Cluster FGM daily calibration

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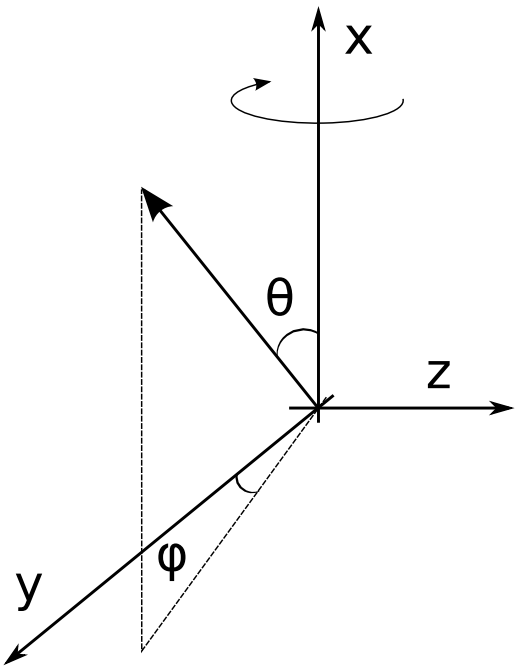
The Cluster FGM instrument(s)

- (inboard + outboard)$\times$4
- very stable during the (long) mission
- however, daily calibration is necessary
- uses ranges depending on field magnitude

range	B_{max} (nT)	resolution (nT)	
2	64	1/128	
3	256	1/32	
4	1024	1/8	
5	4096	1/2	since 2006
6	16384	2	since 2008
7	65536	8	since 2009

Calibration parameters



12 independent parameters

- 3 elevation angles θ_i
- 3 azimuth angles φ_i
- 3 gains G_i
- 3 offsets O_i

$$\begin{bmatrix} B'_x \\ B'_y \\ B'_z \end{bmatrix} = \mathcal{M} \cdot \begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} + \begin{bmatrix} O_x \\ O_y \\ O_z \end{bmatrix}$$

$$\mathcal{M} = \begin{bmatrix} G_x \sin\theta_x \cos\varphi_x & G_x \sin\theta_x \sin\varphi_x & G_x \cos\theta_x \\ G_y \sin\theta_y \cos\varphi_y & G_y \sin\theta_y \sin\varphi_y & G_y \cos\theta_y \\ G_z \sin\theta_z \cos\varphi_z & G_z \sin\theta_z \sin\varphi_z & G_z \cos\theta_z \end{bmatrix}$$

Small orthogonality deviations

Change variables

$$\theta_x \to \theta_x \quad \theta_y \to 90 - \theta_y \quad \theta_z \to 90 - \theta_z$$
$$\varphi_x \to \varphi_x \quad \varphi_y \to \varphi_y \quad \varphi_z \to 90 + \varphi_z$$

Take differences

$$\Delta G_{yz} = G_y - G_z \quad \text{spin plane gain missmatch}$$
$$\Delta\varphi_{yz} = \varphi_y - \varphi_z \quad \text{spin plane nonorthogonality}$$

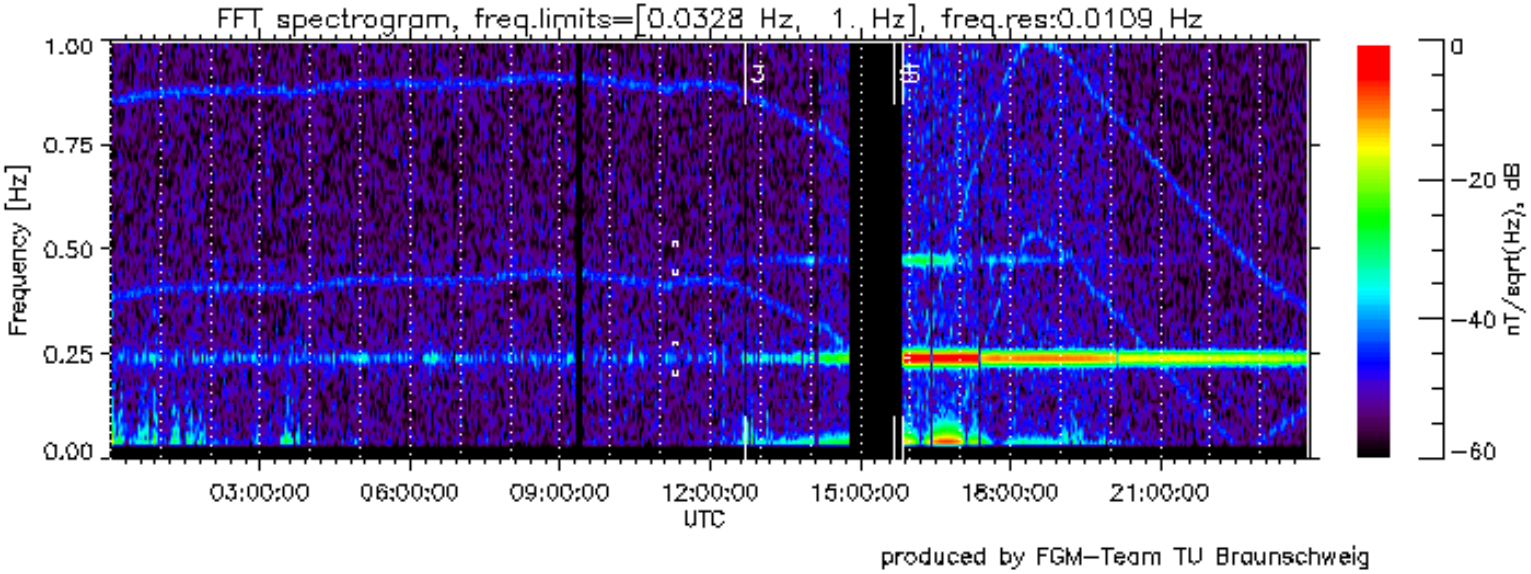
Calibration matrix in the first order:

$$\mathcal{M} = \begin{bmatrix} G_x & G_x\theta_x \sin\varphi_x & G_x\theta_x \cos\varphi_x \\ G_y\theta_y & G_y & -G_y\varphi_y \\ G_y\theta_z & G_y(\varphi_y + \Delta\varphi_{yz}) & G_y + \Delta G_{yz} \end{bmatrix}$$

Finding the right parameters

1. Fourier power spectrum [Kepko et al 1996]
   - errors lead to coherent signals:
     - spin plane $\theta_y,\ \theta_z,\ O_y, O_z$ $\longrightarrow$ ω_{spin}
     - spin plane $\Delta\varphi_{yz},\ \Delta G_{yz}$ $\longrightarrow$ $2\omega_{\text{spin}}$
     - spin axis $\theta_x,\ \varphi_x$ $\longrightarrow$ ω_{spin}
2. Solar wind calibration [Hedgecock 1975]
   - assume no correlation between $\boldsymbol{B}$ and $\boldsymbol{e}_B$
     - spin axis O_x
3. Range change continuity
   - both $\boldsymbol{B}$ and its time derivative
     -

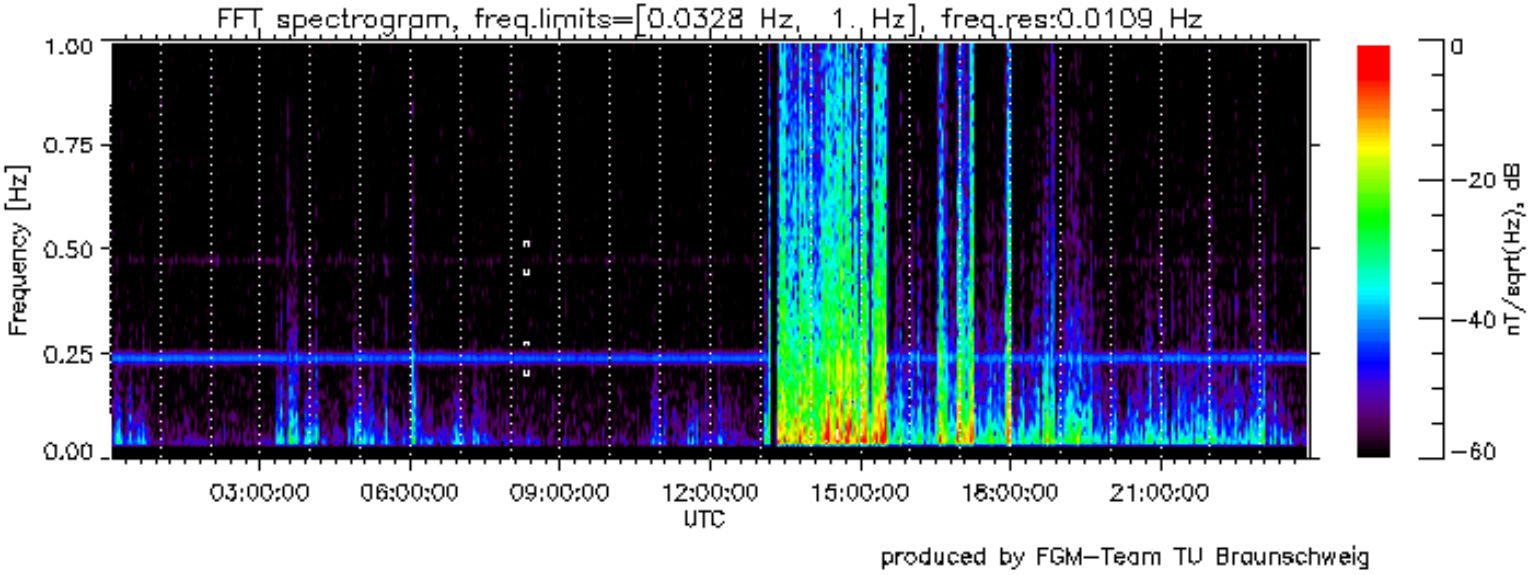
Error effects: spin tone (yz)



- spin plane elevation angles
- spin plane offsets

$$\begin{bmatrix} G_x & G_x\theta_x \sin\varphi_x & G_x\theta_x \cos\varphi_x \\ G_y\theta_y & G_y & -G_y\varphi_y \\ G_y\theta_z & G_y(\varphi_y + \Delta\varphi_{yz}) & G_y + \Delta G_{yz} \end{bmatrix} \cdot \begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} + \begin{bmatrix} O_x \\ O_y \\ O_z \end{bmatrix}$$

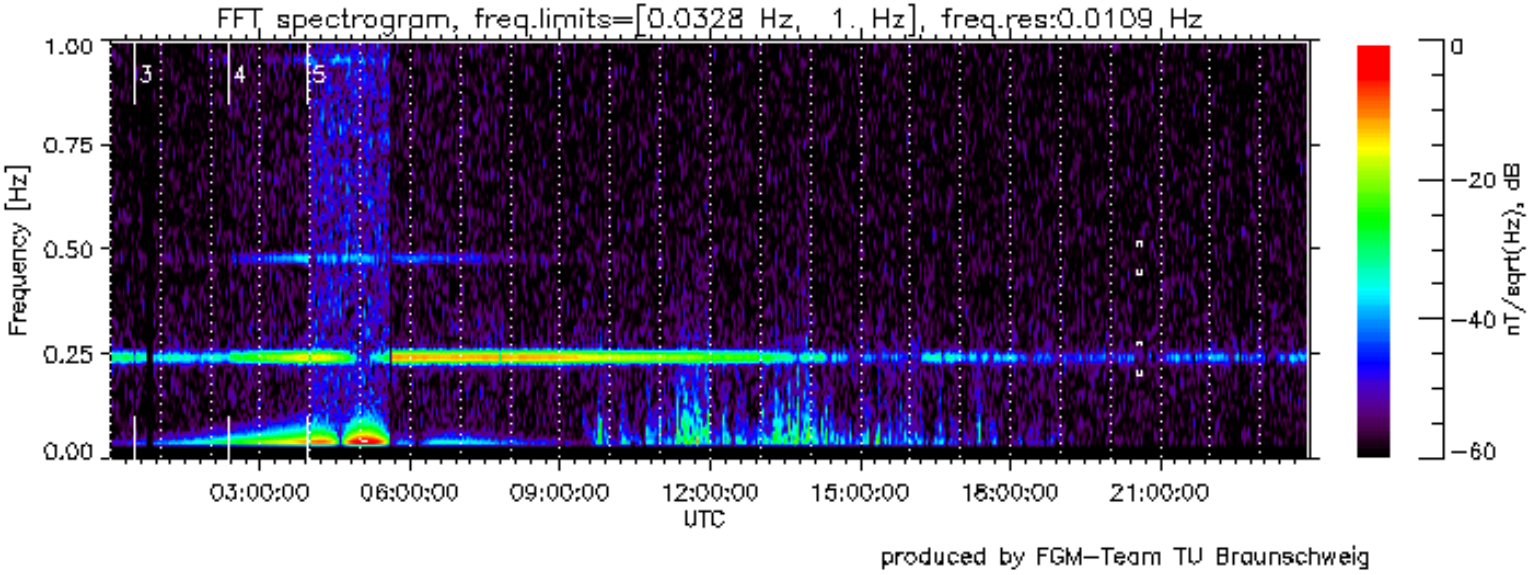
Error effects: spin tone (x)



- spin axis alignment
- the angles are coupled

$$\begin{bmatrix} G_x & G_x\theta_x \sin\varphi_x & G_x\theta_x \cos\varphi_x \\ G_y\theta_y & G_y & -G_y\varphi_y \\ G_y\theta_z & G_y(\varphi_y + \Delta\varphi_{yz}) & G_y + \Delta G_{yz} \end{bmatrix} \cdot \begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} + \begin{bmatrix} O_x \\ O_y \\ O_z \end{bmatrix}$$

Error effects: 2nd harmonic



- spin plane nonorthogonality
- spin plane gain missmatch

$$\begin{bmatrix} G_x & G_x\theta_x \sin\varphi_x & G_x\theta_x \cos\varphi_x \\ G_y\theta_y & G_y & -G_y\varphi_y \\ G_y\theta_z & G_y(\varphi_y + \Delta\varphi_{yz}) & G_y + \Delta G_{yz} \end{bmatrix} \cdot \begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} + \begin{bmatrix} O_x \\ O_y \\ O_z \end{bmatrix}$$

The remaining parameters

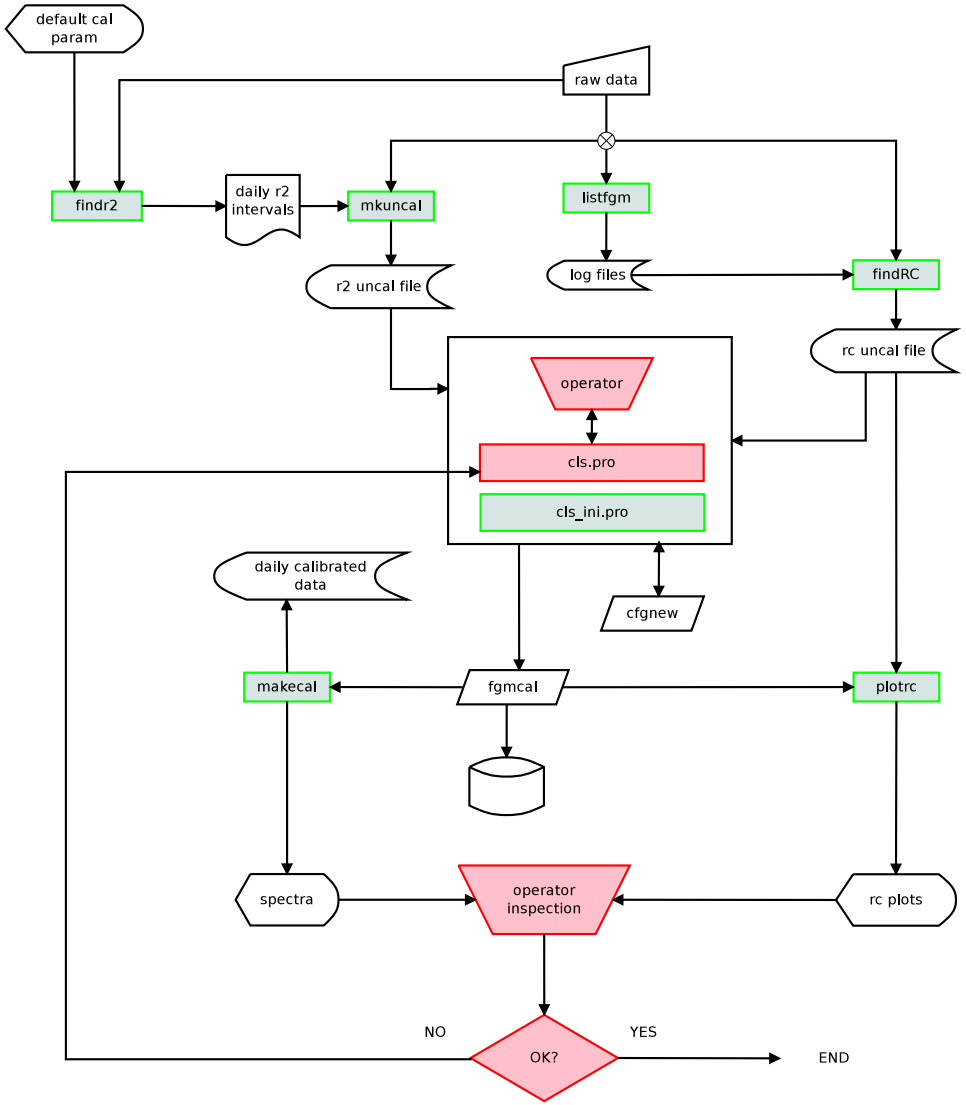
The spin axis offset is determined from SW calibration

$$\begin{bmatrix} G_x & G_x\theta_x \sin\varphi_x & G_x\theta_x \cos\varphi_x \\ G_y\theta_y & G_y & -G_y\varphi_y \\ G_y\theta_z & G_y(\varphi_y + \Delta\varphi_{yz}) & G_y + \Delta G_{yz} \end{bmatrix} \cdot \begin{bmatrix} B_\mathrm{x} \\ B_\mathrm{y} \\ B_\mathrm{z} \end{bmatrix} + \begin{bmatrix} O_\mathrm{x} \\ O_\mathrm{y} \\ O_\mathrm{z} \end{bmatrix}$$

still undetermined:

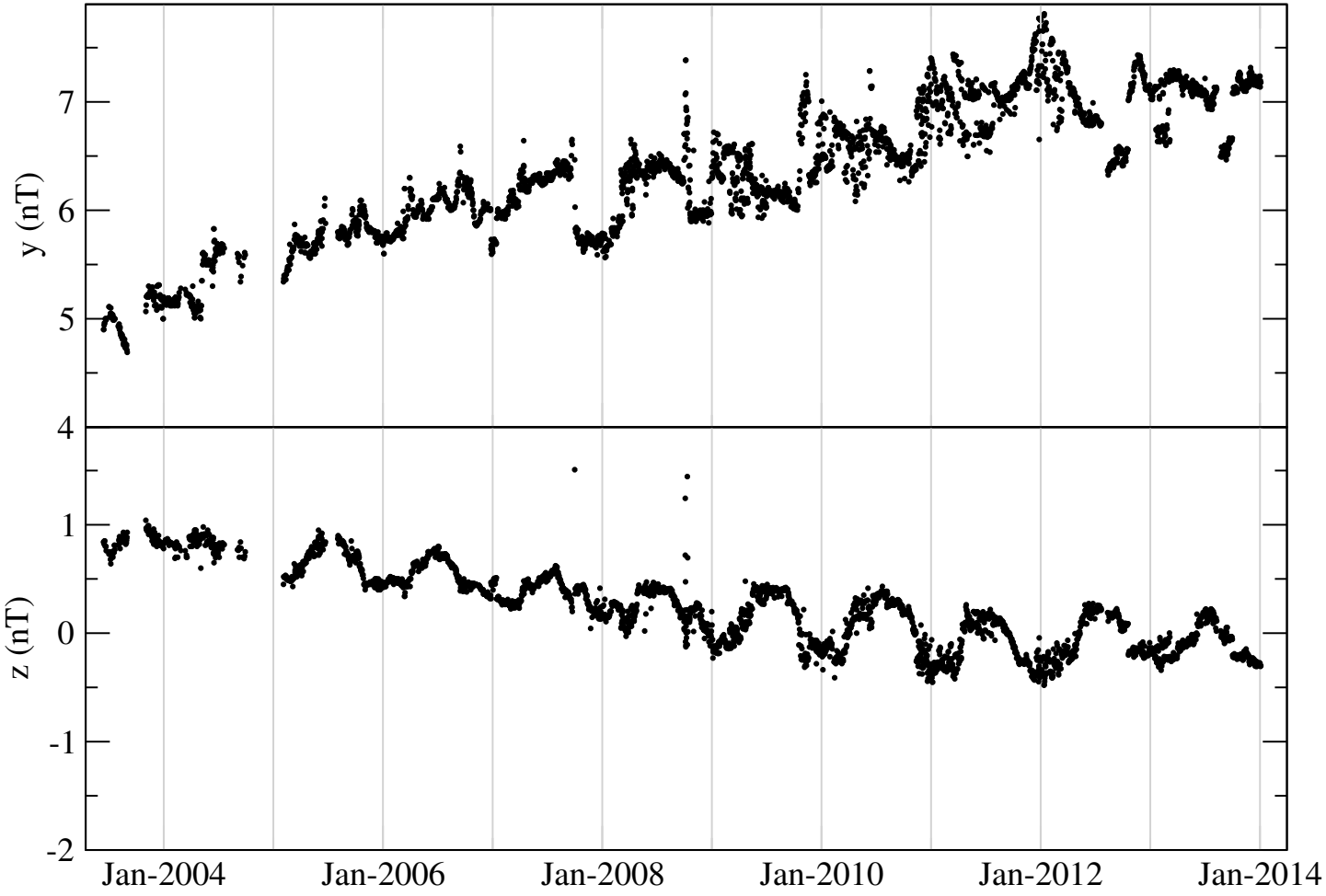
- spin axis gain G_x
- one of the spin plane gains G_y
- spin phase difference φ_y

Daily calibration procedure



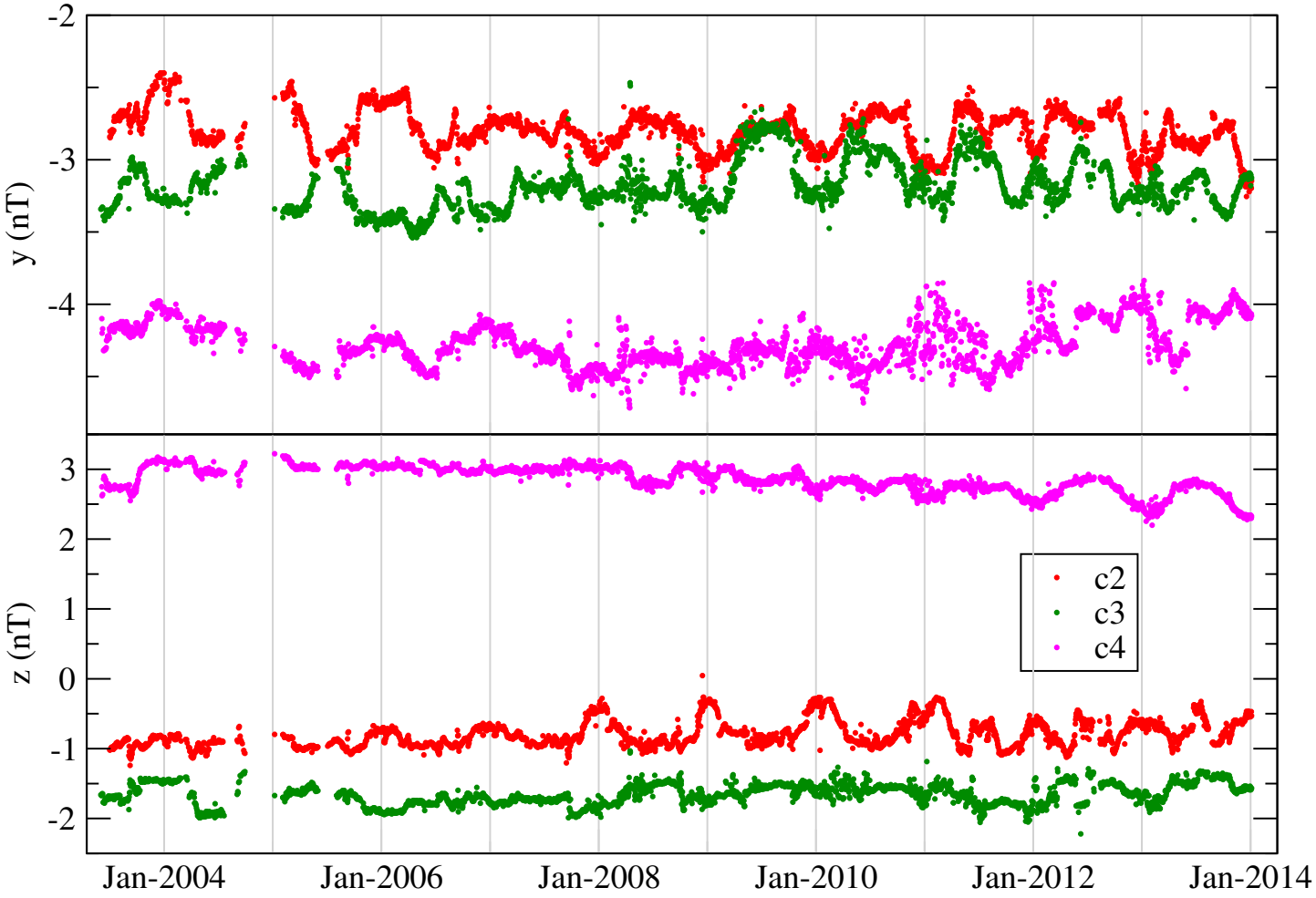
- mix of
  - C
  - Fortran
  - IDL
  - perl
- one month
- SP off: automatic
- other: manual

Long term variation: C1 SP off



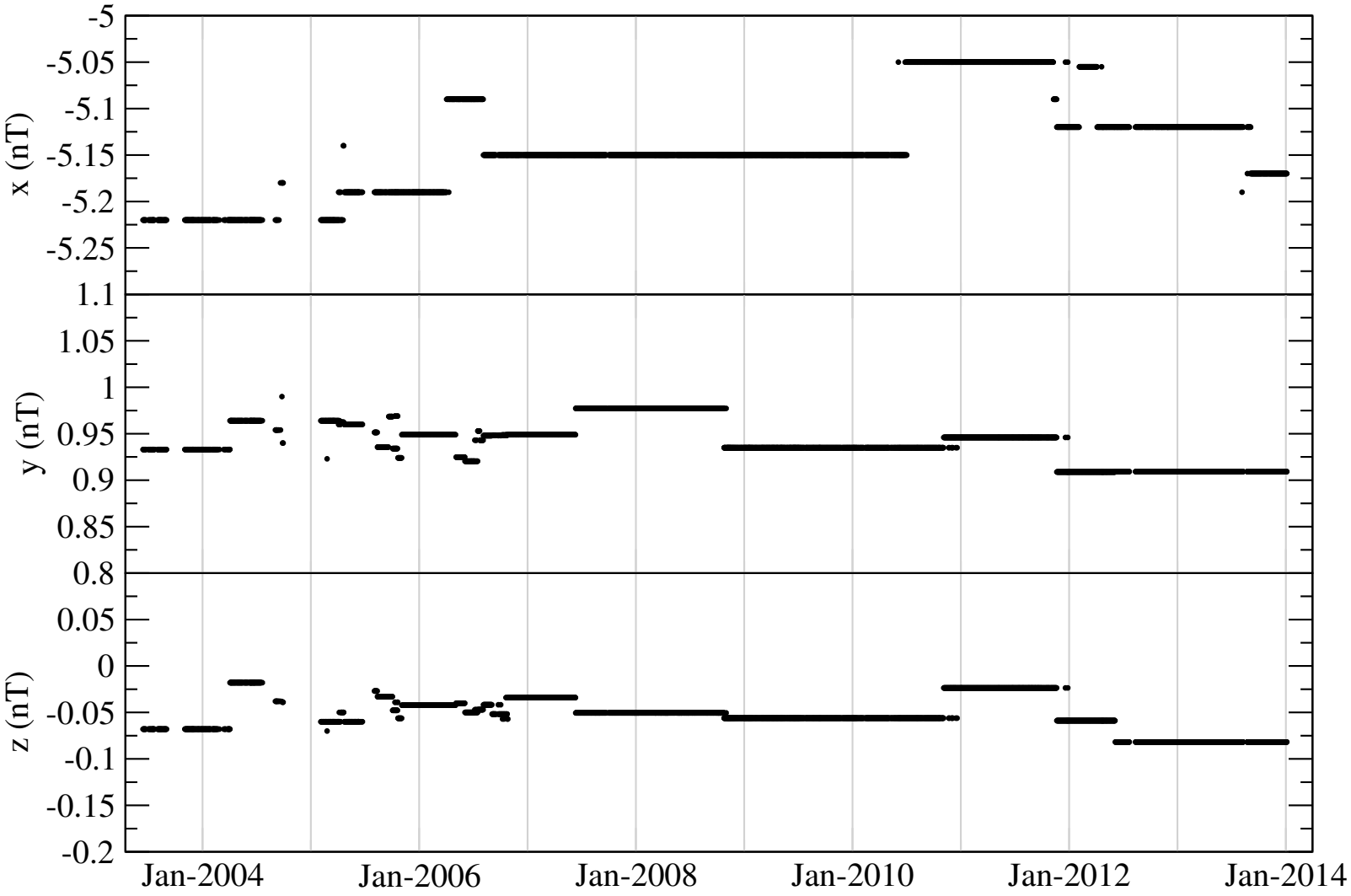
offset drift: O_y: 0.2 nT/yr; O_z: 0.1 nT/yr
seazonal variation: temperature related?

Long term variation: C234 SP off

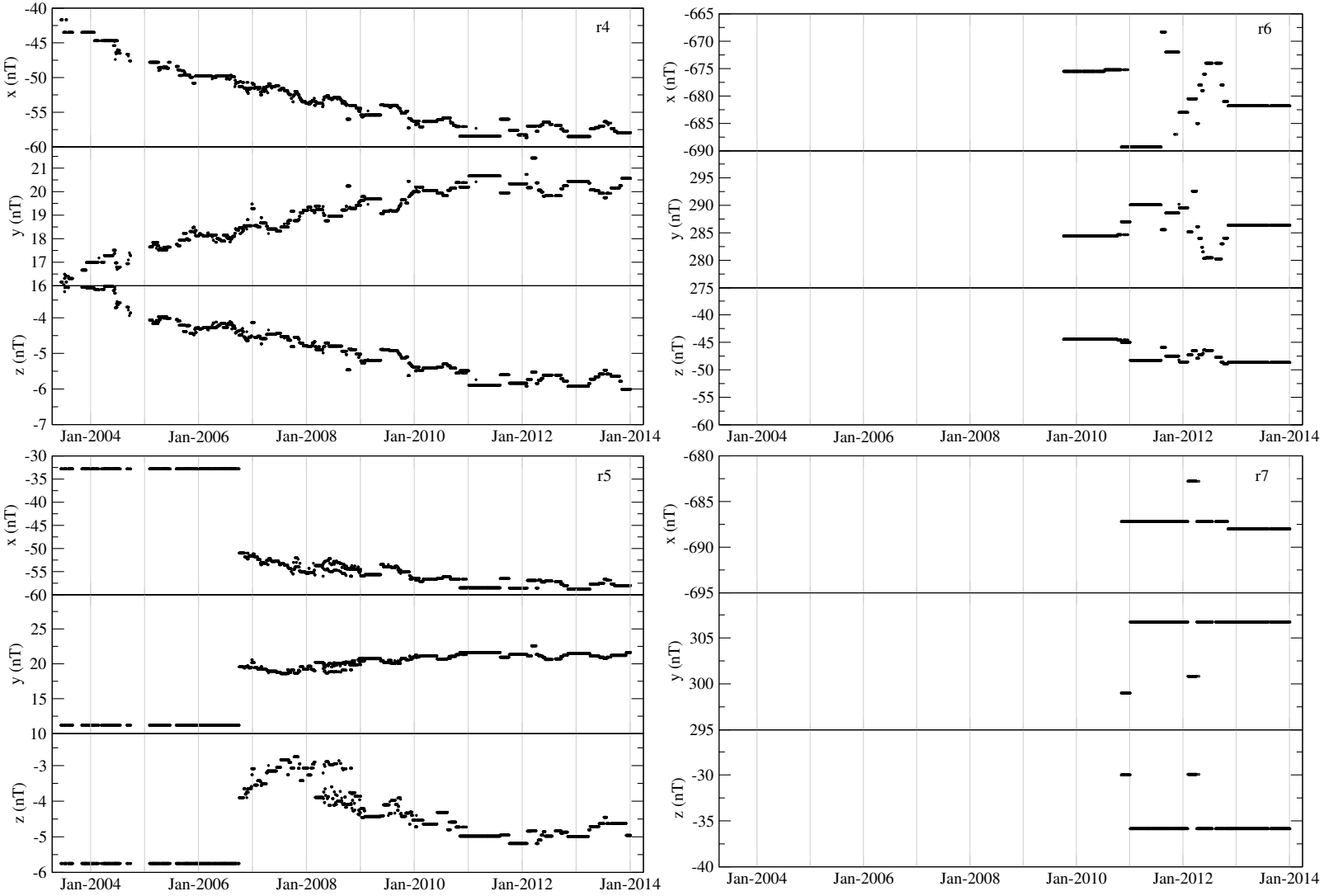


very little (if any) offset drift
visible seazonal variation

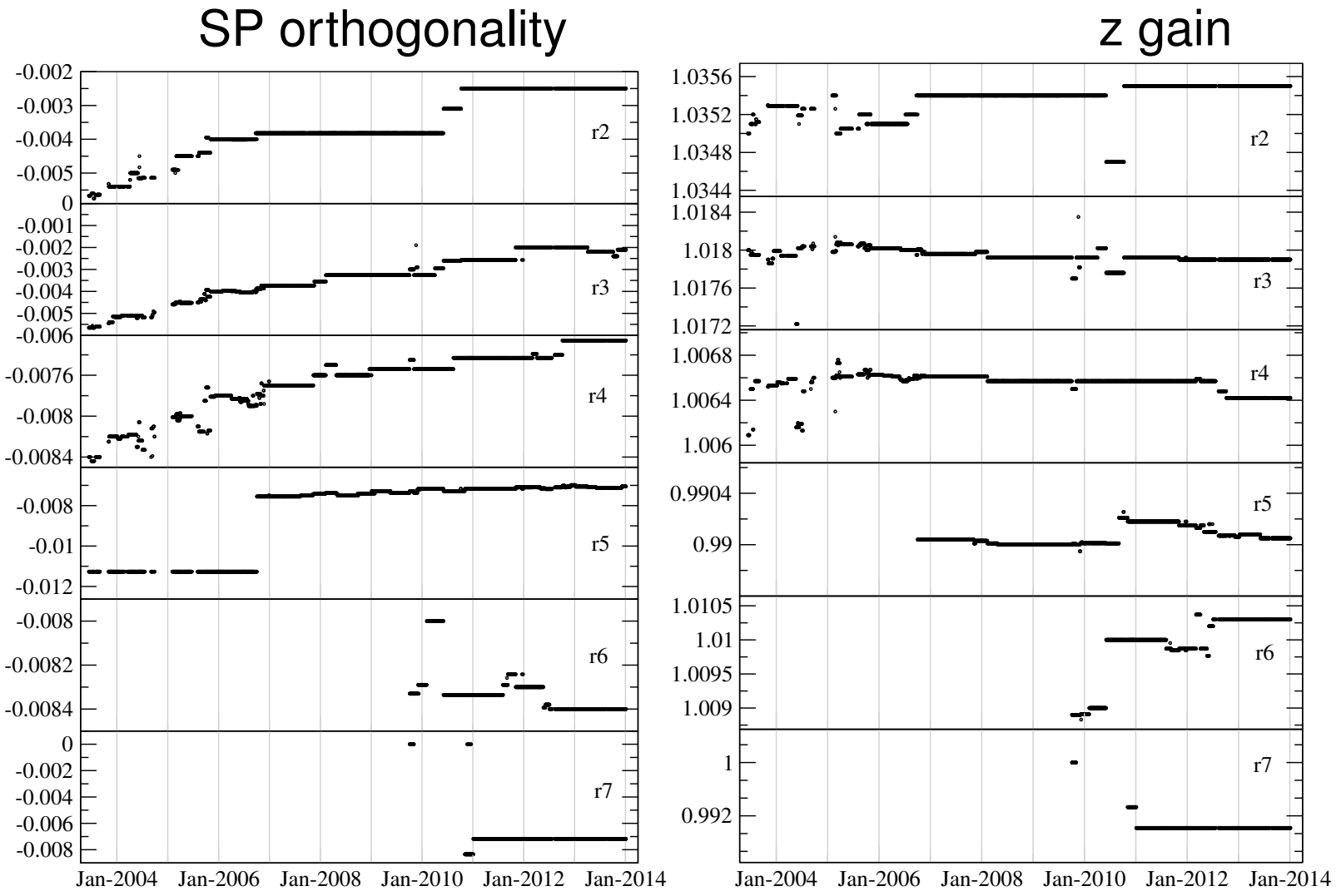
Long term variation: C1r3 off



Long term variation: C1r4567 off



Long term variation: C1 ⊥ & gain



Summary

- 12 independent calibration parameters
- 8 calibration parameters from Fourier spectra
- 1 calibration parameter from the SW cal
- adjustment for rc continuity
- 0.1 - 0.2 nT/yr offset drift for C1
- much smaller drift for the other sc
- seasonal variation of offsets for all sc