Sequential modelling of the Earth core magnetic field

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IPGP, Geomagnetism

Introduction

- **Overall goal :** modelling the core's magnetic field and surface flow at small time scales ($\lesssim$ 1year)
  - Correlation based, sequential data assimilation
  - Co-estimation of the surface flow

- **Results :** time series of core field models for 2000-2020

- **October 1st :** IGRF-13 candidate

Sequential modelling approach

Kalman filter :

- **Analysis:** correlation based bayesian inversion of satellite and observatory data
    - Prior information added through correlation matrices (Holschneider et al, 2016)
      → Two different approaches for building correlation matrices:
      Holschneider et al. (2016) or *Numerical dynamo experiments (Aubert et al.)*
- **Prediction:** estimation of the model at the next time step. Evolution based on a combination of **stochastic prediction** and **Taylor expansion**.
- **Smoothing:** backward smoothing according to RTS (Anderson and Moore 1979)

Continuous data assimilation : allows for continuous assimilation of new SWARM and observatory data

Analysis process

- Data set covers the satellite era. It includes observatory data, CHAMP satellite data and SWARM-A satellite data. Data are selected for magnetically quiet night times
    - **Three months of data** are used for each 3-month analysis period.
    - Data weights are evaluated through iterative Huber-weighting
    - Data set spans exactly from 01/01/2000 to 07/31/2019

- For each analysis step are modelled:
    - **Static core field (SH degree 1 to 18)**
    - **SV core field (SH degree 1 to 18)**
    - Lithospheric field (SH degree 15 to 30 -- known field subtracted from data for SH 30 to 120)
    - Static external field in GSM coordinate system (SH degree 3)
    - Static external field in SM coordinate system (SH degree 3)
    - Dst dependent fields in SM coordinate systems (SH degree 3)
    - IMFBy dependent field in SM coordinate systems (SH degree 3)
    - **Induced field and its time variations in GEO coordinate system (SH degree 6)**
    - Observatory offsets (3x195 observatories)

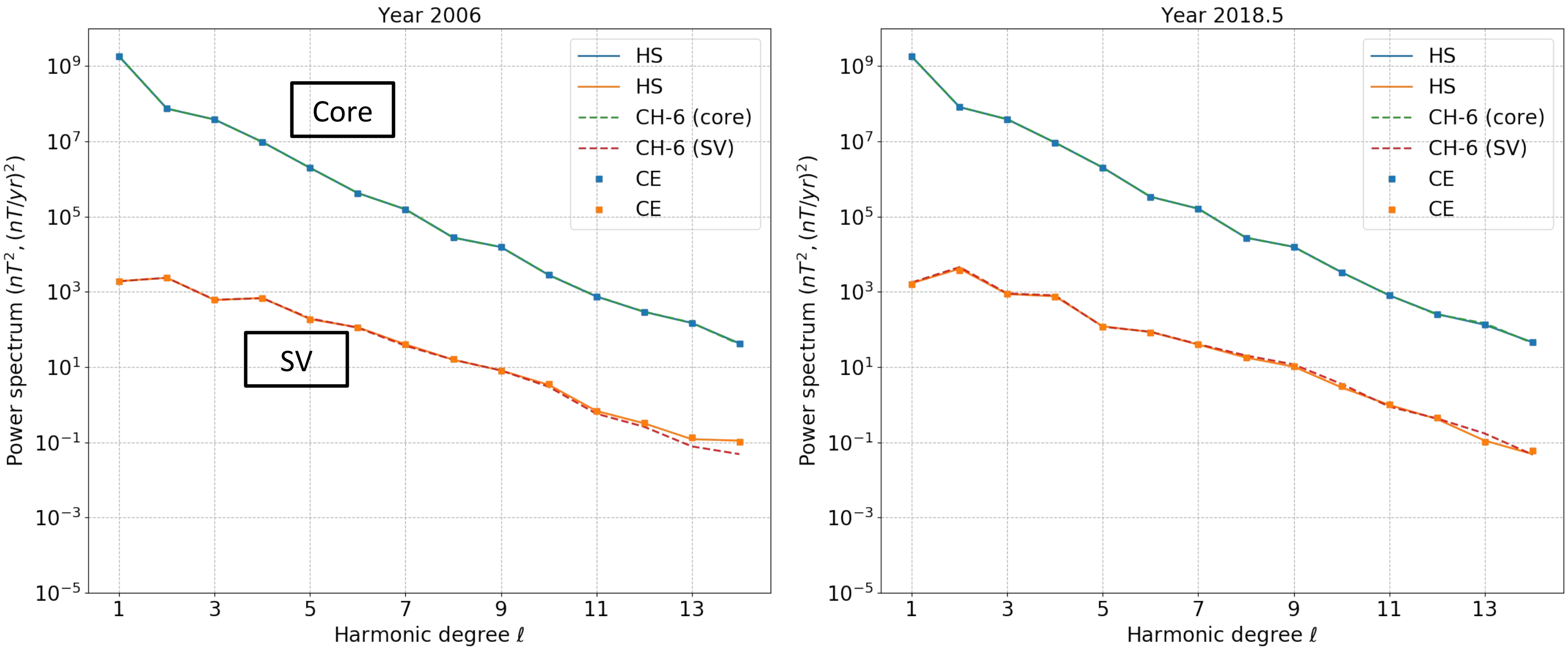
Prediction and smoothing

- Prediction step:
  - Core field: predicted through the SV
  - SV: predicted using a stochastic process (timescale ~ 11-15 years)
  - External fields: no time correlation
  - Lithospheric field: regarded as static (huge timescale)

- Backward smoothing:
  - Performed over the whole era, starting at the last time step.
  - Based on the Rauch-Tung-Striebel (RTS) smoother (Anderson and Moore 1979)

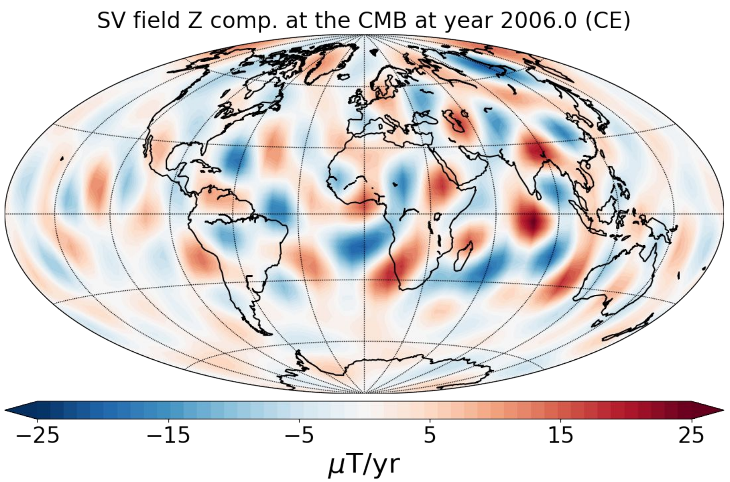
Model MCM-00-20

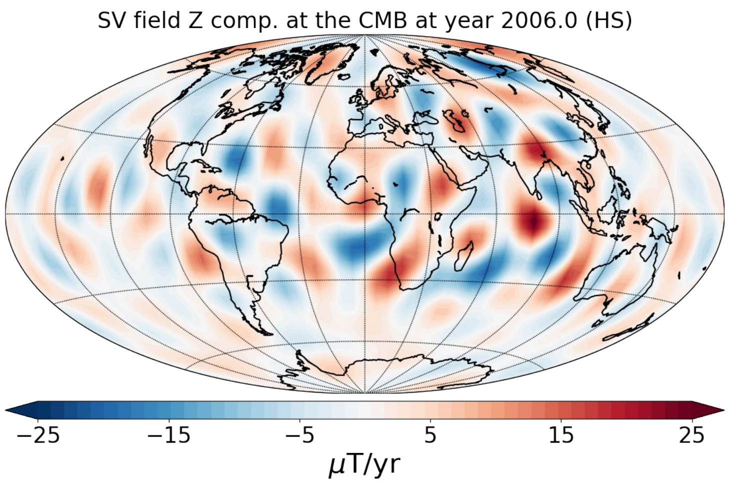
Power spectra at years 2006.0 and 2018.5 (Earth's surface)



Chaos model : Chaos 6x9

Model MCM-00-20





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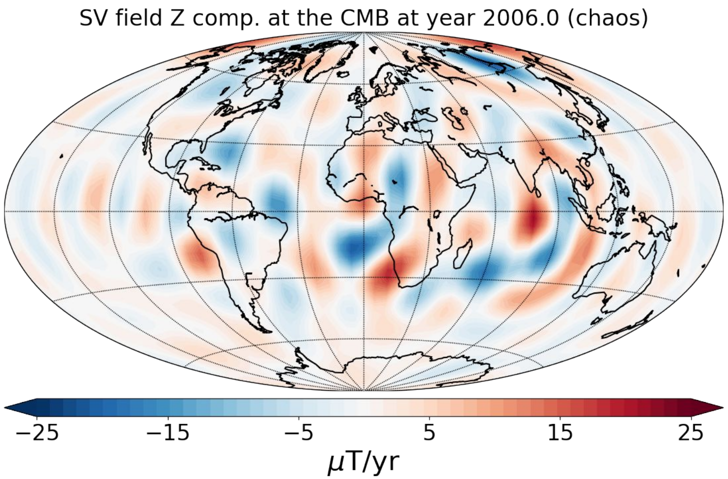
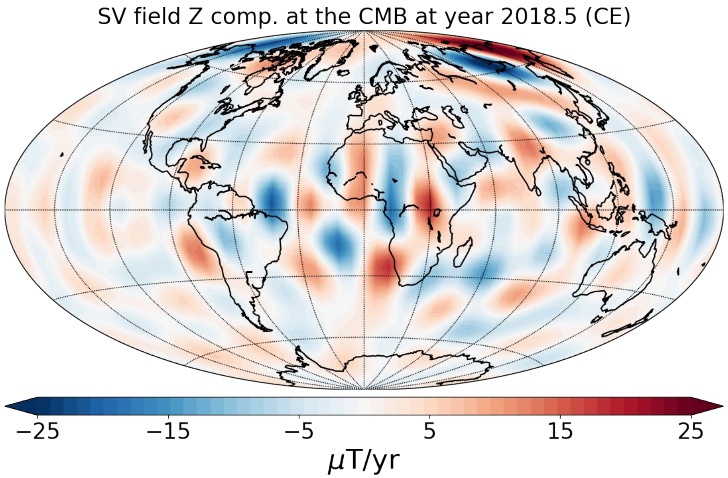
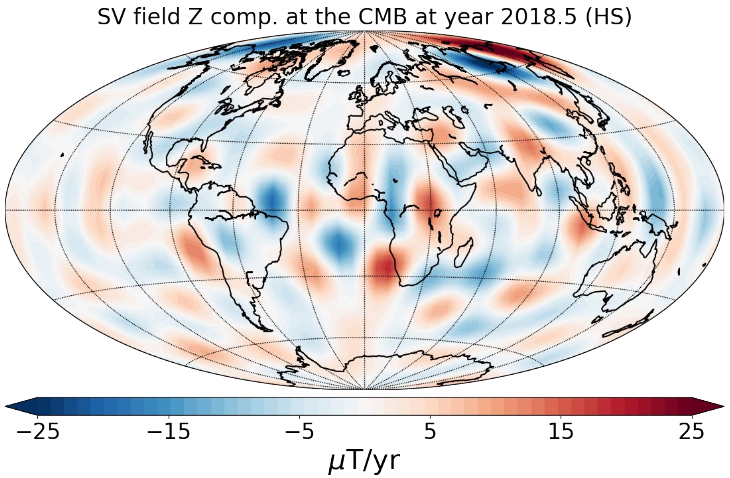
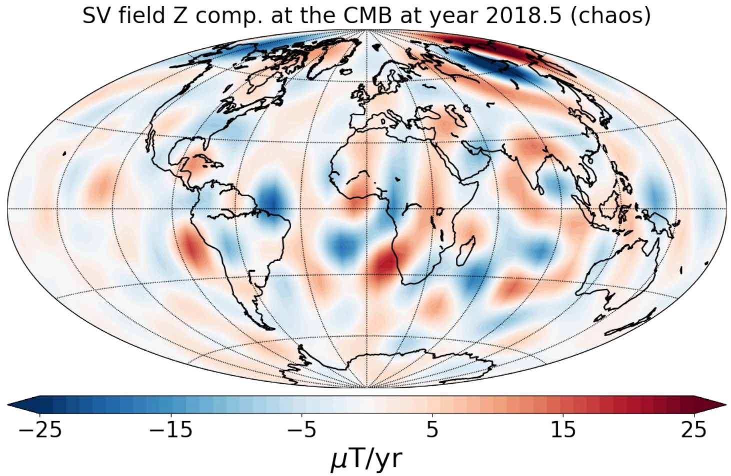


Model MCM-00-20



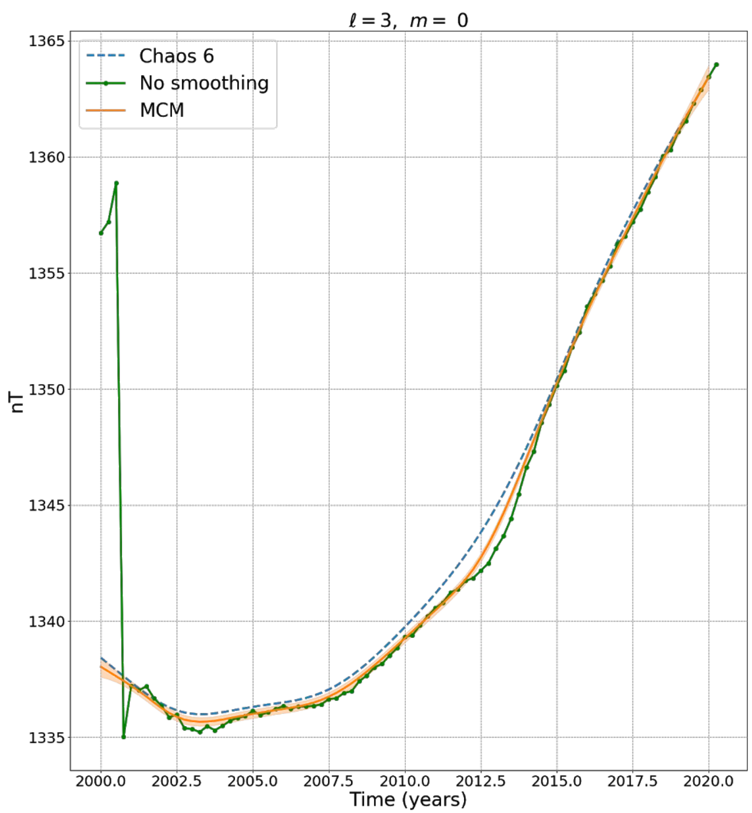




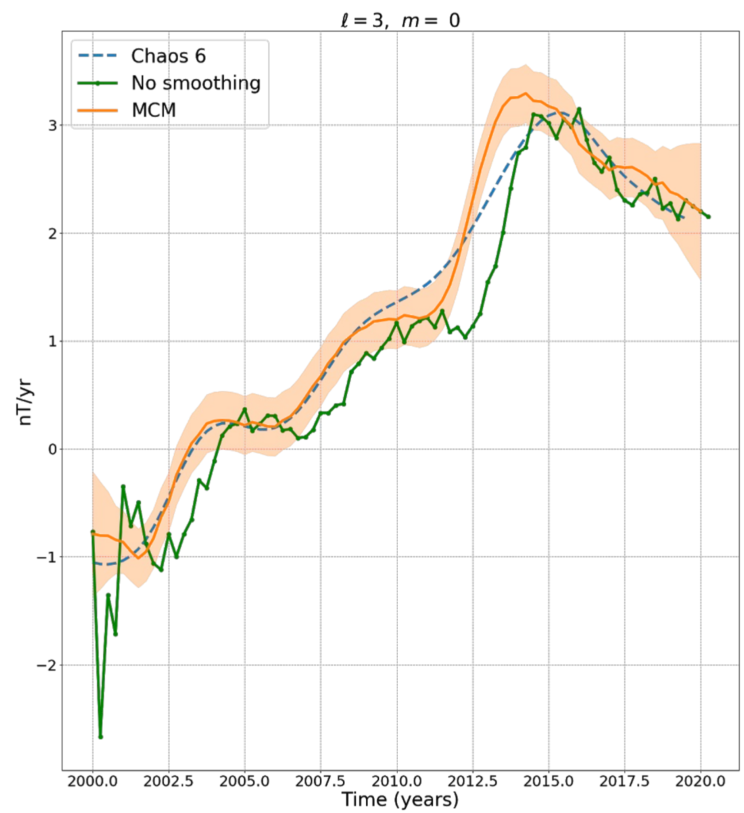
Lmax = 14

Model MCM-00-20

- Times series (*Holschneider* prior)



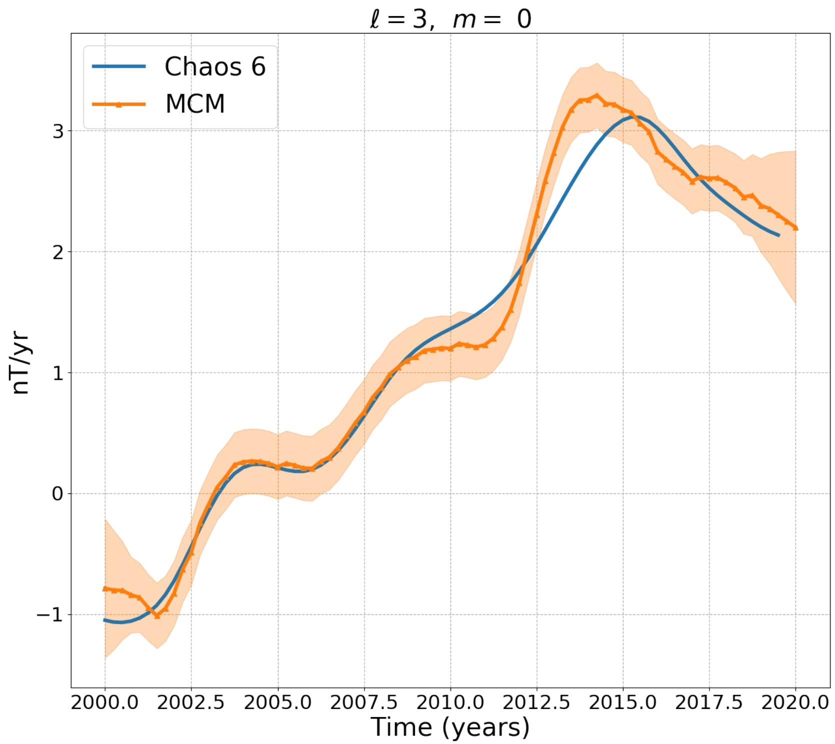
Core field

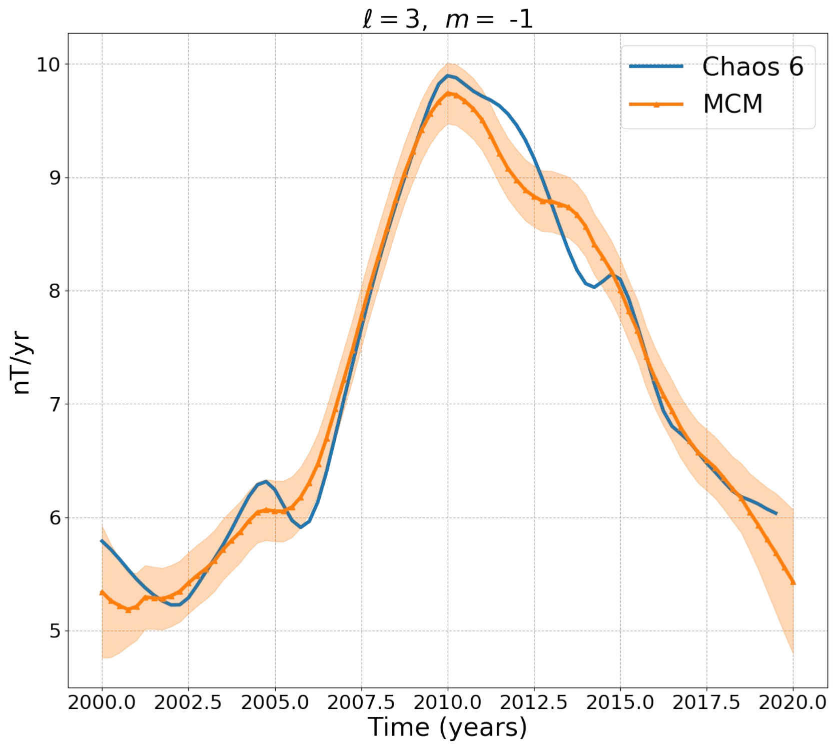


Secular Variation

Model MCM-00-20

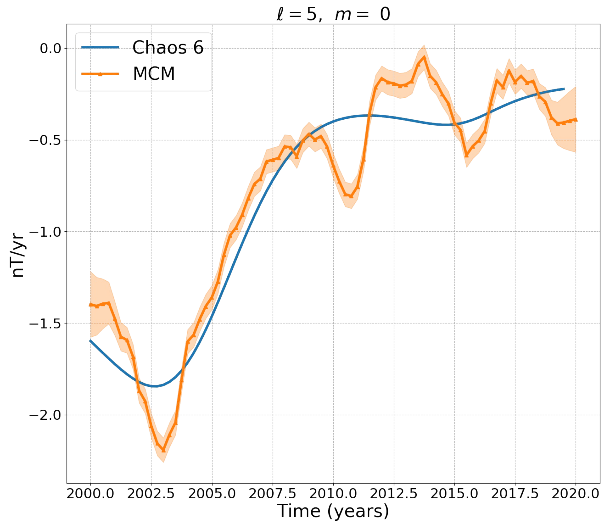
Resolution at low harmonic degrees (large scales)

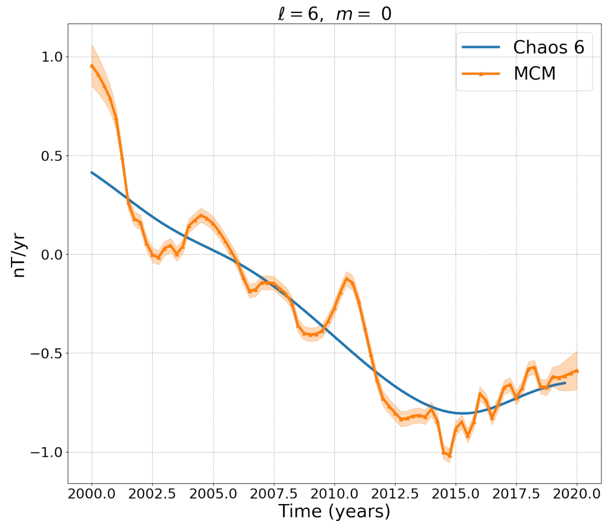


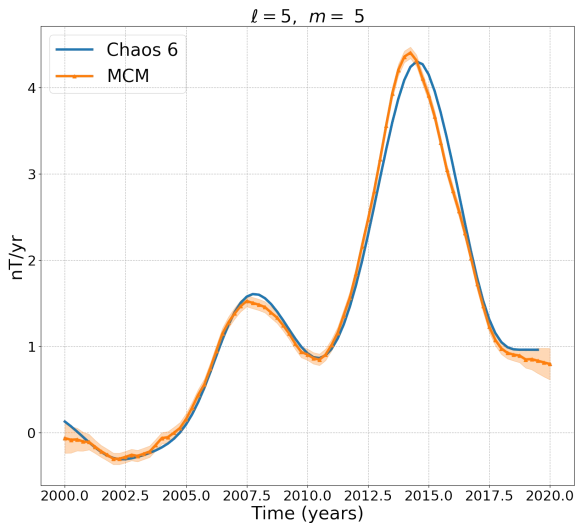


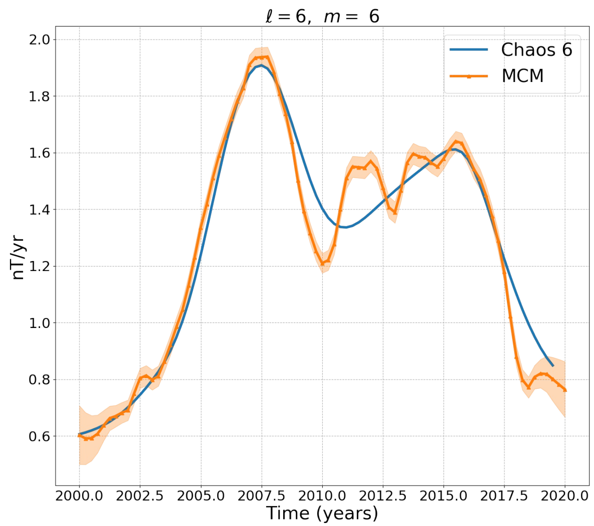
Model MCM-00-20

Resolution at higher harmonic degrees (small scales)

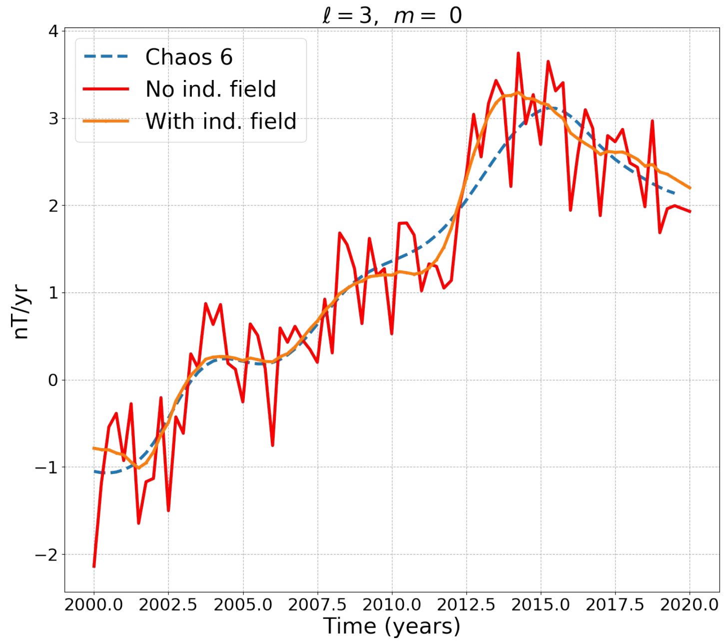


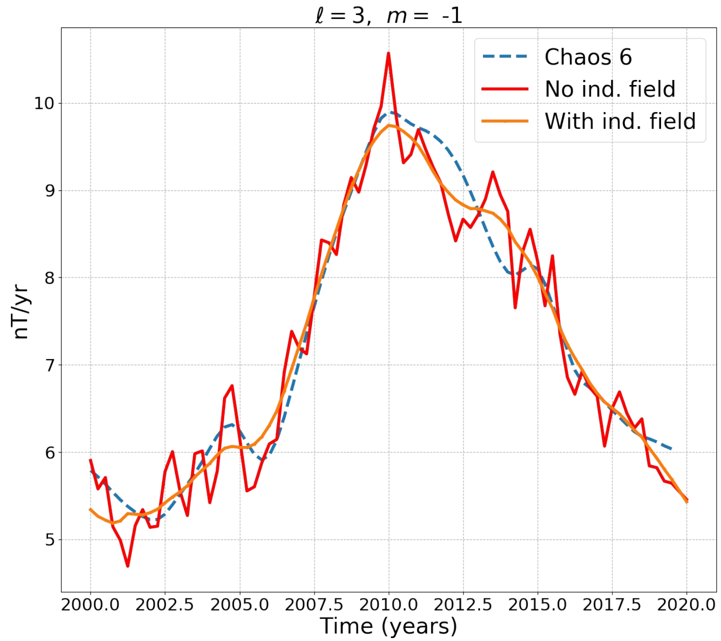






Model MCM-00-20





- Separation of the induced field :
  - Generated by currents induced at 400 km depth by the magnetospheric field
  - Smoother time series
  - Increase in covariance due to separation of sources
- Which features are to be attributed to the induced field ?
- What is the intensity of this contribution ?

Future developments

- 1st objective : IGRF 2019
- Improvement in the modelling of the induced field
  $\longrightarrow$ Set better prior information
- Co-estimation of the core surface flow
- Continuous assimilation of SWARM Data
- Improvements in priors for the external fields (Nikolai Tsyganenko)

Thank you for your attention