The Earth's magnetic field over the South African continent - From main to crustal fields –

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in collaboration with

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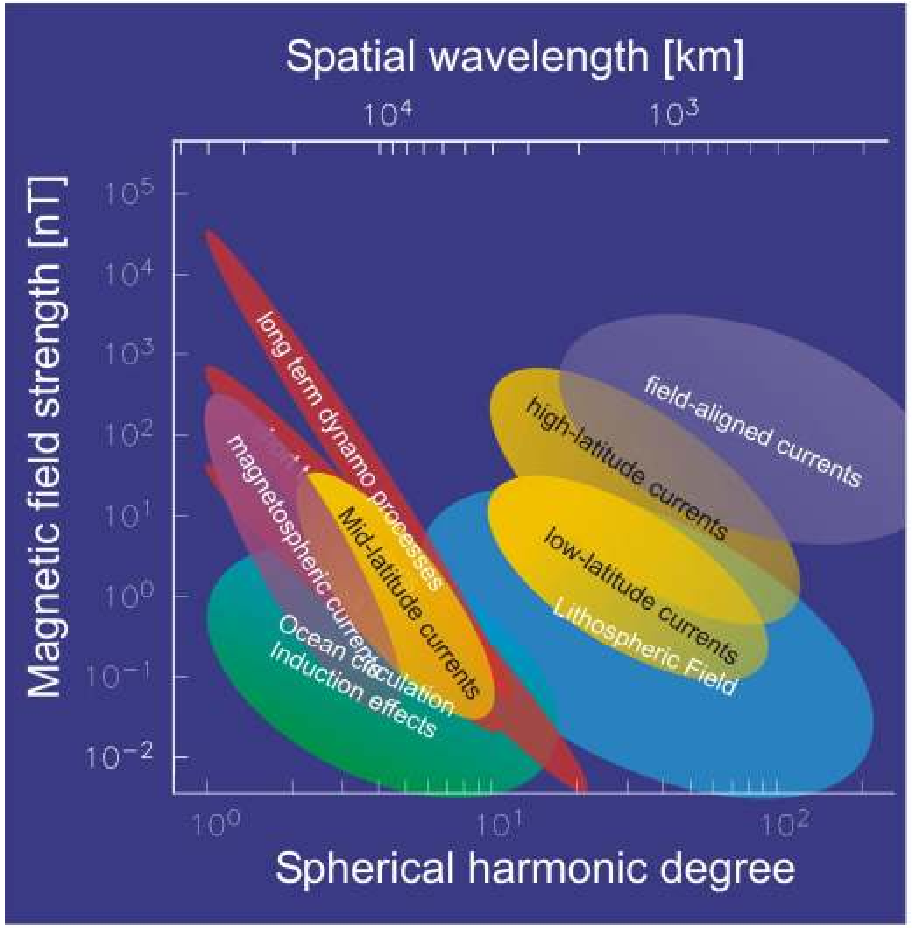
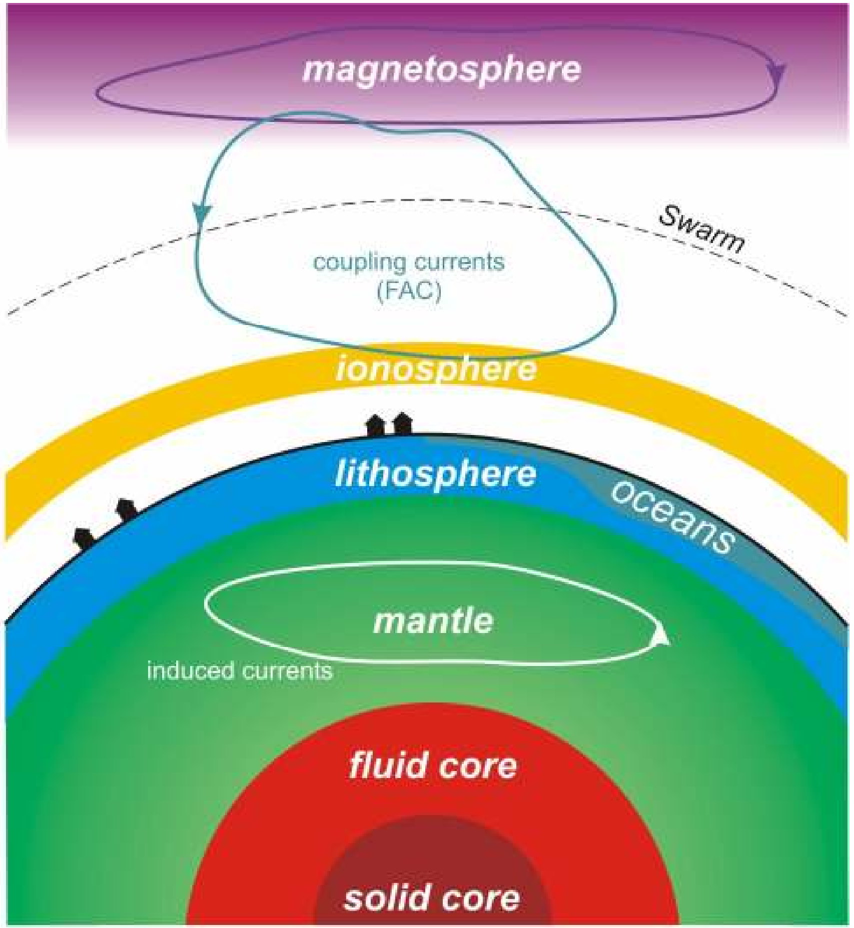
Earth's magnetic field sources

$$B(r,t) = B_{core}(r,t) + B_{ext}(r,t) + B_{crust}(r) + \varepsilon(r,t)$$

Less than 0.1% of the total field at 400 km altitude





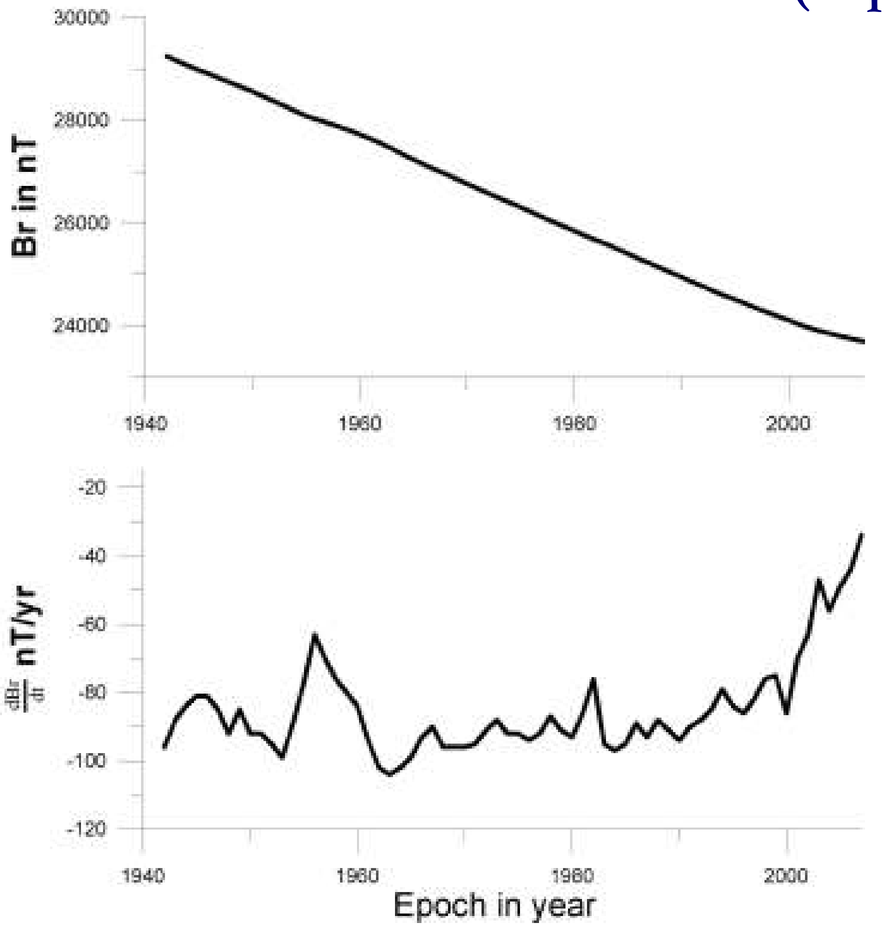
!Khure meeting, 7th July 2009, E. Thébault

http://www.esa.int/esaLP/ESA3QZJE43D_LPswarm_0.html

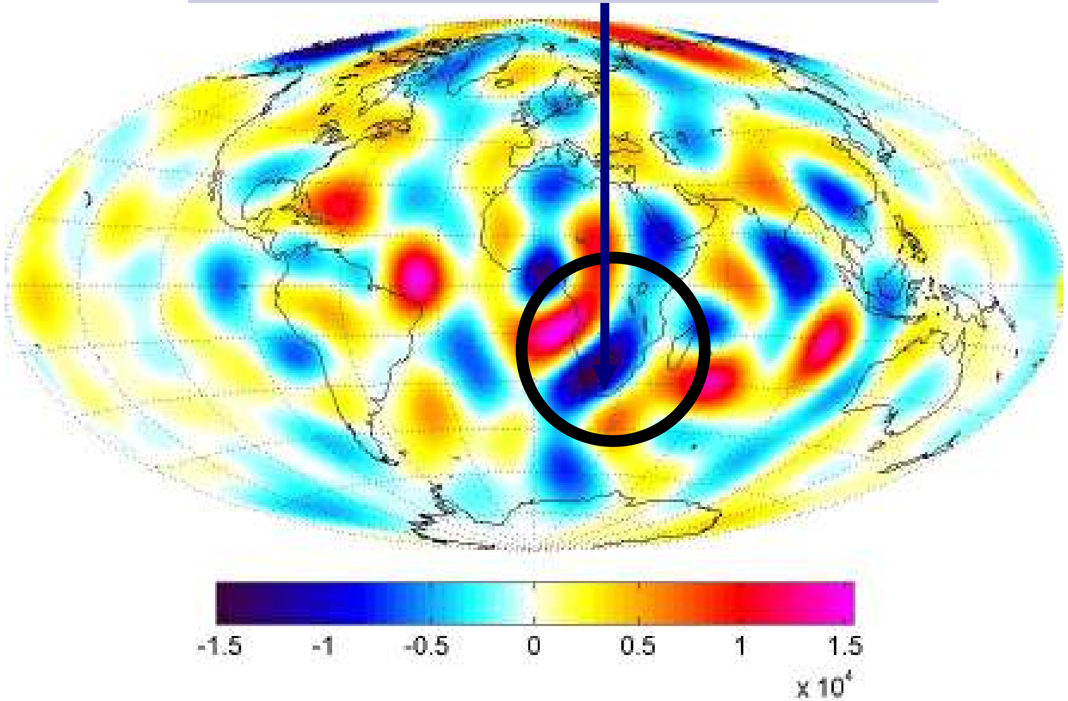
Goals / Scientific Questions

• **For core field modelling: improve the modelling of core flow dynamics, monitoring of South Atlantic Anomaly and hazards to satellites, better quality geomagnetic field models for navigation purposes, etc…**

After Chulliat and Olsen (in prep)



Reversed flux patch plays a significant role in the decrease of the Earth's magnetic field



Core field models at the CMB between OERSTED (2000) and MAGSAT (1980) epochs.

Goals / Scientific Questions

- **Crustal field modelling and the geophysics of deep-seated magnetic anomalies.**
  - What is the amount of induced VS remanent magnetization ?
  - At which spatial scales do they dominate (statistically)?
- **Is the crustal field seen at satellite altitude varying with time ?**
- **Estimation of the magnetic susceptibility and the magnetic crustal thickness with high spatial resolution.**

↓

Requires data and new spectral tools at a regional scale

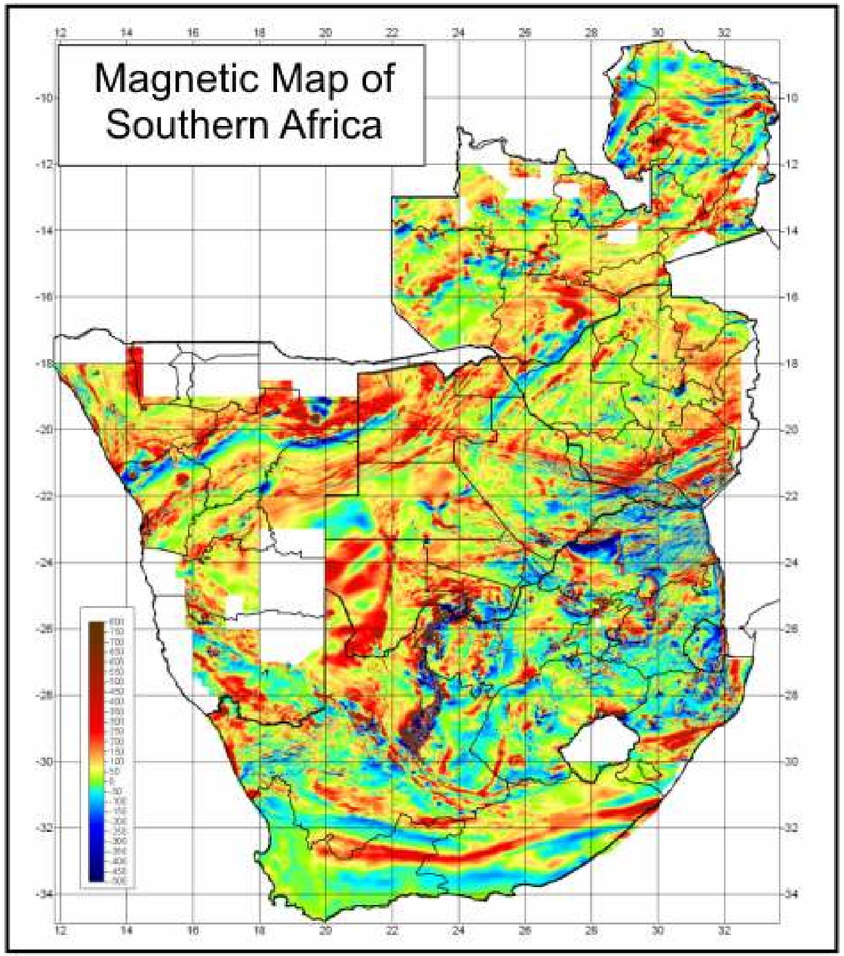
Available magnetic data in South Africa

- Ground based measurements made on a regular basis since the early fifties (observatory and « repeat station data »).
- Aeromagnetic surveys since the early sixties.
- High altitude data during the POGO series of satellites (1965-1970), MAGSAT (1980), OERSTED (since 1999) and CHAMP (since 2000).

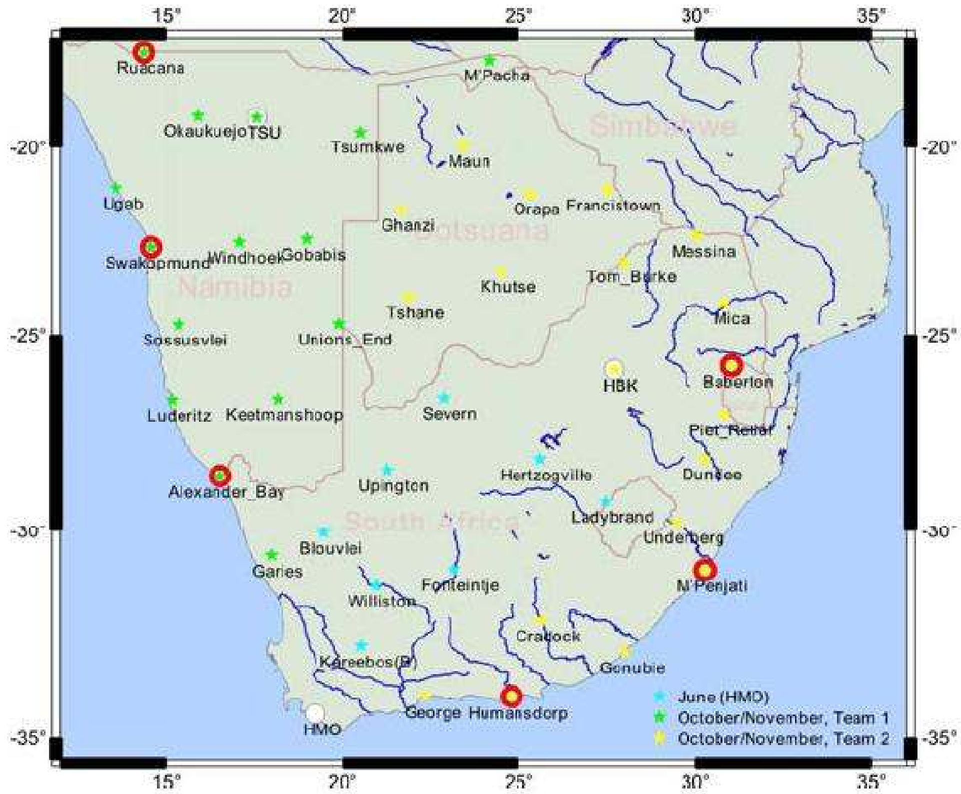
- These three types of complementary measurements offer the opportunity to represent the field over South Africa in space and time.

Available magnetic data in South Africa

- 10 years of satellite vector data between 350 and 900 km altitude.



Scalar aeromagnetic data (5km altitude)



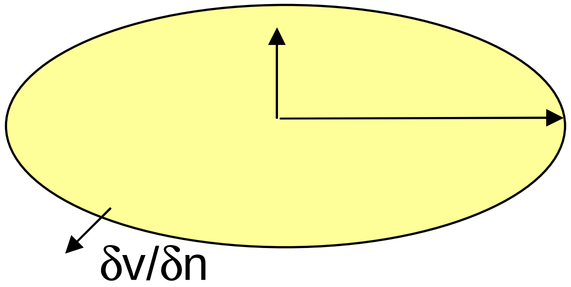
Ground based vector data
(After Kotze et al., 2007)

How do we mathematically represent the data ?

- Spherical Harmonics ?
  - → Near surface data are not regularly distributed in space.
- Polynomial fitting ?
  - No, it does not respect the potential field properties of the magnetic field.
- Rectangular local harmonics ?
  - → No, it cannot deal with multi-level data.

Derivation of a new potential field representation

Spatial magnetic field representation : R-SCHA2D



$$\nabla^2 V_1 = 0$$

$$\left.\frac{\partial V_1}{\partial \theta}\right)_{\theta_0} = 0$$

$$\left.\frac{\partial V_1}{\partial r}\right)_{r=a} = Z_{r=a}$$

$$\hat{G}^m_{2,k} = \left(G^{i,m}_{nk} + G^{e,m}_{nk}\right)$$

$$\hat{H}^m_{2,k} = \left(H^{i,m}_{nk} + H^{e,m}_{nk}\right)$$

Thébault et al., 2006

$$G^0_0 = -\langle Z \rangle_{r=a}$$

SCHA, Haines, 1985

$$V_1 = \sum_{m=0}^{\infty} \sum_{k=0}^{\infty} \left(R_k^{c,m}(r) \hat{G}^m_{1,nk} \cos m\varphi + R_k^{s,m}(r) \hat{H}^m_{1,nk} \sin m\varphi \right) P^m_{n_k}(\cos\theta)$$

De Santis et al., 1999

$$\nabla^2 V_2 = 0$$

$$\frac{\partial V_2}{r \partial \theta} = B_\theta$$

$$\Rightarrow \oint B_\theta \sin \theta d\varphi = 0$$

$$\frac{\partial V_2}{\partial r} = 0$$

$$V_2 = \sum_{m=0}^{\infty} (a/r)^{1/2} (\log(r/a) + 2) \left(G^m_{-1/2} \cos m\varphi + H^m_{-1/2} \sin m\varphi \right) P^m_{-1/2}(\cos\theta)$$

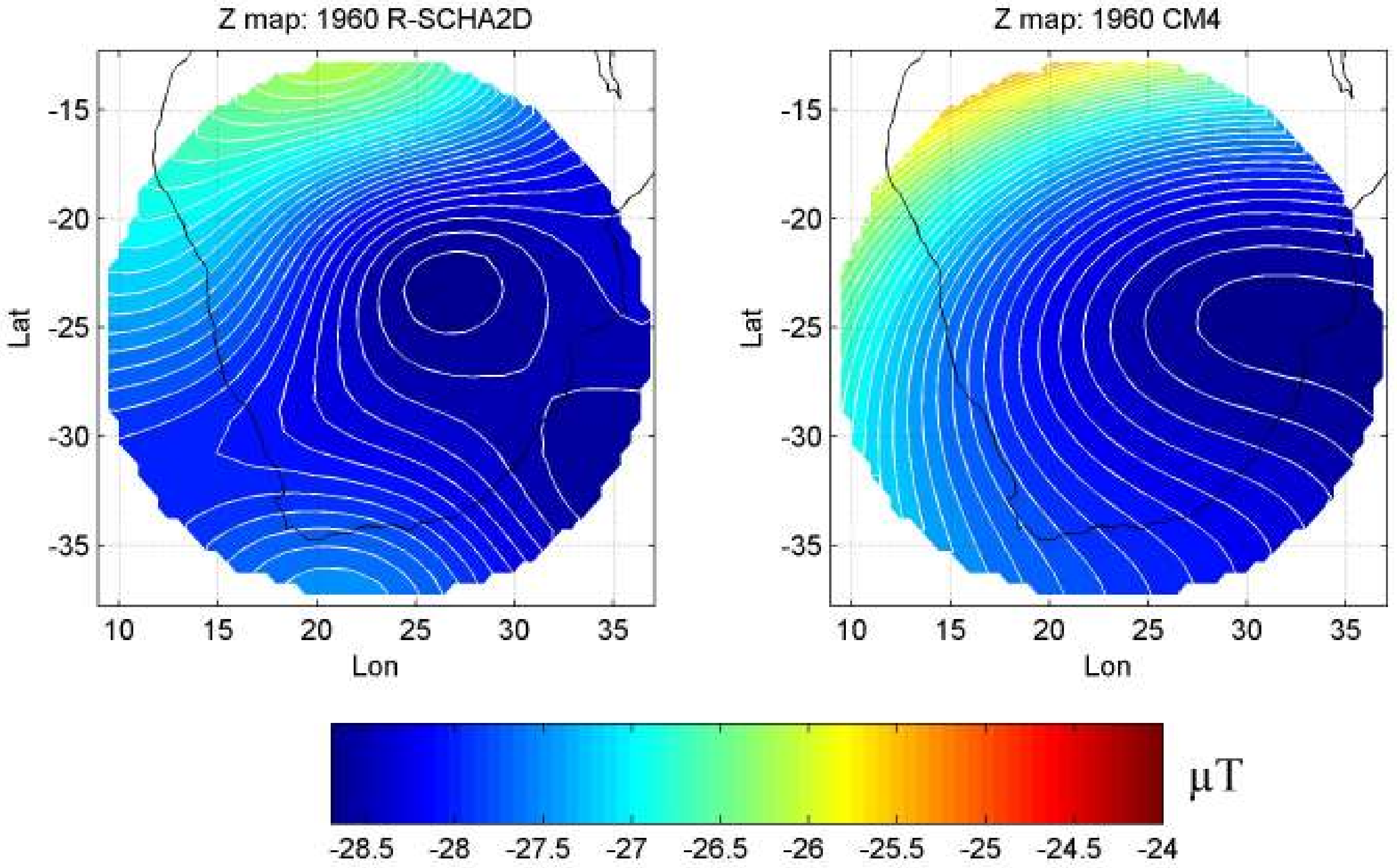
V=V1+V2 without implicit constrain

Thébault, GJI, 2008

A preliminary model from repeat station data

R-SCHA2D plus cubic (or higher order) B-splines

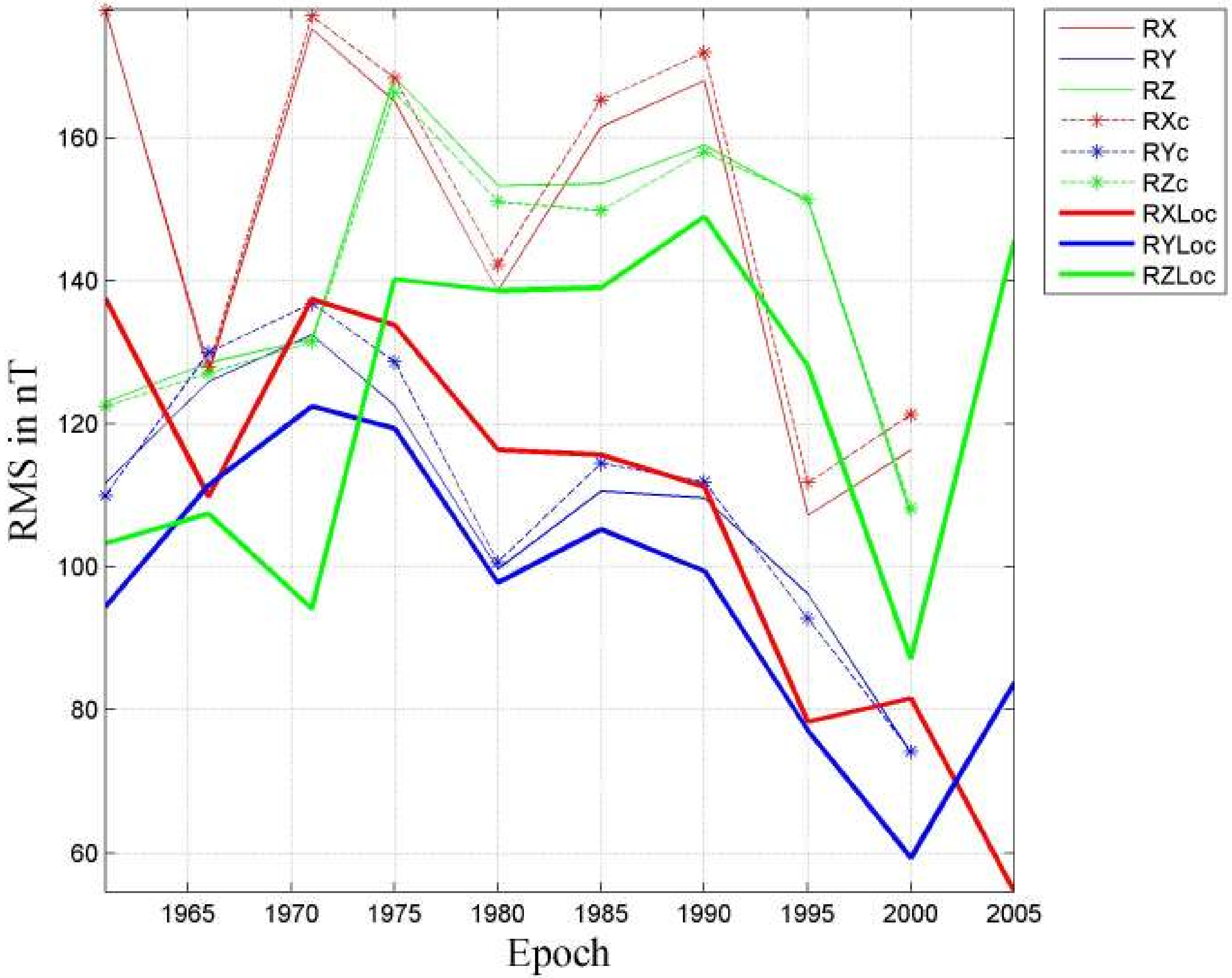
→ Current status: First co-estimation in space and time of the Earth's magnetic field over South Africa at a regional scale.



Thébault et al., in prep.

Quick look to residuals

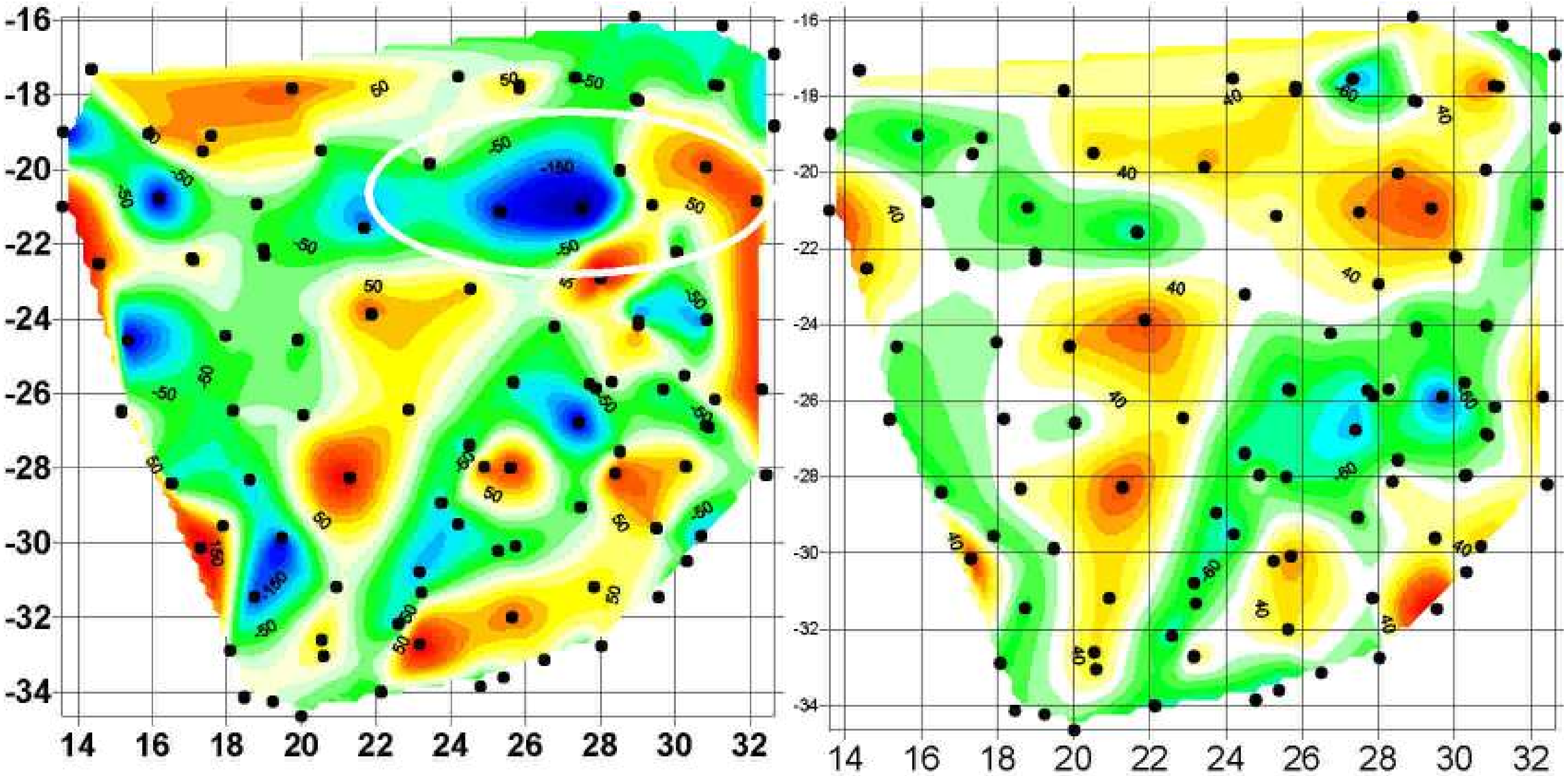
- Time variation of the residual mean square



The RMS is nearly constant with time

Spatial distribution of residuals

R-SCHA2D RESIDUALS **WDMAM (Korhonen et al., 2007) residuals**



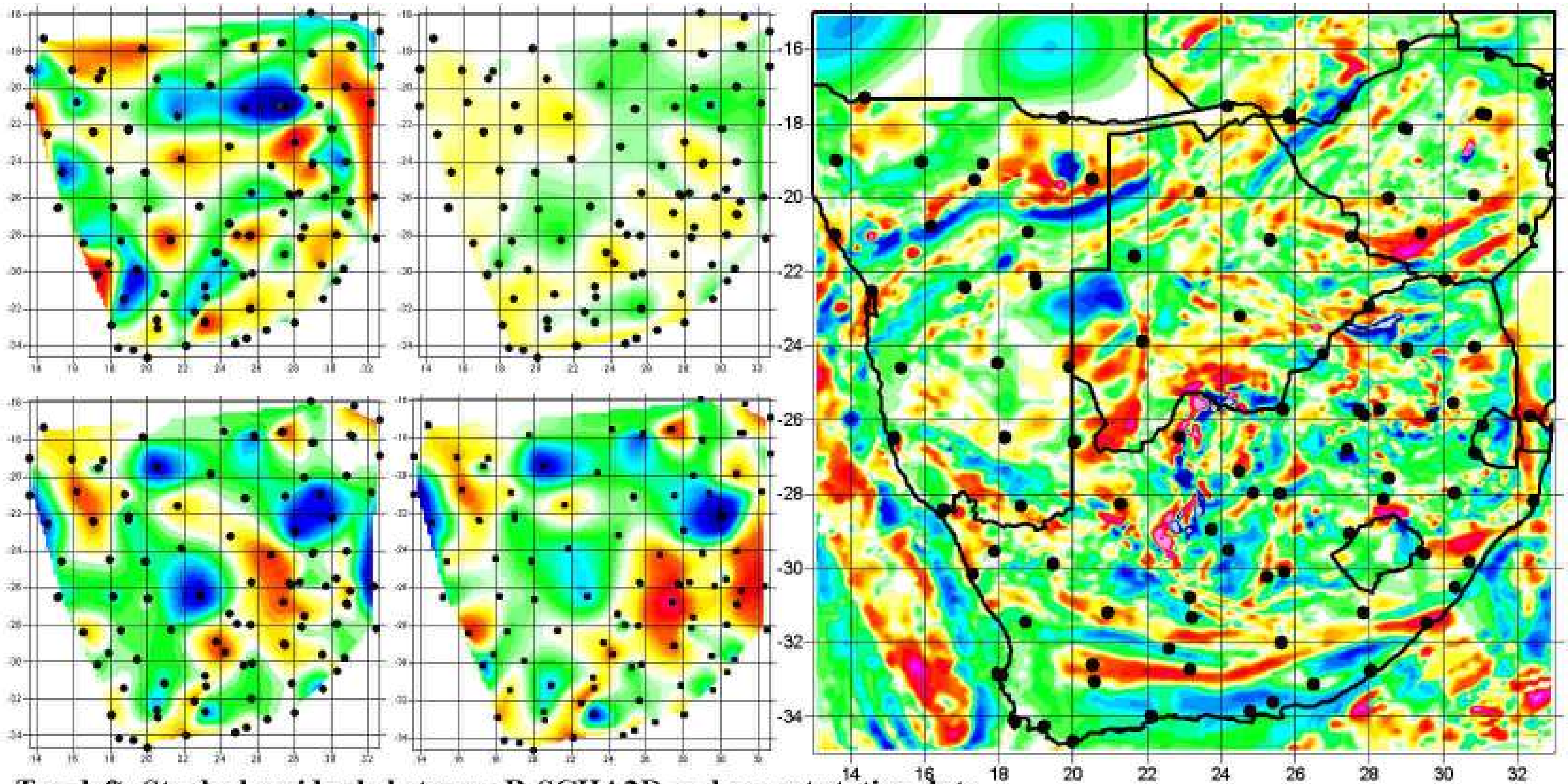
Left: Scalar values of the residuals between the R-SCHA2D model and the data.
Right: WDMAM scalar map calculated at the repeat station location only.

Direct societal applications

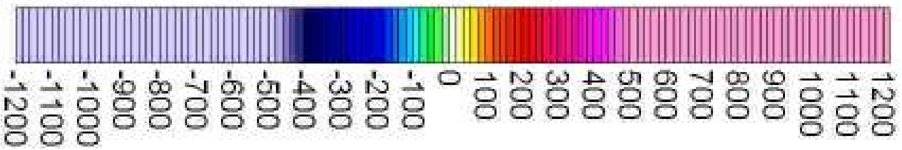
- Aeronautical navigation over South Africa.
- A main field model to reduce aeromagnetic surveys (will allow a better stitching of small-scale surveys).

- **Major limitation:** Accurate Secular variation modelling.
- The crustal field leaks into the model and creates distorted field lines outside
  - →Moving a « repeat station» introduces an artificial magnetic field secular variation caused by different crustal biases.

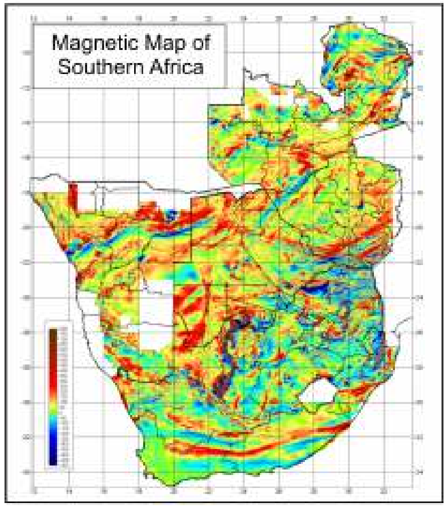
Various estimates for the large scale lithospheric field



Top-left: Stacked residuals between R-SCHA2D and repeat station data.
Top-right: Stacked residuals between MF6 (n=130) and repeat station data.
Bottom-left: Stacked residulas between NGDC720 (n=400) and repeat station data.
Bottom right: Stacked residuals between NGDC720 (n=720) and repeat station data.
Figure right: WDMAM scalar grid over the South African Continent.



Modelling our own lithospheric field



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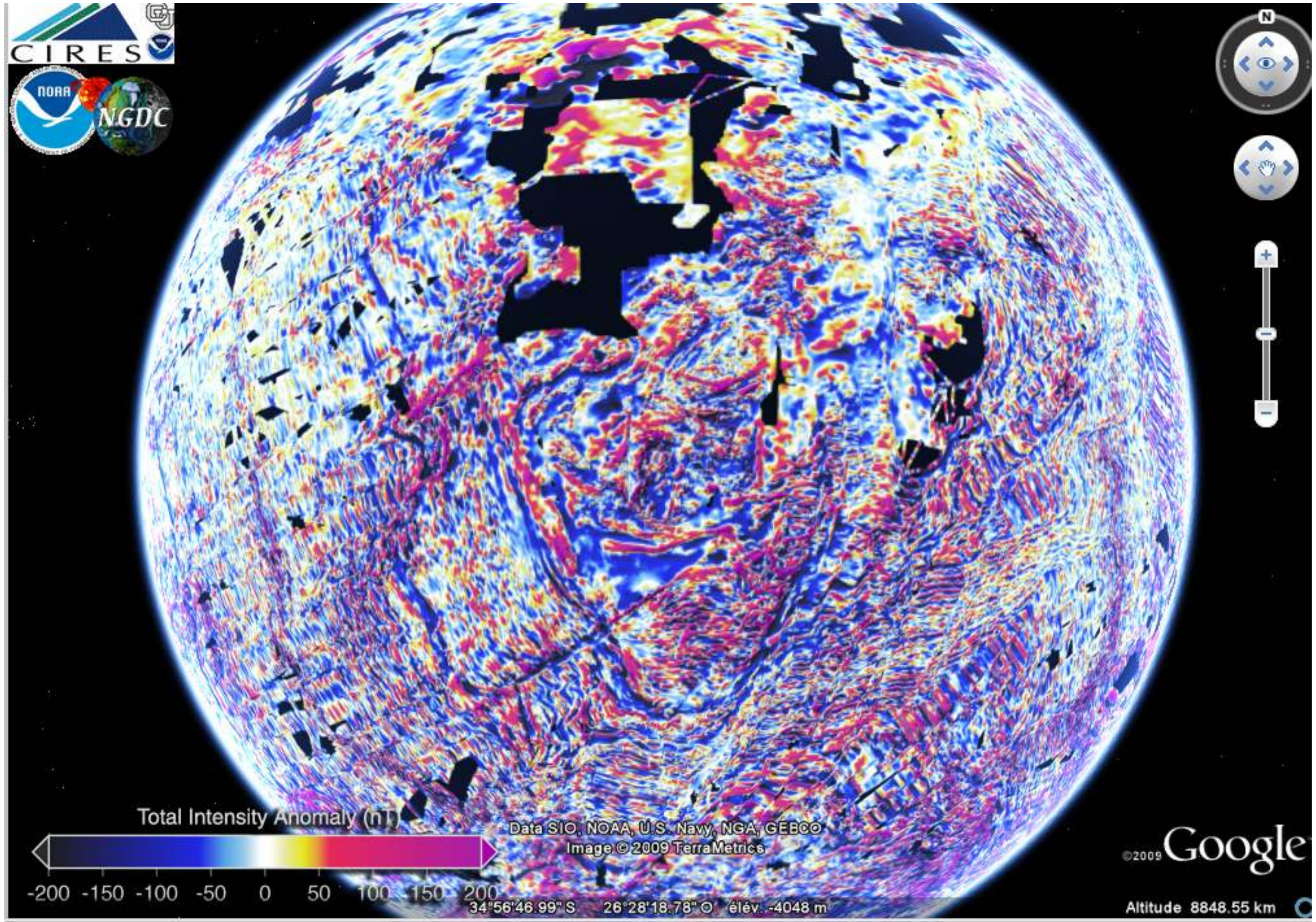
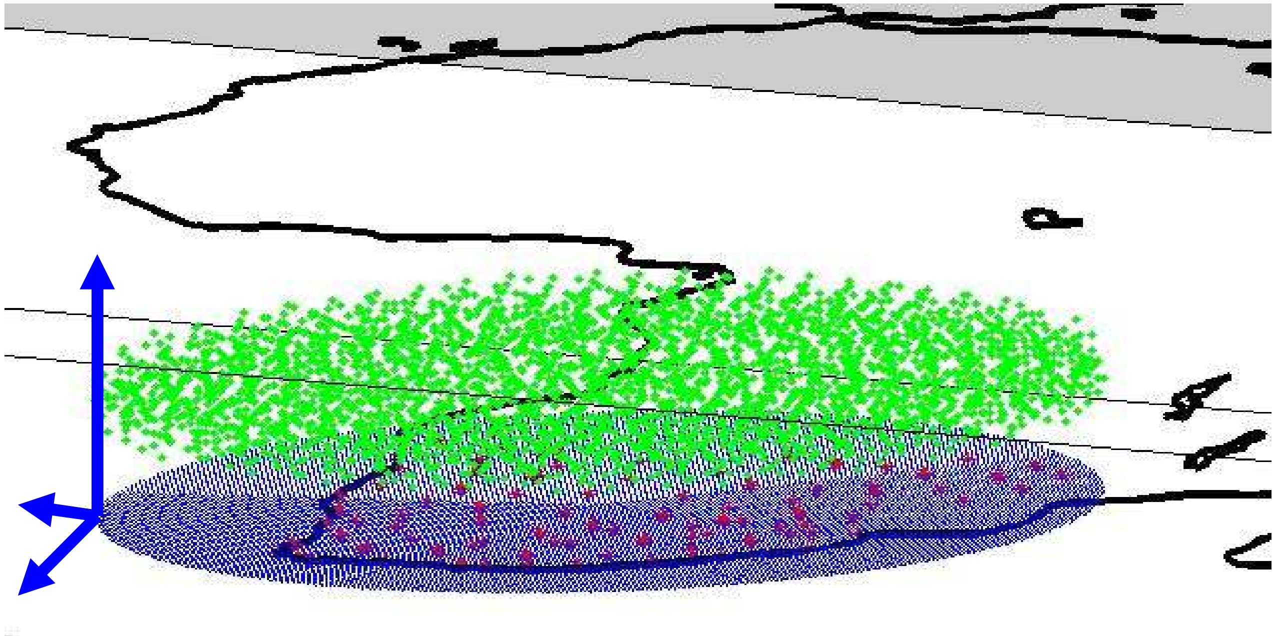


SaNaBoZi compilation

EMAG2 (Maus et al., 2009)

We use the EMAG2 grid over South Africa and Surrounding areas

Modelling our own lithospheric field



Vector repeat station

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Aeromagnetic data

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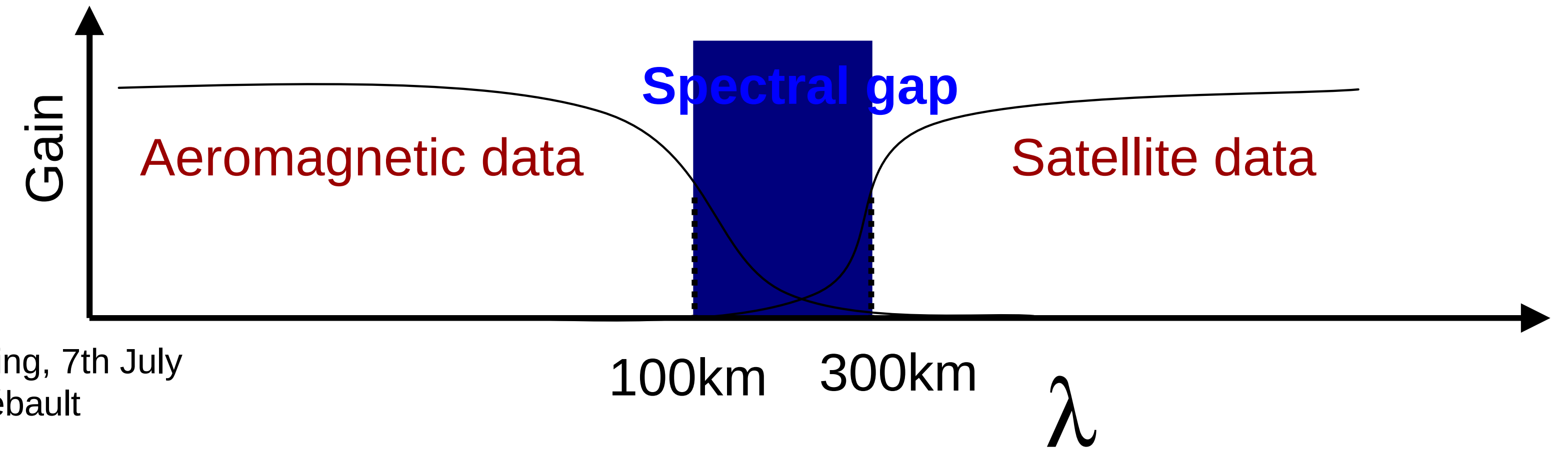
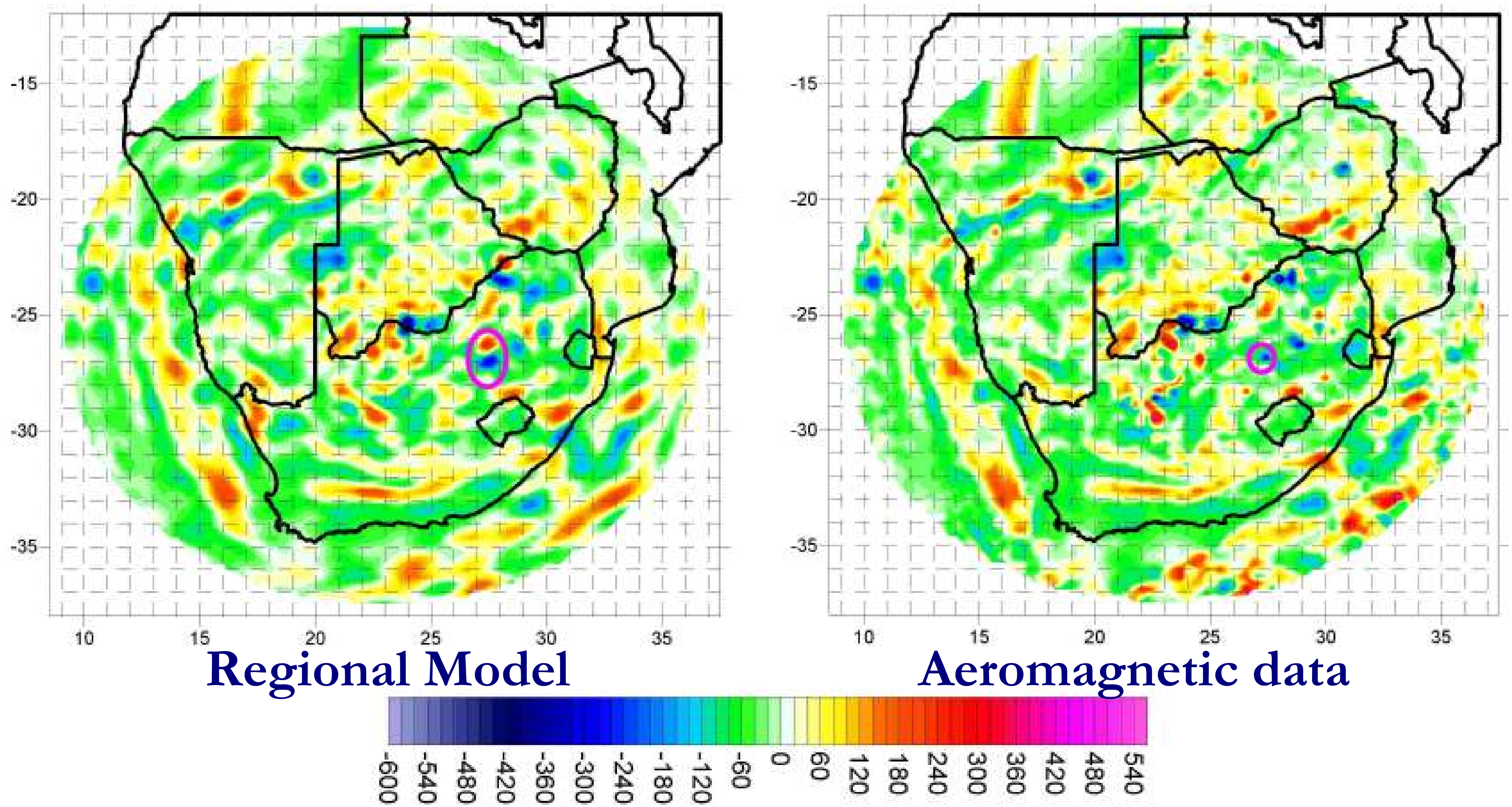
Satellite data



The regional lithospheric field model



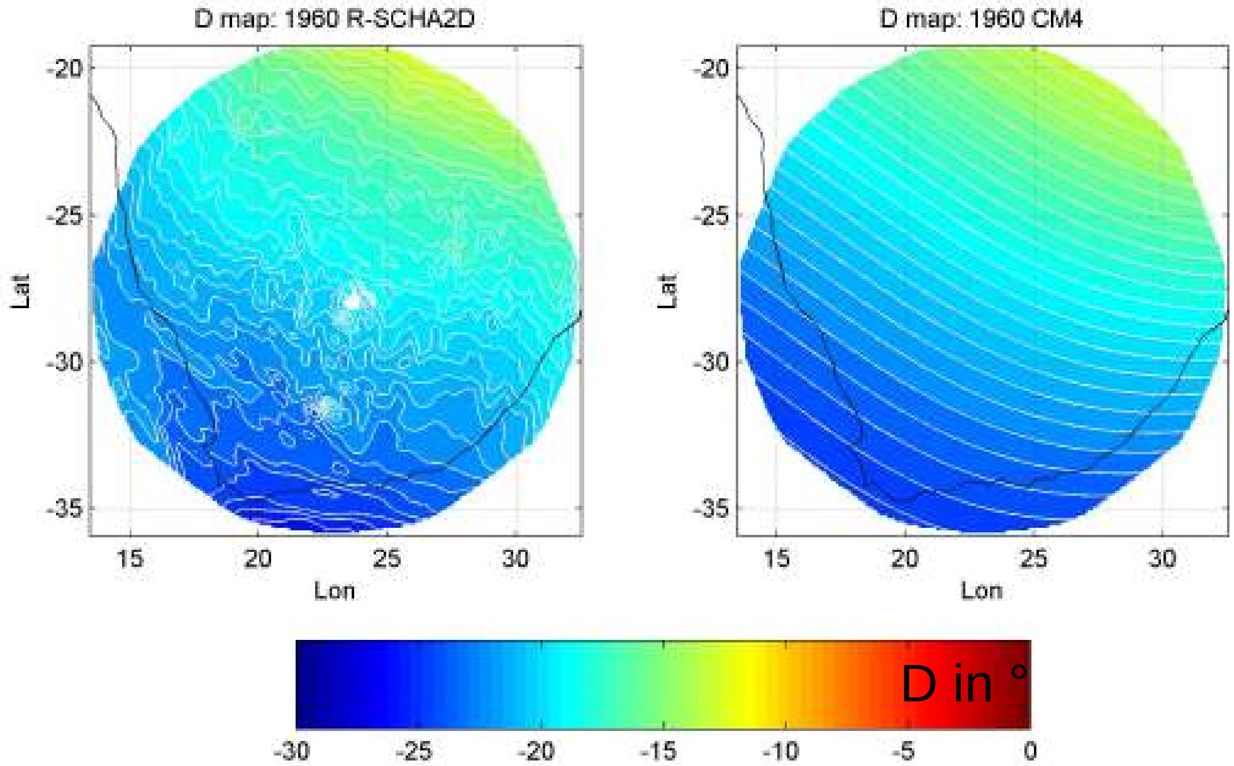
Another level of difficulty: the amount of induced versus remanent magnetization… Work in progress…

Thébault et al. In prep.

Back to the main field

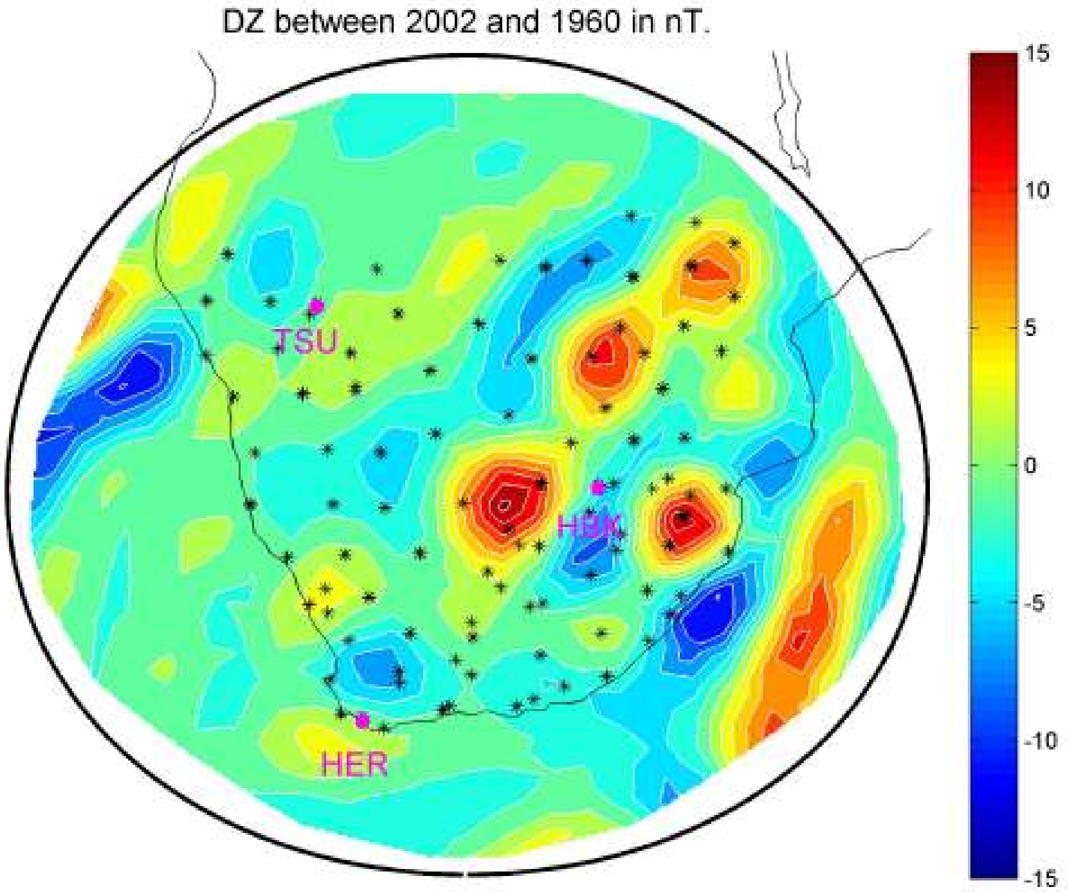
- Now that we have developped a first order lithospheric field model. We may correct Repeat station data for the crustal field… **under development**…
- But, we may also superimpose main and crustal fields to obtain an unprecedented high resolution magnetic field over the region.

Thébault et al., in prep.



Time-varying induced lithospheric field

- The lithospheric field time variation predicted over South Africa may overlap with the secular variation



Thébault et al., 2009

If repeat station data have a sufficiently good quality, we may hope to detect the time-varying signal from the lithsophere.

This, in turns, would help us asserting if the large scale lithospheric field features are induced or not.

Works under development