Improvements of Geomagnetic Field Models Made During the First Years of the International Decade

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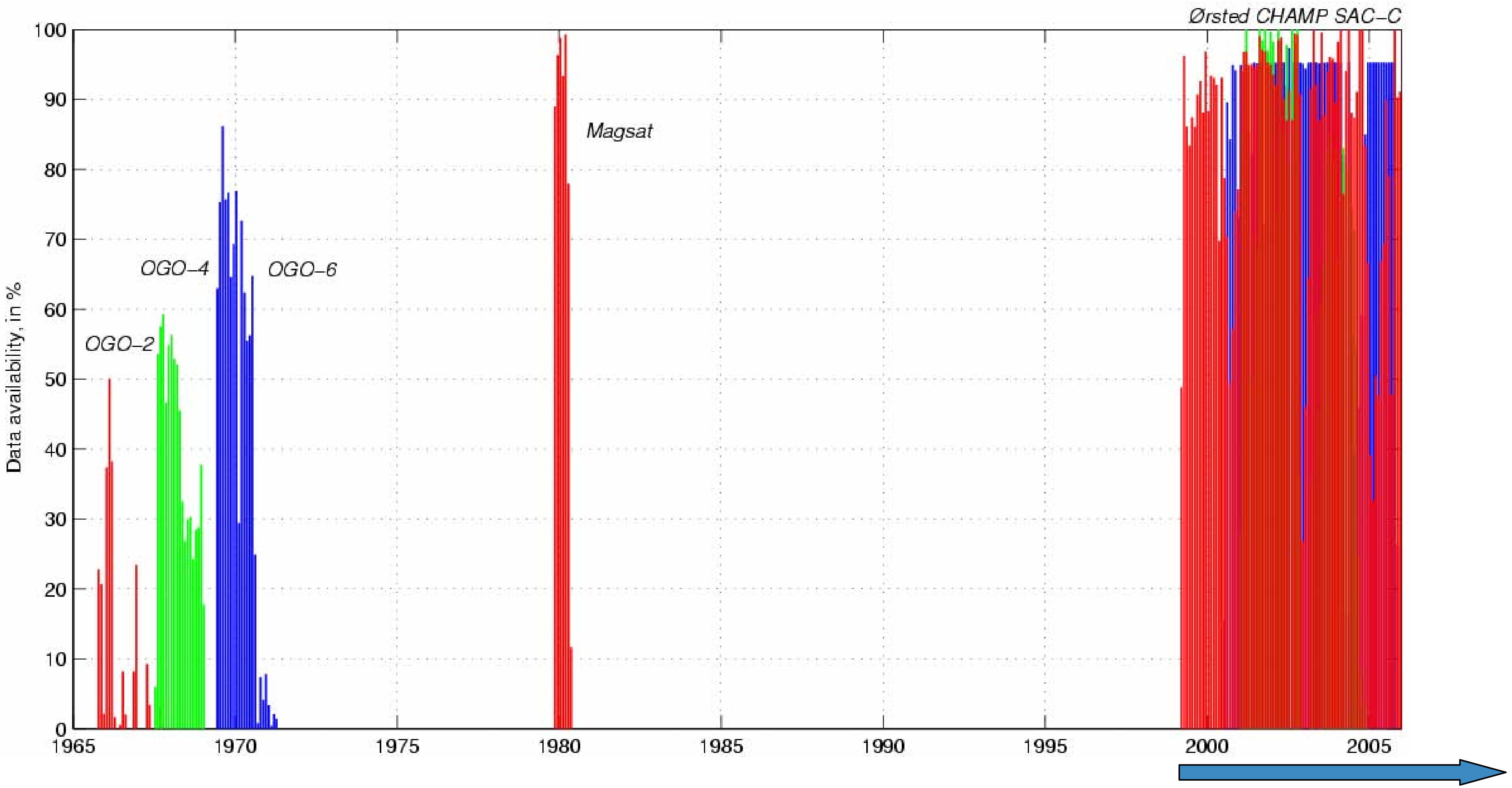
- Satellite Data during the International Decade
- Examples of Recent Field Models
- Satellite Data vs. Observatory Data
- What can be expected from Swarm?

Thanks to

Terence Sabaka, Stefan Maus, Richard Holme, Mioara Mandea, Hermann Lühr, Lars Tøffner-Clausen, Alexei Kuvshinov

Availability of Satellite Data: The Last 40 Years



scalar only

vector and scalar

International Decade of Geopotential Research

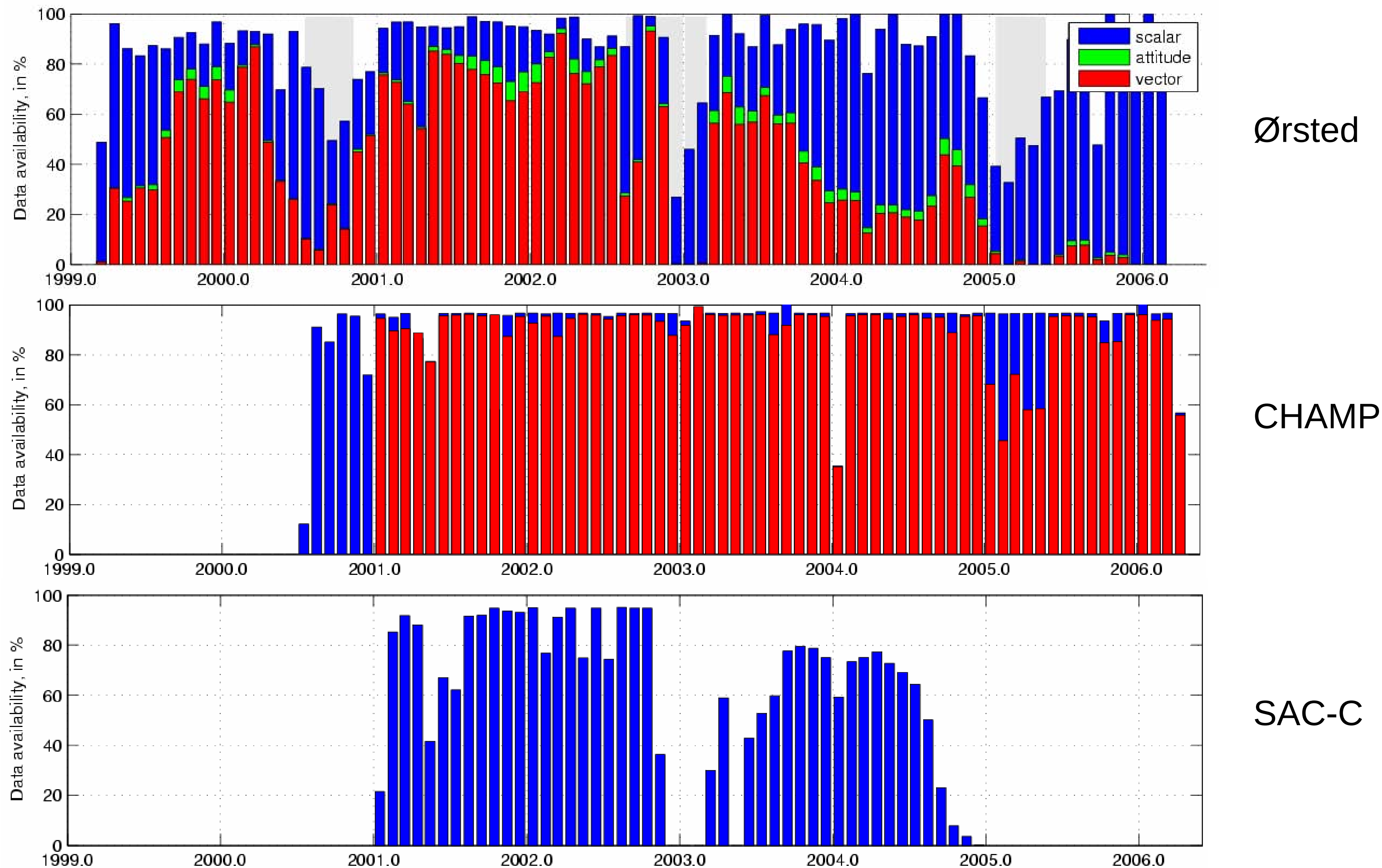
Present Satellites of the International Decade: Ørsted, CHAMP, SAC-C

- **Ørsted**
  First high-precision geomagnetic satellite since Magsat (1979-80)
  Launched on 23^{th} February 1999
  Polar orbit, 650-850 km altitude
  all local times within 790 days (2.2 years)

- **CHAMP**
  Launched on 15^{th} July 2000
  low altitude (400-450 km)
  all local times within 130 days

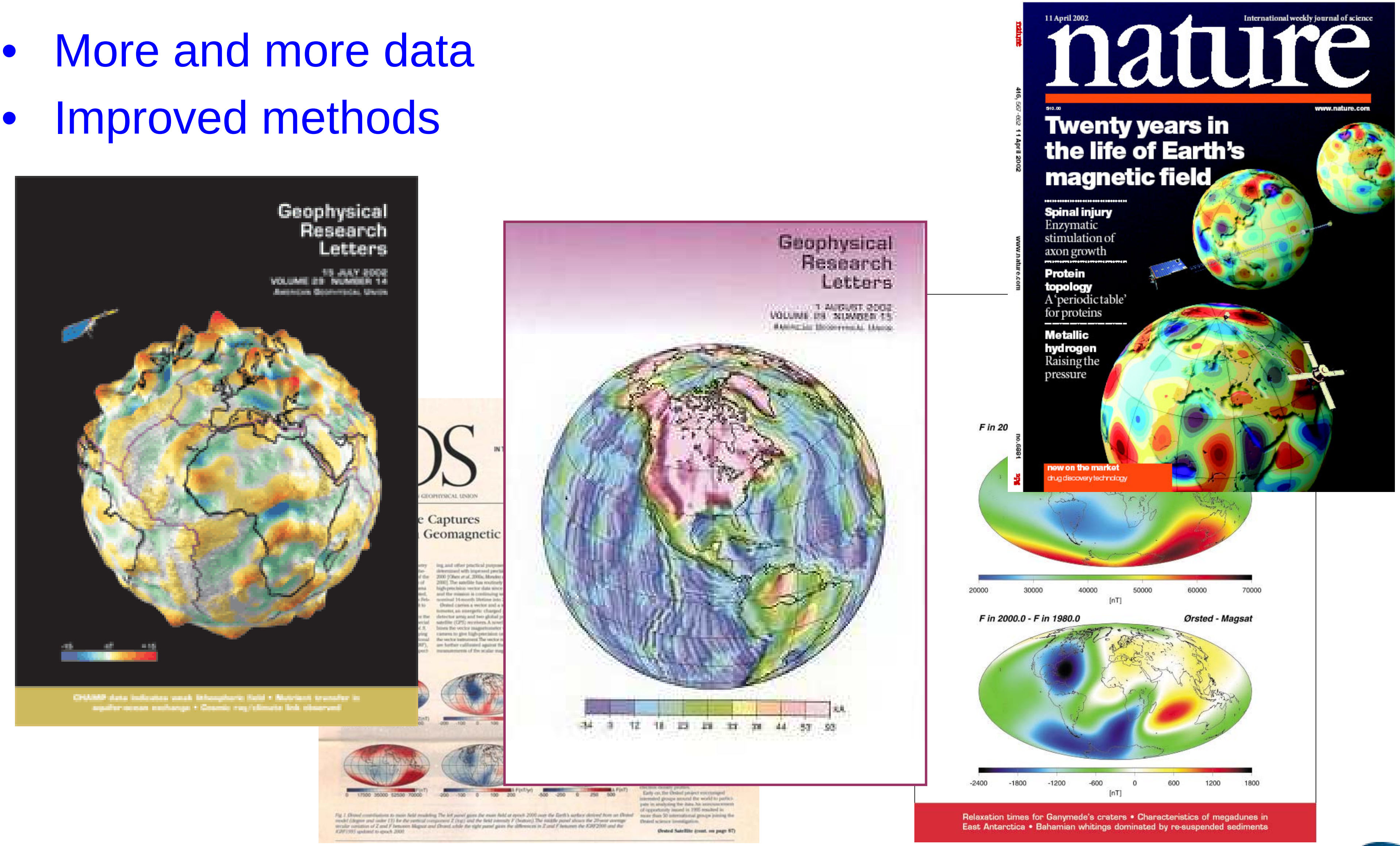
- **SAC-C Ørsted-2**
  Copy of Ørsted experiment
  Launched on 21^{th} November 2000
  700 km altitude, fixed local time $10^{30}/22^{30}$
  (no high-precision vector data due to payload failure)

Availability of Satellite Data during the International Decade



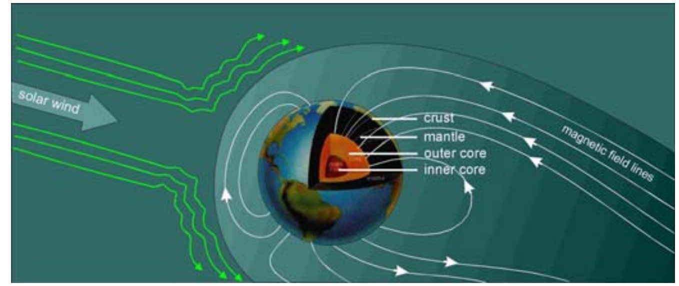
Models of Earth's Magnetic Field

- More and more data
- Improved methods

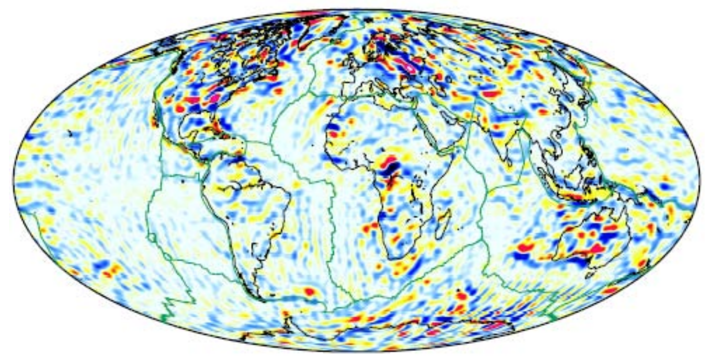


Example of Field Models:

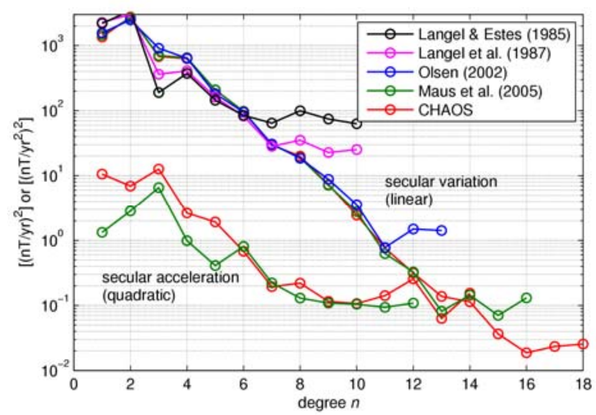
- CM4 (Sabaka et al., 2004)



- MF4 (Maus et al., 2006)

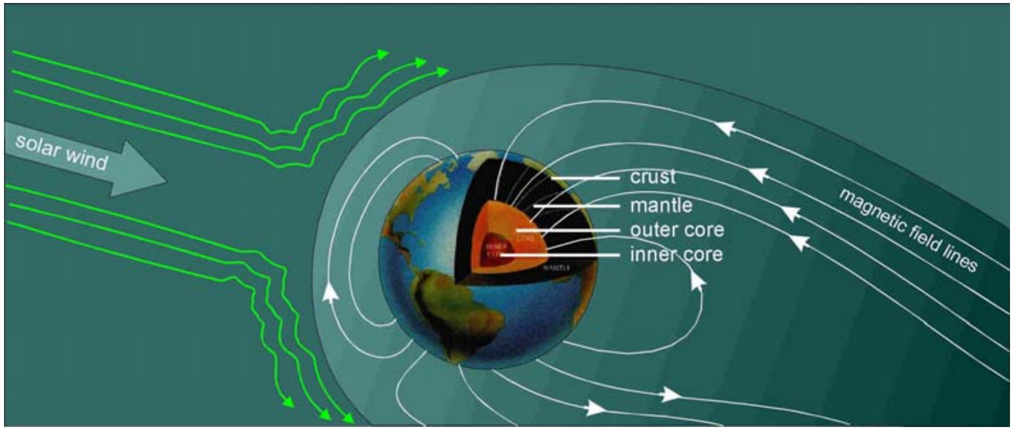


- CHAOS (Olsen et al., 2006)



Comprehensive Model CM4:
Parameterize fields from all major near- Earth sources

- Simultaneous estimation of the time-space structure of
  - main field (core + crust),
  - ionospheric field,
  - magnetospheric field,
  - induced field,
  - field due to currents at satellite height.



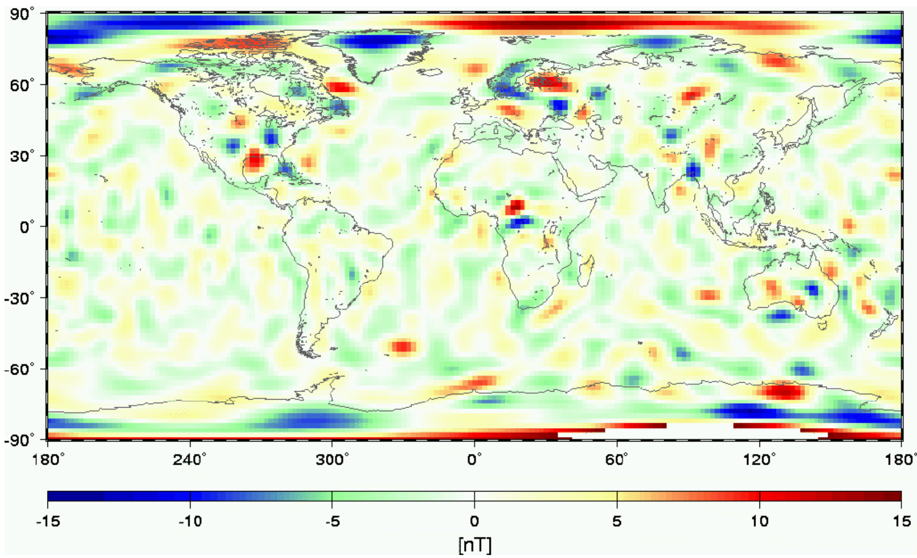
- Data
  - POGO (scalar), 1965-71
  - Magsat (vector + scalar), 1979-80
  - Ørsted (vector + scalar), 1999-2002.5
  - CHAMP (scalar), 2002.5-2002.5
  - observatory data, 1960-2001

- about 2.2 mio observations
- about 25,000 model parameters

Sabaka et al., 2004

Examples of CM4 Results

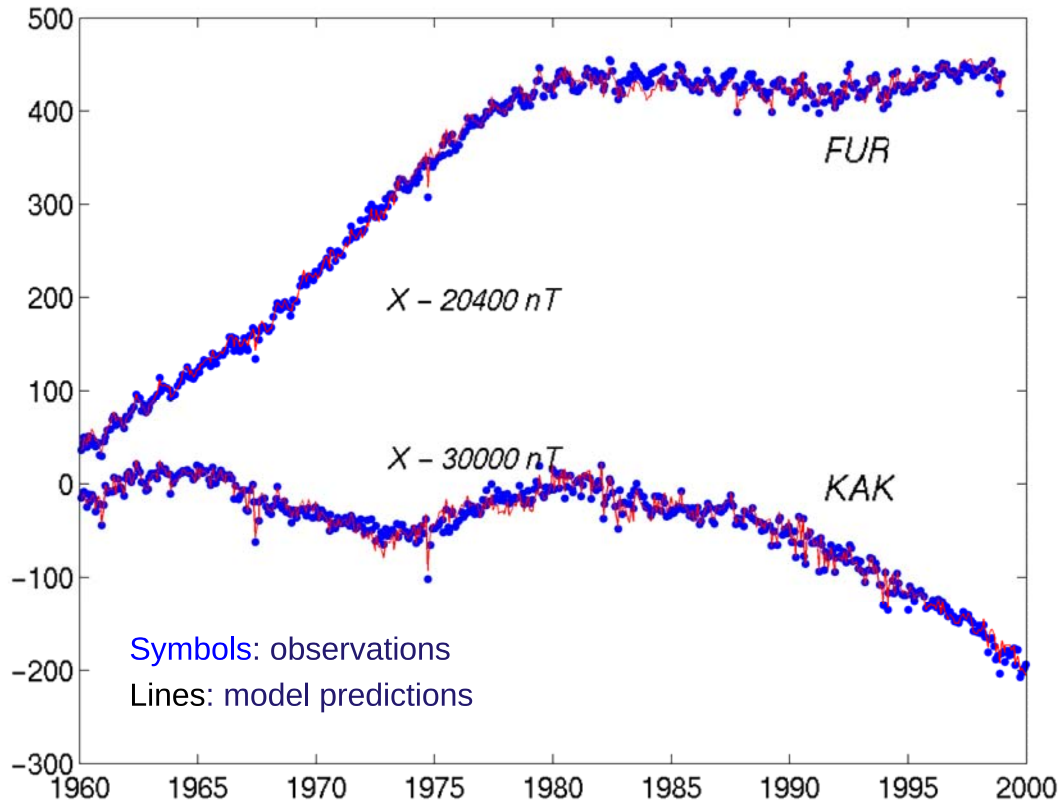
crustal field ...



... and fit to observed North component

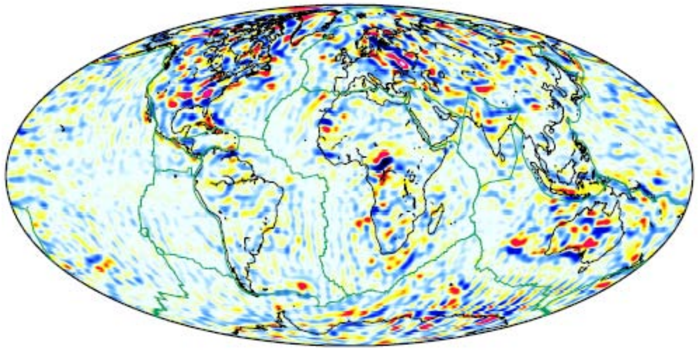
(at 1am on geomagnetic quietest day of each month)

for Fürstenfeldbruck and Kakioka



Sabaka et al., 2004

Lithospheric Field Model MF4

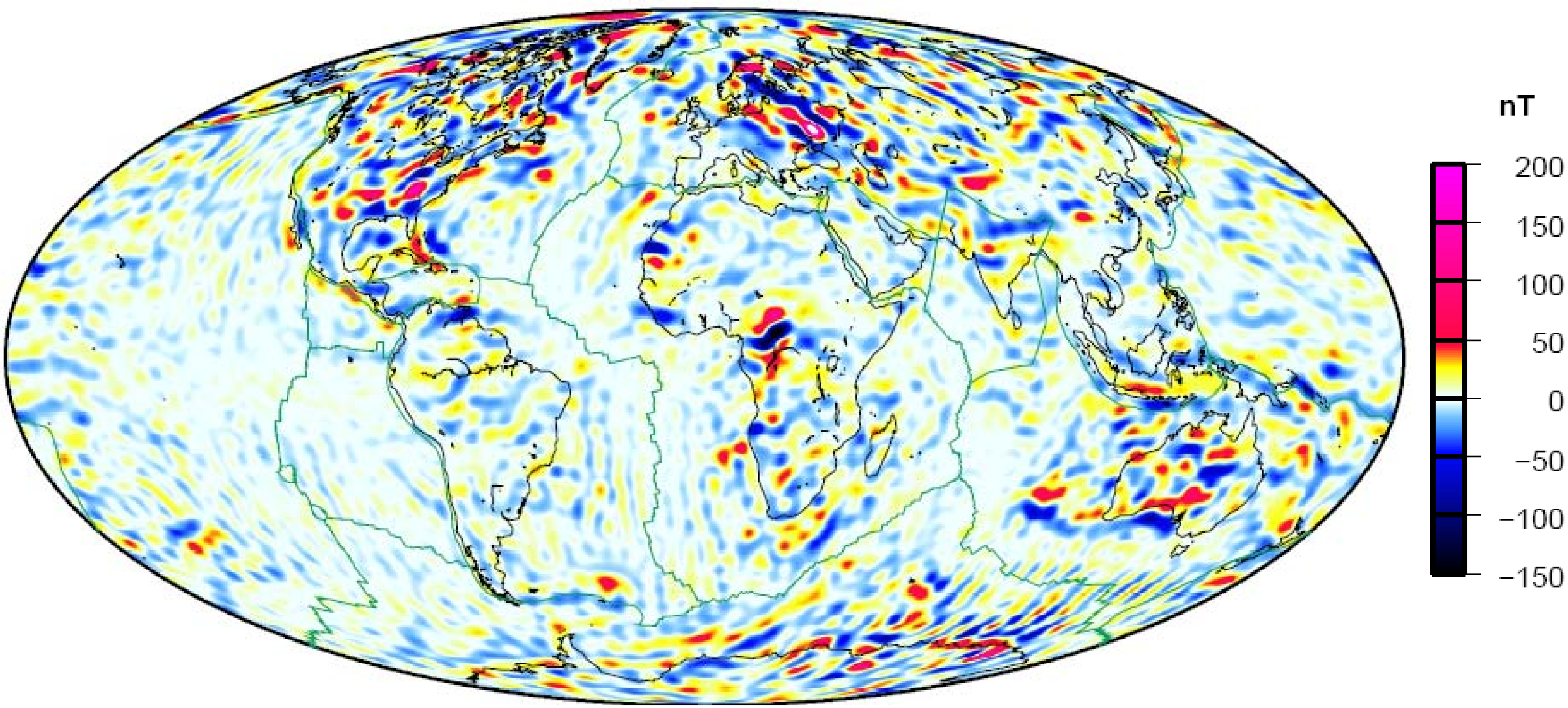


- Derived from almost 5 years of CHAMP data
  - scalar dat at all latitudes
  - vector data equatorward of 65^{o} dipole latitude
- Removal of oceanic tidal signal
- Track-by track high-pass filtering, to remove large-scale magnetospheric field
- Line leveling
- ”Data super selection”: Removal of
  - 30% outliers (non polar latitudes)
  - 95% outliers (polar latitudes)

- Spherical harmonic expansion up to degree/order *n*=90 (regularized for *n* > 60)

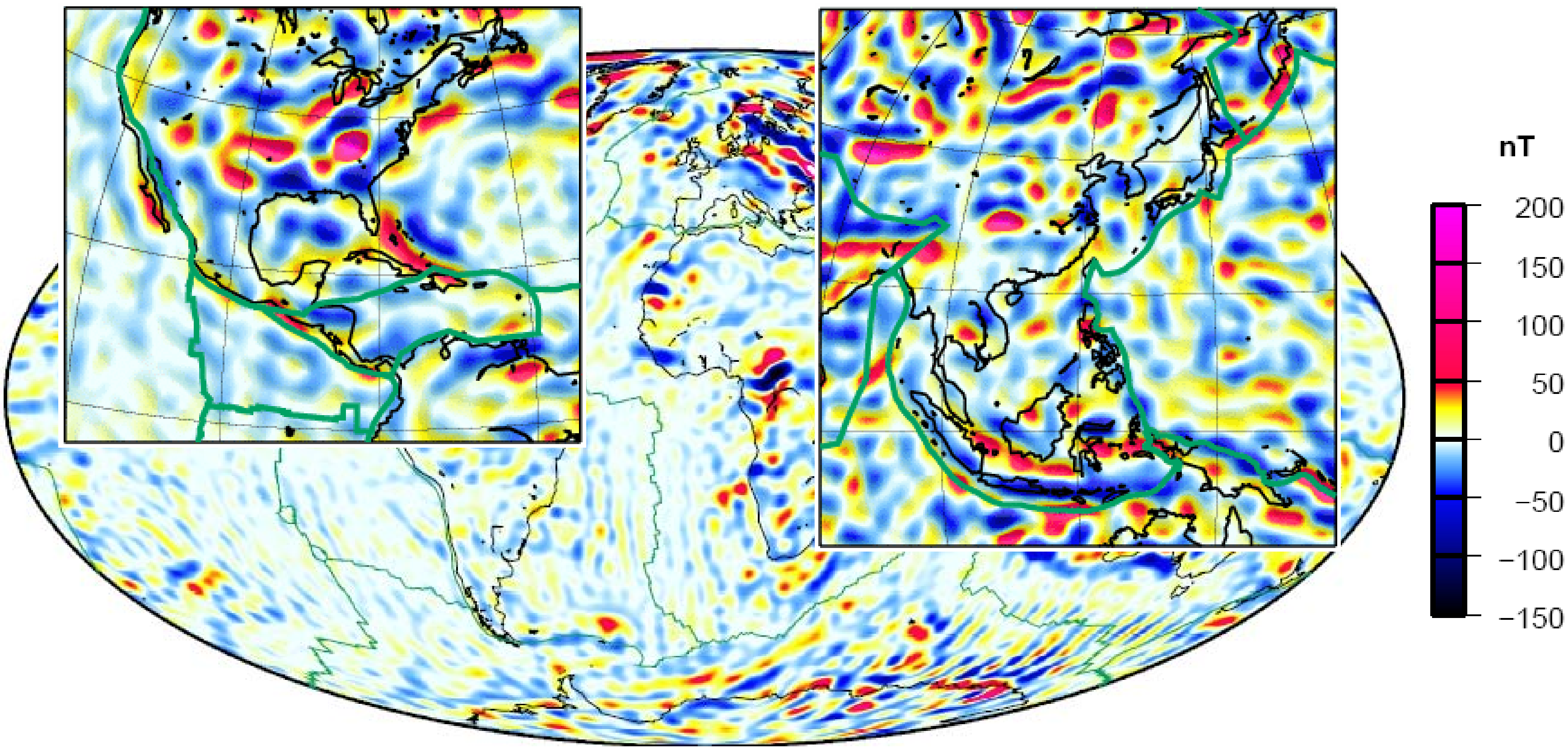
Maus et al., 2006

Example of MF4 Result:
Scalar anomaly at 50 km altitude



Maus et al., 2006

Example of MF4 Result:
Scalar anomaly at 50 km altitude



Maus et al., 2006

CHAOS - CHAMP, Oersted, SAC-C Magnetic Field Model

- Model of Earth's Magnetic Field
  based on almost 7 years of satellite data (March 99 – Dec 05)
- Goal of CHAOS
  ”optimal” description of
  - *static* field, up to *n* = 40
  - ”high-degree” *first time derivative* (linear secular variation), up to *n* = 16
  - time-space structure of core field (temporal spline representation), up to *n*=14
- Multi-satellite vector data alignment
  - Scalar data
  - Vector components ***in magnetometer frame***
  - Attitude data ***in star imager frame***

Vector data alignment is done as part of the field modeling effort by co-estimation of alignment parameters instead of serial estimation

CHAOS Model Parameterization

- Model of core and crustal fields:
  - static: $N_{MF} = 50$
  - *first time derivative:* $N_{SV} = 18$
  - spline parameterisation: $N_{spline} = 14$:
    (1 yr knot spacing)

4752 coefficients

- Model of magnetospheric fields
  - separate estimation large-scale magnetospheric field every 12 hours:

3113 coefficients

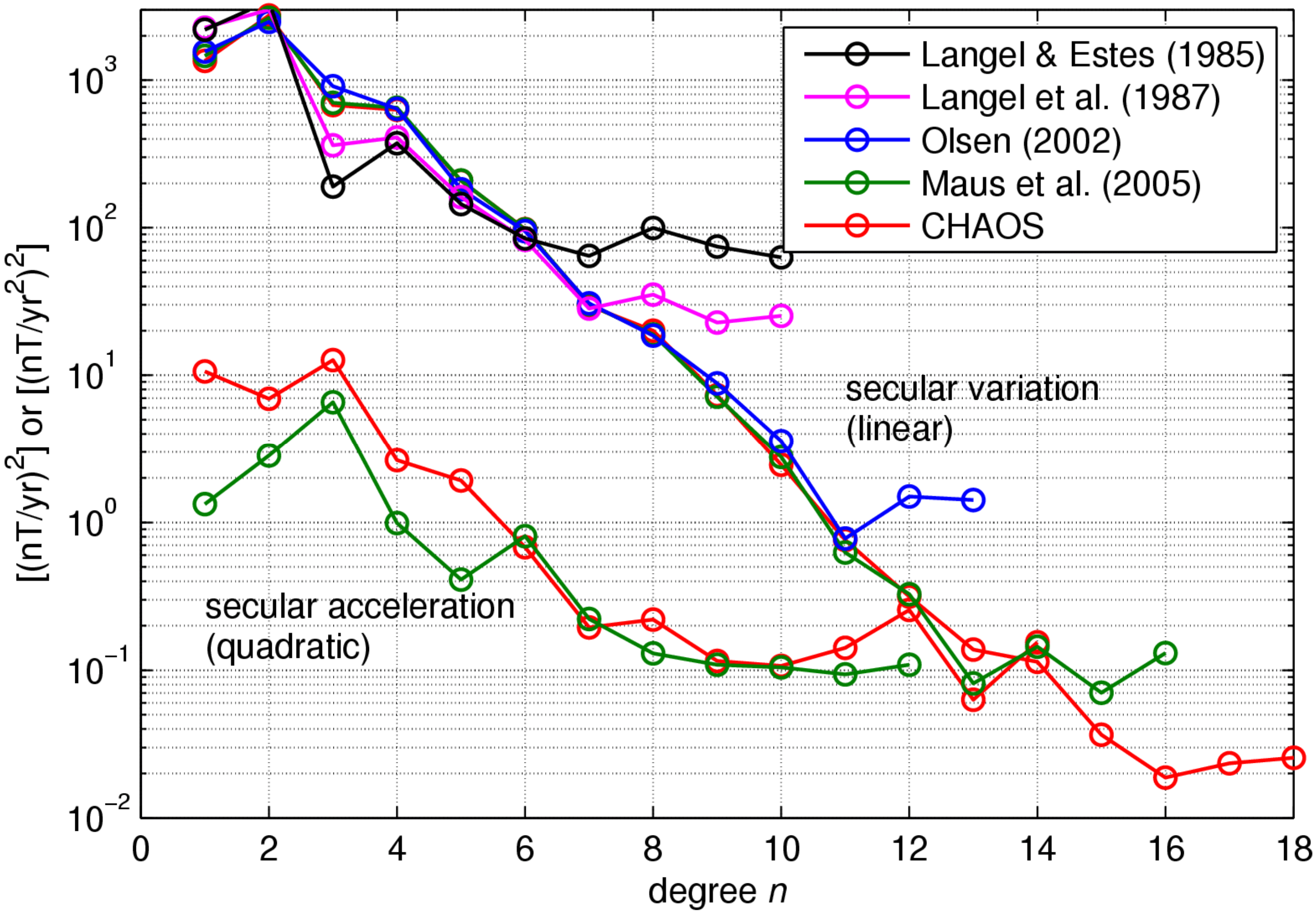
- Vector data alignment (Euler angles)

3 x 113 parameters

- 58% of the model is "target ´field" (core and crustal field)

Result: Power Spectrum of Secular Variation

***Power Spectrum:** mean square magnetic field (at Earth's surface) due to contributions with spherical harmonic degree n (horizontal wavelength λ_n)*



6 month Magsat ...

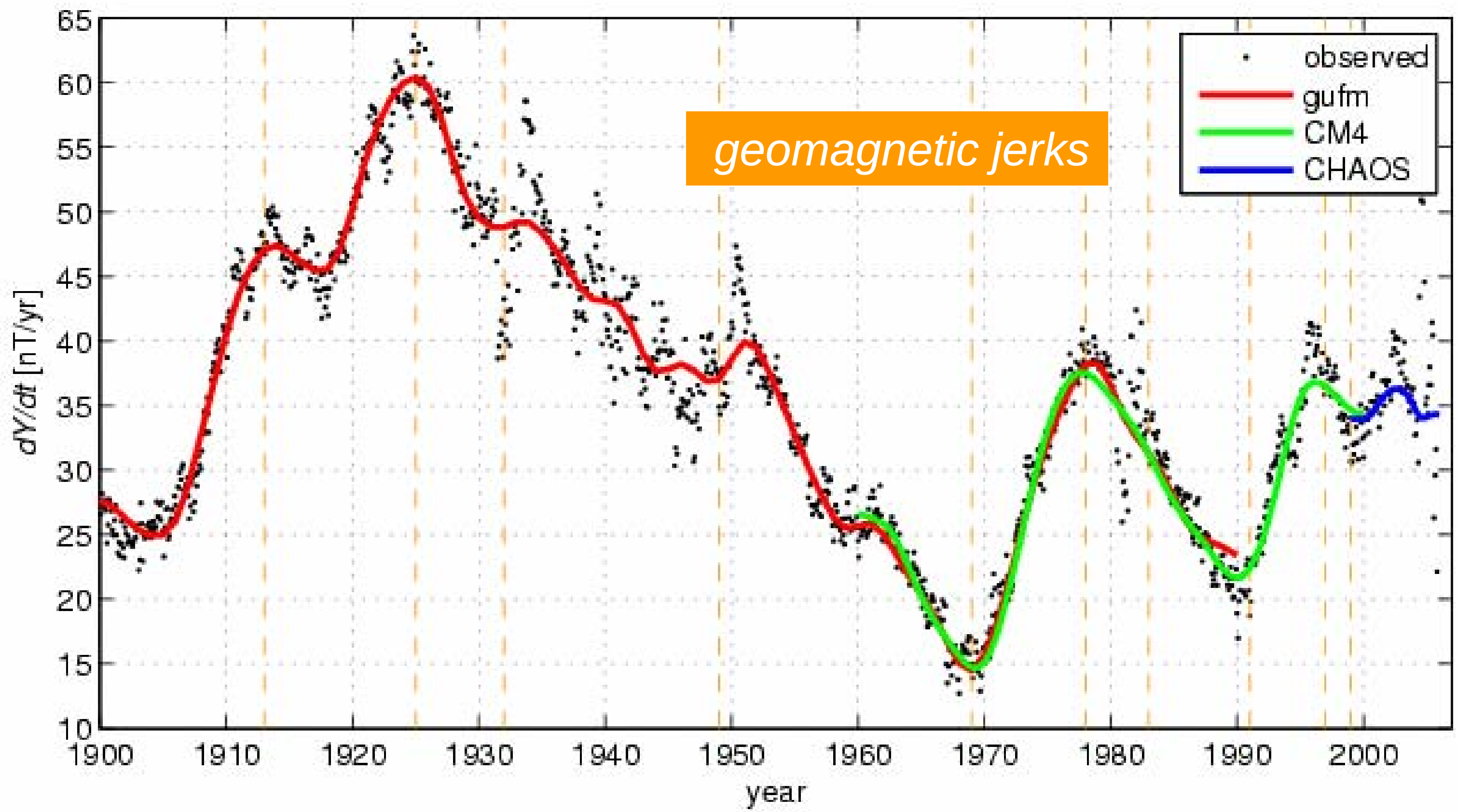
... + DE-2 (1980-82)

2.5 years Ørsted (OSVM)

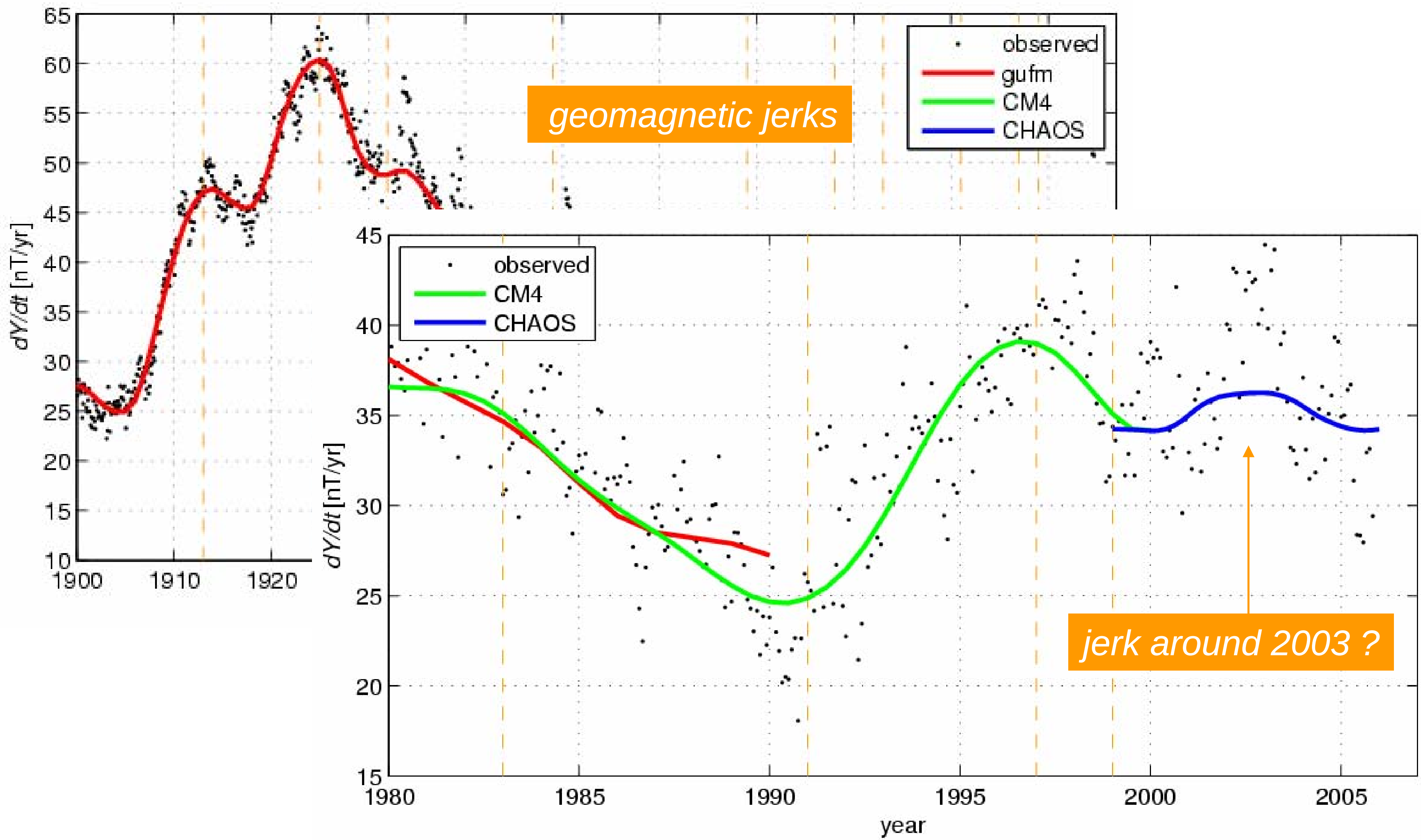
5 years CHAMP + Ørsted (POMME)

CHAOS

dY/dt at Niemegk/Germany

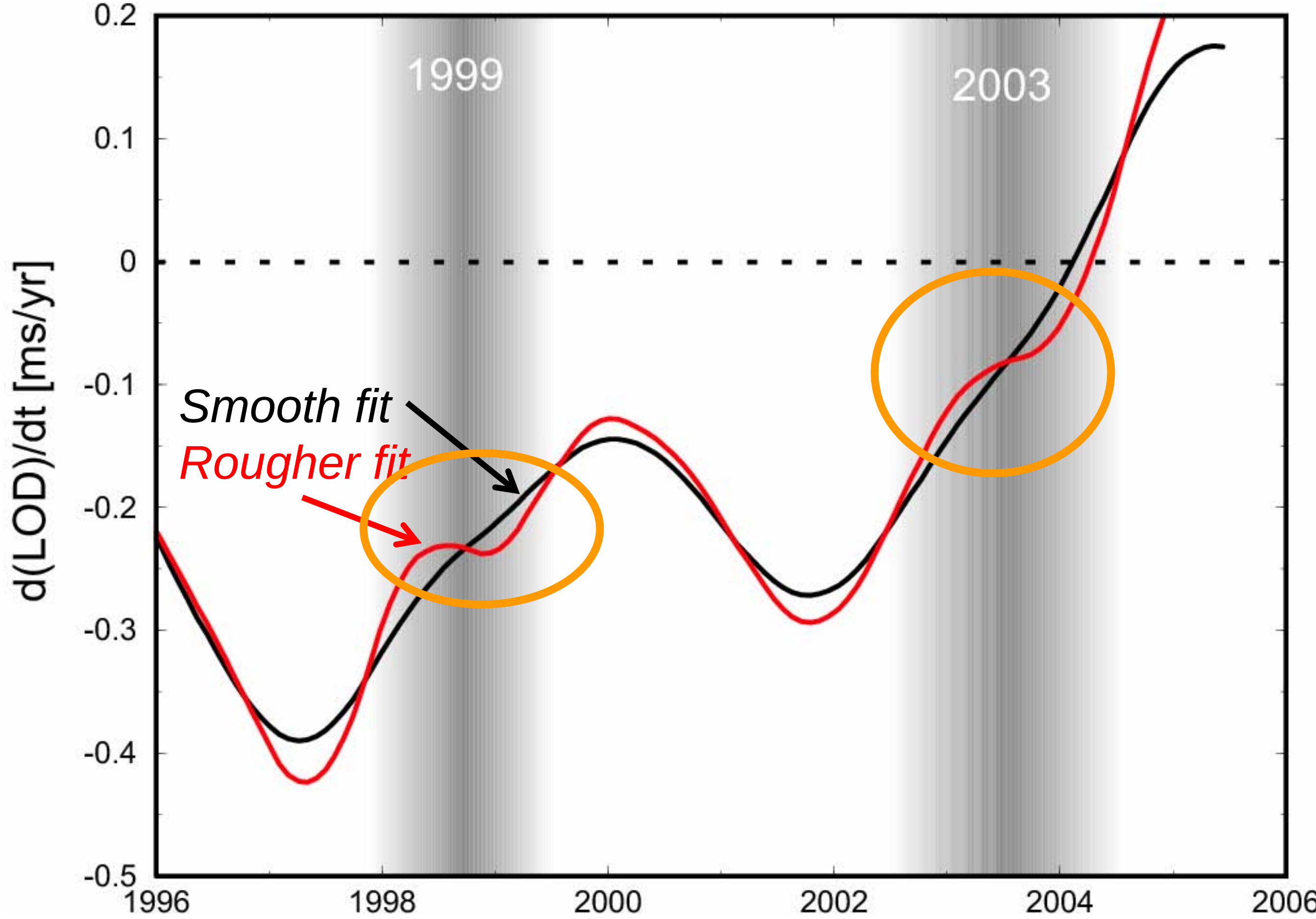


dY/dt at Niemegk/Germany



Evidence for a Jerk around 2003 in LOD

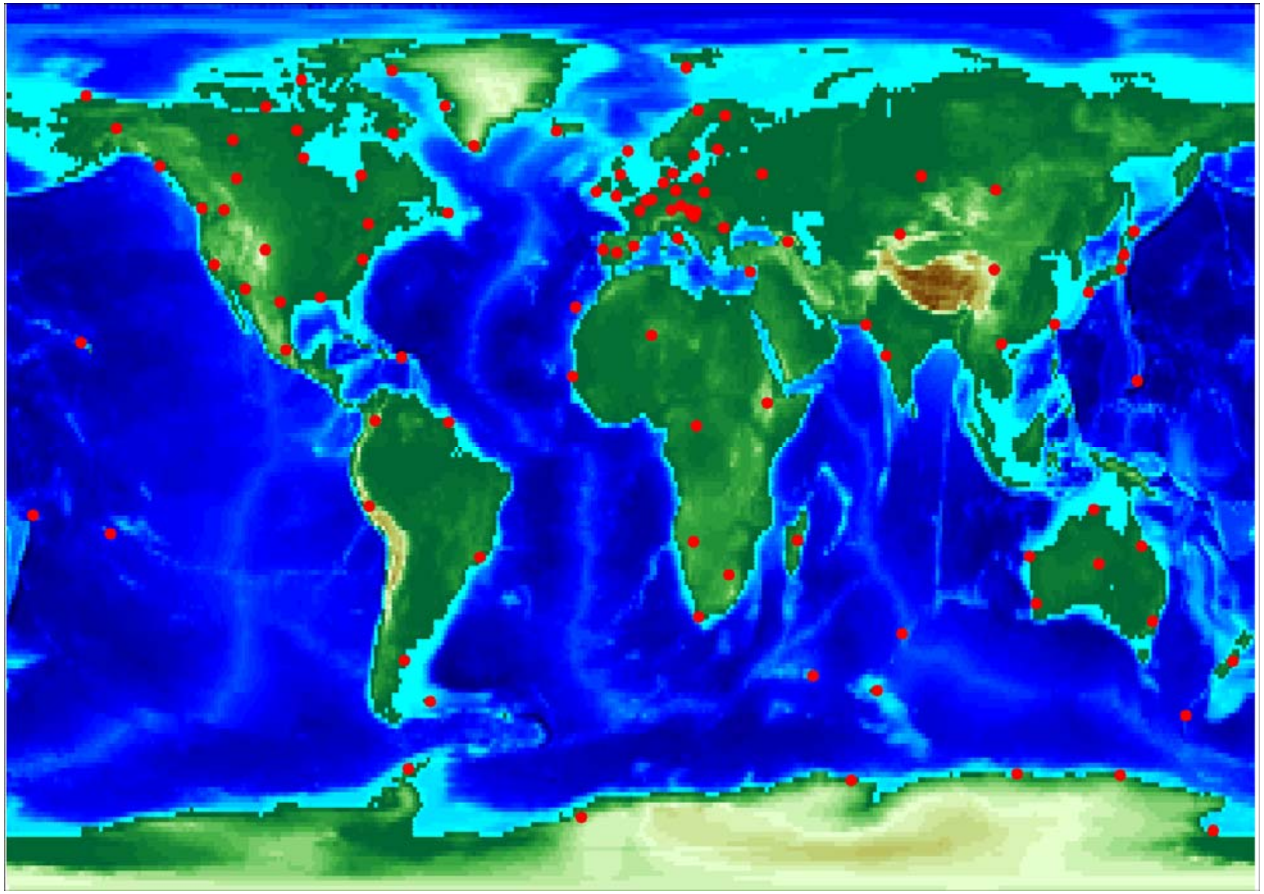
- Length of Day (LOD) curve
- Occurence of ”Wiggles” in d(LOD)/dt are correlated with jerks
  (Holme & de Viron, 2005)



Holme, private communciation, 2006

Time change of LOD suggest occurence of jerk in 1999 and 2003

Distribution of observatories, 1999-2005

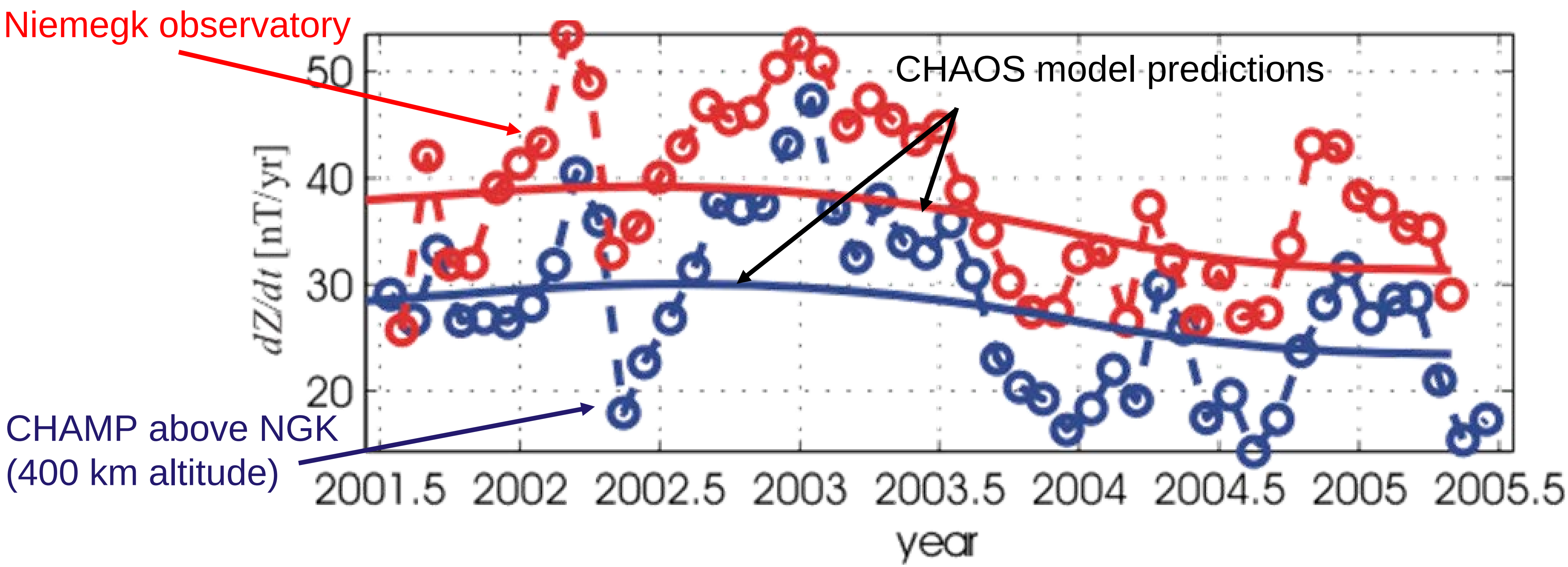


- Observatory data (e.g. monthly means) provide an excellent opportunity to study the magnetic field change at a given point in space
- But very uneven spatial distribution of observatories
- Is it possible to determine secular variation from satellite data obtained at or near the grid points of a regular net ?
- Monthly means at ”virtual observatories”
  in space, similar to observatory monthly means ?

Monthly Means of *dZ/dt* at ground and at 400 km altitude

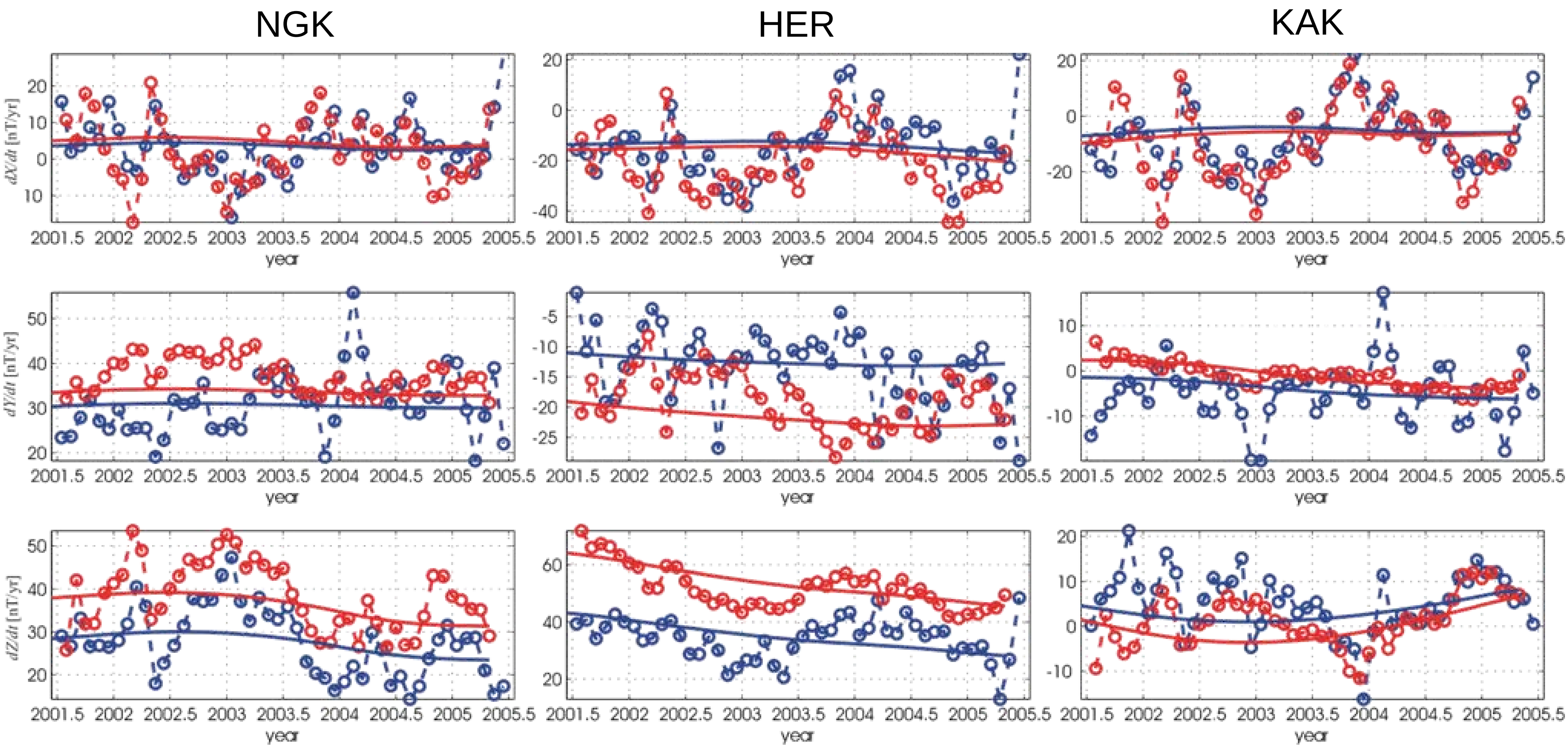
First differences (12 month running mean) of monthly means

Determination of secular variation (monthly means) at given location in space from satellite data in vicinity (e.g., 400 km radius) of ”target point”.



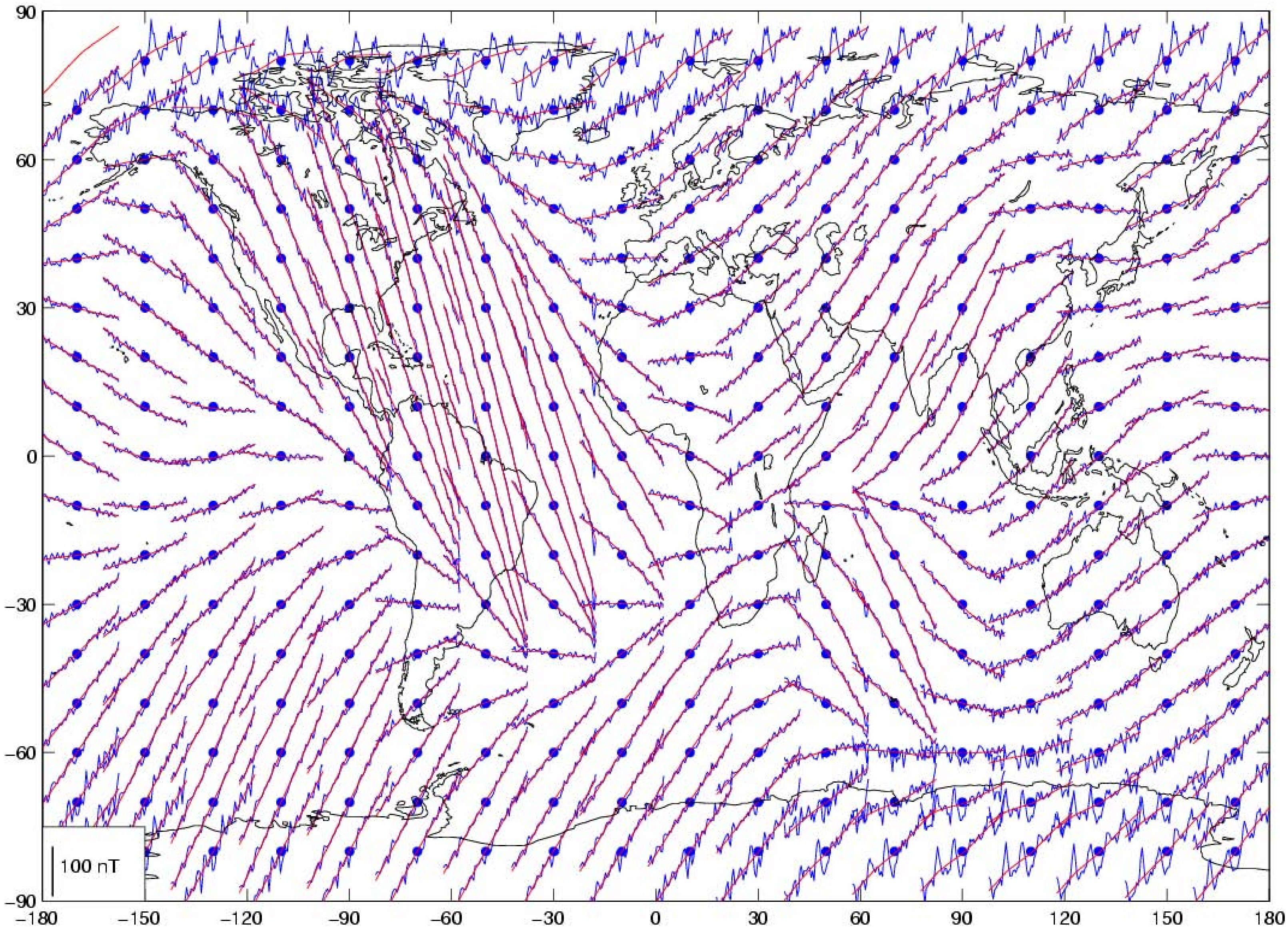
Mandea and Olsen, in review

Monthly Means at ground and at 400 km altitude: Three observatories, all three components ...



Satellite and observatory data contain well correlated signal that is not described by present field models.
Is this signal internal or external in origin?

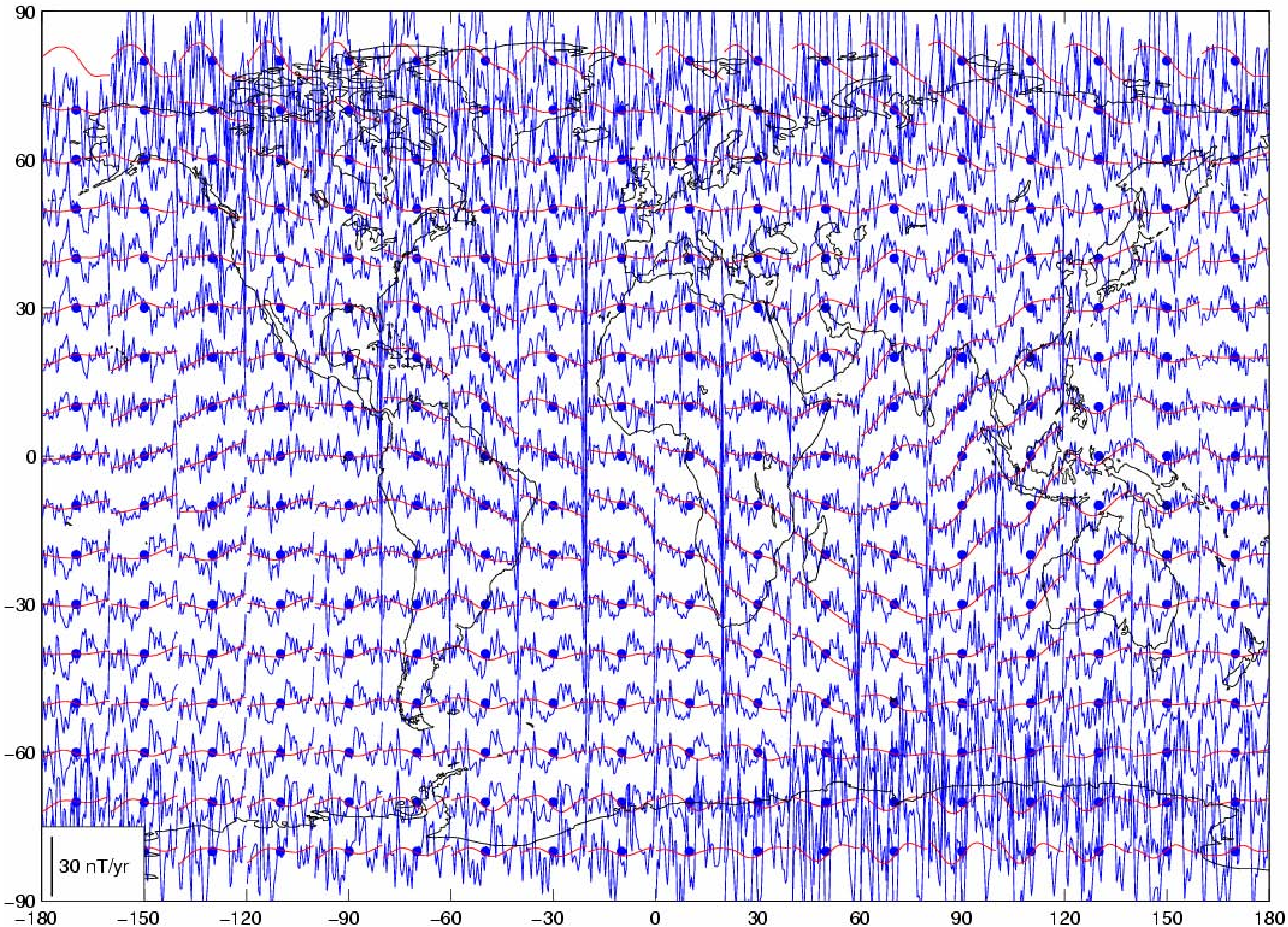
Regular grid of virtual observatories at 400 km altitude: *Z*-component



monthly means

CHAOS model prediction

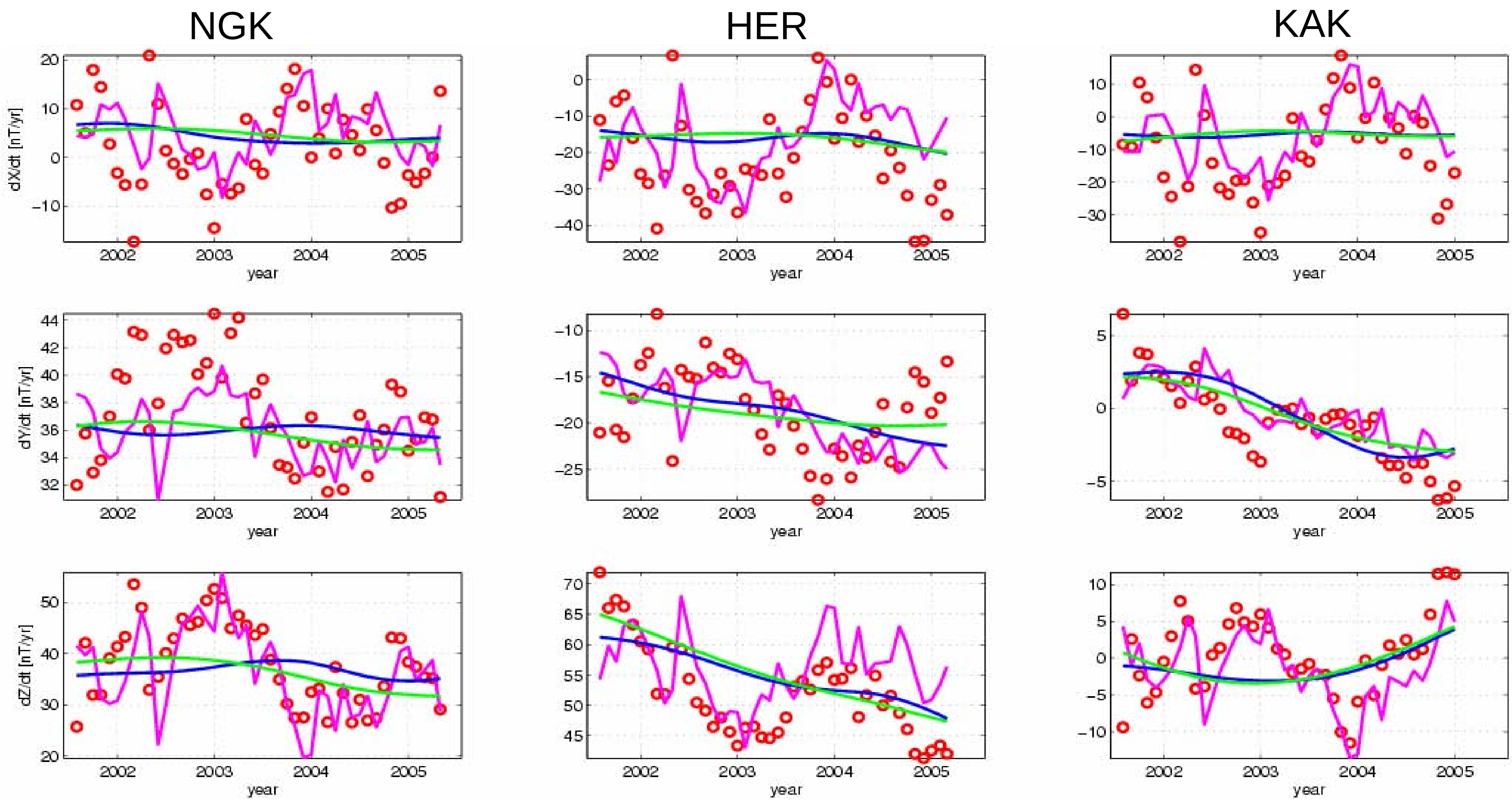
Regular grid of virtual observatories at 400 km altitude: *dZ/dt*



monthly means

CHAOS model prediction

External Field Contributions in Observatory Monthly Means



observatory monthly means

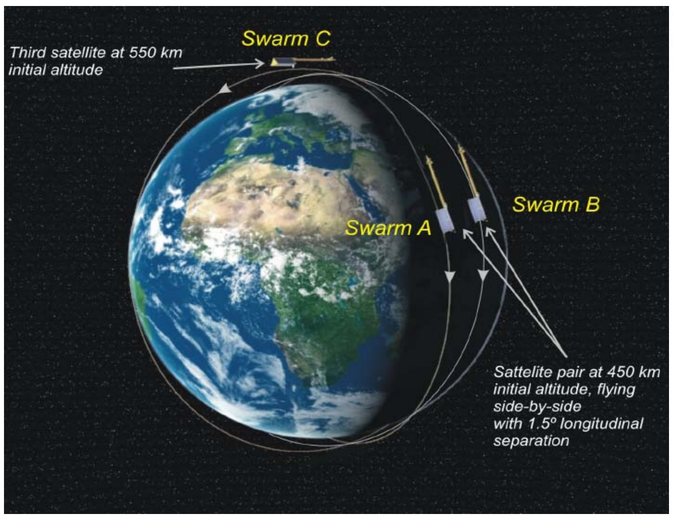
model predictions (based on satallite data only):

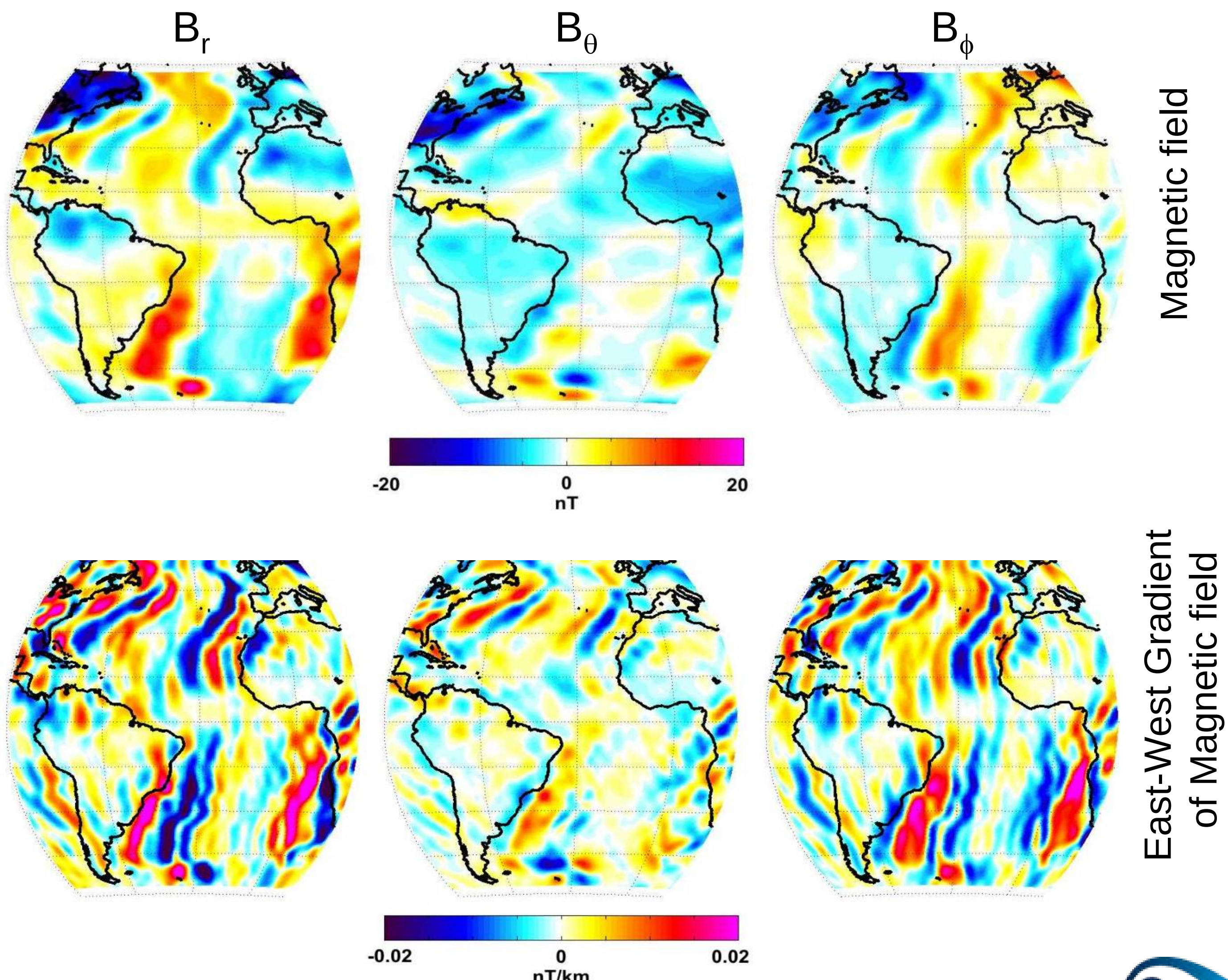
only internal field (CHAOS, modified CHAOS)

internal and external field field

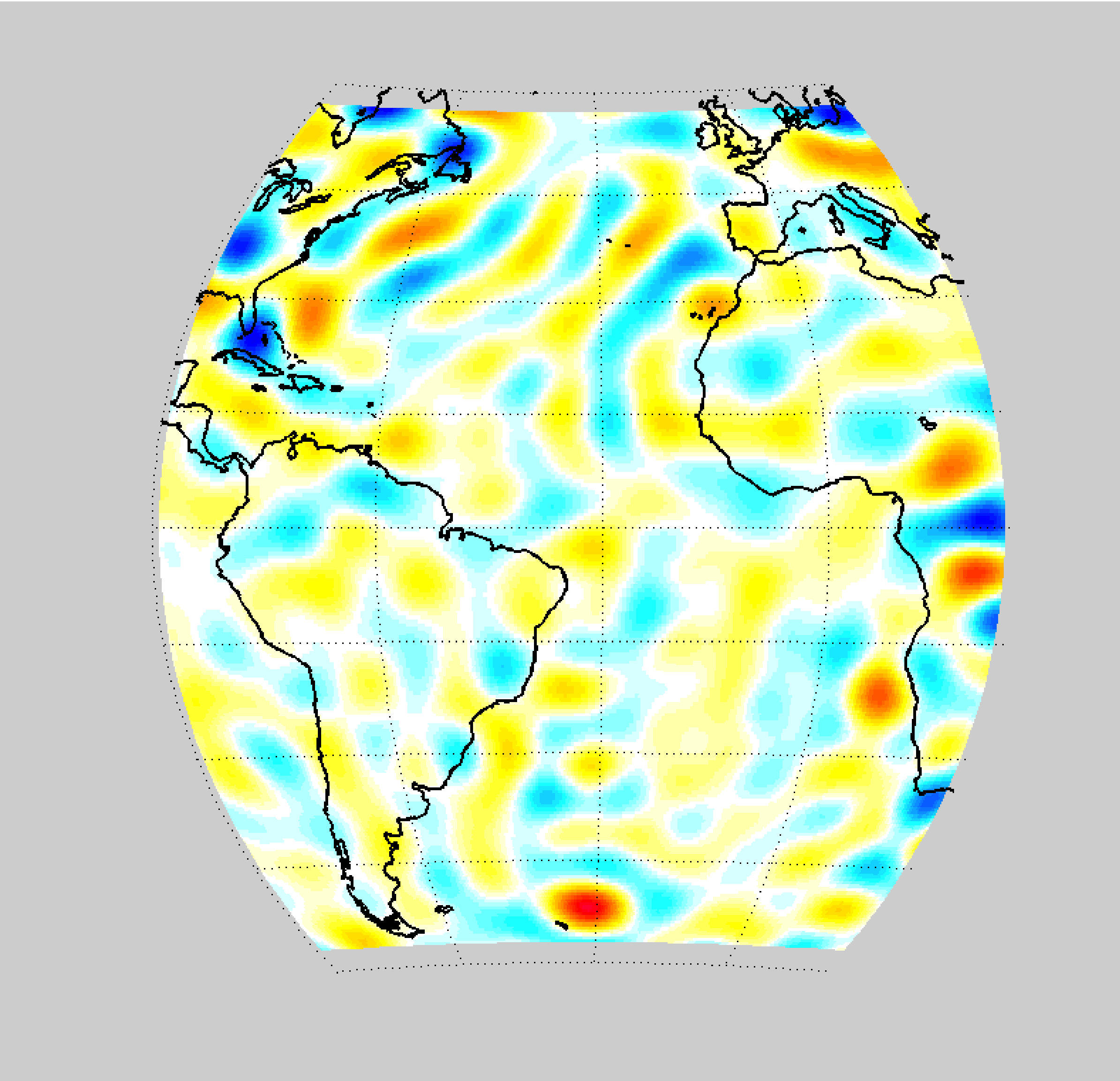
What can be expected from *Swarm*?

Lithospheric Field and Gradient at 400 km altitude





Improvement of Lithospheric Field Model

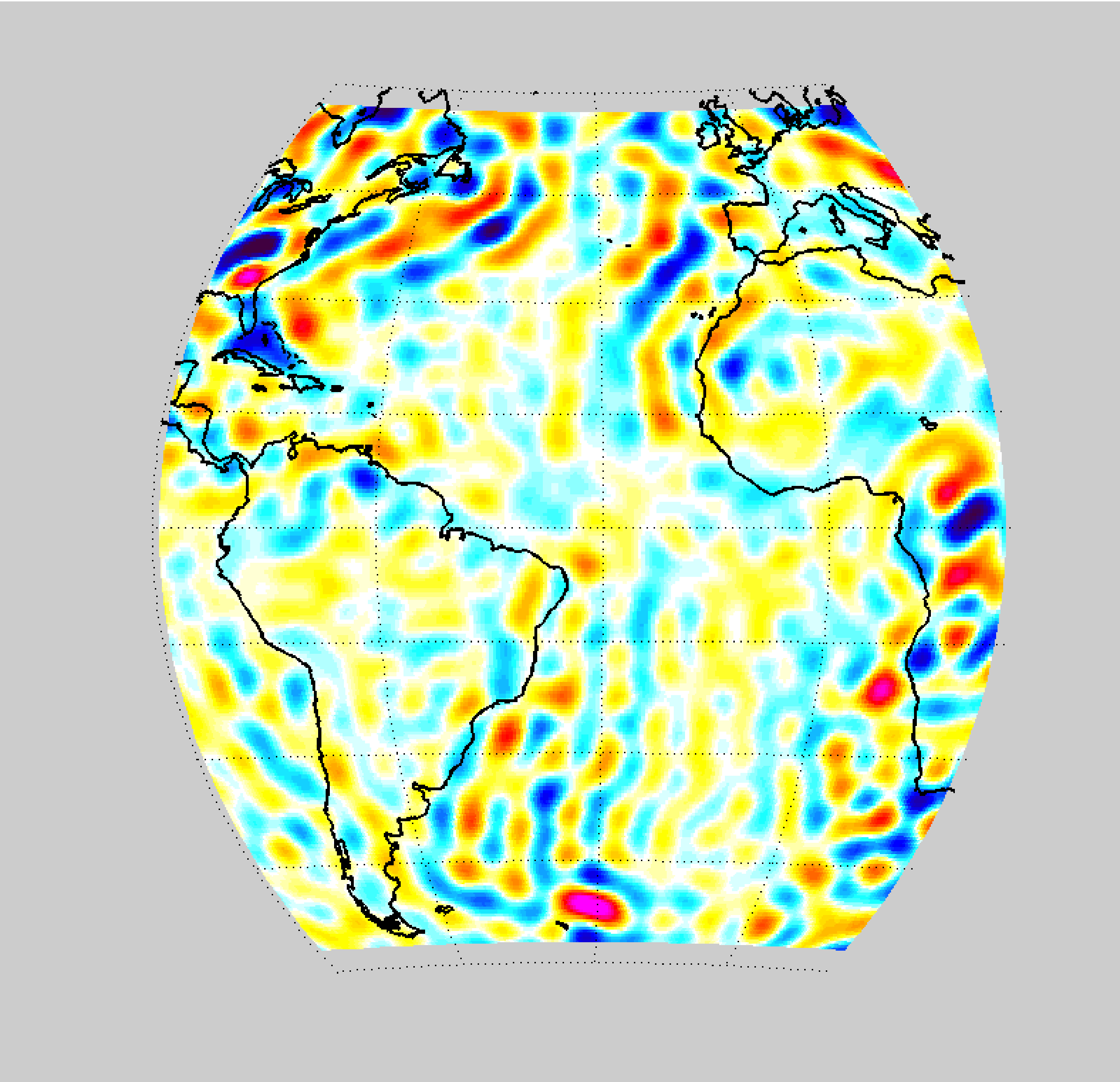


POGO and Magsat ...

N = 40, resolution: 1000 km

Magnetic field of Earth's crust radial component at 10 km altitude

Improvement of Lithospheric Field Model

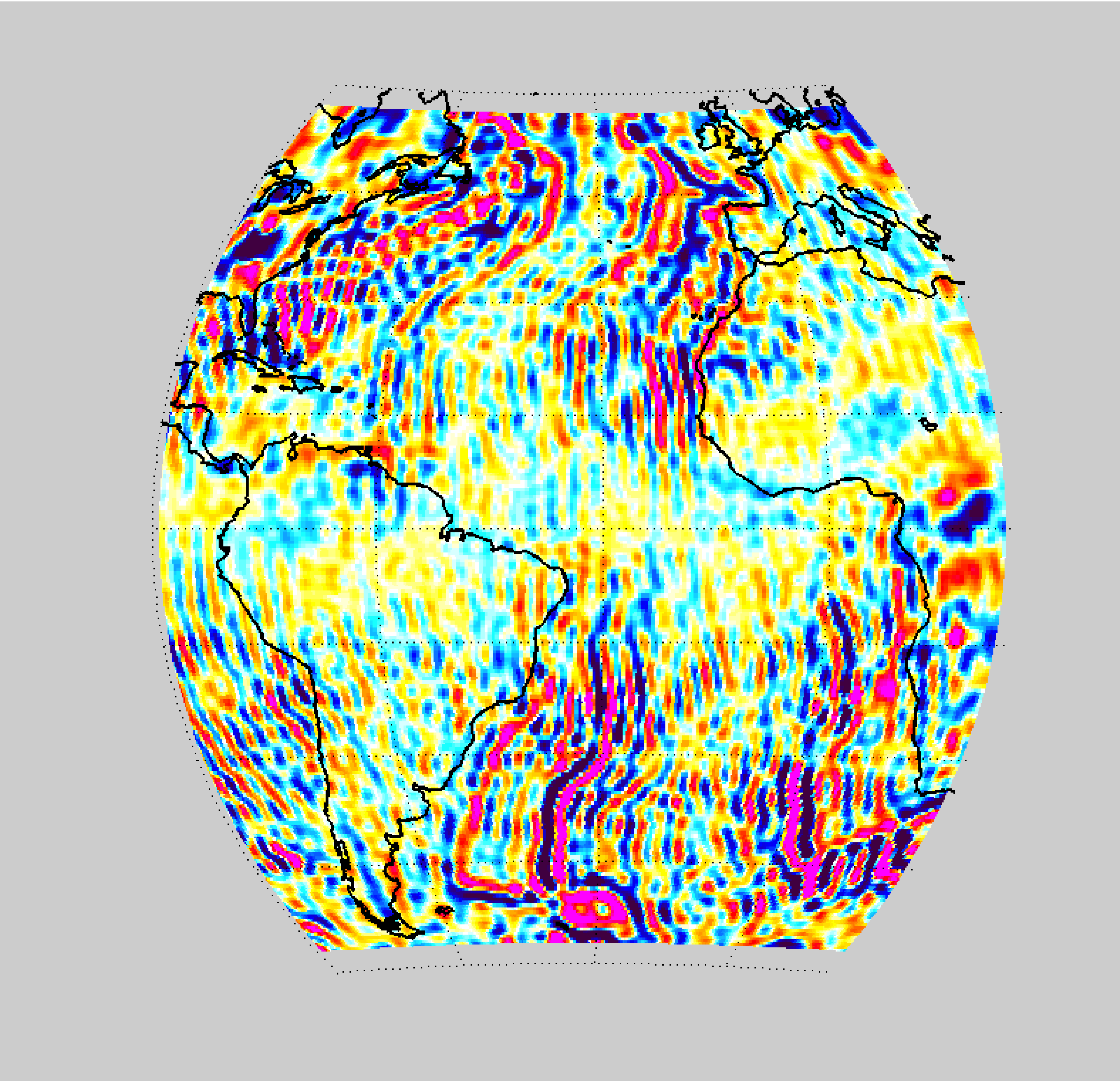


... with present satellites Ørsted and CHAMP ...

N = 65, resolution: 615 km

Magnetic field of Earth's crust radial component at 10 km altitude

Improvement of Lithospheric Field Model



... and with *Swarm*

N = 150, resolution: 270 km

Magnetic field of Earth's crust radial component at 10 km altitude