Magnetic Minima in Earth's Surface Modern Field

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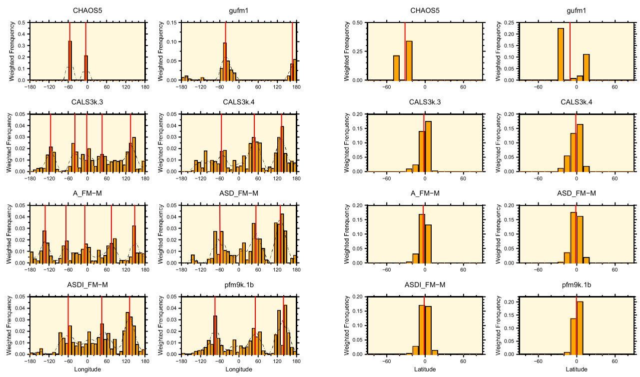
Abstract

The present day geomagnetic field is characterized by a region of weak magnetic field intensity, the so-called South Atlantic Anomaly (SAA). We investigate whether lower mantle thermal heterogeneity (see right frame) may explain the location of the SAA. We run numerical dynamos with heterogeneous core-mantle boundary (CMB) heat flux inferred from mantle tomography, varying internal control parameters and the CMB heterogeneity amplitude. Histograms of the longitude of surface intensity minima show persistent locations. The latitude histograms show southern tendency due to north-south asymmetry of magnetic flux. However, the SAA latitude is larger than that of the surface intensity minima in the dynamo models.

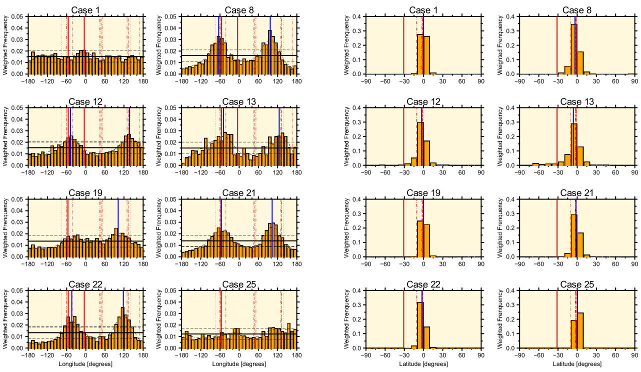
Local minima of surface intensity

Modern, historical and archeomagnetic models: Analyze of geomagnetic field models over various timescales and the construction of histograms of the recurrence of intensity minima and their peaks (red lines).



i. Three persistent longitudes.
ii. Mid-latitudes in historical and modern models.
iii. Equatorial in archeomagnetic models.

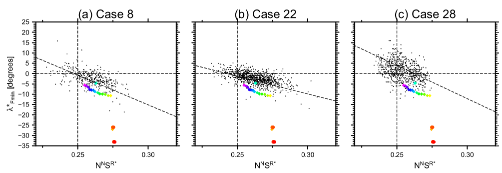
Numerical Dynamos
We then analyze a set of dynamo models using the code MagIC 5.6[6]. In all models we impose a CMB heat flux based on seismic tomography of the lowermost mantle, except some homogeneous models (e.g. case 1) that serve as references. The peaks of dynamo models histograms are in blue lines.



i. The recovery of SAA longitude suggestive of mantle control.
ii. Equatorial location suggests anomalous present-day SAA latitude.

Role of reversed and normal flux

We explain the surface minima latitude with hemispherical asymmetry of reversed and normal flux.



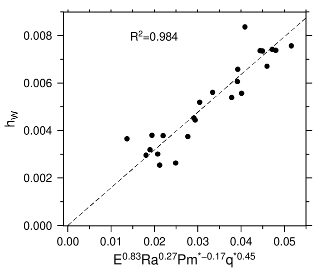
Black points are dynamo models snapshots. Colored diamonds and circles represent the results for the geomagnetic field models gufm1 and CHAOS5, respectively.

(i) Linear fit to dynamo snapshots is in agreement with geomagnetic field at most times, except for the last 30 years.
(ii) Evidence of anomalous present-day field at the Southern Hemisphere.

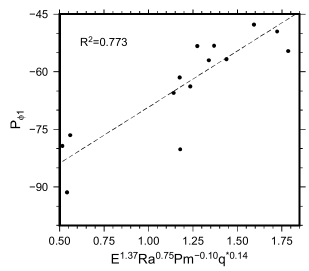
- λ^*_{Fmin} - The weighted averaged latitude of the intensity minima.
- S^R - the portion of Southern Hemisphere reversed flux contribution to ADM normalized by the reversed flux over the entire CMB.
- N^N - the portion of Northern Hemisphere normal flux contribution to ADM normalized by the normal flux over the entire CMB.
- When the distributions of the two types of fluxes are balanced ($N^N S^R = 0.25$) the surface intensity minima are at the equator ($\lambda^*_{Fmin} = 0$).
- More reversed flux in the southern hemisphere and more normal flux in the northern hemisphere gives more southern surface intensity minima.

Scaling laws

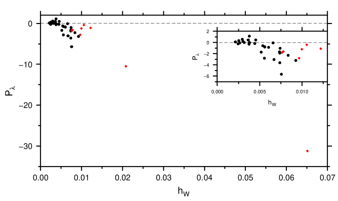
Left: Typical height h_W, which measures the persistence of surface intensity minima peaks. **Middle:** Longitude of Western peak of local minima of surface intensity. **Right:** Persistent latitude of intensity minima versus the typical height h_W. Black circles are dynamo models, red diamonds are geomagnetic field models.



Stronger rotation effects ≈ uniform longitudinal distribution minima. Persistent longitudes of surface minima arise when convection and especially when boundary heterogeneity are increased.



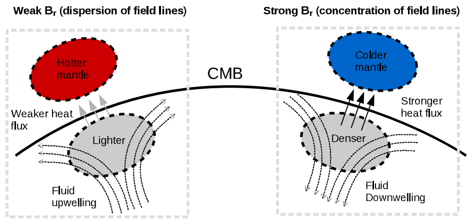
Surface minima are shifted westward when rotation is faster, convection is weaker and the boundary heterogeneity is weaker.



The southern latitude of the surface minima P_λ is correlated with persistence of surface minima longitudes h_W in dynamo models.

Core-mantle coupling

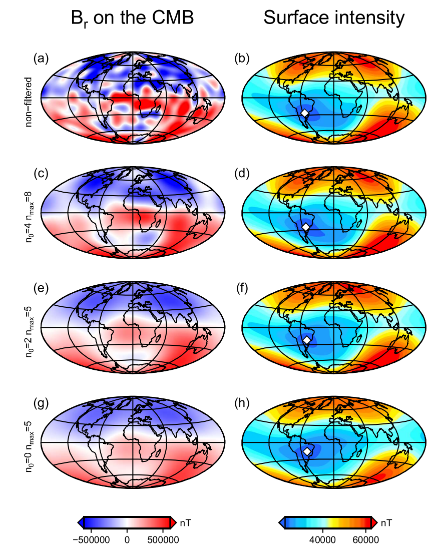
Thermal core-mantle interactions may affect the convection pattern of the outer core and thus the morphology of the Earth's magnetic field[1].



The SAA is related to prominent geomagnetic flux patches on the CMB[2], which may be mantle-controlled[3,4]. Thus the SAA may also be mantle controlled. We explore whether numerical dynamos with a tomographic[5] CMB heat flux pattern can reproduce persistent locations of surface intensity minima as observed in geomagnetic field models.

Resolution test

One possible reason for the discrepancy of latitude could be the low resolution of archeomagnetic field models. We perform a resolution test with a modern field filtered to a resolution even lower than archeomagentic field models.

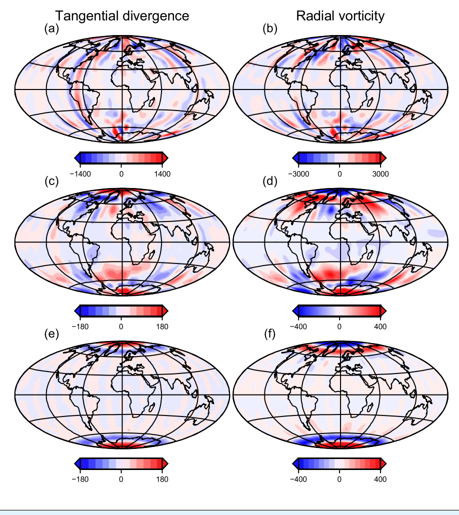


Filtered radial geomagnetic field model CHAOS5 in 2003 at the CMB (left) and intensity at Earth's surface (right) with local intensity minima denoted by white diamonds. Spherical harmonic degrees n_0 and n_{max} indicate the low-pass filtering limits.

Test shows that equatorial location of surface minima is not related to resolution issues.

Flow and outer boundary heat flux

Tangential divergence (left) and radial vorticity (right) at the top of the free stream just below the Ekman boundary layer for a snapshot of a heterogeneous dynamo model (a and b), time-average of the same dynamo model (c and d) and time-average of a homogeneous dynamo model (e and f).



Mantle-driven upwelling below the SAA region (c).

References

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[6] https://magic-sph.github.io/.