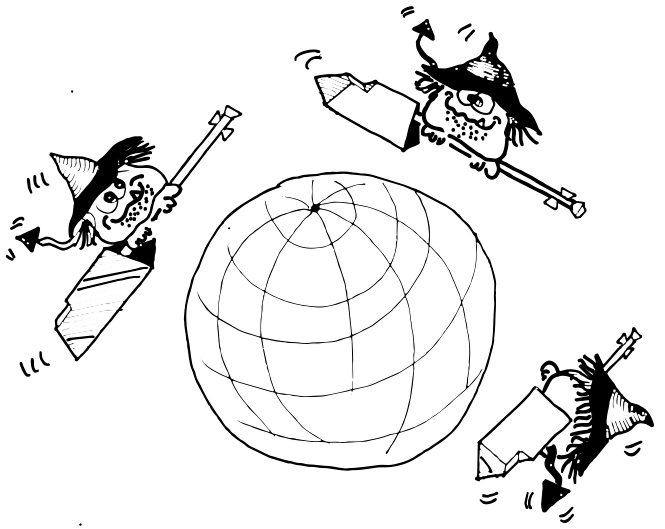
Recommendation for future studies - the Swarm perspective



Nils Olsen
DTU Space

SLIM: Swarm magnetic gradients for lithospheric modelling

- Direct estimate of the different gradient tensor elements from Swarm magnetic data remains difficult
- Much improved signal-to-noise ratio from constrained estimate, based on the physics of the signal (and noise):
  Estimate gradient tensor that is compatible with a Laplacian Potential of internal (to the satellite altitude) origin
- Can be achieved as part of "geomagnetic field modeling"

- Recommendation 1: provide "stand-alone" software for computing the gradient tensor elements for a given position based on a spherical harmonic expansion (*.shc file as for the Swarm L2 products)
- Recommendation 2: new approaches to improve crustal field modeling using Swarm gradient data

The Art of Geomagnetic Field Modeling (1)

- What part of the model is defined (constrained) by the observations?
- Small-scale structure of *all* global crustal field models are regularized
  - CHAOS-6 and MF7: only part n < 75 is purely determined by observations part n = 76 – 133 is constrained by "additional information"
- But what kind of regularization ("additional information") should one use ?
  - Often used: minimization of $|Br|^2_2$ at surface (L2-norm)
  - … but also Maximum Entropy minimization of Br or L1-norm $|Br|_1$
  - None of these constrains is based on physics
- Assumption of a Laplacian Potential Field of internal origin is only physics-based constrain

The Art of Geomagnetic Field Modeling (2)

Important ingredients for efficient field modeling:

- Account for data signal content as much as possible
  - … by data selection
  - … and by model co-estimation
- Account for non-Gaussian data errors (robust data processing)
- Model regularization: which norm, which quantity to regularize?

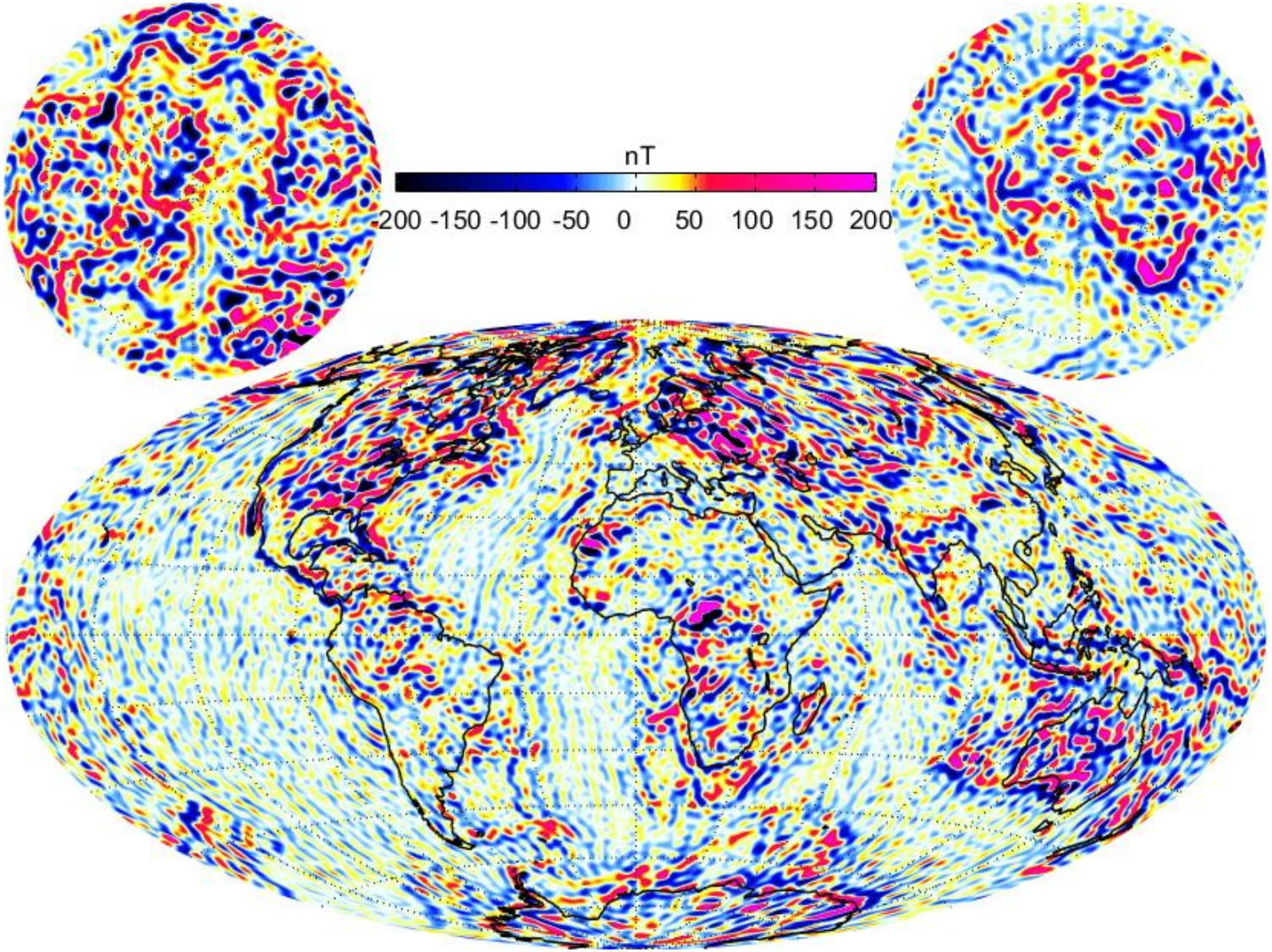
A New Lithospheric Field Model:
Some Preliminary Results

- CHAMP scalar and vector fields
  scalar and vector alongtrack gradients
- Same dataset as for CHAOS-6
  - 15 sec values, geomagnetic quiet conditions
- Removal of CHAOS-6 core field (n up to 15) and magnetospheric field (parameterized by RC-index)
- Crustal field is parameterized by 35.000 "point sources" (monopoles) located 100 km below surface
- **Model regularization**: minimize $|B_r|_1$ (i.e. L1 norm) at surface (ellipsoid)
- **Data misfit**: minimize Huber-weighted (i.e. robust) data misfit

- Finally step: Representation of monopole field Model by spherical harmonics up to n = 185

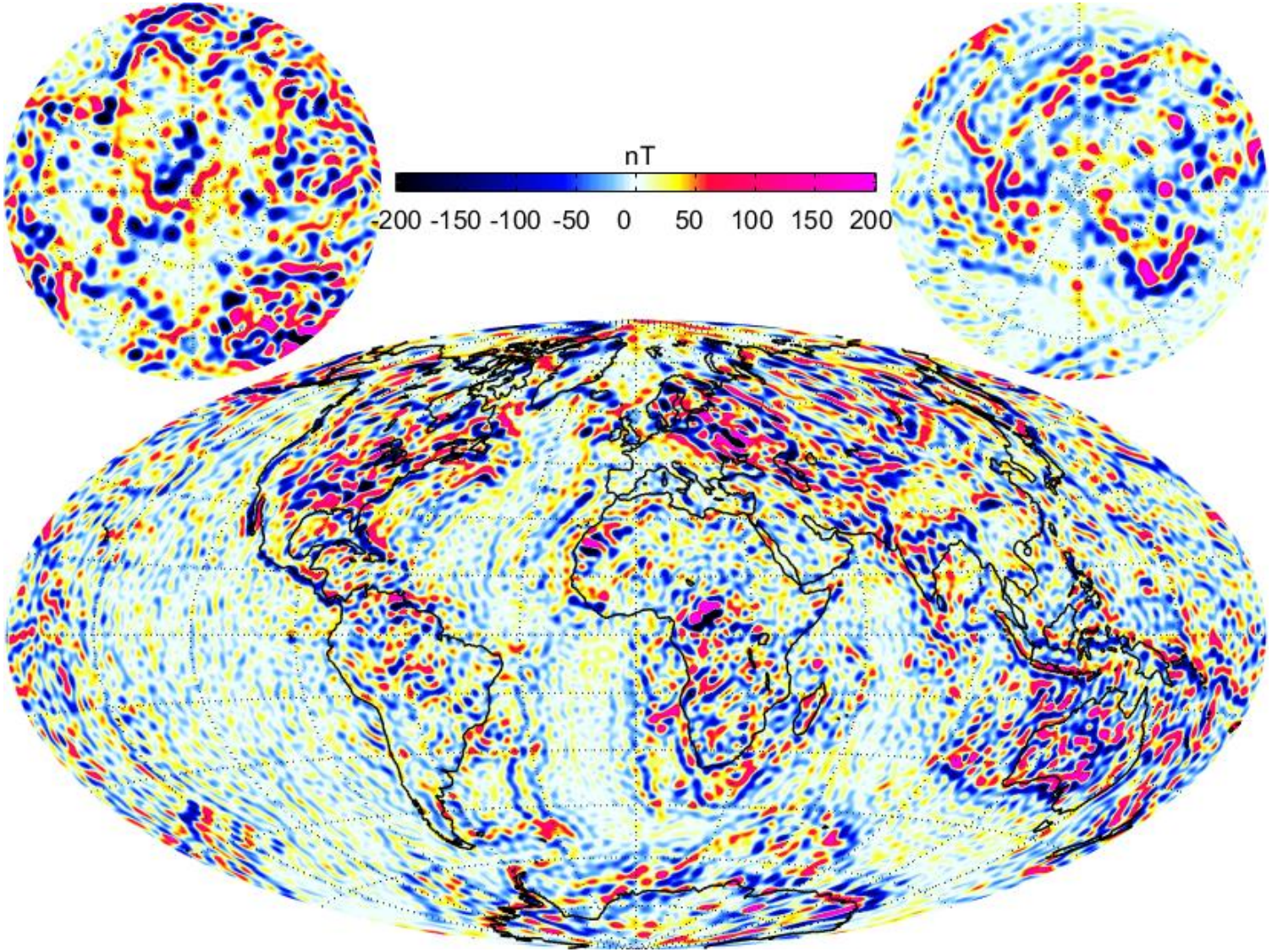
MF7

Br at Earth's surface (n = 16 – 133)



L1 Model

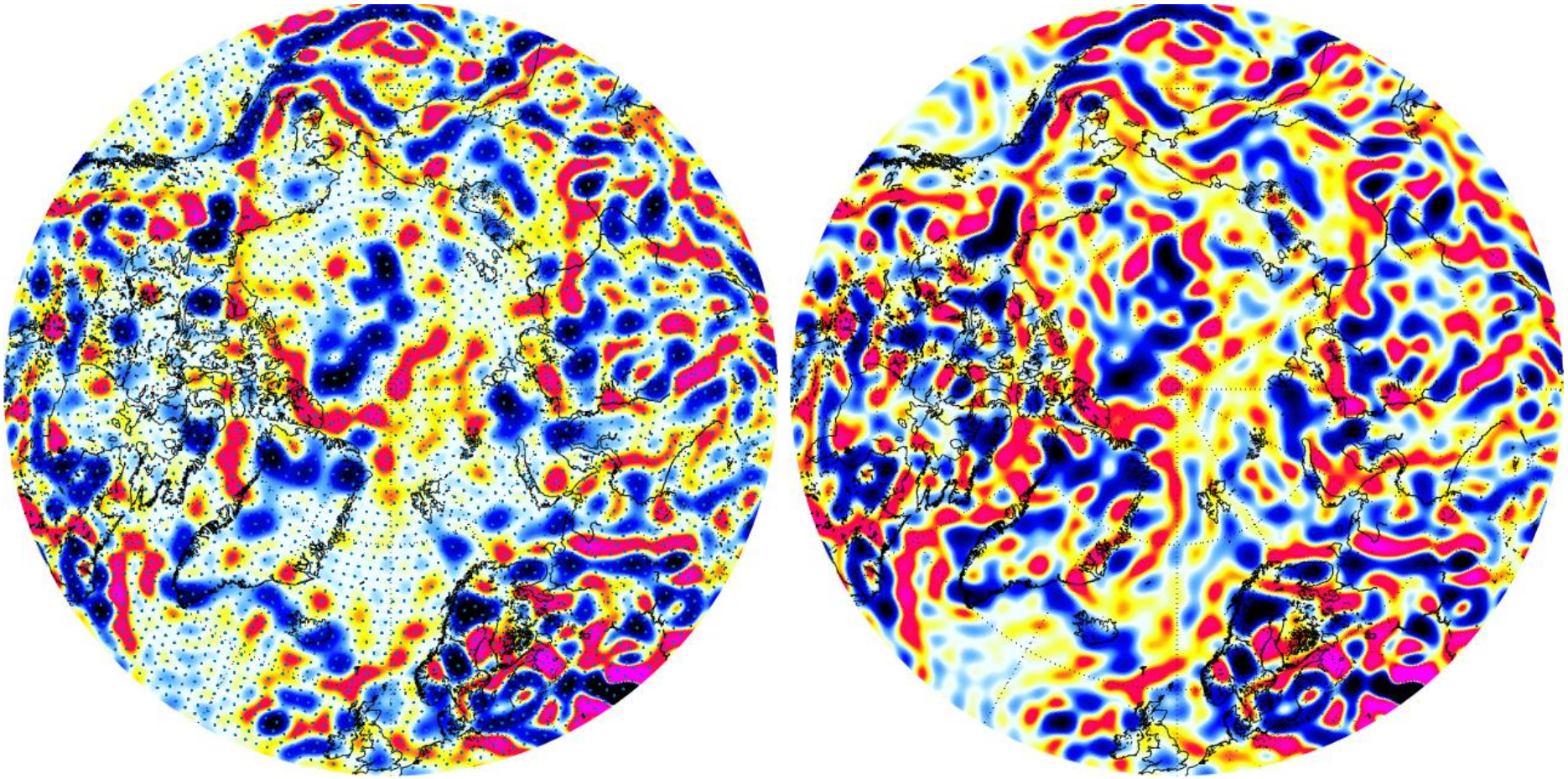
Br at Earth's surface (n = 16 – 133)



Br at Earth's surface (n = 16 – 133)

L1 Model

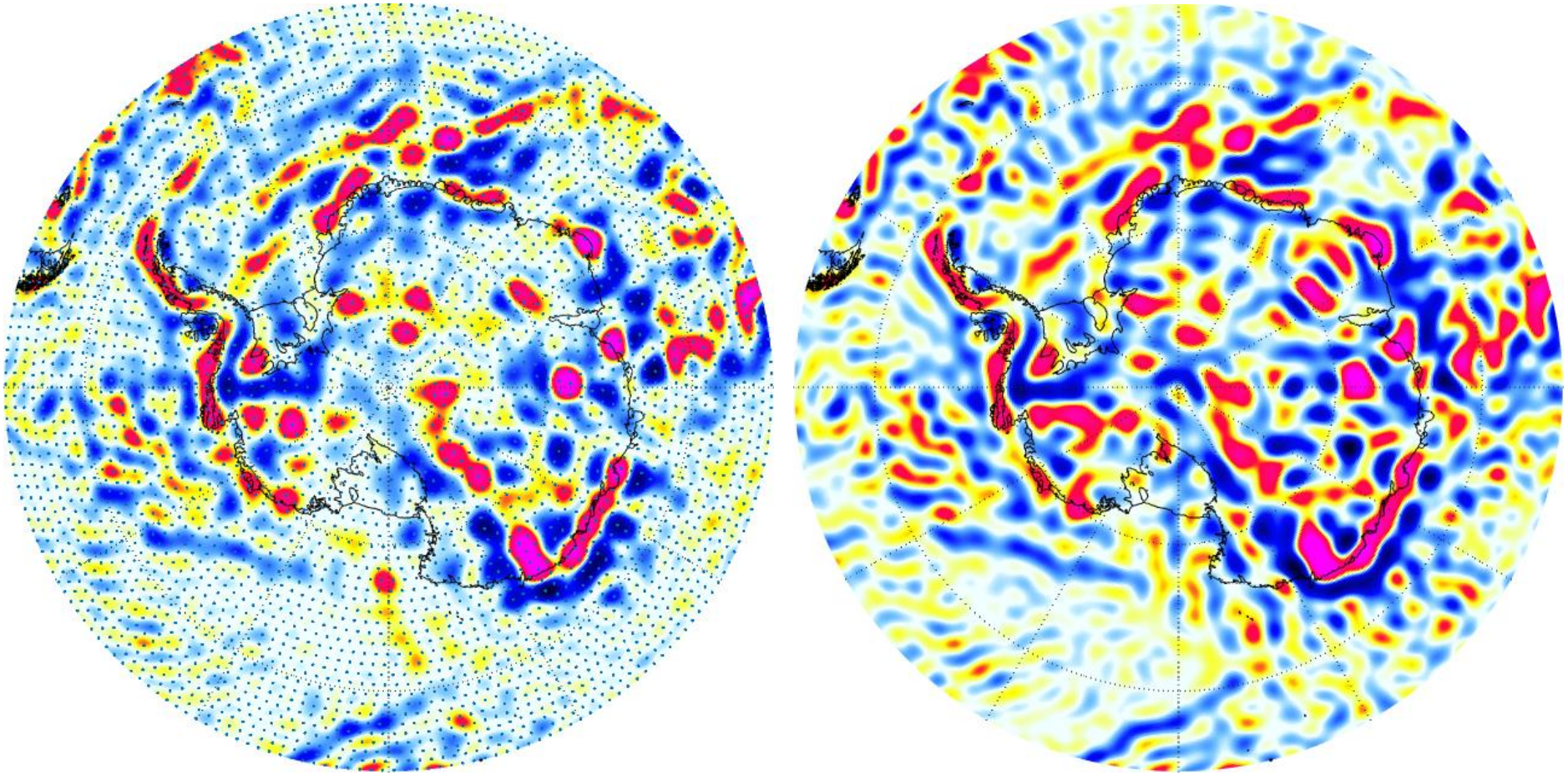
MF7



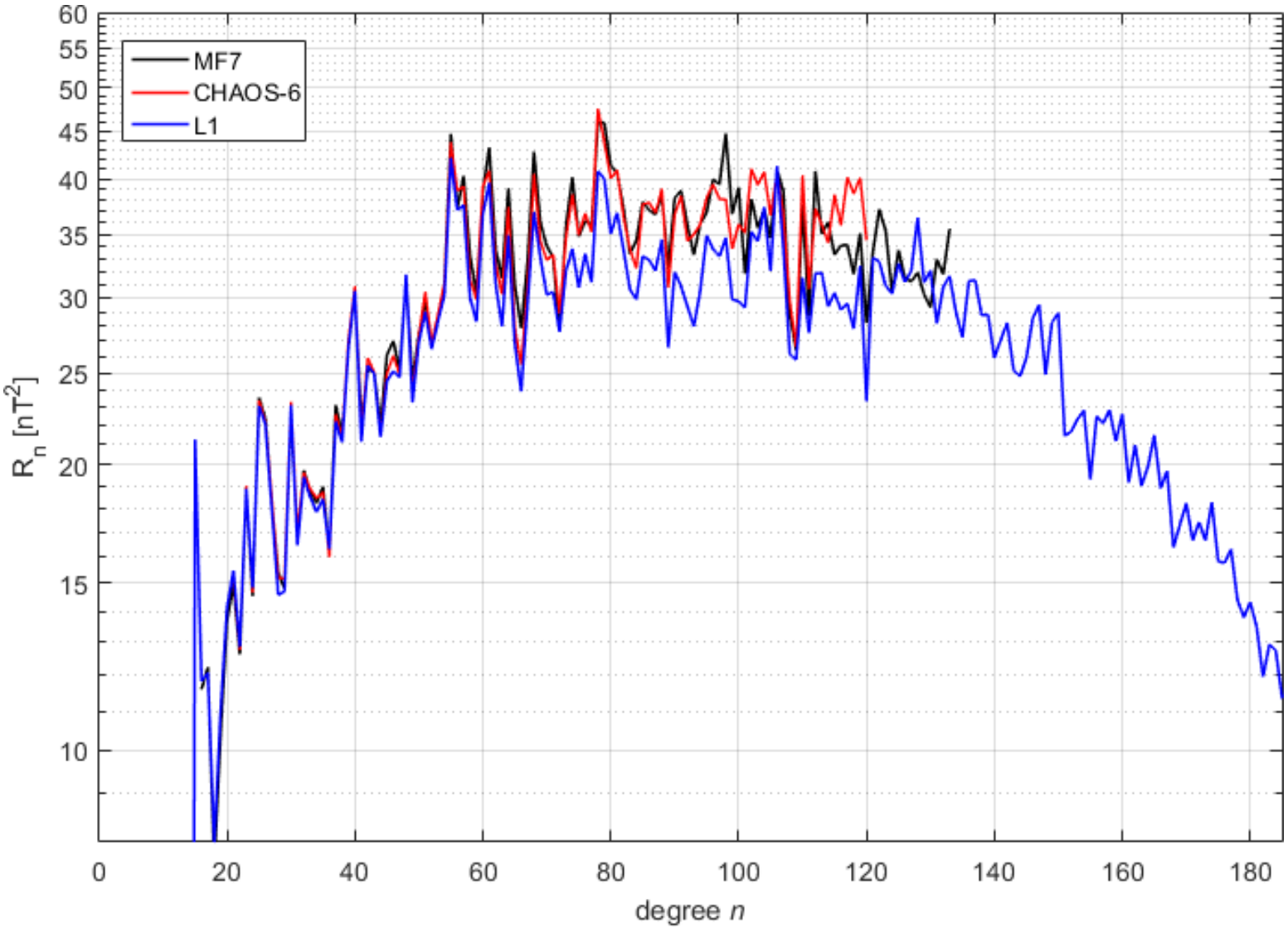
Br at Earth's surface (n = 16 – 133)

L1 Model

MF7



Powerspectra (Earth's surface)



Note: Powerspectrum is a quadratic quantity, which is in favor of L2-regularized models

Back to Swarm …

- Swarm East-West gradient (difference Alpha – Charlie) turned out to be very beneficial for crustal field and core SV determination
- … as shown in SIFM (n = 1 – 70) and SIFMplus (n = 1 – 80)
- … and by Swarm End-To-End mission simulation (n = 1 – 155)

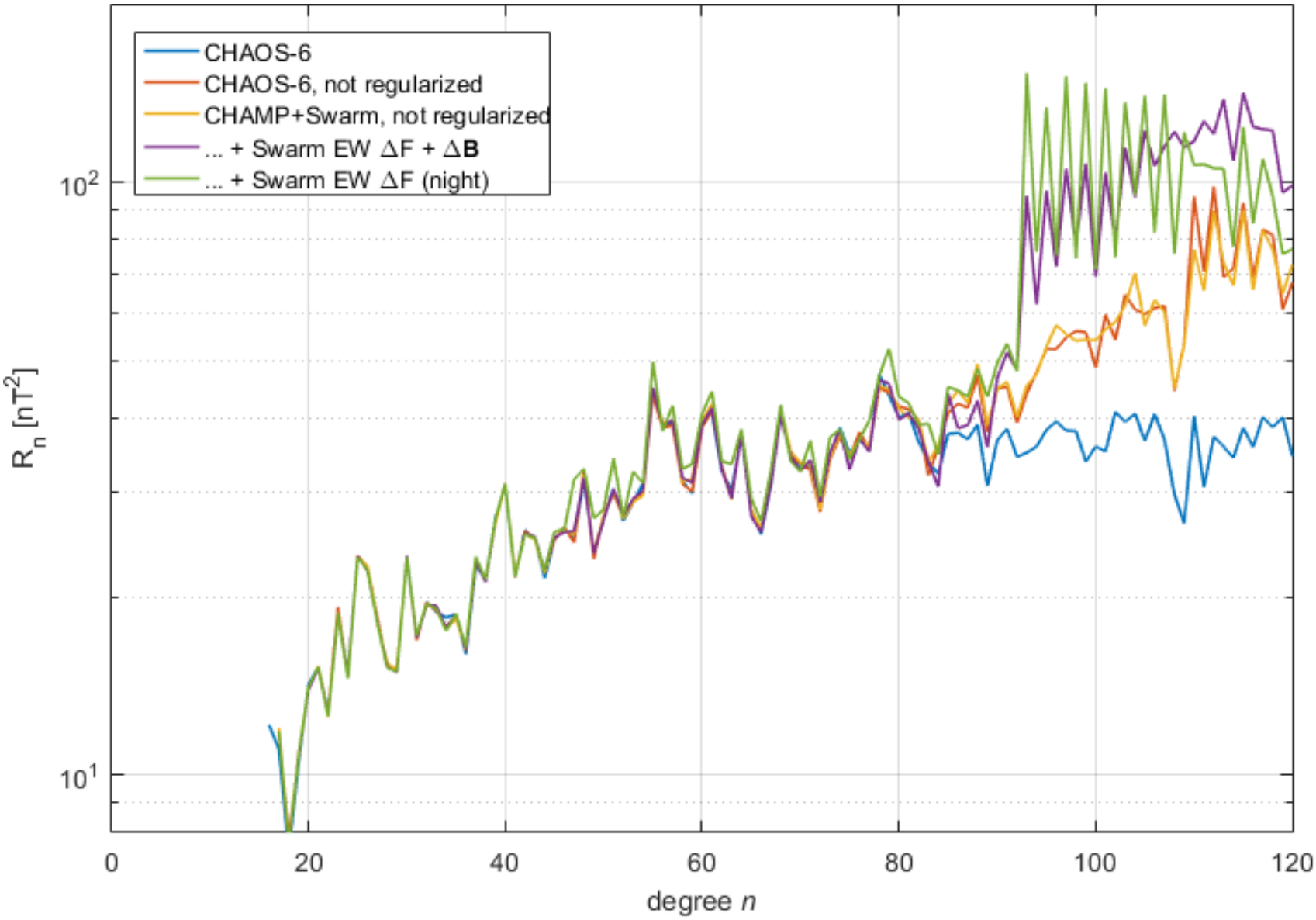
- But what happens at higher degrees ?
- Requires looking at non-regularized crustal field models

In following some very preliminary results

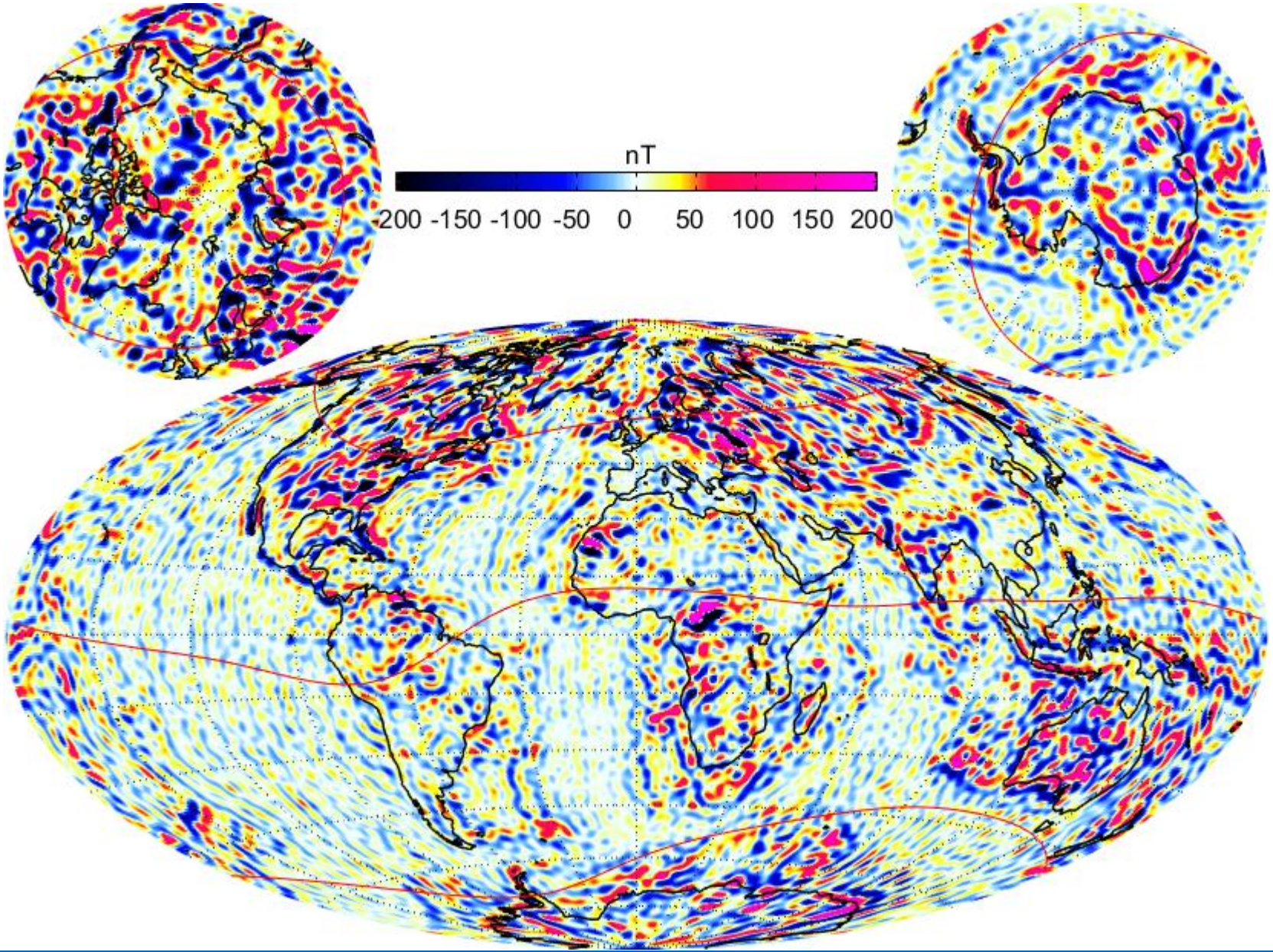
They need (and will) to be checked using an independent approach (ongoing, with NASA/GSFC)

If confirmed, they may have impact on Swarm operation (East-west separation of Alpha and Charlie)

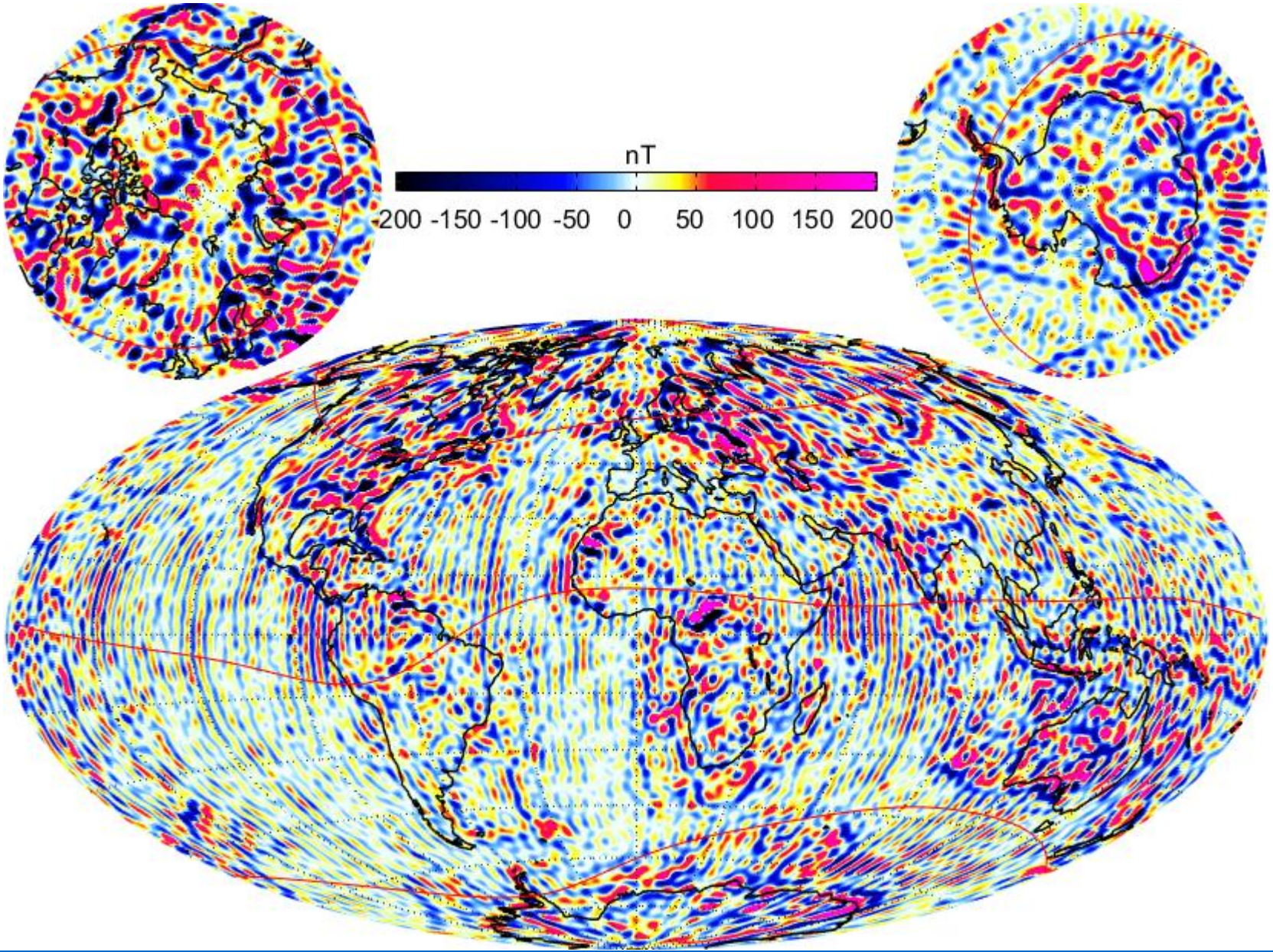
More Powerspectra ...



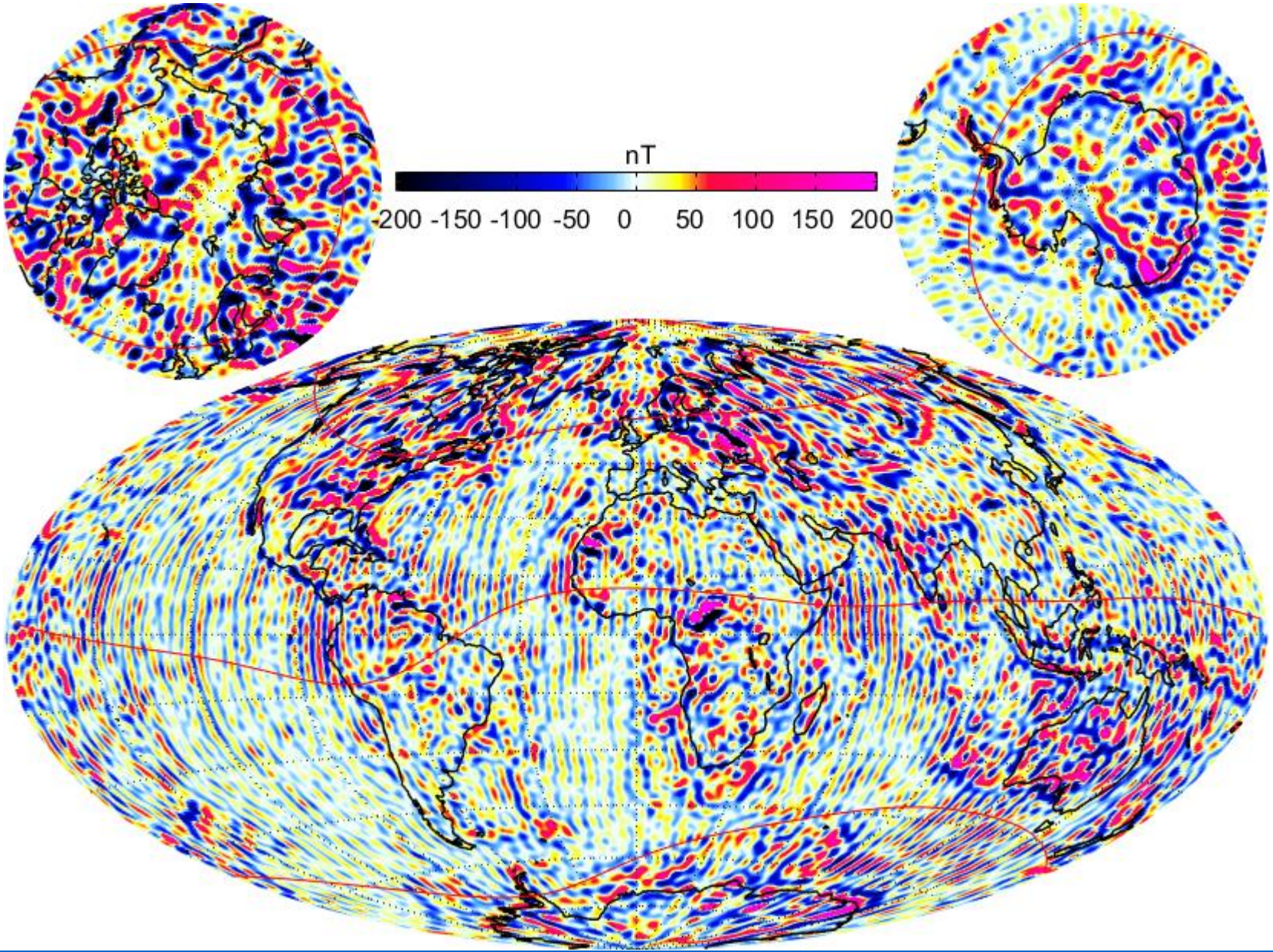
CHAOS-6



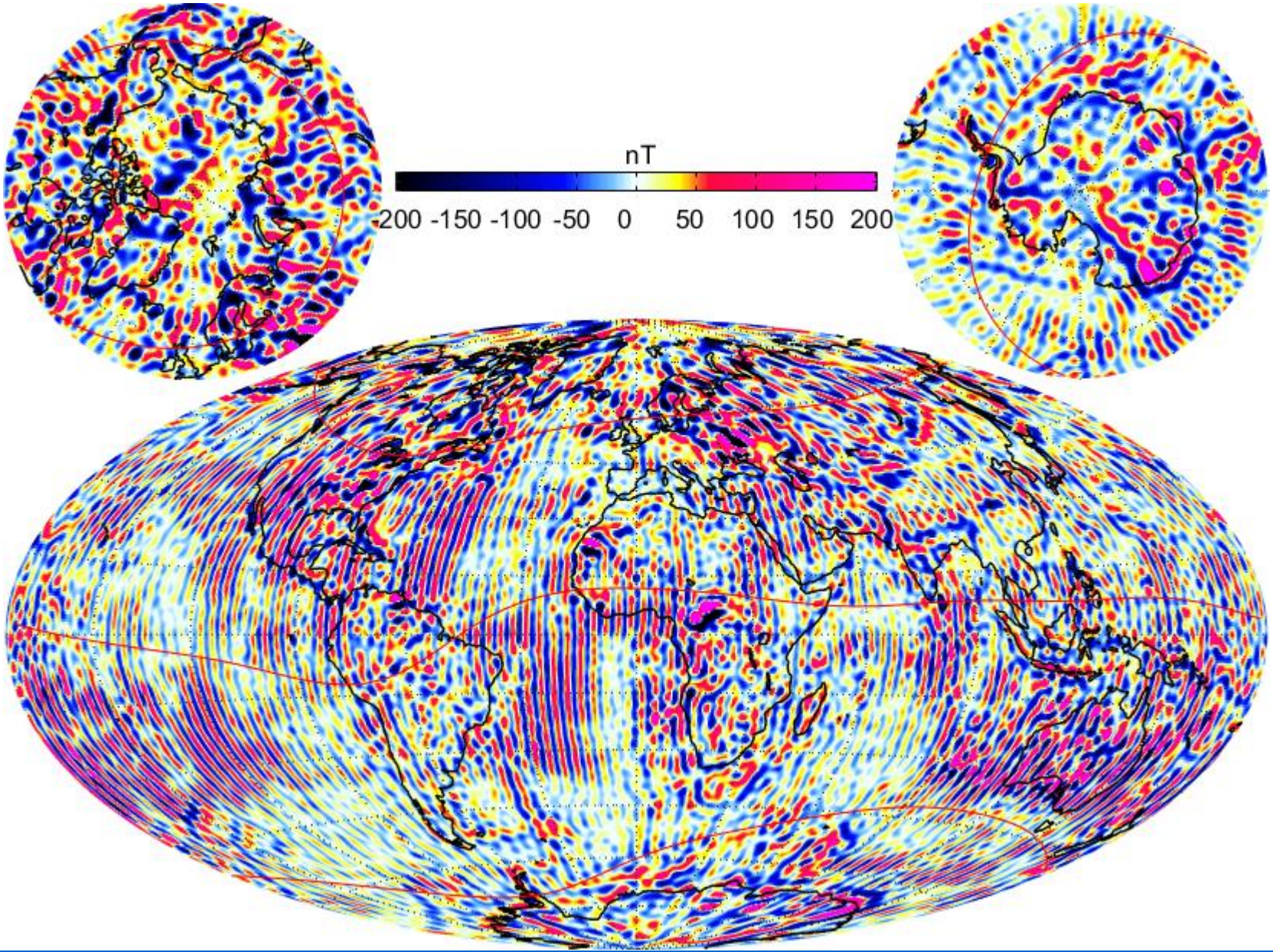
CHAOS-6 not regularized



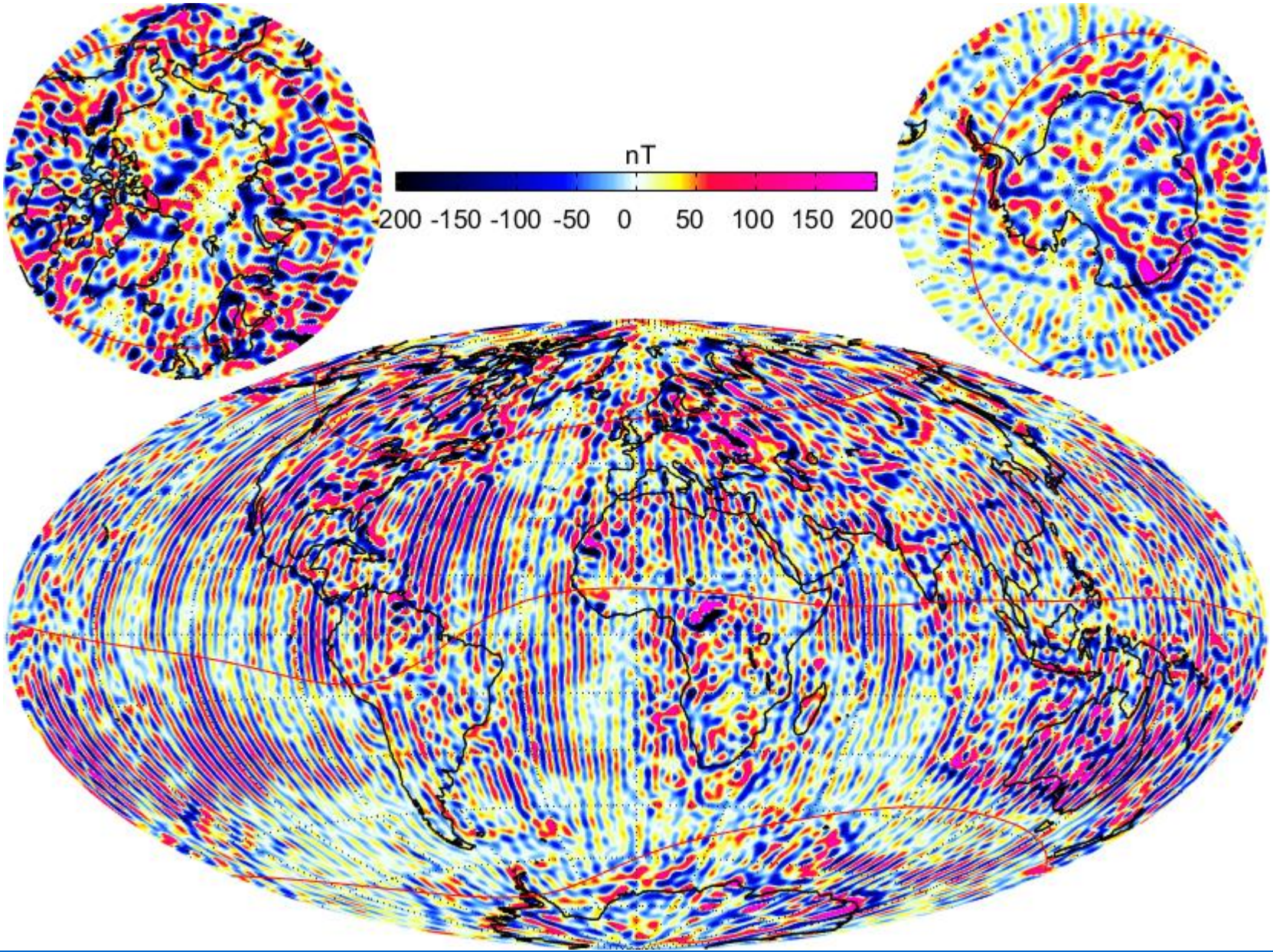
CHAMP + Swarm, not regularized



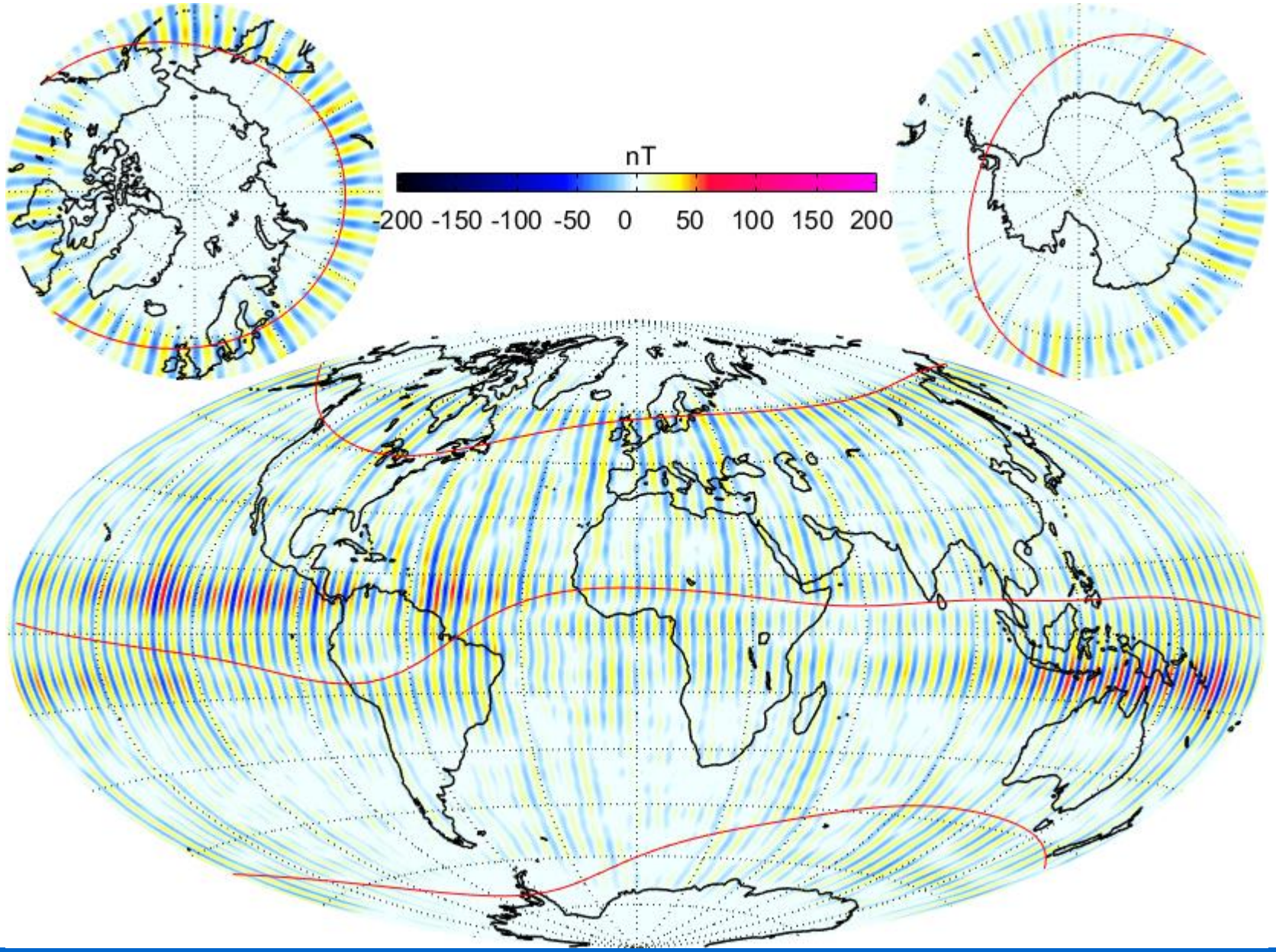
CHAMP + Swarm + EW *F* + B



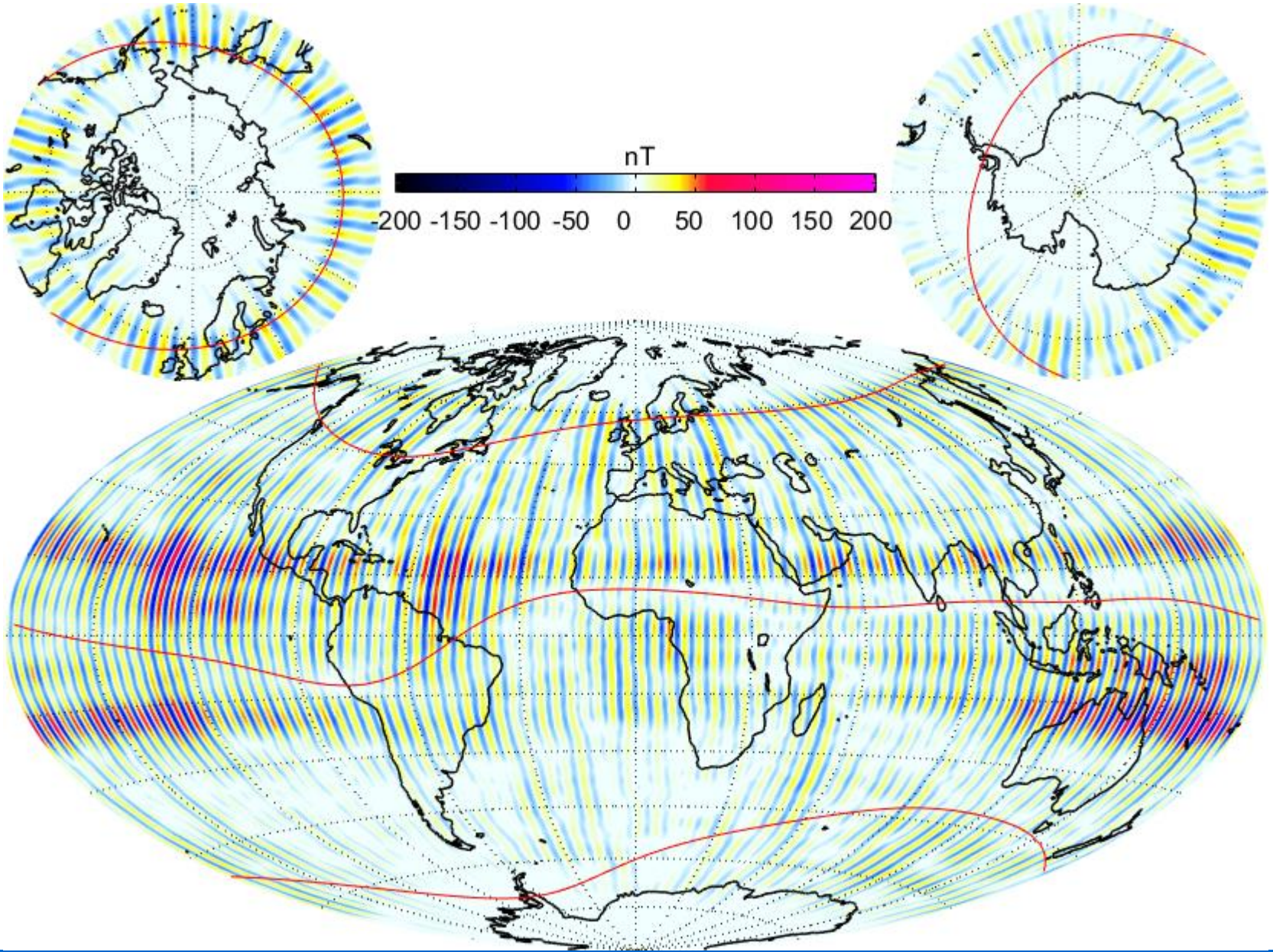
CHAMP + Swarm + EW F (only night)



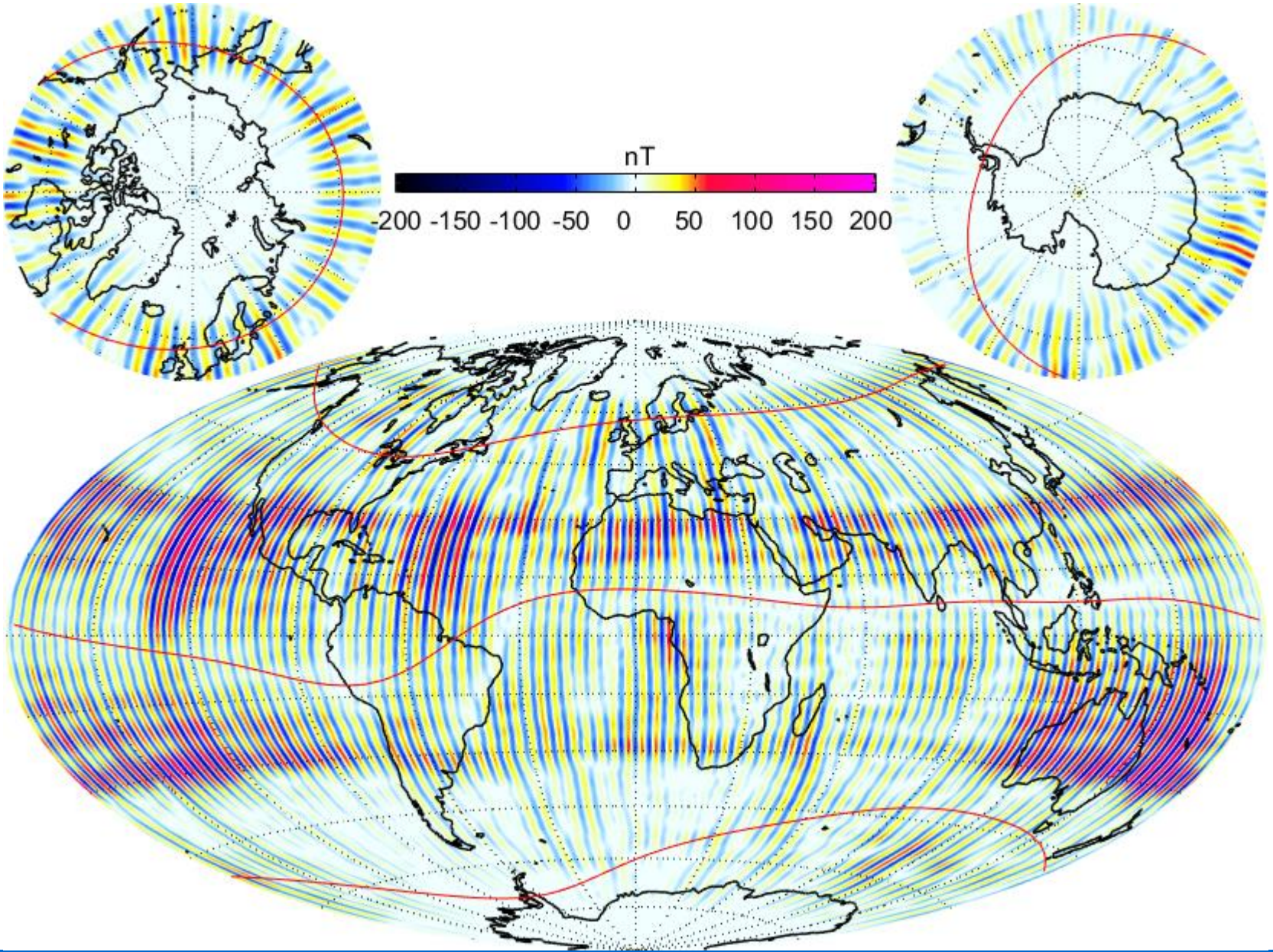
Difference of model with and w/o EW gradient, n < 95



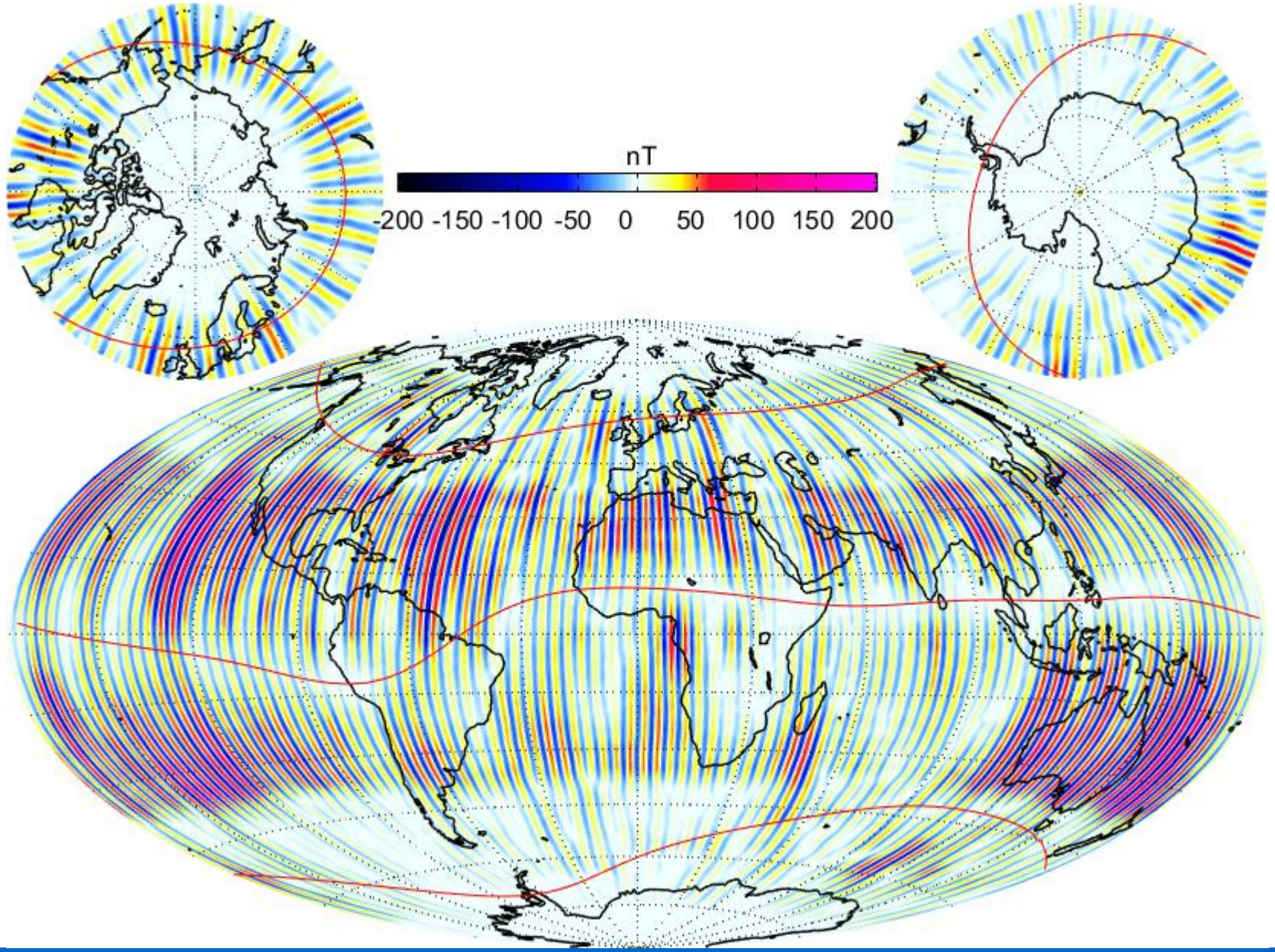
Difference of model with and w/o EW gradient, n < 100



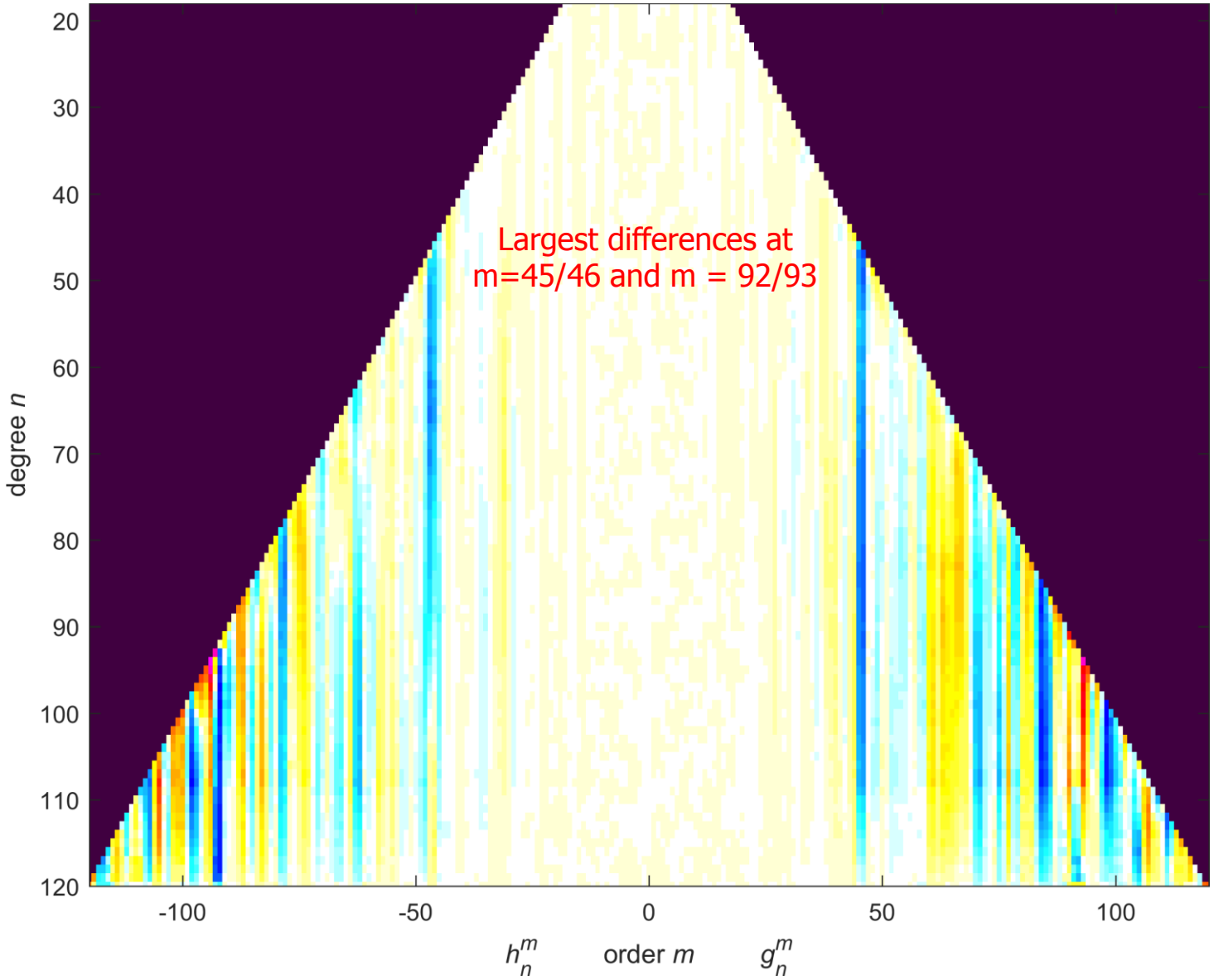
Difference of model with and w/o EW gradient, n < 110



Difference of model with and w/o EW gradient, n < 120



Normalized model coefficient difference

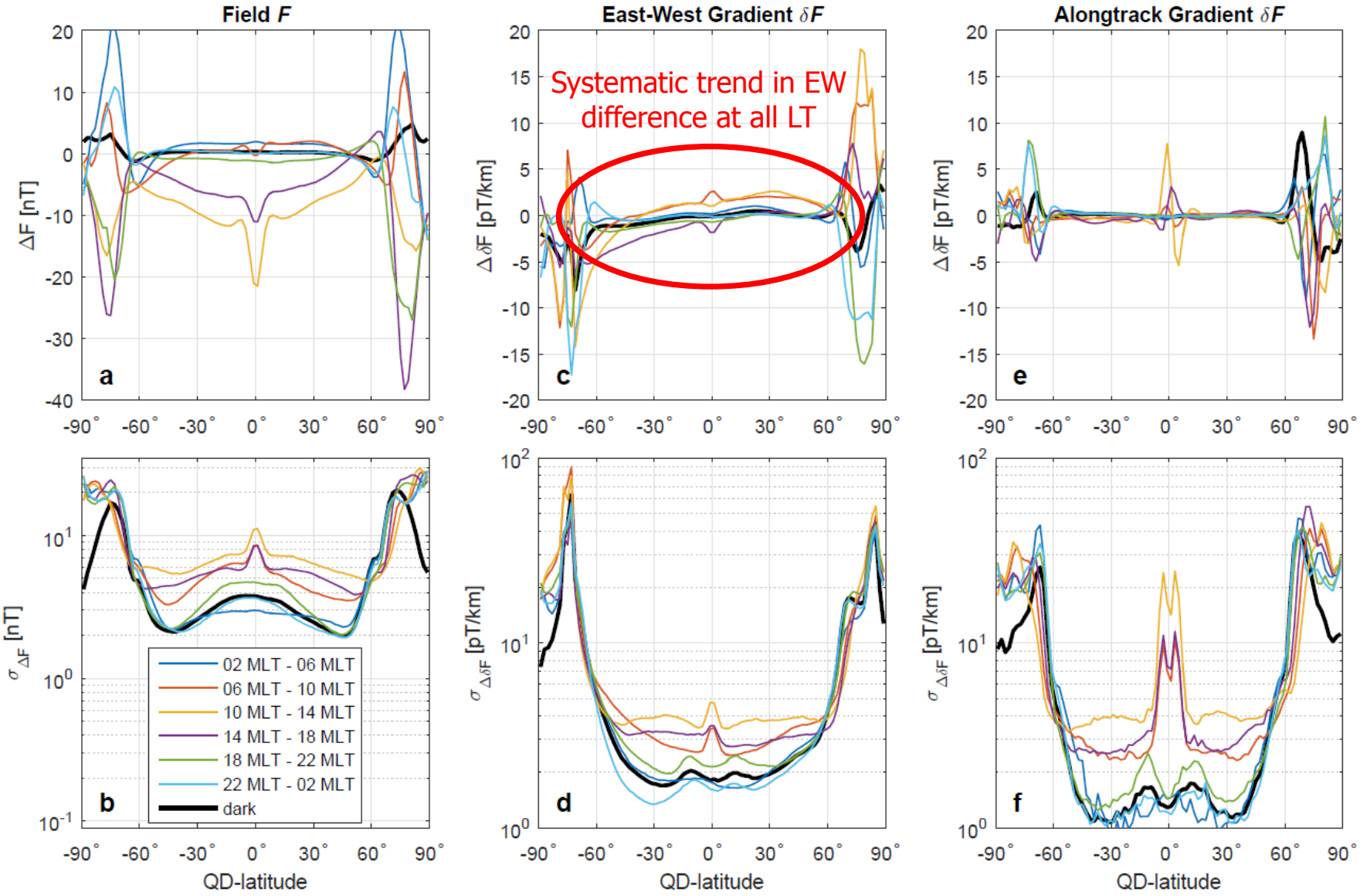


Impact of the observed EW difference ?

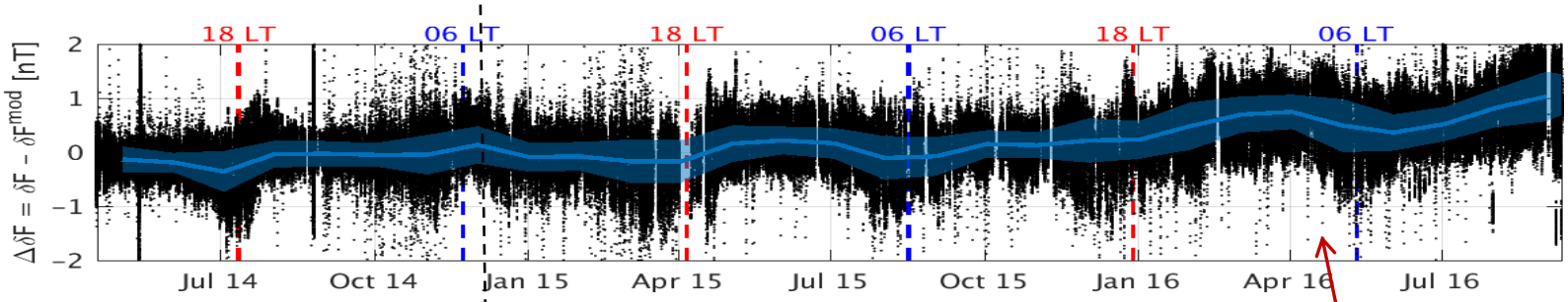
- Non-modeled EW difference signal (or noise?) contaminates estimates of high order m crustal terms
  (large *m* = large EW gradients)
- The higher degree n, the more poleward disturbance structure correlation length of unmodeled EW gradient contributions?
- Caused by systematic difference between Alpha and Charlie?
  … but obviously no effect in polar regions (no instrument or s/c effect?)
- Or by some correlated unmodeled signal ?
  What is the spatial correlation length of ionospheric signals in East-West direction?

Mean value and scatter of *F*

after removal of core, crust and magnetospheric model values



$\Delta\delta F = \delta F_A - \delta F_C$, $\delta F = F_{obs} - F_{mod}$



270 pT rms
$F = F_{ASM}$

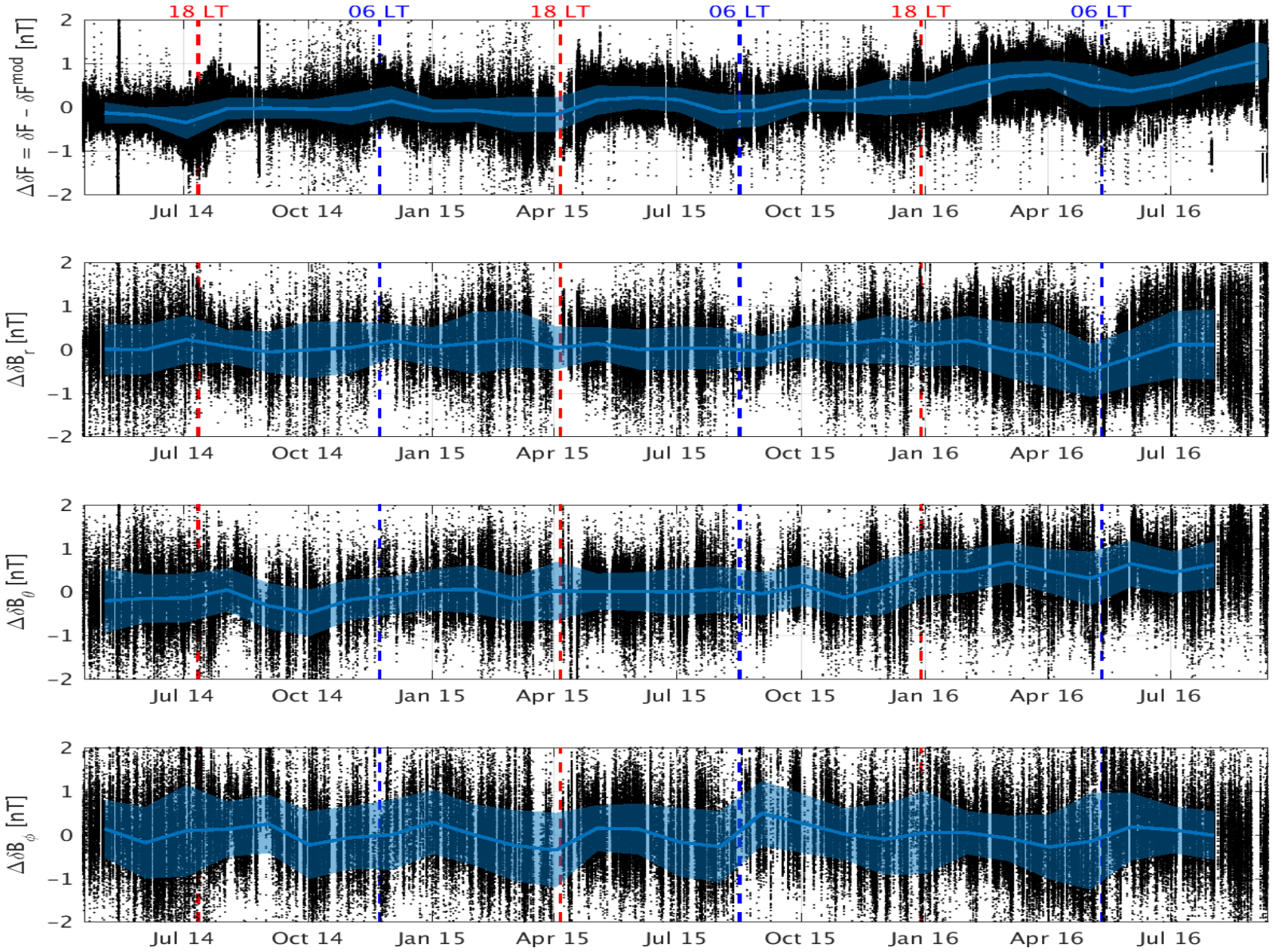
Fatal failure of ASM on Charlie on 4 Nov 2014

340 pT rms
$F = |\mathbf{B}_{VFM}|$

Drift since Jan 2016 probably due to non-optimal instrument calibration (time-dependent scale values)

Model residuals of difference Alpha – Charlie non-polar latitudes, dark regions

$\Delta\delta B = \delta B_A - \delta B_C$, $\delta B = B_{obs} - B_{mod}$



340 pT rms

480 pT rms

500 pT rms

580 pT rms

Conclusions and Recommendations

- investigate new approaches to improve crustal field modeling using Swarm gradient data
- provide user community with "stand-alone" software for computing the gradient tensor elements for a given position based on a spherical harmonic expansion
  (*.shc file as for the Swarm L2 products)
- study the spatial scale of ionospheric magnetic signatures (e.g. plasma-bubbles, gravity gradient currents, F-region dynamo, …)

- Don't forget Deep 3D Earth – the European core community is prepared
  (cf. SEDI meeting this summer, and the recent communications in Science and Nature)