observatory data to aid the Cal/Val effort?***
- The following method will be applied to each satellite during Cal/Val. We will look at how the global results
  a) vary **between satellites**
  b) compare with the results obtained when a similar approach has been applied to **CHAMP** data.

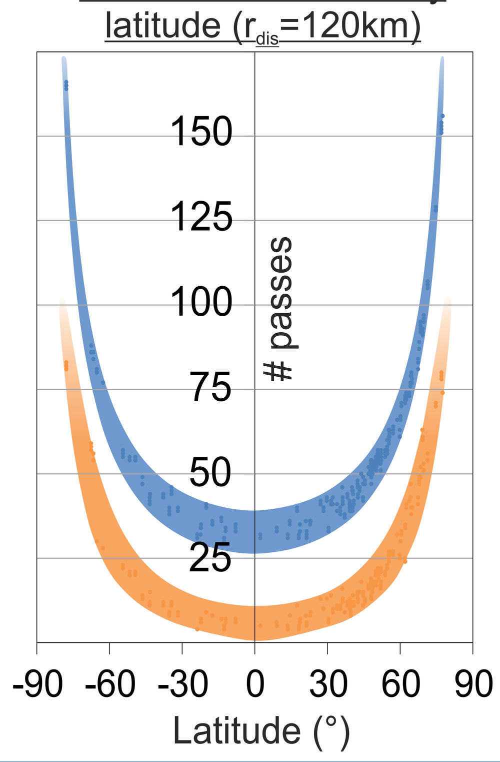
### 3a. Approach

- Radial distance from each observatory, $r_{dis}$, defined at Earth's surface
- Catchment region defined at satellite altitude using simple conical angular projection
- $r_{dis}$ = 120km balances number of passes in 3 month period (enough for meaningful statistical analysis) with maximum distance from observatory




### 3b. Number of passes

- Number of passes in 3 months depends on observatory latitude, $r_{dis}$ and position of satellite orbital insertion.
- Range of expected number of passes shown below in:
**BLUE**= either lower satellite within catchment region
**ORANGE**= both lower satellites within catchment region




### 3c. Method and Champ preliminary study example

*For satellite during pass:*

Calculate & remove along-track core field contribution to data. $B_{sat}$ = mean satellite $B_z$

*For observatory during pass:*

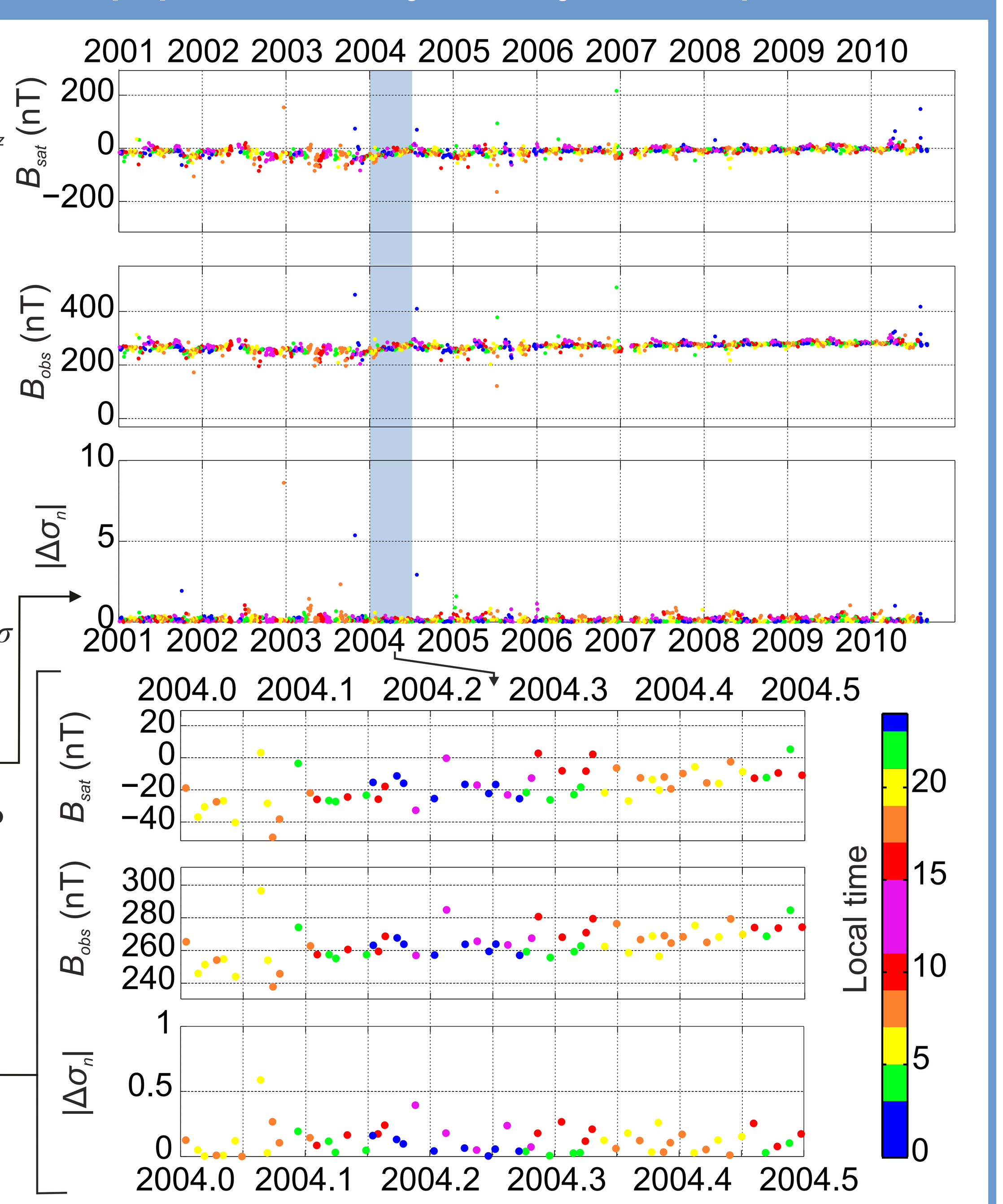
Obtain QD minute mean during closest approach to observatory. Calculate & remove core field contribution. $B_{obs}$ = mean observatory $B_z$

*For ALL passes over 1 observatory:*

1. Group all $B_{sat}$ ; Group all $B_{obs}$
2. Linearly detrend.
3. Calculate mean, $\overline{X}$, and standard deviation, $\sigma$, of each group.
4. Normalise each individual $B_{sat}$ or $B_{obs}$ by $\sigma$ and calculate absolute difference:

$$|\Delta\sigma_n| = \left|\left(\frac{B_{sat}-\overline{X}_{sat}}{\sigma_{sat}}\right)-\left(\frac{B_{obs}-\overline{X}_{obs}}{\sigma_{obs}}\right)\right|$$

- Preliminary study carried out for CHAMP and definitive minute-mean data from >100 observatories between 2001-2011
- Example here shows ESK
- $|\Delta\sigma_N|$ generally <0.5
- Seen more clearly when comparing individual passes (lower plots)




***Good correlation between $B_{obs}$ and $B_{sat}$ for CHAMP at: all local times; different disturbance levels and all latitudes. Similar findings expected for Swarm, but difficult to predict how QD data might compare with the minute means used here for CHAMP***

| ESK $\|\Delta\sigma_N\|$ | <0.5 | <1.0 | <2.0 |
|---|---|---|---|
| % of 2001-2011 passes | 94.8 | 98.9 | 99.6 |

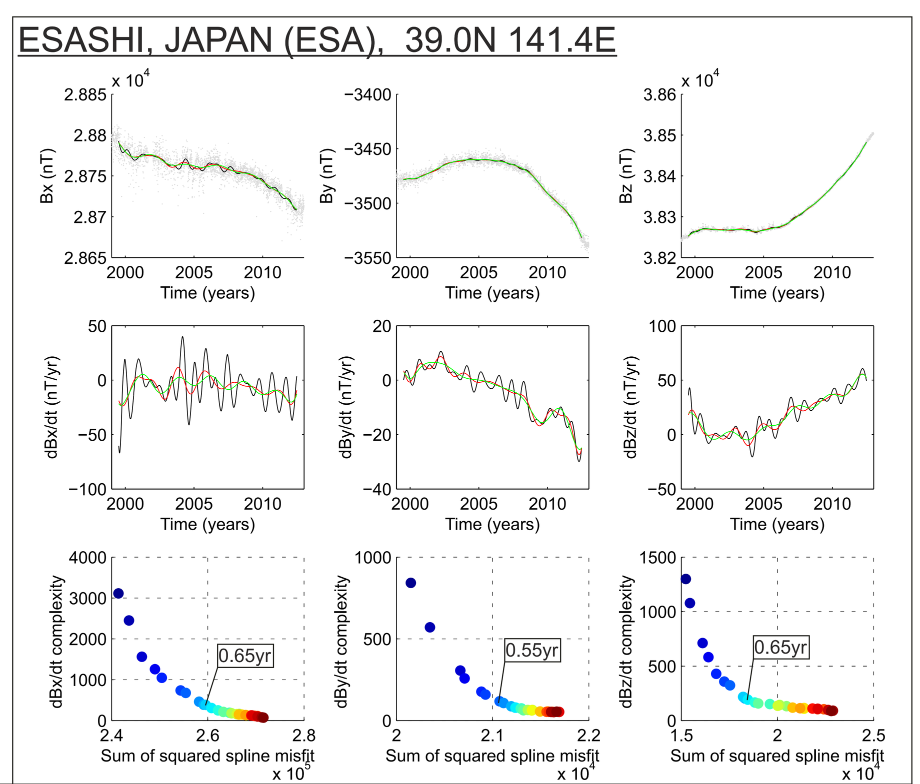
## 4. OBSERVATORY DATA & MODEL TIME PARAMETERISATION

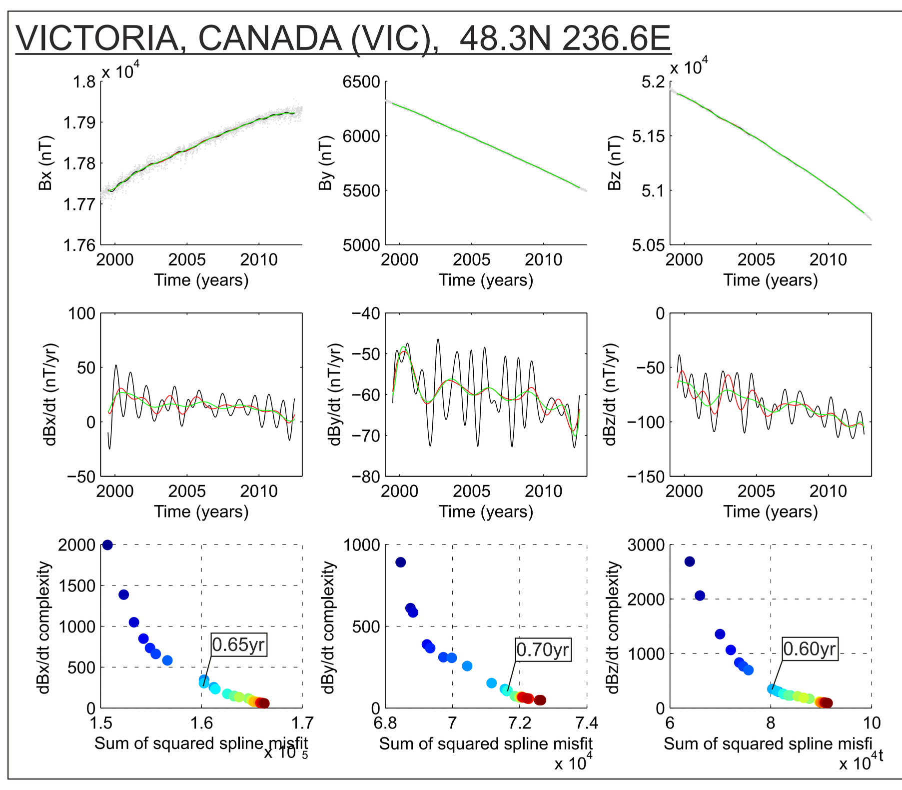
- Global geomagnetic field models typically fit temporal changes to the Earth's core field using order 6 B-splines
- Spline knot spacings and regularisation varies: CHAOS-3 [2] & GRIMM-2 [3] use 0.5 year spacing and smooth the 2nd/3rd time derivative; C$^3$FM2 [4] use 1.2 year knot spacing and smooth by minimising changes to core surface flow
- **Using different knot spacings we fit order 6 B-splines to data from 53 observatories** in an attempt to ascertain the optimal knot-spacings and identify whether a minimum spacing is required to fit the data well
- Prior to fitting splines, the data are detrended to remove annual and semi-annual signals
- We plot **trade-off curves** between the **sum of squared misfit** of the splines to the data and the **complexity of the spline first time derivative** (defined simply using a "length of string" approach)
- To reduce complexity and avoid inflating the parameter space, the splines are not regularised

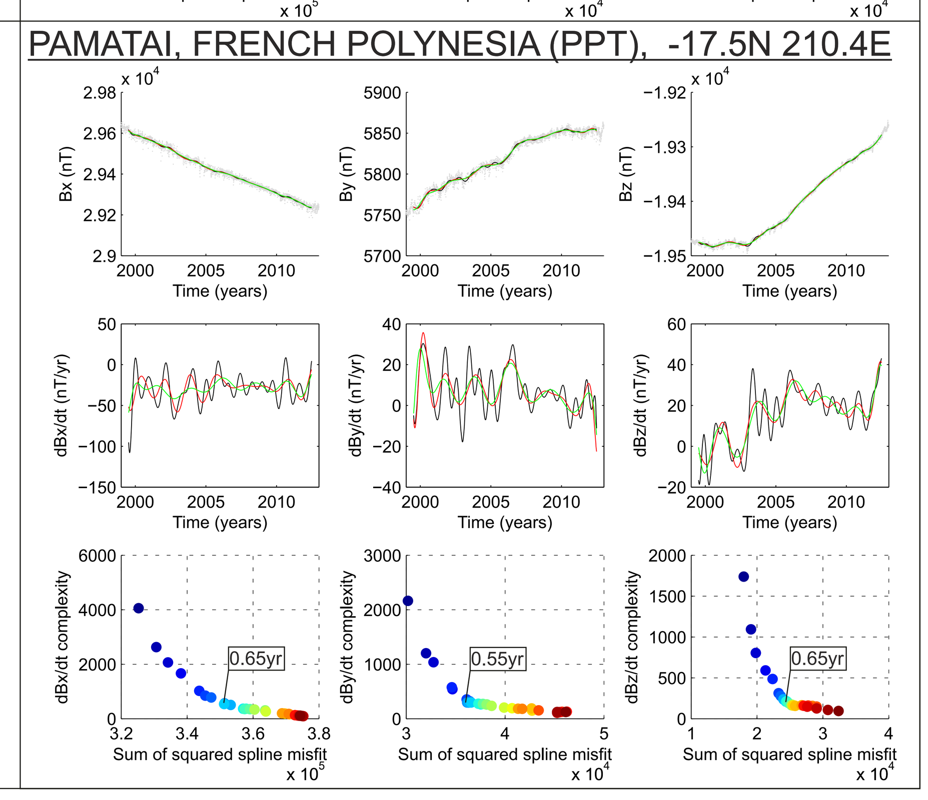
**KEY**

SPLINES AND dB/dt PLOTS
Detrended data (grey)
Knot spacing: 0.4 years (black)
0.8 years (red)
1.2 years (green)

TRADE-OFF CURVES
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
Knot spacing (years)




- Examples for three observatories are shown here
- As expected: with low knot spacing the fit to the data is improved, but the spline dB/dt is unrealistically complex; with higher knot spacing, the fit to the data is worse and dB/dt is much smoother
- The trade-off curve knees signify where further increasing the knot-spacing does not greatly alter the amount of structure in dB/dt, but does increase the data misfit
- Before the knee, a significant increase in spline complexity is seen for lower knot spacings, signifying rapid, unrealistic rates of change being modelled
- There are well defined trade-off curve knees for many observatories (e.g. PPT) but also some more ambiguous results (e.g. ESA); results also vary between Bx, By and Bz
- In some cases, just half a year difference in knot spacing significantly changes the fit and complexity (e.g. VIC)

***Though results vary between observatories (reflecting different secular variation rates by location), knot spacings of <1.0 year are preferred, even without spline smoothing. For most observatories, spacings of at least 0.55-0.70 years are required to adequately fit the field variations.***

## REFERENCES

[1] Macmillan, S.; Olsen, N.. 2013 Observatory data and the Swarm mission [in special issue: Swarm] *Earth Planets Space*, **65**. 1355-1362. 10.5047/eps.2013.07.011
[2] Lesur, V., Wardinski, I., Hamoudi, M. & Rother, M., 2010. The second generation of the GFZ reference internal magnetic model: GRIMM-2, *Earth Planets Space*, **62**, 765–773
[3] Olsen, N., Mandea, M., Sabaka, T.J. & Tøffner-Clausen, L., 2010. The CHAOS-3 geomagnetic field model and candidates for the 11th generation IGRF, *Earth Planets Space*, **62**, 719–727.
[4] Lesur, V., Wardinski, I., Asari, S., Minchev, B. & Mandea, M., 2010. Modelling the Earth's core magnetic field under flow constraints, *Earth Planets Space*, **62**, 503–516