Use of Swarm data in an update of the CHAOS-4 field model

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Talk Outline

1. Introduction

2. The CHAOS series of field models

3. Observations, including Swarm

4. Results: Core field evolution 1999-2014

5. Summary and Outlook

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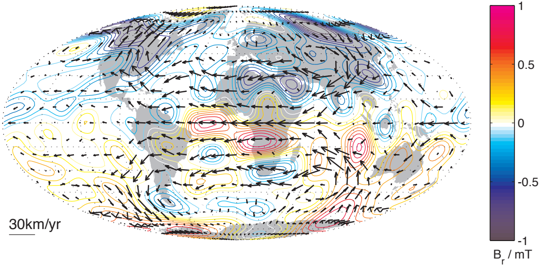
Why do we make models of the internal geomagnetic field?

1. Society requires reference models (e.g. IGRF) for orientation/navigation e.g. in mobile devices, for well drilling, aeronautics etc.

2. Fundamental questions about the deep Earth, require field models that can be downward continued to probe the core.



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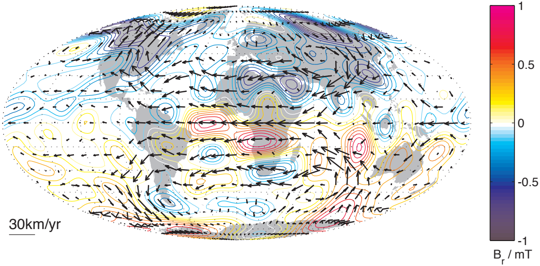

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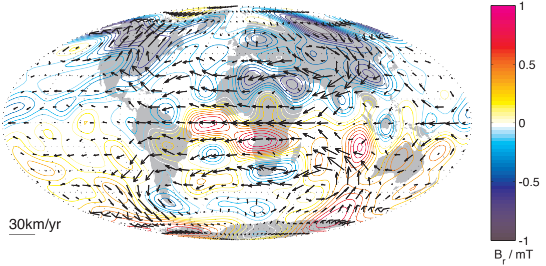

- Need high accuracy data for as long a time span as possible
- **Aim**: Combine *Swarm* and previous missions -> model for 1999-2014

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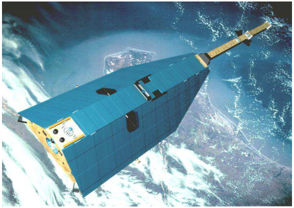
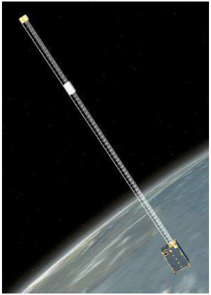
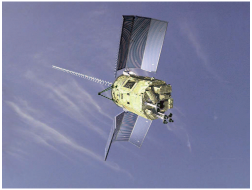
The CHAOS series of field models

- Models of the near-Earth magnetic field (Olsen et al., 2006, 2009, 2010, 2014)
- Aims to describe the internal field with high spatial and temporal resolution
- Initially based on **CH**amp **Ø**rsted and **S**ac-c satellite data -> **CHAOS**
- Latest versions also included ground observatory secular variation data







- This study: Update CHAOS-4 using presently available *Swarm* VFM data

Parameterization of CHAOS model I

- **Potential field approach:** $\mathbf{B} = -\nabla V$ where $V = V^{\rm int} + V^{\rm ext}$.

- The internal part of the potential takes the form

$$V^{\rm int} = a \sum_{n=1}^{N_{\rm int}} \sum_{m=0}^{n} \left(g_n^m \cos m\phi + h_n^m \sin m\phi \right) \left(\frac{a}{r} \right)^{n+1} P_n^m (\cos\theta)$$

- And further expanded in time as

$$\begin{aligned} g_n^m(t) &= \sum_l g_{n,l}^m \cdot M_l(t) && \text{for } n = 1-20 \\ &= g_n^m(t_0) \quad (\text{const.}) && \text{for } n = 21-80 \end{aligned}$$

where $M_l(t)$ are order 6 B-splines with 0.5 yr spacing

Parameterization of CHAOS model II

- Define external potential in SM and GSM co-ordinate systems, with θ_d and T_d being dipole co-lat. and dipole local time

$$
\begin{aligned}
V^{\text{ext}} &= a \sum_{n=1}^{2} \sum_{m=0}^{n} \left(q_n^m \cos mT_d + s_n^m \sin mT_d\right) \left(\frac{r}{a}\right)^n P_n^m(\cos\theta_d) \\
&+ a \sum_{n=1}^{2} q_n^{0,\text{GSM}} R_n^0(r, \theta, \phi).
\end{aligned}
$$

- Degree-1 coefficients in *SM* coordinates dependent on the the RC index

Model estimation

- Work with data in **magnetometer frame** co-estimating Euler angles in 10 day bins
- **Robust non-linear least squares including regularization**, iteratively minimizing

$$[\mathbf{d} - F(\mathbf{m})]^T \underline{\underline{\mathbf{W}}}^{-1} [\mathbf{d} - F(\mathbf{m})] + \lambda_2 \mathbf{m}^T \underline{\underline{\mathbf{\Lambda}}}_2 \mathbf{m} + \lambda_3 \mathbf{m}^T \underline{\underline{\mathbf{\Lambda}}}_3 \mathbf{m}$$

$\underline{\underline{\mathbf{W}}}$ is a Huber weighting matrix, $\underline{\underline{\mathbf{\Lambda}}}_2$ and $\underline{\underline{\mathbf{\Lambda}}}_3$ are regularization matrices

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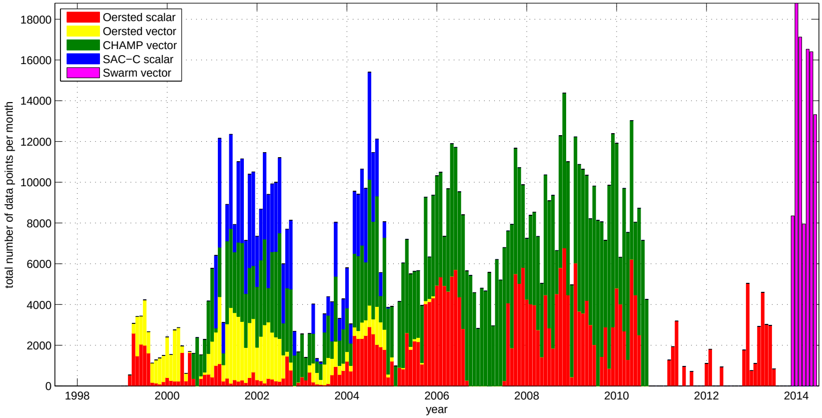
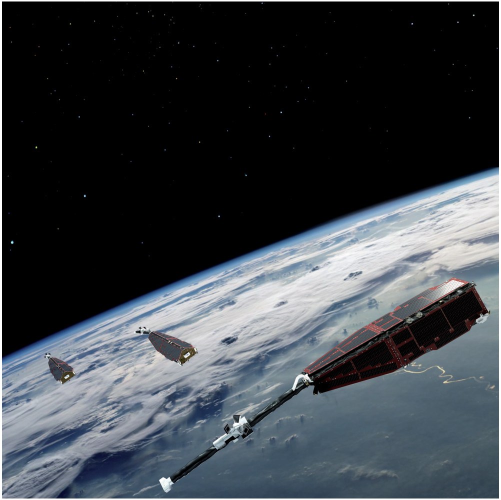
Selection of satellite data

- Quiet times: ($Kp \leq 2$o, $|dD_{st}/dt| \leq 2$nT/hr)
- Night side: data from dark regions, sun 10 deg below horizon
- Vector data below 55 deg geomagnetic latitude
- Only use polar data if E_m averaged over preceding 2hrs ≤ 0.8mV/m

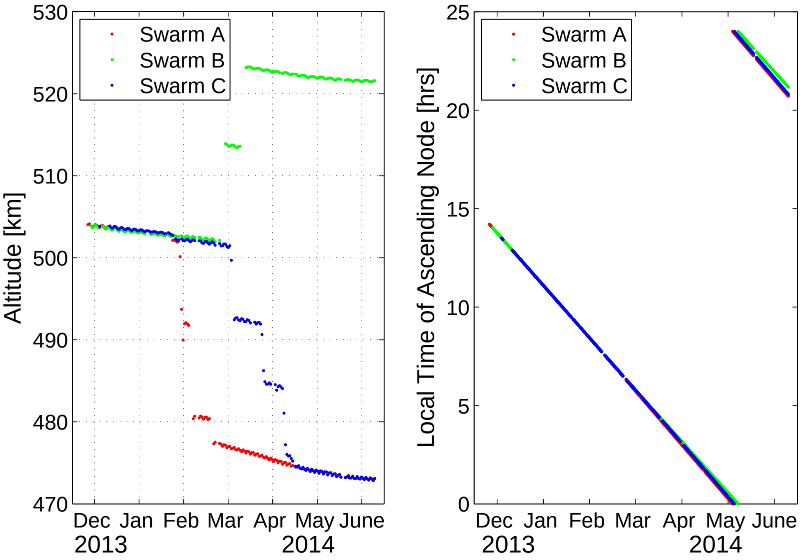


The *Swarm* satellite trio



- Use *Swarm* L1b VFM data (RPRO/OPER 0301), 26th Nov 2013 - 7th June 2014.

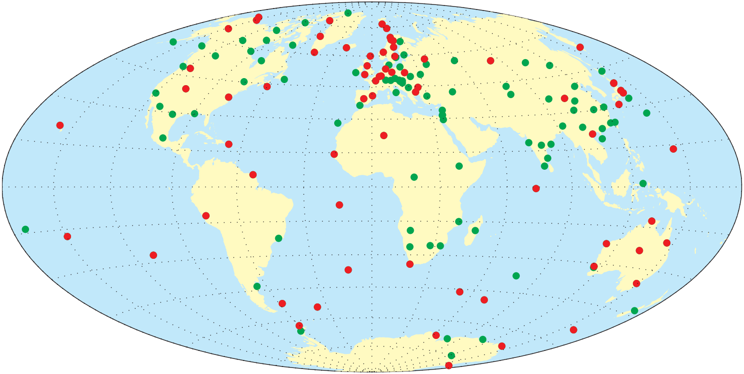
Evolution of *Swarm* constellation



Ground observatories: monthly means

Based BGS's hourly mean database.

(Test auxiliary *Swarm* data product: L2_AUX_OBS)



Those providing data in 2014 are shown in red.

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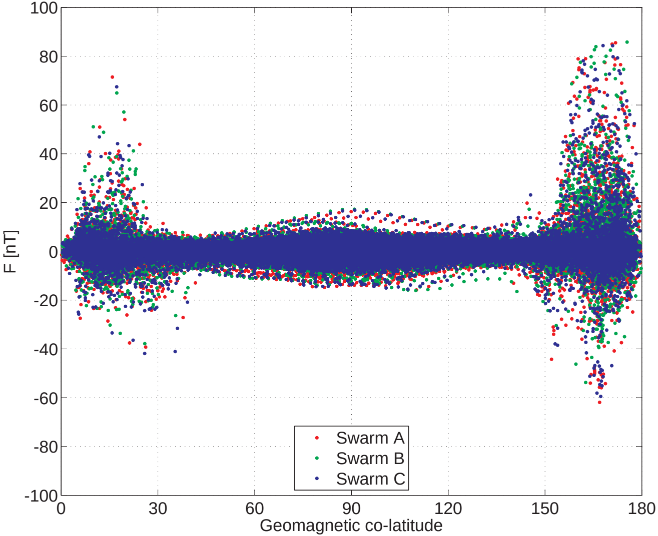
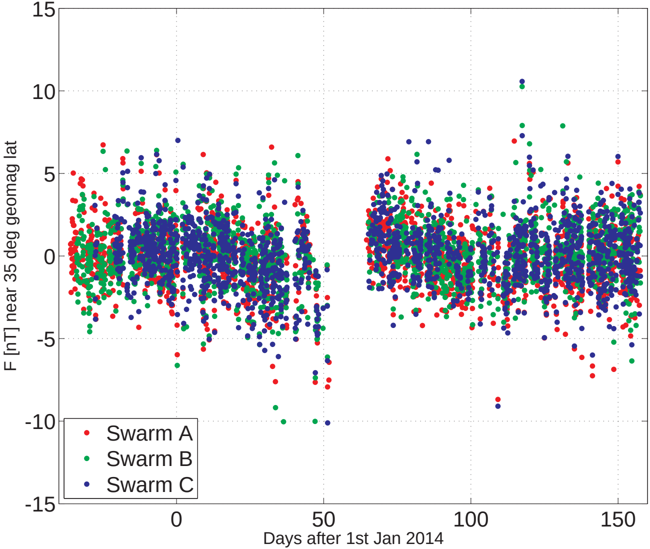
Model misfit to Swarm data, statistics

		Misfit to CHAOS-4plus_V3		
Satellite	Component	N	mean [nT]	rms [nT]
Swarm A	B_r	33,712	-0.03	**1.74**
	B_θ		0.16	**3.07**
	B_ϕ		-0.14	**2.74**
	$F_{\text{non polar}}$		-0.09	2.17
Swarm B	B_r	33,929	0.08	**1.96**
	B_θ		0.13	**3.12**
	B_ϕ		-0.12	**2.81**
	$F_{\text{non polar}}$		0.07	2.12
Swarm C	B_r	30,818	0.18	**1.99**
	B_θ		0.20	**3.21**
	B_ϕ		-0.13	**2.74**
	$F_{\text{non polar}}$		0.05	2.22
CHAMP	B_r	497,376	0.01	**2.80**
	B_θ		0.10	**3.60**
	B_ϕ		- 0.02	**2.76**
	$F_{\text{non polar}}$		-0.11	2.12

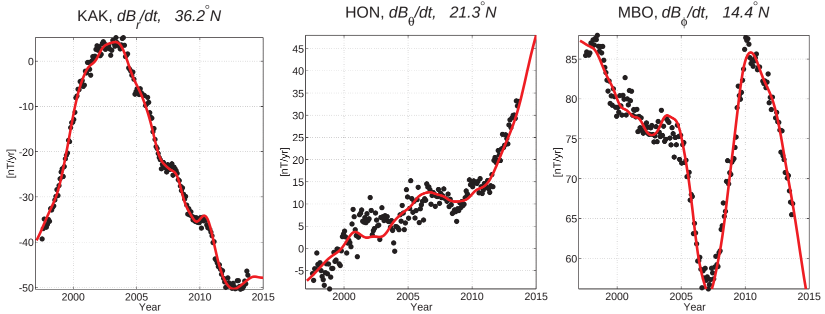
Model misfit to Swarm data, dependence on latitude



Model misfit to Swarm data, dependence on time



Fit to annual differences of observatory monthly means



Core surface radial field in 1999.5

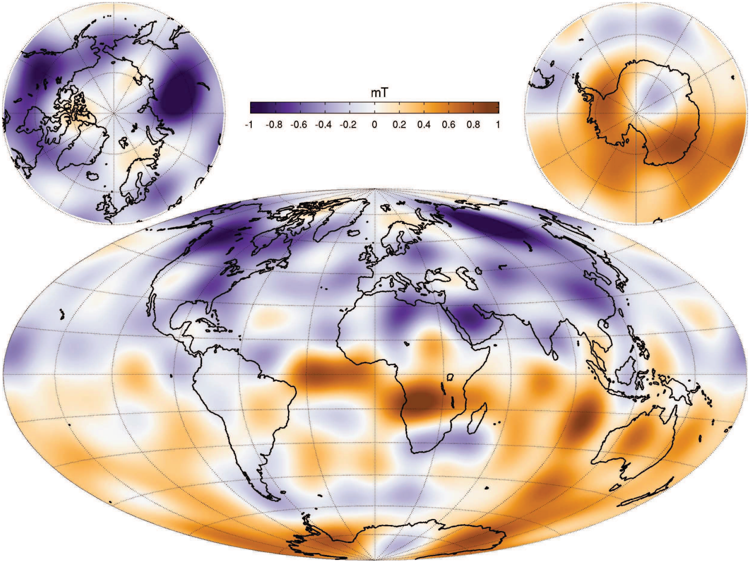


Fig: Radial field at core surface in 1999.5 to $n = 14$. Units: mT.

Core surface radial field in 2014.5

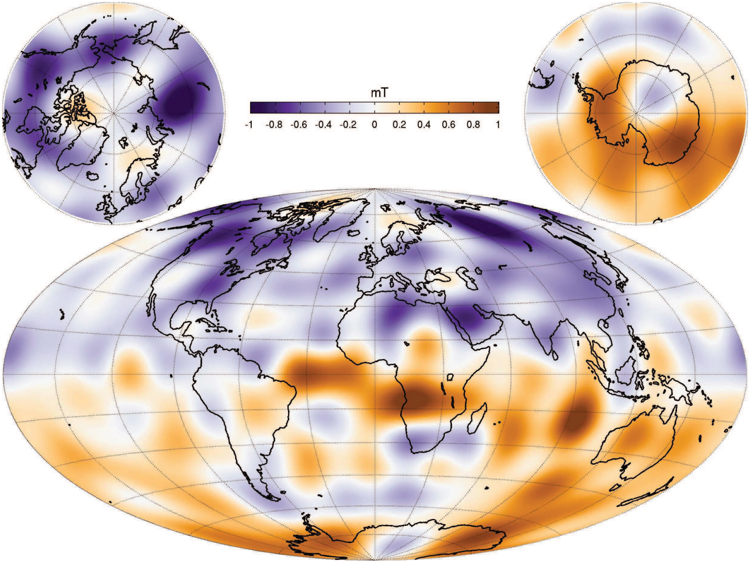


Fig: Radial field at core surface in 2014.5 to $n = 14$. Units: mT.

Core surface SV in 2014.25

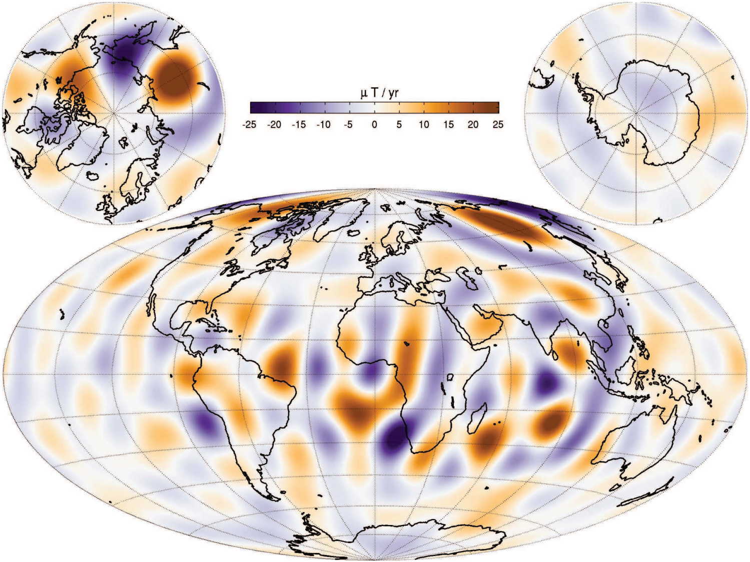
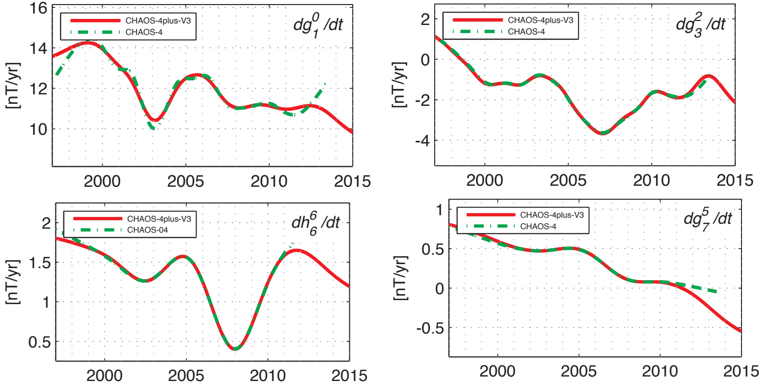
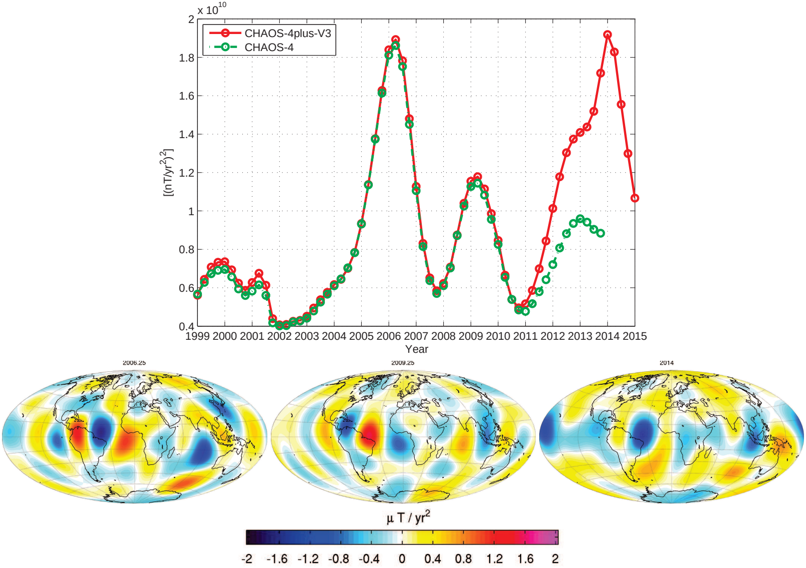


Fig: SV of radial field at core surface in 2014.25 to $n = 15$. Units: nT/yr.

Time-dependence of secular variation coefficients



Secular acceleration pulses at CMB?



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Model presented here, CHAOS-4plus_V3, is available to download from:
http://www.spacecenter.dk/files/magnetic-models/CHAOS-4/

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